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Sustainability Management for Groundwater Irrigation in Barind Tract of Bangladesh

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Sustainability Management for Groundwater Irrigation in *Barind* Tract of Bangladesh

A Dissertation Submitted to the Institute of Bangladesh Studies of Rajshahi University, Bangladesh in Partial Fulfilment of the Requirement for Award of the Degree of Doctor of Philosophy.

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Certificate

This is to certify that the dissertation entitled **Sustainability Management for Groundwater Irrigation in *Barind* Tract of Bangladesh** submitted by Mohammad Rafiul Azam Khan, a PhD Fellow of session 2015-2016 to the Institute of Bangladesh Studies of the University of Rajshahi, Bangladesh in fulfilment of the requirement for the award of the Doctor of Philosophy degree is an original research work done under my supervision and guidance. To the best of my knowledge, this dissertation was not previously submitted for any diploma/degree/fellowship to any other University/Institute. Study related materials/ data collected from different sources have been duly acknowledged in this thesis. I believe that the researcher has worked with utmost sincerity for preparing this dissertation and the submission is, in my opinion, worthy of consideration for the award of PhD.

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Declaration

I do hereby declare that the dissertation entitled **Sustainability Management for Groundwater Irrigation in *Barind* Tract of Bangladesh** submitted to the Institute of Bangladesh of the University of Rajshahi in fulfilment of the requirement for the award of the degree of Doctor of Philosophy is my own original work. Neither the whole, nor any part of this dissertation has previously been submitted for any a degree or any other qualification to this university or any other institutions. The sources of all the materials used or quoted have been duly indicated and acknowledged in the dissertation.

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Mohammad Rafiul Azam Khan

Abstract

The *Barind* tract is rich in mineral resources like coal, peat, hard rock, limestone, white clay, and glass sand, and is suitable for agricultural crops production in which paddy is the leading crop that contribute to ensuring food security in Bangladesh. Although there are three seasons for paddy production in *Barind* area, traditionally *boro* season is used for paddy production in most of the agricultural lands. Irrigation for cultivating paddy is indispensable for which the most convenient source of water is the surface water, but surface water source already has reached to an alarming level from the viewpoint of its availability in this region wherein only four months are attributed as the wet season allowing irrigation using surface water sources, and the rest of the year, that is, during the dry season for irrigation the farmers are to rely entirely on groundwater (GW), which is comparatively costly and limited.

The main purpose of this study is to reveal and evaluate the sustainability status and management practices in the use of GW for irrigation in *Barind* tract of Bangladesh. It started with an endeavour to study legislative measures and framework in GW management for irrigation followed by an assessment of perceptions and examination of the participation of the farmers as well as local government officials in the execution of their action plans to address key management issues and drivers with a view to coming up with a sustainable strategic management approach applicable in the study area and other parts of the *Barind* tract of Bangladesh, thereby ensuring the obtainability of services of natural resources for the next generations.

Both qualitative and quantitative data have been used, but emphasis has been on the qualitative approach for data analysis supplemented by quantitative analysis to endorse the findings based on qualitative analysis. Twenty six (26) key informant interviews (KII), four (4) in-depth interviews, and three (3) FGDs have been conducted where researcher himself was involved in the data collection. Data

acquired through KIIs, in-depth interviews, and FGDs helped sketch the perceptions and implementation practices at the field level of local Government institutions involved as one of the stakeholders in GW irrigation management and also helped reveal its existing sustainability status. For collecting quantitative data, a survey using a questionnaire was conducted on farmers who were engaged in agriculture at Niamatpur upazila, Naogaon; Tanore upazila, Rajshahi and Nachol upazila, Chapai Nawabgonj districts within Barind area of Bangladesh. The simple random sampling technique was used to draw respondents of one hundred and sixty (160) farmers. Data collected through a self-administered semi-structured survey questionnaire were pre-tested with in-depth interviews conducted on eight (8) respondents and a FGD residing in the study area to confirm its validity and reliability. Researcher himself with the assistance of one enumerator completed survey, *e.g.*, data collection. Descriptive statistics have been used to process, present, and analyze the data collected with the help of IBM SPSS version 22 and Microsoft Excel 2013. Secondary sources of data have also been used in the study wherever deemed necessary in order to complete the analysis, draw findings, and reach to the conclusion.

The study has come up with a number of important findings. The first set of findings is related to farmers' perceptions and practices in GW irrigation. The most striking finding is that in the context of the main stream crops, farmers have a mindset to cultivate *boro* so as to safeguard from food crisis, and considering the other emergency activities round the year, they think it as their asset like the liquid bank deposit to spend with. Moreover, they think that they have only gathered the skills and knowledge at *boro* cultivation from their ancestors, and treat themselves unfit for doing anything else. Therefore, they do not want to take any risk for better survival until they get more benefits visibly from producing any other crops with desirable risks. Farmers can perceive the increasingly increasing rate of GW use with its GW depletion gradually as it has been evidenced to them. Causes for GW depletion are excessive extraction especially during *boro* season, inadequate rainfall, presence of insufficient conservation measures and dams at the upstream. Farmers have a little knowledge about keeping water at the optimum level in paddy field. Many of them were used to over irrigating while cultivating paddy. Misuse of irrigation water occurred due to excess use by farmers, improper supply channels used, lack of irrigation knowledge, disinclination to follow the irrigation rules, etc. UPVC pipe used in supply channel is more effective in preventing water misuse though network made of UPVC is not that significant in use. Applying AWD method can play a vital role for preventing the misuse of water but majority of farmers have no knowledge about AWD method. DAE was reluctant to provide proper guidelines for irrigation. Effort of both BMDA and DAE is not sufficient enough to build up awareness for applying AWD. Farmers are not directly benefited from government subsidies on electricity bills, but private pump owners and BMDA are benefited from such subsidy.

The second set of findings reflects execution practices in local Government institutes while implementing their action plans, and existing sustainability status of the GW irrigation. The study reveals that annual average rainfall in the study area is much lower than that of the national average with its evidently decreasing trend in the last two decades in the study area. During 2002-2019, average rainfall was declined by 25.32mm per year with a total decrease in rainfall by 430.47mm at Tanore upazila. In respect of Nachol upazila, the average rainfall was declined by 17.50mm per year with a total decline in rainfall by 314.91mm during same period. During the same period rainfall trend at Niamatpur upazila was upward with an increasing rate of 30.94mm on an average per year.

The study again reveals that in the Tanore upazila static level of GW table was declined by 8.81 meters (about 30 feet) during the years from 1996 to 2019. In the Nachol upazila static level of GW table was declined by 18 meters (59 feet) during the years from 1995 to 2019. In the Niamatpur upazila static level of GW table was declined by 4.78 meters (15.68 feet) during the years from 1995 to 2019. It indicates that Nachol was the riskiest area among the areas under study in terms of decline in water level. Again, most vulnerable months in the dry season include four months from February to May, in April GW aquifer was found to have depleted most in the study area. In the month of April, in the Tanore upazila GW aquifer depleted most during the years 1996-2019, in Nachol GW aquifer depleted most during the period 1995-2019. Whereas, in Niamatpur upazila GW aquifer depleted most both in the months of March and April during the years 2005-2019.

The study also reveals that the static water table was closest to the surface in October in Tanore upazila during the years from 1996 to 2019, the static water table was closest to the surface in both September and October in Nachol upazila during the year from 1995 to 2019, and Niamatpur upazila, in August during the years 2005-2019. Highest difference of static water table between wet and dry season was 2.74 meters (9 feet) in Tanore, 7.8 meters (25.6 feet) in Nachol, and 0.59 meter (1.94 feet) in Niamatpur on an average.

The study also indicates, farmers use excess water for *boro* cultivation. The bills that BMDA and private pump owners charge for irrigation is much higher than the actual electricity bill. During the dry season, a large portion of the farming area does not get optimum water for watering *boro* fields due to the depletion of the GW aquifer. In the dry season, the overall availability of surface water is 1% less than the requirement in Nachol and less than 10% in Niamatpur Upazila. The study reports that one-third of the total wetlands was lost during 1989-2010. The trend towards crop diversification by farmers in the study area was negligible rather they were engaged in a kind of a mono-cropping pattern.

The study further reveals that applying the AWD technique can save irrigation water by 20-30 percent but farmers were reluctant to apply it. UPVC based network as a supply channel for irrigation is not sufficient in terms of benefits that come from the application of modern technique. No artificial recharge well was constructed in the study area and no initiative taken by the authorities either. Political influence is the main barrier to the implementation of laws, was found to be a major cause for the situation getting into a mess.

The water level depletion causes disaster in agricultural production and associated economic activities in many ways: the level of arsenic contamination increases as the water table goes down after a certain level, heavy metals such as iron, copper, cobalt, nickel, etc. move with water causes for long-term health risks, putting a negative impact on the environmental health, leading to severe landslides as the interior reasoning for earthquakes that can change the course of a river or dry it up. If the trend continues, it will wreak havoc on economic activity, biodiversity conservation, drinking and household water supply, and the lives of existing people as well as future generations as a whole. In order to save the society, economy, and environment; researcher urged for an integrated management approach instead of a sector-based approach. In this regard, the integrated water resource management (IWRM) approach emphasizing all the stakeholders' participation in the process within the context of a good governance can be a basis for achieving a sustainable management system for irrigation in the *Barind* tract of Bangladesh.

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Abbreviations and Acronyms

AGM	Assistant General Manager
AWD	Alternative Wetting and Drying
BADC	Bangladesh Agriculture Development Corporation
BMDA	Barind Multipurpose Development Authority
BRDB	Bangladesh Rural Development Board
BREB	Bangladesh Rural Electrification Board
BSCIC	Bangladesh Small and Cottage Industries Corporation
BWDB	Bangladesh Water Development Board
DAE	Department of Agriculture Extension
DGM	Deputy General Manager
DIWRMC	District Integrated Water Resource Management Committee
DTW	Deep Tube-well
DTWs	Deep Tube-wells
ECNWRC	Executive Committee of National Water Resources Council
eGP	e-Government Procurement
EPWAPDA	East Pakistan Water and Power Development Authority
FAP	Flood Action Plan
FGD	Focus Group Discussion
GIS	Geographic Information Systems
GO	Government Organization
GoB	Government of Bangladesh
GoEP	Government of East Pakistan
GW	Groundwater
Hec	Hectare
HSC	Higher Secondary Certificate
IBRD	International Bank for Reconstruction and Development
ICT	Information and Communication Technology
IDWRs	Integrated Distribution of Water Resources

IWRM	Integrated Water Resources Management
KII	Key Informant Interview
km	Kilometer
LG	Local Government
LGD	Local Government Division
LGED	Local Government Engineering Department
LLP	Low Lift Pump
MIS	Management Information Systems
MoA	Ministry of Agriculture
MoPEMR	Ministry of Power, Energy and Mineral Resource
MPO	Master Plan Organization
N	Study Population
n	Sample size
NGO	Non-Government Organization
NMPO	National Master Plan Organization
NOC	No Objection Certificate
NW	National Water
NWP	National Water Plan
NWPo	National Water Policy
NWRC	National Water Resources Council
NWRD	National Water Resource Database
NWRP	National Water Resource Planning
O&M	Organization and Management
PHED	Engineer of Public Health Engineering Department
PM	Prime Minister
PPP	Public Private Partnership
SGMI	Sustainable Groundwater Management for Irrigation
SPSS	Statistical Package for the Social Sciences
sq km	Square Kilometer
SRS	Simple Random Sampling

STW	Shallow Tube-well
STWs	Shallow Tubwells
SW	Surface Water
TAP	transparency, accountability and participation
TWs	Tube-wells
UAO	Upazila Agriculture Office
UIWRMC	Upazila Integrated Water Resource Management Committee
UNO	Upazila Nirbahi Officer
UP	Union Parishad
UpIWRMC	Union Integrated Water Resource Management Committee
UPVC	Underground Polyvinyl Chloride
USA	United States of America
WARPO	Water Resources Planning Organization
WMCS	Water Management Cooperative Society

Chapter One
Introduction

1.1 Prelude

Bangladesh is a riverine country with a huge network with crisscrossed tributaries and distributaries. The rivers are the country's economic lifeline and support diverse agricultural activities, facilitating transportation, industrialization, thereby creating various sources of livelihoods for the inhabitants. Surface water, however, could not be fully exploited for irrigation, due to its poor maintenance and management, and also owing to historical negligence to the development of new surface water infrastructure. Conversely, the use of groundwater (GW) for irrigation has increased dramatically over the last three decades.

Bangladesh consumes most of her water resources through its agricultural sector. GW is an important resource for livelihoods and the food security for the people of Bangladesh. There are three main seasonal types of rice grown in Bangladesh i.e. *aus*, *aman* and *boro*. *Aus* is rainfed, pre-monsoon rice, and is typically low yielding. *Aman* rice is grown during the monsoon and is also low yielding, whereas *boro* is a high yielding variety giving rise to huge production during the dry season. The dramatic increase in *boro* production was due largely to the extensive exploitation of GW. During the dry season, 58 percent of the Bangladesh's available fresh water is allocated to irrigation, 41 percent is used for fisheries and navigation, whereas less than 1percent is used by domestic and industrial sectors.[1] About 80 percent of GW is used for irrigation, of which 73 percent is used exclusively by *boro* farmers.[2]

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[1] Nasima Tanveer Chowdhury, "Water Management in Bangladesh: An Analytical Review," *Online Journal of the World Water Council* 12, no. 1 (2010): 1, http://dx.DOI.org/10.2166/wp.2009.112.

[2] M.W. Rahaman, and R. Ahmed, "Shallow Tub Well Irrigation Business in Bangladesh," Paper presented at Summay and Synthesis Workshop at Kathmandu, Nepal, March 20-24, 2008.

GW irrigation introduced in 1960 by a governmental organization named Bangladesh Agriculture Development Corporation (BADC). Initially BADC launched subsidized programs on deep tube-wells (DTWs) and shallow tube-wells (STWs). Government reduced import duties on water lifting equipment and exempted import duties even in some cases in the late 1970s with a view to increasing the involvement of private sector of the country. But GW irrigation was mainly triggered around 1986–1987 as the result of changes in government policies, limiting government involvement and encouraging private development.[3]

Increased GW accessibility resulting from the expansion of DTWs and STWs helped Bangladesh attain near self-sufficiency in rice production, with national output increasing over 15 million tons in the last two decades.[4] But GW resource management concept has not been emphasized in public or private level. Available evidence suggests that the policy focus so far has been largely on "resource development", and not on "resource management".[5] This has resulted in serious problems, most notably the excessive drawdown in intensively irrigated areas, and the deterioration of GW quality. In many cases, the depth will approximately be doubled by the year 2040, and almost all will be doubled by 2060, if the present trend continues.[6] The forefront challenge, therefore, is to take the necessary corrective measures before the problem becomes acute or insolvable. So, there are growing concerns about achieving sustainable use of GW for irrigation.[7]

However, besides giving rise to an increasing upsurge in the need for energy consumptions GW irrigation is resulting in a rapid decline in the level of GW with its deteriorating quality. Due to high installation, operational, and management costs, the large-scale development of surface water resources in

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[3] Ahmad, "Groundwater Use for Irrigation and Its Productivity," DOI: 10.1007/s11269-014-0560-z.

[4] Qureshi, Ahmed, and Krupnik, "Moving from Resource Development to Resource Management," DOI: 10.1007/s11269-015-1059-y.

[5] Ibid.

[6] Md. Hossain Ali, I Abustan, and AAM Haque, "Sustainability of Groundwater Resources in the Northeastern Region of Bangladesh," *Springer Water Resour Manage* 26 (2012): 623-41.

[7] Ahmad, "Groundwater Use for Irrigation and Its Productivity," DOI: 10.1007/s11269-014-0560-z.

Bangladesh will remain as a challenge in near future. GW irrigation will therefore remain crucial to sustaining agrarian growth in order to meet future food requirements in Bangladesh. Discerning the important role that GW will play in the future in supporting the rural economies of Bangladesh, its availability in terms of quantity and quality must be ensured. Therefore, it is imperative to understand the issues and challenges of GW use in Bangladesh and to evaluate options for its sustainable management.

1.2 Statement of the Problem

Barind Tract is located in the north-western part of Bangladesh. This area is socio-economically backward, agro-based drought prone area where agriculture mainly depends on GW especially during the *boro* season. Surface water is not sufficient for irrigation throughout the year even in rainy season. Long-term average rainfall in that area is substantially lower than national average level, and long-term average rainfall trend is even decreasing significantly in that area. For instance, in Barind tract the rainfall recorded in 1981 was about 1,738 mm, but in 1992 it was about 798 mm only.[8] Due to increasing use of GW and declining average rainfall GW table is declining every year. If the decline of the water-table continues for a long time, it could pose a serious threat to the balance of ecology and to the sustainability of food production, hampering the nation's food security, which will end up putting the future generations in a total mess.

GW recharge in Bangladesh mostly takes place by monsoon rainfall and flooding. Due to its high elevation and being located in flood free zone with lowest amount of rainfall, it is prone to severe drought. The GW recharge mainly depends on rainfall and there is no notable artificial recharge system. There have been almost no attempts made by either public or private sector for correcting the decreasing trend of GW table.

[8] *Banglapedia*, s.v. "Barind Tract." http://www.ebanglapedia.com.

Although a total of 30 ministries with 35 departments under them are responsible for the use of water resources, the main obstacle to good water governance is the lack of coordination among these institutions.[9] Several Acts and policies have already come into existence regarding use of water. But these Acts and policies are not well coordinated, and a few numbers of Acts and policies actually are in force. In the Barind tract, Barind Multipurpose Development Authority (BMDA) provides water for irrigation. Though BMDA gives license for DTWs after maintaining some formal procedure prescribed by Upazila Integrated Water Resources Management Committee (UIWRMC), there is no control over non-stop excessive lifting of GW as well as water tariff, especially in private pump.

Based on the review of several related documents and sample survey it is learned that some Local Government (LG) offices/authorities can contribute to achieving sustainability in the use of GW for irrigation. The authorities include UIWRMC, Upazila Agriculture Office (UAO), Local Government Engineering Department (LGED), Bangladesh Rural Electrification Board (BREB) Upazila Cooperative Office, and Bangladesh Rural Development Board (BRDB) besides BMDA.

Due to lack of proper policy guidance and coordination among the various departments— both governmental and non-governmental, and lack of proper understanding of the importance of adhering to multidisciplinary approach towards the use of water resources, it can easily be come across that in near future present and future generations of Bangladesh is going to face a dismal situation. Bangladesh needs to come out of this dire strait, and for this, researches should focus on achieving an interdisciplinary approach along with policy issues towards ensuring the incessant derivations of benefits from our planet's resources, and this study intends to focus on finding out whether a holistic approach has been so far

[9] *Water Governance in Bangladesh: Challenges and Opportunities Around Policy, Institutional Function and Implementation for a Sustainable Water Future* (Gland: World Wide Fund For Nature, 2014), 19, http://d2ouvy59p0dg6k.cloudfront.net/downloads/ wwf_hm___ water_governance_ in_bangladesh_published.pdf.

built to deal with the problem in question and if so how far it has been effective in dealing with the problem and if not then finding out the reasons for not achieving the sustainability in the use of GW for irrigation.

1.3 Objectives of the Study

The main objective of the study is to evaluate the sustainable management practices in the use of GW for irrigation in Barind tract of Bangladesh. Specific objectives of the study on Barind tract of Bangladesh regarding sustainable GW management for irrigation are as follows:

1. To study the legislative measures and framework for GW management in the context of Bangladesh.
2. To assess the perceptions of the farmers about the existing irrigation practices including roles of various departments (both governmental and non-governmental) in the sustainable management of GW resources.
3. To examine the GW sustainability status in the context of economic, social and environmental perspectives.
4. To analyse the execution practices of local Government institutions in implementing their action plan for GW resource management.
5. To investigate the extent to which existing GW management practices are congruent with sustainable practices and the key issues affecting the sustainable GW management in the area under study.
6. To initiate an effective strategic approach to ensure sustainable GW irrigation management.

1.4 Justification of the Study

The use of surface water for irrigation still cannot be done with highest efficiency due to poor maintenance and management of surface water infrastructure. On the other hand, GW use in irrigation dramatically has increased over the last three decades causing a gradual depletion of its level. For this reason, focus should be on sustainability management in the use of GW for irrigation for the sake of ensuring a sustained water resources for the next generations.

This study might help to find out the reasons or factors contributing to rampant use of GW for irrigation causing rapid decline in its level. Findings may help facilitate the formulation of a suitable policy relating to it and devise well-conceived mechanism for implementation of such upgraded policy through local government so that sustainability in the use of GW is ensured. The present study might reveal the new insights to academics and researcher intending to explore new ideas. Moreover, this study may reveal the very factors hindering the sustainability management practices in the use of GW for irrigation and may urge for a strategic management approach ensuring all the stakeholders and Government of Bangladesh to be engaged in the process of sustainability.

1.5 Limitations of the Study

The present study is not free of limitations. It had some inadequacy in its approach and execution. Data collection was very difficult as the response was voluntary and many of the respondents were not interested to provide opinions for research purposes though later on they were convinced and provided their valuable input. For some respondents number of visits was required as they were not available at those times.

This study has considered only three upazila of drought-prone *Barind* area, *viz*, Tanore of Rajshahi district, Nachole of Chapai Nawabganj district, and Niamatpur of Naogaon district, other upazilas of *Barind* area have not to be considered. The study has paid attention only to problems relating to sustainability management practices and issues in the use of GW for irrigation along with relevant socioeconomic aspects.

Many issues relating to environment, particularly geographical and atmospheric having impact on the water resources could not be taken into account since they were too technical.

1.6 Concept of Key Terms

Sustainability

Sustainability means the ability of the environment to preserve it up for proper functioning which involves meeting the present needs of humans without doing any harm to the welfare of future generation and thereby supporting long-term ecological balance.

Ecological definition of sustainability connects human needs and ecosystem services without compromising with the health of ecosystems.[10] From an economic standpoint, sustainability requires that current economic activities do not disproportionately burden future generations.[11] The prime objective of the economic sustainability is to minimize the social costs. Social sustainability is concerned with some positive conditions within communities, and is concerned with developing a process that can help achieve those conditions.[12] Sustainability in the use of GW in irrigation per se relates to the ecological definition of sustainability and it implies that water management in irrigation should be such that availability and use of water for the underlying purpose can be ensured into future without dismantling the ecological systems involved.

Sustainability Management

Sustainability management is concerned with prioritizing the protection of Earth's systems and resources as well as the spread of social and economic opportunities for all people – present and future, while making best use of earth's natural

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[10] John Lemons, *Environmental Science and Technology Library,* ed. Laura Westra and Robert Goodland, vol. 13, *Ecological Sustainability and Integrity: Concepts and Approaches* (Dordrecht: Springer Netherlands, 1998), http://public.eblib.com/ choice/ publicfullrecord.aspx?p=3106239.

[11] George Foy, "Economic Sustainability and the Preservation of Environmental Assets," *Journal of Environmental Management* 14, no. 6 (November 1990): 771-78, DOI: 10.1007/BF02394171.

[12] Stephen McKenzie, "Social Sustainability: Towards Some Definitions," *Hawke Research Institute Working Paper Series* 27 (2004), http://w3.unisa.edu.au/hawkeinstitute/ publications/downloads/wp27.pdf.

resources. Sustainability management involves the process of bridging present practices in the use of natural resources with various studies in order to apprehend the degree of impacts the rampant use of resources is adversely making on the environment, society and the economy. It does have three branches like- environment, society and the economy. It helps create the ability to keep a system running indefinitely without depleting its resources, upholding economic viability, and meeting the needs of the present and future generations as well.

With a view to obtaining its goal, achieving sustainability often looks at two different factors such as the rate of consumption and the rate of replenishment. The goal is to keep these two factors in equilibrium. In cases where there is a surplus of a resource, consumption outpacing replenishment may be possible. In most cases, there might develop a very real problem if a surplus does not exist.

Sustainability management in the use of GW is needed because it is an important part of the ability to successfully maintain the quality of life on our planet. It is applied to all the aspects of our lives, so that natural resources could be used properly over generations.

Barind Tract

Barind Tract is the largest Pleistocene physiographic unit of the Bengal basin, covering an area of about 7,770 sq. km.[13] Barind Tract, also called Barind, geographic region in parts of north western Bangladesh and north-central West Bengal state, India. In Bangladesh, it covers Rajshahi, Chapai Nawabgonj, Naogaon, Natore, Joypurhat, most of the Pabna, Dinajpur, Rangpur, and Bogura districts of Rajshahi Division and Rangpur Division. The climate of the area is generally warm and humid. Based on rainfall, humidity, temperature and wind pressure the weather condition is classified into four types, such as, (a) pre-monsoon, (b) monsoon, (c) post-monsoon and (d) winter. Barind is a

[13] *Banglapedia*, s.v. "Barind Tract." http://www.ebanglapedia.com.

comparatively high, undulating region, with reddish and yellowish clay soils. Agricultural plots are commonly irrigated and stand between stretches of wasteland and scrub. Rice is the predominant crop, but wheat, mustard, pulses, potato and vegetables also are cultivated.

Irrigation

Irrigation refers to the purposeful wetting of land to prepare it for agriculture. It also means artificial watering on the land to assist in crop production. This is the process of applying a controlled amount of water to plants at required intervals.

Surface water

Surface water is any body of water on the top of the Earth's surface, or above ground such as rivers, lakes, reservoirs, ponds, creeks, and wetlands. This may also be referred to as blue water. The ocean, despite being saltwater, is also considered surface water.

Groundwater

Typically, GW is thought of as water flowing through shallow aquifers, but, in the technical sense, GW is the water present beneath Earth’s surface in soiol pore spaces and in the fractures of rock formations.

Aquifer

A unit of rock or an unconsolidated deposit is called an aquifer when GW can yield a usable quantity of water. Aquifers are typically made up of gravel, sand, sandstone, or fractured rock, like limestone.

Groundwater table

The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called the water table.

Groundwater depletion

GW depletion, a term often defined as long-term water-level declines caused by un-sustained GW pumping. It occurred when GW is withdrawn faster than it is recharged by precipitation.

Aquifer recharge

A phenomenon that replenishes aquifers with water from meteoric sources (because of direct rainfall or through percolation of water from other stream beds) or percolation from adjacent aquifers.

Groundwater recharge

Process by which water is added from outside to the zone of saturation of an aquifer, either directly into formation of an aquifer, or indirectly by way of another formation.

It is a hydrological process, where water moves downward from surface water to GW. This process usually occurs in the unsaturated zone below plant roots and, is often expressed as a flux to the water table surface. GW recharge also encompasses water moving away from the water table farther into the saturated zone. Recharge occurs both naturally through the water cycle and through artificial GW recharge, where rainwater and or recycled water is routed to the subsurface.

Artificial recharge

Artificial recharge is the practice of increasing the amount of water that enters an aquifer through human-controlled means. It is the process of redirecting water across the land surface through canals, infiltration basins, ponds, or recharge well; adding irrigation furrows or sprinkler systems; or simply injecting water directly into the subsurface through injection wells.

Safe yield of GW

Amount of water (in general, long term average amount) which can be withdrawn from a GW basin or surface water system without causing undesirable results.

Khari

Khari is traditional irrigation canals. It is an artificial waterway constructed to allow the passage of boats or ships inland or to convey water for irrigation.

Boro

Boro is a Bengali language word imitated from a Sanskrit word "*BOROB*". It is a rice growing season in Bangladesh which is generally cultivated within January-May in the dry period. *Boro* is also a special type of rice cultivation done in residual or stored water in low-lying areas after the harvest of *kharif* rice.

1.7 Organization of the Dissertation

The dissertation follows a process in which every chapter serves as a foundation for the next chapter. The study has been organized in the following manner.

Chapter One: Introduction— This chapter deals with the introduction of sustainability management of GW irrigation along with some related conceptual definitions, statement of problem, research objectives, justification of the research study, and therefore, concluding remarks on the study.

Chapter Two: Review of Literature and Theoretical Framework—This chapter attempts to exhibit a plethora of previously done various related research works of different scholars on GW irrigation in different national, cross-national and other settings as well. The chapter also incorporated relevant studies relating to the current study. Finally, this chapter has come up with a research gap based on which the current study has been done followed by a chapter conclusion.

Chapter Three: Research Methodology—This chapter deals with the tools and techniques used to examine and analyse data obtained through using three sets of questionnaires and in-depth interview with a panel of experts. It also attempts to present research design, sampling process, data collection methods, data analysis tools used– an overall process to complete the study.

Chapter Four: Involvement of the Institutions in Groundwater Irrigation—The chapter incorporate review of study area along with institutional involvement. It begins with description of the area under study include vital information, institutional profile with their functions, the chapter ends with conclusion.

Chapter Five: Review of Legislative Measures and Framework—This chapter delineates the Act, Rules, policies, guidelines regarding use of groundwater resources and its governance. It starts with water governance in Bangladesh along with its background. The chapter also presents a discussion on Bangladesh Water Act 2013, Bangladesh Water Policy 1999, Bangladesh Water Rules 2018, and Integrated Water Resources Management Guidelines 2019 meant to be followed at the district, upazila and union levels.

Chapter Six: Sustainability Status of Groundwater Irrigation in Barind Tract— The Chapter has made an attempt to examine the status of GW irrigation in Barind tract of Bangladesh in the context of its sustainability. It starts with the trends of natural setting of GW and the surrounding factors that influence its originality and use. Further, this chapter exhibits the perceptions of the major stakeholders involved in irrigation; farmers from demand side and local government institutions from supply side.

Chapter Seven: Sustainable Groundwater Management for Irrigation in Barind Tract of Bangladesh: Issues and Practices—The chapter describes existing practices of management strategies in Barind tract of Bangladesh and identifies the key management issues involved. In line with this, this chapter discusses short-term and long-term strategies from demand-supply side to portray a realistic scenario of management of irrigation in the context of sustainability, and thereafter chapter ends with a conclusion.

Chapter Eight: Summary of Findings and Discussion—The chapter summarizes the key findings of the study It starts with the highlighting the key findings according to the study objectives. Further it discusses the outcomes in the light of the sustainable management and thereafter strives to draw a concluding remarks at end of the chapter.

Chapter Nine: Conclusion— This chapter strives to initiate an effective strategic approach to ensure sustainable GW irrigation management in *Barind* tract, Bangladesh. The chapter specifies short-term strategies, in addition to long-term strategies, emphasizing the enforcement of good governance concept to help achieve sustainable GW management for irrigation in Barind tract of Bangladesh, and finally reaches to a conclusion in accordance with the study objectives, along with the current study implications, and further research areas highlighted to be done in the future. Finally, the chapter has been ended up with a wake-up call.

1.8 Conclusion

GW irrigation will have serious consequences as water levels are declining in the intensively irrigated areas of northern region of Bangladesh with rapid deterioration of GW quality. Due to high installation, operational, and management costs, the sustainable Management of GW resources will remain a challenge for Bangladesh. As GW irrigation is crucial to sustaining agrarian growth necessary to meet Bangladesh's future food requirements, it is necessary to take needful measures immediately before it is too late. There are a growing concern for sustainable use of GW for irrigation and it is important to understand and address the issues and challenges associated with sustainable GW use and its proper management in the context of Bangladesh. In the next chapter relevant literature related to this study has been reviewed and attempts to make theoretical underpinning and framework.

Chapter Two

Review of Literature and Theoretical Framework

2.1 Introduction

This chapter guides researchers to solve research problems with specific knowledge. It includes various research work done by scholars from different countries, nationals and multiple cultures to provide in-depth knowledge for research. Finally, the research gap is resolved to promote the research study. In order to better understand the research gap. The relevant literature related to this study has been reviewed. All possible books, journals, research papers, papers from various sources were reviewed. Therefore, this chapter investigates the research works related to the sustainability management of GW irrigation in order to have a better understanding of sustainability concept.

2.2 Literature Review

Water, without which life would have turned totally impossible to exist. Development of human civilization has been witnessed adjacent to or along the side of extensive water bodies. In recent times, agriculture has represented itself as one of the prime sectors that consume most of the fresh water. Moreover, researchers identified how already scarce water becoming increasingly scarcer because of "rapidly increasing non-agricultural demands for water, changing food preferences, global climate change and new demands for biofuel production, … increasing costs of developing new water, soil degradation, GW depletion, increasing water pollution, the degradation of water-related ecosystems and wasteful use of already developed water supplies."[1] Researchers globally are finding ways to mitigate the crises. As a result, there has been a number of studies carried out on different aspects of GW management in the context of different

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[1] Mark W. Rosegrant, Claudia Ringler, and Tingju Zhu, "Water for Agriculture: Maintaining Food Security under Growing Scarcity," *Annu. Rev. Environ. Resour. 34* (2009): 205–22.

countries. Among them some relevant studies were reviewed in the following sections to grasp the nature of hazard and way out thereof and precautionary measures to develop a base for the present study.

2.2.1 Water Crisis

Not long ago, the issue of water use in agriculture has become the centre of discourses across the globe. As no other sectors require more water than agriculture needs. Increasing supply of freshwater for expanding urban areas, and unplanned abstraction and unscrupulous use of water from water resources located across the globe are increasingly posing threat for future generations. Globally, 80 percent countries are suffering from shortage of water resources that plunge 40 percent of world's population in difficulties.[2]

Bangladesh is an overly populated country and its food security depends largely on irrigation to ensure food for increasing population, which is exposed to its changing climate unleashed by frequent natural calamities. Processes like degradation of land, depletion of the water table and overuse of the chemicals in agriculture make it vulnerable further.[3] On the other hand, it has been revealed that Bangladesh is, on the one hand, a water scarce country and on the other hand, a water abundant country depending on its seasons – during rainy season being flooded with on rush of water from the upstream including rain water and during dry season being suffered from continuous withdrawal and diversion of water at the upstream by the neighbouring country causing severe water scarcity. Bangladesh suffers from both shortage of surface water and contamination with arsenic of its GW with increased salinity in the coastal areas.[4] Additionally, in

[2] M. Qadir, Th.M. Boers, S. Schubert, A. Ghafoor, G. Murtaza, "Agricultural water management in water-starved countries: challenges and opportunities," *Agricultural Water Management 62* (2003): 165–185.

[3] M. Qadir, Th.M. Boers, S. Schubert, A. Ghafoor, G. Murtaza, "Agricultural water management in water-starved countries: challenges and opportunities," *Agricultural Water Management 62* (2003): 165–185.

[4] Nasima Tanveer Chowdhury, "Water management in Bangladesh: an analytical review," *Water Policy 12* (2010): 32–51.

Bangladesh, the water resources have been confronting difficulties because of mixing of wastes being given off from urban and industrial areas with continuous decline in its GW table.[5] The magnitude of the water crisis varies from one place to another place because of the variations in the topography and the size of inhabitants and the nature of their habitats. Bangladesh's problems look unique because of the fact that it gets abundantly wet in rainy season and dried, in extreme cases suffers from draughts, in the dry season.

2.2.2 Agrarian Boom and Groundwater Use

Globally, the 1950s witnessed a kind of development in the GW extraction because of technological changes in tube well and pumps.[6] The subsequent 50 years has observed growing use of GW for agriculture and one-third of arable land being benefitted from such use – giving rise to a global shift. Because of such global shift, the green revolution has started to occur since the 1960s through the 1970s with the use of fertilizer, and development in irrigation systems. The process entered into second phase in the 1980s with augmented use of improved technology in agriculture.[7] Amongst myriad of sources GW has become as commendable one and GW irrigation can be credited for the agrarian boom over the last several decades.[8]

More than two-thirds (70 percent) of this irrigated land stays in Asia and contributed extensively to maintaining the food security and alleviating the poverty.[9] The rice production of Asian countries heightened to a sufficient level

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[5] Anwar Zahid and Syed Reaz Uddin Ahmed, "Groundwater resources development in Bangladesh: Contribution to irrigation for food security and constraints to sustainability," *Groundwater Governance in Asia Series* 1 (2006): 25-46.

[6] Tushaar Shah, *Groundwater Governance and Irrigated Agriculture,* TEC Background Paper 19 (Stockholm: Global Water Partnership, 2014).

[7] Derek Byerlee, "Technical Change, Productivity, and Sustainability in Irrigated Cropping Systems of South Asia: Emerging Issues in the Post-Green Revolution Era,"*Journal of International Development 4,* no. 5 (1992): 477-496.

[8] Tushar Shah, Aditit Deb Roy, Asad S. Qureshi, and Jinxia Wang, "Sustaining Asia's Groundwater Boom: An Overview of Issues and Evidence, *Natural Resources Forum* 27 (2003): 130-141.

[9] Tushaar Shah, *Groundwater Governance and Irrigated Agriculture*, TEC Background Paper 19 (Stockholm: Global Water Partnership, 2014).

over last several decades.[10] The pattern of water use in Asian countries continued based on the belief that the water is unlimited with its numerous sources available. Expansive markets for technology and tools have contributed to the increased access of the poor to irrigation in the Indian sub-continent.[11] The gradual handing over of GW exploitation to the private sector has given rise to its overexploitation, and thereby jeopardizing the sustainable use of water for both agricultural and drinking purposes. Recently, the trends of overexploitation have been showing the signs of water scarcity. A study reports that water scarcity is becoming acute not only for supplying increased water to the arid region but also because of mitigating soaring demands from increased population.[12] Positive sign is that farmers are becoming more concerned for the water resource 'depletion' and 'deterioration.' However, any attempt to make a drastic cut in water use in any time may result in endangering the food security. However, the crucial area of argument lies in the achievement of a degree of balance between the food security and sustainable use of water.

2.2.3 Reasons for the Depletion of Groundwater Table

The growth in population and economic sector, shift in social values created an upsurge in the demand for utilizing water resources in many countries like the USA. Additionally, climate change may affect the demand and the supply pattern of water, and still the rapid rising demand curve may cause the depletion of GW table due to lack of well-planned large-scale project needed for efficient water resource management.[13] In Bangladesh, Shamsuddin Shahid and Manzul Kumar

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[10] Tushar Shah, Aditit Deb Roy, Asad S. Qureshi, and Jinxia Wang, "Sustaining Asia's Groundwater Boom: An Overview of Issues and Evidence, *Natural Resources Forum* 27 (2003): 130-141.

[11] Tushaar Shah, O. P. Singh, and Aditi Mukherji, "Some aspects of South Asia's groundwater irrigation economy: analyses from a survey in India, Pakistan, Nepal Terai and Bangladesh," *Hydrogeology Journal* 14 (2006): 286–309.

[12] Tushaar Shah, *Groundwater Governance and Irrigated Agriculture,* TEC Background Paper 19 (Stockholm: Global Water Partnership, 2014).

[13] Glenn D. Schaible, and Marcel P. Aillery, *Water Conservation in Irrigated Agriculture: Trends and Challenges in the Face of Emerging Demands,* EIB-99 (USA: Department of Agriculture, Economic Research Service, 2012).

Hazarika analysed the GW hydrographs and rainfall time-series, which reveals that increasing GW extraction for irrigation during the dry season together with recurrent droughts are causing the GW level to go down in the region.[14]

Researchers (Tarikul Islam *et al.*) have been expecting that in the next 25 years, food demand of the country is expected to increase by 29 percent which will require increased cropping intensity that will increase pressure on GW and that will ultimately lead to further depletion of the source due to absence of major surface water diversion.[15] Researchers identified the nature of extraction and shortage of GW in northern part of Bangladesh. They argued the area is facing surface water shortages and the unrestricted access to GW through DTWs and STWs by farmers have prompted excessive extraction of GW for irrigation which lead to decrease of GW table.[16]

Repetitive droughts have also been identified as the reason for catastrophic natural disaster occurring because of the extraction of GW during dry season in the drought-prone northwest area of Bangladesh. The sufferings of the people in the area gets aggravated during the summer for failure in extracting GW through STWs causing the GW level to go down word, which , in turn is causing the level of underground watef table to go down too.[17] The situation deteriorated further due to an increase in arable land, production intensification of crops and unscrupulous anthropogenic intervention in the international water bodies, lack of rechargeable aquifers and regulations of GW extraction. The endeavours will continue for good to maintain an uninterrupted supply of food to additional population by resorting to effective management of water resources.

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[14] Shamsuddin Shahid and Manzul Kumar Hazarika, "Groundwater Drought in the Northwestern Districts of Bangladesh." 2010, 1989–2006. DOI:10.1007/s11269-009-9534-y.

[15] Tarikul Islam, M Monowar Hossain, and A F M Afzal Hossain, "Integrated Water Resources Management : A Case Study for Barind Area , Bangladesh,"*IOSR Journal of Mechanical and Civil Engineering* 11, no. 5 (2014): 1–8, www.iosrjournals.org.

[16] Qureshi, Ahmed, and Krupnik, "Moving from Resource Development to Resource Management," DOI: 10.1007/s11269-015-1059-y.

[17] Shamsuddin Shahid, and Manzul Kumar Hazarika, "Groundwater Drought in the Northwestern Districts of Bangladesh," *Water Resour Manage* 24 (2010):1989–2006.

2.2.4 Climate Change and Groundwater

It has been predicted that climate change will turn the water use sustainability vulnerable. However, in a study, the authors argued that in Bangladesh, induced demand for water by climate change will be insignificant and expected to increase up to three percent projected for the year of 2050. According to their modelling, the demand for water will soar aloft up to another 20 percent for the same target year, due to fulfilling demand for food for the increased population.[18]

Richard G. Taylor *et al*. indicates climate change affects GW use through impacting recharge volume directly and through determining use of water indirectly.[19] However, they argue that human society through shifting their activities can counterbalance climate change induced imbalance. In another study, the authors' fundamental argument is that climate change will affect both resources of water and demand for water.[20] Hence, they call for a coordination of resources and demand for achieving a balance between them. However, they warn against 'water-resources depletion, increasing irrigation demand, reduced crop yield, and GW salinization' and ask for actions—data driven decision, exploit seasonal advantage, offer effective prediction, multiple use of irrigation facilities.

The study findings of Habiba *et al.* revealed that farmers became aware of climate change, and drought was the prominent reason for disaster resulted from fluctuation in rainfall and temperature. Moreover, concerns such as 'GW depletion, lack of canal and river excavation, increased population, and

[18] Mohammed Mainuddin, Mac Kirby, Rehab Ahmad Raihan Chowdhury, and Sardar M. Shah-Newaz, "Spatial and temporal variations of, and the impact of climate change on, the dry season crop irrigation requirements in Bangladesh," *Irrig Sci* (2014), DOI: 10.1007/s00271-014-0451-3.

[19] Richard G. Tylor et al., "Ground Water and Climate Change," *Nature Climate Change* 3, no. 4 (April 2013): 322-329.

[20] Yu Zhou, François Zwahlen, Yanxin Wang, and Yilian Li, "Impact of climate change on irrigation requirements in terms of groundwater resources," *Hydrogeology Journal 18* (2010): 1571–1582.

deforestation' remained in their cognizance. The impacts of the climactic shifts became visible in their health and social life.[21]

In Bangladesh global climate change scenarios have been due to recurrent and grave droughts that occurred in north and north western part of Bangladesh. The risk and vulnerability assessment map delivered that the situation in that part aggravated due to presence of persistent poverty, dependency on agriculture and irrigation.[22] Another study suggests that effects of climate change in Bangladesh is observed with water scarcity, more elevated temperature and inadequate level of rainfall, and depleted forest cover. Water scarcity in Bangladesh, particularly in North West part of the country deteriorated because of environmental change due to global climate change and has deteriorated further for action undertaken by the neighbouring country. Consequently, the country has been experiencing a drought in an average of a 1.6-year span for last three decades.[23]The literature reveals a blend of several negative outcomes because of varying intensity of climate change in agriculture. The drought of North West part of Bangladesh is induced by many factors, and climate is one of them but Mainuddin et al.[24] understood that water use sustainability will be more vulnerable for increased population than for climate change.

2.2.5 Unsustainable Groundwater Use

C.S. Jahan and others revealed that GW level declined substantially during the last decade, which has posed a threat to sustainable water use for irrigation in this

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[21] Umma Habiba, Rajib Shaw, Yukiko Takeuchi, "Farmer's perception and adaptation practices to cope with drought: Perspectives from Northwestern Bangladesh," *International Journal of Disaster Risk Reduction 1* (2012): 72–84.

[22] Shamsuddin Shahid, and Houshang Behrawan, "Drought risk assessment in the western part of Bangladesh," *Nat Hazards 46* (2008): 391–413.

[23] Alice Mbugua, *Research Report on Water Scarcity in Northern Bangladesh* (Dinajpur: International volunteer, VSO and GBK, 2011).

[24] Mohammed Mainuddin, Mac Kirby, Rehab Ahmad Raihan Chowdhury, and Sardar M. Shah-Newaz, "Spatial and temporal variations of, and the impact of climate change on, the dry season crop irrigation requirements in Bangladesh," *Irrig Sci* (2014), DOI: 10.1007/s00271-014-0451-3.

region with having impact upon other sectors too.[25]A study, in the USA, reveals that overdraft of ground-water results in lowering of surface water level, loss of vegetation, sink of land and intrusion of saline water from sea.[26] However, the relationship between GW overrating and its impacts in the long run stays complex and the context determine the course. A study in Bangladesh,[27] identifies sustainability in GW use is at stake—because of overdraft of water for agriculture, insufficient level of rainfall, lack of natural recharge, decrease of wetland areas, reduction of surface water level and bodies. However, Bangladeshi water policies until in the past did not focus on sustainability of water use, rather emphasis was put on expanding agricultural production for ensuring food security, safe drinking water and sanitization as well as flood control.[28]

Mobin-ud Din Ahmad and others claim that dry season irrigation mainly uses GW, but the extent of its use is thoroughly unknown to the users. Use of shallow aquifers for irrigation in the *Barind* area of northwest Bangladesh is unsustainable. They also claim in their article that GW is being used unsustainably in some areas and a spatial time series (1990 to 2010) of pre and post-monsoon GW depth changes in the northwest region of Bangladesh suggests that, with the current level of GW use, declining GW levels may constitute a long-term threat to the sustainability of irrigation based agriculture in most of the region.[29]

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[25] C.S. Jahan et al., "Impact of Irrigation in Barind Area, NW Bangladesh - an Evaluation Based On the Meteorological Parameters and Fluctuation Trend in Groundwater Table," *Journal of Geological Society of India* 76, no. 2 (2010): 134-142, http://www.geosocindia.org /index.php/jgsi/article,

[26] S. Zektser, H. A. Loa´iciga, and J. T. Wolf, "Environmental impacts of groundwater overdraft: selected case studies in the southwestern United States," *Environmental Geology 47* (2005): 396–404.

[27] Nepal Chandra et al., *Sustainability of Groundwater Use for Irrigation in Northwest Bangladesh* (Dhaka: National Food Policy Capacity Strengthening Programme (NFPCSP) Phase II, 2013).

[28] Sudip K. Pal, Adebayo J. Adeloye, Mukand S. Babel, and Ashim Das Gupta, "Evaluation of the Effectiveness of Water Management Policies in Bangladesh," Water Resources Development 27, no. 2 (June 2011): 401–417.

[29] Mobin-ud Din Ahmad et al., "Groundwater Use for Irrigation and its Productivity: Status and Opportunities for Crop Intensification for Food Security in Bangladesh," *Water Resources Management* 28, no. 5 (March): 1415-29, http://dx.doi.org/10.1007/s11269-014-0560-z.

The authors of a study believe, "Sustainability of irrigated agriculture will depend partly on whether producers adopt more efficient irrigation production systems that integrate improved on farm water management practices with efficient irrigation application systems."[30] The study of Tiwari and Dinar reveal that 'water use efficiency' in the past relied on engineering or technological improvement, but presently it requires an integrated approach by including government, suppliers, and users as actors and 'economic, institutional, agronomic, and hydrological and ecological constraints' as areas to act with for policy involvement.[31] Over the period scenarios have changed extensively and scarcity of water particularity depletion of GW becoming blatant and thus, confronting challenges through technological feats will not be enough rather require an integrated and a comprehensive actions.

2.2.6 Rate of Groundwater Depletion

Nepal Chandra Dey and others revealed in their research that over the 30-years (1981-2011) GW table was declining, which implies GW use was unsustainable in the NW Bangladesh. The degree of the decline in GW table has been marked between -2.3 to -11.5m during that period. This predominantly occurs due to over exploitation of GW than recharging aquifer.[32] The depletion of GW continues to occur in absence of artificial and natural recharges.

2.2.7 Low Average Rainfall

The average annual rainfall varies from 1,200 mm in the extreme west to over 5,000 mm in the northeast.[33] The researcher, Nasima Tanveer Chowdhury, showed in

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[30] Glenn D. Schaible, and Marcel P. Aillery, *Water Conservation in Irrigated Agriculture: Trends and Challenges in the Face of Emerging Demands*, EIB-99, Abstract (USA: Department of Agriculture, Economic Research Service, 2012).

[31] Dirgha Tiwari and Ariel Dinar, "Role and use of economic incentives in irrigated agriculture," *WORLD BANK TECHNICAL PAPER* (2002): 103-122.

[32] Nepal Chandra Dey et al., *Sustainability of Groundwater Use for Irrigation in Northwest Bangladesh* (Dhaka: National Food Policy Capacity Strengthening Programme, 2013), 3.

[33] Bangladesh Meteorological Department, http://www.bmd.gov.bd

her research that four seasons are identified on the basis of rainfall patterns.[34] About 80 percent of the total rainfall occurs during the monsoon from June to September. In the post-monsoon (October–November) and winter period (December–February) only 10 percent of the annual rainfall is available. Rainfall is extremely unreliable in the subsequent pre-monsoon period (March–May). On an average there is about 10 percent of the annual rainfall in this period. Therefore, there is a seasonal lack of water depending on the presence and the duration of the monsoon. Insufficient raining and drought in the north-western part of Bangladesh crippled local people because of the crisis of drinking water as hand tube-well, turned dry along with surface water bodies and resulted in health problems such as dysentery and diarrhea due to hazardous drinking water.[35] Erratic nature of rainfall increased dependency of local people on GW during dry season as 80 percent of rainfall in rainy season flooded the delta area of Bangladesh.

2.2.8 Decreasing Trend of Wetland

Nepal Chandra Dey and others found in NW Bangladesh where around one-third of total wetlands have been lost during 1989-2010.[36] In addition, the rate of decrease was considerably lower in 2000 - 2010 than in 1989-2000. They also found below average rainfall over the year in the study area. Researchers identified that GW recharge depends on two notable contributors— rainfall and flood where wetland plays as a media for continuously recharging the aquifers.

2.2.9 Vulnerable Groundwater Recharge

A study, based on the Indian state of Orissa, revealed that GW can be used sustainably for enhanced production of crops through resorting to managed aquifer recharge (MAR). The technique involves banking of water underground

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[34] Chowdhury, Nasima Tanveer. "Water management in Bangladesh: an analytical review." *Water policy* 12, no. 1 (2010): 32-51.

[35] Nepal Chandar Dey et al., "Assessing Environmental and Health Impact of Drought in the Northwest Bangladesh," *J. Environ. Sci. & Natural Resources 4* (2) (2011): 89-97.

[36] Dey, *Sustainability of Groundwater Use for Irrigation in Northwest Bangladesh*, 3.

by infiltrating excess water of the rainy season through ASR-wells (aquifer storage and recovery). However, the process could be slowed down because of clogging of recharge-well with unwanted particles, which need to be filtered mechanically and technologically.[37]

In Bangladesh, Md. Abdullah Aziz and others have identified that GW recharge condition is exceedingly poor in the *Barind* area and vulnerable for *boro* rice i.e. irrigated rice and the leading source of recharging GW aquifer in this area is rainfall, but rainfall is also dropping here.[38] Researchers also mentioned that the average rates of maximum intensity (during dry season) and minimum intensity (during wet season) in GW depletion are 0.23 meter/year and 0.38meter/year respectively. The rate of declination of minimum depth is steeper than that of the maximum which implies GW recharge coming down due to withdrawal of excessive GW. Replenishment of aquifer level by artificial recharge has significant effects on balancing GW table.

2.2.10 Intensity of Tube-wells

In Bangladesh, GW extraction has been contributing to increasing food security since the 1960s. The process of GW lifting paced fast during the mid-1970s with installing of DTW with a subsequent shift to STW. About 75 percent of the irrigated land uses GW and the rest uses surface water. Moreover, of the lifted GW nearly 70-90 percent is used for agricultural production purpose and the rest for drinking and other purposes.[39] Historically, in the 1980s, efforts were there to withdraw GW, believed to be abundant in amount, through deep, shallow, and hand tube-wells.

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[37] H.M. Holländer, R. Mull, S.N. Panda, "A concept for managed aquifer recharge using ASR-wells for sustainable use of groundwater resources in an alluvial coastal aquifer in Eastern India," *Physics and Chemistry of the Earth 34* (2009): 270–278.

[38] Md. Abdullah Aziz et al., "Groundwater Depletion with Expansion of Irrigation in Barind Tract: A Case Study of Rajshahi District of Bangladesh," *International Journal of Geology, Agriculture and Environmental Sciences* 3, no. 1 (February 2015): 32, https://www.woarjournals.org.

[39] Anwar Zahid and Syed Reaz Uddin Ahmed, "Groundwater resources development in Bangladesh: Contribution to irrigation for food security and constraints to sustainability," *Groundwater Governance in Asia Series* 1 (2006): 25-46.

Moreover, before the 1980s, the government undertook efforts to popularize the use of GW for irrigation and after the mentioned period, in the subsequent phases emphasis was put on the equitable development and resource management through increased involvement of the private sector.[40]

Nepal Chandra Dey and others reveal that STWs and DTWs are the major GW lifting devices used in the NW Bangladesh.[41] These researchers also revealed that the intensity of using tube wells has increased manifolds – the amount of command area per unit of tube well has drastically reduced from 14.5 to 2.8 hectares during 1984-85 to 2010-11 indicating an increase in the number of tube wells by 8.5 times, which is much more than the increase in irrigated land by 1.6 times. The unrestricted pattern of installing multiple forms of tube wells lead to over extraction and misuse of water jeopardizing the sustainability in the use of GW.

2.2.11 Expansion of *Boro* Area and Wastage of Irrigation Water

Because of expansion of GW facilities, crop areas, particularly of *boro* rice, have increased significantly over time, Nepal Chandra Dey and others argued.[42] The area of 10 chief crops has increased three times where *boro* area alone has increased around 17 times in 2010-11 than that in 1980-81. Due to defects in the present management system of irrigation water, 78.7 percent of the lifted water is essential for *boro* and the rest 21.3 percent was considered as excess water which leads to increases in irrigation as well as production cost. It stands evident here that lack of variation in crop production and excessive inclination to rice production affects GW lifting negatively.

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[40] Sadiqul I. Bhuiyan, "Groundwater Use for Irrigation in Bangladesh: The Prospects and Some Emerging Issues," *Agricultural Administration 16* (1984): 181-207.

[41] Dey, *Sustainability of Groundwater Use for Irrigation in Northwest Bangladesh*, 3.

[42] Ibid.

2.2.12 Man-made Droughts

Shamsuddin Shahid and Manzul Kumar Hazarika found that the declination of GW of NW Bangladesh is not merely due to the deficit of rainfall, but also due to overexploitation of GW resources, it can be concluded that GW droughts in the area is mainly human-induced droughts which are better termed as GW scarcity.[43]

More the poor people are getting engaged in agricultural profession more the deforestation occurs resulting in the increased possibility of man-made droughts being occurred.

2.2.13 Groundwater and Irrigated Economy

In arid western China there are conflicts between pro-environment protectionist and pro-economic development activists. Once the irrigation from the rivers was encouraged highly for potentials of economic development, however, observing negative environmental consequences, attempts have been made to secure sustainable use of water.[44] Nevertheless, the efforts created anger among communities that depend on the river water, the menacing challenges of the areas are still in force to balance between pro-environment protectionist and pro-economic development advocates with diverse information and ideas.

Asad S. Qureshi and others found problems associated with the excessive exploitation of GW notably declining water tables, decreasing water quality, increasing energy costs and carbon emissions are threatening the sustainability of Bangladesh's GW irrigated economy.[45] However, an others' study on crop

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[43] Shahid, and Hazarika, "Groundwater Drought in the Northwestern Districts of Bangladesh," DOI:10.1007/s11269-009-9534-y.

[44] Xiaoping Yang, Jufeng Dong and Paul D. White, "The Key Role of Water Resources Management in X. Yang, J. Dong and P.D. White: Water Resources Management in Ecological Restoration in Western China Ecological Restoration in Western China," *Geographical Research* 44(2), (June 2006): 146–154.

[45] Qureshi, Ahmed, and Krupnik, "Moving from Resource Development to Resource Management," DOI: 10.1007/s11269-015-1059-y.

production reveals an increase in the volume of crops proportionate to water use.[46] Therefore, a dilemma is existing as to determining a balance between the need for keeping the environment intact and need for achieving development.

2.2.14 Water Pricing and Management of Groundwater Demand

The study of Rao in Indian context suggests that increased charges for water would augment water productivity and ensure prudent use of water. However, the study being aware of political viability asks for empowerment of users' organizations or *panchayats* to collect and retain the rates to them to reinvest for better service delivery in future.[47] The study of Alauddin and Quiggin also argues for increasing charge for water to compensate the external cost stemming from 'marginal environmental damage.'[48] Moreover, it concludes that no single effort stands enough to ensure application of the sustainable approach for water use, thus needs integrated measures. Water pricing (elevating) to manage prudent use of water is a worthy efforts, but the question which should be answered is how the poor farmers react with increasing cost on water and overall production.

2.2.15 Management of Groundwater Demand

According to M I U Mollah, studies in Bangladesh have shown that bed planting technique can save up to 40 percent water compared to flood irrigation, in addition to more significant massive margins. Even adoption of alternate wetting drying (AWD)[49] in Bangladesh could save 20–30 percent of the water used in flooded rice,

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[46] Nepal Chandra Dey and his colleagues, *Sustainability of Groundwater Use for Irrigation in Northwest Bangladesh* (Dhaka: National Food Policy Capacity Strengthening Programme (NFPCSP) Phase II, 2013).

[47] C. H. Hanumantha Rao, "Sustainable Use of Water for Irrigation in Indian Agriculture," *Economic and Political Weekly 37*, no. 18 (May 4-10, 2002): 1742-1745.

[48] Mohammad Alauddina, John Quiggin, "Agricultural intensification, irrigation and the environment in South Asia: Issues and policy options," *Ecological Economics 65* (2008): 111-124.

[49] Alternate Wetting and Drying (AWD) is a water management technique used to grow irrigated lowland rice with much less water than conventional systems that maintain continuous water putting in crop fields. This is a controlled and sporadic irrigation method.

amounting to US$ 73.5 million worth of irrigation cost on 4.8 million hectares of *boro* land area.[50]

2.2.16 Resiliency of Farmers against Scarcity of Water

Water scarcity, in one hand, plunge farmers in difficulties and making them resilient on the other hand, because of adoption of varied techniques by them. A study reveals that the farmers employ varied adaptation methods, such as cultivating science invented variety, using natural resources like GW, and adopting crop-switching like extending emphasis on non-rice crops, to mitigate unwanted outcomes of climate change.[51] However, the dominant nature of adaptation strategies follow increased use of natural resources rather than switching to cropping patterns. The farmers came forward to address the issues with adjustment in 'agronomic management, crop intensification, water resource exploitation' and such other measurements. It also revealed that (land) owner farmers displayed comparatively extended capacity to cope with the climate change with increased use of contemporary technologies.[52]

The study of Alam, in Bangladesh, claims that rice farmers with better education, extensive experience, awareness of global change due to climate variability, and access to facilities, and land ownership display augmented resiliency and adaptability against water scarcity in semi-arid areas. The study further argues that farmer's socioeconomic conditions influence the decision on adaptation measures. It also claims that present dependency on GW is not a

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[50] M I U Mollah, M S U Bhuiya, and M H Kabir, "Bed Planting – A New Crop Establishment Method for Wheat in Rice- Wheat Cropping System" *Journal of Agriculture & Rural Development* 7, June 2009: 23–31,http://www.banglajol.info/index.php/jard.

[51] Mohammad Alauddin, Md Abdur Rashid Sarker, "Climate change and farm-level adaptation decisions and strategies in drought-prone and groundwater-depleted areas of Bangladesh: an empirical investigation." *Ecological Economics 106* (2014): 204–213.

[52] Umma Habiba, Rajib Shaw, Yukiko Takeuchi, "Farmer's perception and adaptation practices to cope with drought: Perspectives from Northwestern Bangladesh," *International Journal of Disaster Risk Reduction 1* (2012): 72–84.

sustainable solution to the water scarcity.[53] In this background, Byerlee's paper emphasises more on development of soil quality instead of GW depletion and salinization for ensuring sustainability of grain production.[54] The argument authors forwarded stood on the exploitation of GW to mitigate effects of climate change, however, due to scarcity of GW, innovative alternatives are to be offered and need to be explored.

2.2.17 Lack of Institutional Coordination

Coordination among varied actors stands as key to face changelings regarding water scarcity. For example, local government institutions in Namibia have been struggling to deliver quality services to their constituents. Locally these are trusted more than other private entities, however, need ideologically committed and coordinated support from national government to be effective with good governance.[55] On the other hand, economic incentive measures remain one of the effective ways to ensure efficiency in water use but needs to complement by other policy instruments. It is satisfactory to make 'water management transfer' to the user groups however needs to ensure efficiency in water use. To this end, the paper claimed that existing subsidy system fetches benefits for other actors rather than the impoverished peasants.[56] Thus, there arises a need for achieving coordination amongst varied approaches and actors.

A report regarding water governance in Bangladesh entitled *Water Governance in Bangladesh* explored that a total of seven Ministries have been

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[53] Khorshed Alam, "Farmers' adaptation to water scarcity in drought-prone environments: A case study of Rajshahi District, Bangladesh." *Agricultural Water Management 148* (2015): 196–206.

[54] Derek Byerlee, "Technical Change, Productivity, and Sustainability in Irrigated Cropping Systems of South Asia: Emerging Issues in the Post-Green Revolution Era," Journal of International Development 4, no. 5 (1992): 477-496.

[55] Farhad Hossain, and Tuhafeni Helao, "Local Governance and Water Resource Management: Experiences from Northern Namibia," *Public Admin. Dev. 28* (2008): 200–211.

[56] Dirgha Tiwari and Ariel Dinar, *Role and Use of Economic Incentives in Irrigated Agriculture* (Washington: World Bank, n.d.).

involved with the country's water management.[57] This tale reports that 30 ministries with 35 departments are responsible for use of river water and other water resources altogether. But a considerable lack of coordination among these institutions constitute the principal obstacles to good water governance.

2.2.18 Resource Development vs. Resource Management

The debate goes that what approach should be adopted to make use of resources sustainably. The water development mode regarding water usages needs to be transformed into water management.[58] However, Smith is against the assumption, as he includes, "New irrigation developments should not be completely ruled out."[59] He argues for the 'livelihood-centred' and all-inclusive pattern of evaluation of GW use and suggests taking necessary steps in this line as there stands no substitutive ways other than agriculture in the rural areas; though there exist non-farm activities but they are related to agriculture mostly. Still he is concerned about the cost of the environment and construction that accrued from over-extraction of GW. The high cost incurred in environment may endanger balance between cost and profit of agriculture. Smith further argued that irrigated farming varies widely in its form and impacts and displays diverse local attributes and water resource management decisions must recognize this, in addition to the costs that goes beyond food production objectives.[60] With further development Sophocleous argues for inventing multiple approaches to water management.[61]

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[57] *Water Governance in Bangladesh: Challenges and Opportunities Around Policy, Institutional Function and Implementation for a Sustainable Water Future* (Gland: Worldwide Fund for Nature, 2014), 19, http://d2ouvy59p0dg6k.cloudfront.net/downloads/wwf_hm___water_ governance_in_ bangladesh_ published.pdf.

[58] Tushar Shah, Aditit Deb Roy, Asad S. Qureshi, and Jinxia Wang, "Sustaining Asia's Groundwater Boom: An Overview of Issues and Evidence, *Natural Resources Forum* 27 (2003): 130-141.

[59] Laurence E. D. Smith, "Assessment of the contribution of irrigation to poverty reduction and sustainable livelihoods," *International Journal of Water Resources Development* 20, no. 2, (2004): 243-257.

[60] Laurence E. D. Smith (2004) Assessment of the contribution of irrigation to poverty reduction and sustainable livelihoods, International Journal of Water Resources Development, 20:2, 243-257

[61] Marios Sophocleous, "The evolution of groundwater management paradigms in Kansas and possible new steps towards water sustainability," *Journal of Hydrology* 414–415 (2012): 550–559.

In India, the authors emphasize awareness building for users of GW and general agreement of political and administrative authorities on optimal water resource management. The overriding concerns in the area have been depletion of GW table, increase of salinity due to fall of water table in the coastal areas, quality of GW due to presence of arsenic and fluoride, abortive precautionary measures of government such as laws.[62] On the other hand, in Bangladesh, Asad S. Qureshi and others have identified that the emphasis in the past has been on the development of GW resources, but not on the management of this resource and this ultimately has constituted numerous problems which are threatening the sustainability of irrigated agriculture and future food security of Bangladesh.[63] The issue of development cannot be ignored, and there is a debate on the issue of development or management; however, it needs to be optimum with increased attachment of material techniques.

2.2.19 Policy Reforms

Studies on sustainable water use remain excessive, and so are the policy reforms. A study emphasizes water governance to deal with competent policy formulation, implementation and functioning of water managers at grassroots. Governance is concerned with balancing conflicting interest groups in water use and regulating derogative water use. The strong water governance needs to include the statutory framework applicable for all stakeholders, inclusive decision-making with long-term vision and policy making in the similar direction. For Bangladesh the 2013 Water Act stands as the significant progress in policy level.[64]

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[62] Dhirendra Kumar Singh, and Anil Kumar Singh, "Groundwater Situation in India: Problems and Perspective," *Water Resources Development* 18, no. 4 (2002): 563–580.

[63] Qureshi, Ahmed, and Krupnik, "Moving from Resource Development to Resource Management," DOI: 10.1007/s11269-015-1059-y.

[64] Centre for Resource Development Studies Ltd., *Water Governance in Bangladesh Challenges and Opportunities around Policy, Institutional Function and Implementation for A Sustainable Water Future* (Dhaka: Centre for Resource Development Studies Ltd., 2015).

Asad S. Qureshi and others opined, like other South-Asian countries, that institutional solutions to GW management in Bangladesh have been complicated to implement because political leaders remain under pressure to ensure adequate food supplies for the population and reduce poverty, especially in rural areas.[65] The researchers of this study, identified the absence of coordination between the institutions and their management. In addition, policy reforms are needed to address the managerial and organizational issues of present institutions, with increased clarity in their roles and responsibilities as well.

In another segment, Vincent warns against smallholders' lack of rights and equity in water resources due to existing challenges in the modern era. He argues that sometimes sustainable water use requires the management to use myriad of indigenous social forces more than the mere scientific innovation and/or tools. He further iterates that user-centric frameworks may confirm better practices in water management with sustainability.[66] In similar efforts, the authors of another study emphasized the involvement of indigenous social institutions in water management for sustainability.[67] Correspondingly, Scheumann and Freisemalso reveal that transferring irrigation system to the organizations of the farmers brings augmented results in irrigation systems.[68]

In Bangladesh seasonal rainfalls, geographic and topographic contexts render as impediments to development and previously through water management these constraints were overcome to some extent at the cost of the environment and social undesirable effects.[69] This study also suggests for participation of stakeholders

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[65] ibid.

[66] Linden F. Vincent, "Towards a Smallholder Hydrology for equitable and sustainable Water Management," *Natural Resource Forum* 27 (2003): 108-116.

[67] M. Wakilur Rahman, Mohammad Razu Ahmed, and Rayhan Hayat Sarwer, "An Investigation of Groundwater Irrigation and Command Area Management Issues in Bangladesh," Journal of Knowledge Globalization 4, No.1 (2011): 93-114.

[68] Scheumann, W and C. Freisem, "The role of drainage for sustainable agriculture," *Journal of Applied Irrigation Science* 37, no. 1 (2002): 33 – 61.

[69] Ashim Das Gupta, Mukund Singh Babel, Xavier Albert and Ole Mark, "Water Sector of Bangladesh in the Context of Integrated Water Resources Management: A Review," *International Journal of Water Resources Development* 21:2 (2005): 385-398.

as part of the integrated water management to ensure sustainability. The study asks for decentralized initiatives, valuing water, developing skilled personnel, relevant knowledge-based policy formulation and coordinating with actors outside the national boundaries. Similarly, Jennifer E. Duyne argues for decentralization to stimulate people's participation.[70] Similarly, Dey *et al.* urges for ecological balance through ensuring community participation at grassroots and policy support from the centre to focus on irrigation management, climate change adaptability and crops diversity.[71] However, Duyne emphasized enhancing roles of local bodies at grassroots with discretionary decision-making authority supported by resource supply and indigenous organizations for water management based on local context.[72] Furthermore, she suggests for removal of clientelism relation between local bodies and government/NGOs. In the same manner, other researchers suggest that the sustainability of the GW needs be muscled by conservation measures, achieving of efficiencies in water use, and balancing reallocation of water among the competing demands makers.[73]

Some researchers suggest for applying water pricing mechanism reflecting opportunity cost and use of the economic incentive mechanism in agriculture through incentivizing less water incentive crops.[74]Nevertheless, the study claims that efficiency of water use through pricing stay improbable and thus, needs a decentralized water recourse allocation mechanism through confirming equitable access to water resources.[75]

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[70] Jennifer E. Duyne, "Local Initiatives: People's Water Management Practices in Rural Bangladesh," *Development Policy Review 16* (1998): 265-280.

[71] Nepal Chandra Dey and his colleagues, *Sustainability of Groundwater Use for Irrigation in Northwest Bangladesh* (Dhaka: National Food Policy Capacity Strengthening Programme (NFPCSP) Phase II, 2013).

[72] Jennifer E. Duyne, "Local Initiatives: People's Water Management Practices in Rural Bangladesh," *Development Policy Review 16* (1998): 265-280.

[73] Glenn D. Schaible, and Marcel P. Aillery, *Water Conservation in Irrigated Agriculture: Trends and Challenges in the Face of Emerging Demands,* EIB-99(USA: Department of Agriculture, Economic Research Service, 2012).

[74] Nasima Tanveer Chowdhury, "Water management in Bangladesh: an analytical review," *Water Policy 12* (2010): 32–51.

[75] Robert C. Johanssona, Yacov Tsurb, Terry L. Roec, Rachid Doukkalid, and Ariel Dinar, "Pricing irrigation water: a review of theory and practice," *Water Policy 4* (2002): 173–199.

For ensuring water use sustainability the following areas are presented as key stones to increase water use—ground and surface—efficiency, building barrages over large and average rivers for increased availability of surface water, and building water research institutions for data driven water management.[76] Another study suggests that better water and crop management, augmentation of water supplies with other sources, increased public awareness and education, intensified watershed and local planning, and water conservation is necessary in the north western and northern Bangladesh for reducing the impact of draught.[77]

2.2.20 One Size Might Not Fit All

The process of water use and governance sometimes led to vulnerability of the environment, when experience of one country directly being applied to another country's problem without considering the suitability for its application to solve that problem, since every country has its own unique types of problems. To resolve many of the problems, policymakers replicate water governance of the developed countries of the west without considering the diverse set of contextual elements, resulting in no significant change in reality except for the so called change, which is only found in the paperwork. The study emphasized socio-ecological and political environment as the determining factors of GW management and mentioned GW and aquifers are less important compared to the former elements, particularly, because in South Asian countries almost halves of the population depend on GW, while it is sparse in western countries. As demonstrated, the government concerned did not want to irritate people by implementing tough regulatory provisions and continued providing incentives to GW extraction in one hand and pronouncing rhetoric words for curtailing GW use on the other hand. The study concluded that there was no sole measure for confirming sustainability

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[76] The World We Want, and Global Water Partnership South Asia, *National Stakeholder Consultations on Water: Supporting the Post-2015 Development Agenda*, The Post 2015 Water Thematic Consultation (Dhaka: The World We Want, and Global Water Partnership South Asia, 2013).

[77] Shamsuddin Shahid, and Houshang Behrawan, "Drought risk assessment in the western part of Bangladesh," *Nat Hazards 46* (2008): 391–413.

of GW use and suggested for removal of dualism, and initiatives for capacity building of government and community to enact legal provisions and supply varied administrative instruments to govern water use.[78]

Shah *et al.* principally suggested for a decentralization of management of water resources by involving organizations at the grassroots, communities, NGOs and local government institutions. However, they remain concerned about variety of contexts and warn against following western world's solutions with their variety of technologies and financial muscle to manage water use, as the context and pattern of use of water in the developing countries are different because of high population density and scores of private small individual users.[79]

2.2.21 Innovation

Suggestions are there for Researcher to manage water crisis pervasive in the agricultural sector by adopting technology. The recently developed "alternate wetting and drying" (AWD)[80]—water the irrigated field to a required depth (the depth is measured through a low-cost perforated 'filed water tube') and allow the field to dry and re-irrigate the same field after dissipation of the water—thereby becoming successful in reducing water consumption up to 38 percent and deliver economic benefit 38, 32, and 17 percent in Bangladesh, the Philippines and southern Vietnam respectively. Through national policy support, the technology is being disseminated and implemented extensively in the region.[81]

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[78] Tushaar Shah, *Groundwater Governance and Irrigated Agriculture*, TEC Background Paper 19 (Stockholm: Global Water Partnership, 2014).

[79] Tushar Shah, Aditit Deb Roy, Asad S. Qureshi, and Jinxia Wang, "Sustaining Asia's Groundwater Boom: An Overview of Issues and Evidence, *Natural Resources Forum* 27 (2003): 130-141.

[80] The technology is developed and promoted the International Rice Research Institute (IRRI) and its national agricultural research and extension system (NARES) partners.

[81] Rubenito M. Lampayan, Roderick M. Rejesus, Grant R. Singleton, Bas A.M. Bouman, "Adoption and economics of alternate wetting and drying water management for irrigated lowland rice," *Field Crops Research 170* (2015): 95–108.

To offset the soaring demand for sustainably, the emphasis is on water management, which include changing of the date of the plantation, as their study revealed that earlier and later plantation of a season can help reduce water use. Moreover, the farmers can sow alternate crops, which required less water use.[82]

The study of Rosegrant et al. urges to invest for management and incentive policy reforms to ensure efficiency in water use focusing on three key areas—technical, managerial and institutional by modernizing and upgrading. Through these processes it is expected that irrigation water can be saved, domestic sewerage water can be treated, and industrial wastewater can be recycled for sustainable use of water.[83]

In Bangladesh, the study of Alam suggests for securing soil moisture through mulching and increased use of surface water through water harvesting by building reservoirs to store rain and river water for sustainability against water scarcity.[84] Shahid and Hazarika suggest for surface water resource management and development of rechargeable aquifers as well as regulate GW extraction to sustain the resource.[85]

2.2.22 Comprehensive Efforts

The researchers argued that water resources should be not be considered discretely, rather it should be taken into account as an integral part of social and national development to ensure its efficient use.[86] Prevailing Knowledge of water

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[82] Mohammed Mainuddin, Mac Kirby, Rehab Ahmad Raihan Chowdhury, and Sardar M. Shah-Newaz, "Spatial and temporal variations of, and the impact of climate change on, the dry season crop irrigation requirements in Bangladesh," *Irrig Sci* (2014), DOI: 10.1007/s00271-014-0451-3.

[83] Mark W. Rosegrant, Claudia Ringler, and Tingju Zhu, "Water for Agriculture: Maintaining Food Security under Growing Scarcity," *Annu. Rev. Environ. Resour. 34* (2009): 205–22.

[84] Khorshed Alam, "Farmers' adaptation to water scarcity in drought-prone environments: A case study of Rajshahi District, Bangladesh." *Agricultural Water Management 148* (2015): 196–206.

[85] Shamsuddin Shahid, and Manzul Kumar Hazarika, "Groundwater Drought in the Northwestern Districts of Bangladesh," *Water Resour Manage* 24 (2010):1989–2006.

[86] Rob Koudstaal, Frank R. Rijsberman and Hubert Savenije, "Water and sustainable development," International Conference on Water and the Environment ~ Development Issues for the 21st Century. 2 6 3 1 January 1992, Dublin, Ireland.

governance, traditionally, focuses on resource perspective and the two other perspectives—user and policy perspectives—received reduced attention. Researchers argue that for reducing negative impacts of GW use without hampering long-term benefits, i.e. sustainability management, it is required to blend all these three perspectives through integration of soft science with physical science of hydrology and hydrogeology.[87] Similarly, a workshop in Ethiopia came to a conclusion that as research capacity is fragmented, therefore, interdisciplinary approach incorporating social, physical and biological sciences can be useful to better understanding of sustainable management of water.[88]

Researchers suggest for integration or combination of four pillars to mitigate the problems of the regions of water deficiency and are predicted to be acute more in the future. These four pillars are – 1) balancing needs by exporting crops which require less water and importing water intensive crops, 2) ensuring efficient use of existing resources—water and land, 3) confirming efficient and effective methods for degraded land and polluted water improvement, and 4) warranting "re-use of saline and/or sodic drainage waters via cyclic, blended, or sequential strategies for crop production systems" pragmatically.[89]

Researchers warn against polluted water and degraded soil, negative impacts of climate change and conflict of waters users – agriculture, increased urbanisation and industrialization, etc., particularly in the developing countries, typically produce pressure on water governance. There will be an increased need for water for industrial and domestic uses because of increased population, and surely, the additional requirement for water will be fulfilled by taking away a share

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[87] Aditi Mukherji, and Tushaar Shah, "Groundwater socio-ecology and governance: A review of institutions and policies in selected countries," *Hydrogeol J 13* (2005):328–345.

[88] P.G. McCornick, A.B. Kamara, and Girma Tadesse (eds.), *Integrated water and land management research and capacity building priorities for Ethiopia*, "outcomes of the workshop," proceedings of a MoWR/EARO/IWMI/ILRI international workshop held at ILRI, Addis Ababa, Ethiopia, 2–4 December 2002.

[89] M. Qadir, Th.M. Boers, S. Schubert, A. Ghafoor, G. Murtaza, "Agricultural water management in water-starved countries: challenges and opportunities," Agricultural Water Management 62 (2003): 165–185.

of water from agricultural. Therefore, the crisis for water will worsen further, resulting in a halt in the expansion of agricultural activities with diminishing use of land with declining productivity. Consequently, the developing countries' dependency on import for food security to satisfy internal needs will increase, despite their endeavours to increase cereal yield.[90] There is a need for an integrated measure be taken comprising the global actors with emphasis on promoting indigenous methodology mingled with modern techniques, empowerment of users, ensuring participation of concerned actors, introducing innovative but adaptive measures, ensuring reuse of recourses, resorting to alternatives for maintaining livelihood, invention of sustainable recharge methods, and thereby achieving the sustainability in the use of water.

The review reveals that there is a myriad of paradigms, even sometimes conflicting to each other, suggested regarding water use – development or management – and – food security or water use sustainability. Recent trends focus more on sustainability management denouncing development model obsolete. On this backdrop, this study, in general endeavours to understand sustainability management of water use in Bangladesh and particular focus has been given on the *Barind* Tract in the northwest part of Bangladesh.

2.3 Theoretical Underpinning and Conceptual Framework

Demographic pressures, that is, pressure of changing population composition, rapid economic and technological development and another factor like political, among others have brought about unprecedented changes over time in the state of GW systems, resulting in a growing awareness as to the finiteness and vulnerability of this critical resource among the stakeholders concerned. In response to this, GW resources management has been structured by the initiation of the government with a view to pursuing controlled exploitation and adequate protection for GW toward achieving broad society goals. Though GW resources

[90] Mark W. Rosegrant, Claudia Ringler, and Tingju Zhu, "Water for Agriculture: Maintaining Food Security under Growing Scarcity," *Annu. Rev. Environ. Resour. 34* (2009): 205–22.

management can be formed in many ways, and but it needs to be customized to suit to the unique local conditions. GW management is an inseparable part of overall water resources management, it requires to have special attention due to its specific hidden, invisible nature of the resource. The common-pool resource features of GW, close connection of GW with the use of land, limited understanding of policy makers about the characteristics and its eventual impacts on the geological processes pose challenges for the management concerned.[91]

Management is concerned with the approaches, models, principles, and use of information to make well-conceived decisions.[92] It involves activities purposefully done to enable the accomplishment of goals and objectives.[93] According to the UN's Food and Agriculture Organization (FAO), policy involves a set of decisions which are meant to guide as to how a long term purpose or goal can be achieved or a particular problem can be solved.[94] Policymaking is synonymous with decision-making, and not only in public-sector institutions but also all sectors of any society, at any level, with having a stake in governance. Once policies are formulated, putting them in action requires a variety of instruments, tools, rules, protocols, and other procedures. These may include laws, sets of rights, registrations, permits, and regulations that allow to make choices between various ways of compliances, economic incentives and disincentives such as subsidies, taxes, tradable pollution permits, and pricing structures, and civil-society actions including those that motivate voluntary actions or induce behavioural changes.[95]

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[91] Robert G., Varady Frank van Weert, Sharon B. Megdal,"Groundwater Policy And Governance," *Thematic Paper No. 5,* one of the products

[92] Karen Bakker, "The "commons" versus the "commodity": Alter-globalization, anti-privatization and the human right to water in the global south," *Antipode* 39, no. 3 (2007): 430-455.

[93] Rob C. De Loë and Reid D. Kreutzwiser, "Closing the groundwater protection implementation gap," *Geoforum* 36, no. 2 (2005): 241-256.

[94] Food and Agriculture Organization of the United Nations (FAO), 2011. http://www.fao.org/wairdocs/ILRI/x5499E/x5499e03.htm.

[95] Insa Theesfeld, "A review on national groundwater policy instruments–Grasping institutional aspects for transboundary groundwater governance," In *Proceedings of the 12th annual International Association for the Study of the Commons (IASC) Conference. Cheltenham, England.*

Policies aimed at GW management are a subset of policies generally targeting the water management, and those in turn are eventually nested within broader policies meant for managing natural resources and the environment. Leaving aside the important notion that water and environment can be easily commodified as natural resources, the management of these require analogous approaches. There exist specific features of water governance and GW governance and given the particular nature of watercourses, repositories, flows, quality, and distribution, managers and decision-makers encounter diverse forms of water—from natural bodies such as streams, lakes, ponds and aquifers, to engineered structures such as canals, barrages, hydropower dams and treatment plants. Given the fluid, fugitive nature of water and natural fluctuations in the availability of the resource, water resources require effective and well-timed management.[96] Current opinion emphasizes that effective governance of such complex systems must involve an integrated management system being equipped with suitable infrastructure allowing to function effectively technical, economic, judicial, social, institutional, and administrative structures in a cohesion manner.[97] It has been observed that good water and GW governance entails responsible resource use, which leads to environmental and economic sustainability besides inducing sensitivity and helping to make an adaptation to topography and environment, customs, cultures, political systems, and prevailing practices and paradigms, awareness towards strong stakeholder participation and social acceptance; equitable access to water; fair distribution of costs and benefits; and attention to preferences and to winners and losers.[98] It is worthwhile mentioning here that

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[96] Food and Agriculture Organization of the United Nations (FAO), 2011. http://www.fao.org/wairdocs/ILRI/x5499E/x5499e03.htm.

[97] Craig Clifton et al, *Water and climate change: impacts on groundwater resources and adaptation options*, (World Bank, 2010), ix and Kathrin Knüppe, "The challenges facing sustainable and adaptive groundwater management in South Africa" *Water SA* 37, 1 (2011).

[98] Kathrin Knüppe, "The challenges facing sustainable and adaptive groundwater management in South Africa" *Water SA* 37, 1 (2011), Jamie Linton, and David B. Brooks, "Governance of transboundary aquifers: new challenges and new opportunities," *Water International* 36, 5 (2011): 606-618, Linda Nowlan, and Karen Bakker, *Practising shared water governance in Canada: A primer,* (Vancouver, Canada: UBC Program on Water Governance, 2010), 7,

good GW governance is supposed to lead to the application of sustainability concept while managing the water resources because of having its multi-interpretability and close relationship with concepts like equity and fairness.[99]

Experts in GW use around the world agree that too little is known about the institutions and policies governing the use of these resources.[100] Nonetheless, innovative approaches to GW management have been developed in many parts of the world over the past decade.[101] Among these approaches, the most notable ones the researcher reviewed briefly in the present section covering a variety of instruments to manage GW with variant features.[102] In the past decades, the classical governmental approach towards GW resources management was based on a plan-and-control and engineering-centered approach. In many countries, GW management decisions are made and interventions are planned in (partly decentralized) in concerned governmental departments such as ministries and departments dealing with water resources, agriculture etc. having strong connection and collaboration with specialized research institutes like geological survey of Bangladesh to provide the necessary data and expert knowledge to develop policies and make informed decisions.

The various related issues that GW resource management have to deal with depend on the level of GW development in their mandated area.[103] In recent

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Jac Van der Gun, and Annukka Lipponen, "Reconciling groundwater storage depletion due to pumping with sustainability," *Sustainability* 2, no. 11 (2010): 3418-3435 and Miguel Solanes, and Andrei Jouravlev, *Water governance for development and sustainability*, (ECLAC, 2006), 7-8.

[99] Jeni Klugman, "Human Development Report 2011. Sustainability and Equity: A better future for all" *Sustainability and Equity: A Better Future for All (November 2, 2011), UNDP-HDRO Human Development Reports* (2011).

[100] Aditi Mukherji, and Tushaar Shah, "Groundwater socio-ecology and governance: a review of institutions and policies in selected countries," *Hydrogeology Journal* 13, no. 1 (2005): 328-345.

[101] George De Gooijer et al, "Innovations in groundwater governance in the MENA region," in *Middle East North Africa Seminar Report from World Water Week*, 2008.

[102] Insa Theesfeld, "Institutional challenges for national groundwater governance: policies and issues," *Groundwater* 48, no. 1 (2010): 131-142.

[103] Albert Tuinhof et al, *Groundwater resource management: an introduction to its scope and practice* (Paris, France: 2002).

decades, many countries have followed more or less the same incremental and changing institutional path from initial development to GW management. When there arises a need to increase GW use in a particular region and if there happens to have any potential to do so, their work focuses on identifying usable GW volumes along with supporting supply-side interventions to enable an initial access to the GW resources. As the level of GW abstractions increases, negative consequences may appear like falling of GW tables. To sustain GW use in such stressed aquifers, interventions need to be developed that will slow down or reverse aquifer depletion, emphasizing a proper management of GW demand and a conjunctive use of surface water. Allocation issues receive more importance due to the rising scarcity. Conserving the productive capacity of aquifers requires constant monitoring of GW quantity and quality along with protection of aquifers. The notion of the importance of environmental sustainability has encouraged some of the forward-thinking GW resources managers to strive to include the management of GW-dependent ecosystems as part of their management activities.

GW resource management involves a wider set of assessment and planning, controlling, and behaviour-changing instruments, vested with a variety of governmental institutions.[104] These include:

- technical instruments like surveying, GW quantity and quality monitoring and modeling, other diagnostic analyses including sustainable aquifer yield estimations.
- managerial and planning instruments such as IWRM-plans, land use and spatial planning, environmental impact assessment, GW protection zoning,

[104] Albert Tuinhof et al, *Groundwater resource management: an introduction to its scope and practice* (Paris, France: 2002), K. Kemper, Instruments and institutions for groundwater management, in *the agricultural groundwater revolution: opportunities and threats for development*, ed. M. Giordano and K.G. Villholth (Cambridge, MA: CABI, 2007), 153-172 and Insa Theesfeld et al, *Adapting agricultural water governance to climate change: Experiences from Germany, Spain and Californi,* (German: German Development Institute/Deutsches Institut für Entwicklungspolitik (DIE), 2011), Vol. 6.

clear definition of responsibilities and roles of various GW resources management entities.

- regulatory instruments like GW propiety and usufruct rights, well licensing and registering, drilling accreditation, water legislation, GW caps, bans on hazardous human activities risking GW being contamination.
- economic instruments such as GW pricing, environmental taxes, tradable rights and GW markets and behaviour-changing instruments; training, information sharing etc.

Moench and others[105] argue that this classic approach presumably has an ability to identify and quantify the nature of interactions and to clearly define the boundaries of systems. It also presumes that for social institutions like rights systems and regulatory organizations, sufficient organizational capacity is made available so that its implementation can occur in a planned and integrated manner. It needs to be noted here that this formalized type of GW management is relatively a recent institutional phenomenon. Many historical and more recent examples exist where bottom-up approaches towards GW irrigation were in practice. Extensive work by the Ostrom School managed to modify various factors that foster or limit such approaches like the level of salience, homogeneity of user groups and the existence of effective conflict resolution mechanisms. GW governance often emphasizes community involvement to enable some degree of self-governance along with more formal, instrumental approaches being adhered to the concerned laws, regulations, and pricing schemes requiring more government involvement.[106] The institutions, or "rules of the game"[107], within the

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[105] Marcus Moench, Jacob J. Burke, and Yarrow Moench, *Rethinking the approach to groundwater and food security* 24, (Food & Agriculture Org., 2003).

[106] Edella Schlager, Community management of groundwater, in *the agricultural groundwater revolution: opportunities and threats to development*, eds. Mark Giordano and Karen G. Villholth, (Cambridge, MA: CABI, 2007), 131-152 and Mark Giordano, and Karen G. Villholth, eds. *The agricultural groundwater revolution: opportunities and threats to development*, Vol. 3, CABI, 2007.

[107] Douglass C. North, *Institutions, institutional change and economic performance*, (Cambridge: Cambridge university press, 1990).

framework of which stakeholders act, define the instruments, processes, and organizational context of governance.[108]

However, diverse political and institutional obstacles impeding the process of establishing sustainable water management practices include sector fragmentation, poverty, corruption, stagnated budgets, declining level of development assistances and investment in the water sector, inadequate institutions and limited stakeholder participation.[109] The OECD has also pointed out some major water governance gaps arising due to limited capacity at the local level, unclear allocation of roles and responsibilities, paucity of transparency, lack of strategic planning, weak economic regulation, and poorly-drafted legislation.[110] On balance, good governance can be pursued by establishing an appropriate framework of interest-articulation and decision-making involving an assortment of non-state actors as well as formal state agencies.[111] Accountability and participations of the stakeholders involved are the cornerstones of good governance; accountability entails legislative, legal, and social responsibilities as well as remedies. Critical features are the primacy of the rule of law upheld and applied through an impartial and effective legal system with the ability to ensure legal accountability, a high degree of transparency and accountability in public and corporate processes, following a participatory approach towards service delivery to assure effective public services. Good water governance is the product of how viable, strong and well-informed a pluralistic civil society is. Institutional pluralism involves the development of a partnership between civil society and governmental agencies based on dialogue, consultation and collaboration

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[108] K. Kemper, Instruments and institutions for groundwater management, in *the agricultural groundwater revolution: opportunities and threats for development*, ed. M. Giordano and K.G. Villholth (Cambridge, MA: CABI, 2007), 153-172.

[109] John Magrath, "Water: A Shared Responsibility: The United Nations World Water Development Report 2," (2007): 309-311.

[110] OECD, *Water governance in OECD countries: a multi-level approach,* (Paris: OECD Publishing, 2011).

[111] Jamie Linton, and David B. Brooks, "Governance of transboundary aquifers: new challenges and new opportunities," *Water International* 36, 5 (2011): 606-618.

facilitating negotiation, consultation and networking within civil society. In addition, good governance entails a set of rules that enable the institution to perform its role efficiently and effectively.

Experts emphasize an attention to be paid to additional institutional aspects of GW management, such as the need for consistent policies, legislation and legal frameworks, strategic management planning, and resource administration capacity.[112] The institutional and political aspects of governance also tend to include active public participation and stakeholder involvement to help ensure greater accountability.[113] Participation of the stakeholders demands good, symmetric, transparent and reliable information to facilitate logical and objective cooperation.[114] Learning, sharing, and co-producing knowledge are key aspects to GW governance.

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[112] Vishnu P. Pandey et al, "A framework for measuring groundwater sustainability," *Environmental Science & Policy* 14, no. 4 (2011): 396-407, Foster, Stephen, and Daniel P. Loucks, "Non-renewable groundwater resources." *A guidebook on socially sustainable management for water policy makers, IHP series on Groundwater* 10 (2006) and Shammy Puri, *Internationally shared (transboundary) aquifer resources management: their significance and sustainable management*, United Nations Educational, Scientific and Cultural Organization (UNESCO), 2001.

[113] K. Kemper, Instruments and institutions for groundwater management, in *the agricultural groundwater revolution: opportunities and threats for development*, ed. M. Giordano and K.G. Villholth (Cambridge, MA: CABI, 2007), 153-172, Foster, Stephen, and Daniel P. Loucks, "Non-renewable groundwater resources." *A guidebook on socially sustainable management for water policy makers, IHP series on Groundwater* 10 (2006), Nathan L. Engle and Maria Carmen Lemos, "Unpacking governance: building adaptive capacity to climate change of river basins in Brazil," *Global Environmental Change* 20, 1 (2010): 4-13, P. Taylor et al, "Groundwater Management in IWRM: Training Manual" *Cap-Net, Africa Groundwater Network (AGW-Net) and Ground Water Management Advisory Team (GW-MATE),Available online at: www. capnet. org/sites/cap-net. org/files/Cap-Net% 20Groundwater* 20 (2010), Vishnu P. Pandey et al, "A framework for measuring groundwater sustainability," *Environmental Science & Policy* 14, 4 (2011): 396-407, Linda Nowlan and Karen Bakker, *Practising shared water governance in Canada: A primer*, (Vancouver, Canada: UBC Program on Water Governance, 2010), Tom Gleeson et al, "Towards sustainable groundwater use: Setting long-term goals, back casting, and managing adaptively," *Groundwater* 50, 1 (2012): 19-26, and Yoram Eckstein and Gabriel E. Eckstein, "Transboundary aquifers: Conceptual models for development of international law," *Groundwater* 43, 5 (2005): 679-690.

[114] Aditi Mukherji, and Tushaar Shah, "Groundwater socio-ecology and governance: a review of institutions and policies in selected countries," *Hydrogeology Journal* 13, no. 1 (2005): 328-345, Shammy Puri, *Internationally shared (transboundary) aquifer resources management: their*

Good governance also calls for a close ing between the scale of ecological processes and the institutions that govern GW resources[115] Problems of having a fit between various biophysical systems can result in non-compliance with GW governance,[116] Considering the broader trends in environmental and water governance involving multi-partnerships and hybrid approaches, it is imperative to build a capacity across the multiple and diverse governance scales.[117] In addition, interplay between both formal and informal institutions, and across and within scales is viewed as important institutional and political elements of governance.[118] Research has emphasized the need for institutional capacity building to adapt to uncertainty and change in order to be more resilient in a social-ecological system.[119] For water governance, this might mean existence of flexible governance mechanisms that can help stakeholders to anticipate and adapt to various uncertainties and changing circumstances.[120] In GW governance,

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significance and sustainable management, United Nations Educational, Scientific and Cultural Organization (UNESCO), 2001, Sharon B.Megdal and Christopher A. Scott, "The importance of institutional asymmetries to the development of binational aquifer assessment programs: The Arizona-Sonora experience," *Water* 3, 3 (2011): 949-963 and Mark Giordano and Karen G. Villholth, (Cambridge, MA: CABI, 2007), 131-152.

[115] Graeme S. Cumming et al, "Scale mismatches in social-ecological systems: causes, consequences, and solutions," *Ecology and society* 11, no. 1 (2006).

[116] Alice Cohen, and Karen Bakker, "Groundwater governance: explaining regulatory non-compliance," *International Journal of Water* 5, no. 3 (2010): 246-266.

[117] John Kerr, "Watershed management: lessons from common property theory," *International Journal of the Commons* 1, no. 1 (2007): 89-109.

[118] Oran R. Young and Les Gasser, *The institutional dimensions of environmental change: fit, interplay, and scale*, (London: MIT press, 2002).

[119] Carl Folke et al, "Adaptive governance of social-ecological systems" *Annu. Rev. Environ. Resour.* 30 (2005): 441-473 and Gilberto C. Gallopín, "Linkages between vulnerability, resilience, and adaptive capacity," *Global environmental change* 16, no. 3 (2006): 293-303 and Oran R. Young and Les Gasser, *The institutional dimensions of environmental change: fit, interplay, and scale*, (London: MIT press, 2002).

[120] Alena Drieschova, Itay Fischhendler, and Mark Giordano, "The role of uncertainties in the design of international water treaties: an historical perspective," *Climatic Change* 105, no. 3 (2011): 387-408. Alena Drieschova, Mark Giordano, and Itay Fischhendle, "Governance mechanisms to address flow variability in water treaties," *Global Environmental Change* 18, no. 2 (2008): 285-295, Claudia Pahl-Wostl et al, "The importance of social learning and culture for sustainable water management," *Ecological economics* 64, no. 3 (2008): 484-495, Patrick Huntjens, Claudia Pahl-Wostl, and John Grin, "Climate change adaptation in European river basins." *Regional Environmental Change* 10, no. 4 (2010): 263-284.

institutional adaptation and flexibility are gaining greater attention.[121] Emphasis on more adaptive approaches are likely to result in better integration between community and various governmental departments vests with GW governance.[122]

With the growth of world population, more attention is being given to the water sources essential for day to day human life. In 2010 two reputed journals widely read by general audiences such as *National Geographic* and *The Economist* published special issues on water to bring attention to the challenges associated with meeting an increasing worldwide demand for water.[123] As water demands increase relative to its supplies, reliance on GW increases with a greater focus on GW governance. The explicit integration of socio-cultural principles into GW governance can result in the development and implementation of effective policies. These policies can yield a set of practices for 'responsible GW use' including equity, sustainability, and efficiency considerations.

Scholars of water-resources management argue that a major paradigm shift in management is underway, from a historically strong emphasis on engineering and technical solutions to a focus on integrated management highlighting the importance of culture and social learning.[124] The Global Water Partnership[125] emphasizes that effective governance stresses the importance of adhering to the principles of equity, efficiency, and importance of achieving diverse knowledge integration, which are important for dealing with the problems of water resource

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[121] Kathrin Knüppe, "The challenges facing sustainable and adaptive groundwater management in South Africa," *Water SA* 37, no. 1 (2011), Craig Clifton et al, *Water and climate change: impacts on groundwater resources and adaptation options*, (World Bank, 2010) and Andrew Ross and Pedro Martinez-Santos, "The challenge of groundwater governance: case studies from Spain and Australia," Regional *Environmental Change* 10, no. 4 (2010): 299-310.

[122] Mark Giordano and Karen G. Villholth, (Cambridge, MA: CABI, 2007), 131-152.

[123] M. Nanni et al, Legal and institutional considerations in: S. Foster and D.P. Loucks (eds.), *Non-renewable groundwater resources–A guidebook on socially-sustainable management for water policy-makers*, UNESCO-IHP series on groundwater n. 10National Geographic, 2010Special Issue, Water, our thirsty world, April, 2006.

[124] Claudia Pahl-Wostl et al, "The importance of social learning and culture for sustainable water management," *Ecological economics* 64, no. 3 (2008): 484-495.

[125] TAC, GWP, "Integrated Water Resources Management, TAC Background Paper No. 4," *Global Water Partnership Technical Advisory Committee, Stockholm* (2000).

management. Recent literature and evidence-based analysis on water governance shows that technical, institutional, and financial solutions to the water crisis have been emphasized, and the implementation and adaptation of these solutions on the ground to develop specific place-based policy responses still remain challenging.[126] GW governance is intimately linked to the development and implementation of norms and principles that bring about changes in the behaviour of actors across each scale at which GW is managed.[127] Contemporary focus on finding transitional governance approaches to help society move from current unsustainable governance paradigms to future sustainable governance paradigms hinge on the strong interdependencies and synergies between formal and informal institutions that are embedded in a particular culture.[128] Institutions — the formal and informal rules that provide the framework for the behaviour of human beings — include codified laws and regulations as well as the socially-shared rules and norms that develop through social interactions and shared learning.[129]

Socio-cultural principles are deeply rooted into the governance — even if until recently they have remained largely ignored in the dominant management literature—as good governance involves a regulatory system that shows qualities of accountability, transparency, legitimacy, public participation, justice, efficiency, the rule of law, and an absence of corruption.[130] Hassan[131] introduces the notion of

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[126] OECD, *Water governance in OECD countries: a multi-level approach,* (Paris: OECD Publishing, 2011).

[127] Claudia Pahl-Wostl, Joyeeta Gupta, and Daniel Petry, "Governance and the global water system: a theoretical exploration," *Global Governance: A Review of Multilateralism and International Organizations* 14, 4 (2008): 419-435.

[128] Claudia Pahl-Wostl, Joyeeta Gupta, and Daniel Petry, "Governance and the global water system: a theoretical exploration," *Global Governance: A Review of Multilateralism and International Organizations* 14, 4 (2008): 419-435 and Claudia Pahl-Wostl et al, "The importance of social learning and culture for sustainable water management," *Ecological economics* 64, no. 3 (2008): 484-495.

[129] Claudia Pahl-Wostl, "Social learning and water resources management," *Ecology and society* 12, 2 (2007).

[130] Claudia Pahl-Wostl, Joyeeta Gupta, and Daniel Petry, "Governance and the global water system: a theoretical exploration," *Global Governance: A Review of Multilateralism and International Organizations* 14, 4 (2008): 419-435.

[131] Fekri A. Hassan, *Water and ethics: a historical perspective*, UNESCO, 2004.

an 'integrative ethics of water management' that endorses the cooperation between the different users, policymakers, financial agencies, and professionals to exchange information and to achieve trust while promoting accountability and transparency. The need for making difficult choices, regarding rates of water consumption, wasteful practices, and recycling, stresses the importance of considering the role of culture in GW management. The role of culture in governance recognizes that culture is critical to understanding barriers to changing practices and the adoption of technologies and new management strategies, and to successfully exchanging experiences between developed and developing countries.[132] The concept of social learning process emerging as key to effective water management is gradually gaining importance with emphasis on collective action and conflict resolution, requiring people involved to learn about their interdependences and differences in order to deal and negotiate with other parties constructively. The integration of social learning into governance implies obviously a major shift to a style of governance based on collaboration, adaptation, and ongoing learning in a complex and perennially changing world.[133]

The idea of social inclusion is now an important aspect of governance. Since water is absolutely essential for human survival, deliberate exclusion of people from access to it is universally considered as inhuman and *in extremis*, even a crime. Social inclusion in governance calls for determining a policy framework that includes an evaluation of the interests of all groups within a society and that all groups are treated with a same level of fairness. A special case of social inclusion is gender mainstreaming, which has been propagated since the conceptualization of IWRM and which has improved the access to and control of women over water resources

[132] Claudia Pahl-Wostl et al, "The importance of social learning and culture for sustainable water management," *Ecological economics* 64, no. 3 (2008): 484-495.

[133] Claudia Pahl-Wostl, "Social learning and water resources management," *Ecology and society* 12, 2 (2007), Claudia Pahl-Wostl et al, "The importance of social learning and culture for sustainable water management," *Ecological economics* 64, no. 3 (2008): 484-495 and Margaret Wilder et al, "Adapting across boundaries: climate change, social learning, and resilience in the US–Mexico border region," *Annals of the Association of American Geographers* 100, no. 4 (2010): 917-928.

in many areas to ensure equity in treatment. Another dimension of social inclusion is to target marginalized groups like people below a certain poverty level.

Historically, public policy relating to water has tended to focus primarily on one level: local, basin-scale, national, or global. In recent years, however, water has been the subject of the globalization phenomenon that has re-characterized politics and economics.[134] Recognition is growing to multi-scale, polycentric governance models that appreciate that a large number of stakeholders in different institutional settings can make innovative contribution to the overall management of resources.[135] Thus multi-level governance based on partnerships across scales represents a kind of hybrid governance that integrates government agencies and diverse stakeholders.[136] The OECD defines multi-level governance as the explicit or implicit sharing of policy-making authority, responsibility, development and implementation at different administrative and territorial levels. Irrespective of the variations in the form of water governance, all face common coordination and capacity gaps when designing and implementing water policy, and mitigating water challenges. These gaps may be of several types, including administrative, information, policy, capacity, funding, objectives, and accountability gaps.[137]

The need for collaboration is gaining importance because interdependence between government bodies and stakeholders is increasing while government budgets are decreasing and the efficacy of traditional command-and-control management is getting reduced. Furthermore, the combination of top-down and bottom-up formation of institutional arrangement may in fact lead to a greater acceptance across the wide range of stakeholders involved in the governance

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[134] Robert G.Varady et al, "Strengthening global water initiatives," *Environment: Science and policy for sustainable development* 50, no. 2 (2008): 18-31.

[135] Claudia Pahl-Wostl, "Social learning and water resources management," *Ecology and society* 12, 2 (2007).

[136] Claudia Pahl-Wostl, Joyeeta Gupta, and Daniel Petry, "Governance and the global water system: a theoretical exploration," *Global Governance: A Review of Multilateralism and International Organizations* 14, 4 (2008): 419-435.

[137] OECD, *Water governance in OECD countries: a multi-level approach,* (Paris: OECD Publishing, 2011).

process.[138] Recognizing the need for development of an adaptive co-management of complex social-ecological systems is getting crucial through integrating dynamic social learning opportunities within a cooperative management framework that stress the importance of networks, leadership, diversity, and trust for accumulating experiences and collective memory that can be used to effectively cope with surprise disturbance, such as drought.[139]

Challenges are still remaining in terms of effectively integrating socio-cultural principles, including equity, culture, social learning, and cooperation into existing GW governance regimes. Considering the kind of arrangements that impact the interests of individuals and communities with regard to their use of water resources, The Food and Agriculture Organization of the United Nations[140] identifies three core principles need to be considered include security, sustainability, and equity. However, balancing the three principles is a key challenge for policy- and decision-makers as concerns for security tend to outweigh considerations of sustainability and equity. Water resources play a crucial role in fulfilling basic needs and maintaining livelihoods, and therefore, gender and social equity factors must be taken into account in policy-making. Consequently, hard decisions about water resource allocation (increasingly more frequently, re-allocation) under conditions of water scarcity must be perceived as fair by all stakeholders and water users involved.

Institutional and cultural arrangements further complicate water management decisions when holders of water rights under informal, customary arrangements reject formal water tenure arrangements. In the 1980s, for example, Douglas Merrey and his associates recognized the critical role of *izzat* (Islamic

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[138] Claudia Pahl-Wostl, "Social learning and water resources management," *Ecology and society* 12, 2 (2007).

[139] Carl Folke et al, "Adaptive governance of social-ecological systems," *Annu. Rev. Environ. Resour.* 30 (2005): 441-473.

[140] Food and Agriculture Organization of the United Nations (FAO), 2011, http://www.fao.org/wairdocs/ILRI/x5499E/x5499e03.htm.

honour) in decision-making for irrigation systems in Pakistan and northern India.[141] And a recent case study from Bukhara, Uzbekistan, highlights how water governance can be affected by socio-cultural considerations, such as underlying traditions and ethics of water use. In Bukhara, the historic role of water judges illustrates how sharing of water has been organized, both institutionally and ethically, in many regions. Although an oasis in a water-short region, Bukhara became a brilliant metropolis because of an elaborate irrigation system used by the population for daily social exchanges. Bukhara is a good example of the importance of social organization in water management, in this case via irrigation.[142]

Economics is concerned with the allocation of scarce resources. Physical access to GW requires the ability to extract the resource, and in absence of restrictions, one person's access does not prevent another from tapping into the same aquifer. Rather than seeing water being exchanged through a typical market mechanism involving multiple buyers and sellers acting as economic agents, water is often distributed to customers in a community by a monopoly provider. It may be distributed to the agricultural users through a cooperative irrigation arrangement. Alternatively, GW users may own and operate their own extraction wells too. For many, GW may not be the only source of water and its use may or may not be subjected to regulation. Pricing or price signals can be used to assist in the allocation of all types of water including GW. However, where markets are nonexistent or imperfect, pricing may not accurately reflect the costs and benefits of supplying and consuming the good. Measuring the economic benefits or value of GW is important for maintaining a sustainable management of its quality and quantity, which is difficult to accomplish.[143] Understanding all the costs associated

[141] D. J. Merrey and J. M. Wolf, "Irrigation Management in Pakistan: Four Papers. IIMI Research Paper No. 4," *International Irrigation Management Institute, Digana Village* (1986).

[142] Jean Fried, "Water governance, management and ethics: new dimensions for an old problem," *Santa Clara J. Int'l L.* 6 (2008), 1.

[143] Benjamin Görlach and Eduard Interwies, "Economic Assessment of Groundwater Protection: A Survey of the Literature Final Report," *European Commission* (2003), 86.

with water provision is important but challenging.[144] Furthermore, water prices rarely reflect the full costs of water provision, and do not typically assign any cost of the water molecules themselves.[145]

The economic implications of GW provision is difficult to measure due to the absence of key data.[146] As the quantity of GW in storage depends on the differences between GW recharge and extraction rates, which is often not known. The water quality in terms of the impacts of contaminant intrusion is also difficult to measure. GW use often cannot be measured, making it difficult to connect economic payment with utilization. Where water is priced, water prices incorporate the known and measurable costs of water provision, such as construction, operation, maintenance and administration of the water extraction and distribution system. Yet, these costs may not fully reflect the costs of water extraction, such as instances where electricity rates are subsidized for certain users.[147]

Water prices rarely include consideration of the third party and environmental impacts of GW use.[148] For example, water extracted by one user can result in higher pumping costs compared to that of the nearby well owner. Those pumping GW rarely have to pay the costs of environmental degradation due to declining water levels. Water pricing should facilitate the allocation of water to highest valued uses, and the ability to pay is a critical consideration.

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[144] Aditi Mukherji, and Tushaar Shah, "Groundwater socio-ecology and governance: a review of institutions and policies in selected countries," *Hydrogeology Journal* 13, no. 1 (2005): 328-345.

[145] S. B. Megdal, "Water Pricing Has Potential to Promote Water Conservation," *Arizona Water Resource* (2005). https://wrrc.arizona.edu/publications/AWRColumn/Water.Pricing.and. Conservation_%20JanFeb05.pdf)

[146] Phoebe Koundouri, "Potential for groundwater management: Gisser-Sanchez effect reconsidered," *Water resources research* 40, no. 6 (2004) and Phoebe Koundouri, "Current issues in the economics of groundwater resource management," *Journal of Economic Surveys* 18, no. 5 (2004): 703-740.

[147]Aditi Mukherji, and Tushaar Shah, "Groundwater socio-ecology and governance: a review of institutions and policies in selected countries," *Hydrogeology Journal* 13, no. 1 (2005): 328-345.

[148] Stephen Foster, "Groundwater—sustainability issues and governance needs," *Episodes Journal of International Geoscience* 29, no. 4 (2006): 238-243.

Physical characteristics of GW systems partly determine the nature of use. This necessitates the application of ecological principles in order to sustainably manage GW resources. In many parts of the world, GW resources of good quality are ubiquitously available in large volumes. Developing access to these resources in such places is rather simple and cheap, and often does not require any large governmental coordination or support. Mukherji and Shah[149] mention that these intrinsic hydrological advantages of GW give rise to several scale-neutral socio-economic benefits, making it a favoured grass-roots level source. The phenomenon that GW sources tend to be more reliable and predictable than surface water sources often helps yield significantly higher economic returns per cubic meter of water used for irrigation. This adds to the preferred choice for using GW.[150]

Aquifers possess both conducive and diffusive properties. The first characteristic results in a physical consequence that effects of interventions in the aquifer may propagate through it while the second characteristic slights this effect over time and distance to the location of the intervention through natural or artificial recharge. Additionally, most aquifers are not isolated physical systems but an integral part of hydrological cycle process and indivisibly connected to other water systems. GW systems are replenished through infiltrating precipitation, infiltrating rivers and lakes and irrigation return flow. On the other hand, GW being discharged into surface water bodies get transpired resulting in the GW-table being declined compounded by transpiration due to the extent of vegetation. Hence, effects of interventions in GW systems not only propagate through aquifers, but into the linked systems as well and vice versa.[151] A result is that humans, by interfering with GW pumping, may affect other locations. In turn, this can disrupt others users'

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[149] Aditi Mukherji, and Tushaar Shah, "Groundwater socio-ecology and governance: a review of institutions and policies in selected countries," *Hydrogeology Journal* 13, no. 1 (2005): 328-345.

[150] Jac Van der Gun, and Annukka Lipponen, "Reconciling groundwater storage depletion due to pumping with sustainability," *Sustainability* 2, no. 11 (2010): 3418-3435.

[151] Emilio Custodio, "Aquifer overexploitation: what does it mean?," *Hydrogeology journal* 10, no. 2 (2002): 254-277.

ability to employ the GW system, thus causing so-called externalities. This insight has led to more holistic management and recognition that the scale of management should fit the scale of the physical systems.

In some cases, GW is a renewable resource. As the aquifer is connected to both surface water systems and the land surface, it has the ability to be replenished with the passage of time. This renewability is dependent on the level of connectedness with these systems and with the availability of water in these systems such as filled rivers and excess precipitation.[152] GW resources in aquifers without this connectedness and replenishment, or in aquifers where the rate of abstraction exceeds the rate of replenishment, are assumed to be non-renewable and have to be mined. Mining of such natural resources appears to violate the narrow physical definition of sustainability, which is usually interpreted by hydro-geologists and GW resources managers as the ability to continue pumping without aquifers' exhaustion. Such practices may, however, be justifiable from a broader definition of sustainability that reconciles the use of the non-renewable resource with the sustainability of human life.[153]

To save GW resources for future generations is a crucial and salient question. GW mining requires a successful exit strategy, implying that by the time the GW resource is substantially depleted, society will have used it to advance economically, socially, and technically so as to enable future generations to develop substitute water sources at an affordable cost. It is also important to know how to deal with the environmental sustainability of ecosystems that are GW-dependent. The bottom line is that sustainability has many dimensions and interpretations, and that decision-making to achieve sustainability often includes tradeoffs between these different notions or aspects. As the level of connectedness and hence renewability is often strongly dependent on aquifer depth, different

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[152] Stephen Foster and Daniel P. Loucks, "Non-renewable groundwater resources," *A guidebook on socially sustainable management for water policy makers, IHP series on Groundwater* 10 (2006).

[153] Jac Van der Gun, and Annukka Lipponen, "Reconciling groundwater storage depletion due to pumping with sustainability," *Sustainability* 2, no. 11 (2010): 3418-3435.

types of governance including sustainability considerations are suggested for different depths of the aquifer.[154] Furthermore, because of its subsurface nature and the inherent difficulty of monitoring GW systems are characterized by inadequate information or epistemic uncertainty.[155] Often even the boundaries of the systems remain ambiguous.[156] Because of the vastness of the systems, negative consequences of aquifer overexploitation and contamination appear after a certain time period.[157] The impact of excessive withdrawals can initially be largely invisible.[158] The open access nature of the vast GW systems allows GW use to be distributed to unknown users even when they consist of large numbers of independent GW users.[159]

With climate and global change, GW balances in many areas are being changed gives rise to another level of uncertainty.[160] Hence GW systems could be defined as complex adaptive systems characterized by self-organization, adaptation, heterogeneity across scales and distributed control.[161] As relevant data on the status of the aquifers are limited even when many abstractors are involved and impacts are not easily detected and sometimes commonly emerge with a delay, there are substantial uncertainties and risks that have to be taken into account in managing non-renewable GW resources.[162] These characteristics require

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[154] Elena Lopez-Gunn and W. Todd Jarvis, "Groundwater governance and the Law of the Hidden Sea," *Water Policy* 11, no. 6 (2009): 742-762.

[155] Anita Milman and Isha Ray, "Interpreting the unknown: uncertainty and the management of transboundary groundwater," *Water international* 36, no. 5 (2011): 631-645.

[156] Insa Theesfeld, "Institutional challenges for national groundwater governance: policies and issues," *Groundwater* 48, no. 1 (2010): 131-142.

[157] Ibid.

[158] Jamie Linton, and David B. Brooks, "Governance of transboundary aquifers: new challenges and new opportunities," *Water International* 36, 5 (2011): 606-618.

[159] Ibid.

[160] Timothy R. Green et al, "Beneath the surface of global change: Impacts of climate change on groundwater," *Journal of Hydrology* 405, no. 3-4 (2011): 532-560.

[161] Claudia Pahl-Wostl, "Transitions towards adaptive management of water facing climate and global change," *Water resources management* 21, no. 1 (2007): 49-62.

[162] Jac Van der Gun, and Annukka Lipponen, "Reconciling groundwater storage depletion due to pumping with sustainability," *Sustainability* 2, no. 11 (2010): 3418-3435.

the application of risk-based and adaptive approaches to get along with the changing conditions and unexpected consequences.

While aquifers are much less vulnerable to anthropogenic pollution than surface water bodies, when aquifers become polluted, contamination is persistent and difficult to remediate due to their large storage, long residence times and physical inaccessibility.[163] Some aquifers hold a natural attenuation capacity and are able to partially degrade contamination substance. However some of the derivatives of such processes may be equally toxic and/or mobile as the original pesticide compounds themselves.[164] This irreversible characteristic of aquifer systems plus the limited ability to predict its system behaviour justify the use of the precautionary principle which generally implies that there is a social responsibility to protect the public from exposure to harm, when scientific investigation has found a plausible risk. Only after research findings manifesting the proof that no harm will occur the protective measures can be relaxed.

Because of the vastness of GW systems with multifaceted characteristics it is costly and difficult to monitor GW abstraction and to exclude potentially new GW appropriators or polluters. The nature of GW use is the result of interplay of above-mentioned physical characteristics of diffusiveness, conduciveness, slow attenuation rates and sometimes limited renewability, additional GW development and land use. These combined features put GW system in the category of common property resources which makes them vulnerable to over-exploitation and/or under-management.[165]

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[163] Stephen Foster, "Groundwater—sustainability issues and governance needs," *Episodes Journal of International Geoscience* 29, no. 4 (2006): 238-243.

[164] S. S. D. Foster and P. J. Chilton, "Groundwater: the processes and global significance of aquifer degradation," *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences* 358, no. 1440 (2003): 1957-1972.

[165] Elinor Ostrom, *Governing the commons: The evolution of institutions for collective action,* (Cambridge: Cambridge university press, 1990).

GW users have incentives to find solutions to local issues when coordination yields substantial benefits. As Schlager[166] points out, "owners of closely situated wells, for instance, may readily realize the effect that their pumping has on one another as water levels in their wells decline under heavy pumping and begin to recover as they reduce their abstractions". Users may be willing to rely on spatial or temporal restriction on the use of the resources. Unfortunately, information on GW budget is often lacking, difficult to collect and to analyse.[167] Defining aquifer boundaries, structure or capacity of GW requires assistance from engineers and hydrologists. Also, GW users themselves cannot easily determine the number of other pumps, how much water they are taking, the effects of their pumping on the overall productivity of the GW basin, etc. therefore, tackling appropriation problems for GW is not always that easy.

Principles for sustaining long-enduring, common pool resource systems on a local scale as well as for establishing or sustaining a governance system to deal with the challenges and uncertainties related to complex, cross-boundary GW systems may be expected to be distinct for several reasons.[168] First, complexity is substantially increased since larger-scale water resources usually must be managed across different time-frames and at different scales e.g. local, regional, national and international. Second, in contrast to traditional planning for infrastructure, governments and stakeholders at all levels it needs to be flexible under changing conditions when determining GW policies and measures. This is especially the case when considering the uncertain impacts of climate change[169] and socio-economic developments on GW systems. Third, knowledge about the effectiveness of

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[166] Edella Schlager, "Community management of groundwater," *The agricultural groundwater revolution: Opportunities and threats to development* 3 (2007): 131-152.

[167] Verena Fritz, Kai Kaiser and Brian Levy, "Problem-driven governance and political economy analysis: good practice framework," *World Bank* (2009).

[168] John Grin, "3. Reflexive modernisation as a governance issue, or: designing and shaping re-structuration," *Reflexive governance for sustainable development* (2006): 57.

[169] Stéphane Hallegatte, "Strategies to adapt to an uncertain climate change," *Global environmental change* 19, no. 2 (2009): 240-247.

alternative interventions is incomplete and knowledge that exists, and is important to management, is often dispersed amongst several different stakeholders.[170]

For dealing with complexities and uncertainties related to GW governance and climate change adaptation additional or adjusted institutional design propositions are necessary that will facilitate learning processes. This is especially the case for dealing with complex, cross-boundary and large-scale resource systems, such as the GW systems in Morocco, Kenya, Tanzania, South-Africa and India.[171] Besides, they cover structural, agency and grasping of the governance challenge and they provide a strong initial framework with a view to exploring key institutional issues in GW governance. They do not specify the blueprints, but encourage GW governance suitable to the unique features of local geography, ecology, economies and cultures.

Generally, a high value is put on GW resources as they get abstracted and consumed or used as a production factor in agriculture. The aquifer is hence traditionally valued because of its provision of services. However, the systems-based approach in research led to the understanding that GW often plays an important role in sustaining marine, aquatic and terrestrial ecosystems on which humans depend. Hence increasingly, the notion of the importance to reserve some GW for nature (or recharging) plays an important part in GW management decisions. This eco-system approach broadens the notion of sustainability. According to Van der Gun and Lipponen,[172] the key to maintaining sustainable GW system does not relate to how the system is developed allowing sustainability, but relates to how the complexity of natural resources to which that GW system

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[170] Patrick Huntjens et al, "Institutional design propositions for the governance of adaptation to climate change in the water sector," *Global Environmental Change* 22, no. 1 (2012): 67-81.

[171] Elinor Ostrom, *Understanding institutional diversity*, (New Jersey: Princeton University press, 2005): 393-432 and Patrick Huntjens et al, "Institutional design propositions for the governance of adaptation to climate change in the water sector," *Global Environmental Change* 22, no. 1 (2012): 67-81.

[172] Jac Van der Gun and Annukka Lipponen, "Reconciling groundwater storage depletion due to pumping with sustainability," *Sustainability* 2, no. 11 (2010): 3418-3435.

belongs allows and supports sustainable socio-economic development and preservation of desired environmental conditions in the region.

Governance involves a set of values, policies and institutions by which a society manages its economic, political and social affairs through interactions within and among the States, civil societies and the private sectors and relates to the broad social system of governing. Understanding governance can help us match a nation's policy objectives with the mechanisms for translating those objectives into actual outcomes. United Nations Development Program in 1997, adopted set of good governance principles that emphasize rule of law, participation, responsiveness, transparency, equity, accountability, consensus orientation, effectiveness and efficiency, and strategic vision. According to UNDP, governance can no longer be a closed system and confines only to the state, but transcends it by taking in the private sectors and civil society concerned. Following the UNDP principles, a number of organizations in the past decade have adopted similar good governance approaches, including the Global Water Partnership (GWP).[173] Empirical evidences demonstrate strong causal relationship between good governance and better development outcomes. Governance assessment has traditionally focused on examination of formal governance structures and processes, and less on the interactions between actors or institutions. In recent years, however, governance analysis has looked more at the way these formal structures actually work, taking into account the underlying political economy drivers with an emphasis on power relations, incentives, formal and informal processes.[174] Political economy refers to the way the political environment and the economic system influence each other. It is concerned with "the distribution of power and wealth between different groups and individuals, the processes that create, sustain and transform these relationships

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[173] Peter Rogers and Alan W. Hall, *Effective water governance*, Vol. 7, (Stockholm: Global water partnership, 2003).

[174] UNDP et al, "Analysing governance and political economy in sectors – Joint donor workshop," *Workshop Report,* 5th – 6th November, 2009.

over time."[175] It has become widely accepted that understanding the political economy context of reforms is useful from a diagnostic perspective in order to be able to assist effectively in designing and implementing development strategies and policies for country.[176]

Water governance again has been defined as "the political, social, economic and administrative systems that are in place, and which directly or indirectly affect the use, development and management of water resources and the delivery of water service delivery at different levels of society."[177] As a subset of the above, GW governance is concerned with the enabling conditions in terms of policies, planning function, framework of laws, rights and regulations, incentive, and the organizational set up to implement these things through developing and managing GW resources in a socially responsible, environmentally sustainable and economically efficient manner. In this connection, common pool resources like GW requires specific governance arrangements if objectives of sustainability, efficiency and equity are to be attained. Common pool resources are those where there are few barriers to access but where abstraction by one user diminishes the pool availability to others includes fisheries, forests, pastures or water.

Hardin[178] mentions that common pool resources are overused and eventually face ultimate destruction because individual users have no incentive to curtail their use of the resources. Anyone preserving it for future use simply leaves it for others to use. Over-abstraction often imposes costs on third parties in terms of subsidence of overlying lands, changes in water quality and loss of GW

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175 Sarah Collinson, ed. *Power, livelihoods and conflict: case studies in political economy analysis for humanitarian action*, (London: Humanitarian Policy Group, Overseas Development Institute, 2003).

176 Verena Fritz, Kai Kaiser and Brian Levy, "Problem-driven governance and political economy analysis: good practice framework," World Bank, (2009).

177 Peter Rogers and Alan W. Hall, *Effective water governance*. Vol. 7. (Stockholm: Global water partnership, 2003).

178 Garrett Hardin, "The tragedy of the commons," *Journal of Natural Resources Policy Research* 1, no. 3 (2009): 243-253.

dependent ecosystems. Under such woeful circumstances the only solution, according to Hardin, is either government control or privatization of the resources be ensured so that users have an incentive for sustainability. Ostrom and others[179] have pointed out that collective management of common pool resources is an alternative approach that has been observed to be successful historically. It can help avoid some of the shortcomings with government control, such as excessive overhead costs and lack of management capacity, and some of the problems of privatization such as inequitable access to the resources.

The social system that depends on the GW resources includes household, community, economic sectors, rules and institutions, which are involved in numerous mutual interactions or transactions and these interactions are of very complex in nature.[180] Because of such complexity, simple models of governance and behaviour have been found to have limited value and research suggests shifting of the focus from seeking optimal states and the determinants of maximum sustainable yield, to analysing system resilience with a focus on adaptive resource management and adaptive governance.[181] Innovative strategies such as community engagement and building institutional capacity allow holistic solutions tailored around community needs.[182] Such interventions generally address multiple connected issues, such as health, livelihoods, environment with a view to resolving shared GW problems resulting in an enhanced community cohesion and wellbeing. In his connection technical capabilities to assess hydrologic balance, improve irrigation efficiency, crop selection, enhance GW

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[179] Elinor Ostrom et al, "Revisiting the commons: local lessons, global challenges," *science* 284, no. 5412 (1999): 278-282.

[180] Brian Walker et al, "A handful of heuristics and some propositions for understanding resilience in social-ecological systems," *Ecology and society* 11, no. 1 (2006), www.ecologyandsociety.org/vol11/iss1/art13/.

[181] J. Walter, *World disaster report 2004: Focus on community resilience*, ed, Geneva, Switzerland. International Federation of Red Cross and Red Crescent Societies (IFRC), (2004).

[182] M. Moench, H. Kulkarni and D. Macdonald, "The management challenge: what can be done?," in **"**Community management of groundwater resources in rural India," ed, R. Calow and D. Macdonald, *British Geological Survey Background Paper on the Causes, Symptoms and Mitigation of Groundwater Overdraft in India*, (2005): 39-70.

recharge or ensure substitute supplies will be required. Importantly institutional capabilities to influence supply and extraction, to build and maintain infrastructure and to finance such activities are also necessary, generally evolving from existing community cooperative arrangements and structures.[183] These actions can occur at decentralized level by motivated communities with technical support without necessarily waiting for any national or state policy reforms. Although this would certainly expedite broader-spectrum of effective action and help make technical expertise more accessible.[184] Therefore, the bottom line is that a multidisciplinary approach including social science is the key to understanding and improving GW governance for sustainable GW irrigation management.

In Bangladesh, all the legislative and institutional measures are put into action through the various Local Government organizations (UIWRMC, BMDA, UAO, LGED, Cooperative office, BRDB, BREB) to the user level. The researcher under this study has examined the sustainability practices and various measures regulating the GW irrigation practices both at the institutional level and user level and identified the impediments towards effective sustainable GW irrigation management in *Barind* tract of Bangladesh. Bearing this in mind, conceptual framework for sustainable GW irrigation management was developed for this study which is outlined in the following figure. The framework is based on an extensive literature review and is a hybrid of frameworks developed by Dillon & others and Wijnen & others as the major source. Additionally, it also considered the frameworks of Huntjens, Huntjens & others, and Pahl-Wostl & Lebel.

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[183] K.Wegerich, "Community based management: a review of the issues, in "Community Management of Groundwater Resources in Rural India," ed, R. Calow a D. Macdonald, *British Geological Survey Background Paper on the Causes, Symptoms and Mitigation of Groundwater Overdraft in India*, (2005): 71-85.

[184] Héctor Garduño et al, "India groundwater governance case study," *Water paper*, (2011): 64.

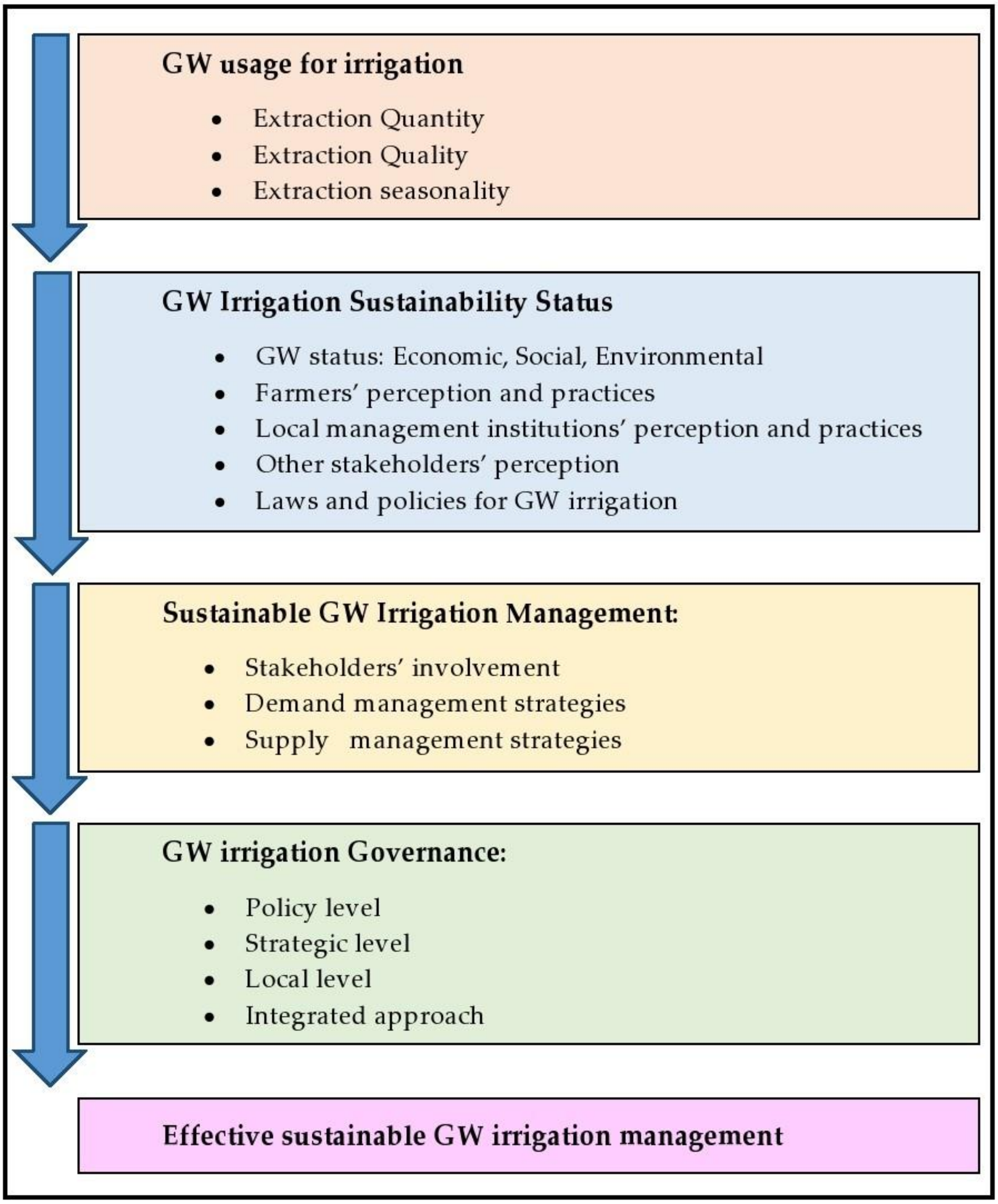

Figure 2.1: Framework for effective SGMI (Modified by researcher)[185]

Operational definitions for the identified items are given below:

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185 Peter Dillon, Enrique Escalante Fernandez, and Albert Tuinhof, "Management of aquifer recharge and discharge processes and aquifer storage equilibrium, IAH contribution to GEF-FAO Groundwater Governance Thematic Paper 4," (2012) and Marcus Wijnen et al., "Managing the Invisible: The Governance and Political Economy of Groundwater" (World Bank, 2012), https://edepot.wur.nl/431659, 1-9.

Groundwater usage for irrigation: It denotes the abstraction of GW and the usage pattern for irrigation in terms of quantity, quality and seasonality against GW storage.

Groundwater irrigation sustainability and its present status: It defines the sustainability issues e.g. economic, social, and ecological aspects (social dimension focuses on equity in access and use of GW resources; economic dimension focuses on efficiency in GW allocation and use; environmental dimension emphasizing the use of GW keeping the ecosystem's balance intact) in GW irrigation and its status like GW properties, farmers' practices, institutional (govt. and non-govt.) settings and participation of other stakeholders.

Groundwater irrigation management: It involves a combination of three elements, e.g., GW discharge under demand-side, and GW recharge or storage, and alternative supplies or conjunctive use under supply-side strategies, which can help sustain a prolonged GW resources and maximize the value of their utilisation.

Groundwater irrigation governance: It includes the following levels of governance in sequence:

Policy level refers to the processes by which a nation establishes its objectives for GW, integrates those policies with water, land and environmental policies, and aligns and harmonizes them with other related policies affecting GW such as agricultural policy, trade policy, policies on the determining the public and private responsibilities, decentralization, and the role of stakeholders' participation.

Strategic level denotes the institutions and instruments designed by a nation to align stakeholder behaviour and actual outcomes with policy objectives. Generally, it includes the following five components:

- An Integrated Water Resource Management (IWRM) planning function capable of allocating water in line with society's policy goals;
- A framework of laws, rights and regulatory instruments adapted to the context;

- An incentive framework that supports good GW management;
- A framework for subsidiary and support to local water management on a partnership basis;
- Acquisition and management of knowledge and information about the resource and its uses, and communications with stakeholders.

***Local level* involves** the organizations and institutions that control actual outcomes on the ground and respond in varying degrees to the rules and incentives from strategic level of governance. This level includes responsiveness to strategic level of governance. It includes:

- **Public agencies** include ministry branches, local authorities, basin agencies which may directly control part of the resources or they may influence outcomes by the application of a regulatory system, or by working in partnership with local collective management institutions or with individuals.
- **Local collective management institutions** include collective organizations and its rules, sanctions, and dispute resolution mechanisms developed by communities and interest groups.
- **Individual STW/DTW owners**, whose well development and abstraction behaviours are determined by individual, household or family goals.

Effective sustainable groundwater irrigation management: The output comes with the management practices through governance. If these practices are followed and implemented properly, effective sustainable GW irrigation can be attained.

2.4 Conclusion

The chapter highlighted related literature, theoretical underpinning and conceptual framework for the study. The next chapter is fanatical to providing the research methodology for the dissertation.

Chapter Three
Research Methodology

3.1 Introduction

This chapter is organized with the tools and techniques used to complete the study through maintaining a scientific process. It includes research design, sampling process, data collection methods, data analysis tools– overall a process to complete the study.

Research method is an organized system for collecting data and solving research problems based on the analysis of these data. The reliability of the research depends on the appropriate method. Therefore, methodology is an indispensable part of any research and must be carefully selected to achieve the research goals. Methodology should enable researchers to collect valid and reliable data and analyse the data to arrive at correct decisions. From this perspective, researchers strive to adopt realistic methods. This chapter discusses the methods used for the research study.

3.2 Design of the Study

Research design refers to an overall strategy in which a researcher chooses to assimilate different components of research in a harmonious and rational way to ensure effective solutions to research problems. It establishes the blueprint for data collection, measurement, and analysis. The study objectives determine the type of research design that should be used.

This research is basically a qualitative study, supplemented by limited-scale quantitative data. This approach can be called dominant-non-dominant design.[1] Here, the foremost design is qualitative data, and the less leading design is quantitative data. Denzin calls it “triangulation”, the purpose is to refer to the

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[1] John W. Creswell, *Research design: Qualitative and quantitative approaches* (London: Sage Publications, 2014), 3.

application of a combination of methods when studying similar phenomena.[2] Qualitative research illustrates various specific views or helps learn about demographic behavior through interviews with a small sample of population members.[3] Qualitative procedures can often give people a deeper understanding of the phenomenon. The study also followed data collection techniques and tools that conform to qualitative methods.[4] Another reason for adopting this method is that the required data is mostly collected in the form of narration and description.

3.3 Selection of Study Area

Selection of the study area is a vital step, which depends mainly on the research objectives. Due to time and resource constraints, it is not possible to include the entire *Barind* area of Bangladesh into the scope of the data collection. *Barind* Tract is located in the north-western region of Bangladesh. It consists of the present districts of Rajshahi Division and some areas of Rangpur Division. Three districts namely Rajshahi, Chapai Nawabganj and Naogaon have been selected purposively as they possess same sub-tropical climate and geophysical characteristics. After that one upazila from each district has been selected i.e., Tanore from Rajshahi, out of 9 upazilas, Nachole from Chapai Nawabganj, out of 5 upazilas, and Niamatpur from Naogaon, out of 11 upazilas following Simple Random Sampling (lottery method). Again as each upazila has some unions; therefore, one union from each upazila has been selected in the same manner. Finally, three villages were selected in the same technique i.e., one village from each union. The process of the study area selected is shown in the following figure:

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[2] Norman K. Denzin, *The research act: A theoretical introduction to sociological methods*, 2nd ed. (New York: McGraw-Hill, 1978), 291.

[3] Harrie Jansen, "The Logic of Qualitative Survey Research and its Position in the Field of Social Research Methods," *Forum Qualitative Sozialforschung*11, no. 2, art. 11 (May 2010), http://www.qualitative-research.net/index.php/fqs/article/view/1450/2946.

[4] Bruce L. Berg, *Qualitative Research Methods for the Social Sciences*, 4th ed. (London: Allyn and Bacon, 2001), 2-4.

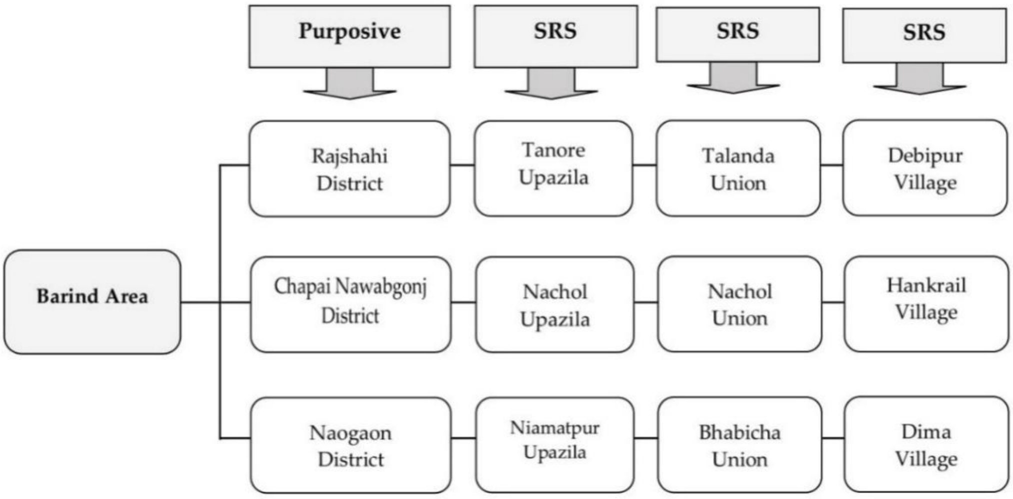

Figure 3.1: Process of the study area selection

3.4 Determination of Sample Size and Distribution

3.4.1 Sampling for Users/ Farmers

When selecting samples for research purpose, two factors need to be considered. The sample size should be as large as possible to allow sufficient freedom for statistical analysis. On the other hand, data collection, processing and analysis should be managed within the limits of physical, human and financial resources.

For selecting appropriate sample size, the first task of researcher is to identify the population of the study area. The population of the present study was the numbers of households engaged in agricultural activities living permanently in the villages selected randomly. Head of the households were considered as respondents for the study. Interviews for the purpose of collecting data were made only with those families engaged in agriculture. Total number of households engaged in different professions in the selected three upazilas was 142158.[5] Total number of households engaged in only agriculture in the selected three upazilas was 116154[6], which accounts for 82% of total households engaged in agriculture in

[5] Bangladesh Bureau of Statistics (BBS), *Community Report, Population and Housing Census 2011*, http//:www.bbs.gov.bd.

[6] *Document review*, Upazila Agriculture Office, Tanore, Nachol and Niamatpur.

the study area. Total number of household in selected three villages was (159+261+236) = 656.[7] Therefore, size of the study population (N) was 538, which is 82% of the households in those three villages under study. As it was not practically possible to consider all the agriculturally dependent families or households in those villages under study as the sample size. Therefore, for minimizing cost and time besides the need for maintaining the requirements for conducting various statistical analyses to satisfy the objectives of the study a simple random sampling technique was followed in the present study. According to probability sampling technique, the determined sample size was 160. Following formula was used for determining the sample size.[8]

$$n = \frac{z^2.N.p.q}{e^2(N-1)+z^2.p.q} = \frac{(1.96)^2 \times 538 \times .82 \times .18}{.05^2(538-1)+(1.96)^2 \times .82 \times .18} = \frac{305.0569}{1.9095} = 159.76 \text{i.e., } 160$$

Here, n= Sample size

N= Total number of households (engaged in agriculture)

z= 1.96 (at 95% confidence interval)

e= Acceptable error (error limit 5%, i.e., 0.05)

p= Estimated population proportion= 0.82[9]

q= (1–p) = (1–0.82) = 0.18

Table 3.1: Sample Distribution for Users/ Farmers

Types of Respondents	Data Collection Methods	Sample Villages	Total Households	Households Engaged in Agriculture (N)	Sample Households (n)
User/ farmer	Questionnaire Survey	Debipur	159	$N_1 = 130$	$n_1 = 39$
User/ farmer		Hankrail	261	$N_2 = 214$	$n_2 = 63$
User/ farmer		Dima	236	$N_3 = 194$	$n_3 = 58$
Total			**656**	**N = 538**	**n = 160**

[7] BBS, *Community Report, Population and Housing Census 2011*, http//:www.bbs.gov.bd.

[8] C.R. Kotheri, *Research Methodology: Methods and Techniques,* 2nd ed. (New Delhi: New Age International Limited, 2014), 179.

[9] Ibid.

Sample household for each village (n_i) has been calculated by using following formula:

$$n_i = \frac{N_i}{N} \times n$$

Here, n_i = Size of sample village i.

N_i = Study population of village i.

N = Total number of study population.

n = Sample size

3.4.2 Reserve Sample

18% of households of the study area were not engaged in agriculture. In addition, in some cases selected respondents were not be able to respond due to temporary migration or other demographic reasons. Considering all these 20% of sample was kept reserved initially.[10] The reserved sample for this study was 33.

Table 3.2: Reserve Sample Distribution

Sample Village	Sample Size	Distribution	Reserve Sample
Debipur	39	39×0.20	8
Hankrail	63	63×0.20	13
Dima	58	58×0.20	12
Total			33

3.4.3 Sampling for Qualitative Data

Purposive sampling method has been applied for KII and in-depth interviews. The main reason for choosing the purposive sampling method is that all the officials involved in the local level administration are not involved in GW management. Therefore, the purposive sampling method has been implemented to ensure that the respondents are the officials or individuals with proper knowledge related to GW management and implementation. An in-depth interview with a water expert, an economist, an environmentalist and a sociologist was conducted to collect

[10] Leyla Mohadjer, Tom Krenzke and Wendy Van de Kerckhove, *"Survey of Adult Skills Technical Report"* 25, Chap 14, https://www.oecd.org/skills/piaac/Technical%20Report_ 17OCT13.

valuable data. In this case the purposive sampling method has also been applied to ensure that these experts have long experience in GW management research.

As the field of the study is concerned with the GW irrigation in the *Barind* tract, and it possesses different geophysical and topographical characteristics than the other parts of Bangladesh do. Understanding the complexity of the existing irrigation systems utilizing the different water resources (both ground and surface) including its short and long term impacts on the environment, economy, and society, the agricultural produces cultivated in different seasons needing different irrigation means and amount of watering, and the impact of all these activities in totality requires to hold general conversations and interviews with different people having expertise in this field and years of experience because of holding positions in different Govt. departments directly or indirectly dealing with the water resources of the area under study. Therefore, the following table exhibits the sample distribution of experts and key informants including the types of sampling followed in selecting the expert and key informants, and data collection methods used.

Table 3.3: Sampling Distribution Qualitative Data

<table>
<tr><th>Types of Respondent</th><th>No. of Respondent</th><th>Data Collection Methods</th><th>Types of Sampling</th><th>Total</th></tr>
<tr><td>Water expert</td><td rowspan="4">1 from each field</td><td rowspan="4">In-depth Interview</td><td rowspan="4">Purposive</td><td rowspan="4">4×1= 4</td></tr>
<tr><td>Environmental expert</td></tr>
<tr><td>Sociologist</td></tr>
<tr><td>Economist</td></tr>
<tr><td>BMDA Engineer</td><td rowspan="8">1 from each office in each upazila</td><td rowspan="8">KII (Key Informant Interview)</td><td rowspan="8">Purposive</td><td rowspan="8">8×3= 24</td></tr>
<tr><td>DAE</td></tr>
<tr><td>LGED Engineer</td></tr>
<tr><td>BRDB Officer</td></tr>
<tr><td>Co-operative Officer</td></tr>
<tr><td>DGM/AGM of BREB</td></tr>
<tr><td>Upazila Chairman</td></tr>
<tr><td>Chairman of UIWRMC (UNO)</td></tr>
<tr><td>NGO Representative</td><td></td><td>KII</td><td></td><td>2</td></tr>
<tr><td>Total</td><td></td><td></td><td></td><td>30</td></tr>
</table>

3.5 Sources of Data

The study was conducted on the basis of both primary and secondary data. Primary data was collected from the respondents of the study area. Water experts, environmental experts, sociologists, economists, different local Government officials, NGO officials, pump operators, users of GW recognized as primary source. Relevant documents of concerned local government offices have also been treated as primary data. Secondary data, bearing utmost significance, collected from the different publication, such as books, articles, journals, dissertations, annual reports, Government orders, Government gazette, dailies, rules, regulations and acts, and websites etc. to review the previous literature.

3.6 Data Collection Tools

3.6.1 Questionnaire Survey

A questionnaire is a research tool that consists of a set of questions or other types of prompts designed to collect information from respondents. Research questionnaires are usually a combination of close ended and open-ended questions. Open-ended, long-form questions enable interviewees to express their thoughts freely. In order to collect primary data a structured questionnaire embodying close ended questions supplemented with open ended ones was used to receive the insights in details. For this study 160 households were selected using the probability rules. Head of the households were considered as respondents for the study. It was not made possible to survey 13 household samples. Besides this, 9 questionnaires had to be rejected for incomplete answers. The lacking in the number of collected questionnaire, occurred due to above two reasons, have been filled by taking replies from the reserved samples. The researcher himself being well-trained enumerator conducted the questionnaire survey.

3.6.2 Key Informants Interview (KII)

Key informant interviews involve interviewing a selected group of individuals who may provide the required information, ideas, and insights for a specific topic. In the study area some local Government offices are engaged in GW management.

The local Government officials have in-depth knowledge about GW management. Besides, some NGOs are also functioning on GW related field in the study area. These people have been considered as key informants for the study. For this, 3 Upazila Chairman, 3 UNO (Head of the Upazila Integrated Water Resource Committee), 3 BMDA Engineer, 3 Upazila Agriculture Officer, 3 LGED Engineer, 3 BREB Engineer, 3 Upazila Cooperative Officer, 3 BRDB Officer, and 2 NGO official in total of 26 of them have been selected purposively as key informants to include their views, ideas, knowledge, and comments to perceive the scenario comprehensively. The investigator, researcher himself, has conducted interviews with the help of a guideline, and during interview sessions, notes have been taken and instrument such as audio recorder has been used with the consent of the interviewees. The interviews were taken in Bengali and later translated into English.

3.6.3 In-depth Interview

In-depth interview is another vital qualitative tool which helps obtain a variety of information and build concept and idea about any issues involved. In-depth interview is defined as a qualitative research technique where intensive individual interviews are conducted. Expert opinion is crucial to understanding the various issues relating to sustainable use of GW irrigation without damaging the environment, economy and society of a particular region. That's why some experts' (such as water expert, environmental expert, economist, and social expert)opinions were collected through in-depth interview being conducted through conversation, note taking and audio recording with the consent of interviewees using a checklist. The researcher himself conducted the interviews and the duration of each interview occurred was in between one and two hours. Interviews were conducted in Bengali and subsequently translated into English.

3.6.4 Focus Group Discussion (FGD)

FGD is another important tool of qualitative data gathering method. A guideline was developed by researcher for facilitating the FGD to collect views and comments, experiences, ideas, and expectations regarding sustainable use and management of GW for irrigation ensuring such use. It helped the researcher share and note down their achievements, and problems they faced while they were involved with the GW irrigation system. For study purposes 3 FGDs carried out, one at each upazila, which have been organized consisting of 10 participants to engage in the discussion session.

Table 3.4: Participants of FGD

Category of participants	No. of participants
End user (farmer)	3
Elected public representative	1
BMDA Official	1
Official DAE	1
BREB official	1
NGO representative	1
BMDA pump operator	1
Private pump operator	1
Total	**10**

3.6.5 Observation

Observation in qualitative research is one of the oldest and most basic research methods. This method involves using one's own feelings to collect data, especially observing and listening in a systematic and meaningful way to understand the phenomenon of interest.[11] For study purpose, besides collecting data using a questionnaire, the researcher also observed the context of interest while collecting data, and while he was present as an observer in each of focus group discussion held in the study area. Researcher also conducted interviews with the local government officials and had the opportunity to sense the environment. In addition, various ongoing projects of BMDA were also visited and observed by the researcher.

3.6.6 Document Review

Different types of documents were collected from different local Government Departmental offices such as BMDA, DAE, LGED, and BREB. The analyses of

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[11] Lynne EF. McKechnie, "Observational research," *The SAGE encyclopedia of qualitative research methods* 1 (2008): 573-575.

these documents contributed to study in multidimensional ways that include understanding discussions and decisions of GW sustainability status, basic data of the study area, GW aquifer status, rainfall trend etc. Moreover, GW related Acts, rules, policy, guidelines etc. have taken under consideration in a bid to measure sustainability status. Unavailability of the documents, unprepared circumstances, heterogeneous demonstrations, and inaccessibility to the targeted personnel posed as drawbacks to the process.

3.7 Data Analysis and Interpretation

The present study makes an effort to explore simple analytical approach with the help of acquired knowledge obtained by review of the relevant literature on sustainable GW irrigation management. The study describes the sustainability management of GW irrigation. For qualitative part of the study primary data collected through KIIs, in-depth interviews, FGDs, and observation were synthesized and translated into some key factors that influence sustainability management practice regarding irrigation. For quantitative part of the study, only relevant, accurate, unbiased representative data were gathered from the reliable sources. The data collected through the field survey coded, compiled, tabulated, and edited to remove inconsistencies to tailor to the objectives of the study. Graphs, charts, tables, diagram etc. were used to present collected data to make these data comprehensible. Qualitative were analysed through inductive reasoning process for drawing the appropriate inference. Statistical Package for the Social Sciences (IBM SPSS version 22) and Microsoft Excel software used where needed. On the whole, the study has adopted pertinent statistical tools to analyse the data. Following the above procedures, and based on the objectives of the research, data obtained from respondents were summarized and categorized in appropriate manner to ease the conduct of required analyses and discussion thereon. Moreover, for drawing final inferences, results from qualitative and quantitative data were synthesized and interpreted as needed, though they have triangulated each other.

3.8 Reliability and Validity of Data

Validity is one of the significant strong point of qualitative research. It refers to the fidelity of data, which is subject to the measurement of the phenomenon, and research problem. Validity and reliability of the collected data have been facilitated through triangulation of data by using different methods of data collection, such as questionnaire survey, key informant interviews, in-depth interviews, FGD, observation, and document review. Moreover, in some cases statements have been cross- examined with the respondents.

3.9 Units of Analysis

Unit of analysis has led the researcher to identify the units on which the researcher has generalized his findings. Three key properties direct the formulation of unit of analysis including social entities, time, and space. However, the key area of the unit of analysis originates from the social entities; it contains a person or an institution, or groups. More explicitly individuals, groups, artefacts, geographical units, social interaction can be included in the unit of analysis.[12]

3.10 Conclusion

The focus of this chapter was on adopting methods which are suitable for conduct of the current study. The next chapter will discuss about the involvement of the institutions in GW irrigation.

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[12] Social Research Methods, "Unit of Analysis," https://www.socialresearch methods.net/kb/unitanal.php.

Chapter Four
Involvement of the Institutions in Groundwater Irrigation

4.1 Introduction

This chapter attempts to present an overview of the study area including the institutional involvements making up the management of GW irrigation. This chapter strives to reveal the various units of area under study including the profiles of various Governmental Departments involved in management of GW irrigation in Bangladesh, particularly in the *Barind* area.

4.2 The Study Area

4.2.1 *Barind* Tract

Barind Tract is the largest Pleistocene physiographic unit of the Bengal basin, covering an area of about 7,770 sq. km.[1] It is fragmented being made up of several separate sections in the northwestern part of the country covering mostly old alluvium. The part of greater Rajshahi, Dinajpur, Rangpur and Bogura District of Bangladesh and the Indian territorial Maldah District of West Bengal are geographically identified as *Barind* Tract. Compared to other parts of the country, the hard red soil in these areas is very remarkable. To the west, the main area is tilted up, and to the east this area is tilted downwards. In this area more extreme temperature variations (ranging from 45 degrees Celsius down to 5 degrees Celsius) have been experienced. It is divided into three units: The Recent Alluvial Fan, the *Barind* Pleistocene, and the Recent Floodplain.

The *Barind* Tract lies in the monsoon region of the summer dominant hemisphere. The tropic of cancer lies on the south of this region. The climate of the area is generally warm and humid. Based on rainfall, humidity, temperature and

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[1] *Banglapedia*, s.v. "*Barind* Tract." http://www.ebanglapedia.com.

wind pressure the weather condition is classified into four types, such as, (a) pre-monsoon, (b) monsoon, (c) post-monsoon and (d) winter. Average rainfall is comparatively little in this region than the national average. It mainly occurs during the monsoon. Rainfall varies from place to place as well as year to year.

The total cultivable area being 1.44 million acres, out of which 34% is loamy, 10% is Sandy, 49% is clayed and the rest of 7% is others.[2] Out of the total cultivable land, 84% are single cropped, 13% are double cropped and the rest are triple cropped. The cropping intensity was 117%.[3]

Compared with other parts of the country before 1947, Rajshahi Barind Tract was very prosperous and its socio-economic activities were much better. Trade and commerce were dependent to a large extent on Kolkata, and it was the hinterland of the port of Kolkata.

After India's partition, the region's trade and commerce with Kolkata were completely interrupted, and almost all social and economic activities were hampered. As there was no good road connection with other parts of the country or even with the capital Dhaka; there was no effort to develop or improve the socio-economic structure of the region. Consequently, this land was lagging behind at all stages of its development with little economic activity being in force. In addition, there occurred meagre developments in the country's domestic industrialization in the region. As a result, compared to other parts of the country, the living standards of the people in this area were lower. Recently, the situation is being changed remarkably due to carrying out of huge development activities in this region.

4.2.2 Tanore Upazila

Tanore upazila is in the Rajshahi district, Bangladesh. Tanore upazila is bordered by Niamatpur upazila of Naogaon district in the northwest, Manda upazila in the

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[2] "Background of the BMDA," *Barind* Multipurpose Development Authority (BMDA), accessed December 11, 2020, http://www.bmda.gov.bd/site/page/cc476d52-3552-4192-901d-efb7aac2e8af/-.

[3] Ibid.

Naogaon district in the northeast, Nachol and Chapai Nawabgonj sadar of Chapai Nawabgonj district in the west, Paba upazila in the south and southeast, Godagari upazila in the southwest, and Mohanpur upazila in the east.

Tanore upazila is divided into 2 Municipality named Nachol and Mundumala and 7 UPs, specifically Kalma, Badhair, Panchondar, Soronjai, Talanda, Kamargaon, and Chanduria. The UPs are subdivided into 211 mauzas and 233 villages.

4.2.3 Nachol Upazila

Nachol upazila is in the Chapai Nawabganj district, Bangladesh. Nachol upazila is bordered by Gomostapur upazila in the northwest, Niamatpur upazila in the Naogaon district in the northeast, Tanore upazila in the Rajshahi district in the southeast, and Chapai Nawabganj Sadar upazila in the southwest.

Nachol upazila is divided into Nachol Municipality and four UPs, specifically Fatehpur, Kosba, Nachol, and Nezampur. The UPs are subdivided into 201 mauzas and 191 villages.

4.2.4 Niamatpur Upazilla

Niamatpur upazila is in the Naogaon district, Bangladesh. Nimatpur upazila is bordered by Porsha upazila on the north, Manda and Mahadebpur upazilas on the east, Nachol upazila of Chapai Nawabgonj district and Tanore upazila of Rajshahi district on the south, Gomastapur and Nachol upazila of Chapai Nawabgonj district on the west.

Niamatpur upazila is divided into Niamatpur Municipality and eight UPs, specifically Hajinagar, Chandan Nagar, Bhabicha, Niamatpur, Rasulpur, Parail, Sreemantapur, and Bahadurpur. The UPs are subdivided into 321 mauzas and 341 villages.

4.2.5 Basic information on upazilas under study

Item	Tanore[4]	Nachol[5]	Niamatpur[6]
Location	Between 24°29' and 24°43' north latitudes and 88°24' and 88°38' east longitudes	Between 24°38' and 24°51' north latitudes and 88°15' and 88°21' east longitudes	Between 24°41' and 24°59' north latitudes and in between 88°23' and 88°40' east longitudes
Area (sq. km)	295.39	283.68	449.10
Number of Population living in each upazila	222853	170360	248351
Number of Agro families in each upazila	30456	31687	38210
Number of Municipality	2	1	1
Number of Unions	7	4	8
Number of agricultural Block	23	13	24
Number of Mauza	212	201	321
Number of Village	210	230	341
Amount of Cultivable land (hec)	23688	25050	33200
Amount of Single crop cultivable land (hec)	1270	3321	4418
Amount of Double crop cultivable land (hec)	5131	15148	19388
Amount of Triple crop cultivable land (hec)	16499	6570	9394
Fourfold crop cultivable land (hec)	-	11	-

[4] "Tanore upazila at Glance," Tanore upazila, accessed December 13, 2020, http://tanore.rajshahi.gov.bd, "Tanore upazila at Glance," Upazila Agriculture Office, accessed December 13, 2020, http://dae.tanore.rajshahi.gov.bd, and "Tanore upazila at Glance," Barind Multipurpose Development Authority (BMDA), accessed December 13, 2020, http://bmda.tanore.rajshahi.gov.bd.

[5] "Nachol upazila at Glance," Nachol upazila, accessed December 13, 2020, http://nachol.chapainawabganj.gov.bd, "Nachol upazila at Glance," Upazila Agriculture Office, accessed December 13, 2020, http://dae. nachol.chapainawabganj.gov.bd, and "Nachol upazila at Glance," Barind Multipurpose Development Authority (BMDA), accessed December 13, 2020, http://bmda. nachol.chapainawabganj.gov.bd.

[6] "Niamatpur upazila at Glance," Niamatpur upazila, accessed December 13, 2020, http://niamatpur.naogaon.gov.bd, "Niamatpur upazila at Glance," Upazila Agriculture Office, accessed December 13, 2020, http://dae. niamatpur.naogaon.gov.bd, and "Niamatpur upazila at Glance," Barind Multipurpose Development Authority (BMDA), accessed December 13, 2020, http://bmda. niamatpur.naogaon.gov.bd.

Fallow land (hec)	88	95	-
Irrigated land (hec)	10356		
Cropping intensity (%)	267	213	215
Density of Land use (%)	78.5	88.30	73.94
Variety of crops	Rice, potato, wheat, oilseed, dal, jute, onion, garlic, vegetables.	Rice, wheat, oilseed, dal, potato, jute, onion, garlic, vegetables.	Rice, potato, wheat, oilseed, dal, jute, onion, garlic, vegetables.
Number river			1 (4 km)
Number of pond	5384	4827	4981
DTWs	545	522	603
STWs	956	902	932

4.3 Institutional measures

Following are the different institutions and bodies involved in managing and controlling the utilization of water resources both ground and surface.

4.3.1 Basic Profile of the Local Government Organizations

Indicators	BMDA	DAE	LGED	BREB
Established	1992	1982	1992	1977
Status	Government autonomous	Government agency	Government agency	Government agency
Governing laws	The BMDA resolution 1992 The Groundwater Management Ordinance 1985	Executive order	National Water Policy 1999 Guidelines for Participatory Water Management 2000	Rural Electrification Board Act, 2013 Rural Electrification Board Ordinance, 1977
Controlling authority	Ministry of Agriculture (MoA)	Ministry of Agriculture (MoA)	Local Government Division(LGD)	Ministry of Power, Energy and Mineral Resource (MoPEMR)
Governing Body	Board of Directors	Board of Directors	LGD	Member of Board
Headquarter	Rajshahi	Dhaka	Dhaka	Dhaka
Administrative Head	Executive Director	Director General	Chief Engineer	Chairman

Working area	Rajshahi and Rampur Division	Whole of Bangladesh	Whole of Bangladesh	Whole of Bangladesh
Total Staffs	1563		4968	
ICT infrastructure	Website MIS Software	Website	Website MIS Software eGP Own email domain	Website
Major Functions	Irrigation Surface water modernization Rural road construction Seed production Tree plantation Electrification of DTWs	Provide training Celebrate Field Day Exhibition plot Distribution of fertilizers and seeds Provide information related to agriculture Awareness raising	Development of rural infrastructure Small scale water resources development Rural infrastructure maintenance Technical assistance to local governments Implementation of infrastructures of other ministries Development of growth centre & hatbazar	Power generation, operation, conversion and distribution Manufacture, repair, and maintenance of electrical equipment Agricultural development and establishment of rural industries Assistance in expansion and drainage of irrigation facilities

4.3.2 *Barind* Multipurpose Development Authority (BMDA)

The *Barind* Multipurpose Development Authority (BMDA) is an autonomous and multipurpose agricultural development agency under the MoA. BMDA is the leading irrigation service agency in *Barind*. It has an extensive network that can irrigate almost the entire area of Rajshahi and Rangpur division. It is responsible for developing GW resources for irrigation, improving traditional SW storage by repairing and re-excavating ponds, canals and bells, and promoting SW irrigation in the *Barind* region. Although this is an irrigation provider, the use of irrigation wells is also restricted and can only be used to supply water to nearby rural settlements through pipelines. In addition, BMDA has played an important role in the construction and maintenance of rural roads, promotion of agricultural product sales, environmental protection by tree planting, improvement of seed production and the electrification of irrigation wells.

However, BMDA is the first institution in Bangladesh, which has established an extensive and planned underground pipeline irrigation network. As a result, the loss of water through irrigation channels has almost stopped. In order to operate DTWs, BMDA appointed private operators by providing commission. On the other hand, it introduced prepaid smart cards to distribute irrigation water to farmers. The agency has also developed first-level smart card sellers, who actually sell irrigation hour directly to farmers through smart cards. This smart card system greatly reduces the conflict between farmers and operators over water pumping time and water volume.

It enables farmers to receive irrigation water based on the available money balance of the smart card, and can also irrigate easily in convenient time. BMDA is the only public organization in the water sector that operates on its own income. Its basic advantage is its human resources, well-trained field officials are capable of providing technical solutions and maintenance to DTWs. It has established a realistic and organized irrigation tariff system. Surprisingly, the agency has achieved almost 100% irrigation tariffs from farmers. BMDA has again succeeded in reaping benefits from SW irrigation programs, which is almost unusual for other BWDB’s irrigation projects.

- BMDA is a multi-purpose development organization whose responsibilities are to provide GW irrigation, SW irrigation, excavation of ponds, canals, construction and maintenance of rural roads, seed production and environmental protection, etc. Main effort of BMDA has employed in GW based irrigation, not as a water resources management planner for integration.

- Since its establishment in 1992, BMDA has been drawing GW from the *Barind* area, which is plagued with water resource constraint. There is scientific and general evidence that GW resources are under tremendous pressure and its aquifer levels are falling down at a shocking rate. In many areas, DTWs cannot work normally due to the depletion of GW levels. Further extraction of water for crops that consume more water (such as boro rice) may shrink GW balance. But BMDA is continuing to irrigate through DTWs in order to earn "appreciable" irrigation income.
- Unsustainable and desperate method of BMDA for extracting GW may cause dissatisfaction among local people in the future, and many achievements of BMDA may be tarnished in the future, which may affect the organization's image and reputation.
- Excessive dependence on GW irrigation income may lead the organization to despair in the future because of indiscriminate extraction of GW.
- The BMDA approach does not allow any citizen to participate in the decision-making process.
- The irrigation and drinking water program is led by BMDA's water user associations. Due to the lack of adequate supervision and support from BMDA, these WUAs cannot operate functionally.
- Unresolved issues (such as the use of human resources in the government's revenue budget structure) have created huge tensions between employees and distrust with top level management. Such tension is affecting daily activities.
- BMDA officials are also concerned about the huge fear of BADC's devouring.
- The conservative mentality of BMDA officials has been limiting their credibility, further expansion and gradual planning.
- Unwillingness to use SW for irrigation and excessive reliance on GW has created a crisis in the organization's image, which may make it acceptable to people in the *Barind* region.

4.3.3 Local Government Engineering Department (LGED)

LGED is one of the largest infrastructure development organizations in Bangladesh, working directly under local government departments. For the first time, it incorporates water resources components into rural development plans. LGED emphasized the use of a participatory approach in the operation and maintenance of small-scale water resources projects and demonstrated the success of project management. This result inspired the authority to establish an independent IWRM department in early 2003, headed by an additional chief engineer. The department prepares regional water resources assessments through private consulting companies that interact with local stakeholders to a prescribed level, supports water management cooperative associations, ensures the maintenance of completed projects, and plans and designs new water resources plans.

This expansion is a positive and LGED is involved in rural water supply and sanitation projects, but the role of the department is limited to promoting SW elevation and re-excavating canals and ponds for agricultural purposes. The IWRM department should play a broader role to implement IWRM truly, not just dealing with SW management. It has made little effort to promote water-saving technologies, water-saving crops, wastewater treatment, GW replenishment, water-saving awareness, the use of renewable energy to extract water, household-level rainwater collection and use, etc. In many cases, LGED uses underground concrete pipes and uniform concrete drainage pipes to distribute irrigation water. Because of its frequent leakage, cracking and breaking, the maintenance of concrete pipes is very difficult, and surface drainage is very expensive, and the land with low irrigation efficiency takes up a lot of valuable land. Another criticism from stakeholders is that after handing over the operation and maintenance of the SW program, LGED did not properly supervise the governance of the association. As a result, there were conflicts in the water fee, irrigation time, the amount of water available and the disposal of the association's funds.

Therefore, to overcome these difficulties, LGED authorities should take necessary steps, such as:

- The capacity and governance of the existing WMCSs in the LGED implementation plan are not sufficient to properly operate O&M. LGED needs to work with NGOs to strengthen the capacity of these cooperatives and improve their governance.
- LGED is working directly with the WMCA. In most cases, these associations are not enough to manage the fund needed for improvement, expansion, and operations. Moreover, in many cases, the activities of the association are hindered by local conflicts. LGED can allow local government agencies to participate in the management of these programs to minimize conflicts and mobilize resources.
- LGED can work with other GO-NGO to deal with projects in a timely manner, and seize opportunities and operate projects through PPPs.
- LGED needs to extend its water resources authorization to implement IWRM duly through promotion of water-saving technologies, water reuse, rainwater harvesting, GW replenishment, SW modernization, maintenance of water quality and safety, wastewater treatment, etc.
- LGED needs to prepare and update GIS-based water resources maps, open-source databases and integrated MIS to effectively plan, manage and execute water resources projects.

4.3.4 Department of Agriculture Extension (DAE)

The vision of the DAE is to provide eco-friendly, safe, climate-resistant, sustainable production of good agricultural practices and maintain natural resources to ensure food security and commercial agriculture with a view to accelerating the country's socio-economic development. The mission of the DAE is to provide effective, effective, decentralized, site-specific, demand-responsive and comprehensive extension services to all types of farmers to acquire and use better knowledge to increase sustainable and profitable crop production; ensure the country's socio-economic development.

The DAE works at the field level to raise awareness in the farmers, provide ideas about low water absorbing crops, crop diversification and AWD, provide information on modern methods to farmers through Field Days, provide agricultural training, etc. In fact, DAE is not directly involved in any work on GW or surface water management. However, they work with BMDA and LGED in integration for some extent. Although this department is not involved in any project related to irrigation, there is ample opportunity to play a role in this regard. This is because the farmers have a direct relationship with the manpower working in this department.

4.4 Bangladesh Rural Electrification Board (BREB)

The BREB is responsible for the electrification of rural Bangladesh. Motto of BREB is to provide quality electricity at grass root level in a democratic manner. Since the implementation of the program, electricity has been used as a means to create opportunities for improving agricultural production and promoting social and economic development in rural areas, thereby improving people's living standards and quality of life for rural people.

BREB plays a direct role in the expansion and drainage of irrigation facilities among other works. According to the license issued by the District / Upazila Integrated Water Management Committee, BREB is providing electricity connection to the irrigation system and assisting in the repair and maintenance of electrical equipment as required.

4.5 Other Organizations

At the local government level, some other organizations are working as part of the executive branch of the government, such as BRDB, Upazila Cooperative Office, etc. These organizations are not directly involved in any work related to irrigation.

Although these institutions are not directly involved in GW irrigation management, these institutions have the opportunity to play a role in integrated water resources management. BRDB is mainly involved in providing loans on behalf of the Government for agriculture, fisheries, dairy, poultry and various economic activities. Most of the members of the BRDB affiliated association are involved in agriculture. So, BRDB officials can make the members of these associations aware about the use of water in a sustainable way. Similarly, by making the members of the cooperative societies under the Upazila Cooperative Society aware about sustainable water management, they can play a positive role in the management of sustainable water resources. UIWRMC is a committee on sustainable water resources management, headed by UNO, with officials working in various departments of the upazila. This committee takes the necessary steps to ensure sustainable GW management for irrigation.

4.6 Conclusion

This chapter discussed the study area and identified the institutions involved in the management of GW irrigation and their origin, nature, and functions. Next chapter will review the legislative measures and framework related to sustainability management of GW irrigation in Bangladesh.

Chapter Five
Review of Legislative Measures and Framework

5.1 Introduction

This chapter describes the legislative measures and the framework related to sustainability management of GW irrigation in Bangladesh. The chapter also presents the existing water resource management laws and regulations in Bangladesh. Water governance in Bangladesh and its background have been highlighted at the beginning. Subsequently, different policies and legal issues related to GW resource management such as Bangladesh Water Act 2013, National Water Policy 1999, Bangladesh Water Rule 2018, and Integrated Water Resource Guideline 2019 have been reviewed. Finally, the effectiveness and limitations of the relevant laws and regulations have been attempted to examine.

Bangladesh has a number of laws and regulations related to water resources management. The main purpose of these laws and regulations is to take necessary steps to conserve, distribute and manage water resources in a sustainable manner. Institutions and users of water resources determine their course of actions within the purview of these laws. The chapter presents the water resources laws and regulations regarding GW, different law-making and enforcement agencies and their activities along with the conservation, distribution, use and management of water resources in a sustainable manner emphasizing particularly the management of GW. This chapter also sheds light on the rules to be followed for installation of irrigation pumps, provisions regarding declaration of water stress areas etc.

All the discussions made in this chapter highlight the study objectives— to analyse legislative measures and framework for GW management for irrigation (objective no: 1, cited in chapter 1).

5.2 Water Governance in Bangladesh and Its Background

Water governance is at the core of any country's water management approach and it is concerned with balancing the competing or diverse water resources interests of the different quarters for fulfilling the long-term demand for water of the people in a country. It is also concerned with controlling the harmful activities of specific actors to prevent the shared water resources and the systems thereof from being damaged. The Governance, particularly relating to water is comprised of some legislative and institutional measures to look after how water resources and utilization of water are administered locally.

Water resources planning in Bangladesh dates back to 1964, when East Pakistan Water and Power Development Authority (EPWAPDA) (now BWDB) developed a 20-year master plan. After the severe floods occurred in 1954 and 1955, some important studies were carried out. The most important outcomes of that efforts include the Kruger Mission Report of 1957, General Hardin's Report of 1963, and Professor Thijsse's Report of 1964. The master plan for 1964 focused on large-scale flood protection, drainage and irrigation projects to increase agricultural production levels, which influenced the development of the water sector until 1975.[1]

The International Bank for Reconstruction and Development (IBRD) delegates reviewed the 1964's master plan and proposed a strategy to place high priority for low- and medium-cost, low-volume, labor-intensive projects based on light irrigation. By the mid-1970s, with the rapid increase in the number of TWs and LLPs, SW and GW began to be widely used in many sub-sectors.[2]This led to a shortage of water during the driest period of the year, which was further exacerbated by the massive withdrawal of the Ganges River in Farakka Barrage in 1975. Gradually, people's attention has gradually focused on the development of the water sector affecting the environment, fisheries, forests, biodiversity and salt

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[1] "Background," http://www.warpo.gov.bd, November 14, 2018, http://www.warpo.gov.bd/site/page/3ee10cbe-3fb6-41a6-bde8-5a8c8d8f16b7/-.

[2] Ibid

management because of the increased use of SW and GW in household, agricultural and industrial purposes.

A joint mission of the World Bank and the then Government of East Pakistan (GoEP) recommended in 1970 a national water plan based on a systematic assessment of water resources and demands thereof. Subsequently, the government established the National Master Plan Organization (NMPO) under the Ministry of Water Resources in 1983. The NMPO launched the National Water Plan (NWP) project in 1983 to develop a vision plan (1985-2005) meant for water resources development, through an inclusive and comprehensive assessment of water resources (both surface and GW) and all the related needs including navigation, fisheries and the environmental issues. It collected extensive information, developed a series of planning models and analytical tools, and recommended strategies and plans for the water department. The National Water Plan (NWP), which was completed in 1987 was updated in 1991. The plan proposed to institutionalize the country's water plans and long-term water management processes. According to its recommendations, the Water Resources Planning Organization (WARPO) was established in 1992 to implement the task of national water resources planning.

5.3 WARPO and Its Vision, Mission and Initiatives

In June 1992, the MPO was changed into Water Resources Planning Organization (WARPO), whose mandate was issued on December 22, 1991 in the Bangladesh Gazette.[3]

5.3.1 Vision and Mission of WARPO

WARPO's vision is to achieve sustainable water development in Bangladesh through the implementation of Integrated Water Resources Management (IWRM).[4]

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[3] Ibid.

[4] "Vision and Mission," www.warpo.gov.bd, November 14, 2018, http://www.warpo.gov.bd/site/page/f5e29c81-3794-4fd2-837f-1e57f6e78f42/-.

Mission of WARPO are to become an apex organization in macro-level planning, a centre of excellence for the management and integrated development of water resources, the central coordinating body for all relevant activities in the water sector, the custodian of National and Regional Water Resources Databases and Information systems, to act as secretariat to the NWRC and ECNWRC.[5]

5.3.2 Initiatives and Achievements of WARPO

According to desire of Government of Bangladesh (GoB), and based on the recommendations of some organizations and demand of stakeholders, WARPO took some initiatives regarding water act, water policy, guidelines for water use etc. These are:[6]

- National Water Plan-I (NWP-I), 1987
- National Water Plan-II (NWP-II) 1991
- 26 Flood Action Plan (FAP) Studies
- Bangladesh Water and Flood Management Strategy, 1995
- National Water Policy, (NWPo) 1999
- NWMP Development Strategy Report, 2001
- National Water Management Plan – 2001 (Approved on 31 March 2004)
- Guidelines for Environmental Assessment of Water Management (Flood Control, Drainage & Irrigation) Projects, 2001
- National Water Resources Database (NWRD) and MIS
- Integrated Coastal Resources Database (ICRD), 2005
- Options for Ganges Dependent Area Study (OGDA), 2001
- State of Water Resources System, 2001 (Draft)
- Coastal Zone Policy, 2005
- Coastal Zone Strategy, 2006
- Impact Assessment of Climate Changes in the Coastal Zone
- Bangladesh Water Act, 2013
- Bangladesh Water Rule, 2018

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[5] Ibid.

[6] "Major Achievements," www.warpo.gov.bd, November 14, 2018, http://www.warpo.gov.bd/site/page/f5e29c81-3794-4fd2-837f-1e57f6e78f42/-.

From the legislative measures, cited above, researcher will analyse about only those, which are directly or indirectly related with GW irrigation.

5.4 National Water Act 2013

The Water Act 2013 in Bangladesh was the newest and most important water policy. It incorporated many contents from previous water Rules and replaces all previous water-related policies. There are many other policies, the contents of which were found to be overlapping and have interrelation with the current Water Act, such as the Forest Act 1927, GW Management Ordinance 1985, National Forest Policy 1994, Environment Conservation Act 1995, National Policy for Safe Water Supply & Sanitation 1998, the Coastal Zone Policy 2005, Coastal Development Strategy 2006, Integrated Small-Scale Irrigation Policy 2011, and the Disaster Management Act 2012.

For integrated development, management, abstraction, distribution, use, protection, and conservation of water resources, GoB formulated an act, named Bangladesh Water Act, 2013.[7] According to 'Bangladesh Water Act, 2013', all rights over the GW within the state territory shall, on behalf of the people, vest upon the State.[8]

5.4.1 National Water Resources Council (NWRC)

For the purposes of implementing the National Water Act, a council named National Water Resources Council (NWRC) was formed headed by the PM of Bangladesh. Ministers of different concerned ministries, Senior Secretaries or Secretaries of relevant ministries, Director Generals of concerned different offices, water experts, NGO representative and other concerned people are the members of NWRC.[9] The NWRC is the highest decision making body regarding water resource with the following functions:

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[7] Government of People's Republic of Bangladesh. Ministry of Law, Justice and Parliamentary Affairs, Legislative and Parliamentary Affairs Division, *Bangladesh Water Act, 2013*. 14 of 2013, Dhaka: Bangladesh National Parliament, 2013, p 1.

[8] Ibid, p 1.

[9] Ibid, p 4.

- To make policies, and give instructions for integrated development, proper use, safe abstraction, proper distribution, proper protection, and proper conservation of water resources;
- To give instruction in respect of making National Water Resource Plan (NWRP) for ensuring IDWRs;
- To approve the NWRP, and ensure implementation thereof; and
- To perform such other functions regarding water resources, as may be determined by the NWRC.[10]

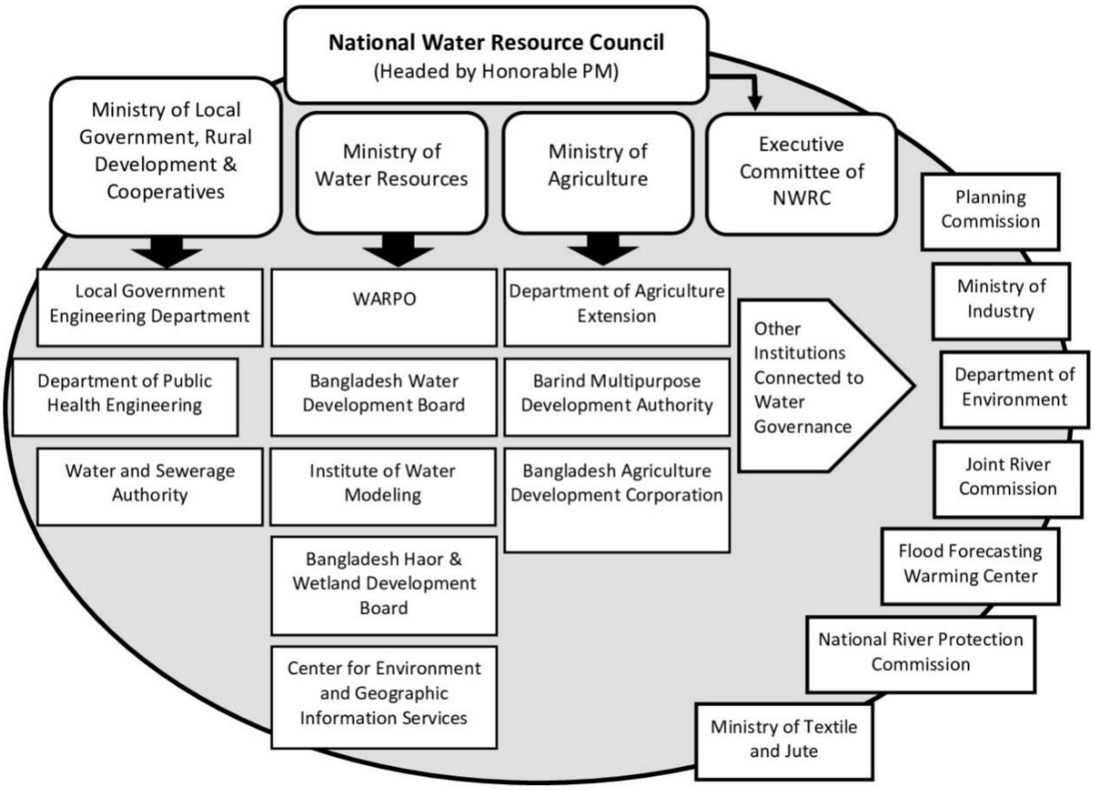

Figure 5.1: Water Governance Bodies and Connected Institutions

5.4.2 Executive Committee of National Water Resources Council (NWRC)

For making NWRC functional, which was framed under the National Water Act 2013, an Executive Committee of National Water Resource Council was framed, headed by the Minister of the Ministry of Water Resources. Ministers and State

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[10] Ibid, p 5.

Minister of different concerned ministries, Member (Agriculture) of Planning Commission, Senior Secretaries or Secretaries of relevant ministries, Director General of Directorate of Environment, Director General of Bangladesh Water Development Board, Chief Engineer of Local Government Engineering Department, Chief Engineer of Department of Public Health Engineering, Member of Joint Water Commission, two water experts, one NGO representative and other concerned people are the members of the executive committee.[11] Director General of WARPO acts as the member secretory to the executive committee. The executive committee have some functions, namely—(a) to publish, distribute, monitor and evaluate the Council's instructions and recommendations on water resources; (b) to promote, monitor and evaluate NWP and NWRP; (c) to take action on any planning, management and inter-sectorial coordination of water resources; (d) to regularly inform and advise the Council on water management issues; (e) to coordinate with relevant departments, formulate policies on disputes between departments, resolve disputes, and issue instructions when necessary; and (f) to perform other duties as may be assigned by the Council.[12]

5.4.3 Fixing the Lowest Safe Yield Level of Aquifer and Restrictions on Abstracting GW[13]

- Notwithstanding anything to the contrary in any other current law, the Executive Committee may notify the official gazette of the results of the necessary inquiry, review or investigation to determine the minimum safe yield level of any aquifer in any area.
- In the notification issued in the previous section, reference should be made to the *Mouza* map and its plot number to specify the area boundary where the minimum safe yield level applies.
- Anyone or an appropriate authority may sink STWs or DTWs into the ground for extraction of GW in the manner prescribed by the rules, subject

[11] Ibid, p 7.
[12] Ibid, p 7-8.
[13] Ibid, p 13.

to maintaining the minimum safety yield level based on the provisions of concerned law or other related laws that are in effect at the time of enforcement.

- To ensure the safe extraction of water from aquifers, the Executive Committee may impose restrictions by issuing protection orders without violating the provisions of this Act.

5.5 National Water Policy 1999

In the Bangladesh Water Act of 2013, there is a provision to adopt a National Water Policy (NWPo) by notification in the official Gazette.[14] According to formulation of NWPo the Government can arrange for a public hearing to collect the opinions of the communities and organizations concerned with water resources. In the NWPo, the Government may include the policies for pricing of water and consider the following issues while pricing:[15]

a. Purpose, and sectors of water use;
b. Affordability of the water users; actual cost of water abstraction and distribution;
c. Financial ability and backwardness of water users or any group thereof;
d. Demand and supply of water, and
e. Any other issues considered relevant by the Government.

After execution of Bangladesh Water Act of 2013, GoB has not yet formulated any further NWPo. In the Act of 2013, there is provision that until new NWPo is adopted by the Government, immediately enacted NWPo would be remaining in force.[16] That is why National Water Policy 1999 still is in force in Bangladesh.

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[14] Ibid, p 7.
[15] Ibid, p 6.
[16] Ibid, p 7.

Since water is crucial for human survival and the country's socio-economic development as well. Hence protecting the natural environment is a policy of the Bangladesh government and the necessary means and measures have been taken to manage comprehensively the country's water resources in a unified and fair way. The purpose of the NWPo is to ensure continued progress in economic development in any poor country through providing relief, ensuring food security and health care for the people and decent living standards, and thereby ensuring protection for natural environment.[17]

5.5.1 Objectives of National Water Policy

The government's water policy aims to provide guidance to all agencies working with the water sector and one or more forms of institutions related to the water sector reach the specified goal. These objectives are:[18]

- Address issues related to the governance and development of various forms of SW effective and equitable management of GW and these resources.
- Ensuring water for all segments of society, including the poor and the poor vulnerable groups, taking into account the special needs of women and children.
- Accelerating the development of sustainable public and private water systems adopt appropriate legal and financial measures and incentives, including delineation of waters rights and water prices.
- Institutional reforms will help decentralized water management Resources and empower women in water management.
- Establish a legal and regulatory environment to help decentralization, sound environmental management and improved investment environment provide water resources development and management services to the private sector.

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[17] Government of People's Republic of Bangladesh. Ministry of Law, Justice and Parliamentary Affairs, Legislative and Parliamentary Affairs Division, *National Water Policy 1999*. Dhaka: Bangladesh National Parliament, 1999.

[18] Ibid, p 3.

- Develop the state of knowledge and capacity to enable the country to design combining economic efficiency, gender equality, Social justice and environmental awareness to promote water achieve management goals through broad public participation.

5.5.2 Water and Agriculture

To support private development of GW irrigation for agricultural growth where feasible, continue to develop surface water. But there will be new concerns improve irrigation water efficiency through various measures including drainage recovery, rotation irrigation, and water-saving crop technology where feasible, use GW and SW together.

Water distribution in irrigation systems must be done equitably and with social justice. At the same time, non-point source pollution of water systems should be carefully considered that fertilizers or pesticides are leached into the GW or washed away from the fields to rivers and lakes. To this end, the government's policy is:[19]

- Encourage and promote sustainable development of small-scale irrigation where feasible without affects drinking water supply.
- Encourage future GW development for irrigation both public and private segments, but subject to Rules that the government may prearrange from time to time.
- Improve resource efficiency by combining all forms of surfaces water and GW for irrigation and urban water supply.
- Amplify crop diversification programs to effectively use of water resources.
- Strengthen the supervision system of agricultural chemicals that pollute the ground and SW resources, and establish control mechanisms to reduce non-point source pollution from agricultural chemicals.
- Strengthen appropriate monitoring agencies to track GW recharge, surface and GW use and changes in surface and GW quality.

[19] Ibid, p 11.

5.6 Bangladesh Water Rule 2018, Integrated Water Resource Management Guideline 2019

With the provision made under Section 45 of the Bangladesh Water Act 2013, the Government made Bangladesh Water Rules 2018.[20] These rules were formulated to serve the purpose of Bangladesh Water Act.

For sustainable management of water resources in Bangladesh, according to the section 16of Bangladesh Water Act 2013[21] and Bangladesh Water Rules 2018 (Section 13), the Executive Committee shall provide approval or permission to any project, whether it be of dredging, irrigation, flood control, drainage of water, and embankment construction and its protection, through the authorities ranging from directorate level down to union level as mentioned below.[22]

- In the case of WARPO, the Director General;
- In the case of District Committee, the concerned Deputy Commissioner;
- In the case of Upazila Committee, the concerned UNO; and
- In the case of Union Committee, the concerned Chairman of UP.

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[20] Government of People's Republic of Bangladesh. Ministry of Law, Justice and Parliamentary Affairs, Legislative and Parliamentary Affairs Division, *Bangladesh Water Act, 2013.* 14 of 2013, Dhaka: Bangladesh National Parliament, 2013, p 23 and Government of People's Republic of Bangladesh. Ministry of Water Resources, *Bangladesh Water Rules, 2018.* SRO No 250-act/2018, Dhaka: Ministry of Water Resources, 2018.

[21] The main purpose of section 16 of the Bangladesh Water Act, 2013 is to issue NOC for water resource development projects. In compliance with the national water resources plan, individuals or organizations undertaking the water resources development project will apply to the NWRC, in accordance with the rules and regulations set forth in the Rules. Upon receipt of the application, it will issue the NOC by approving the application in accordance with the procedure and conditions prescribed by the rules or inform the reasons for the rejection. If the person or agency violates the terms of the NOC, the authority may withdraw the NOC granted in favor of the project by providing a reasonable opportunity for a hearing. Bangladesh Water Act, 2013, 15.

[22] Government of People's Republic of Bangladesh. Ministry of Law, Justice and Parliamentary Affairs, Legislative and Parliamentary Affairs Division, *Bangladesh Water Act, 2013.* 14 of 2013, Dhaka: Bangladesh National Parliament, 2013, p 15 and Government of People's Republic of Bangladesh. Ministry of Water Resources, *Bangladesh Water Rules, 2018.* SRO No 250-act/2018, Dhaka: Ministry of Water Resources, 2018, 13.

The Government of the Peoples' Republic of Bangladesh has formulated the guidelines for each individual level, which include District Integrated Water Resource Management Guideline 2019, Upazila Integrated Water Resource Management Guideline 2019, and Union Integrated Water Resource Management Guideline 2019, to ensure district integrated water resource management in accordance with Section 17 of the Bangladesh Water Rules, 2018.[23]The principles of integrated water resources management are:[24]

- Drinking water, which is essential for living, development and the environment is limited and at risk.
- Development and management of water resources should be done in a participatory manner, with water users, planners, policy makers involved at all levels.
- Women have a central role in the management and protection of water resources.
- Water has economic value when it comes to all types of water use. Water should be considered an economic asset.

5.6.1 District Integrated Water Resources Management Committee

In order to fulfill the purpose of Bangladesh Water Rules 2018, a committee called District Integrated Water Resources Management Committee (DIWRMC) has been formulated in each district in accordance with Section 14 (1) of the Rules 2018 and Section 2.1 (1) of District Guideline 2019.[25]

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[23] Government of People's Republic of Bangladesh, *District Integrated Water Resource Management Guideline 2019*. Dhaka: WARPO, 2019, Government of People's Republic of Bangladesh, *Upazila Integrated Water Resource Management Guideline 2019*. Dhaka: WARPO, 2019 and Government of People's Republic of Bangladesh, *Union Integrated Water Resource Management Guideline 2019*. Dhaka: WARPO, 2019

[24] Ibid.

[25] Government of People's Republic of Bangladesh. Ministry of Water Resources, *Bangladesh Water Rules, 2018.* SRO No 250-act/2018, Dhaka: Ministry of Water Resources, 2018, p 13 and Government of People's Republic of Bangladesh, *District Integrated Water Resource Management Guideline 2019*. Dhaka: WARPO, 2019, 7.

5.6.1.1 Formation of Committee

According to Section 14(2) of Bangladesh Water Rules, 2018 and Section 2.1 (2) of District Integrated Water Resource Management Guideline 2019, the Deputy Commissioner of the concerned district will be the Chair of the DIWRMC.[26] The Chief Executive Officer of Zilla Parishad, an Additional Deputy Commissioner, District Fisheries Officer, a representative of the District Chamber of Commerce, an NGO representative, a district level representative of BSCIC (if any), the Deputy Director of the Environment Department (if any).) Must be a member of the District Committee. Under the same section, the Deputy Director of the Agriculture Extension Office, Executive Engineer of the Bangladesh Water Development Board (BWDB), Executive Engineer of the Local Government Engineering Department, Executive Engineer of Public Health Engineering Department (PHED), Executive Engineer of Bangladesh Agricultural Development Corporation, Executive Engineer of the City Corporation (if any), Executive Engineer of *Barind* Multipurpose Development Authority(if any), Executive Engineer of Bangladesh Inland Water Transport Authority(if any), Municipal Executive Engineer (if any), and the representative nominated by the Director General of Haor and Wetlands Development Directorate in the districts of Haor region are included as Technical Member in the District Committee.[27]

The representative of the WARPO will be the Member Secretary to the District Committee. Provided that, in the absence of a representative from the WARPO, the Executive Engineer of the Water Development Board shall serve as the Member Secretary.[28]

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[26] Ibid.

[27] *Bangladesh Water Rules, 2018*, p 14 and *District Integrated Water Resource Management Guideline 2019*, 7.

[28] Ibid.

The DIWRMC may co-opt any other member if it deems necessary besides the above mentioned members.[29]The Chairman of the Zilla Parishad and concerned Member of Parliament can advise the District Committee as an advisor.[30]

5.6.1.2 Duties and Responsibilities of District Committee

Section 14 (5) of Bangladesh Water Rules 2018 and Section 2.2 of District Integrated Water Resource Management Guideline 2019has provided DIWRMC with the following responsibility with a view to fulfilling the objective of the water rules of 2018.[31]

On consideration of the report of the District Technical Committee on the project, DIWRMC will make recommendation for the issuance of project clearance within the estimated project cost limit.

a. Identifying and reviewing opportunities, barriers and possibilities of using water resources and accordingly recommending the appropriate district water resource plan under existing legal framework for sustainable water resources management.
b. Monitor the activities of the union and upazila integrated water resource management committees and assist the committee if necessary.
c. To coordinate and supervise the activities of public and private owned establishments or agencies operating in the water resources sector within the district.
d. To follow and monitor the orders or directives issued by the WARPO or any organization, agency, person or authority authorized by it and submit a report to the WARPO accordingly.

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[29] *Bangladesh Water Rules, 2018*, Section 14 (3), 14 and *District Integrated Water Resource Management Guideline 2019*, Section 2.1 (3), 7.

[30] *Bangladesh Water Rules, 2018*, Section 14 (4), 14 and *District Integrated Water Resource Management Guideline 2019*, Section 2.1 (4), 7.

[31] *Bangladesh Water Rules, 2018*, Section 14 (5), 14 and *District Integrated Water Resource Management Guideline 2019*, Section 2.2, 8.

e. To recommend cancellation if any project related to water resources breaches the conditions mentioned in the project clearance.
f. Creating a database related to water resources and sharing it with WARPO.
g. To ensure integrated development and sustainable management of water resources as per guidelines.
h. To establish liaison with the Upazila Committee and WARPO for greater coordination.
i. Recommending compliance orders, removal orders or, in the case, issuing protection orders.
j. To take action to settle the application received under section 16 of Bangladesh Water Act 2013.
k. To perform other responsibilities as provided by WARPO.

5.6.2 Upazila Integrated Water Resources Management Committee

In order to fulfill the purpose of Bangladesh Water Rules 2018, a committee called Upazila Integrated Water Resources Management Committee (UIWRMC) has been formed in each upazila in accordance with Section 14 (1) of the Rules 2018 and Section 2.1 (1) of Upazila Guideline 2019.[32]

5.6.2.1 Formation of Committee

According to Section 14(2) of Bangladesh Water Rules, 2018 and Section 2.1 (2) of Upazila Integrated Water Resource Management Guideline 2019, the Upazila Nirbahi Officer (UNO) of the concerned upazila will be the Chair of the UIWRMC.[33] The Assistant Commissioner (Land), Chairman of concerned Union Parishad, an NGO representative, the representative nominated by District Chamber of Commerce, the representative of water management cooperative society (if any) nominated by chair of Upazila Committee, Assistant Engineer of concern municipal

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[32] *Bangladesh Water Rules, 2018*, Section 14 (1), p 15 and *Upazila Integrated Water Resource Management Guideline 2019*, Section 2.1 (1), 6.

[33] Ibid. *Bangladesh Water Rules, 2018*, Section 14 (2), p 15 and *Upazila Integrated Water Resource Management Guideline 2019*, Section 2.1 (2), 6.

(if any) must be member of Upazila Committee. Under the same section, the Sub-divisional Engineer of BWDB, Upazila Engineer of LGED, Assistant Engineer of BADC, Upazila Agriculture Officer, Upazil Fisheries Officer, Representative of Public Health Engineering Department (if any), Assistant Engineer of BMDA (if any), Project Implementation Officer, and the representative nominated by the Director General of *Haor* and Wetland Development Directorate in the districts of *Haor* region are included in the Technical Member of Upazila Committee.[34]

The representative of the WARPO will be the Member Secretary to the Upazila Committee. Provided that, in the absence of a representative from the WARPO, the Upazila Engineer of the LGED shall serve as the Member Secretary.[35]

In accordance with Section 15 (3), the UIWRMC may co-opt any other member if it deems necessary besides the above mentioned members.[36] In accordance with Section 15 (4), the Chairman of the Upazila Parishad can advise the Upazila Committee as an advisor.[37]

5.6.2.2 Duties and Responsibilities of Upazila Committee

Section 15 (5) of Bangladesh Water Rules 2018 and Section 2.2 of Upazila Integrated Water Resource Management Guideline 2019has assigned the following responsibility of the UIWRMC.[38]

- Considering the report of the Upazila Technical Committee, recommending for issuance of project clearance.

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[34] *Bangladesh Water Rules, 2018*, 16 and *Upazila Integrated Water Resource Management Guideline 2019*, 6.

[35] Ibid.

[36] *Bangladesh Water Rules, 2018*, Section 15 (3), 16 and *Upazila Integrated Water Resource Management Guideline 2019*, Section 2.1 (3) p 6.

[37] *Bangladesh Water Rules, 2018*, Section 15 (4), 16 and *Upazila Integrated Water Resource Management Guideline 2019*, Section 2.1 (4) 6.

[38] *Bangladesh Water Rules, 2018*, Section 15 (5), 16 and *Upazila Integrated Water Resource Management Guideline 2019*, Section 2.2 6-7.

- Identifying and reviewing opportunities, barriers and possibilities of using water resources and accordingly recommending the approval of the relevant Upazila Water Resources Plan (if any) under existing legal framework for sustainable water resources management.
- Monitor the activities of the Union Integrated Water Management Committee and assist the committee if necessary.
- To coordinate and supervise the activities of public and private owned establishments or agencies operating in the water resources sector within the upazila.
- Compliance and monitoring of orders or directives issued by WARPO and submitting report to the District Committee accordingly.
- If any project related to water resources breaches the conditions mentioned in the exemption, recommend cancelling the exemption.
- Creating a database related to water resources and sharing it with WARPO.
- Ensure integrated development and sustainable management of water resources as per guidelines.
- Establish liaison with the District Committee and WARPO for greater coordination.
- Recommending compliance orders, removal orders or, in the case, issuing protection orders.
- Take action to settle the application received under section 16 of Bangladesh Water Act 2013.
- Perform other responsibilities as provided by WARPO.

5.6.3 Union Integrated Water Resources Management Committee

In order to fulfill the purpose of Bangladesh Water Rules 2018, a committee called Union Integrated Water Resources Management Committee has been formed in each union in accordance with Section 16 (1) of the Rules and Section 2.1 (1) of Union Guideline 2019.[39]

[39] *Bangladesh Water Rules, 2018*, 17 and *Union Integrated Water Resource Management Guideline 2019*, 7.

5.6.3.1 Formation of Committee

According to Section 16(2) of Bangladesh Water Rules, 2018 and Section 2.1 (2) of Union Integrated Water Resource Management Guideline 2019, the Chairman of Union Parishad of the concerned union will be the Chair of the Union Committee.[40] Member of concerned ward of the Union Parishad, female member of concerned wards, Assistant Officer of fisheries department, an NGO representative nominated by UNO, the representative of water management cooperative society must be member of Union Committee. Under the same section, the Sub-assistant Engineer of LGED, Sub-assistant Agriculture Officer of Agriculture Extension Directorate, Sub-assistant Engineer of Public Health Engineering Department, representative of BWDB (if any), local representative of BADC (if any), Sub-assistant engineer of BMDA (if any) are included in the Technical Member of Union Committee.[41]

The representative of the WARPO will be the Member Secretary to the Union Committee. Provided that, in the absence of a representative from the WARPO, the Sub-assistant Engineer of PHED shall serve as the Member Secretary.[42] Also provided that, in absence of Sub-assistant Engineer of PHED, any technical member nominated by UNO, shall serve as the Member Secretary.[43]

5.6.3.2 Duties and Responsibilities of Union Committee

Section 16 (3) of Bangladesh Water Rules, 2018 and Section 2.2 of Union Integrated Water Resource Management Guideline 2019has assigned the following responsibility of the Union Committee:[44]

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[40] *Bangladesh Water Rules, 2018*, Section 16 (2), p 17 and *Union Integrated Water Resource Management Guideline 2019*, Section 2.1 (2), 7.

[41] Ibid.

[42] *Bangladesh Water Rules, 2018*, Section 16 (2), 87 and *Union Integrated Water Resource Management Guideline 2019*, Section 2.1 (2), 7.

[43] Ibid.

[44] *Bangladesh Water Rules, 2018*, Section 16 (3), 17 and *Union Integrated Water Resource Management Guideline 2019*, Section 2.2, 7-8.

a. Considering the report of the Union Technical Committee, recommending for issuance of project clearance.
b. Identifying and reviewing opportunities, barriers and possibilities of using water resources and accordingly recommending the approval of the relevant Union Water Resources Plan (if any) under existing legal framework for sustainable water resources management.
c. Monitor the activities of the Ward Integrated Water Management Committee and assist the committee if necessary.
d. To coordinate and supervise the activities of public and private owned establishments or agencies operating in the water resources sector within the union.
e. Compliance and monitoring of orders or directives issued by WARPO and submitting report to the Upazila Committee accordingly.
f. If any project related to water resources breaches the conditions mentioned in the exemption, recommend cancelling the exemption.
g. Creating a database related to water resources and sharing it with WARPO.
h. Ensure integrated development and sustainable management of water resources as per guidelines.
i. Recommending for issuance of project clearance for water resources use and development project as per guidelines.
j. Establish liaison with the Upazila Committee, District Committee and WARPO for greater coordination.
k. Recommending compliance orders, removal orders or, in the case, issuing protection orders.
l. Take action to settle the application received under section 16 of Bangladesh Water Act 2013.
m. Perform other responsibilities as provided by the WARPO, District Committee and the Upazila Committee.

5.6.4 Formation of Technical Committees

In order to fulfill the purpose of Bangladesh Water Rules 2018, a committee called Technical Committee has been formulated in each district[45], upazila[46], and union[47] in accordance with Section 21 (1) of the Rules.[48]

5.6.4.1 District Technical Committee

In case of District Technical Committee, out of the technical members of the DIWRMC, 5 (five) members will be appointed as members of technical committee. From the technical committee, 1 (one) member will be appointed as Convener of the committee on the basis of seniority.[49]

At the meeting of the District Technical Committee, no representative of the implementing agency of the project mentioned in the application will be allowed to attend or participate during the consideration of the project.[50]

5.6.4.2 Upazila Technical Committee

In case of Upazila Technical Committee, out of the technical members of the UIWRMC, 5 (five) members will be appointed as members of technical committee. From the technical committee, 1 (one) member will be appointed as Convener of the committee on the basis of seniority.[51]

At the meeting of the Upazila Technical Committee, no representative of the implementing agency of the project mentioned in the application will be allowed to attend or participate during the consideration of the project.[52]

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[45] *District Integrated Water Resource Management Committee Guideline 2019*, Section 2.4 (1), 9.

[46] *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 2.4 (1), 8.

[47] *Union Integrated Water Resource Management Committee Guideline 2019*, Section 2.4 (1), 8.

[48] *Bangladesh Water Rules, 2018*, Section 21 (1), 22.

[49] *Bangladesh Water Rules, 2018*, Section 21 (2), 22 and *District Integrated Water Resource Management Committee Guideline 2019*, Section 2.4 (2), 9.

[50] *Bangladesh Water Rules, 2018*, Section 21 (3), 22 and *District Integrated Water Resource Management Committee Guideline 2019*, Section 2.4 (3), 9.

[51] *Bangladesh Water Rules, 2018*, Section 21 (2), 22 and *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 2.4 (2), 8.

[52] *Bangladesh Water Rules, 2018*, Section 21 (3), 22 and *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 2.4 (3), 8.

5.6.4.3 Union Technical Committee

In case of Union Technical Committee, out of the technical members of the Union Integrated Water Resource Management Committee, 3 (three) members will be appointed as member of technical committee. From the technical committee, 1 (one) member will be appointed as Convener of the committee on the basis of seniority.[53]

At the meeting of the Union Technical Committee, no representative of the implementing agency of the project mentioned in the application will be allowed to attend or participate during the consideration of the project.[54]

5.6.5 Responsibilities of District, Upazila, and Union Technical Committees

In accordance with Section 20 of Bangladesh Water Rules, 2018, the concerned technical committee will review the information and documents of the proposed project and check whether the project is compatible with the National Water Resources Plan.[55] The technical committee may seek advice from WARPO on any matter if necessary.[56] If all the necessary documents, particulars, information or reports are not attached with application form, the relevant technical committee will provide a recommendation to reject the application.[57] Guidelines, prepared by the Council, Executive Committee or WARPO, in the light of National Water Resources Plan and other documents, will verify and evaluate applications, documents attached to the application, and opinions of local people, and will prepare a technical

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[53] *Bangladesh Water Rules, 2018*, Section 21 (2), 22 and *Union Integrated Water Resource Management Committee Guideline 2019*, Section 2.4 (2), 8.

[54] *Bangladesh Water Rules, 2018*, Section 21 (3), 22 and *Union Integrated Water Resource Management Committee Guideline 2019*, Section 2.4 (3), 8.

[55] *District Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (1), 9; *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (1), 8 and *Union Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (1), 9.

[56] *District Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (2), 9; *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (2), 8 and *Union Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (2), 9.

[57] *District Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (3), 9; *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (3), 8 and *Union Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (3), 9.

report on the positive and negative impact of water resources utilization.[58] During the verification and evaluation of the application form, the technical committee shall provide the applicant with a hearing in such a manner it thinks fit.[59]

The Technical Committee will prepare consistent technical reports, and for this purpose, the technical committee shall have the right to examine any document or information, to enter a courtyard, to collect a sample of an object, and to collect information on a person concerned, and in such cases, the person, organization or appropriate authority shall be required to cooperate.[60] The technical committee may seek the assistance of any professional to pursue opinion or advice on the technical issues of any project under its consideration.[61]When preparing technical reports and inquiry reports, the Technical Committee may provide, in such a manner as it may deem appropriate, the applicant or, the project clearance holder with an opportunity for participating at a hearing on the project.[62] The hearing will be held at the date, time and place set by the Technical Committee.[63] The Technical Committee shall issue notice of the hearing to the person or authority concerned as specified in the reason for the hearing.[64]Any

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[58] *District Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (4), 9; *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (4), 9 and *Union Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (4), 9.

[59] *District Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (5), 10; *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (5), 9 and *Union Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (5), 9.

[60] *District Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (6), 10; *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (6), 9 and *Union Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (6), 10.

[61] *District Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (8), 10; *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (8), 9 and *Union Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (8), 10.

[62] *District Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (9), 10; *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (9), 9 and *Union Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (9), 10.

[63] *District Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (10), 10; *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (10), 9 and *Union Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (10), 10.

[64] *District Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (11), 10; *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (11), 9 and *Union Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (11), 10.

person may give their opinion either verbally or in writing or both at the time of the hearing, and in the case of oral opinion, the technical committee shall arrange to write a statement or opinion or summary.[65]

5.6.6 Declaration of Water Stress Area

For the sustainable management of Bangladesh's water resources, in order to fulfill the objectives of section 17of Bangladesh Water Act 2013[66] and Bangladesh Water Rules 2018 (Section 26), to protect any water source or any aquifer, the Government can, on the recommendation of the ECNWRC made upon the outcomes of required enquiry or scrutiny or survey, announce, by notification in the official Gazette, any zone or any part thereof or any land linked thereto with such water resource as water stress area for a period specified therein.[67] If an area needs to be identified as a water stress area, the WARPO will conduct surveys or inquiries to gather the necessary information about the water resources or sources of water in that area, and will receive public opinion by providing a public hearing.[68]

The criteria to consider when declaring a water stress area are— whether the safe yield underground or GW level of the area has been exceeded, whether there has been excessive pollution of the area or whether the source of water in the area has been transformed.[69] According to the rules, whether there are any other scientific, socio-economic or environmental criteria, it must also be taken into consideration.

[65] *District Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (12), 10; *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (12), 9 and *Union Integrated Water Resource Management Committee Guideline 2019*, Section 2.5 (12), 10.

[66] The main objective of section 17 of the Bangladesh Water Act, 2013 is to declare and manage water crisis areas for control of water use and protection & preservation of water resources. *Bangladesh Water Act, 2013*, 16.

[67] *Bangladesh Water Act, 2013*, Section 17 (1), 16 and *Bangladesh Water Rules, 2018*, Section 26, 27.

[68] *Bangladesh Water Rules, 2018*, Section 26 (1), 27.

[69] Ibid, Section 26 (6), p 28.

On the recommendation of the ECNWRC, the Government will declare the proposed area as a water stress area. Public notice regarding declaration of water stress area should be published in at least one widely publicized Bengali and one English national daily newspaper. The public notice must be published on the national radio and television or on a private radio or television channel and on the website of WARPO.[70]

5.6.7 Preferential Use of Water in the Water Stress Area and Exemption thereof

Notwithstanding anything contained contrary in any other law for the time being in force, abstraction and use of water from any water stress area shall, subject to the availability of water therein, be made in accordance with the following order for the national interest and the interest of the local communities, namely[71]—

a. use of water as potable;
b. use of water in household;
c. use of water in agriculture;
d. use of water in aquaculture;
e. use of water for balancing eco-system;
f. use of water for wild life;
g. use of water for natural river flow;
h. use of water in industry;
i. use of water for salinity control;
j. use of water for power generation;
k. use of water for amusement; and
l. use of water for other purpose.

[70] *Bangladesh Water Act, 2013*, Section 17 (3), 17 and *Bangladesh Water Rules, 2018*, Section 26 (7) & 26 (8), 28.

[71] *Bangladesh Water Act, 2013*, Section 18 (1), 16.

Depending on the socio-economic condition, and on the opinion of the general people, the ECNWRC may, by a notification in the official Gazette, may change the order cited above.[72]

5.6.8 Management of Water Stress Area

To ensure the proper management of water stress areas, the ECNWRC or the officer empowered thereafter can take such actions as to hold discussion with the people of the area to identify ways to overcome the crisis, to monitor the water resources of the area to overcome the crisis, to provide guidance to the appropriate authorities or persons concerned in the management of water resources in the area, and to impose necessary rules.[73]

5.6.9 Protection, Conservation and Management of Groundwater

In chapter 10 of the Bangladesh Water Rules 2018 states the provision for the protection, conservation and management of GW.[74]

5.6.9.1 Determination of Lowest Safe Yield Level[75] of Aquifer

Safe yield level of aquifer is not the same in all regions of Bangladesh. Safe yield level of aquifer in *Barind* tract, in particular, varies widely. The use of GW changes the safe yield level of aquifer over the time. As a result, there is a need to set lowest safe yield level of aquifer. For the ECNWRC, WARPO sets the minimum safe yield level of aquifer for GW in different areas over a period of time based on appropriate findings, tests or survey results.[76] Subject to the approval of the ECNWRC, the Government publishes it through a Gazette notification.[77]The boundary of the area, to which lowest safe yield level applies, shall be specified in

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[72] Ibid, Section 18 (2), 16.

[73] *Bangladesh Water Rules, 2018*, Section 27, 28-29.

[74] Ibid, 29.

[75] 'Safe yield level' means the amount of abstraction of water that keeps the aquifer safe and protective. *Bangladesh Water Act, 2013*, 17.

[76] *Bangladesh Water Act, 2013*, Section 19 (1), 17 and *Bangladesh Water Rules, 2018*, Section 28, 29.

[77] *Bangladesh Water Act, 2013*, Section 19 (1), 17 and *Bangladesh Water Rules, 2018*, Section 28 (2), 29.

the notification issued by referring the *mouza* map and plot numbers therein.[78] Any person or appropriate authority may, subject to the lowest safe yield level, and the provisions of this Act or any other law for the time being in force, sink STW or DTW, in the manner prescribed by rules, into the ground for abstracting GW.[79] To ensure safe abstraction of water from aquifers, the ECNWRC may impose restrictions by issuing a protection order.[80]

It is important to note here that in the area where the survey program will be held, the potential sufferers or affected persons in that area should be notified about the survey activities before taking a survey and consider the minimum number of casualties.[81]

5.6.9.2 Projects that Require Project Clearance

In case of any of the following projects undertaken by an individual or appropriate authority, the project clearance mandatorily be adopted under section 16 of the Bangladesh Water Act 2013, namely[82]—

- Flood control or management projects;
- Part of a project or projects related to the collection, supply or use of surface water;
- Irrigation projects by surface water;
- Hydraulic infrastructure construction project;
- Water conservation project;
- Flood-plain land or wetland development projects;
- Surface water use project for the industry;
- River bank conservation project;
- River excavation or dredging project;

[78] *Bangladesh Water Act, 2013*, Section 19 (2), 17.
[79] Ibid, Section 19 (3), 17.
[80] Ibid, Section 19 (4), 17.
[81] *Bangladesh Water Rules, 2018*, Section 28 (2), 29.
[82] *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.2 (1), 11; *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.2 (1), 10 and *Union Integrated Water Resource Management Committee Guideline 2019*, Section 3.2 (1), 11.

- Canal excavation or re-excavation project;
- Fisheries development project in surface water;
- Part of a project or project related to the extraction, supply or use of GW.

According to Guideline 2019, except for obtaining a clearance certificate from the issuing authority, no person or institution can undertake or initialize the initiative in any of the above mentioned projects.[83]If a person or organization violates the rules imposed, initiates or operates a project without obtaining clearance from the issuing authority of the project, then action[84] can be taken against the person or organization as per the relevant provisions of the law.[85]

5.6.9.3 Exemption from NOC

In accordance with Rules and Guideline, in certain tube-wells, the need for NOC is exempted.[86] Namely—

- In a shallow tube-well, a maximum of 0.5 cusecs of water is available for agricultural purposes.
- In case of drinking water for household drinking and household work by hand tube-wells or deep-set shallow tube-wells.
- In case of water extraction by hand-operated deep tube-wells for drinking and household purposes.

It is important to note here that in areas where there is a severe underground water crisis, the NOC must be received in the prescribed manner, subject to certain conditions, as per the order issued by WARPO.

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[83] Ibid.

[84] In accordance with Article 29 of Bangladesh Water Act, 2013, shall be punished with a maximum of 5 (five) years imprisonment or a fine not exceeding taka 10 (ten) thousand or both.

[85] *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.2 (1), 11; *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.2 (1), 10 and *Union Integrated Water Resource Management Committee Guideline 2019*, Section 3.2 (1), 11.

[86] *Bangladesh Water Rules, 2018*, Section 29 (1), 29; *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.9, 15-16 and *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.9, 14-15.

5.6.9.4 NOC providing authority for setting up tube-wells

For the purpose[87] of subsection (1) of section 19 of the Bangladesh Water Act, 2013, from the safe yield level of aquifer, there will be the following NOC providing authorities at different levels for setting up a tube-well equipped with suction method for agricultural work.[88] Namely-

- The upazila committee shall have the authority to issue permission for lifting of water up to a maximum level of 1.00 cusec from 0.5 cusecs.[89]
- The district committee shall have the authority to issue permission for lifting of water up to a maximum level of 3.00 cusecs from 1.00 cusecs.[90]

The District Committee shall be the authority to provide NOC for lifting from safe yield level of aquifer using suction system for non-agriculture, small and medium industrial purposes.[91] WARPO will be the authority to provide NOC in the extraction of water from the safe yield level of aquifer by setting up a force mode DTW for any purpose.[92] It should be noted here that water cannot be used for any purpose other than the purpose for which the NOC will be obtained.[93]

5.6.9.5 Application procedure for obtaining NOC for tube-well

To install a tube-well, the NOC should be taken from the NOC issuing authority. For lifting the water from safe yield aquifer by DTW and STW, the applicant have

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[87] Any person or appropriate authority may, subject to the lowest safe yield level, and the provisions of this Act or any other law for the time being in force, sink STW or DTW, in the manner prescribed by rules, into the ground for abstracting ground water.

[88] *Bangladesh Water Rules, 2018*, section 30 (1), p 29.

[89] *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.10 (1), 15.

[90] *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.10 (1), 16.

[91] *Bangladesh Water Rules, 2018*, Section 30 (2), 30; *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.10 (2), 16 and *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.10 (2), 15.

[92] *Bangladesh Water Rules, 2018*, Section 30 (3), 30; *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.10 (3), 16 and *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.10 (3), 15.

[93] *Bangladesh Water Rules, 2018*, Section 30 (4), 30; *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.10 (4), 16 and *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.10 (4), 15.

to fill the prescribed application form (Form-7).[94]If the application is made without stipulated amount of fee as prescribed by WARPO in an office order,[95] no application for tube-well will be entertained by the NOC issuing authority.[96]Upon receipt of the application, the appropriate authorities will arrange for inspection to ensure the propriety of installing the tube-well. Based on the inspection report, if the authorities are satisfied that by installing the applied tube-well[97]—

a. the area where the tube well is to be installed will benefit;
b. the environment will not be adversely affected;
c. there will be other benefits; and
d. there will be no adverse effect on the storage and quality of GW.

If that is the case, the NOC granting authority will approve the application for the installation of a tube well.

If the authority of the NOC issuer is convinced that the terms of the NOC have been violated, or that the NOC is suspended for any other reason, then by the specified written order, any tube-well may be temporarily suspended. The matter must be reported to WARPO immediately. Provided, however, that the NOC issuer must provide the recipient of NOC with a reasonable time for hearing before the issuance of the NOC suspension order. Further provided that if the NOC suspension order is not served to the NOC recipient within 15 (fifteen) days from the date of temporary suspension, then the order of NOC suspension shall be

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[94] *Bangladesh Water Rules, 2018*, Section 31 (2), 30; *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.11 (2), 16 and *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.11 (2), 15.

[95] Fee for NOC is taka 500. *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.14 (1), 18 and *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.14 (1), 17.

[96] *Bangladesh Water Rules, 2018*, Section 31 (3), 30; *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.11 (3), 16 and *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.11 (3), 15.

[97] *Bangladesh Water Rules, 2018*, Section 31 (5), 30; *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.11 (5), 16-17 and *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.11 (5), 15-16.

deemed as being terminated after the expiry of that time.[98] NOC suspension period will be maximum 45 (forty five) days after the final approval of suspension order.[99]

Based on the inspector's report, if it appears that the NOC recipient has violated the conditions stated in the NOC; or, the NOC has been suspended 3 (three) or more times within the first 1 (one) year before the NOC cancellation order was issued, NOC can be cancelled by the authority. Provided, however, that no NOC can be cancelled without providing reasonable opportunity for a hearing.[100]

5.6.9.6 The NOC of the existing tube well

Any person, competent authority, and local government agency willing to continue water harvesting, except for the suspended tube-well, which is suspended under the provisions of section 29 of Bangladesh Water Rule 2018, shall apply for the NOC by making a payment of certain fees within 6 months after the rules is in effect.[101] Provided that, on logical ground, the DG of WARPO may extend the deadline for lodging the prayer for NOC up to 3 (three) months, at request of the applicant's.[102]

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[98] *Bangladesh Water Rules, 2018*, Section 31 (8), 31; *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.11 (8), 17 and *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.11 (8), 16.

[99] *Bangladesh Water Rules, 2018*, Section 31 (9), 31; *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.11 (9), 17 and *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.11 (9), 16.

[100] *Bangladesh Water Rules, 2018*, Section 31 (11), p 31; *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.11 (11), p 17 and *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.11 (11), p 16.

[101] *Bangladesh Water Rules, 2018*, Section 32 (1), 31; *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.12 (1), 17 and *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.12 (1), 16.

[102] *Bangladesh Water Rules, 2018*, Section 32 (2), 31; *District Integrated Water Resource Management Committee Guideline 2019*, Section 3.12 (2), 18 and *Upazila Integrated Water Resource Management Committee Guideline 2019*, Section 3.12 (2), 17.

5.7 Efficacy of the Water Laws and Limitations

The principal objective of existing water laws of Bangladesh is to achieve an integrated approach towards management, development, extraction, use, protection and conservation of water resources.

5.7.1 Strength

- The framework law of the water sector of Bangladesh.
- Water rights have been declared as the highest priority and reserved easement of any individual on both private and public land.
- Emphasize the integrated decision-making, planning, use, management of water resources on national level and coordination of international cooperation in the development, and the establishment of a high-powered inter-ministerial agencies (NWRC) headed by the Prime Minister.
- Formed executive committee of the NWRC to be responsible for inter-ministerial coordination and dispute settlement.
- Provision of taking clearance certificate for executing any water resource projects has made mandatory.
- To protect any area from further mining government can be clear that area as water stress area and management thereof.
- In order to protect any area from further exploitation, the government can clearly designate the area as a water-scarce area and its management.
- Provision for fixing the safe yield level of aquifer for sustainable use of water.
- Provide some administrative measures to protect water resources, such as removal orders, protection orders and compliance orders.

5.7.2 Critiques

- It is impractical to retain almost all executive powers and functions of ECNWRC, which may cause complexity, unnecessary delays, or implementation inconvenience.

- The delegation of power and responsibility is not clear and enough.
- Failure to address possible governance expectations like— social issues (i.e., inclusiveness, fairness and compensation to affected people), citizen participation in the decision-making process (such as public hearings, participation and promotion of water community-based water management organizations in the implementation process), operation and maintenance of the implemented schemes, economic issues (such as the economic value of water, water tariff, incentives and water efficiency etc.), administrative issues (rationalization of the role of water management organizations, regulation and monitoring mechanism, registration, licensing of TWs and water lifting pumps, cost sharing by the community, implementing public-private projects, resolve disputes, etc. particularly at field level), environmental issues (GW recharge, drought and flood resilience, rainwater harvesting, water quality etc.).
- Ignore water pollution and water safety issues.
- Ignores water transportation (one area to another), export and industrial abstraction.
- Existing regulations on surface water management and development are not enough.
- The Act does not explicitly mention anchoring and implementing organizations that may cause problems in the implementation process.
- It needs to be harmonized with other water-related laws.
- The water sector in Bangladesh lacks a dedicated regulatory authority or agency. WARPO is currently performing the regulatory functions under these Act, but according to the WARPO Act 1992, it is a planning agency. Therefore, these issues should be clarified.
- Due to the lack of a regulatory authority, there is no provision for oversight and supervision of the 'Mobile Court Challenge' to ensure compliance.

5.8 Conclusion

In this chapter attempt has been made to achieve integration among the water resources laws and regulations related to GW, different legislative and law enforcement agencies and their activities, as well as the protection, distribution, use and management of water resources, especially with a view to enhancing the capacity of GW management. This chapter also clarifies the rules to be followed in the installation of irrigation pumps, and the regulations on declaring water shortage areas. All the discussions were made in accordance with the first objective of the current study. Next chapter will discuss on the sustainability status of GW irrigation in *Barind* tract.

Chapter Six
Sustainability Status of Groundwater Irrigation in *Barind* Tract

The Chapter presents the status of GW irrigation in *Barind* tract of Bangladesh from the perspective of sustainability. It starts with the trends of natural setting of GW and the surrounding factors that influence its originality and use. Further, this chapter expresses the perceptions of the major stakeholders involved in irrigation; farmers from demand side and local government institutions from supply side.

6.1 Introduction

GW is fresh water located in the pores of soil and rocks. Water also flows in the aquifer below the GW level. GW is a major and unique resource that is widely available. It provides security against drought, but is closely related to surface water resources and hydrological cycles. Compared with other water sources, its reliability in water supply, uniformity in quality and temperature, relative turbidity and freshness, minimal evaporation loss and low development cost have made the use of GW more attractive.

6.2 Sustainability and its elements

Sustainability aims to protect our natural environment, human and ecological health, while promoting innovation without harming our lifestyle.[1] It means striving to increase human productivity without harming or destroying society or the environment.[2] In this context, GW sustainability refers to the development and

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[1] Matthew Mason, "What is Sustainability and Why is it Important?", Environmentalscience.Org, Last modified 2020, https://www. environmentalscience.org/ sustainability.

[2] R.W. Flint, What does sustainability mean to the individual in the conduct of their life and business, In. G.M. Mudacumura (ed.), *Handbook of Development Policy Strategies*, (New York: Marcel Dekker, Inc., 2010).

utilization of GW resources to meet current and future beneficial uses without causing unacceptable environmental or socio-economic consequences.[3]

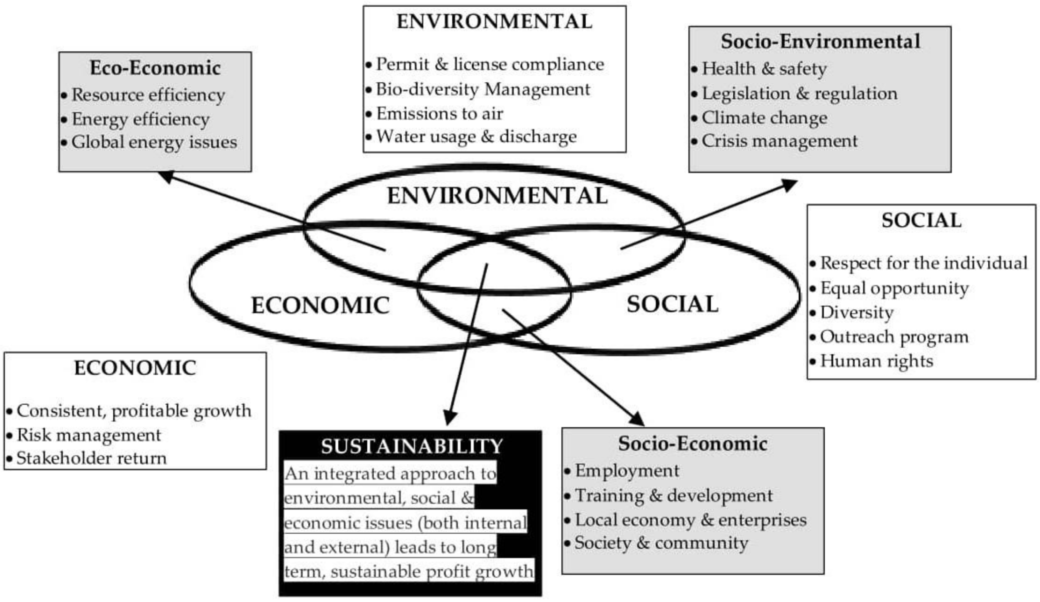

Figure 6.1: Key elements of sustainable development.

Economic sustainability can be defined as achieving growth, efficiency and fair distribution of wealth.[4] Economic validity protect or increase the economic efficiency (compatible with nature) development of natural resources by improving management practices, policies, technology, efficiency and lifestyle changes.[5]

Environmental sustainability refers the integrity of different ecosystems, respects (carrying) capacity and the ability to protect natural resources (including biodiversity).[6] Ecological integrity (natural ecosystem capabilities) understand the

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[3] "Groundwater | Groundwater Sustainability", Ngwa.Org, Last modified 2020, https://www.ngwa.org/what-is-groundwater/groundwater-issues/groundwater-sustainability#:~:text=NGWA%20consensus%20definition,(USGS%20Circular%201186.).

[4] Anita Frajman Ivković, Marija Hum and Josipa Mijoč, "Measuring Objective Well-Being and Sustainable Development Management", *Journal of Knowledge Management, Economics and Information Technology* no. 2 (2014): 1-29, http://www.scientificpapers.org.

[5] Smith Ethan Timothy. 2010. Water Resource Sustainability, *Watershed Update* 8(1).

[6] Anita Frajman Ivković, Marija Hum and Josipa Mijoč, "Measuring Objective Well-Being and Sustainable Development Management", *Journal of Knowledge Management, Economics and Information Technology* no. 2 (2014): 1-29, http://www.scientificpapers.org.

natural system processes of landscapes and watersheds to guide the design of reasonable economic development strategies to protect these natural systems.[7]

Social sustainability implies participation in making decisions, mobility and cohesion, fulfillment of social identity, development of institutions and alike.[8] Social equity (balanced competitive environment) can ensure that all people have equal work (income), education, natural resources and services to achieve overall social well-being.[9]

Therefore, the concept of sustainable development is based on three main elements include unified economic growth, protection and preservation of the environment, and respect and improvement of society and human rights.[10] This development method is called an integral or holistic approach and these three interrelated elements must be sustainable at the same time. Therefore, sustainable development as a concept is closely related to the desire to build a harmonious society oriented towards greater economic prosperity, social cohesion and environmental protection.

The ratio of the amount of GW use to that of the surface water use is much higher in *Barind* tract compared to other parts of Bangladesh. Anthropogenic activities tended to have a severe negative impact on water resources and eco-systems of *Barind* tract in the recent years. All the rivers and cannels of the area dry up during the dry season, making the people completely dependent on GW.[11]

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[7] Smith Ethan Timothy. 2010. Water Resource Sustainability, *Watershed Update* 8(1).

[8] Anita FrajmanIvković, Marija Hum and Josipa Mijoč, "Measuring Objective Well-Being and Sustainable Development Management", *Journal of Knowledge Management, Economics and Information Technology* no. 2 (2014): 1-29, http://www.scientificpapers.org.

[9] Smith Ethan Timothy. 2010. Water Resource Sustainability, *Watershed Update* 8(1).

[10] Anita Frajman Ivković, Marija Hum and Josipa Mijoč, "Measuring Objective Well-Being and Sustainable Development Management", *Journal of Knowledge Management, Economics and Information Technology* no. 2 (2014): 1-29, http://www.scientificpapers.org.

[11] Shamsuddin Shahid, "Spatial and temporal characteristics of droughts in the western part of Bangladesh," *Hydrological Processes* 22, no. 13 (2008): 2235-47, http://dx.doi.org /10.1002/hyp.6820. And NC Dey et al., "Assessing Environmental and Health Impact of Drought in the Northwest Bangladesh", *Journal of Environmental Science and Natural Resources* 4, no. 2 (2012): 89-97.

During 1980s and 1990s, STWs were adopted as an extensive irrigation technology in most parts of the *Barind* tract, especially to support the production of rice over the year. But this technology could not remain technically viable in most parts of Rajshahi division due to declining GW levels.[12] The National Commission on Agriculture estimated that all the extractable aquifer for sustainable irrigation had almost been exhausted by STWs by 1996.[13]

Depletion of GW level during dry season has posed a major threat to the irrigation based agriculture system. Drought is a common phenomenon of the region during the dry season.[14] Over the last 40 years the area was inflicted with eight major droughts.[15] Frequent droughts, scarcity of surface water and easy availability of irrigation equipment are the main reasons for the people to be dependent on GW irrigation. During 1980-2000, GW irrigation covering the area rose from 6 to 75% in Bangladesh.[16] Increasing GW extraction for irrigation and the declining rate of rainfall have caused the GW to fall to a bottom level, which cannot get replenished or recharged fully during wet season causing overdraft of GW in northwest Bangladesh.[17]

This chapter is divided into two sections to present the practices, perceptions of stakeholders and sustainability status of GW in the *Barind* region.

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[12] Mohammad A. Mojid et al., "Water Table Trend—A Sustainability Status of Groundwater Development in North-West Bangladesh," *Water* 11, no. 6 (2019): 1182, http://dx.doi.org/10.3390/w11061182.

[13] Nepal Chandar Dey et al., "Sustainability of Groundwater Use for Irrigation of Dry-Season Crops in Northwest Bangladesh", *Groundwater for Sustainable Development* 4 (2017): 66-77.

[14] Shamsuddin Shahid, "Spatial and temporal characteristics of droughts in the western part of Bangladesh," *Hydrological Processes* 22, no. 13 (2008): 2235-47, http://dx.doi.org/10.1002/hyp.6820.

[15] Bimal Kanti Paul, "Coping Mechanisms Practised By Drought Victims (1994/5) In North Bengal, Bangladesh", *Applied Geography* 18, no. 4 (1998): 355-373.

[16] BADC (Bangladesh Agricultural Development Corporation). Survey report on irrigation equipment and irrigated area in *Boro*/2001 season, (2002). Bangladesh Agricultural Development Corporation, Dhaka.

[17] Government of Bangladesh. Second national report on implementation of United Nations convention to combat desertification. Bangladesh. Government of Bangladesh (GOB) Report, Ministry of Environment and Forests, Dhaka (April, 2002).

The first section reveals the practices and perceptions of end users or farmers and the second section attempts to reveal the practices and perceptions of local government managers involved in GW management, and the existing sustainability status in the *Barind* region.

6.3 Farmer's perceptions

Farmer's perceptions are very significant for GW irrigation because they are the end users of GW. For sustainable management of GW irrigation, farmers' perceptions are to be acknowledged. The descriptive statistics followed by the interpretations thereof have been made to reveal the farmers' demographic pattern, economic status, and perceptions towards irrigation practices including GW, irrigation technique, and cultivation pattern among others based on field survey (2019).

6.3.1 Demographic patterns

Different attributes of demographic composition such as age, marital status, educational qualification, other economic activities along with agriculture, and family members of the respondent have been considered in demographic pattern. As the sample areas for the study include three districts such as Rajshahi, Chapai Nawabgonj, and Naogaon, the distributions of respondents have been exhibited in terms of various attributes mentioned above along each of the districts in the concerned table.

Table 6.1: Distribution of respondents according to their ages

Age (in Years)	District			Total	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
25-35	9	10	16	35	21.9
35-45	14	21	14	49	30.6
45-55	7	15	16	38	23.8
55-65	7	16	11	34	21.3
65-75	2	1	1	4	2.5
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.1 shows that the age of farmers engaged in the agriculture range from 25 years to 75 years. The farmers belonging to age group of 35-45 years occupy 30.6% of the total farmers under study followed by the age group of 45-55 years comprising 23.8% of the total.

Table 6.2: Distribution of respondents according to marital status

Marital Status	District			Total	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Married	39	60	58	157	98.1
Widower	0	3	0	3	1.9
Total	**39**	**63**	**58**	**160**	100.0

Table 6.2 shows that 98% of the respondents are married who bear the responsibility of the family on their shoulder.

Table 6.3: Distribution of respondents according to educational qualifications

Educational Qualification	District			Total	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Around Primary	18	48	39	105	65.6
Secondary	10	14	15	39	24.4
HSC	1	1	2	4	2.5
Graduate	6	0	0	6	3.8
Post Graduate	4	0	2	6	3.8
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.3 reveals that 66% of the respondents completed around primary education which implies the major portion of the farmers' inability to exercise modern agricultural practices resorting to technology based irrigation and modern techniques for agriculture requiring optimal use of water, and switching between a variety of crops allowing the GW level to be replenished.

Table 6.4: Economic activities besides agriculture of the respondents

Other economic activities	District			Total	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Dairy/ poultry	0	0	1	1	0.6
Day laborer	3	2	2	7	4.4
Service	9	0	4	13	8.1
Business	5	2	5	12	7.5

According to the Table 6.4 above, besides agriculture, some of the respondents are engaged in other economic activities like services (8.1%), businesses (7.5%), day-laborers (4.4%), and dairy/poultry farming (0.6%). It depicts that farmers are heavily dependent on agriculture for their livelihood and other economic activities do not make any significant added contributions to their income.

Table 6.5: Family size of the respondents

Family size (in number)	District			Total	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
2-6	35	37	49	121	75.6
6-10	4	21	9	34	21.3
10-14	0	4	0	4	2.5
14-18	0	1	0	1	0.6
Total	**39**	**63**	**58**	**160**	**100.0**

According to the table above, about 76% of the respondents have the family size group of 2-6 members implying that they are of a kind of nuclear family. Both the family size groups of 10-14 and 14-18 indicate that around 3 % of the respondents belong to a kind of joint family.

6.3.2 Economic Status of Farmers

Economic characteristics in terms of total as well as different categories of land such as ownership of total land, ownership of agro-land, household land, garden, pond, and cultivable land of the respondents have been considered to bring out the economic status of the farmers under study.

Table 6.6: Total ownership of land

Land (in Decimal)	District			Total	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
0-500	34	42	34	110	68.8
500-1000	4	9	12	25	15.6
1000-1500	0	6	6	12	7.5
1500-2000	1	1	3	5	3.1
2000-2500	0	1	2	3	1.9
2500-3000	0	3	0	3	1.9
3000-3500	0	1	1	2	1.3
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.6 shows that the majority of respondents belonging to the three districts under study account for 69% of their total who have only a total land of less than or equal to 500 decimals only. This implies that majority of farmers can not resort to using modern technology in agriculture due the small size of the land they own.

Table 6.7: Ownership of agro-land

Land (in Decimal)	District			Total	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
0-500	35	43	34	112	70.0
500-1000	3	9	13	25	15.6
1000-1500	1	5	6	12	7.5
1500-2000	0	1	3	4	2.5
2000-2500	0	4	1	5	3.1
2500-3000	0	0	1	1	0.6
3000-3500	0	1	0	1	0.6
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.7 above reveals that about 70% of the respondents hold the ownership of agro-land ranging from 0 to 500 decimals which is relatively small in terms of economic outcome they gain from the land.

Table 6.8: Ownership of household-land

Land (in Decimal)	District			Total	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Less than 10	18	14	22	54	33.8
10-20	10	20	22	52	32.5
20-30	4	12	5	21	13.1
30-40	4	11	6	21	13.1
40-50	2	5	2	9	5.6
50-60	0	1	1	2	1.3
70-80	1	0	0	1	0.6
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.8 indicates that about 34% of the respondents (highest in number) have the ownership of household-land of less than 10 decimals, and about 33% of the respondents have the ownership of household-land within 10 to 20 decimals.

Table 6.9: Ownership of Garden-land

Land (in Decimal)	District			Total	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Less than 100	18	8	24	50	89.3
100-200	2	0	2	4	7.1
300-400	0	1	0	1	1.8
400-500	0	0	1	1	1.8
Total	**20**	**9**	**27**	**56**	**100.0**

Table 6.9 shows that only 35% of the respondents have garden-land. Of these respondents, about 89% have the garden-land below 100 decimal which is unproductive for a healthy return.

Table 6.10: Ownership of pond

Land (in Decimal)	District			Total	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Less than 20	3	8	6	17	41.5
20-40	9	7	2	18	43.9
40-60	1	3	1	5	12.2
100-120	0	1	0	1	2.4
Total	**13**	**19**	**9**	**41**	**100.0**

Table 6.10 indicates that 74% of the respondents have no ownership of pond and only 26% have the ownership of pond, of this 42 % and 44% of the respondents have ownership of pond less than 20 and within20-40 decimal respectively that are not sufficient enough to use for storing water for GW recharge through rainwater harvesting.

Table 6.11: Ownership of cultivable-land

Land (in Decimal)	District			Total	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Less than 500	35	44	34	113	70.6
500-1000	3	8	13	24	15.0
1000-1500	1	5	6	12	7.5
1500-2000	0	1	3	4	2.5
2000-2500	0	4	1	5	3.1
2500-3000	0	0	1	1	0.6
3000-3500	0	1	0	1	0.6
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.11 reveals that about 71% of the respondents have less than 500 decimals of cultivable land which indicates that they possess the characteristics of a marginal farmer.

6.3.3 Farmers' Perceptions towards GW Irrigation – Groundwater Use, Irrigation Techniques and Cultivation patterns

Farmers' perceptions towards different issues relating to GW irrigation practices have been explored. Effort has been made based on their perceptions to bring out the rate of GW and surface water uses, sources of surface water, GW aquifer, reasons for the GW decline, cultivation methods being used, knowledge about rules of irrigation, irrigation guidelines, irrigation methods, number of irrigation required for cultivating different crops, maintaining interval in irrigation, impact of continuous paddy cultivation in the same field, effectiveness of different types of supply channel, misuse of irrigation water, knowledge about AWD, impact of over irrigation on production, profitability of *rabi* crops cultivation other than *boro*, role of surface water in GW recharge, artificial recharge, risk of over extraction of

GW on different measures, charge of watering, maintenance cost, benefit of Government subsidy etc.

Table 6.12: Rate of GW use in irrigation

Rate (in percent)	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
50%-60%	3	4	4	11	6.9
60%-70%	20	18	49	87	54.4
70%-80%	15	28	5	48	30.0
80%-90%	1	13	0	14	8.8
Total	39	63	58	160	100.0
Mean value	69%	73%	65%	69.06%	

Table 6.12 exhibits that the mean value of the rate of GW use is 69.06 i.e. about 69 percent of the water acquired for irrigation from GW. Farmers in Rajshahi perceive that about 69 percent of the water they use from GW source for irrigation; farmers in Chapai Nawabgonj perceive that about 73 percent of the water is used for irrigation from GW; and in Naogaon, about 65 percent of the water used for irrigation through GW.

Table 6.13: Rate of surface water use in irrigation

Rate (in percent)	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
10%-20%	10	32	1	43	26.9
20%-30%	21	24	33	78	48.8
30%-40%	7	5	24	36	22.5
40%-50%	1	2	0	3	1.9
Total	39	63	58	160	100.0
Mean value	25%	21%	29%	25.94%	

Table 6.13 shows that the mean value of the rate of surface water use is 25.94% i.e. about 26 percent of the water is used for irrigation from SW. Farmers' in Rajshahi perceive that about 25 percent of the water used for irrigation is SW; in Chapai Nawabgonj, about 21 percent of the water used for irrigation is SW; and in Naogaon, about 29 percent of the water used for irrigation is SW.

Table 6.14: Sources of surface water

Source	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Canal (Khari)	0	50	0	50	31.3
Pond	39	13	58	110	68.8
Total	**39**	**63**	**58**	**160**	**100.0**

From the Table 6.14, it is seen that 69% of the respondents opined that pond is the main source of SW for cultivation. In Rajshahi and Naogaon, all respondents opined that pond is the main source of SW, but in Chapai Nawabgonj, about 79 percent of the respondents opined that *khari* (canal) is the prime source of SW.

Table 6.15: GW aquifer in the study area

Aquifer (in feet)	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
60-80 feet	6	0	11	17	10.6
80-100 feet	31	4	15	50	31.3
100-120 feet	2	39	32	73	45.6
>120 feet	0	20	0	20	12.5
Total	39	63	58	160	100.0
Mean value	88	115	104	102	

The above Table 6.15 indicates that mean value of aquifer static level is 102 feet, i.e., farmers' perceptions of GW aquifer is about 102 feet deep into the underground from the surface, while about 88 feet deep in Rajshahi, about 115 feet deep in Chapai Nawabgonj, and about 104 feet deep in Naogaon.

Table 6.16: GW aquifer in the study area before 10 years

Aquifer (in feet)	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
20-40 feet	14	2	15	31	19.4
40-60 feet	21	32	43	96	60.0
60-80 feet	4	16	0	20	12.5
>80 feet	0	13	0	13	8.1
Total	39	63	58	160	100.0
Mean value	45	63	45	52	

The above Table 6.16 indicates that mean value of aquifer static level is 51.88 feet, i.e., farmers' perceptions of GW aquifer was about 52 feet deep into the underground from the surface before 10 years, while about 45 feet deep in Rajshahi, about 63 feet deep in Chapai Nawabgonj, and about 45 feet deep in Naogaon.

Table 6.17: GW falls due to excess use

Aquifer (in feet)	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Strongly disagree	1	5	0	6	3.8
Disagree	2	4	1	7	4.4
Neutral	2	4	2	8	5.0
Agree	26	44	24	94	58.8
Strongly agree	8	6	31	45	28.1
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.17 shows that majority of the respondents (~87%) were agreed that GW falls due to excess use. In Rajshahi, about 87% of the respondents; in Chapai Nawabgonj, 79% of the respondents; and in Naogaon, 95% of the respondents agreed with the said reason.

Table 6.18: GW falls due to insufficient rainfall

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Neutral	0	2	0	2	1.3
Agree	18	49	15	82	51.3
Strongly agree	21	12	43	76	47.5
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.18 reveals that the majority of people in the study area (~98%) are of the opinion that GW water is declining due to insufficient rainfall. In Rajshahi and Naogaon, all respondents, and in Chapai Nawabgonj, about 97% of the respondents agree on the said reason.

Table 6.19: GW falls due to preservation system

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Disagree	0	5	0	5	3.1
Neutral	9	12	5	26	16.3
Agree	21	37	31	89	55.6
Strongly agree	9	9	22	40	25.0
Total	**39**	**63**	**58**	**160**	**100.0**

From the Table 6.19, it is seen that the majority of the respondents (~81%) agree that GW falls due to lack of preservation. In Rajshahi, Chapai Nawabgonj, and Naogaon, 77%, 73% and 91% of the respondents agreed on the same reason respectively.

Table 6.20: GW falls due to barrage at upstream

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Strongly disagree	1	9	1	11	6.9
Disagree	12	17	2	31	19.4
Neutral	10	18	21	49	30.6
Agree	14	18	21	53	33.1
Strongly agree	2	1	13	16	10.0
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.20 indicates that 43% of the respondents opined in favor of the statement that GW falls due to existence of dams in the upstream, but almost one-third of the respondents (~31%) remain neutral to the statement. In Rajshahi 41%, in Chapai Nawabgonj 30%, and in Naogaon 59% of the respondents believe that dams in the upstream are impeding to ensuring sustainable GW.

Table 6.21: GW falls due to lack of artificial recharge

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Neutral	16	17	29	62	38.8
Agree	17	40	15	72	45.0
Strongly agree	6	6	14	26	16.3
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.21 results that majority of the respondents (~61%) opined that GW decreases due to lack of artificial recharge. In Rajshahi 59%, in Chapai Nawabgonj 73%, and in Naogaon 50% of the respondents believe that artificial recharge system can improve the existing aquifer level although it is observed by the researcher that respondents (farmer) do not have sufficient knowledge about artificial recharging system.

Table 6.22: Cultivation method at the study area

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Traditional method	0	1	0	1	0.6
Modern method	30	41	26	97	60.6
Mixed (traditional and modern)	9	21	32	62	38.8
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.22 above shows, about 61% of farmers cultivates their land by using modern method leaving the traditional technique followed by 38.8 % of the respondents using mixed method of cultivation.

Table 6.23: Views of the respondents towards having knowledge about rules/policies of the irrigation

Question item	No. of respondents having knowledge		No. of respondents having no knowledge		Percent
Whether having Knowledge about rules/policies of the irrigation.	111 (69.37%)		49 (30.63%)		100
Practices they perform and their disposition towards rules	Perform irrigation according to the rules	Perform irrigation defying the rules	Importance of acquiring knowledge of irrigation rules	No need for having knowledge of irrigation rules	
	62 (38.75%)	49 (30.63%)	48 (30%)	1 (0.62%)	100

Table 6.23 indicates that about 69% of the respondents have the knowledge about the rules of irrigation; 39% of them perform irrigation according to rules

prescribed by the concerned authority, and 31% of them perform irrigation defying the rules. Among the respondents who have no idea or knowledge regarding irrigation rules is 30.63%, and 30% of them opined that the knowledge of irrigation rules is required.

Table 6.24: Responses of the respondents towards having knowledge about regular interval during irrigation

Issue	No. of respondents with positive reaction	No. of respondents with negative reaction	Actual practices of the respondents with positive reaction to the issue in question			
				Frequency	**Percent**	**Mean**
Having knowledge about regular interval during irrigation	145 (90.63%)	15 (9.38%)	Completely	2	1.4	2.76
			Moderately	50	34.5	
			Seldom	74	51.0	
			Never	19	13.1	
			Total	145	100.0	

Table 6.24 shows that about 91% of the respondents know the necessity of interval in irrigation; of them 51% follow the practice seldom and 34.5% follow it sometimes.

Table 6.25: Views of the respondents towards having knowledge about four stages[18] of paddy cultivation requiring varied levels of water

Category	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Well known	1	1	1	3	1.9
Moderately known	16	37	13	66	41.3
Very little known	16	23	34	73	45.6
Not known	6	2	10	18	11.3
Total	**39**	**63**	**58**	**160**	**100.0**

[18] Four stages of paddy cultivation are nursery stage (from sowing to transplanting), vegetative stage (transplanting to panicle initiation including tillering), reproductive stage (from panicle initiation to flowering), and ripening stage (from flowering to full maturity). *Determination of the Irrigation Schedule for Paddy Rice*, www.fao.org/3/t7202e/t7202e07.htm

Table 6.25 indicates that near to half of the respondents (~46%) bears little knowledge on four stages of paddy cultivation and about 41% of the respondents moderately know it while in Rajshahi and Chapai Nawabgonj, about 41%, and in Naogaon, 59% farmers. Majority of the respondents have very little or no knowledge.

Table 6.26: Views of the respondents towards having knowledge about keeping optimum level of water at each stage of paddy cultivation

Category	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Well known	1	1	1	3	1.9
Moderately known	14	39	9	62	38.8
Very little known	18	21	25	64	40.0
Not known	6	2	23	31	19.4
Total	**39**	**63**	**58**	**160**	**100.0**

According to the above Table 6.26, about 40% of the respondents agree that they have very little knowledge about keeping optimum level of water at each of the four different stages of paddy cultivation requiring varied levels of water, and 39% of them have moderate knowledge regarding optimum level of water at different four stages.

Table 6.27: Keeping water as per rules of irrigation directed for paddy cultivation

<table>
<tr><th>Issue</th><th>No. of respondents with positive reaction</th><th>No. of respondents with negative reaction</th><th>Actual practices of the respondents with positive reaction to the issue in question</th></tr>
<tr><td>Keeping water as per rules of irrigation directed for paddy cultivation</td><td>53 (33.13%)</td><td>107 (66.88%)</td><td><table>
<tr><th></th><th>Frequency</th><th>Percent</th><th>Mean</th></tr>
<tr><td>Moderately</td><td>45</td><td>84.9</td><td rowspan="2">2.15</td></tr>
<tr><td>Very few</td><td>8</td><td>15.1</td></tr>
<tr><td>Total</td><td>53</td><td>100.0</td><td></td></tr>
</table></td></tr>
</table>

Table 6.27 shows that about 67% of the respondents does not maintain water level in the paddy field as per rules denoting optimum level. Whereas, 33% of the respondents keep water at optimum level, and 84.9% of them keeps it 'moderately'.

Table 6.28: Provide irrigation guidelines by agriculture office

<table>
<tr><th>Item/factor/ Variable</th><th colspan="2">No. of respondents acknowledge</th><th>No. of respondents do not acknowledge</th><th>Percent</th></tr>
<tr><td>Provide 'irrigation guidelines' by agriculture office</td><td colspan="2">22 (13.75%)</td><td rowspan="2">138 (86.25%)</td><td>100</td></tr>
<tr><td rowspan="2">Practices they perform and their disposition towards guidelines</td><td>Perform irrigation according to the guidelines</td><td>Perform irrigation defying the guidelines</td><td></td></tr>
<tr><td>17 (10.63%)</td><td>5 (3.12%)</td><td></td><td>13.75</td></tr>
</table>

Table 6.28 indicates that only 13.75% of the respondents opined that agriculture office provide 'irrigation guidelines', among them 10.63% of the respondents follows the guideline. About 86.25% of the respondent acknowledged that agriculture office do not provide any guidelines for the irrigation.

Table 6.29: Irrigation method in the study area

Aquifer (in feet)	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Modern method	39	62	58	159	99.4
Mixed method	0	1	0	1	0.6
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.29 indicates that except for some respondents in negligible number, all the farmers are used to using modern method in agriculture for irrigation.

Table 6.30: Number of irrigations done for different crops cultivation per *bigha* during *boro* (*robi*) season

Number of irrigation	Number of the respondents						
	Paddy	Wheat	Corn	Dal	Vegetables	Potato	Oilseed
1	-	5 (3.12%)	35 (21.88%)	55 (34.38%)	1 (0.63%)	11 (6.88%)	143 (89.38%)
2	-	103 (64.38)	95 (59.38)	103 (64.38)	47 (29.38%)	85 (53.13%)	17 (10.63%)
3	-	52 (32.5%)	30 (18.75%)	2 (1.25%)	-	32 (20%)	-
4	-	-	-	-	61 (38.13%)	3 (1.88%)	-
5	-	-	-	-	12 (7.5%)	17(10.63%)	-
6	-	-	-	-	39 (24.38%)	12 (7.50%)	-
7	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-
10	5 (3.13%)	-	-	-	-	-	-
11	6 (3.75%)	-	-	-	-	-	-
12	28 (17.50%)	-	-	-	-	-	-
13	47 (29.38%)	-	-	-	-	-	-
14	73 (45.63%)	-	-	-	-	-	-
15	1 (0.63%)	-	-	-	-	-	-
Total (N)	**160**	**160**	**160**	**160**	**160**	**160**	**160**

Table 6.30 indicates that for paddy cultivation during *boro* season 10 to 15 times of irrigation is required. 45.63% of the farmers opined that 14 times of irrigation was required for paddy cultivation. 1 to 3 times for wheat, corn, and dal. Most of the farmers (64.38%, 59.38% and 64.38% respectively) opined that 2 times of irrigation was required for wheat, corn, and dal respectively. Though corn is an important profit generating crop, it is observed by the researcher that most of the farmers do not cultivate corn due to lack of proper marketing system. They added that 1 to 6 times of irrigation was required for potato and vegetables while most of the cultivators (53.13 and 38.13%) opined that 2 and 4 times of irrigation was required for potato and vegetables cultivation respectively. At best 2 times of irrigation is required for oilseed while most of the farmers (89.38%) usually irrigate a single time only for oilseed cultivation.

Table 6.31: Maintaining Intervals between irrigations for paddy cultivation

Interval (in days)	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
2-4 days	0	0	1	1	0.6
4-6 days	1	0	17	18	11.3
6-8 days	5	25	33	63	39.4
8-10 days	27	36	6	69	43.1
10-12 days	6	2	1	9	5.6
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.13 indicates that about 43% of farmers maintain the interval of 8 to 10 days for irrigation in the paddy field (in *boro* season) while 39% of the farmers maintain interval of 6 to 8 days. In Rajshahi about 69% and in Chapai Nawabgonj 57% of the farmers maintain interval of 8 to 10 days. On the other hand, 57% of farmers make interval of 6 to 8 days in Naogaon, for the irrigation of *boro*.

Table 6.32: Height of water level in paddy field

Indicators	Height (in inch)					Total (N)
	2	3	4	5	6	
Height of water during transplantation	7	94	44	15	-	160
Height of water in seven days after transplantation	3	96	33	22	6	160
Height of water in between 'eighth day after transplantation and flowering'	-	21	98	30	11	160
Height of water during flowering	1	6	93	29	31	160
Height of water in between 'after flowering and before harvesting'	1	130	26	3	-	160
Total (N)	**160**	**160**	**160**	**160**	**160**	

According to the Table 6.32, it is seen that about 59% (94) of the respondents maintain the height of water in the paddy field during transplantation of 3 inch. About 60% (96) of the respondents maintain the height of water in the paddy field up to seven days after transplantation of 3 inch. About 61% (98) of the respondents maintain the height of water in the paddy field between eighth day after transplantation and just before flowering of 4 inch. About 58% (93) of the respondents maintain the height of water in the paddy field at the stage of flowering of 4 inch. About 81% (130) of the respondents maintain the height of water in the paddy field for the time after flowering to harvesting is 3 inch as required.

Table 6.33: Negative impact on fertility of land due to continuous paddy cultivation every year in the same field

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Strongly disagree	2	1	0	3	1.9
Disagree	2	1	5	8	5.0
Neutral	3	14	3	20	12.5
Agree	22	40	34	96	60.0
Strongly agree	10	7	16	33	20.6
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.33 shows that most of the cultivators (~81%) agreed that there is a negative impact on fertility of land due to continuous farming of paddy over the years while others opined either disagree or neutral in this case. The table also indicates that 19% of the respondents have no knowledge about the negative impact on fertility for the repetition of the same crop especially paddy.

Table 6.34: Supply channel of water used for irrigation

Supply channel	District			Total	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
UPVC	39	63	58	160	100.0
Concrete drain	-	-	-	-	-
Soil drain	39	63	58	160	100.0
Hose pipe	39	62	3	104	65.0

Table 6.34 shows that all of the farmers are used to UPVC and soil drain in respect to supply channel for irrigating water in their different fields as a whole while few of the cultivators use hose pipe for the same. Again, 65% of the cultivators use hose pipe especially LLP for their different lands as a whole while no use of concrete drain found.

Table 6.35: Views regarding Misuse of water occurs in different irrigation channels

Issue	No. of respondents with positive reaction	No. of respondents with negative reaction	Impact of positive reaction of respondents
Misuse of water due to different irrigation channels	120 (75%)	40 (25%)	See below

Misuse of water for using UPVC pipe

Misuse (%)	Frequency	Percent	Mean
0-5	107	89.2	3.04%
5-10	12	10.0	
10-15	1	0.8	
Total	120	100.0	

Misuse of water for using soil drain

Misuse (%)	Frequency	Percent	Mean
0-5	1	.8	15.58%
5-10	19	15.8	
10-15	31	25.8	
15-20	43	35.8	
>20	26	21.7	
Total	120	100.0	

Misuse of water due to hose pipe

Misuse (%)	Frequency	Percent	Mean
0-5	36	50.0	5.56%
5-10	31	43.1	
10-15	2	2.8	
15-20	3	4.2	
Total	72	100.0	

According to the Table 6.35, it is seen that 87.5% of the respondents reported that misuse of irrigation water due to supply channel usually occurs. In soil drain, misuse of irrigation water is the highest (15.58%) while the lowest (3.04%) UPVC pipe among the supply channels.

Table 6.36: Views regarding the effectiveness of UPVC pipe compared to others in irrigation channels

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Neutral	10	6	8	24	15.0
Agree	13	13	29	55	34.4
Strongly agree	16	44	21	81	50.6
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.36 shows that 85% of the respondents are agreed to the effectiveness of UPVC pipe as irrigation watering channel and it is to be noted, 51% are strongly agreed to it.

Table 6.37: Views regarding the effectiveness of concrete drain compared to others in irrigation channels

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Disagree	0	1	1	2	1.3
Neutral	37	57	55	149	93.1
Agree	2	5	1	8	5.0
Strongly agree	0	0	1	1	0.6
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.37 indicates that almost all the respondents (93%) are neither agreed nor disagreed in case of the effectiveness of concrete drain compared to other water supply channel because there is no use of concrete drain for irrigation water supply in the study area.

Table 6.38: Views regarding the effectiveness of soil drain compared to others in irrigation channels

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Strongly disagree	8	18	8	34	21.3
Disagree	20	31	39	90	56.3
Neutral	10	8	9	27	16.9
Agree	1	6	1	8	5.0
Strongly agree	0	0	1	1	0.6
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.38 indicates that respondents (78%) opined that the soil drain do not have effectiveness or positive impact in irrigation.

Table 6.39: Views regarding the effectiveness of hose pipe compared to others in irrigation channels

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Neutral	11	16	54	81	50.6
Agree	25	41	3	69	43.1
Strongly agree	3	6	1	10	6.3
Total	**39**	**63**	**58**	**160**	**100.0**

According to the Table 6.39, it is seen that about 51% of the farmers opined as satisfactory and 49% were agreed to the significant effect of the hose pipe in use as water supply channel in the irrigation.

Table 6.40: Misuse of irrigation water due to unconsciousness

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Strongly disagree	0	6	0	6	3.8
Disagree	7	14	5	26	16.3
Neutral	7	11	4	22	13.8
Agree	23	30	37	90	56.3
Strongly agree	2	2	12	16	10.0
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.40 reveals that most of the respondents (66.3%) acknowledged that misuse of water occurs due to their unconsciousness.

Table 6.41: Misuse of irrigation water due to excessive use

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Strongly disagree	1	6	2	9	5.6
Disagree	20	20	10	50	31.3
Neutral	1	5	9	15	9.4
Agree	12	30	22	64	40.0
Strongly agree	5	2	15	22	13.8
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.41 shows that most of the respondents (~54%) agree that misuse of water in irrigation also occur due to over lifting.

Table 6.42: Misuse of water due to lack of knowledge about optimum level of watering for irrigation

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Strongly disagree	0	1	0	1	0.6
Disagree	4	3	0	7	4.4
Neutral	15	26	12	53	33.1
Agree	19	33	34	86	53.8
Strongly agree	1	0	12	13	8.1
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.42 indicates that respondents of about 62% perceives that water misuse in irrigation arises for their insufficient knowledge on it.

Table 6.43: Misuse of irrigation water due to faulty supply channel

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Strongly disagree	0	1	0	1	0.6
Disagree	2	4	0	6	3.8
Neutral	9	21	1	31	19.4
Agree	26	36	45	107	66.9
Strongly agree	2	1	12	15	9.4
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.43 shows that most of the farmers (~76%) opine that irrigation is hampered due to defective supply channel of irrigation watering.

Table 6.44: Knowledge about AWD regarding irrigation

<table>
<tr><th>Item/factor/ Variable</th><th colspan="2">No. of respondents having knowledge</th><th>No. of respondents having no knowledge</th><th>Percent</th></tr>
<tr><td>Knowledge about AWD regarding irrigation</td><td colspan="2">27 (16.88%)</td><td rowspan="2">133 (83.13%)</td><td>100</td></tr>
<tr><td rowspan="2">Practices they perform and their disposition towards AWD</td><td>Practices of AWD method in irrigation</td><td>Do not applying AWD method</td><td></td></tr>
<tr><td>8 (5%)</td><td>19 (11.88%)</td><td></td><td>16.88</td></tr>
<tr><td rowspan="2">Decrease of misusing water in AWD method</td><td>Decrease of misusing water</td><td>Do not decreasing misuse</td><td></td><td></td></tr>
<tr><td>15 (9.38%)</td><td>12 (7.5%)</td><td></td><td>16.88</td></tr>
<tr><td rowspan="2">Impact (positive) of AWD method in production</td><td>Increase the production</td><td>Do not increase the production</td><td></td><td></td></tr>
<tr><td>17 (10.63%)</td><td>10 (6.25%)</td><td></td><td>16.88</td></tr>
</table>

Table 6.44 shows that about 83% of the respondents has no knowledge about AWD while 17% has the knowledge. 12% of the respondents do not practice AWD, 9.38% of the respondents opined that it decrease the misuse of water, and 10.63% of them reported that it has positive impact on productivity those who have the knowledge (16.88%).

Table 6.45: Impact of over irrigation on production

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Increase of production	20	32	11	63	39.4
Decrease of production	19	31	47	97	60.6
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.45 indicates that most of the farmers (about 61%) are experienced with the decrease of production due to over irrigation.

Table 6.46: Cultivation of crops other than paddy in *boro* season

Crops	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Wheat	24	54	19	97/160	60.6
Corn	2	2	1	5/160	3.1
Oilseed	34	61	54	149/160	93.1
Dal	8	38	2	48/160	30
Vegetables	19	14	13	64/160	40
Potato	38	7	2	47/160	29.4

Table 6.46 shows that priority is given to cultivate oilseed and wheat (93.1% and 60.6% respectively) in the *boro* season after paddy in terms of profit. In Chapai Nawabgonj priority is set for dal after oilseed and wheat. In Naogaon priority is set for vegetables after oilseed and wheat. In Rajshahi priority is set for potato comparing to oilseed and wheat. Besides, corn is less prioritized crop (3.1%) in the study area. Though the corn cultivation is more profitable, farmers are not interested to farming it due to lack of proper marketing system.

Table 6.47: lucrative crops cultivation other than paddy in *boro* season

Crops	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Wheat	0	28	5	33	20.6
Oilseed	0	29	52	81	50.6
Dal	0	6	0	6	3.8
Vegetables	3	0	1	4	2.5
Potato	36	0	0	36	22.5
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.47 observes that oilseed and wheat (~51% and ~21% respectively) are the most profitable crops after paddy during *boro* season. In Rajshahi potato is the most profitable (~92%); in Chapai Nawabgonj oilseed (~46%) and wheat (~44%)

are the most profitable; and in Naogaon oilseed (~90%) is the most profitable crop other after paddy in the *boro* season.

Table 6.48: Views regarding the effectiveness of rainfall, river, pond, *beel*, and well in GW recharging

Source of water	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Rainfall	38	63	58	159/160	99.4
River	30	32	56	118/160	73.8
Pond	37	58	58	153/160	95.6
Beel	36	41	58	135/160	84.4
Well	21	31	55	107/160	66.9

Table 6.48 indicates that the river plays the major role in recharging GW opined by 99.4% followed by pond, *beel*, and well respectively.

Table 6.49: Knowledge of having artificial recharge system(s)

Source of water	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Yes	6	6	3	15	9.4
No	33	57	55	145	90.6
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.49 indicates that most of the respondents (~91%) are not well known to artificial recharge systems.

Table 6.50: Continuous depletion of water level may put agriculture at risk due to overuse (extraction) of GW

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Strongly disagree	0	1	0	1	0.6
Disagree	1	6	0	7	4.4
Neutral	2	4	0	6	3.8
Agree	22	35	24	81	50.6
Strongly agree	14	17	34	65	40.6
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.50 indicates that most of the participants (~91%) believe that the water level depletes gradually due to extreme extraction of GW in the *boro* season. This is why; farmers are worry about the agriculture sector to be fallen in a risky condition.

Table 6.51: Views regarding whether the Economic activities associated with agriculture be at risk due to overuse (extraction) of GW

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Strongly disagree	0	1	0	1	0.6
Disagree	4	5	0	9	5.6
Neutral	6	9	5	20	12.5
Agree	20	41	32	93	58.1
Strongly agree	9	7	21	37	23.1
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.51 exhibit that the majority of the cultivators (81%) believe that the economic condition might fall at risk due to overuse of GW.

Table 6.52: Biodiversity may be at risk due to overuse (extraction) of GW

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Strongly disagree	0	2	0	2	1.3
Disagree	5	5	0	10	6.3
Neutral	14	15	14	43	26.9
Agree	13	35	28	76	47.5
Strongly agree	7	6	16	29	18.1
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.52 shows that biodiversity is going to fall at risk due to extreme use of GW. Most of the respondents (~66%) favour the statement.

Table 6.53: Drinking water supply may be at risk due to overuse (extraction) of GW

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Disagree	2	2	1	5	3.1
Neutral	1	2	0	3	1.9
Agree	28	35	37	100	62.5
Strongly agree	8	24	20	52	32.5
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.53 indicates that maximum no. of respondents (~96%) reported that the supply of drinking water might be fall in risk to extract.

Table 6.54: Household use of water may be at risk due to overuse (extraction) of GW

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Strongly disagree	0	1	0	1	0.6
Disagree	2	4	1	7	4.4
Neutral	6	9	6	21	13.1
Agree	27	36	33	96	60.0
Strongly agree	4	13	18	35	21.9
Total	**39**	**63**	**58**	**160**	**100.0**

Above Table 6.54 shows that the water level gradually falls due to overuse of GW experienced by the majority of the respondents (~82%).

Table 6.55: Livelihood of people may be at risk in future due to overuse (extraction) of GW

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Strongly disagree	1	0	0	1	0.6
Disagree	6	4	5	15	9.4
Neutral	12	16	18	46	28.8
Agree	16	33	21	70	43.8
Strongly agree	4	10	14	28	17.5
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.55 shows that about 61% of respondents believe that the people might fall at risk and face extreme difficulty in continuing livelihood for the reason of over lifting of GW.

Table 6.56: Livelihood of next generation may be at risk due to overuse (extraction) of GW

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Disagree	2	2	1	5	3.1
Neutral	6	9	2	17	10.6
Agree	25	41	37	103	64.4
Strongly agree	6	11	18	35	21.9
Total	**39**	**63**	**58**	**160**	**100.0**

According to the Table 6.56, it is seen that most of the respondents (86%) predict that the livelihood for the next generation will fall in risk because of overuse of GW.

Table 6.57: Arrangements for getting supply of water for irrigation

Method of payment	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Prepaid card	33	62	58	153/160	95.6
Contract	38	55	0	93/160	58.1
Cooperative	-	-	-	-	-

Table 6.57 reveals that most of the farmers (95.6%) are used to pay against the bill through prepaid card for watering the paddy field.

Table 6.58: Payment of amount in taka per hour watering against prepaid card in general (in taka)

Amount (in Tk.)	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
105.00	0	0	1	1	0.6
110.00	0	2	0	2	1.3
115.00	0	56	0	56	35.0
120.00	13	3	51	67	41.9
125.00	16	2	2	20	12.5
130.00	10	0	4	14	8.8
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.58 shows that about 42% of the respondents opined that charge of prepaid card is Tk. 120 per hour watering. In Rajshahi all the respondents reported that it is Tk. 120 to Tk. 130, in Chapai Nawabgonj about 89% of the respondents opined that it is Tk. 115, and in Naogaon about 88% of the respondents reported that it is Tk. 120. As the amount of bill payment for watering through prepaid card usually depends on capacity of water lifting pump, BMDA determine the watering charge per hour according to water lifting capacity of the pumps.

Table 6.59: Views regarding whether any kind of additional payments are to be made other than the payment made against the prepaid card

<table>
<tr><th>Issue</th><th>No. of respondents with positive reaction</th><th>No. of respondents with negative reaction</th><th>The amount of payment to pump operator other than watering for payment through prepaid card (in taka)</th></tr>
<tr><td>Any kind of additional payments (for pump operator) are to be made other than the payment made against the prepaid card</td><td>103 (64.38%)</td><td>57 (35.63%)</td><td>Misuse of water for using UPVC pipe
<table>
<tr><th>Amount</th><th>Frequency</th><th>Percent</th><th>Mean</th></tr>
<tr><td>70-100</td><td>57</td><td>55.3</td><td>114.95</td></tr>
<tr><td>100-130</td><td>15</td><td>14.6</td><td></td></tr>
<tr><td>130-160</td><td>13</td><td>12.6</td><td></td></tr>
<tr><td>160-190</td><td>6</td><td>5.8</td><td></td></tr>
<tr><td>190-220</td><td>9</td><td>8.7</td><td></td></tr>
<tr><td>220-250</td><td>3</td><td>2.9</td><td></td></tr>
<tr><td>Total</td><td>103</td><td>100.0</td><td></td></tr>
</table></td></tr>
</table>

Table 6.59 indicates that about 67% of the respondents pay extra money to the pump operator amounted to an average of Tk. 115 other than watering through prepaid card in a season. Researcher also reveals that farmers give a certain amount of paddy instead of cash in some cases.

Table 6.60: Views regarding whether maintenance fees are to be paid BMDA for using irrigation pump

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Yes	38	61	1	100	62.5
No	1	2	57	60	37.5
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.60 indicates, 62.5% of the respondents reported that they pay maintenance fee to BMDA for using irrigation pump while in Rajshahi and Chapai Nawabgonj majority of the respondents (both are about 97%) opined that maintenance fee is charged by BMDA, but in Naogaon about 98% of the respondents opined that BMDA do not charge anything as maintenance fee.

Table 6.61: Amount of payment to be made for watering per *bigha* under the contract with owner of private pump (in taka)

Amount (in Tk.)	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
1500.00	37	30	2	69	43.1
1600.00	1	33	56	90	56.3
1800.00	1	0	0	1	0.6
Total	**39**	**63**	**58**	**160**	**100.0**

Table 6.61 shows that about 56% of the respondents reported that watering per *bigha* in case of contract with owner of private pump is Tk. 1600 in *boro* season while in Rajshahi maximum number of respondents (~95%) pays Tk. 1500, in Chapai Nawabgonj the view is mixed in their opinion, and in Naogaon (~97%) it is Tk. 1600.

Table 6.62: Views as to whether the respondents get any benefit because of Government subsidy on electricity bill for irrigation

	District			Total (N)	Percent
	Rajshahi	Chapai Nawabgonj	Naogaon		
Yes	11	29	2	42	26.3
No	28	34	56	118	73.8
Total	**39**	**63**	**58**	**160**	**100.0**

According to the Table 6.62, it is seen that maximum no. of farmers (73.8%) reported with a sorry figure against benefit from the government subsidy on electricity bill for irrigation while only 26.3% respondents reported they are benefited from the subsidy.

The study found that the local population in the study area used about 70 percent of the GW, but only 26 percent of the SW came from ponds and canals.

They have confirmed that the use of GW is increasing day by day. Causes for GW depletion are excessive extraction especially in *boro* season, inadequate rainfall, insufficient conservation measures, and dams at upstream. Farmers have a little knowledge about keeping water at the optimum level in paddy field. Many of them were used to over irrigating in their farm.

Respondents of 87.5% opined, misuse of irrigation water occurs due to faulty supply channel. Farmers of 67% opined, they do not keep water in paddy field as per rules. About 84% of the respondents reported that agriculture office does not provide any guideline for irrigation dully. It has also been identified that UPVC as a supply channel is more effective in preventing water misuse. However, the use of UPVC across the region is not enough compared to demand. In case of soil drain, misuse of irrigation water was the highest (15.58%) while the rate of misuse through UPVC pipe was the lowest (3.04%) among the channels. It is evident that the application of AWD method can play a vital role from preventing the misuse of water up-to 30%, but 83% of the farmers have no knowledge about AWD method. Surprisingly, among those who have knowledge on AWD, 70% of them do not apply it and much reluctant though 63% of them believe the positive impact of it on productivity.

The study found, farmers' do not have any knowledge or idea about artificial recharge of GW as there was no answer to the question of artificial recharge. Existing land is slowly losing its fertility due to cultivation of the same crop (paddy) repeatedly over the years. Farmers are more interested in producing paddy rather than other crops reasoning its economic value, tradition and storage facility round the year. Although oilseeds and pulses are profitable to cultivate in the study area, they are not interested at all for the same reason favoring the boro cultivation.

In this situation, depleting the water level caused disaster in agriculture and associated economic activities. If this depletion continues, it will be a threat to economic activity, biodiversity, drinking and household water supply, and the lives of current people as well as future generations as a whole, respondent reported.

It is estimated through the study that the electricity bill paid through the prepaid card by the farmers than the amount of actual consumption of electricity against the amount of water extracted. Again, Government subsidy of 20% on electricity bill does not results in no direct benefit to the marginal farmers; rather it goes to the private operators or BMDA. About 67% of the respondents reported that extra amount of money of Tk. 115 requires to pay to the pump operator on an average for confirmation of watering in the field during *boro* season though the agreement between farmers and operators does not reveal that additional payment. Researcher also revealed that in some cases farmers give a certain amount of paddy instead of cash as that additional payment.

6.4 Perceptions of Local Government Institutions towards Sustainable Groundwater Irrigation

The key impediments to sustainability of GW use for irrigation that have been identified include over exploitation of GW, increase of *boro* rice cultivation, excessive water use in irrigation, depletion of surface water, reduction in wetland areas, below average rainfall causing the GW level to fall to a level where it is difficult to get fully replenished for lack of water, giving rise to overdraft in the study area. This section has also attempted to reveal the LG managers' perceptions, practices, and sustainability status of GW irrigation based on the thematic analysis of the qualitative data obtained through Key Informant Interview (KII), in-depth interview, and reviewing the previously done related works.

6.4.1 Declining Trend of Rainfall

Rice, a water consuming crop, is the dominant crop in the *Barind* area. The NW region alone supplies about 35 percent of the irrigated *boro* rice and about 60 percent of the wheat for the whole country.[19] About 78%, 67% and 47% of cultivated areas are used for *aman*, *boro* and *aus* cultivation respectively; wheat and

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[19] Mohammad A. Mojid et al., "Water Table Trend—A Sustainability Status of Groundwater Development in North-West Bangladesh," *Water* 11, no. 6 (June): 1182, http://dx.doi.org/10.3390/w11061182.

potato are cultivated in 27% and 39% of the cultivable area; and vegetables both in *rabi* (winter) and summer seasons are cultivated in less than 5 % area.[20] The *Barind* area has the lowest average annual rainfall compared to all hydrological regions in Bangladesh, and the region has a thick (6.10–21.34m) clay layer.[21] Both the factors hinder the recharging of the aquifers, and consequently, contribute to the declining trend of GW table both during dry and monsoon seasons. Figure 6.2 shows the rainfall data and trend of Tanore upazila from 2002 to 2019. According to the figure, highest rainfall was 2109mm in 2008 and lowest rainfall was 918mm in 2010. The trend line shows the downward tendency of rainfall. Trend line reveals that every year 25.32 mm rainfall had declined on an average. Trend also shows that from 2002 to 2019, a decrease in total rainfall was 430.47mm. Figure 6.3 shows the rainfall data and trend of Nachol upazila from 2001 to 2019. Figure shows that highest rainfall was 2029cm in 2007 and lowest rainfall was 742cm in 2012. The trend line shows the downward tendency of rainfall. Trend line shows that every year 17.4951 mm rainfall had declined on an average. Trend also shows that from 2001 to 2019, decrease in total rainfall in that area was 314.912mm.

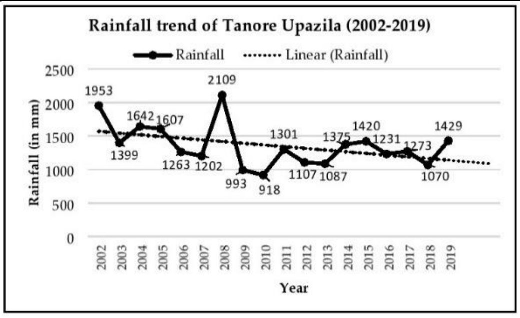

Figure 6.2: Rainfall data and trend of Tanore upazila.
Data source: BMDA, Tanore Zone, Rajshahi.
22 September 2020.

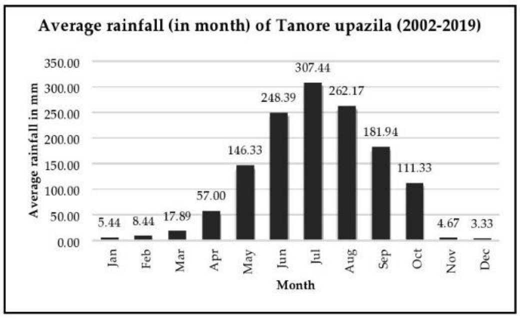

Figure 6.3: Average monthly rainfall (in mm) from 2002 to 2019 of Tanore upazila.
Data source: BMDA, Tanore Zone, Rajshahi.
22 September 2020.

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[20] ATM Sakiur Rahman et al., "Evaluation of spatio-temporal dynamics of water table in NW Bangladesh: an integrated approach of GIS and Statistics," *Sustainable Water Resources Management* 2, no. 3 (2016): 297-312.

[21] Md. Marufur Rahman and A. Q. M. Mahbub, "Lithological Study and Mapping of Barind Tract Using Borehole Log Data with GIS: In the Context of Tanore Upazila," *Journal of Geographic Information System* 04, no. 04 (2012): 349-57, http://dx.doi.org/10.4236/jgis.2012.44040.

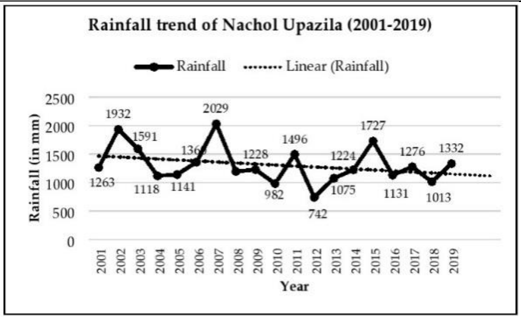

Figure 6.4: Rainfall data and trend of Nachol upazila.
Data source: BMDA, Nachol Zone, Chapainawabgonj.
12 August 2020.

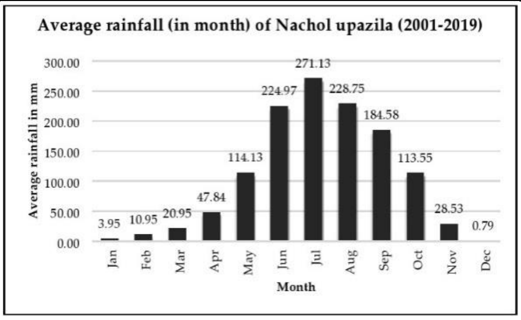

Figure 6.5: Average monthly rainfall (in mm) from 2001 to 2019 of Nachol upazila.
Data source: BMDA, Nachol Zone, Chapainawabgonj.
12 August 2020.

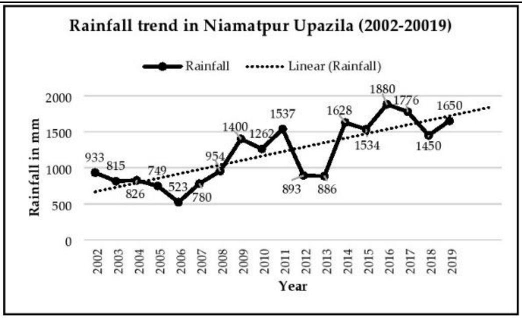

Figure 6.6: Rainfall data and trend of Niamatpur upazila.
Data source: BMDA, Niamatpur Zone, Naogaon.
15 August 2020.

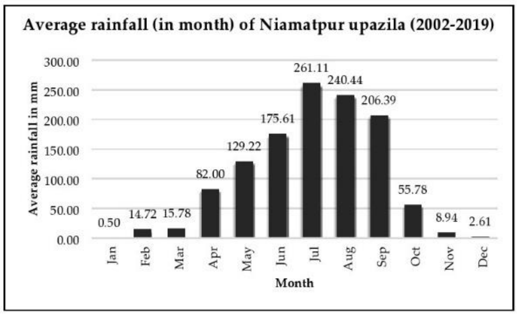

Figure 6.7: Average monthly rainfall (in mm) from 2002 to 2019 of Niamatpur upazila.
Data source: BMDA, Niamatpur Zone, Naogaon.
15 August 2020.

Figure 6.4 shows the rainfall data and trend of Niamatpur Upazila from 2002 to 2019. Figure shows that highest rainfall was 1880mm in 2016 and lowest rainfall was 523mm in 2006. The trend line shows that there was an upward tendency of rainfall. Trend line shows every year 30.94mm rainfall had increased on an average.

Figure 6.5 shows the average monthly rainfall (in mm) from 2002 to 2019 of Tanore upazila of Rajshahi district. Figure shows that highest average rainfall was in the month of July and lowest average was in the month of December. Figure also shows that the period from June to September is the wettest period and November to March is the driest period.

Figure 6.6 shows the average monthly rainfall (in mm) from 2001 to 2019 of Nachol Upazila of Chapai Nawabgonj district. Figure shows that highest average rainfall was in the month of July and lowest average was in the month of

December. Figure also shows that the period covering June to September is the wettest period and November to March is the driest period.

Figure 6.7 shows the average monthly rainfall (in mm) from 2002 to 2019 of Nachol upazila of Naogaon district. Figure shows that highest average rainfall was in the month of July and lowest average the period was in the month of January. Figure also shows that the period from June to September is the wettest period and November to March is the driest period.

A research reports that the GW level had a downward trend in the past 30 years (1981-2011), which indicates that the use of GW in the study area is unsustainable.[22] The severely depleted areas identified were Rajshahi, followed by Pabna, Bogura, Dinajpur and Rangpur. During the period, mentioned earlier, the magnitude of the GW level drop was between -2.3 and -11.5m.[23] This is mainly due to excessive exploitation of GW rather than recharge of aquifers.

6.4.2 Decreasing Trend of Wetland

Wetland management is very important for maintaining natural balance and sustainable agricultural irrigation. Environmental Expert[24] said, *in the wetlands, a certain types of plants grow and a specific biodiversity exists. The water here is very suitable for agriculture as it is usually free from pollution and rich in nutrients, and hence useful for agriculture. Wetlands regulate the levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) in water.*

A decreasing trend in wetland area has been found in the study area where around one-third of total wetlands was lost during 1989-2010, though the rate of decrease was much lower in 2000-2010 than that in 1989-2000.[25] Long-term trend

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[22] Nepal Chandra Dey et al., *Sustainability of Groundwater Use for Irrigation in Northwest Bangladesh* (Dhaka: National Food Policy Capacity Strengthening Programme, 2013), 3.

[23] Ibid.

[24] An in-depth interviewee.

[25] Nepal Chandra Dey et al., *Sustainability of Groundwater Use for Irrigation in Northwest Bangladesh* (Dhaka: National Food Policy Capacity Strengthening Programme, 2013), 3.

of the area under study shows that average rainfall is not sufficient, and as already cited earlier, and the area under study is situated in a flood free zone. Rainfall and flood are two major contributing phenomena for GW recharging, where wetland plays as the media for continuously recharging aquifer.

Environmental Expert in line with this added, *wetland management has never really been done in Bangladesh. In order to get good results in the agricultural sector, wetland management has to be ensured not only in the field of agriculture, but also in the field of housing or road construction. The government of the country has a role to play in wetland management.*

6.4.3 Declining Trend of GW Aquifer

In Northwest Bangladesh, especially in *Barind* area, GW table is declining day by day. According to farmers' perception, GW aquifer is 102 feet deep from the surface. GW aquifer is about 88 feet deep from the surface in Rajshahi, GW aquifer is about 115 feet from surface in Chapai Nawabgonj, and in Naogaon GW aquifer is about 104 feet from the surface. Ten years before GW aquifer level was up from what it is now. GW aquifer depletion is occurring at an alarming rate. Water extraction level is 80 to 120 feet in Nachol and 60 to 100 feet in Niamatpur upazila, according to BMDA Engineers of Nachol and Niamatpur respectively. They also opined that 10 years ago water table was 5 feet up in comparison to the present time. BMDA Engineer of Tanore reiterated that GW aquifer was declining at the rate of one foot to one and half feet per year. Upazila Chairman of Nachol and Niamatpur, and DASCOH official noted that first layer of GW would exhaust within the next 10 years, which is alarming. Several recent studies in Bangladesh report declining trends in GW level which indicate unsustainable GW due to abstraction of water indiscriminately for both irrigation and urban water supplies.

Figures 6.8, 6.10, and 6.12 show the static GW table data and trend of Tanore upazila (from 1996 to 2019), Nachol upazila (from 1995 to 2019), and Niamatpur upazila (from 2001 to 2019) respectively. Figures 6.9, 6.11, and 6.13 show the average monthly depth of static GW table of Tanore upazila (from 1996 to 2019), Nachol upazila (from 1995 to 2019), and Niamatpur upazila (from 2001 to 2019) respectively.

Figure 6.8 exhibits that in 1996 static GW table of Tanore upazila was 6.8 meters (22.31 feet) deep from the surface and in 2019 it was 15.61 meters (51.21 feet) deep from the surface. In the Tanore upazila static level of GW table was depleted by 8.81 meters (about 30 feet) during the years from 1996 to 2019.

Figure 6.10 shows that in 1995 static GW table of Nachol upazila was 16 meters (52.5 feet) deep from the surface and in 2019 it was 34 meters (111.5 feet) deep from the surface. In the Nachol upazila static level of GW table was depleted by 18 meters (59 feet) during the years from 1995 to 2019.

Figure 6.12 reveals that in 2005 static GW table of Niamatpur upazila was 16.9 meters (55.45 feet) deep from the surface and in 2019 it was 21.68 meters (71.13 feet) deep from the surface. In the Niamatpur upazila static level of GW table was depleted by 4.78 meters (15.68 feet) during the years from 1995 to 2019.

Figures 6.9, 6.11, and 6.13 reveal that most vulnerable months in the dry season include four months from February to May, in April GW aquifer was found to have depleted most in the study area. These figures revealed that in the month of April, in the Tanore upazila GW aquifer depleted most during the years 1996-2019, in Nachol GW aquifer depleted most during the years 1995-2019. Whereas, in Niamatpur upazila GW aquifer depleted most both in the months of March and April during the years 2005-2019.

These figures also exhibited that the static water table was closest to the surface in October in Tanore upazila during the years from 1996 to 2019, the static water table was closest to the surface in both September and October in Nachol upazila during the year from 1995 to 2019, and Niamatpur upazila, in August during the years 2005-2019. Highest difference of static water table between wet and dry season was 2.74 meters (9 feet) in Tanore, 7.8 meters (25.6 feet) in Nachol, and 0.59 meter (1.94 feet) in Niamatpur on an average.

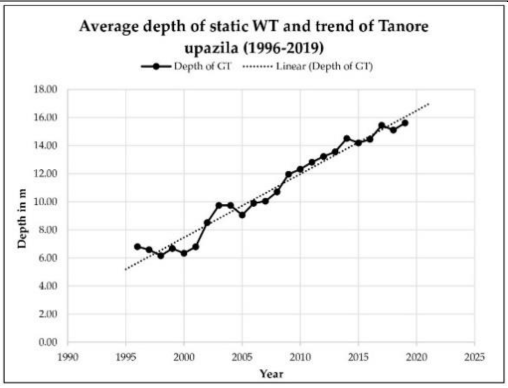

Figure 6.8: Depth of static WT and trend from 1996 to 2019 of Tanore upazila.
Data source: BMDA, Tanore Zone, Rajshahi.
22 September 2020.

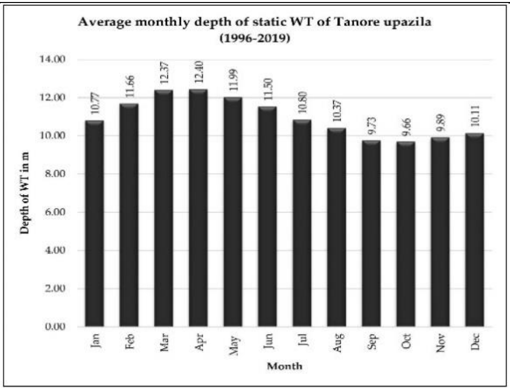

Figure 6.9: Average monthly depth of static WT from 1996 to 2019 of Tanore upazila.
Data source: BMDA, Tanore Zone, Rajshahi.
22 September 2020.

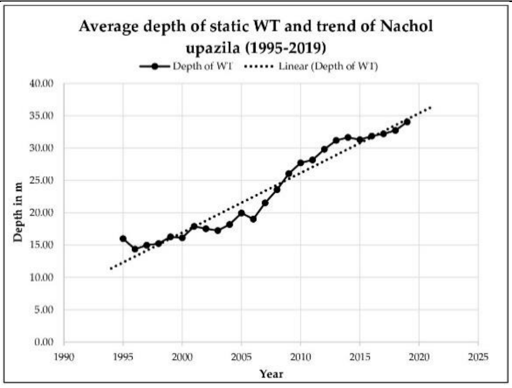

Figure 6.10: Depth of static WT and trend from 1995 to 2019 of Nachol upazila.
Data source: BMDA, Nachol Zone, Chapainawabgonj.
12 August 2020.

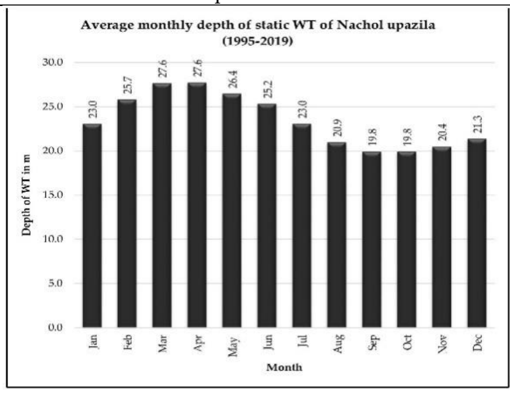

Figure 6.11: Average monthly depth of static WT from 1995 to 2019 of Nachol upazila.
Data source: BMDA, Nachol Zone, Chapainawabgonj.
12 August 2020.

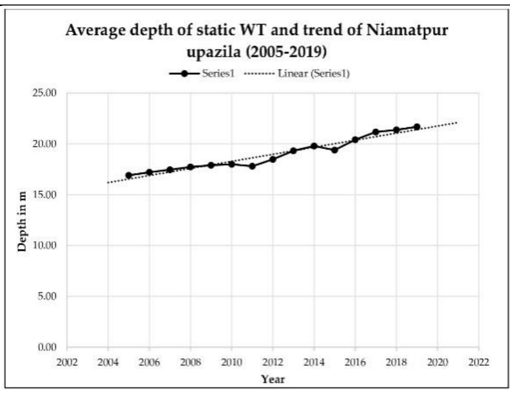

Figure 6.12: Depth of static WT and trend from 2005 to 2019 of Niamatpur upazila.
Data source: BMDA, Niamatpur Zone, Naogaon.
15 August 2020.

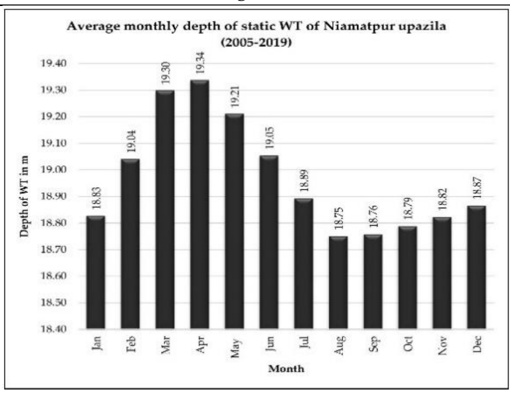

Figure 6.13: Average monthly depth of static WT from 2005 to 2019 of Niamatpur upazila.
Data source: BMDA, Niamatpur Zone, Naogaon.
15 August 2020.

When the GW level drops to the water suction level making it difficult for the pump to lift water, then there occurs a reduction in the discharge of many STWs, requiring more time to irrigate the same land area, leading to higher production costs, usually accounting for an increase in total production costs by more than 50%.[26] Consequently, many farmers and families become completely dependent on DTWs in nearby areas. At the peak of water use during the *rabi* season, many DTWs have difficulty supplying water.

6.4.4 Increasing Trend of *Boro* Cultivation

Much more increase in *boro* cultivation has occurred in the study area. Almost all farmers cultivate *boro* because of its higher yielding. Climate of dry season is most favourable for paddy cultivation than other paddy growing seasons. Therefore, *boro* cultivation is increasing over the years. Cultivation of *boro* have increased significantly over the past time in the study area due to ease of using the means for water lifting and easy excess to GW. In the study area, compared to 1980-81, *boro* cultivation alone has increased by 17 times more than the other ten types of crops, which increased only three times in 2010-11.[27]

6.4.5 Excess Water Use for *Boro* Cultivation

Imperfections in the present irrigation water management system have been identified in the study area. Current study exhibits that about 54% of farmers in the study use more water than they need for *boro* cultivation (Table 6.41). Assistant Engineer (AE) of BMDA (Nachol) opines that about 30% of the lifted water in *boro* cultivation is excess than needed. AE of BMDA (Tanore) thinks that it was about 20%, than the needed amount of water and on the other hand, AE of Niamatpur opines that excess lifting of water varies from 15% to 20%. A study reveals that

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[26] Asad Sarwar Qureshi, Zia Uddin Ahmed and Timothy J. Krupnik, Groundwater Management in Bangladesh: An Analysis of Problems and Opportunities, Cereal Systems Initiative for South Asia – Mechanization and Irrigation (CSISA-MI), CIMMYT, Dhaka (Dhaka: Cereal Systems Initiative for South Asia – Mechanization and Irrigation (CSISA-MI), CIMMYT, 2015).

[27] Nepal Chandra Dey et al., *idiom,* 3.

78.7% of the lifted water is important for *boro* rice production and the rest 21.3% was considered as excess water, which is calculated by subtracting irrigation water requirement to crops from lifted water.[28] This excess water increases irrigation as well as production cost. Analysis also revealed that 68% of the GW is lifted by STWs and rest by DTWs.[29] Use of excess water leads to less production, and reduces productive use of water, accelerating the depletion of water table.

6.4.6 Irrigation Cost for *Boro* Cultivation

As there is almost no surface water available, GW use for irrigation has become increasingly important although cost of irrigation has increased substantially, farmers have to use GW. At the same time, the prices of agricultural inputs such as fuel, electricity (also prepaid smart card which is introduced by BMDA), agrochemicals, land rent, labor, etc. have gradually increased. Eventually production costs are rising, which threatens the overall sustainability of agricultural production in Northwest Bangladesh. It has been observed that the money that BMDA and private pump owners charge for irrigation is much higher than the actual electricity bill. AE of BMDA (Niamatpur) said, *farmers who use irrigation water from private pump pays much more than those of BMDA users. So, production cost varies significantly.* AE of BMDA (Tanore) said, *private STWs charged Tk. 2000 per bigha for irrigation in hard Barind area, which is much more than BMDA charges.* Upazila Chairman of Niamatpur said, *Most of the private STWs charged Tk. 2200-2500 per bigha for irrigation water that is beyond justification. To stop this, a new rate has been set for remote areas of the upazila such as Tk. 1600 per bigha for Rasulpur, Hazinagar, and some parts of Parul union, and for the rest of the area is Tk. 1500 per bigha, per season. BMDA charges in huge amount for irrigation water that is not also justified. For the activities like salary for office work, allowance, salary of pump operator etc., they charge more for irrigation water which is not mentioned in the written agreement of rate determination for irrigation water. Moreover each farmer has to pay Tk. 100 to 150 taka or*

[28] Ibid.
[29] Ibid.

at least 5 kg of paddy to the night guard (pump operator also act as a night guard) to safeguard transformer and pump. Upazila Chairman of Nachol said, *DTWs per hour charge for irrigation is determined based on capacity of the pump in terms of horsepower, and that is done according to the assessment of BMDA though it was not been verified by technical committee for its justification.* Upazila Chairman of Tanore reiterated the same statement.

UNO (also Chair of UIWRMC) of Niamatpur said, *some privately owned STW operators charge at a higher rate arbitrarily per bigha defying the rate set by the District and Upazila integrated irrigation committee. Operators charge Tk. 1200 to 3000 taka per bigha with a whimsical attitude. Most of the times, some farmers' complaints about unjustified rate they charge. To hold in check their unlawful practices, at regular interval, UNO in a team investigates to curb such fraudulent practices and take punitive measures like giving warning, taking of legal action such as cancellation of license to operate the pump, if the same offense takes place repetitively.* According to Economist interviewed, *the administration is not showing their sincerity to restrict the bad practices of operators, which encourage them to continue their offensive practices*. On the other hand, according to UNO, *electricity bills vary as horsepower or water lifting capacity varies, and consequently prepaid meter charges vary according to the principle that 'the less the horsepower the high the rate in terms of electricity bill. It is found that BMDA also charges 50 to 60 percent more than normal or actual charge as electricity bill. It seems that BMDA is doing so to support some of their hidden expenses, like expenses for maintaining employees beyond the payroll. DTWs per hour charge for irrigation rate was determined according to the assessment of BMDA though they are not legally authorized. Moreover, no technical committee reviewed it either. But farmers are satisfied with BMDA as they are paying much less to BMDA than the private STWs.* Water Expert and Economist are of the same opinion but Economist also added that BMDA is not transparent in their process.

According to Deputy General Manager (DGM) of BREB (Niamatpur), *BMDA and private owners of DTWs or STWs charge huge amount to the marginal farmers* *though electricity bill they (BMDA and private owners) pay is 50 to 70% less than the amount charged. Definitely, it implies a kind of hidden cost is there, which is not logical.*

The most obvious consequences of depletion of GW aquifers include the loss of a long-term water supply and the increased costs of pumping GW as the water table declines further below the ground surface. Most farmers opined that the cost of irrigation had increased due to increases in pumping costs from depleted aquifers. Other studies support this finding where it was reported that irrigation expenses is highest in the northwest compared to other regions due to declining GW level at many places during the dry season, and such situation occurs because of GW aquifers not being recharged naturally.[30] Economic analysis shows that due to the continuous decrease of the GW level, irrigation costs gets increased due to the increase in fuel and labor costs, which leads to an increase in production costs.[31] The water stored in the ground can be compared to money being kept in a bank account. If withdrawal of money occurs from a bank account more frequently than the frequency of money being deposited in the same account, then eventually there will occur shortages of money and smooth supply of money to meet future need will be disrupted. Extracting water from the source of GW at a rate faster than rate it is replenished (recharged) at over a long-term will give rise to similar problems.

6.4.7 Most Profitable Crop in *Rabi* Season

In the study area *boro* is the leading cultivated crops in *rabi* season. Current study reveals that priority is given to cultivating oilseed and wheat (93.1% and 60.6% respectively) during the *boro* season other than paddy on the ground return and

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[30] Asad Sarwar Qureshi, Zia Uddin Ahmed and Timothy J. Krupnik, Groundwater Management in Bangladesh: An Analysis of Problems and Opportunities, Cereal Systems Initiative for South Asia – Mechanization and Irrigation (CSISA-MI), CIMMYT, Dhaka (Dhaka: Cereal Systems Initiative for South Asia – Mechanization and Irrigation (CSISA-MI), CIMMYT, 2015).

[31] Nepal Chandra Dey et al., *Idiom,* 3-4.

profit. In Chapai Nawabgonj priority has been found to set for *dal* after oilseed and wheat. In Naogaon priority is set for vegetables after oilseed and wheat. In Rajshahi priority is set for potato than oilseed and wheat. Besides, it has been observed the corn is less prioritized crop (3.1%) in the study area. A large number of farmers including DAE and experts opined that corn cultivation is profitable but farmers are not interested in its farming due to lack of proper marketing. With regard to financial and economic profitability, a study shows that the highest benefit-cost ratio has been found for lentils, followed by wheat, mustard, and potatoes respectively, and cultivation of lentils could be an efficient way to replace imports.[32]

6.4.8 Increasing Trend in the Use of STWs and DTWs

STWs and DTWs are the main GW lifting equipment in the study area. The current study brings out that the number of installation of tube wells has increased in the study area. In this connection a study reports that the command area for a tube-well has drastically reduced from 14.5 to 2.8 hectares during 1984-85 to 2010-11 with an increase in the number of tube-wells by 8.5 times, which is much more than the increase in irrigated land being increased only 1.6 times during the same phase.[33]

6.4.9 Awareness of Farmers

Current survey on farmers reveals that all of them are in know of the declining GW level in their farming area, and they claimed that during the dry season a large portion of the farming area did not have optimum level of water for watering their *boro* field. Another study reports that 73% of them are well aware of the drop in GW levels in the agricultural sector, while 53% of farmers claim that they do not get enough water for irrigation, and more than 88% of farmers are aware of excessive extractions.[34]

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[32] Ibid, 4.
[33] Ibid, 3.
[34] Ibid, 4.

According to AE of BMDA (Nachol), average availability of surface water at Nachol, especially at the time *boro* cultivation, is 1% less than what is available during rainy season. But AE of BMDA (Niamatpur) claimed that it is less than 10%. AE of BMDA (Tanore) is of the opinion that overall use of surface water is 15% to 20% round the year. Various programs are taken to induce farmers' awareness towards irrigation sustainability such as field day, consultation through village committee, training programme, and various types of cultural programs like drama, music, *gamvira* (a traditional local cultural programme), and other recreational activities highlighting irrigation sustainability techniques, according to the officials of BMDA and DEA in the area under study. GW is unseen and remains beneath the surface. The process of making farmers, locals, and also educated people awareness of the dire situation is still in its beginning. People have little knowledge about the water cycle, the interdependence of SW and GW, ecological balance and its services, quantity and quality, supply and demand, and most importantly, the sustainability of the entire system.

6.4.10 Cropping Zone and Crop Diversification

Crop diversification is an important technique to ensure sustainable use of GW. But the crop diversification among farmers in the study area has been found to be very low. They have been cultivating paddy on the same land year after year, especially during the *boro* season. By producing crops that require less irrigation (e.g., oilseed, dal, potatoes, wheat, corn etc.) during the *boro* or *rabi* seasons, it is possible to reduce the growing pressure on GW abstraction. BMDA Engineer of Nachol said, *scheduled cropping zone by the Government, and setting price of crops prior to production would reduce pressure and extraction of GW to a great extent and discourage more boro production. Moreover, Government dictates the irrigation scheduling, which is monitored by the block supervisors under the supervision of UNO.* Upazila Chairman of Nachol are of the opinion that *farmers think of cultivating boro as their tradition, they do not know how to produce other crops efficiently. Moreover, it can be preserved round the year, which is not possible in respect of other robi crops. They also think that this area* *is popular exclusively for boro production. So, they are afraid of losing sales of boro if they switch to other crops as a main stream production. Again, they are not sure of getting convenient marketing system against familiar, easiest and already set marketing system for boro though robi crops are much more profitable compared to boro production.* Chairman of Niamatpur upazila claimed, *more cultivation of seasonal crops like robi crops are encouraged against boro production. They are not interested in wheat, and corn for avoiding the risk of less production, creating seasonal imbalance in production, and allowing attack of rats etc. High yielding paddy, less water consuming paddy or other crops could be a good choice for crop diversification. Again, providing incentives for cultivating crops other than boro may discourage boro cultivation gradually.*

Economist claimed, *farmers will be interested in introducing crop diversification or types of high yielding, and less water consuming paddy when it will benefit them directly and ensure security at least for a year to maintain their livelihood, considering the cost-benefit analysis. Profitability of crops will ensure introduction of crop diversification by farmers.* He reiterated that since introducing *cropping zone needs large amount of lands it will not work in Barind area as well in Bangladesh for our farmers own too many small amount of fragmented pieces of land individually.* According to Executive Director of ASSODO, *the change in crop pattern and diversification need a total support for more lucrative crop variety and convenient marketing system. Some new high yielding, less water consuming, and variety of paddy requiring short time to yield, wheat, dal are going to be introduced very soon and transformation in marketing system to suit to the marking and distribution of them is underway, which is encouraging.*

Cost effectiveness of using irrigation water for different crops in different regions needs to be examined so that the appropriate crops in terms of their profitability may be grown in different locations. Public-private joint initiatives for crop diversification need to be taken to ensure sustainable use of GW. In order to motivate the farmers of the *Barind* region to diversify their crops, it has to be ensured that they will be able to fetch more profit if they produce other crops than the *boro* during the *rabi* season and this has to be made possible by ensuring a fair price for the crops they will produce.

6.4.11 Optimum Use of Irrigation Water

Existing irrigation practices of farmers in the study area is characterized by excessive irrigation tendencies. Reducing the tendency to excess irrigation can help reduce the pressure on GW. As per report of the International Rice Research Institute, irrigation efficiency in Bangladesh is the lowest in the region.[35]

BMDA Engineer of Nachol reported that the rate of excess water use by farmers in the study area was almost 30 percent more than the amount they actually need, BMDA Engineer of Niamatpur opined it was 15 to 20 percent, whereas Chairman of Niamatpur reported that it was 20 percent in the study area. AE of BMDA (Tanore) were of the same opinion. It has a severe negative impact on production, making static aquifer level volatile. In this case, the application of AWD may be a good option. Studies have shown that applying the AWD technique can help reduce irrigation by 20 to 30 percent.[36]

Water is also wasted due to faulty supply channels. In the study area, BMDA provides irrigation water through UPVC pipes with a length of up to 1000 feet. The rest is supplied through traditional soil drains. Water gets wasted because of leakage and evaporation when it is supplied using soil drains. There has been no concrete drain to supply irrigation water in the area under study, the methods used in the study area do not match with concept of sustainability. Installing more UPVC pipes with length up to 1000 feet in the command area of each of DTWs and STWs will reduce water wastage a lot, according to BMDA Engineers. 85 percent farmers in the study area recommended UPVC pipes for supplying irrigation water. BMDA Engineer of Nachol claimed that use of UPVC pipe as an irrigation

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[35] Mark Smith, K. Cross, M. Paden, and P. Laban, "Spring–Managing groundwater sustainably," *IUCN, Gland, Switzerland* (2016).

[36] Mohammad A. Mojid et al., "Water Table Trend—A Sustainability Status of Groundwater Development in North-West Bangladesh," *Water* 11, no. 6 (2019): 1182.

supply channel is 30 percent more effective than the other methods. Whereas, BMDA Engineer of Niamatpur claimed the effectiveness of UPVC pipe is 50 percent more than the other methods being used in the area under study.

Water expert, during the course of taking his interview, said, *some pilot projects are being run to innovate less water consuming paddy, high yielding paddy with a view to bringing to the fore the water saving techniques in irrigation. But the issue that is impeding water saving techniques to come to fore is that until or unless the farmers are benefited directly from using the same nothing will work like AWD technique practiced in irrigation. Moreover, the farmers are also ignorant of the benefits of reducing boro production by switching to the production of dal, wheat, and other robi crops. Farmers should be educated through demonstration of the benefits of these projects to them, arranging seminar and workshop to provide the farmers with the comparative idea of cost-benefit of the projects and profitability thereof. Moreover, introduction of incentives to all marginal farmers may help them feel secured and motivate to do the same.*

6.4.12 Cropping Pattern

Cropping pattern refers to the proportion of land where different crops are planted at different time points. This indicates the timing and arrangement of crops in a particular area of land. The main cropping pattern of agriculture in Bangladesh is mainly rice based. In the study area mono-cropping pattern usually followed by farmers. *Boro*-fallow-*t.aman* was the leading cropping pattern in the study area, and the second foremost cropping pattern in *Barind* area was *boro*-fallow-fallow.[37] Due to following mono-cropping pattern year after year, fertility of land was diminishing and ultimately productivity was affected negatively because of such practice. For maintaining sustainability mixed cropping or crop rotation must be followed.

Water Expert (during the course of interview with the researcher) opined, *traditionally farmers cultivate paddy in the study area. Cropping pattern needs to be*

[37] M. Harun Ar Rashid et al., "Cropping systems and land use pattern in Rajshahi Region," *Bangladesh Rice Journal* 21, no. 2 (2017): 237-254.

changed as quickly as possible. 'BR 52' paddy can be produced within 90 days, 'Braus' can be a good choice in low land areas. Some farmers are experimenting these.

6.4.13 Incentives and Subsidies

The government provides various incentives and subsidies to patronize the agricultural sector. It provides seeds, in some cases free of cost including low cost agricultural inputs. It also provides farmers with subsidies on chemical fertilizers, subsidies on electricity bills for agricultural irrigation etc. so that marginal farmers can be benefited and agriculture can play its due role in the macro economy of the country. In order to obtain low cost and uninterrupted irrigation system in the *Barind* area, DTWs have been installed through BMDA at nominal cost. Government allowed a rebate, which is 20% of the total electricity bill for a DTW or a STW and it is deducted from the total charge before the bill is paid. But the marginal farmers complain that they do not get benefit directly from the subsidy on electricity consumption for irrigation and ultimately benefit goes to the pump owners.

DGM of BREB (Niamatpur) said, *BMDA and privately owned STW operators pay the bill, not the farmers. The two parties work as racketeers to make more money by charging the farmers higher for the supply of irrigation water while paying less for the electricity bills. Actually, the benefits of subsidy go to BMDA and private operators, not to the marginal farmers.* In this regard, UNO of Niamatpur said, *Government initiated subsidy for more production and survival of the farmers. But few entrepreneurs turned it commercially to their advantage and installed STWs to earn as much as possible relegating the Government spirit of protecting farmers to save agriculture. Again, subsidy is not directly provided to farmers, BMDA and entrepreneurs enjoy it.* Water Expert and Economist also did raise the same voice.

Economist said, *subsidy at the farmers' level will create more problems. Until organizations and entrepreneurs concerned are guided by good governance, subsidy will give rise to more discrimination, undue influence, corruptions, practice of bribery etc. the Entrepreneurs in possession of the large fields or entrepreneur for doing the business more* *commercially, and BMDA are being benefited from the subsidy, not the marginal farmers. Bangladesh do not have such administrative structure to distribute subsidy directly to farmers according to the ratio of the land size.* He also added, *as farmers do not have food security, and the Government provides subsidy to irrigation watering electricity bill, directly benefiting the operators and BMDA, and thereby exploiting the farmers in the process will ultimately create an imbalance in the agricultural sectors tilting the balance of development in other sectors. Sustainable GW management includes integrated development of various sectors attached to it. So, it should not keep pressure on other sectors. Through BREB subsidy to electric bill is deducted from the total bill. It reduces the revenue of BREB. It keeps mounting pressure on financial viability, and it would create an imbalance in irrigation, and other electrification processes. That is why, the benefits of subsidy would not come by for a long time and its objective will lose its economic justification. Moreover, food culture would lead to an optimum production, not high production of paddy. Again, availability of surface water would reduce irrigation watering cost. All these might help support withdrawal of subsidy.* He also opined, *suddenly the production of boro in this area cannot be stopped because its share in total production is 30%, occupying a major portion. If Government provides more subsidies for wheat or other robi crops in comparison to others, there will be a dead weight loss. It will lead to stop to other economic value addition activities. So, efficient use of capital is needed. Therefore, subsidy might be given to the farmers to benefit them directly for introducing new technique or new technology use, quality seed, quality fertilizer etc. and maintaining intra-sector based livelihood. Side by side, small entrepreneurs would be provided with minimum subsidy as well.*

Incentives for cultivating other crops than *boro* may discourage *boro* cultivation gradually, according to BMDA Engineers. Incentive can act as a magic, but if amount of incentive is scant compared to farmers' requirement, and in cases where incentives are not provided or distributed properly, the purpose of the incentive will be hampered.

In some cases, subsidy on electricity bill creates negative impact on GW abstraction. It accelerates water pumping because bill to be paid is lower than price of actual consumption. Imposing charges on GW abstraction is the most direct method allowing incentives for users to enjoy economies on GW use. This requires metering of water use, or a reliable method of estimating abstraction, and administering of the resources, including compliance and enforcement. BMDA Engineer of Nachol supported it and uttered the same opinion. As an alternative to where administrative capacity is low a rural electricity pricing method as an incentive can be used to reduce pumping. In Bangladesh, these two alternatives are not implementable. Because if imposition of charges on GW abstraction or raising the price of electricity consumption in rural areas occurs, it will make an excessive impact on food security and most of the farmers will be demotivated to cultivate rice, and ultimately, economic value addition will depress.

6.4.14 Enforcement of Laws and Policies

According to the law, for setting up DTW and STW licenses are to be obtained from UIWRMC or DIWRM subject to the completion of prescribed formalities. In order to ensure sustainable use of GW in the *Barind* region, the concerned ministry issued an office order in 2014 to discourage the issuance of new licenses for irrigation pump. But in some cases, STWs are still being approved.

In private level, DTW and STW establishments are still underway though Government discouraged installation of any new DTW and STW in 2014. From 2014 to 2019, 50 to 60 have already been established, and another 30 to 40 STWs are under process for providing licenses to different private parties. All this is being happened because of undue political pressure, according to the BMDA Engineer of Niamatpur zone. Upazila chairman of Nachol said, what *number of DTW is to be installed in a year determined beforehand. The amount of fund that is allocated to BMDA is not enough to install required number of DTWs to cover the wide area for irrigation. That is why to maximize coverage, private owned STWs were encouraged. Licenses are given in line with the spirit that no piece of arable land is left uncultivated because of remaining outside the irrigation coverage. It is done for the sake of ensuring food security.* Upazila Chairman of Tanore uttered same opinion. According to the UNO of

Niamatpur upazila, *the number of licenses being provided under political pressure are still within tolerable limit. Right now, giving licenses by BMDA for DTWs is postponed as per the office order of the concerned ministry in 2014. But for private owners, license providing process is still afoot and a new short list of private owners has already been made to allow them to install STWs in the upazila.* The UNO of Niamatpur upazila reiterates, in the line with voice of the Upazila chairman of Nachol, *existing number of DTWs are not sufficient enough to cover the wide area. For more coverage of agriculture land for irrigation, private owned STWs were encouraged. Still a few licenses are given to honour the spirit of brining every inch of land under cultivation and lowing not arable land uncultivated. To ease the survival of farmers and to create employment opportunity for them round the year through agricultural activities the installation of STWs are allowed. On the whole, again, according to him it is done in the greater sense of ensuring food security.* UNO also added that BMDA are capable enough to cover the total irrigation area by installing more DTWs though unavailability of fund is a problem in this regard. But BMDA Engineer of Nachol said that fund is not a problem for installing more DTWs. Chairman of Niamatpur upazila said, *new licenses for STWs are being provided to the private owners though office order in 2014 from the concerned ministry discouraged providing such licenses. To cover a large area for irrigation as it is a large portion of Barind tract for paddy production, and to allow farmers to maintain their livelihood, licenses are still issued.* Both the Chairman of Nachol and Tanore added, there is no political pressure to give DTW installation licenses while Chairman of Niamatpur opined, in few cases, political pressure comes into play. UNO of Nachol agreed that political pressure influences in providing licenses for irrigation pump. Economist also said, *in providing licenses political pressure sometimes matters. Right now, giving licenses by BMDA for DTW is postponed as per the office order of the concerned ministry in 2014. But for private owners, STW licenses are provided for sake of farmers' livelihood and more production defying justification for saving GW.*

There is a lack of integrity and coordination in Upazila Integrated Water Resource Management Committee. Upazila irrigation committee consists of 18 members, and DGM of REB is one of them but the committee or member secretary never invited him, according to the DGM of BREB (Niamatpur). Both the Engineers of BMDA (Nachol and Niamatpur) opined that, upazila committee needs to hold a meeting in every three months as per the concerned statute, but it has yet held any such meeting since the time of forming the committee under the new guideline of 2019. In connection with this, Water Expert said, *at the national level, water resources management includes water act, water management policy, and water rules. Organizations that work in Barind tract for water management have the same focus, but their functions and approaches are not integrated, in fact they work in isolation to each other.*

According to the Bangladesh Water Rules 2018, all DTWs and STWs established before 2009 have to take NOC within 6 months of the enactment of the rule. But some problems have arisen in the process of issuing NOCs to these DTWs and STWs. BMDA Engineer of Niamatpur said that DTWs and STWs those were installed before 2009 and those DTWs and STWs which did not take NOCs under BMDA rules, all tube-wells have to be made to take NOCs immediately as per instruction of Water Rules 2018 (formulated under Bangladesh Water Act 2013). Chairman of Niamatpur upazila uttered the same thing. At the private level, some STWs have been installed illegally violating the rules for maintaining command area under each STW's jurisdiction or distance from one STW to another, and thus creating difficulties issuing NOC to the operators violating the command area rule and distance rule. But there has been no such directions in any form before the Water Rules of 2018, according to the UNO, Chairman and BMDA Engineer of Niamatpur. In this regard, there is a lack of consistency in the Bangladesh Water Act 2013 and Bangladesh Water Rules 2018, and notwithstanding existence of the inconsistency between them the objectives of the water rules can be properly implemented at grass route level as uttered by BMDA Engineers of Tanore, Nachol and Niamatpur upazila respectively. The concerned laws meant for need to be amended for proper functioning of the process, the political influence is the biggest barrier to implementing the laws, according to the BMDA Engineer of Niamatpur.

6.4.15 Farmers' Traditional Mindset to *Boro* Cultivation

Boro is traditionally cultivated by farmers in the *Barind* area. They acquire the kind of skills and knowledge required for *boro* paddy cultivation from their families. Farmers in the study area feel that they lack the necessary skills and knowledge to produce crops other than *boro*. Through *boro* cultivation they can ensure year-round food security for the family, which is not possible with other crops, although other *rabi* crops are economically profitable. Farmers feel helpless if they cannot ensure food security for their families throughout the year. It can be preserved round the year to use, but such preservation is not possible in respect of *robi* crops. They also think that this area is popular exclusively for *boro* production. *As the main stream crop, farmers are dedicated to cultivating boro as they have a mindset that it is their asset like liquid bank deposit maintained with a bank all-round the year to meet up food issues and other emergency requirements,* according to Water Expert, Economist, and Chairman of Nachol upazila. UNO of Niamatpur upazila added, *farmers' have a fixed mindset to cultivate boro cultivation. They want output only, they do not want to think about budging off an inch from the traditional stream of cultivation of boro in order to switch to any other crops though cultivation thereof has been found to more lucrative and nature friendly, requiring less watering and allowing quick harvesting.*

Many farmers are aware of the excessive use of water in *boro* cultivation and are aware of the possibility of severe water crisis in the region in the future, but they are not interested in cultivating any other crops except *boro* cultivation. While collecting data, a farmer said, "I know that paddy cultivation requires more irrigation and future generations may have to pay higher prices for this reason, but as long as we get irrigation water, we will continue to cultivate paddy."

Some farmers have little interest for cultivating other *rabi* crops but cannot do that for various reasons. "I want to cultivate oilseed in some land, but my land is surrounded by *boro* land. Due to water leakages from the *boro* land the oilseed land gets moistened too much , resulting in reduced production as oilseed is not a water tolerant crop," one of the farmers claimed.

6.4.16 Retention of GW Table

Retaining GW at the desired level is dependent on many issues. Rate of GW use, amount of surface water use, rainfall, floods, rivers, reservoirs, canals, ditches, ponds, forests, natural and artificial recharge etc. are some of the factors involved in maintaining GW at a sustainable level. The *Barind* region has fewer rivers, less rainfall than the national average, and is a flood-free area. There are no large or medium sized reservoirs. On the other hand, there is a scarcity for surface water in the dry season and agriculture becomes heavily dependent on GW. The GW table is constantly declining as a result of excessive use of GW during the *boro* season besides other kinds of use. In order to counter the threats the declining GW is posing the stream thinkers of GW irrigation have put a premium on the GW recharge and considers GW recharging a normal phenomenon while using GW. GW recharge needs to be understood on an emergency basis for making GW irrigation sustainable through integrating all possible options.

Nachol upazila does not have any rivers. In Niamatpur there is a river named Shiv, but is not flowing over the upazilla. A little portion of the river falls under the upazila. In Tanore upazila, some of the areas get wet because of the flowing of river Shiv, but it is not significant during the dry season. There does not exist any reservoir in the study area. A negligible number of *khari* (canals) with cross dam are existing in the study area, but they remain dry most of the times, and provide water for only 2 to 4 months. A good number of private and *khas* (public) ponds are existing in the area, but these ponds are not useful for irrigation. Authority leases *khas* ponds for fisheries. They apply feeds and fertilizers that make the water unusable for irrigation. Moreover, they use GW to pour the ponds whenever necessary. They use it commercially to have maximum profit. *Overnight a number of cooperatives have been formed, they get registrations within a month and thereafter get lease of the ponds. The total process is done under political influence of the local and regional leaders. Government must intervene and reserve some ponds exclusively for irrigation purpose,* according to ED of ASSODO.

Overall availability of surface water in Nachol, Tanore and Niamatpur upazila is 1percent, 10 percent and less than 10 percent respectively other than the rainy season, especially in *boro* season.

Recharge of GW aquifers is a complex hydro-geological incidence influenced by a number of factors such as intensity and amount of rainfall, underground flow from nearby rivers, geology, geomorphology, and pedology of the land surface, vegetation coverage and land use pattern of that area.[38] These factors have a significant impact on aquifer recharge; which is an important determinant of sustainable use of GW. Since the amount of natural recharge in the study area is less than required, artificial recharge can play an optimistic role in keeping the GW table at the desired level. Although a couple of recharge wells for artificial recharge were constructed under a pilot project, but no such artificial recharge wells were actually constructed in the study area at the initiative of the authorities.

Only 2 artificial recharge wells exist at Niamatpur upazila, another 150 to 160 artificial recharge wells needed to develop aquifer level, BMDA Engineer of Niamatpur claimed. He also added *that a few number of dug wells are available here, which is actually lees in number than required, though dug well is not a sustainable idea for irrigation as well as retention of GW table. Water Expert, Economist, and Social Expert supported this statement.* Economist also added, *there is a need for constructing sufficient number of recharge wells in this area. Dug well is a totally wrong idea to recharge or used for irrigation. Drip irrigation practice might be introduced in our country like China and Rajasthan of India since much water is wasted because of irrigation system we are using in Barind tract. Reservoir needs to be constructed like that of Kustia district to use the water of the river Padma.* Water Expert added, *in 2019, more or less 2000 mm of rain was recorded in this area. But only 10% of water sipped through the ground. Only 4 months' irrigation can be met using the rainwater, rest of the 8 months remain without rain. Consequently, scantiness of surface water due to paucity of rain in this area cannot*

[38] Nepal Chandar Dey et al., "Sustainability of Groundwater Use for Irrigation of Dry-Season Crops in Northwest Bangladesh," *Groundwater for Sustainable Development* 4 (2017): 66-77.

help recharge GW in dry season. Therefore, a proper irrigation management practice be introduced emphasizing an approach towards integrating the utilization of both surface water and GW sources in a nature friendly manner, which can be considered as a sustainable GW management. He also added, *recharge well is very effective in this area and more recharge well should be started to harvest rain water. Use of dug well is a wrong concept and totally wastage of investment. BMDA also does not like this though already installed a number of dug wells.* In Tanore no artificial recharge well or dug well exists. In Nachol, there are 10 dug wells have been constructed, each covering irrigation of 20-30 *bighas* of land for cultivation of *rabi* crops. It allows extraction of 2 liters of water per second. In Niamatpur, 22 dug wells are in operation.

6.4.17 Inter-dependency between GW and Surface Water, and Development of Surface water

Surface water interacts with GW almost everywhere on the planet. This interaction occurs through the loss of surface water to GW, the leakage of GW to surface water bodies giving rise to a two way round interactions. Underlying aquifers of GW gain water from the wetland or reservoir. Wetland is decreasing in the *Barind* area (stated earlier) and no reservoir exists here. In fact, water management institutions, central or local, have no initiative to create any. Rivers are available in the *Barind* area but its impacts with regard to covering of area for irrigation and recharging GW sources are insignificant compared to requirements. Water Expert said, *as surface and GW are interrelated and serve as sources for each other, non-availability of surface water put pressure on GW extraction. Water management organizations in the study area totally failed to manage and develop the sources of surface water, and dependence on GW sources has increased many times. Recently, the optimum extraction level has fallen down to an alarming level, which lopsided the availability GW for irrigation with the requirements in the Barind tract. Consequently, irrigation cost for extracting GW has increased. The application of Individual sector approaches, without having any coordination among them, towards managing the water resources is the major cause behind the water governance failure. Here, organizations failed to prevent such upset situation. If they had been proactive in developing sources of surface water, and searched for dynamic,* *advanced and effective agriculture techniques along with efficient use of GW, there would not have been any crisis for GW.*

To prevent the rapid depletion of GW table, sources of surface water have to be developed. Development of barrage, excavation of large-scale reservoirs, re-excavation of *khari* and ponds, etc. should be initiated through Government agency or public private partnership (PPP) for increasing the availability of surface water sources. In this regard, water expert said, *a construction of a reservoir with the help of barrage to store the water of the river Tista is under consideration in collaboration with China. Another project named North Rajshahi Irrigation Project (NRIP) is under processing. At Goalanda (in Rajbari district), there will be a Ganga-barrage. It will be used for irrigation in Barind area.* He added, *Barind area will have a project that will transfer water through pipeline from the river Padma to the Khari of Godagari (in Rajshahi), there will be sufficient number of cross-dams for irrigating a large area. As river water contains more minerals, and particles, it will help produce more crops per bigha.* To use surface water as the main source of irrigation, more model projects have to be under taken, related expertise has to be built up, and continuous researches should be done to explore innovative and suitable approaches as soon as possible, the Economist opined.

6.4.18 Governance Status

Good governance is indispensable for GW management. At the stage of LG, BMDA is the prime implementing authority though some other institutions are also associated with GW management. Lack of integration among the LG institutions is a gigantic problem. BMDA predominantly provides irrigation water to farmer which is extracted from GW table, which they do not control or manage. Water Expert said, *individually, the local level organizations are poor in terms of governance. Internal consistency of governance is so poor in terms of transparency, accountability, social equity, integrity, efficiency, effective participation and so on. BMDA is better than others in terms of those criteria.* But Economist said, *BMDA is inefficient to provide irrigation water in time as they are reluctant to do so, meddle distribution serials by force and many more unjustified delays they make. If farmers' associations are formed at the field* *level, they could be able to contribute to maintaining the situation in a better way as because they would do it for the sake of their livelihood.* He added, *BMDA has totally failed to maintain a proper irrigation system. Under the same structure a new body or committee should be formed with ensuring a good governance. Activities like crop diversification, subsidy, training, drip agriculture etc. will be done in a more efficient way than BMDA does. Activities of BMDA should be diminished gradually.*

Implementation of law and order should be strictly made while practicing the local irrigation management. Most of the employees associated with implementation of irrigation and local administrative people do not want to stay in rural areas under study, resulting in the hamper of a smooth irrigation process. To protect GW, use of technology with new ideas is a must in the management and control of WG irrigation system in a sustainable manner.

6.4.19 Change in Food Culture and Consumption

Food culture and consumption habit of the community in study area is changing and it is happening due to the health consciousness and the sense of leading a healthy life the people in the study have developed in them. Change of food culture and consumption pattern would play a big role to reduce the pressure on rice. Economist said, *as people are become conscious about health and nutrition, and they are having less rice, more vegetables, fruits, and less fat gaining items. Moreover, people used to consume 600 gm of rice on an average over the last 20 years ago, but now it has come down to 400 to 450 gm as taking of other food options have increased a lot. Consequently, the need for vegetables, robi crops, fruits like mango, orange, malta, guava, dragon, papaw, banana etc.is going to stand out as a prime demand of the people of the study area. So, horticulture for ensuring more nutrients is going to occupy an important place besides their stable food, rice. If the current food culture emphasizing rice as a stable food can be replaced by the alternative foods as mentioned earlier, then it would be a great breakthrough for saving the GW because of requiring less rice production.* In line with this, nearly 40% of the farmers are planting to grow those on their land on an experimental basis, as DASCOH official reported.

6.5 Overall Scenario of Sustainability Status

The overall scenario with regard to sustainability status of GW has been presented in this section based on the data and observations relating to both demand and supply sides.

Demand side

Farmers' dispositions influencing their activities directly and indirectly put a mammoth impact on GW depletion. The causes for GW depletion include—

a. Their tradition of sticking to *boro* production only because of the following reasons:
   i. Positive cost-benefit analysis of cultivating *boro* from the farmers' perspective;
   ii. Feeling of a sense of better survival due to having the storage of *boro* crop over the year;
   iii. Feeling of a sense of security in cultivating the *boro* crop because it can survive any natural odds better than the other crops can do and it helps fetch more penny for the farmers than the other crops do;
   iv. Feeling of easiness in cultivating the *boro* crop because of inheriting the experience of its cultivation from their ancestors.
b. Lack of proper skill and training at cultivating other crops, determining and maintaining optimum level of water at the field while cultivating crop, switching between different crops to allow natural recharging of GW as well as maintaining intervals to allow revitalization of soil;
c. Avoidance of using modern technologies like AWD, a device for sensing level of moister in the paddy field;
d. Poor knowledge about increase productivity;
e. Illiteracy;
f. Short orientation in their planning for future crop cultivation due to severe poverty.

g. Excessive dependency on *boro* for food security ignoring or having no idea about the future consequence of water crisis.

Thus, GW use for irrigation has increased monumentally with substantial increase in the cost of irrigation. Cost effectiveness of using irrigation water for different crops in different regions needs to be examined to identify the crops that are suitable for cultivation in a particular location and that may be most lucrative from a location's perspective. As per report of the International Rice Research Institute, irrigation efficiency in Bangladesh is the lowest in the region, where the cost of irrigation is much higher compared to India, Thailand, Vietnam and many more countries.

Supply side

With the initiation of green revolution in 1987, to meet up the demand for food grains across the country through huge production leading to achievement of self-sufficiency for food, technological revolution, cropping pattern switching from one crops to three crops cultivation, and decline in the rate of rainfall as well as insufficient surface water sources leaving very little or no chances for GW level to be recharged naturally caused the GW to fall to a bottom level.

A huge number of government machinery are involved in water resource governance in the *Barind* tract has made the management complexed creating a situation of multiple and multitier authority giving rise to a kind of red tapism and anarchy in the execution of the concerned policy emphasizing the importance of ensuring sustainability in the use of GW in irrigation.

There is a lack of long term strategies to develop sufficient surface water sources besides dearth of strategies for maintaining GW optimum level through implementing a proper ratio of surface water use to GW extraction in order to deter GW depletion, which is consistent with the spirit of the Government policy.

WARPO and local Government offices situated in the study area are reluctant to follow the integrated plan meant for bringing about necessary changes and overcoming the complexity in the implementation of the related law, rules and regulations and guidelines that come down through the proper channel from the top. The above mentioned dysfunctional situation exists at all the levels of water governance system from top to bottom - national, regional and local. Again, institutional governance lacks enough responsibility and accountability in respect of maintaining the law and order strictly. Sheer flexibility and reluctance fraught with increased biasness, nepotism, red tapism compounded with undue political pressure have altogether thwarted the proper functioning of the governance system. DTW and STW recommendations and installations, and their maintenances, more commercial or undue benefit motive on the part of people involved along with undue practices of private owned STW and DTW operators, discrimination in respect of charges and in getting serial for watering, depriving farmers of due rights, illegal activities are the common phenomena eroding the governance of the water resources in the study area.

Farmers also inappropriately lift water ignoring the importance of sustainability of ground sources and they do this due to lack of proper knowledge, indiscriminate installation of DTWs and STWs, and lack of up-to-date technologies. All these have multifarious impacts upon interlinked sources of water table which is declining alarmingly. The GW account for major share of total water required for irrigation, its sustainability is at risk because of its present menacingly low quantity in the northwest region.[39] Frequent shortages of water in the region may have adverse impacts on socio-economic and environmental systems.[40] Present status of the situation under study has already given rise to a number of problems that are becoming more acute to dismantle the

[39] Shamsuddin Shahid, "Impact of Climate Change on Irrigation Water Demand of Dry Season Boro Rice in Northwest Bangladesh", *Climatic Change* 105, no. 3-4 (2010): 433-453.

[40] Nepal Chandar Dey et al., "Assessing Environmental and Health Impact of Drought in the Northwest Bangladesh", *Journal of Environmental Science and Natural Resources* 4, no. 2 (2012): 89-97.

ecosystem. More specifically the GW management practices that are in force right now in the study are to be under sheer scrutiny for ensuring a balance among the criteria of economic viability, social equity, and thereby keeping the environment intact for the present and future.

The existing irrigation practices might have an adverse effect on the environment and the ecosystem in the long run. If decline in GW keeps going it will have an undesirable impact on the health of the environment. This can lead to impurity in the crops inflicted by increased arsenic contamination and mixing of heavy metals in the water, having deleterious impact on public health in the long run. To get rid of this condition it is necessary to reduce the use of GW during the *boro* season.

Although huge GW are being used for *boro* rice production in the dry season which is being continued until the decline takes place below the GW static level, because *boro* crop production is playing a prime role in ensuring food security for the community of the study area and even across the country. The Northwest region alone provides about 35% of the country's irrigated *boro* rice and 60% of wheat.[41] Therefore, *boro* production cannot be stopped abruptly. Doing so would jeopardize the country's food security, making a large portion of farmers jobless, and reducing economic value addition, which would affect the balance of the overall economy.

When a tradition goes on for a long time, taking the initiative to change it abruptly has an effect on social stability. Rice production is at the root of the agrarian social system that the inhabitants of the *Barind* region are carrying on. Due to high yield of paddy in *boro* season and availability of GW for irrigation, farmers in the study area are more interested in *boro* paddy production than other seasons though there is certain availability of surface water in other seasons. Therefore, it

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[41] Mohammad A. Mojid et al., "Water table trend—a sustainability status of groundwater development in North-West Bangladesh," *Water* 11, no. 6 (2019): 1-.15.

is not easy to induce the farmers of the study area to produce other crops to prevent them from producing *boro*. But it is vital to limit *boro* production to protect inhabitants from long-term environmental hazards in the study area. Therefore, in order to bring any change in the agricultural heritage in the *Barind* area, the thinking pattern of the inhabitants of this area, their interest in the kind of change, the mentality of accepting the change, the overall balance of the society, etc. must be taken into consideration. Measures must be taken to ensure that no section of society is deprived of the opportunities that will result from change.

Therefore, the urgency to save the society, economy, and environment sectorial approach needed to be replaced by a holistic approach i.e., integrated water resource management (IWRM) for sustainable irrigation management should be commenced with top urgency.

6.6 Conclusion

This chapter demonstrated the natural setting of GW and the related influencing factors. This chapter also attempted to disclose the perceptions of farmers and local government institutions towards the status of sustainability of GW irrigation in *Barind* tract, Bangladesh. Another discussion has been made to highlight the factors influencing the upsurge in the demand for more water and measures for ensuring increased supply of water to meet the gradually increasing demand unleashing a bad impact on the sustainability in the use of GW in irrigation. In the next chapter an attempt has been made to present the various GW management issues and GW irrigation practices from the standpoint of achieving sustainability in the use of GW.

Chapter Seven

Sustainable Groundwater Management for Irrigation in *Barind* Tract of Bangladesh: Issues and Practices

In this chapter an effort has been made to present existing water management practices done under different sectorial approaches in *Barind* tract, Bangladesh and to identify the key management issues involved. Accordingly, in this chapter discussions have been made on the current short-term and long-term strategies being pursued to bring the demand for irrigation water in line with supply of water with a view to portraying a realistic scenario of how effective are the various measures adopted and the practices that are in force in ensuring sustainable use of water in irrigation.

7.1 Introduction

In respect to sustainable GW management for irrigation, sustainable yield and safe yield are crucial for the management practices. The concept of 'safe yield' to manage GW resources is widely used, but very little is explored on it that immensely has led to poor GW management in the several parts of the world.[1] So, water administrators have the opportunity to understand the concept of basin yield in a systematic manner. The explanation of 'safe yield' was originally proposed based on a very simple point of view, that is, how to develop GW basins to maximize water pumping. Gradually, the concept has expanded in covering economic, legal, and water quality issues.[2] But no improvement has been found in terms of its application to real-world GW issues. On the other hand, the concept of 'sustainable yield' emerges around the complex interdependence of society and

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[1] John D. Bredehoeft, "Safe yield and the water budget myth," *Ground Water* 35, no. 6 (1997): 929-930, John D. Bredehoeft, "The water budget myth revisited: why hydrogeologists model," *Groundwater* 40, no. 4 (2002): 340-345, and Marios Sophocleous, "Managing water resources systems: Why 'safe yield' is not sustainable," *Ground water* 35, no. 4 (1997): 561.

[2] William M. Alley and Stanley A. Leake, "The journey from safe yield to sustainability," *Groundwater* 42, no. 1 (2004): 12-16.

the environment, and it believes, an environmental problem cannot be solved alone.[3] The concept is rather feasible that the GW extraction system is measured within the prescribed planning time, can withstand acceptable levels of stress and protect the relevant economic, social and environmental values.[4] However, this concept is consistent with the principle of sustainability.[5] As a result, it is recommended not to use the term 'safe yield', but to use 'sustainable yield'.

It is widely recognized that GW pumping not only affects the surface water supply needed for human beings but also affects the maintenance of water demand for fish and other aquatic species, the health of river banks and wetland areas, also the other environmental requirements.[6] The trade-off between the GW used for irrigation and the environmental impact for GW pumping becomes the driving force to determine the sustainability of GW system.[7] Therefore, without careful interpretation of assumptions about the acceptable effects of GW development on the relevant ecosystems, the basin yield should not be defined as sustainable.[8]In

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[3] John D. Bredehoeft, "Safe yield and the water budget myth," *Ground Water* 35, no. 6 (1997): 929-930, and William M. Alley, Thomas E. Reilly, and O. Lehn Franke, *Sustainability of ground-water resources* Vol. 1186, (US: US Department of the Interior, US Geological Survey, 1999).

[4] Frans RP Kalf, and Donald R. Woolley, "Applicability and methodology of determining sustainable yield in groundwater systems," *Hydrogeology journal* 13, no. 1 (2005): 295-312.

[5] Ibid.

[6] Thomas C. Winter, Judson William Harvey, O. Lehn Franke, and William M. Alley, *Ground water and surface water: a single resource,* Vol. 1139. (Collingdale, PA: DIANE Publishing Inc., 1998), Marios Sophocleous, "Interactions between groundwater and surface water: the state of the science," *Hydrogeology journal* 10, no. 1 (2002): 52-67, Igor S. Zektser, and Lorne G. Everett. *Groundwater and the environment: applications for the global community*, (Boca Raton, Florida: CRC Press, 2000), Christian Steube, Simone Richter, and Christian Griebler, "First attempts towards an integrative concept for the ecological assessment of groundwater ecosystems," *Hydrogeology Journal* 17, no. 1 (2009): 23-35, and William Frank Humphreys, "Hydrogeology and groundwater ecology: Does each inform the other?," *Hydrogeology Journal* 17, no. 1 (2009): 5-21.

[7] William M. Alley, Thomas E. Reilly, and O. Lehn Franke, *Sustainability of ground-water resources* Vol. 1186, (US: US Department of the Interior, US Geological Survey, 1999), Mario Sophocleous, "From safe yield to sustainable development of water resources—the Kansas experience," *Journal of hydrology* 235, no. 1-2 (2000): 27-43, and Marios Sophocleous, "Groundwater recharge and sustainability in the High Plains aquifer in Kansas, USA," *Hydrogeology Journal* 13, no. 2 (2005): 351-365.

[8] Kevin M. Hiscock, Mike O. Rivett, and Ruth M. Davison, "Sustainable groundwater development," *Geological Society, London, Special Publications* 193, no. 1 (2002): 1-14.

addition, aquifers and ecological responses are not only spatial in nature but also related to time. Therefore, 'sustainable yield' must be defined within a specific time period under a given hydrogeological and climatic background, and must be monitored and modified over time.[9]In order to properly manage GW resources; accurate information about the input, i.e., recharge and output, i.e., GW pumping and natural discharge within each GW basin, is required which allows to estimate or reevaluate the long-term behavior of the aquifer system and its sustainable yield.[10]

When the interdependence of GW, surface water and ecosystems for the development of land and water resources gets intensified, then it is obvious that the level of development of GW or surface water affects the quantity and qua lity for each other.[11] In fact, almost all surface water bodies such as streams, lakes, reservoirs, and wetlands interact with GW in various natural and climatic landscapes while natural processes and human activities affect the interaction between surface water and GW. There is no doubt that GW, surface water and aquatic ecosystems are closely related, and can no longer be independently managed and regulated. Therefore, sustainable GW management requires an accurate understanding of the interaction between GW and surface water under such conditions.[12] Therefore, it is urgent to regulate GW and surface water considering them as a single resource in the catchment scale. Policymakers and water officials in developing countries like Bangladesh, specifically at the *Barind* tract including the study area may incorporate modern and evolving concepts of sustainable management of GW and surface water resources (conjunctive) while

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[9] Ibid.

[10] Marios Sophocleous, "Groundwater recharge and sustainability in the High Plains aquifer in Kansas, USA," *Hydrogeology Journal* 13, no. 2 (2005): 351-365

[11] Thomas C. Winter, Judson William Harvey, O. Lehn Franke, and William M. Alley, *Ground water and surface water: a single resource,* Vol. 1139. (Collingdale, PA: DIANE Publishing Inc., 1998).

[12] Thomas C. Winter, Judson William Harvey, O. Lehn Franke, and William M. Alley, *Ground water and surface water: a single resource,* Vol. 1139. (Collingdale, PA: DIANE Publishing Inc., 1998) and Marios Sophocleous, "Interactions between groundwater and surface water: the state of the science," *Hydrogeology journal* 10, no. 1 (2002): 52-67.

formulating plans and policies and take the necessary actions to implement the concept of sustainable development at the national, regional and local levels.

Recognizing the importance of GW resources preservation and growing demand for GW resources created a dilemma. Therefore, there is an urgent need to find out effective GW management strategies to achieve an optimum balance between GW preservation and demand for extraction.

7.2 Sustainable Groundwater Irrigation Management

As sustainable GW irrigation management outlines both short-term and long-term strategies, this study also looks forward to highlighting the same. Therefore, in the context of sustainable GW management, demand and supply management work in two phases; short-term and long-term strategies to settle a proper balance. These are discussed below:

7.2.1 Short-term Strategies

The problems of GW management are multifaceted and involve reliable assessment of available water, its scope includes its supply and escalation, distribution, reuse or recycling, its existing declination, pollution, and protection against declination and degradation. In the context of the impact of climate change and spatial change during drought; two major gaps in GW management have emerged which have a significant impact on sustainable development: (i) unable to deal with the problem of accelerated degradation of GW system because of excessive extraction, and unable to effectively consume resources because of quality changes or pollution, and (ii) the inability to solve the problem of requirement for GW and aquifer services.[13]

GW mining has enabled many farmers to supplement their irrigation needs and respond to changes in surface supply. Inexpensive drilling technology allows

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[13] Dr Saleem Romani, "Ground water Management: A key for sustainability," *CESS papers* (2005).

farmers to use GW to irrigate their crops has led to the amazing development of agriculture and helped millions of people to get rid of poverty. Surprisingly, management of GW could not keep up with this development as they were reluctant to the issue of losing water resources. For growing concern over the issue, the following direct and indirect management approaches were used to control the excessive exploitation of GW over the last two decades.

7.2.1.1 Direct Measures

During the last two decades, the water regulatory authority has issued laws regulating GW in Bangladesh. In 2009, licensing system was introduced to limit the installation of private DTWs and STWs in the *Barind* area where GW was declining faster and GW quality was deteriorating rapidly across Bangladesh. However, enforcement of laws, licensing for installation and permit systems were mostly unsound. The number of acts, rules, and guidelines that were tried to elevate the situation could not produce any better results due to red tapism, ineffectiveness, inefficiency, absence of integration, reluctant to the call to the local needs, unviable projects, and the most destructive political pressure. Although many laws and policies had been enacted, the relevant authorities were very reluctant to implement them seriously. Moreover, unlike the management of surface water resources, no effort was made to manage aquifers that crossed the administrative capacity. Another complication of GW management was that organizations engaged in water resources management were having different missions and methods for the same goal; no integration was found among the strategies followed by different bodies. Therefore, implementation of whatever measures they tried to improve the situation did not bring any fruitful outcome.

Facts have proved that the institutional solutions for GW management are much more critical than what were originally thought. The authorities' plan for managing GW and compromise to allow GW extraction without any limit for irrigation for the sake of meeting food sufficiency led them into a critical point. Moreover, they are not interested to developing surface water resources either. Due to the sharp decline in the availability of public funds for making major investments in surface water and irrigation systems, the extended use of GW resources has facilitated the continued expansion of irrigated agriculture without any consideration of its recharge or control over excessive extraction. As the farmers of the study area under *Barind* tract were relying solely on GW irrigation for their livelihoods, the relevant authorities are seemed to be flexible and reluctant to enforce regulatory laws to restrict or control over exploitation of GW for irrigation.

7.2.1.2 Indirect Measures

Bangladesh tried with indirect measures while direct control failed to come up with any success. The strategy of providing subsidy on 'electricity bill pricing policy' introduced was thought to be a powerful toolkit for indirect management of GW. But in reality, subsidy directly went to the private pump owners and BMDA, rather than going to the marginal farmers. Consequently, such step could not bring any good to farmers' livelihood or uplift their motivation in the process. However, introduction of long-term subsidies would make BREB fall into a financial pressure, making its survival difficult.

Moreover, subsidies for high-quality seeds and subsidies for fertilizers were supposed to help farmers reduce cultivation and irrigation costs, but it also did not bring any good result. As GW is essential to meet the growing demand for food with insufficient surface water resources, and maintaining farmers' livelihood continue with *boro* cultivation could not really solve the real problem of GW's overspending. Thus, subsidies had little effect on controlling GW overdrafts, even accelerated GW mining had occurred as a worst outcome.

Again, the authorities' tried to introduce crop diversification through awareness-raising programs, consultations, free seeds, and incentives to encourage the cultivation of alternative crops consuming less water to prevent *boro* production and reduce pressure on GW. The LG institutions and other concerned organizations also introduced modern technologies for irrigation such as AWD to optimize the use of GW. But this technology was yet to be proved effective as farmers' were accustomed to relying on their experience of pouring water though it was not scientific at all and proved to be wastage of GW. More alarming was that, farmers' had their own traditional mindset for *boro* cultivation with a view to storing rice all year round and achieving as a sense of security to meet their regular needs, sometimes in times emergency or crisis. Therefore, introduction such technology could not motivate farmers to use it and help reduce over-exploitation of GW in *Barind* tract under the study areas.

GW management in Bangladesh is truly critical to employing a single solution. Direct and indirect approaches did not help achieve the expected results rather increased abuse of GW. Lack of information database stood as the main obstacle in the process of resource development to resource management. Despite the tough efforts of local and global organizations, incorrect information on GW availability, quality, water withdrawal, and other variables, make all efforts ineffective and inefficient.

All these clearly demonstrates the need for searching more innovative ways or creative strategies to solve the problem of GW overexploitation while maintaining the current levels of agricultural production in view of continuing food sufficiency for food security. Therefore, the methods or measures discussed above could not provide pragmatic and viable solutions rather they proved to be unrealistic. The above mentioned management techniques were all about achieving control over the situation without taking into account their long term consequences and the philosophy of sustainability. Therefore, transition from GW control for irrigation to sustainable GW management for irrigation calls for pursuing long-term strategies along with short-term strategies as there does not exist any single solution for the problem. An application of integrated and unified approach towards managing the GW in a holistic manner, considering the various impacts it can have on the society, economy and ecological system, can made possible through achieving a mechanism of coordination from field level to national level.

7.2.2 Long-term Strategies

7.2.2.1 Demand Management Strategies

'Demand-side' management strategies are of much important like supply expansion to confirm sustainability of water and other resources across the future generations.[14]

Managing Conjunctive Use of Surface and Groundwater

The conjunctive utilization of surface water and GW is one of the best strategies being practiced in many countries for water supply management, and under such practice the consideration is to optimize the development, management and protection of water resources in water basins. Artificial recharge of aquifers is also undoubtedly one of the widely used tools in many countries to manage GW for this purpose.[15]

Water Saving Techniques and Improving Water Productivity

Notwithstanding the overall shortage, the existing irrigation practice of farmers still is to over-irrigate, which calls for some appropriate measures to be taken. Efficient irrigation methods, such as AWD irrigation method (20%-30% water saving) and drip irrigation should be introduced.[16]

Introduction of mulching reduces soil surface evaporation or evapotranspiration, which can help in turn reduce the GW extraction from the aquifers, allowing the aquifers to be recharged more. Adopting buried pipe (UPVC) for water distribution, and application of AWD irrigation method can

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[14] Charles F. Hutchinson, Robert G. Varady, and Sam Drake, "Old and new: changing paradigms in arid lands water management," In *Water and sustainability in arid regions*, (Dordrecht: Springer, 2010) 311-332.

[15] Madan K. Jha, Y. Kamii, and K. Chikamori, "Cost-effective approaches for sustainable groundwater management in alluvial aquifer systems," *Water resources management* 23, no. 2 (2009): 219-233.

[16] Mohammad A. Mojid et al., "Water Table Trend—A Sustainability Status of Groundwater Development in North-West Bangladesh," *Water* 11, no. 6 (2019): 1182.

reduce cost of irrigation and this may allow expansion of command area. Higher water efficiency can ultimately reduce aquifer replenishment by minimizing leakage and percolation losses in canals and crop fields, because a considerable part of the water used in irrigation projects refills the underlying aquifer.[17]

Therefore, water-saving management practices provide clear evidence that due to the expansion and long-term existence of this low-permeable plough pan reduces the recharge of aquifers. The application of AWD is very limited, because the farmers want to rely on their own experience and avoid the risk of delayed supply of water because of a long queue.

Water pricing structures which make water savings financially attractive are unlikely to be introduced in the near future. Therefore, more efforts should be concentrated on adopting water conservation techniques in the irrigated agriculture because agriculture is the biggest user of water. Relatively modest increases in water productivity would result in significant increases in food production without increasing the volume of water extracted.

Introducing Water Conservation Technologies

Subsidies should be provided to marginal farmers to switch from flood irrigation to drip irrigation, to improve the flatness of arable land, and take cover measures (mulching) to protect the useless water loss caused by soil evaporation. Precise land leveling, zero tillage, high-bed planting, furrow planting, micro-irrigation, sprinkler irrigation and other resource-saving technologies have also greatly reduced the water consumption in the field. Zero tillage technology has been widely adopted in many countries such as the United States, Brazil, Argentina and Zimbabwe. Compared with basin irrigation method, furrow bed irrigation method can save up to 40% of irrigation water.[18] Water conservation will have a huge impact on the

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[17] Ibid.

[18] Asad Sarwar Qureshi, Tushaar Shah, and Mujeeb Akhtar, *The groundwater economy of Pakistan*, Vol. 64. IWMI, 2003.

existing agricultural water use, thereby reducing the extraction of GW. The results show that the best crop yield can be obtained by applying irrigation equivalent to 80% of the total crop evapotranspiration (deficit irrigation).[19]

The adoption of these technologies should be encouraged for mass scale implementation. Conservation agriculture can help save water by reducing the evaporation of the soil surface during the dry season, but it may have a negative impact during the rainy season because it reduces the recharge of the inferior aquifer. However, by breaking the plough pans through deep plough at the beginning of the wet season, the advantages of conservation agriculture in terms of water saving can be used. These measures are effective only if farmers do not expand the area of arable land or increase the intensity of cultivation.[20]

Rationalizing Cropping Patterns

The production of *boro* crops has promoted from increased irrigation supplies or availability. Since rice is a high water-consuming crop, it is necessary to limit rice production to meet its domestic demand and convert it into a crop that consumes less water to reduce the pressure on GW encourage direct seeding of rice or aerobic rice. In comparison to traditional (transplanted) rice planting, directly sown rice requires less irrigation water by 20% to 25%.[21] Likewise, strategies should be developed to reduce water consuming and high market value crops.

For sustainable cropping pattern, cultivation of *robi* crops by this time been stimulated and a few number of cultivators are doing it. However, in order to ensure the safety of their livelihoods and face emergencies, there are rice storage

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[19] Sanmugam A. Prathapar and Asad S. Qureshi, "Modelling the effects of deficit irrigation on soil salinity, depth to water table and transpiration in semi-arid zones with monsoonal rains," *International Journal of Water Resources Development* 15, no. 1-2 (1999): 141-159.

[20] Mobin-ud-Din Ahmad et al *Water saving technologies: Myths and realities revealed in Pakistan's rice-wheat systems*, International Water Management Institute (IWMI), 2007.

[21] Asad Sarwar Qureshi, Ilyas Masih, and Hugh Turral, "Comparing Water Productivities of Transplanted and Direct Seeded Rice for Pakistani Punjab," *Journal of Applied Irrigation Science* 41, no. 1 (2006): 47-60.

facilities throughout the year, so *boro* rice can help them do this. They worry that due to the limitations of storage facilities and market systems, they have a very little interest to adopt diversified or highly profitable alternative robi crops to ensure survival. Bangladesh may begin to shift its agricultural development from the northwest to the southwest.[22]

Regulation of Groundwater Development

One of the important strategies for sustainable GW management is to supervise GW development in key areas. Overexploitation of GW resources is increasingly recognized as a major problem. The trend of over-exploitation of GW resources is rooted in dynamic pumping technology, resource characteristics, demographic changes and the rapid spread of government policies. There are few efforts to measure and monitor the overexploitation and regulation of GW resources. However, without community support and awareness raising, it will be difficult to implement laws to regulate and control GW.

Compared to other countries in the world, water use productivity in Bangladesh for *boro* production is much poor. Many piecemeal efforts have been made in the past. However, it is necessary to formulate comprehensive policies at the national level to ensure continuity in this regard. In addition, farmers should be educated to optimize crop yields by reducing water consumption, rather than maximizing crop yields through excessive GW irrigation. In demand-side management, the socio-economic level plays an important role in the management of water and land users. Unless different community groups are fully involved and supported, regulatory interventions such as water rights and permits and economic measures of water prices will not succeed. In order to effectively manage GW resources, it is necessary to establish awareness among different groups of water users and specific sustainable development plans in the workout area.

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[22] Mohammad A. Mojid et al., *Idiom*, 1182.

7.2.2.2 Supply Management Strategies

Rainwater Harvesting and Recharge Well

Usually rainfalls on the surfaces anywhere is captured in tanks (above or below ground) and make a room to slowly infiltrate into the soil.[23] Farmers should be encouraged to collect rainwater and adopt watershed management strategies to increase the productivity of rain-fed systems and reduce the demand for GW. Farmers should be provided with facilities for harvesting rainwater, and necessary knowledge and training should be provided. In rural areas, it is considered feasible to change the natural flow of water by changing appropriate civil structures, such as infiltration ponds, dams, *Nala* Bund, and ditch plugs, and artificial recharge technology is considered feasible. The roof rainwater harvesting structure can also be built up and thereafter a provision should be made to get the water released into dedicated tank and in turn into a well for increasing the storage capacity of GW, if there happens to remain any additional amount of water after use.[24]

Artificial Recharge of Aquifers

Aquifer management is considered to be the most effective way to establish a balance between discharges and recharge components. This practice has been widely used in industrialized countries such as United States, Germany, Switzerland, the United States, the Netherlands, and Sweden.[25] In recent years, India has also taken serious steps to use the collected rainwater to replenish the aquifer and allocate a lot of funds to further promote this practice. However, it is clear that GW recharge interventions have had a positive impact on the availability of GW. Methods usually practiced are as follows:[26]

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[23] P. Dillon, *Strategies for Managed Aquifer Recharge (MAR) in semi-arid areas*, Edited by Ian Gale, (Paris: UNESCO, 2005): 34.

[24] Dr Saleem Romani, *Idiom*.

[25] Jin-Yong Lee et al., "Statistical evaluation of geochemical parameter distribution in a ground water system contaminated with petroleum hydrocarbons," *Journal of environmental quality* 30, no. 5 (2001): 1548-1563.

[26] P. Dillon, *Strategies for Managed Aquifer Recharge (MAR) in semi-arid areas*, Edited by Ian Gale, (Paris: UNESCO, 2005): 34.

Popularizing and wider adoption of such methods as ponds for infiltrating water into the ground, soil-aquifer treatment, in which overland water flows can be poured into to allow GW recharge;

In-channel modifications include percolation ponds to allow leakage, sand storage dams to allow water dripping, underground dams, leaky dams and recharge releases, all these are kinds of river channel modifications made to increase recharge GW;

Well, shaft and borehole recharge include kinds of infrastructure to be developed to pump water in an aquifer to recharge it and then either withdraw it at the same from a nearby source for use;

Induced bank infiltration includes processes to increase recharge through bank infiltrations or dune infiltrations by withdrawing GW at one location to create a hydraulic gradient to allow increased recharge.

Artificial recharge of GW and harvesting of rainwater are the two basic technologies used for sustainable water resources management. Artificial recharge of GW can offset the vulnerability of naturally recharged GW that arises due to changes in precipitation, so it is one of the popular measures used for adapting to climate change. In many parts of the world, high land costs and environmental issues coupled with large surface reservoirs have increased the need for artificial replenishment because it is a means for sustainably regulating water for human needs. State-of-the-art methods to improve the sustainability in the management of GW resources usually include the use of aquifers as reservoirs, the combined use of surface water and GW, and the use of recycled or reclaimed water, artificial recharge of water through wells or the surface flow,[27] while the cost-effective

[27] William M. Alley, Thomas E. Reilly, and O. Lehn Franke, *Sustainability of ground-water resources* Vol. 1186, (US: US Department of the Interior, US Geological Survey, 1999).

method of artificial replenishment is to increase river flow, replenish through irrigation, drains, water tanks, ponds, and replenish from rice fields.[28]

In order to effectively perform supply-side management, it is necessary to fully understand the production and behavior of GW level to control abstraction pressure, and pursue strategies for the interaction of surface water and GW because of changes in river base flow and recharge dates (timing or season across the year) due to their exploitation.

The main challenge in this technique is to properly prioritize the allocation of water resources without affecting the GW level and agricultural productivity. Therefore, sustainable GW irrigation management strategies rely on the assessment of the actual water resources allocated to agriculture for maintaining the balance of the ecosystem. More specifically, it should focus on achieving a balance between the use of GW for irrigation, improving water productivity, irrigation efficiency and proficiency, and post-harvest processing based on cost-benefit analysis. Therefore, the use of modern/ integrated approaches enabling the maintenance of such conditions may bring a desired outcome.

7.3 Conclusion

This chapter attempted to identify the management issues and discussion has been made on the present management practices in the short-term and long-term perspectives highlighting the demand and supply side strategies followed in Bangladesh, more specifically in *Barind* tract. In the next chapter an attempt has been made to summarize the findings of the study.

[28] Madan K. Jha, Y. Kamii, and K. Chikamori, *Idiom*, 219-233.

Chapter Eight
Summary of Findings and Discussion

This chapter attempts to draw a summary of the findings based on the study. It starts with the enumerating the findings in line with the study objectives, and presents the outcomes of the study with a view to providing a testimony for sustainable management of GW irrigation and thereafter ended up drawing concluding remarks.

8.1 Introduction

Though GW never gets the priority and receives the attention it deserves to have, even then it ensures the benefits worldwide to human societies (social and economic development) and to ecosystems to sustain. Therefore, GW management needs to be sustainable to ensure food security and multiple dimensions of development to support the achievement of sustainability.

8.2 Summary of Findings

8.2.1 Sustainability Status

GW depletion will cause havoc. It will increase cost of living and reduce the means for livelihood, create scarcity for drinking water, huge migration of people from a place where there is a dearth of water to a place with availability water, put pressure on other limited opportunity for economic activities, decline agriculture forcing switching to other work elsewhere for survival, imbalance ecosystem. On the whole such depletion will destroy resources for the next generation.

- In Tanore upazila, from 2002 to 2019 rain fall trend was declining, highest rainfall recorded was 2109 mm in 2008 and lowest rainfall was 918mm in 2010. Every year 25.32 mm rainfall had declined on an average and decrease of total rainfall was 430.47mm. Highest average rainfall was in the month of July and lowest was in the month of December. June to September was the wettest period and November to March was the driest period.

- In Nachol upazila, from 2001 to 2019 rain fall trend was declining, highest rainfall was 2029mm in 2007 and lowest rainfall was 742mm in 2012. Every year 17.50 mm rainfall had declined on an average and decrease of total rainfall was 314.91mm. Highest average rainfall was in the month of July and lowest was in the month of December. June to September was the wettest period and November to March was the driest period.
- In Niamatpur upazila, from 2002 to 2019 rainfall followed an upward trend, highest rainfall was 1880mm in 2016 and lowest rainfall was 523mm in 2006. Every year 30.94 mm rainfall had increased on an average. Highest average rainfall was in the month of July and lowest was in the month of January. June to September was the wettest period and November to March was the driest period.
- During the period from 1984-85 to 2010-11 the number of tube wells was increased by 8.5 times, which was much more than the increase occurred in the amount irrigated land, which got increased only by 1.6 times.
- Around one-third of total wetlands was lost during 1989-2010, though the rate of decrease in wetland was much lower in 2000-2010 than it was in 1989-2000. Wetland management has never really been done in Bangladesh.
- *Boro* cultivation has much more increased in the study area. *Boro* area alone has increased by 17 times where area for other crops cultivation increased only by three times in 2010-11.
- Imperfections in the present irrigation water management system have been identified in the study area. The current study reveals that about 54% of farmers in the study area are of the opinion that farmers use more water than they need for *boro* cultivation. In Nachol, about 30% of lifted water in *boro* cultivation was in excess of need, in Tanore upazila it was about 20%, and in Niamatpur excess amount of water lifted varied from 15% to 20%. It further explores that 78.7% of the lifted water is necessary for *boro* rice production and

the rest 21.3% was considered as excess which was calculated by subtracting the actual water requirement for irrigation from the lifted amount of water. This excess lifting of water causes waste of water and increases production cost. Analysis also reveals that 68% of the GW is lifted by STWs and rest by DTWs. The excess water remaining unused is a sign of unproductive use of resources resulting in less production and reduced water productivity, accelerating the depletion of water table.

- The study reveals that the money that BMDA and private pump owners charge for irrigation is much higher than the actual electricity bill they are to pay. Farmers who use irrigation water from private pump pays much more than those of BMDA users. So, production cost varies significantly. It is revealed that according to horsepower or water lifting capacity of the pump prepaid meter charge is adjusted following the principle of 'the lesser the horsepower the higher the rate of electricity bill.' It is found that BMDA and private owners of DTWs or STWs charge huge amount to the marginal farmers though electricity bill they (BMDA and private owners) pay is 50 to 70% less than the amount charged to them. Definitely, it implies a kind of hidden cost is there, which is not logical.
- In the study area *boro* is the leading cultivated crops in *rabi* season. Current study reveals that priority is given to cultivating oilseed and wheat (93.1% and 60.6% respectively) during the *boro* season other than paddy on the ground of return and profit. In Chapai Nawabgonj priority has been given to *dal* after oilseed and wheat. In Naogaon priority is set for vegetables after oilseed and wheat. In Rajshahi priority is set for potato than oilseed and wheat.
- The survey on the farmers reveals that all of them know about declining GW level in their farming area, and they complained that during the dry season a large portion of the farming area did not get optimum water for watering their *boro* field. 73% of them were found to be aware of the declining GW level in the agricultural sector, while 53% of farmers claimed that they did not get enough

water for irrigation, and more than 88% of farmers were aware of the excessive extractions.

- Average availability of surface water at Nachol, especially at the time of *boro* cultivation, is 1% less than what is available during rainy season. But in Niamatpur it is less than 10%. In Tanore overall use of surface water accounts for 15% to 20% round the year.
- Various programs were taken to induce farmers' awareness towards irrigation sustainability such as field day, consultation through village committee, training programme, and various types of cultural programs like drama, music, *gamvira* (a traditional local cultural programme), and other recreational activities highlighting various irrigation sustainability techniques.
- The process of making farmers, locals, and also educated people aware of the dire situation is still in its beginning. People have little knowledge about the water cycle, the interdependence of SWs and GWs, ecological balance and its services, quantity and quality, supply and demand, and most importantly, the sustainability of the entire system.
- In *Barind* area, GW aquifer depletion is occurring at an alarming rate. Ten years back GW aquifer level was up from what it is now. In the present situation, water extraction level is 80 to 120 feet in Nachol, and 60 to 100 feet in Niamatpur upazila. GW aquifer is declining at the rate of one foot to one and half feet per year. First layer of GW would exhaust within the next 10 years, which is alarming.
- In 1996 static GW table of Tanore upazila was 6.8 meters (22.31 feet) deep from the surface and in 2019 it was 15.61 meters (51.21 feet) deep from the surface. In the Tanore upazila static level of GW table was depleted by 8.81 meters (about 30 feet) during the years from 1996 to 2019.
- In 1995 static GW table of Nachol upazila was 16 meters (52.5 feet) deep from the surface and in 2019 it was 34 meters (111.5 feet) deep from the surface. In the Nachol upazila static level of GW table was depleted by 18 meters (59 feet) during the years from 1995 to 2019.

- In 2005 static GW table of Niamatpur upazila was 16.9 meters (55.45 feet) deep from the surface and in 2019 it was 21.68 meters (71.13 feet) deep from the surface. In the Niamatpur upazila static level of GW table was depleted by 4.78 meters (15.68 feet) during the years from 1995 to 2019.
- Most vulnerable months in the dry season include four months ranging from February to May, in April GW aquifer was found to have depleted most in the study area. The present study revealed that in the month of April, in the Tanore upazila GW aquifer depleted most during the years 1996-2019, in Nachol GW aquifer depleted most during the years 1995-2019. Whereas, in Niamatpur upazila GW aquifer depleted most both in the months of March and April during the years 2005-2019.
- The static water table was closest to the surface in October in Tanore upazila during the years from 1996 to 2019, the static water table was closest to the surface in both the months of September and October in Nachol upazila during the year from 1995 to 2019, and in Niamatpur upazila, the water table got closed to surface in the month of August during the years 2005-2019. Highest difference of static water table between wet and dry seasons on an average was 2.74 meters (9 feet) in Tanore, 7.8 meters (25.6 feet) in Nachol, and 0.59 meters (1.94 feet) in Niamatpur.
- Crop diversification is an important technique to ensure sustainable use of GW. But the crop diversification among farmers in the study area has been found to be very low. They have been cultivating paddy on the same land year after year, especially during the *boro* season. By producing crops that require less irrigation (e.g., oilseed, dal, potatoes, wheat, corn etc.) during the *boro* or *rabi* seasons, it is possible to reduce the growing pressure on GW abstraction.
- Use of Scheduled cropping zone done by the Government, and setting price for crops prior to production would reduce pressure on and extraction of GW to a great extent and discourage more *boro* production. Moreover, Government dictates the irrigation scheduling, which is monitored by the block supervisors under the supervision of UNO.

- *Boro* is traditionally cultivated by farmers in the *Barind* area. They acquire the kind of skills and knowledge required for *boro* paddy cultivation from their families. Farmers in the study area feel that they lack the necessary skills and knowledge to produce crops other than *boro*. Through *boro* cultivation they can ensure year-round food security for the family, which is not possible with other crops, although other *rabi* crops are economically profitable. Farmers feel helpless if they cannot ensure food security for their families throughout the year. It can be preserved round the year for use, but such preservation is not possible in respect of *robi* crops. Again, they are not sure of getting convenient marketing system against familiar, easiest and already set marketing system for *boro* though *robi* crops are much more profitable compared to *boro* production.
- Farmers are not interested in wheat, and corn for avoiding the risk of less production, creating seasonal imbalance in production, and allowing attack by rats etc. High yielding paddy, less water consuming paddy or other crops could be a good choice for crop diversification. Again, providing incentives for cultivating crops other than *boro* may discourage *boro* cultivation gradually.
- Cropping zone needs large amount of lands, such concept will not work in *Barind* area and greater Bangladesh as well for our farmers own too many small amount of fragmented pieces of land individually.
- The change in crop pattern and diversification needs a total support for more lucrative crop variety and convenient marketing system. Some new high yielding, less water consuming, and a variety of paddies requiring short time to yield besides wheat, dal are going to be introduced very soon and transformation in marketing system including distribution of them is underway, which is encouraging.
- Existing irrigation practices of farmers in the study area is characterized by excessive irrigation tendencies. The rate of excess water use by farmers in the study area was almost 30 percent more than the amount they actually needed.

- Excess water using tendency has a severe negative impact on production, making static aquifer level volatile. Studies have shown that applying the AWD technique can help reduce irrigation by 20 to 30 percent. But the issue that is preventing water saving techniques from coming to fore is that until or unless the farmers are benefited directly from using the same nothing will work like AWD technique used in irrigation.
- Water is also wasted due to faulty supply channels. In the study area, BMDA provides irrigation water through UPVC pipes with a length of up to 1000 feet. The rest is supplied through traditional soil drains. Water gets wasted because of leakage and evaporation when it is supplied using soil drains.
- There has been no concrete drain to supply irrigation water in the area under study, the methods used in the study area do not match with the very concept of sustainability.
- Installing more UPVC pipes with a length up to 1000 feet in the command area of each of DTWs and STWs will reduce water wastage a lot. 85 percent of farmers in the study area recommended UPVC pipes for supplying irrigation water.
- Use of UPVC pipe as an irrigation supply channel is 30 to 50 percent more effective than the other methods being used in the area under study.
- Some pilot projects are being run to innovate less water consuming paddy, high yielding paddy with a view to bringing to the fore the water saving techniques in irrigation.
- The main cropping pattern of agriculture in Bangladesh is mainly rice based. In the study area mono-cropping pattern usually followed by farmers. *Boro*-fallow-*t.aman* was the leading cropping pattern in the study area, and the second foremost cropping pattern in *Barind* area was *boro*-fallow-fallow. Due to following mono-cropping pattern year after year, fertility of land was diminishing and ultimately productivity was affected negatively because of such practice. For maintaining sustainability, mixed cropping or crop rotation must be followed.
- In order to obtain low cost and uninterrupted irrigation system in the *Barind* area, DTWs have been installed through BMDA at nominal cost. Government

allowed a rebate, which is 20% of the total electricity bill for a DTW or a STW and it is deducted from the total charge before the bill is paid. But the marginal farmers complain that they do not get benefit directly from the subsidy on electricity consumption for irrigation and ultimately benefit goes to the pump owners. Bangladesh do not have such administrative structure to distribute subsidy directly to farmers according to the ratio of the land size.

- As farmers do not have food security, and the Government provides subsidy to irrigation watering electricity bill, directly benefiting the operators and BMDA, and thereby exploiting the farmers in the process will ultimately create an imbalance in the agricultural sectors tilting the balance of development in other sectors. Sustainable GW management includes integrated development of various sectors attached to it. So, it should not put pressure on other sectors. Through BREB subsidy to electric bill is deducted from the total bill. It reduces the revenue of BREB. It keeps mounting pressure on financial viability, and it would create an imbalance in irrigation, and other electrification processes. That is why, the benefits of subsidy would not come by for a long time and its objective will lose its economic justification.
- Therefore, subsidy might be given for introducing new technique or new technology use, quality seed, quality fertilizer etc. and to consider inter-sector livelihood to the farmers to benefit them directly. Side by side, small entrepreneurs would be provided with minimum subsidy as well.
- In some cases, subsidy on electricity bill creates negative impact on GW abstraction. It accelerates water pumping because bill to be paid is lower than price of actual consumption.
- Food culture and consumption habits of the community in study area is changing and it is happening due to the health consciousness and the sense of leading a healthy life the people in the study have developed in them. Change of food culture and consumption pattern would play a big role to reduce the pressure on rice.

8.2.2 Enforcement of Laws and Policies

- According to the law, for setting up DTW and STW licenses are to be obtained from UIWRMC or DIWRM subject to the completion of prescribed formalities.
- In order to ensure sustainable use of GW in the *Barind* region, the concerned ministry issued an office order in 2014 to discourage the issuance of new licenses for irrigation pump. But in some cases, STWs are still being approved.
- Existing number of DTWs are not sufficient enough to cover the wide area. For more coverage of agriculture land for irrigation, private owned STWs were encouraged. To ease the survival of farmers and to create employment opportunity for them round the year through agricultural activities the installation of STWs are allowed. On the whole, it is done in the greater sense of ensuring food security.
- BMDA are capable enough to cover the total irrigation area by installing more DTWs though unavailability of fund is a problem in this regard.
- According to Bangladesh Water Rules 2018 and Water Guidelines 2019, UIWRMC consists of 18 members. Upazila committee needs to hold a meeting in every three months as per the concerned statute, but some members were not invited in the meeting. So, there is a lack of integrity and coordination in UIWRMC.
- At the national level, water resources management includes water act, water management policy, and water rules. Organizations that work in *Barind* tract for water management have the same focus, but their functions and approaches are not integrated, in fact they work in isolation to each other.
- According to the Bangladesh Water Rules 2018, all DTWs and STWs established before 2009 have to take NOC within 6 months of the enactment of the rule. But some problems have arisen in the process of issuing NOCs to these DTWs and STWs. DTWs and STWs those were installed before 2009 and those DTWs and STWs which did not take NOCs under BMDA rules, all tube-wells have to be made to take NOCs immediately as per instruction of Water Rules 2018 (formulated under Bangladesh Water Act 2013). At the private level, some STWs

have been installed illegally violating the rules for maintaining command area under each STW's jurisdiction or distance from one STW to another, and thus creating difficulties issuing NOC to the operators because of violating the command area rule and distance rule. But there have been no such directions in any form before the Water Rules of 2018. In this regard, there is a lack of consistency in the Bangladesh Water Act 2013 and Bangladesh Water Rules 2018, and notwithstanding the existence of inconsistency between them the objectives of the water rules can even be properly implemented at grass route level. The political influence is the biggest barrier to implementing the laws.

- The *Barind* region has fewer rivers, less rainfall than the national average, and is a flood-free area. There are no large or medium sized reservoirs. A good number of private and *khas* (public) ponds are existing in the area, but these ponds are not useful for irrigation. Authority leases *khas* ponds for fisheries. Therefore, there is a scarcity for surface water in the dry season and agriculture becomes heavily dependent on GW. The GW table is constantly declining as a result of excessive use of GW during the *boro* season besides other kinds of use.
- Since the amount of natural recharge in the study area is less than required, artificial recharge can play an optimistic role in keeping the GW table at the desired level. Although a couple of recharge wells for artificial recharge were constructed under a pilot project, but no such artificial recharge wells were actually constructed in the study area at the initiative of the authorities.
- A few numbers of dug wells are available here, which is actually lees in number than required, though dug well is not a sustainable idea for irrigation as well as for retention of GW table.
- The local level organizations are poor in terms of governance. Internal consistency of governance is so poor in terms of transparency, accountability, social equity, integrity, efficiency, effective participation and so on. In respect to post operation services, organizational deficiency is so high in these organizations.

- BMDA is inefficient to provide irrigation water in time as they are reluctant to do so. They meddle the distribution serials by force and make many more unjustified delays. If farmers' associations are formed at the field level, they could be able to contribute to maintaining the situation in a better way as because they would do it for the sake of their livelihood.
- BMDA has totally failed to maintain a proper irrigation system. Under the same structure a new body or committee should be formed with ensuring a good governance. Activities like crop diversification, subsidy, training, drip agriculture etc. will be done in a more efficient way than BMDA does. Activities of BMDA should be diminished gradually.
- As surface and GW are interrelated and serve as sources for each other, non-availability of surface water put pressure on GW extraction. Water management organizations in the study area totally failed to manage and develop the sources of surface water, and dependence on GW sources has increased many times. Recently, the optimum extraction level has fallen down to an alarming level, which lopsided the availability GW for irrigation to match with the requirements in the *Barind* tract. Consequently, irrigation cost for extracting GW has increased. The application of Individual sector approaches, without having any coordination among them, towards managing the water resources is the major cause behind the water governance failure. Here, organizations failed to prevent such upsetting situation. If they had been proactive in developing sources of surface water, and searched for dynamic, advanced and effective agriculture techniques along with efficient use of GW, there would not have been any such crisis for GW.

8.2.3 Farmers' Perception towards Sustainable Management

- The study found that the local population in the study area used about 70 percent of the GW, but only 26 percent of the SW came from ponds and canals. They have confirmed that the use of GW is increasing day by day. Causes for GW depletion are excessive extraction especially in *boro* season, inadequate rainfall, insufficient conservation measures, and dams at upstream. Farmers have a little knowledge about keeping water at the optimum level in paddy field. Many of them were used to over irrigating in their farm.

- It has also been noted that UPVC as a supply channel is more effective in preventing water misuse. However, the use of UPVC across the region is not enough compared to demand. They do not have proper knowledge about artificial recharging. (There was 'No' answer to the question of artificial recharge). Existing land is slowly losing its fertility because of cultivating same crop (paddy) over the year. Farmers are more interested in producing paddy than other crops on their land for its economic value, tradition and storage facility. Although oilseeds and pulses are profitable, they are not interested in the same (oilseeds and pulses) for their food security.
- Farmers in the study area feel that they lack the necessary skills and knowledge to produce crops other than *boro*. Through *boro* cultivation they can ensure year-round food security for the family, which is not possible with other crops, although other *rabi* crops are economically profitable. Farmers feel helpless if they cannot ensure food security for their families throughout the year. It can be preserved round the year for future use, but such preservation is not possible in respect of *robi* crops. They also think that this area is popular exclusively for *boro* production. As the main stream crop, farmers are dedicated to cultivating *boro* as they have a mind-set that it is their asset like a liquid bank deposit maintained with a bank all-round the year to meet up food issues and other emergency requirements. They do not want to think about budging off an inch from the traditional stream of cultivation of *boro* to any other crops cultivation, which have been found to more lucrative and nature friendly, requiring less watering, allowing quick harvesting.
- Many farmers are aware of the excessive use of water in *boro* cultivation and are aware of the possibility of severe water crisis in the region in the future, but they are not interested in cultivating any other crops except *boro* cultivation.

- Some farmers have little interest for cultivating other *rabi* crops but cannot do that for various reasons.
- In this situation, depleting the water level caused disaster in agriculture and associated economic activities. If this depletion continues, it will be a threat to economic activity, biodiversity, drinking and household water supply, and to the lives of current people as well as future generations as a whole, respondents reported.
- Usually the farmers pay the electricity bill using the prepaid card which because of which the charges become higher than the amount of actual consumption of electricity. Government subsidize 20% electricity bill from which the farmers are not getting the benefit directly. This benefit ultimately goes to the private pump owner and BMDA as well.

8.3 Constraints to Sustainable Groundwater Management for Irrigation

Unsustainable management of GW resources cannot be continued for long because such practice will threaten the survival and development of human society. For achieving the balancing between economic development and maintaining a healthy water resource system, governments and water managers are currently facing tremendous pressure, risks and conflicts.[1] There is an urgent need to widely recognize that GW is an important source which is limited and in at risk. For present and future generations, it must be used efficiently, fairly and in an ecologically sound manner. In a broader sense, it can be defined, 'sustainable water use' as, "the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it."[2]

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[1] Madan K. Jha, "Sustainable management of groundwater resources in developing countries: Constraints and challenges," in *On a Sustainable Future of the Earth's Natural Resources* (Berlin, Heidelberg: Springer, 2013), 325-348.

[2] P. H. Gleick, "Global water resources in the 21st century: where should we go and how should we get there?," In *Proceedings of the Stockholm Water Symposium (Sweden)* no. 5. 1995.

Bangladesh faces some basic problems such as growth of population, poverty and unemployment. Therefore, effective resource management has become the main goal to prevent the mismanagement of natural resources such as water, land and forests, and other numerous environmental problems. In this section, various constraints or obstacles that hinder the efficient management of important GW resources are presented. The main constraints or obstacles to sustainable GW management can be grouped into two broad categories—technical impediments, and institutional impediments as described below.

8.3.1 Technical Constraints

- **Poor knowledge of the complexity of GW**: Insufficient understanding of the interaction between GW and humans, and an absolute lack of comprehensive multidisciplinary methods for GW development and management; lack of knowledge in geological environment, the type of aquifer, the interdependence of GW and surface water, the impact of human activities on the ecosystem, and the importance of formulating national or local policies for GW, many GW studies are still conducted in an isolated and a temporary manner.
- **Ignorance of proper GW monitoring:** Usually, there is no proper GW monitoring facility, if there is any, does not suffice to fulfil the requirements; this does not mean that the area or technology being investigated is insufficient. In addition, there is a lack of well-trained professionals to be engaged in GW monitoring and investigation. As an outcome, Bangladesh is suffering from sufficient, high-quality GW data in ideal spaces and continuous scales. Even a large areas do not have the supplementary data needed for GW research. There is no doubt that these limitations have severely hindered research and development actions in the GW field. It should be pointed out that if there is not enough high-quality data from field and proper GW infrastructure, no matter how effective policies or plans are, GW resources cannot be managed effectively.
- **Insufficient knowledge of promising and rapidly developing technologies:** Appropriate education and training of potential users remain as the key factors

hindering the widespread use of complex instruments and equipment as well as modern tools and technologies. This obstacle leads to an absolute lack of effective use of these technologies to solve the GW problem.

- **Insufficient management plans.** The installation of dug wells for irrigation water is an example. Dug wells are not enough to provide water, even for crops that consume less water.

8.3.2 Institutional Constraints

- Lack of consciousness of the significance and nature of GW resources; marginal farmers still believe that GW is a free gift and sacred resource of nature. Therefore, stakeholders or users of GW do not realize the importance and necessity of prudent use and protection of GW.
- GW is a dynamic resource and development activities related to it are increasing continuously. It must be evaluated at specified interval to promote better understanding of GW systems including related tools and technologies, and analysis of new or more field data.
- Lack of effective GW management institutions. In fact, there is no special regulatory agency and no strict regulations to control the exploitation and management of GW or protect this important resource. As an outcome, unsustainable GW extraction continues.
- There is a lack of long-term vision besides the absence of operational plans for GW development and management. The ongoing plan is mainly short-sighted and crisis management oriented. Therefore, there is a lack of scientific, rational, well-defined and action-oriented policies for the sustainable use of GW resources.
- Poor coordination exists between national, regional and local governments and different water agencies and related organizations. Issues related to availability of and accessibility to information, and sharing thereof among national, regional and local levels are given less importance. In addition, there has not

been made enough investment or committed fund to understand GW dynamics and effective management to control the dynamism.

- Lack of skilled, loyal and dedicated water officials to manage GW resources. Therefore, improving GW governance; better planning, practice and management are the most important issues.
- Lack of sufficient structure for disseminating the problems, limited accessibility to it, lack of appropriate presentation thereof, nonexistence of a framework coordinating the researchers and policymakers or planners and end users are turning situation from bad to worse one.

8.4 Challenges to Sustainable Groundwater Management for Irrigation

Introducing sustainable GW management has become a major concern in *Barind* tract of Bangladesh. There exist many tools, techniques, and approaches for effective processing. The challenge is to integrate these tools. Techniques, and methods into a cohesive whole for effective implementation through IWRM practices emphasizing good governance in each of the phases.

Considering the educational, technical, and institutional constraints to effective GW management discussed, there are many challenges to achieving sustainable water resources management for GW and surface water. These challenges are mainly related to GW management and can be summarized as follows:

- The leading challenges to GW security are associated with technological deprivation and scarcity of energy.[3] In this connection, how the country can manage the shrinking GW resources in a sustainable manner is the key to these challenges.
- Generating robust dedication to sustainable GW management is essential to ensure good governance, appropriate and sustainable infrastructure, and sustainable sponsoring to improve the management of GW resources.

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[3] Peter Rogers, "Water governance, water security and water sustainability," *Water crisis: myth or reality* (2006): 3-36, and D. Molden, ed., *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture* (London: Earthscan, 2007), 20.

- Strengthening harmonization and alliance between national, regional and local governments and related government organizations who are generally responsible for management of GW.
- There is an excessive necessity to build human resources and infrastructure at the national, regional and local levels to develop comprehensive GW management. In turn, this will augment the importance of imparting education, training, and conducting research and development for the planning and management of GW resources.
- Establishing a strong and articulate coordination arrangement between the researchers, decision makers or planners and the end users represents a kind of challenge. Attempting to instil the practice of knowledge sharing, and to disseminate data management practices between the scientific community and water regulating agencies remain the major challenges for many scientific and government organizations, especially, in developing countries.
- Raising people's awareness towards the importance of water, and promote water conservation, and instilling conservation culture among farmers at different levels.
- Eliminating corruptions and political influence is the biggest challenge. Unless there exists a whistle blowing system to detect the corruptions and instantaneous adoption of measures against it is taken, it is by any measure impossible to accomplish sustainable GW management practices at any scale.
- Challenges should be understood and appropriately addressed by decision makers at the national, regional and local levels to ensure the sustainable management of GW. There is a crucial prerequisite to framing the scientific, reasonable and actionable policies, and creating more commitments and making investments in GW governance institutions. Such policy formulation must be based on reliable information. There is also a need for an urgent initiative to be taken for conducting sincere and dedicated research and development efforts, which can help recover the overwhelming situation.

8.5 Conclusion

This chapter summarized the findings of the research work with regard to enforcement of related laws and policies, status of the sustainable GW management based on farmers' opinion, and both technical and institutional constraints impeding the adoption of sustainable management for GW and the impending challenges the authority will encounter implementing the sustainability concept in managing GW resources for irrigation of the area under study. The next chapter will present an integrated/holistic approach to race towards sustainable GW management for irrigation in *Barind* tract of Bangladesh.

Chapter Nine
Conclusion

This chapter attempts to recapitulate the various chapters of the study report in an abridged form to provide a bird's eye view of the whole study followed by a recommendation emphasizing a holistic approach towards achieving an effective sustainable GW management system for irrigation in *Barind* Tact. In line with this, an attempt has been made in the current chapter by considering the short term and long term strategies along with emphasizing good governance to craft a sustainable GW management system for irrigation in *Barind* tract of Bangladesh through following the holistic approach. Finally, this chapter describes some research areas that deserve to be investigated into further to augment the understanding of the philosophy of sustainability for helping sustain a better environment.

9.1 Conclusion

GW irrigation will have serious consequences as water levels are declining in the intensively irrigated areas of northern region of Bangladesh with rapid deterioration of GW quality. Due to high installation, operational, and management costs, the sustainable Management of GW resources will remain a challenge for Bangladesh. As GW irrigation is crucial to sustaining agrarian growth necessary to meet Bangladesh's future food requirements, it is necessary to take needful measures immediately before it is too late. There are a growing concern for sustainable use of GW for irrigation and it is important to understand and address the issues and challenges associated with sustainable GW use and its proper management in the context of Bangladesh. Related literature and previously done research works were gone through to make a theoretical underpinning, and conceptual framework for the study. Qualitative research methods supplemented by quantitative methods were adopting based on suitability for the conduct of current study. The study covered the *Barind* Tract of Bangladesh as its geographical jurisdiction, and identified the institutions involved in the management of GW irrigation and their origin, nature, and functions.

Again, attempts have been made to present the water resources laws and regulations relating to GW, besides providing a panoptic description of different legislative and law enforcement agencies and their activities, as well as the measures with regard to protection, distribution, use, and management of water resources, especially with a view to enhancing the capacity of GW management. The rules that are to be followed in the installation of irrigation pumps have been clarified with a discussion on the regulations on declaring water shortage areas. The natural settings of GW resources and the various influencing factors thereon have been discussed. An attempt has been made to disclose farmers' and local government institutions' perceptions towards GW irrigation sustainability in *Barind* tract, Bangladesh. Another discussion has been made to highlight the factors influencing the upsurge in the demand for more water and measures for ensuring increased supply of water to meet the gradually increasing demand keeping a bad impact on the sustainable use of GW in irrigation. Various management related issues and present management practices in the short-term and long-term perspectives have been discussed with a focus on the demand and supply-side strategies followed in Bangladesh, more specifically in the *Barind* tract.

A summary of the findings of the research work with regard to enforcement of related laws and policies, the status of the sustainable GW management based on farmers' opinion have been presented. Both the technical and the institutional constraints impeding the adoption of sustainable management for GW have been discussed. The impending challenges the authority will encounter while implementing the sustainability concept in managing GW resources for irrigation of the area under study have also been highlighted.

9.2 Sustainable Groundwater Management for Irrigation in *Barind* Tract: A Holistic Approach to a Way Forward

Food security and sustainable development are the principal global issues in the 21st century. Despite the phenomenal advances made in agricultural technology, various strategies on ground water management for irrigation in Bangladesh clearly show that successful management of GW for irrigation needs an interdisciplinary approach incorporating all stakeholders, technocrats, hydro-geological conditions, local specific environmental issues, indigenous methods of water conservation and usage etc.

A holistic approach includes both short-term and long-term views in achieving sustainability. Realizing the present management practices, researcher provides for an integrated strategic management practice under the nomenclature holistic strategic approach that considers both short-term and long-term perspectives for sustainability.

9.2.1 Short-term Strategies

With regard to the short-term practices in the study area, researcher puts an overall observation to reduce overexploitation of GW resources:

- Authority should encourage cultivation of high value crops rather than *boro* in the study area. According to in-depth interviews of LG authorities and researcher's observation, emphasis should be given on the production of wheat, and oilseeds at Niamatpur, Naogaon and Nachol, Chapai Nawabgonj and potato at Tanore, Rajshahi since return is higher from investment in these crops compared to *boro* cultivation. Moreover, corn is also high value crops rather than *boro* in the study area, but farmers are reluctant to cultivate that reasoning an ineffective marketing system.
- Managed aquifer recharging process should be undertaken as a national program, and strategy considering the differences in regional contexts can be applied by adopting a series of activities like harvesting of surface and

rainwater and their storage and conservation through re-excavation of existing canals, ponds, *kharis*, and water bodies in a massive scale as a geographical topography warrants.

- Local planners should consider recharging areas when planning land use that could cause decline in GW level and deteriorate its quality.
- Strengthen appropriate monitoring process for tracking GW recharge, surface and GW use, and improvement of surface and GW quality.
- Regional cooperation should guarantee a sustained future in terms of water availability since the basin areas of the river systems is dissected by international boundaries.
- Irrigation water price might be determined under a rule on volumetric basis in order to meet equity, efficiency and economic principles. The price of irrigation by private STWs should be revised which is much more than that of DTWs under BMDA. Irrigation rate introduced by BMDA should also be rationalized.
- Optimization of command area for each DTW and STW should be made through consultation with Water Users' Association where electric connection to pumps is the key component for regulation on GW use and that has to be implemented in phases following short-term, medium-term and long-term planning.
- Modern water management technology like AWD, water saving technology like hose pipe irrigation, drip irrigation, climate smart agriculture, climate change adaptive technology such as drought tolerant crop variety, etc. would bear no value without carrying out irrigation volumetrically.
- Awareness, campaign and advocacy on sustainable water management concepts, principles and methods should be in force.
- An estimated water budget should be prepared that includes recharge, extraction and change in the storage of aquifer(s).
- National Sustainable Development Strategies by the government can be an effective effort to achieve sustainability in all developmental activities specially in the management of GW resources of the country under one umbrella.

- Effective coordination and sharing of GW data among local, regional and national levels can help improve data analysis, and ensure proper and timely dissemination of related information to the stakeholders. Data should be made available from the established website to continually update GW basin data.
- Need to establish independent Water Regulatory Authority (WRA)/GW Directorate (GD) or any other existing bodies like BADC, BMDA might be entrusted with establishing governance and management of GW resources to fix and regulate the water tariff system and charges as per Policy Framework.
- Plan of Action in line with basic policies namely Bangladesh Water Act 2013, National Water Policy 1999, Bangladesh Water Rules 2018, etc. might be formulated under proposed GD or WRA or BMDA on short-term, medium-term and long-term basis.
- Community involvement in a proper manner may play a big role; local administration, important personalities, private-owned STW operators, influential marginal farmers, teachers, agriculture officer, experts, social workers, *imam* of mosque to share experiences. The need for training, awareness campaign, education and knowledge about social equity, environment, benefit of the farmers, improvement of their livelihood through agro-related activities, use of advanced technologies, productivity of both crops and agriculture, viability of agriculture in union and upazila are to be taken into account to create a willingness for participation on the part of all stakeholders of GW in order to exert an integrated effort based on proper coordination and to launch an aggregate movement towards accomplishing a sustainable GW irrigation system.
- Water managers and policy-makers need to make accurate estimations of irrigation for its effective monitoring and efficient management. They identified three main strategies by which agricultural water management can deal with these large trade-offs: a) improving water management practices on agricultural lands, b) better linkage with management of downstream aquatic ecosystems, and c) paying more attention to how water can be managed to

create multifunctional agro-ecosystems. They suggested that if ecological landscape processes are better understood the values of ecosystem services other than food production are also well recognized.

- A structured approach, based on zoning of potential areas, is recommended for GW development and its use. Farmers and public officials must determine acceptable levels of the direct and indirect costs involved in sustaining irrigated agriculture.[1] The environmental costs of irrigation and drainage have increased over time, inducing some observers to suggest that irrigation should be discontinued in some areas with an action plan such as GW recharge using various structural approach. On the other hand, Non-structural measures include use of drought tolerant crop variety, crop rotation or cropping pattern change, improvement of technical performances of existing technologies, introduction of appropriate technologies, social interventions such as awareness development, etc.
- The use of GW should be ecology-friendly based on sound policy on recharge of GW through conservation and community participation. A focal-point organization at national level should be identified for planning and execution of concerned activities. It is also imperative to follow best irrigation management practices and climate change adaptation techniques for sustainable use of GW.
- Policy level interventions are necessary to achieve sustainable use of GW for irrigation aiming to achieve food security and ecological balance. Policy formulation on water resources need to be well planned with specific time frame and should be in line with basic policies. Planning, development and management of GW and water resources as a whole should be done in line with the formulated policies and strategies. Identifying a number of key areas is

[1] Dennis Wichelns and J. D. Oster, "Sustainable irrigation is necessary and achievable, but direct costs and environmental impacts can be substantial," *Agricultural water management* 86, no. 1-2 (2006): 114-127.

consistent with attaining sustainable use of GW, which will assist in achieving the sustainable food security of the country as well as protection of ecosystem.

- Management Practices of other countries may be considered that might serve as the guidelines for formulating action plans for the GW management of the country.
- In order to get good results in the agricultural sector wetland management has to be ensured not only in the field of agriculture, but also in the field of housing or road construction. The government of a country has a role to play in wetland management.
- Public-private integrated initiatives for crop diversification need to be taken to ensure sustainable use of GW. In order to motivate the farmers of the *Barind* region to diversify their crops, it has to be ensured that they will be getting more profit from producing other crops than *boro* during the *rabi* season, and this has to be visibly proved with ensuring a fair price for the crops they produce.
- Farmers in the study area still have excessive irrigation tendencies. Reducing the tendency to excess irrigation can reduce the pressure on GW.
- Usage tendency of excess water has a severe negative impact on production and static aquifer level. In this case, the application of AWD may be a good option. Study has shown that applying the AWD technique can reduce irrigation by 20 to 30 percent. But the important issue is that, until farmers are not benefited directly, nothing will work like AWD practices in irrigation or reducing *boro* production. Therefore, farmers should be made familiar with these practices through arranging seminars and workshops on cost-benefit analysis, and profitability associated with such practices.
- BMDA provides irrigation water through UPVC pipes with a length up to 1000 feet each, adding another 1000 feet to it in the command area of each DTWs and STWs will help reduce water wastage a lot.
- Traditionally farmers cultivate paddy in the study area and mono-cropping pattern usually followed by them. For sustainability mixed cropping or crop

rotation may be followed. Cropping pattern needs to be changed as quickly as possible. 'BR 52' paddy can be produced within 90 days, and *Braus* can be a good choice in low land areas immediately after harvesting *robi* crops.

- Government provides Subsidy of 20% on total electricity bill to DTWs or STWs which is deducted from the total charge before the bill is paid. As subsidy on electricity bill is not directly provided to farmers, so benefit goes to BMDA and private operators, not to the marginal farmers. Moreover, food culture of the farmers in the *Barind* Tract emphasizing subsistence would lead to an optimum production, not excess production of paddy. Again, making availability of surface water through development of barrage, excavation of large scale reservoirs, re-excavation of *kharis*, ponds, and so on would reduce irrigation watering cost. All these might help withdrawal of subsidy. Subsidy might be given to the farmers to benefit them directly for introducing new technique or new technology use, quality seed, quality fertilizer etc. and maintaining intra –sector based livelihood. Side by side, small entrepreneurs would be provided with minimum subsidy as well. In fact, subsidy on electricity consumption cannot be stopped all of a sudden because *boro* production occupies more or less 30% of the total paddy production, a major portion.
- Charging prices for GW abstraction on a unit basis can be the most effective method for making the users to be economic in GW use. This will require metering of water use, or a reliable method of estimating abstraction, as well as an effective monitoring of the process. Charging prices for GW abstraction or raising the prices for electricity consumptions in rural areas may have an excessive impact on the food security, and consequently, most of the farmers will lose their courage to cultivate rice, thereby impeding the value addition process. GoB should be strengthening its organizational capacity to provide subsidy directly to farmers according to the land size if it is needed.
- Government must intervene to develop and reserve some ponds exclusively for irrigation purposes.

- Drip irrigation practices might be introduced like china and Rajasthan of India as much water is wasted in irrigation in *Barind* tract. Reservoirs need to be constructed like Kustia district to ease the use of water of the river Padma.
- Law and orders with regard to irrigation practices should be strictly maintained. Most of the employees involved at the operational level of the irrigation system besides local administrative people stay out of their respective work stations in the area under study. Government has to ensure that employees associated with operations are staying in rural areas.

  The management of GW resources obviously will use the latest technology that can be made possible to use but the management process will not only end up monitoring the activities at the implementation level rather they should keep on evaluating the various alternative action plans against each other in order to find out the best possible alternative that will ensure sustainable management of GW water resources.
- To use surface water as the main source of irrigation, various model projects emphasizing innovation in the use of technology, seeds, structural and non-structural approaches with related expertise are to be launched as soon as possible.
- Next generation farmers have to have formal agricultural knowledge, entrepreneurship skills, and specialization to with the complex process of growing agricultural products to marketing thereof. Few knowledge-based agrarian are doing well in Bangladesh. Again, there will be a transformation of agrarian economy into industrial economy with more people adopting other profession than agriculture, wherein they will feel comfortable. They will adapt to the situation automatically but with a decrease in both the GDP and the food security as the side effect in the long run.
- Farmers will automatically use surface water, if it is available and cheaper than GW. So, sufficient numbers of surface water projects are necessary to build fairly quickly. Re-excavation of ponds and canals which exist in the area under

study, huge number of cross dams across canal, and recharge wells are needed immediately to reduce the pressure on GW.

- Pricing of the product and marketing system have to be compatible to ensure more profitability for farmers because of crop diversification and changed cropping pattern.
- As marginal farmers have very little land to cultivate for their livelihood, short term paddy, and different varieties of paddies needing a little amount of water might be introduced based on the results of more researches. Research to find out 'draught-prone spicy paddy' that is much less water consuming paddy is going on. When the research will be successful, this area would be benefited.
- The changes occurred in irrigation practices have given rise to a lack of integration among the following laws such as the Bangladesh Water Act 2013, Bangladesh Water Rules 2018 and Water Guidelines 2019, which need to be amended or revised from time to time as needed.
- GW policies should be integrated with broader national water policy by providing a room for GW management system to address their any specific needs. Policies, being tailored to suit to the local needs and to get rid of the local vulnerabilities, should promote integration across sectors and between surface and GW resource management.

9.2.2 Long-term Strategies

9.2.2.1 Adaptive Management Approach

Due to changes and uncertainties in socioeconomic and natural environment, it is necessary to constantly review and revise management approaches. In fact, consideration of global environmental changes and uncertainty of future warrant a development and adaptation of strategies for natural resource development and management, which stand as the prerequisite for sustainable development. The concept of 'adaptive management' is the only feasible way to deal with the uncertainty of our knowledge and the changes in society's attitudes towards resources over time. Adaptive management can be defined as "A systematic process for continually improving management policies and practices, as appropriate, by learning from the outcomes of implemented management strategies and the improved knowledge."[2] The concept is based on the recognition that our knowledge of natural systems is limited, so our ability to predict key future factors is also inherently limited that affect ecosystems, system behavior and response.[3] Therefore, adaptive management treats management strategies and operations as experiments rather than fixed strategies. This requires that the management plan should be flexible and adaptable; as experience grows, new information or insights and priorities change, it should be continuously improved.

There arises an uncertainty when defining operational goals for different management goals, conflicts of interest between different stakeholders require a participatory goal setting and a clear understanding of the uncertainties involved. Any environmental or socio-economic changes require a system to bring about change in itself. It links science, values, and the experience of stakeholders and managers with their skills to arrive at better management decisions.[4] With regard to water resources system, a method that comprehensively considers and expresses all aspects of system flexibility can be used.[5] Unfortunately, for many reasons, including those listed as technical and institutional impediments, the use of 'adaptive management' methods in practice is extremely limited.

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[2] Daniel P. Loucks and Eelco Van Beek, *Water Resource Systems Planning and Management: An introduction to methods, models, and applications,* (New York, NY: Springer, 2016), 9-19, and Peter Van der Keur et al., "Identification of major sources of uncertainty in current IWRM practice. Illustrated for the Rhine Basin," *Water Resources Management* 22, no. 11 (2008): 1677-1708.

[3] Daniel P. Loucks and Eelco Van Beek, *Water Resource Systems Planning and Management: An introduction to methods, models, and applications,* (New York, NY: Springer, 2016), 9-19, and Claudia Pahl-Wostl, "Transitions towards adaptive management of water facing climate and global change," *Water resources management* 21, no. 1 (2007): 49-62.

[4] Mark Maimone, "Defining and managing sustainable yield," *Groundwater* 42, no. 6 (2004): 809-814.

[5] Chi-hsiang Wang and Jane M. Blackmore, "Resilience concepts for water resource systems," *Journal of Water Resources Planning and Management* 135, no. 6 (2009): 528-536.

9.2.2.2 Integrated Water Resources Management (IWRM) Approach

Due to population growth, economic development, improved sanitation, technological revolution, and continuous changes in legislative and administrative conditions, GW resources management is changing globally. These changes will continue in the future as expected, and their intensity depends on the demographic and economic processes in different regions of the world. As the pressure on GW limits the potential for expanding new water supplies, the imminent threat of climate change has complicated the demand-supply relationship of GW. Climate change has already severely affected the GW cycle, and will continue to do so if it is not held in check and will have adverse impact on human society and ecological systems.[6] Therefore, the best option is to effectively manage it through the most promising approach prescribed by many scholars as 'Integrated Water Resources Management' (IWRM).

IWRM is an important component of water governance, which has emerged twenty years back. IWRM is a process that promotes coordinated and synchronized development of water, land and related resources to achieve maximum social and economic benefits without conceding to importance of maintaining the sustainability of vital ecosystems. It can be viewed as an alternative to top-down, sector-by-sector management, and it serves to endorse many of the governance principles outlined earlier in this section. IWRM attempts to achieve physical (geographical), sectoral, and organizational integration,[7] through institutional arrangements to provide a kind of coordination in arriving at decisions on water allocation and management.[8] The existence of sufficient

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[6] Martin Parry et al., eds, *Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC*, Vol. 4 (Cambridge: Cambridge University Press, 2007).

[7] Sue Kidd and Dave Shaw, "Integrated water resource management and institutional integration: realising the potential of spatial planning in England," *Geographical Journal* 173, no. 4 (2007): 312-329.

[8] Hans Bressers and Stefan Kuks, "Integrated governance and water basin management," In *Integrated Governance and Water Basin Management*, (London: Springer, 2004. 247-265.

human and institutional capacity is key to the implementation of any institutional development.[9] There are four underlying principles of IWRM:

Finite and vulnerable resources: In respect of GW resources, this calls for attentions of the concerned authority to the vulnerability and limits of the resources.[10]

Participatory approach: The involvement of stakeholders in planning and management decisions is an important component of IWRM.[11] Bringing in on the decision making process as many stakeholders as possible can make water management decision-making process fair and more equitable.[12] It will also support adaptation and learning including implementation, and can help make the management system to be better responsive to uncertainties and changes.[13]

Important role of women: The involvement of women in the process has been made from the ethical perspective [14] and calls for an attention to creating gender awareness, and also calls for attention to rural women as water users.[15]

Water as an economic good: This view is in line with the Dublin Principles[16] and representing water as an economic good creates greater attention for achieving

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[9] Frank GW Jaspers, "Institutional arrangements for integrated river basin management," *Water policy* 5, no. 1 (2003): 77-90.

[10] S. S. D. Foster and A. C. Skinner, "Groundwater protection: the science and practice of land surface zoning," *IAHS Publications-Series of Proceedings and Reports-Intern Assoc Hydrological Sciences* 225 (1995): 471-482 and Stephen Foster et al, "Utilization of non-renewable groundwater," *The GW-Mate, The World Bank, Washington, USA* (2005): 1-6.

[11] Global Water Partnership, *Catalyzing change: A handbook for developing integrated water resources management (IWRM) and water efficiency strategies*, (Stockholm: Global Water Partnership Secretariat, 2004).

[12] Global Water Partnership (GWP), "How IWRM will contribute to achieving the MDGs," *Technical Committee Policy Brief No. 4*, Stockholm, Sweden. 2007 and Kevin Watkins, "Human Development Report 2006-Beyond scarcity: Power, poverty and the global water crisis," *UNDP Human Development Reports (2006)*, Basingstoke, UK.

[13] Claudia Pahl-Wostl, "Transitions towards adaptive management of water facing climate and global change," *Water resources management* 21, no. 1 (2007): 49-62 and Carl Folke et al, "Adaptive governance of social-ecological systems," *Annu. Rev. Environ. Resour.* 30 (2005): 441-473.

[14] Alice Aureli and Claudine Brelet, *Women and water: an ethical issue*, UNESCO, Paris, 2004.

[15] K. Asmal, *Water in Civil Society, Arid African Upstream Safari: A Transboundary Expedition to Seek and Share New Sources of Water*, UNESCO, Paris, 2004.

[16] The Dublin Statement on Water and Sustainable Development was agreed at the International Conference on Water and the Environment (ICWE), a preparatory meeting of the UNCED, on 26-31 January 1992, which is known as Dublin Principles. It includes four principles: fresh

economic efficiency in water governance. As for GW, the economic value of water is seen important in making allocation decisions for competing users by different sectors associated with water resources, and thereby guiding the decision-makers in prioritizing the investment opportunities.[17]

IWRM explicitly aims at avoiding the classic fragmented approach to water management and focuses on a holistic and multi-disciplinary approach, thereby addressing the inter-linkages between GW, socio-economic development, environmental issues and their sustainability. It emphasizes participation in the national policy and legislative formulation process, establishing good governance mechanisms, and effective systems and regulatory arrangements to achieve sustainable decision-making.[18] A series of tools such as social and environmental assessment, economic instruments, and information and surveillance systems support this process. It is also advocated as a smart approach to adapt with climate change.[19] Therefore, it can play a key role in respect of GW irrigation, realizing GW security, food security, energy security and environmental security – the main challenges of the 21st century.

Modern approaches such as adaptive management and IWRM have great potential to promote more efficient and sustainable use of GW resources. The design and operation of sustainable water resources systems make them more adaptable, robust and resilient to changing environments and uncertain futures.

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water is a finite and vulnerable resource, essential to sustain life, development, and the environment; water development and management should be based on a participatory approach, involving users, planners, and policy-makers at all levels; women play a central part in the provision, management and safeguarding of water; and water is a public good and has a social and economic value in all its competing uses. [Dublin-Rio Principles, Global Water Partnership, Stockholm, Sweden.]

[17] P. Taylor et al, "Groundwater Management in IWRM: Training Manual," *Cap-Net, Africa Groundwater Network (AGW-Net) and Ground Water Management Advisory Team (GW-MATE). Available online at: www. capnet. org/sites/cap-net.org/files/Cap-Net% 20Groundwater* 20 (2010).

[18] Madan K. Jha, "Sustainable management of groundwater resources in developing countries: Constraints and challenges," in *On a Sustainable Future of the Earth's Natural Resources* (Berlin, Heidelberg: Springer, 2013), 325-348.

[19] C. W Sadoff and M. Muller, "Better water resources management: Greater resilience today, more effective adaptation tomorrow," *GWP TEC Perspectives Paper, Global Water Partnership, Stockholm* (2009).

Like other systems, sustainable systems may fail, but if they fail, they must be able to recover and operate normally without undue cost.[20] Therefore, water experts strongly recommend implementing IWRM within the catchment scale to achieve sustainable GW management.[21] As IWRM is multi-disciplinary/inter-disciplinary in approach, it conducts a comprehensive study in the context of long-term environmental, economic and social impact on SGMI. Since sustainable development brings a better life for contemporary people, and better survival for future generations, it has become the complete guiding principle for sustainability.

IWRM requires changes in water governance, e.g., changes in political, social, economic and administrative systems, which are responsible for the development, control, and SGMI in *Barind* tract of Bangladesh and fits in a new setting to implement IWRM properly. In this respect good governance can be viewed as the prerequisite for an effective management practices that can help implement IWRM successfully, which in turn will help implement SGMI effectively in *Barind* tract of Bangladesh.

9.3 Good Governance to Implement IWRM

The focus of 'GW governance' is on exercising appropriate power and promoting responsible collective actions to ensure a sustainable and effective use of GW resources for the benefit of humans and inter-dependent ecosystems. In governing GW resources as an important public pool resource the Ostrom Principle is applied which suggests some general methods,[22] specifically a well-defined boundaries for resource assessment and allocation purposes, consistency between resource allocation and prevailing local conditions and constraints. The government officially recognizes the right to use the resources of community organizations,

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[20] Daniel P. Loucks and Eelco Van Beek, *Water Resource Systems Planning and Management: An introduction to methods, models, and applications,* (New York, NY: Springer, 2017), 25.

[21] Malin Falkenmark, "Shift in thinking to address the 21st century hunger gap," In *Integrated Assessment of Water Resources and Global Change*, (Dordrecht: Springer, 2006), 3-18 and Madan K. Jha, "Sustainable management of groundwater resources in developing countries: Constraints and challenges," in *On a Sustainable Future of the Earth's Natural Resources* (Berlin, Heidelberg: Springer, 2013), 325-348.

[22] Elinor Ostrom, *Understanding Institutional Diversity*, Princeton Paperbacks (Princeton: Princeton University Press, 2005), 1-351.

collective arrangements for stakeholder participation in decision-making, the presence of stakeholder hierarchy in order to cope with a larger resource system, and to ensure effective monitoring. It is also closely related to environmental governance, other land and water resources. Therefore, societal demand for improved environmental quality, and climate change adaptability can play a positive role in influencing the adoption of GW resource governance.

9.3.1 Dimensions of Water Governance

The influence of various interest groups and the role of power politics in water-related decision-making are important components to be considered when analyzing governance dynamics. These dynamics are complex. It may be helpful to have a discussion on the four basic aspects of water governance.[23] There are four fundamental dimensions of water governance, which are giving rise to its dynamism:

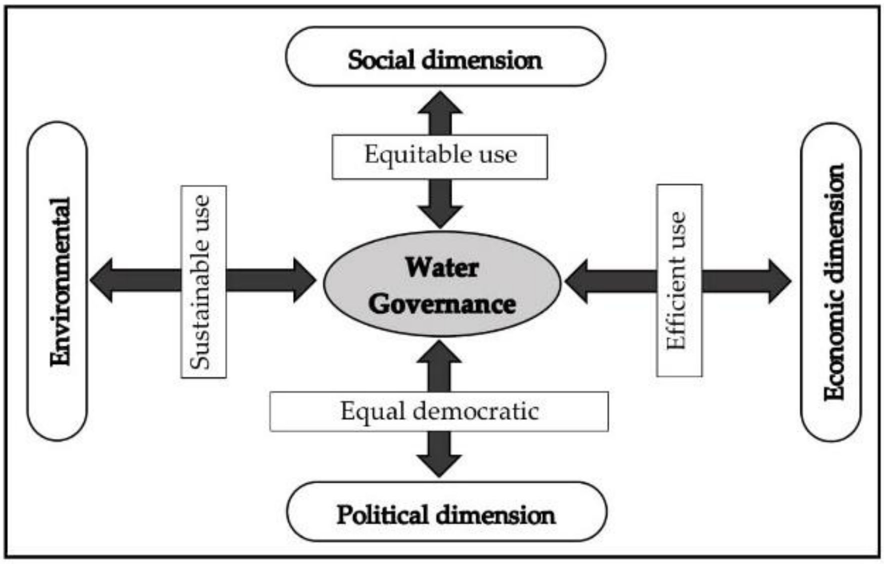

Figure 9.1: Four components of GW governance (Systemized by the researcher).[24]

[23] Maria Jacobson et al., "User's Guide on Assessing Water Governance", UNDP, (Oslo, Norway: Oslo Governance Center, 2013).

[24] Hakan Tropp, 'Water Governance Challenges', in World Water Assessment Programme, The United Nations World Water Development Report 2: Water, a shared responsibility, UNESCO, Paris (2006)

Social dimension: The social dimension focuses on fairness in terms of access to and use of water resources. This includes issues such as the equitable and transparent distribution of water resources and services between various social and economic groups and their impacts on society.

Economic dimension: The economic aspect highlights the efficiency in water distribution and its utilization including the role of water in overall economic growth. Effective poverty reduction and economic growth depend to a large extent on the use of water and other natural resources. Improved water management will help achieve sustainability, and can help increase the benefits for the marginal farmers from investment made in managing the water resources effectively.

Political dimension: The political dimension focuses on maintaining equal rights and opportunities for water stakeholders, who participate in the decision-making process. Participation helps make more informed decisions, execute such decisions effectively and enhance the ability to resolve conflicts.

Environmental dimension: The GW governance is defined as making responsible interactions with the environment to avoid depletion or degradation of GW or other natural resources and achieving long-term environmental quality. The environmental aspect emphasizes the sustainable use of water and related ecosystem services.

9.3.2 Components of Water Governance Assessment Framework[25]

The water governance assessment framework helps determine the important issues and key elements that consider the different backgrounds of water governance, which can be used as a conceptual starting point when selecting or developing an assessment framework.

The framework is built around three main components. These include: 1) Power (analysed from the perspective of stakeholders, institutions, and interests);

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[25] Maria Jacobson et al., *Idiom.*

2) Principles (especially transparency, accountability and participation); and 3) Governance performance (including the efficiency and effectiveness of the government in achieving and delivering its goals).

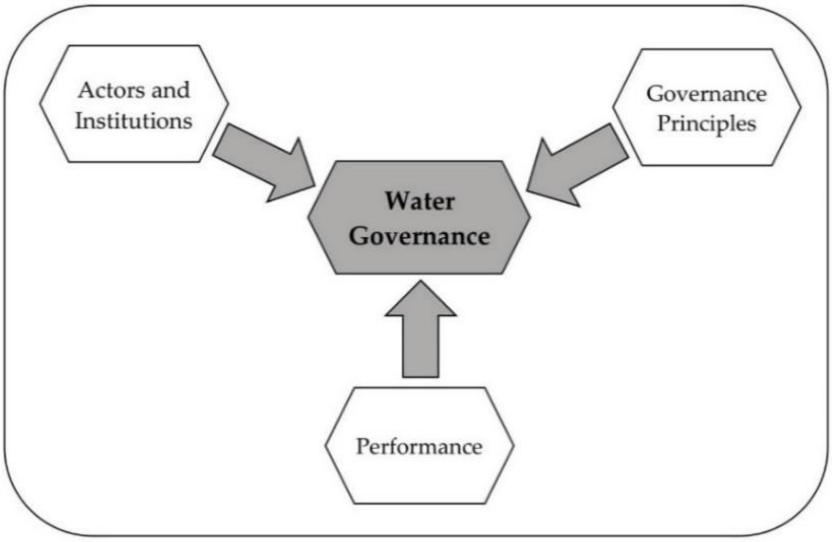

Figure 9.2: Components of water governance assessment framework.

Institutions and stakeholders: This component provides a framework for evaluating and analyzing specific interests, capabilities, and power dynamics that exist among the various water conservancy institutions and stakeholders. Such analysis helps deepen the understanding of how water governance adapts to the broader governance and political and economic environment.

Governance principles: This component focuses on transparency, accountability and participation (TAP), and can be used to analyse the institutional performance and the behaviour and interrelationships among stakeholders.

Performance assessment: Institutional, stakeholder and TAP analyses provide inputs for evaluating the performance and impact of specific water-related functions such as distribution, service provision, planning, and capacity development. This provides a basis for formulating evaluation indicators for the performance and impact of the water sector.

9.3.3 Indicators for Assessing GW Governance

Performance: A performance indicator can be defined as a measure of end-results of a program or activities expressed in percentage, index, ratio, or other forms of comparison. This information is regularly monitored and compared with one or more standards.[26]

Institutions: Institutions, whether it is formal and informal, provides 'rules of the game' that determine how GW is governed. Understanding how institutions operate is very important because they define how the public sector is organized, and how the current policies and laws, and implementation methods are determined.[27]

Transparency: Transparency can be understood as the degree of openness as well as fairness of governance processes including the degree of access to information. It also refers to the extent to which the public, citizens, media, and others can review the public decision-making process and results.[28]

Accountability: Accountability refers to a series of control measures, checks and balances and supervision methods that make officials and institutions in the public and private sectors accountable for their actions, and that ensures that sanctions are taken against poor performance, illegal acts, and abuse of power.[29] In the water sector, a well-functioning accountability mechanism can help clarify the commitments of actors involved in water governance, thereby leading them towards following effective management of financial resources, taking initiatives for protecting water resources and strengthening control over the behavior of public and private stakeholders, and thereby ensuring minimum Quality Standard.

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[26] Office of Public Management, *Health Improvement/ Health Service Planning Kit,* An OPM Report, New South Wales (1990), 54.

[27] Maria Jacobson et al., *Idiom*.

[28] Ibid.

[29] Ibid.

Participation: Participation means that citizens have the possibility to provide informed, timely and meaningful opinions to influence decision-making at all levels. Participating in the decision-making process of the GW sector can be viewed as the prerequisite for the social accountability system.[30] There are different public participation mechanisms, that is, different ways can be found to encourage citizens to express their opinions, and to influence decision-making and procedures in the political, economic and social fields.

Social accountability: Social accountability refers to actions taken by citizens and civil society organizations to hold the country accountable as well as the efforts made by governments and other actors, like media, private sector, donors to support these actions, forming a system.[31]

Environmental integrity: The environmental integrity of water resources is the natural ability of everyone to support the irrigation processes based on the determination of required components and services. The environmental integrity does dictates that it is no longer the responsibility of people using water resources to protect the resources. The responsibility of protecting the nature and resources has to be surrogated by each and every member of a society.[32]

Efficiency: Efficiency describes the amount of inputs like time, energy, or money to produce a given level of outputs. Therefore, more efficiency means minimum inputs required to produce a given level of outputs. Effectiveness is mainly related to the extent to which results are achieved, while efficiency is related to generating results/impact with the least amount of time, expense or unnecessary work.[33]

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[30] Ibid.

[31] Ibid.

[32] H.C. Biggs and K.H. Rogers, *An Adaptive System to Link Science, Monitoring and Management in Practice*, Chapter 9 in "The Kruger Experience: Ecology and Management of Savanna Heterogeneity" edit. JT du Toit, H.C. Biggs and K.H. Rogers, (Washington DC: Island Press, 2003), 189-218.

[33] Maria Jacobson et al., *Idiom*.

Effectiveness: Effectiveness describes the extent to which result is achieved by utilizing minimum resources. Therefore, more efficient an organization is, lower of costs of inputs required to produce a given level of outputs.[34]

9.3.4 Good Governance Structure

A good governance structure is a guide for GW users and management players, hydro-geologists, and policy makers to put in place the tools and to take steps needed for a transition from over-exploitation of GW to a sustainable GW management system for irrigation. It serves as a practical guidance to the roles various actors should play, and how they can work in collaboration with each other for making it an effective process.

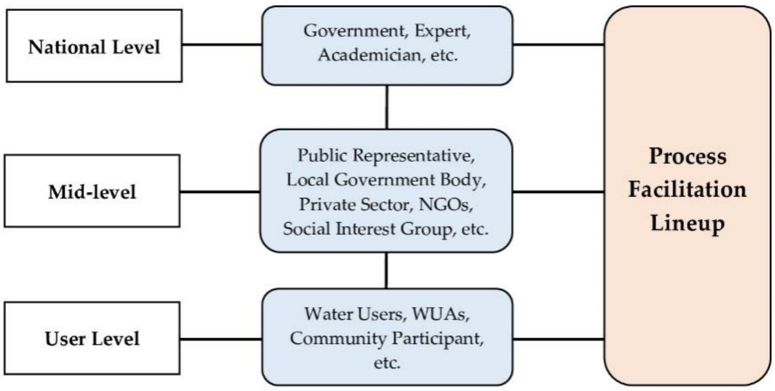

Figure 9.3: Structure of a good governance[35] (modified by the researcher)

Figure indicates the levels of stakeholders in water governance, with the process facilitation lineup enhancing dialogue and concerted action within and between stakeholder levels.

In the NWRC of Bangladesh has representation of many ministries, departments and offices, but the number of independent expert members on this committee is very little. The opportunity to play a direct role by the elected

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[34] Ibid.

[35] Patrick Moriarty, *The EMPOWERS approach to water governance: guidelines, methods and tools*, INWRDAM, 2007.

representatives in the middle level committee (such as at the district level) is limited (according to Bangladesh Water Guideline 2018). The opportunity to perform a direct role by the public representatives in local level committees is also limited. The local level committees do not have water resource users as their members and consequently have less community involvement. But it is important to take necessary steps to increase the role of independent expert members on the national level committee for sustainable use of water resources and good governance. Middle and local level committees need to ensure participation of public representatives as well as users (both male and female), and thereby ensuring community involvement. For good governance, decisions should be made at the lowest possible level,36 stakeholder platforms are best organized at the level where shared interests can be focused and made relevant for the required scale of operations. However, creating the necessary vertical linkages between these more-or-less horizontal platforms is essential to ensure that higher levels are informed of the local concerns and priorities, and have understanding of the scenario at the local level, and thereby enabling all to better relate their priorities to those at other scales.

9.3.5 Engaging Stakeholders

Processes for bringing about change in the current form of GW management towards sustainable GW management are most likely to be initiated by local or national advocates like government or NGO-led projects or sector-specific interest groups or a coalition among these groups. One of the first actions then will be needed is to identify and engage process facilitators. Good process facilitators are service providers; they are usually independent from government and widely viewed as neutral, knowledgeable and committed. They are trusted by most stakeholders. If the process is successful in bringing the GW users on in participatory decision making process, it can be perceived that the process

[36] Patrick Moriarty et al., "5. Learning alliances for local water resource management in Egypt, Jordan and Palestine: Lessons from the EMPOWERS project," *Learning Alliances* (2007): 81.

facilitators selected have the experience of working with local communities, and have the ability to help them (users) participate effectively and equitably in multi-stakeholder processes. The process facilitators usually come from civil society. Examples of process facilitators could be independent advisors with experience of facilitation, NGOs with staff who have built credibility and a trusted mandate for facilitating change, or who have conducted a project specifically designed to develop and facilitate stakeholder planning processes.

Process of Facilitating: Process facilitators need to create a platform for stakeholders to unite them together. A critical activity has to be performed beforehand, which may include mapping of stakeholder interests, differentiating the interests between women and men, and conducting an in-depth stakeholder analysis. This should be done to ensure that all relevant stakeholders are identified, and that necessary outreach to them takes place, that the process is designed to be open to their participation, and that men and women can participate equitably. Process facilitators need to build communication channels with community groups, government agencies, scientists and policy makers. They need to be skilled in moderating forums that bring these groups together in processes in which participants are able to jointly engage in a planning cycle for formulating vision, assessment plan and strategies. Most importantly, process facilitators have the task of ensuring that local ground-water users are comfortable with and are empowered in processes of decision making, and that this is done in a transparent way.

To succeed, process facilitators may have to help stakeholders to resolve conflicts, as well as ensure that there is support available to build capacities and skills of participants needed for a good process, for an improved technical understanding and for implementation of management actions. Process facilitators assist with establishing shared databases and mechanisms for compiling and sharing information. They also support documenting of learning, decisions and plans, and ensure these are shared and communicated among communities, sector groups, technical agencies and government ministries having responsibilities for implementing agreed plans and actions.

It is necessary to raise the voice for the integration among the stakeholders on the issue of participation towards achieving sustainability in GW irrigation. A holistic approach comprising short-term and long-term strategies with good governance all together has been depicted for achieving sustainable management system for GW resources.

9.4 Implications of the Study

9.4.1 Theoretical Implications

- The current study is found to be appreciable as its findings endorse various issues of previous works reviewed for developing a framework of the study and for achieving an encompassing understanding of the problem of the study.
- Its findings, in particular, the key drivers impeding the achievement and sustenance of sustainability in the use of ground water resources, and demand and supply side perceptions and major current management issues including food culture of the farmers in the area under study will add new dimension to the understanding of groundwater management system.
- This study might create an urge for conducting similar study on other parts of Bangladesh by taking the present study as a basis.
- Outcome of the study can contribute to achieving a sustainable management system for GW resources based on the short term and long term strategies that have been outlined in the current study.
- The ways of achieving sustainability in the use of any resources may differ due to differences in the topography and underground formation of the area. Therefore, there does not exist any universal methods for achieving sustainability in the use of resources, that is, the philosophy of sustainable management being remained the same its methods may differ owing to geographical differences.

9.4.2 Sustainable Management Practices

This study established that holistic management approach is obligatory instead of sectorial approach for GW resource management especially in *Barind* tract of Bangladesh. Appropriate enactment of IWRM might serve as a safeguard for the inhabitant of *Barind* area and their economy, society, and environment. With focus on the findings pertaining to existing sustainability status, initiatives can be taken by the government to map the existing faults in a timely manner so that the depleted GW resources of the *Barind* region can be protected in a planned manner for ensuring its use in the long run. By relating the adopted good governance structure with the water users and community participation mechanisms a link between them and implementing agencies can be created, which in turn will help portray the real picture of the situation at the user level and help take initiative to formulate well-conceived policies and successful implement thereof.

9.5 Future Research Opportunity

Based on the current study a good number of ramifications can be identified, which in turn call for further researches to evaluate their impacts. Further researches on the same issues and limitations of the current study highlights the following opportunities for future researches anywhere since paradigms are being changed continually.

- IWRM indicators and components of good governance practices can be evaluated anywhere.
- This field could be carried out in other parts of Bangladesh.
- As the study of farmers this study was cross-sectional in nature, there is an ample opportunity for future studies using longitudinal approaches to come up with more insightful outcomes.
- Cross-cultural research may be done in this field covering   several countries.

9.6 Wake-up Call

It is now high time to wake-up and learn from the past oversights and inaccuracy in managing GW for irrigation in *Barind* tract of Bangladesh. Lip service, ad hoc approaches and short-sightedness to be avoided to ensure efficient GW management in a real sense. In addition, there is a pressing need to come to a sense that GW irrigation problems could be minimized by taking appropriate measures and sometimes by preventive measures, and it is important to note that the cost of prevention is much smaller than that of remedial.

Bangladesh needs to launch a serious debate about whether to pump their aquifers to the maximum or face the consequences thereof, or be more proactive by now to have a better managed abstraction, and to invest in recharge. For effective GW management, policy is required to introduce frameworks and instruments that are suitable to its needs. The frontline challenge is not just confined to supply-side innovations but to put in place a range of corrective mechanisms before the problem becomes either insolvable or not worth solving. The possible solutions presented in this research need enabling policies and, more importantly, their effective implementation to complement existing efforts for achieving SGMI in the area under study, and this should be done before it is too late.

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Appendices

Questionnaire for Farmers (কৃষকদের জন্য প্রশ্নমালা)

Sustainability Management for Groundwater Irrigation in Barind Tract of Bangladesh

[The collected data will only be used in academic research through this questionnaire and the identity of the respondents will also be kept confidential. (এই প্রশ্নমালার মাধ্যমে সংগৃহিত সকল তথ্য শুধুমাত্র একাডেমিক গবেষণা কাজে ব্যবহৃত হবে এবং তথ্য প্রদানকারীর পরিচয় সম্পূর্ণ গোপন রাখা হবে।)]

0. Name of the Family Head (পরিবার প্রধানের নাম):
1. Village (গ্রাম): 1. □ Debipur (দেবীপুর) 2. □ Hacrail (হাকরাইল) 3. □ Dima (ডিমা)
2. Upazila (উপজেলা): 1. □ Tanore (তানোর) 2. □ Nacol (নাচোল) 3. □ Niamatpur (নিয়ামতপুর)
3. Zilla (জেলা): ১. □ Rajshahi (রাজশাহী) ২. □ Chapainawabganj (চাপাই নবাবগঞ্জ) ৩. □ Nawgaon (নওগাঁ)
4. Age (বয়স): Gender (লিঙ্গ): □ Male (পুরুষ) □ Female (মহিলা)
5. Marital Status (বৈবাহিক অবস্থা):

   1. □ Married (বিবাহিত) 2. □ Unmarried (অবিবাহিত) 3. □ Divorced (তালাকপ্রাপ্ত) 4. □ Widow (বিপত্নীক)
6. Education (শিক্ষা):

   1. □ Primary (প্রাথমিক) 2. □ Secondary (মাধ্যমিক) 3. □ HSC (এইচএসসি)
   4. □ Honours (স্নাতক) 5. □ Masters (স্নাতকোত্তর) 6. □ Others (অন্যান্য):
7. Skill (দক্ষতা):

	7.1 Agriculture (কৃষি)	1. □ Yes (হ্যাঁ)	2. □ No (না)
	7.2 Dairy/Poultry (ডেইরি/ পোল্ট্রি)	1. □ Yes (হ্যাঁ)	2. □ No (না)
	7.3 Day Labour (দিন মুজুর)	1. □ Yes (হ্যাঁ)	2. □ No (না)
	7.4 Job (চাকুরি)	1. □ Yes (হ্যাঁ)	2. □ No (না)
	7.5 Business (ব্যবসায়)	1. □ Yes (হ্যাঁ)	2. □ No (না)

8. Total no. of members in family (পরিবারের মোট সদস্য):
9. Ownership of land in decimal (জমির মোট মালিকানা - শতাংশ):

   9.1 Homestead (বসতবাড়ী): 9.2 Agriculture (কৃষি): 9.3 Garden (বাগান):
   9.4 Pond (পুকুর):

10. Amount of Cultivable land (চাষযোগ্য জমির পরিমাণ):

10.1 Amount of *barga* land (বর্গা জমির পরিমাণ):

10.2 Amount of mortgaged land (বন্ধকী জমির পরিমাণ):

11. Mortgaged cost per bigha (বিঘা প্রতি বন্ধকী খরচ):

12. Which source of water is used more in agricultural activities? (কৃষি কাজে কোন উৎসের পানি বেশি ব্যবহার করেন)?

1. □ Groundwater (ভূ-গর্ভস্থ) 2. □ Surface water (ভূ-উপরস্থ)

13. Usage percentage in comparison of groundwater and surface water in irrigation for agriculture? (কৃষি সেচে ভূ-গর্ভস্থ পানির ব্যবহার ও ভূ-উপরস্থ পানির ব্যবহারের হার কত?)

13.1 Groundwater (ভূ-গর্ভস্থ) [%] ১৩.২ Surface water (ভূ-উপরস্থ) [%]

14. Sources of surface water (ভূ-উপরোস্থ পানির উৎসসমূহ):

□ River (নদী) □ Canal (খাল) □ Lake (দিঘী) □ Pond (পুকুর) □ Others (অন্যান্য):

15. What is level of groundwater below the surface level in this village for agricultural uses/activities? (এই গ্রামে কৃষি কাজে ব্যবহারযোগ্য ভূ-গর্ভস্থ পানির স্তর গড়ে কত ফুট নিচে?)

1. □ Less than 40 Feet (৪০ ফুটের কম) 2. □ 40-60 Feet (৪০ - ৬০ ফুট)
3. □ 60-80 Feet (৬০-৮০ ফুট) 4. □ 80-100 Feet (৮০-১০০ ফুট)
5. □ More than 100 Feet (১০০ ফুটের বেশি)

16. What was the level of groundwater below the surface level for agricultural uses before10 years from now? (১০ বছর পূর্বে ভূ-গর্ভস্থ পানির স্তর গড়ে কত ফুট নিচে ছিল?)

1. □ Less than 20 Feet (২০ ফুটের কম) 2. □ 20-40 Feet (২০-৪০ ফুট)
3. □ 40-60 Feet (৪০-৬০ ফুট) 4. □ 60-80 Feet (৬০-৮০ ফুট)
5. □ More than 80 Feet (৮০ ফুটের বেশি)

17. Reasons behind declining level of groundwater, if so (ভূ-গর্ভস্থ পানির স্তর নিচে নেমে যাওয়ার কারন):

17.1 Groundwater level is decreasing due to extreme/spontaneous uses. (অতিরিক্ত ব্যবহারের ফলে ভূ-গর্ভস্থ পানির স্তর নিচে নেমে যাচ্ছে।)

1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

17.2 Groundwater level is going down as a result of insufficient rainfall (অপর্যাপ্ত বৃষ্টিপাতের ফলে ভূ-গর্ভস্থ পানির স্তর নিচে নেমে যাচ্ছে।)

1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

17.3 Groundwater level is going down due to lack of water conservation facilities (পানি সংরক্ষণের ব্যবস্থা না থাকায় ভূ-গর্ভস্থ পানির স্তর নিচে নেমে যাচ্ছে।)

1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

17.4 Groundwater level is going down for not having any upstream barrier (উজানে বাঁধ দেয়ায় নদীর নাব্যতা না থাকার ফলে ভূ-গর্ভস্থ পানির স্তর নিচে নেমে যাচ্ছে।)

1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

17.5 Groundwater level is going down for the absence of artificial recharge facilities (কৃত্রিম রিচার্জের ব্যবস্থা না থাকার ফলে ভূ-গর্ভস্থ পানির স্তর নিচে নেমে যাচ্ছে।)

1. ☐ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. ☐ Disagree (অসম্মত) 3. ☐ Neutral (জানি না)

4. ☐ Agree (সম্মত) 5. ☐ Strongly Agree (সম্পূর্ণ সম্মত)

18. Which method you use in cultivation? (চাষাবাদে কোন পদ্ধতি ব্যবহার করেন?)

1. ☐ Conventional (গতাণুগতিক) 2. ☐ Modern (আধুনিক) 3. ☐ Mixed (মিশ্র)

19. Do you know the rules and regulations of water Irrigation? (আপনি কি কৃষি সেচের নিয়ম-নীতি সম্পর্কে জানেন?) 1. ☐ Yes (হ্যাঁ) 2. ☐ No (না)

20. If the answer is yes, do you irrigate the land following the rules and regulations? (যদি উত্তর হ্যাঁ হয়, আপনি কি এসকল নিয়ম-নীতি মেনে জমি সেচ দেন?) 1. ☐ Yes (হ্যাঁ) 2. ☐ No (না)

21. If the answer is no, do you agree to know the rules and regulations? (যদি উত্তর না হয়, এ সংক্রান্ত নিয়ম-নীতি জানা প্রয়োজন বলে মনে করেন কি?) 1. ☐ Yes (হ্যাঁ) 2. ☐ No (না)

22. Do you know that an irrigation process completes with one or more intervals? (পানি সেচে নির্দিষ্ট পদ্ধতিতে বিরতি দিতে হয়— এ বিষয়টি আপনি জানেন কি?) 1. ☐ Yes (হ্যাঁ) 2. ☐ No (না)

23. If the answer is yes, do you follow the process/method for irrigation? (যদি উত্তর হ্যাঁ হয়, আপনি কি পানি সেচে নির্দিষ্ট পদ্ধতিতে বিরতি দেওয়া অনুসরণ করেন?)

1.☐ Absolutely (পুরোপুরি) 2.☐ Fairly (মোটামুটি)

3.☐ Not very often (খুব একটা না) 4. ☐ Do not follow (অনুসরণ করি না)

24. Do you know the 4 stages of rice cultivation (time of Planting seeds, Up to 7 days from planting, From the 7th day till the emergence of rice husk and From there till the sheaf comes out)? [আপনি কি ধান চাষের ৪টি পর্যায় (চারা রোপণ, রোপন থেকে ৭দিন পর্যন্ত, ৮ম দিন থেকে ধানের শীষ বের হওয়ার পূর্ব পর্যন্ত এবং সেখান থেকে শীষ বের হওয়া পর্যন্ত) সম্পর্কে জানেন?]

1.☐ Know well (ভালোভাবে জানেন) 2.☐ Fairly know (মোটামুটি জানেন)

3.☐ Know a bit (সামান্য জানেন) 4. ☐ Don't know (জানেন না)

25. Do you know the required amount of water to be kept in the land at different times of paddy cultivation? (ধান চাষের বিভিন্ন পর্যায়ে জমিতে যে পরিমাণ পানি রাখতে হয় তা আপনি জানেন কি?)

1.☐ Know well (ভালোভাবে জানেন) 2.☐ Fairly know (মোটামুটি জানেন)

3.☐ Know a bit (সামান্য জানেন) 4. ☐ Don't know (জানেন না)

26. Do you keep the required amount of water in the paddy field? (আপনি কি ধানের জমিতে নির্দেশিত পরিমাণ পানি রাখেন?) 1. ☐ Yes (হ্যাঁ) 2. ☐ No (না)

27. If the answer is yes, what is the degree you follow to keep required amount of water in the land? যদি উত্তর হ্যাঁ হয়, জমিতে নির্দেশিত পরিমাণ পানি রাখার বিষয়টি কতটুকু অনুসরণ করেন?

1.☐ Absolutely (পুরোপুরি) 2.☐ Fairly (মোটামুটি)

3.☐ Not very often (খুব একটা না) 4. ☐ Do not follow (অনুসরণ করি না)

28. Did the agriculture office provide any guideline for water irrigation? (কৃষি অফিস পানি সেচের কোনো নির্দেশিকা দিয়েছে কি?) 1. ☐ Yes (হ্যাঁ) 2. ☐ No (না)

29. If the answer is yes, do you follow it? (যদি উত্তর হ্যাঁ হয়, আপনি তা অনুসরণ করেন কি?) 1. ☐ Yes (হ্যাঁ) 2. ☐ No (না)

30. Water irrigation system you use (পানি সেচ পদ্ধতি):

1.☐ Conventional (গতানুগতিক) 2.☐ Modern (আধুনিক) 3.☐ Mixed (মিশ্র)

31. The Conventional method (গতানুগতিক পদ্ধতি):
1.□ Doon (দোন) 2.□ Shovel (বেলচা) 3.□ Seuti (সেউতি)

32. The Modern method (আধুনিক পদ্ধতি):
1.□ DTW (গভীর নলকূপ) 2.□ STW (অগভীর নলকূপ) 3.□ LLP (অল্প উচ্চতায় উত্তোলন পাম্প)

33. Which method is more efficient and effective (কোন পদ্ধতি অধিক কার্যকরী?)
1.□ DTW (গভীর নলকূপ) 2.□ STW (অগভীর নলকূপ) 3.□ LLP (অল্প উচ্চতায় উত্তোলন পাম্প)
4.□ Doon (দোন) 5.□ Shovel (বেলচা) 6.□ Seuti (সেউতি)

34. Which method is more affordable (কোন পদ্ধতি অধিক সাশ্রয়ী?)
1.□ DTW (গভীর নলকূপ) 2.□ STW (অগভীর নলকূপ) 3.□ LLP (অল্প উচ্চতায় উত্তোলন পাম্প)
4.□ Doon (দোন) 5.□ Shovel (বেলচা) 6.□ Seuti (সেউতি)

35. What is the water usage rate per bigha (Boro Season) at different stages of crop production? নিম্নোক্ত ফসল (বোরো মৌসুমে) উৎপাদনের বিভিন্ন পর্যায়ে বিঘাপ্রতি পানি ব্যবহারের হার কেমন?

No. (ক্রম)	Crops (ফসল)	Number of irrigations (সেচের সংখ্যা)	No. (ক্রম)	Crops (ফসল)	Number of Irrigations (সেচের সংখ্যা)
35.1	Paddy (ধান)		35.5	Vegetables (সবজী)	
35.2	Wheat (গম)		35.6	Potato (আলু)	
35.3	Corn (ভুট্টা)		35.7	Oilseeds (তৈলবীজ)	
35.4	Pulses (ডাল)				

36. Interval of irrigation you practice in paddy cultivation (ধান চাষে পানি সেচের বিরতি):
1.□ 2-4 Days (২-৪ দিন) 2.□ 4-6 Days (৪-৬ দিন) 3.□ 6-8 Days (৬-৮ দিন)
4.□ 8-10 Days (৮-১০ দিন) 5.□ 10-12 Days (১০-১২ দিন)

37. Water level in the land at different stages of paddy cultivation (inches) you practice [ধান চাষের বিভিন্ন পর্যায়ে জমিতে পানির উচ্চতা]:
37.1. Time of planting (চারা রোাপনের সময়)
37.2. 7 days after planting (চারা রোপনের পরবর্তী ৭ দিন)
37.3. From the 7th day tilt the flowering (৮ম দিন থেকে শীষ বের হওয়ার পূর্ব পর্যন্ত)
37.4. At the stage of flowering (ধানের শীষ বের হওয়ার সময়)
37.5. After flowering to maturity (শীষ বের হওয়ার পর থেকে পাকা পর্যন্ত)

38. As a result of paddy production in the same land every year, the fertility of the land is having a negative impact. (প্রতিবছর একই জমিতে ধান উৎপাদনের ফলে জমির উর্বরতায় নেতিবাচক প্রভাব ফেলছে):
1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

39. What method of drainage/supply system is used to irrigate your land? (One or more methods) [আপনার জমিতে সেচ দেয়ার জন্য কোন পদ্ধতির ড্রেন/ সরবরাহ ব্যবস্থা ব্যবহার করা হয়? (এক বা একাধিক পদ্ধতি)]
39.1□ PVC Pipe (পিভিসি পাইপ) 39.2 □ Concrete drain (পাকা ড্রেন)
39.3 □ Soil drain (মাটির ড্রেন) 39.4 □ Hosepipe (ফিতা পাইপ)

40. Do you think water is being wasted due to irrigation channel? (পানি সেচ পদ্ধতির কারনে পানির অপচয় হচ্ছে কি?) 1. □ Yes (হ্যাঁ) 2. □ No (না)

If answer is yes (উত্তর হ্যাঁ হলে):
40.1 Percentage of wastage if PVC pipe is used (পিভিসি পাইপ ব্যবহার হলে অপচয়ের হার):
1. □ 0-5% 2. □ 5-10% 3. □ 10-15% 4. □ 15-20% 5. □ 20% and More (২০% ও বেশি)

40.2 Percentage of wastage if concrete drain is used (পাকা ড্রেন ব্যবহার হলে অপচয়ের হার):
1. □ 0-5% 2. □ 5-10% 3. □ 10-15% 4. □ 15-20% 5. □ 20% and More (২০% ও বেশি)

40.3 Percentage of wastage if soil drain is used (মাটির ড্রেন ব্যবহার হলে অপচয়ের হার):
1. □ 0-5% 2. □ 5-10% 3. □ 10-15% 4. □ 15-20% 5. □ 20% and More (২০% ও বেশি)

40.4 Percentage of wastage if hosepipe is used (ফিতা পাইপ ব্যবহার হলে অপচয়ের হার):
1. □ 0-5% 2. □ 5-10% 3. □ 10-15% 4. □ 15-20% 5. □ 20% and More (২০% ও বেশি)

41. Most effective drainage/supply system for irrigating the land to you (জমিতে সেচ দেয়ার জন্য কার্যকর ড্রেন/ সরবরাহ ব্যবস্থা):

41.1 Water supply through PVC pipes is very effective for irrigating the land (জমিতে সেচ দেওয়ার জন্য পিভিসি পাইপের মাধ্যমে পানি সরবরাহ পদ্ধতি অধিক কার্যকর।)
1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

41.2 Water supply through concrete drain is very effective for irrigating the land (জমিতে সেচ দেওয়ার জন্য পাকা ড্রেনের মাধ্যমে পানি সরবরাহ পদ্ধতি অধিক কার্যকর।)
1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

41.3 Water supply through soil drain is very effective for irrigating the land (জমিতে সেচ দেওয়ার জন্য কাঁচা ড্রেনের মাধ্যমে পানি সরবরাহ পদ্ধতি অধিক কার্যকর।)
1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

41.4 Water supply through hosepipe is very effective for irrigating the land (জমিতে সেচ দেওয়ার জন্য ফিতা পাইপের মাধ্যমে পানি সরবরাহ পদ্ধতি অধিক কার্যকর।)
1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

42. What are the reasons for the wastage of irrigation water? (কোন কোন কারনে পানির অপচয় হয়?)

42.1 Inefficiency results in wastage of water (অসতর্কতার ফলে পানির অপচয় হয়।)
1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

42.2 Wastage of irrigation water due to excessive use (অতিরিক্ত পানি ব্যবহারের ফলে পানির অপচয় হয়।)
1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

42.3 Waste of irrigation water due to lack of knowledge on the amount of use (সেচের পরিমাণ না জানার ফলে পানির অপচয় হয়।)
1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

42.4 Your opinion about the irrigation water wastage due to faulty supply system (ত্রুটিপূর্ণ সরবরাহ ব্যবস্থার ফলে পানির অপচয় হয়।)
1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

43. Do you know about AWD method in irrigation? (পানি সেচে AWD পদ্ধতি সম্পর্কে আপনি জানেন কি না?) 1. □ Yes (হ্যাঁ) 2. □ No (না)

43.1 If yes, do you use AWD method in irrigation? (উত্তর হ্যাঁ হলে, পানি সেচে AWD পদ্ধতি আপনি প্রয়োগ করেন কি না?) 1. □ Yes (হ্যাঁ) 2. □ No (না)

43.2 If yes, whether this method reduces water wastage? (উত্তর হ্যাঁ হলে, এ পদ্ধতির কারনে পানির অপচয় হ্রাস পায় কিনা?) 1. □ Yes (হ্যাঁ) 2. □ No (না)

43.3 Whether the use of this method affects rice production? (এই পদ্ধতি ব্যবহারের ফলে ধানের উৎপাদনে প্রভাব পড়ে কি না?)

1. □ Increases Production (উৎপাদন বৃদ্ধি পায়) 2. □ Decreases Production (উৎপাদন হ্রাস পায়)
3. □ Not affect (প্রভাব পড়ে না)

44. What kind of effect does excess water have on production due to irrigation? (অতিরিক্ত পানি সেচের কারনে উৎপাদনে কি ধরণের প্রভাব পড়ে?)

1. □ Increases Production (উৎপাদন বৃদ্ধি পায়) 2. □ Decreases Production (উৎপাদন হ্রাস পায়)
3. □ Not affect (প্রভাব পড়ে না)

45. Whether crops produce as an alternative to paddy in the boro season? (বোরো মৌসুমে ধানের বিকল্প হিসেবে অন্য কোনো ফসল উৎপাদন করেন কি না?)

45.1 □ Wheat (গম) 45.2 □ Corn (ভুট্টা) 45.3 □ Oilseeds (তৈলবীজ)
45.4 □ Pulses (ডাল) 45.5 □ Vegetables (সবজী) 45.6 □ Potatos (আলু)

46. Which alternative crop(s) of paddy is more profitable in Boro season? (বোরো মৌসুমে ধানের বিকল্প কোন ফসল অধিক লাভজনক?)

45.1 □ Wheat (গম) 45.2 □ Corn (ভুট্টা) 45.3 □ Oilseeds (তৈলবীজ) 45.4 □ Pulses (ডাল)
45.5 □ Vegetables (সবজী) 45.6 □ Potatos (আলু) 45.7 □ Others (অন্যান্য):

47. Which sources play the role to increase/reserve the groundwater level? ভূ-গর্ভস্থ পানি বৃদ্ধি/ সঞ্চয়ে কোন কোন উৎস ভূমিকা পালন করে?

45.1 □ Rain (বৃষ্টি) 45.2 □ River (নদী) 45.3 □ Pond (পুকুর)
45.4 □ Beel (বিল) 45.5 □ Well (কুয়া) 45.6 □ Others (অন্যান্য):

48. Do you know, there is any artificial method of recharging groundwater? (আপনার জানামতে ভূ-গর্ভস্থ পানি রিচার্জের বা পূরণের কোনো কৃত্রিম পদ্ধতি আছে কি না?) 1. □ Yes (হ্যাঁ) 2. □ No (না)

49. As the groundwater level continues to fall due to the constant use of groundwater in irrigation, agricultural activities will suffer in this region in future. (কৃষিতে ভূ-গর্ভস্থ পানি ক্রমাগত ব্যবহারের ফলে পানির স্তর নিচে নেমে যাচ্ছে, ফলে ভবিষ্যতে এ অঞ্চলে কৃষি ঝুঁকির মুখে পড়বে।)

1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

50. As the groundwater level continues to fall due to the constant use of groundwater in irrigation, economic activities associated with agriculture will suffer. (কৃষিতে ভূ-গর্ভস্থ পানি ক্রমাগত ব্যবহারের ফলে পানির স্তর নিচে নেমে যাচ্ছে, ফলে কৃষির সাথে সংযুক্ত অর্থনৈতিক কর্মকাণ্ডের ঝুঁকি বাড়বে।)

1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

51. As the groundwater level continues to fall due to the constant use of groundwater in irrigation, the risk of biodiversity will increase. (কৃষিতে ভূ-গর্ভস্থ পানি ক্রমাগত ব্যবহারের ফলে পানির স্তর নিচে নেমে যাচ্ছে, ফলে জীববৈচিত্রের ঝুঁকি বাড়ছে।)

1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

52. As the groundwater level continues to fall due to the constant use of groundwater in irrigation, water crisis may occur in future. (কৃষিতে ভূ-গর্ভস্থ পানি ক্রমাগত ব্যবহারের ফলে পানির স্তর নিচে নেমে যাচ্ছে, ফলে ভবিষ্যতে খাবার পানির সংকট দেখা দিতে পারে।)

1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

53. As the groundwater level continues to fall due to the constant use of groundwater in irrigation, there may be water crisis for household activities in the future. (কৃষিতে ভূ-গর্ভস্থ পানি ক্রমাগত ব্যবহারের ফলে পানির স্তর নিচে নেমে যাচ্ছে, ফলে ভবিষ্যতে গৃহস্থলি কাজে পানির সংকট দেখা দিতে পারে।)
1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

54. As the groundwater level continues to fall due to the constant use of groundwater in irrigation, this area may not be livable due to water crisis. (কৃষিতে ভূ-গর্ভস্থ পানি ক্রমাগত ব্যবহারের ফলে পানির স্তর নিচে নেমে যাচ্ছে, ফলে ভবিষ্যতে পানির অভাবে এই এলাকা বসবাসযোগ্য নাও থাকতে পারে।)
1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

55. As the groundwater level continues to fall due to the constant use of groundwater in irrigation, the next generation will suffer a lot. (কৃষিতে ভূ-গর্ভস্থ পানি ক্রমাগত ব্যবহারের ফলে পানির স্তর নিচে নেমে যাচ্ছে, ফলে পরবর্তী প্রজন্ম ঝুঁকির মুখে পড়বে।)
1. □ Strongly Disagree (সম্পূর্ণ অসম্মত) 2. □ Disagree (অসম্মত) 3. □ Neutral (জানি না)
4. □ Agree (সম্মত) 5. □ Strongly Agree (সম্পূর্ণ সম্মত)

56. What is the payment system of using irrigation water? (কৃষি কাজে পানি সেচের মূল্য কীভাবে পরিশোধ করা হয়?)
1. □ Prepaid Card (প্রিপেইড কার্ডের মাধ্যমে)
2. □ Based on Cooperative (সমবায়ের ভিত্তিতে)
3. □ Based on the contract with the owner of the pump (পাম্পের মালিকের সাথে চুক্তির ভিত্তিতে)

57. What is the per hour pricing rate for watering through prepaid card in general? (প্রেপেইড কার্ডের মাধ্যমে সাধারণত প্রতি ঘণ্টায় কতটাকা মূল্য পরিশোধ করতে হয়?)

58.1 Is there any additional amount to be paid to the pump operator? (প্রিপেইড কার্ডের মাধ্যমে মূল্য পরিশোধের ক্ষেত্রে, পাম্প অপারেটরের জন্য আলাদা কোন অর্থ ব্যয় করতে হয় কি না?) 1. □ Yes (হ্যাঁ) 2. □ No (না)

58.2 If yes, how much to pay as additional to the pump operator? (উত্তর যদি হ্যাঁ হয়, প্রিপেইড কার্ডের মাধ্যমে মূল্য পরিশোধের ক্ষেত্রে, পাম্প অপারেটরের জন্য কত টাকা ব্যয় করতে হয়?)

59. In case of payment through prepaid card, is there any cost to bear for pump maintenance? (প্রিপেইড কার্ডের মাধ্যমে মূল্য পরিশোধের ক্ষেত্রে রক্ষণাবেক্ষণের জন্য আলাদা কোন অর্থ ব্যয় করতে হয় কি না?) 1. □ Yes (হ্যাঁ) 2. □ No (না)

60. What is the rate of payment per bigha for irrigation on the basis of contract with the pump owner? (পাম্পের মালিকের সাথে চুক্তির ভিত্তিতে সেচ প্রদান করলে বিঘা প্রতি মূল্য পরিশোধের হার কত?)

61. On the basis of contract with the owner of the pump, is there any additional charge to be paid for supply system or drainage for irrigation water? (পাম্পের মালিকের সাথে চুক্তির ভিত্তিতে সেচ প্রদান করলে সরবরাহ ব্যবস্থা বা ড্রেনের জন্য আলাদা কোনো অর্থ প্রদান করতে হয় কি না?) 1. □ Yes (হ্যাঁ) 2. □ No (না)

62. Are you benefited from the amount of government subsidy provided in electricity bill for irrigation? (কৃষি সেচে বিদ্যুৎ বিলের ক্ষেত্রে সরকারি যে ভর্তুকি প্রদান করা হয় তা থেকে আপনি উপকৃত হন কি না?) 1. □ Yes (হ্যাঁ) 2. □ No (না)

Check list (Key Informant)

Upazila: ______________ District: ____________________ Date: ________________

Name:________________________________ Position: _________________________

Experience of working: ____

1. Introduction of your organization/ institution
2. Goals, objectives, vision, and mission of your organization/ institution
3. Functions of your organization/ institution
4. Inter-dependency between GW and surface water
5. Development of surface water
6. Trend of rainfall
7. Trend of GW aquifer
8. Trend of STWs and DTWs
9. Optimum use of irrigation water
10. Trend of wetland
11. Trend of *boro* cultivation
12. Water use for *boro* cultivation
13. Irrigation cost for *boro* cultivation
14. Most profitable crop in *rabi* season
15. Cropping zone and crop diversification
16. Cropping pattern
17. Incentives and subsidies
18. Awareness of farmers
19. Enforcement of laws and policies
20. Farmers' mindset to *boro* cultivation
21. Retention of GW Table
22. Change of food culture and consumption
23. Governance status
24. Overall sustainability of economy
25. Overall sustainability of society
26. Overall sustainability of environment

Check list (In-depth Interview)

Date: ________________

Name: __________________________________ Position: _______________________

Experience of working: ____

1. Introduction
2. Inter-dependency between GW and surface water
3. Development of surface water
4. Trend of rainfall
5. Trend of GW aquifer
6. Trend of STWs and DTWs
7. Optimum use of irrigation water
8. Trend of wetland
9. Trend of *boro* cultivation
10. Water use for *boro* cultivation
11. Irrigation cost for *boro* cultivation
12. Most profitable crop in *rabi* season
13. Cropping zone and crop diversification
14. Cropping pattern
15. Incentives and subsidies
16. Awareness of farmers
17. Enforcement of laws and policies
18. Farmers' mindset to *boro* cultivation
19. Retention of GW Table
20. Change of food culture and consumption
21. Governance status and approach for sustainable groundwater management
22. Impact of existing irrigation practice on economy
23. Impact of existing irrigation practice on society
24. Impact of existing irrigation practice on environment

FGD Form

Upazila: ________________ District: ____________________ Date: _______________

Sl No	Name	Age	Occupation	Education	Income	Family member	Comment
1.							
2.							
…							