ASSESSMENT OF AGRICULTURAL WATER SECURITY FOR DIFFERENT AGRO-ECOSYSTEMS USING ANALYTIC HIERARCHY PROCESS

by

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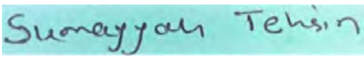

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Dedicated to

My Beloved Father *Mr. Mohiuddin Ahmed*

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ABSTRACT

Water security is the ability to access sufficient quantities and qualities of water to maintain adequate standards of food and goods production, proper sanitation and sustainable health care. Water logging, salinity, etc. are among the major factors that hamper agricultural production and hence influence water security in the south-west coastal region of Bangladesh. Sea level rise, occurrence of natural disasters, changes in climatic patterns and man-made alteration of natural settings are further deteriorating the water security situation. This study assessed agricultural water security for three selected agro-ecosystems of Tala Upazila of Satkhira district and suggested suitable strategies to improve the security. The study followed an interdisciplinary approach to produce an integrated assessment of water security, linking physical dimensions of water availability with socioeconomic variables that reflect water security. Five components of water security like water availability, access to water, water use, capacity to use water and disaster management were considered to develop the water security index. Within each major component, there were a number of sub-components. Water security indices were developed using Analytical Hierarchical Approach. Required data and information like source of water for irrigation, adequacy of water, quality of water and existing hazards for agricultural production were collected from the local people using focus group discussion and questionnaire survey, and from the local key informants using semi-structured interview. The agricultural water security index was found to be 2.3 on a scale of 5 at Khanpur, and 2.0 at Kheshra. According to the values, both the agro-ecosystems were water insecured for agricultural production, mainly due to water logging and salinity problems. At Bhorot Bhaena, the index was found to be 4.2 which indicated that the area was water secured for agricultural production. The high value at Bhorot Bhaena was due to the implementation of tidal river management (TRM). Suitable strategies for improving agricultural production at Khanpur were found to be TRM, mixed cropping system and flood-tolerant rice varieties. For Kheshra, the suitable strategies to improve agricultural water security were found to be saline-resistant crop cultivation, rice-prawn farming and rainwater harvesting. Agricultural productivity at Bhorot Bhaena can be further improved using strategies like rainwater harvesting and rice-prawn farming.

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ABBREVIATIONS AND ACRONYMS

BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
TRM	Tidal River Management
GBM	Ganges-Brahmaputra-Meghna
IWM	Institute of Water Modeling
IWFM	Institute of Water and Flood Management
WARPO	Water Resources Planning Organization
WSI	Water Security Index
ADB	Asian Development Bank
BBS	Bangladesh Bureau of Statistics
DPHE	Department of Public Health Engineering
ECR	Environmental Conservation Rules
EGIS	Environment and Geographic Information Services
GOB	Government of Bangladesh
SRDI	Soil Resource Development Institute
SMEC	Snowy Mountain Engineering Corporation
UNDP	United Nations Development Program
WHO	World Health Organization
LLP	Low Lift Pump
KII	Key Informant Interview
O & M	Operation and Maintenance
RI	Random Index
CR	Consistency Ratio
FGD	Focus Group Discussion

CHAPTER ONE
INTRODUCTION

1.1 Background and Present State of the Problem

Water security is the reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks (David and Claudia, 2007). The concept of water security has received increased attention over the past decade, in both policy and academic debates. Water is identified as one of the most important natural resources because it is viewed as a key to prosperity and wealth (Arbués et al, 2003). However, water tables are falling and aquifer depletion is becoming an emerging problem (Brown, 2001). It is documented that less than 10 countries have about 60% of globally accessible water (Swaminathan, 2001), suggesting inequitable distribution of water globally and nationally. Lately, global climate change and its impact on rainfall availability and variability in time and space is becoming a concern. Natural factors, as well as human actions, are directly responsible for water security problems. Human activities may alter the hydrological cycle in uncertain ways resulting in greenhouse induced climate changes. Population growth directly or indirectly is expected to shift about 55% of the World's population towards water stress or severe water insecurity over the next generation (Rockström, 2001). Genuine concerns are therefore raised about future water security because of the important role water plays in sustainable development and quality of life. The international conference on freshwater held in Bonn, Germany in 2001 and the third world water forum held in Kyoto, Japan in 2003 are examples attesting to these concerns. Water insecurity situation is severe in developing countries, with an estimate of about 1.2 billion people in 20 'water-scarce' developing countries without access to 'safe water' (WHO, 1998).

Water serves a range of productive, environmental and social purposes in the agricultural sector and wider economy. Governments, water managers and consumers/users have a role to ensure that mechanisms and actions are in place to make certain that water is allocated and used to achieve socially and economically beneficial and efficient outcomes in a manner that is environmentally effective and sustainable. But the management of water resources in agriculture is being severely tested with rising food and energy prices, growing competition for water resources between different users, an expanding global population, and concerns related to climate change. Agriculture is one of the most dominant sectors of water use. Agriculture is a primary target for policies of sustainable management of water as it uses about 70% of the world's freshwater withdrawals (OECD, 2010). The anticipated growth in the world population from 7 billion currently to 9 billion by 2050 will involve a major expansion in demand for water. Agriculture contributed 19.41% (including fishery) of the total GDP of Bangladesh in fiscal year 2011-12 and a major portion of the country's labor force, about 47.5%, engaged in agriculture (Economic Review, 2013). Global population and income growth results in higher demand for more and better food. To meet this demand, agriculture will have to expand irrigation water use. Yet, competition for water resources is expected to intensify and climate change will further stress water availability. Within these constraints, the optimal solution is to improve the productivity of water in agriculture - higher agricultural production with the same amount of water or the same production with less water.

Agriculture benefits livelihood of the rural poor people who account for majority of the population. The term economic development is therefore directly related to agriculture as this sector is the prime contributor of income and employment generation in the country. But agriculture is the most vulnerable sector to climate change as it is very susceptible to change in climatic phenomena and its effects. Geographic location, low topography (dominance of flood plains and low elevation from the sea), demographic (high population density and growth rate) and poor socio-economic (high poverty level, climate dependent traditional rural agrarian economy, institutional weakness, etc.) features make Bangladesh one of the most vulnerable countries in the world to climate change (UNDP, 2007). Particularly, the coastal area (southern and south-eastern parts) of Bangladesh is more vulnerable to climate change as it locates at the tip of an inverted funnel shaped Bay of Bengal (Sharma, 1965). According to population census of 2011, 38 million people lived in coastal areas which were about 26.7 percent of the total population (BBS, 2011). Agriculture in the coastal areas of Bangladesh is more vulnerable to climate change than other parts of the country due to its geographical location. Agricultural sector is vulnerable to different kinds of climate variability and there is regional differentiation of these vulnerabilities (Dasgupta, 2010). Agriculture in the coastal area of Bangladesh is severely vulnerable to natural hazards and it is expected that climate change will decline coastal agricultural system through intensifying and frequenting the natural hazards (Hossain, 2013). Especially, the natural setting of coastal regions of

Bangladesh makes it different from the rest of the country. It is the region being located in the interface of land and sea.

This research has tried to analyze coastal agricultural water security and different vulnerabilities associated with coastal agriculture in Bangladesh. In particular, this study has been conducted in selected areas of Tala upazilla of Satkhira district of Bangladesh to investigate agricultural water security of the areas. Though agricultural land of the study areas is silted and fertile, which is good for agricultural production, but water logging and salinity are the major problems to make the areas agriculturally water secured (Field observation, 2015). The study has developed an agricultural water security index for the region. Important parameters for developing agricultural water security index like water availability, access, water use and capacity have been considered.

Decision making, for which we gather most of our information, has become a mathematical science today (Figuera et al, 2005). It formalizes the thinking we use so that, what we have to do to make better decisions is transparent in all its aspects. We need to have some fundamental understanding of this most valuable process that nature endowed us with, to make it possible for us to make choices that help us survive. Decision making involves many criteria and sub criteria used to rank the alternatives of a decision. Not only one need to create priorities for the alternatives with respect to the criteria or sub criteria in terms of which they need to be evaluated, but also for the criteria in terms of a higher goal, or if they depend on the alternatives, then in terms of the alternatives themselves. The criteria may be intangible and have no measurements to serve as a guide to rank the alternatives and creating priorities for the criteria themselves in order to weigh the priorities of the alternatives and add over all the criteria to obtain the desired overall ranks of the alternatives is a challenging task. The analytical hierarchical process is the method of decision making under which we gather information and rank suitable alternatives for decision making (Figuera et al, 2005). It formalizes the thinking we use so that, what we have to do to make better decisions is transparent in all its aspects. In the present study, agricultural water security index and suitable strategies to improve agricultural water security have been developed using Analytical Hierarchical Process (AHP).

1.2 Objectives of the Study

The overall aim of the study is to analyze agricultural water security at selected areas of Tala upazila of Satkhira district. Two specific objectives of the study are:

i) To develop and compare agricultural water security indices for selected areas of Tala upazila; and

ii) To identify suitable strategies to improve water security for agriculture of the study areas using AHP.

1.3 Central Question of the Research

The study was carried out with the following central research question in view: How can the agricultural water security at different agro-ecosystems be understood using Analytic Hierarchy Process (AHP) and how the condition of agricultural water security be improved at different agro-ecosystems? A number of sub-questions were developed to address the central question:

1. What is agricultural water security?
2. How agricultural water security can be assessed using AHP?
3. What are the conditions of agricultural water security at different agro-ecosystems of the study area?
4. How can the condition of agricultural water security be improved at different study sites?

1.4 Possible Outcome

Water security for agriculture is an important issue in coastal region of Bangladesh due to salinity, water logging and flooding problems. Analysis of agricultural water security will help development planners and relevant authorities to initiate suitable strategies to mitigate hazards and improve agricultural production in general and in the study areas in particular.

1.5 Limitations of the Study

Every research or project has some limitations and constraints. This study also has been conducted under various limitations and constraints. A comprehensive study of water security was not possible due to time and budgetary limitations. Due to shortage of time and budget, the study was carried out in a limited way and extensive survey of the area could not be conducted. Manpower was limited to conduct focus group discussion. Sometimes, people were unwilling to provide information and biased information was found, which might have created incorrect results. Sometimes people answered the questions without realizing the factors properly. So their original perception about some respects was not properly known. Sometimes, the required information collected from the local people and officials became contradictory. In some cases, the collected secondary report did not provide specific information. Very few studies were conducted related to water logging and TRM (Tidal River Management). As a result, there was no sufficient literature to enrich the analysis of this study by reviewing the past study findings.

1.6 Organization of the Thesis

This thesis contains five chapters. The organization of different chapters is described below:

Chapter One: This chapter contains the background of the study, specific objectives with which the study was conducted. It also provides the limitations of the study and organization of the thesis chapters.

Chapter Two: A vast literature review has been completed on the south-west coastal zone of Bangladesh including the common natural disasters, water logging and salinity problems of the coastal area, Tidal River Management, agricultural water security assessment using analytic hierarchy process, etc., in this chapter.

Chapter Three: This chapter is structured with a general description of the study area, the methods followed during this study which includes selection of tools, collection of primary and secondary data, and interpretation of collected data. The methods and materials used in the research are clearly described in this chapter.

Chapter Four: This chapter is structured with the results and discussions of the research. The results and discussions cover condition and comparison of agricultural water security at different agro-ecosystems and strategies to improve agricultural water security at the selected study sites.

Chapter Five: The conclusions of the study are made in this chapter and a set of recommendations for further study is also presented.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Bangladesh extends over 147,570 square km, out of which land area comprises 134,000 square km. The country has a fairly large area under water bodies. About 79,000 square km (60 percent of the land) is arable (USAID, 2010). The rapidly growing population and increased urbanization have caused the cultivated areas to decline at a rate of 1 percent per year. To meet the increasing food demand, the growth in agriculture has to result from crop intensification, diversification and value addition as well as from increased irrigation efficiency (World Bank, 2011).

Among other sectors, agriculture is facing the worst impact from hydrology and climate change related natural disasters, and as agriculture is the main livelihood option for the coastal people of Bangladesh, they are bearing the ultimate loss and damage. Among the phenomena that affect agriculture include the projected changes of river flows, inundation resulting from inadequate surface drainage, sea level rise, salt water intrusion, and increased occurrence of floods (USAID, 2010). Hence, agricultural adaptation approach is one of the key aspects that are helpful to reduce agricultural crop vulnerability in the coastal zone of Bangladesh (Basar, 2015).

In this chapter, a review of relevant literatures on salinity, water logging and Tidal River Management (TRM) focusing southwest coastal region of Bangladesh, and water security and Analytic Hierarchy Process (AHP) focusing water sector are presented.

2.2 Salinity of Groundwater in Southwest Coastal Bangladesh

The coast of Bangladesh consists of 19 districts, covers 32% of the country, and accommodates more than 35 million people (Huq and Rabbani, 2011). Increasing salinity is a crucial issue for the people of the coastal region of Bangladesh. Due to increasing salinity in the water and soil, the people of the region are suffering from scarcity of safe drinking water, irrigation, agriculture and other uses. Ecology of the coastal region, especially in the southwest region, is greatly impacted with higher salinity.

Most of the research works in Bangladesh to date have been carried out mainly on irrigation, drainage, flood control and diversion of the Ganges flows during the dry season. Though salinity in water is a normal phenomenon in the southwestern coastal region, very few studies have been on water salinity aspect. Based on a survey conducted during 2009, SRDI (2010) reported that about 0.035 million hectares of new lands were affected by various degrees of salinity during the last 9 years from 2000 to 2009 only. The study indicates that the salinity affected area has increased from 8330 square km in 1973 to 10560 square km in 2009 (SRDI, 2010).

The SRDI study identified that all the cultivable coastal lands were not being utilized for crop production, mostly due to soil salinity. Increased soil salinity limits growth of standing crops and affects overall crop production, and also makes the soil unsuitable for many potential crops. Soil salinity has also been considered a major constraint to food grain production in coastal areas of the country (Huq, 1999). Increased level of water salinity impacts livelihood operation in several ways. First, it makes the whole coastal belt's water availability insecured and pushes poor people's lives to a more vulnerable position than before. Second, water salinity also causes an increase in soil salinity which further decreases the agricultural productivity and brings enormous pressure on food security (Basar, 2012). In this situation, management of salinity intrusion is a vital issue for Bangladesh. With the mission of saline water proofing by structural management, such as coastal embankment projects, sluices, regulators, etc., and coastal area zoning as non-structural management to change the land use and other activities were found to be the vision of sustainable livelihood and environment of Bangladesh.

The unconsolidated river borne alluviums and semi-consolidated sedimentary sequences form extensive aquifers over most of Bangladesh. Groundwater can be abstracted from aquifers at varying depths. The upper aquifer in Khulna region in general contains brackish to saline water (Haskoning and Iwaco, 1981). Based on a comprehensive field data collection, the study reported that the fresh-saline groundwater interface lies at depth between 200 m and 300 m. The chloride contents in the deep aquifers ranging from less than 25 ppm to 100 ppm were found at Dumuria. MPO (1986) based on the information of UNDP (1982) mentioned that sufficient groundwater is available in Khulna region with the transmissivity in the range of 1000 m^2/day to 2000 m^2/day in the main aquifer. Halcrow and Partners (1993) tried to relate freshwater and groundwater interactions at a conceptual state only. In the upper aquifers, the position of the saline fronts can be controlled by regional flow of groundwater towards the sea and prevailing recharge conditions. In addition, freshwater lenses may occur overlying the saline water. Under natural conditions only minor seasonal changes take place in these relationships between fresh and saline waters. EGIS (2001) reported groundwater salinity between 40 and 200 m below ground surface in the coastal belt. It was revealed from IWM (2002) study that groundwater level varies from 0 m to 2.0 m above mean sea level in the Khulna region. In general, salinity level exists 1000 -1500 ppm.

2.3 Water Logging Problem in Southwest Bangladesh

Water logging is one of the major problems in southwest coastal Bangladesh. The Kobadak River has been experiencing huge siltation over a long reach that has reduced its drainage capacity. The decrease of flushing flow from upstream and substantial reduction of tidal flooding area along the river due to construction of polders caused severe siltation over a long stretch of the river (Shampa *et al*, 2012). Human interventions, such as construction of polders and bridges, and encroachment on the river, had deteriorated the condition of the Kobadak River. UNDP (2011) studied the water logging problem, its causes and effects in Satkhira district. It was found that, due to perpetual siltation in the rivers and as a consequence of unplanned development interventions on the river system, long-lasting water-logging in the human settlements took place in Tala, Satkhira Sadar, Kolaroa, Debhata, Assasuni and Kaliganj Upazilas including the municipal areas of Satkhira district. Rahman and Rahman (2011) also investigated the causes of water logging.

The water logging has affected every sphere of people's lives including cultivable lands, employments, culture fish production, grazing lands, bio-diversity and livestock (Shampa *et al*, 2012). The Kobodak basin was found to be under the peril of water-logging due to the natural and human interventions (Rahman and Rahman, 2011). The water logging resulted in considerable losses and damages to dwelling houses, standing crops, shrimp farms, roads, educational institutions, and so on (UNDP, 2011). Floods and prolonged water-logging also caused significant displacement presenting humanitarian challenges in safe water supply, sanitation, shelter and food security (UNDP, 2011). The UNDP study further identified the gaps between needs and responses in relation to water logging.

The effect of long-term water logging on human livelihood in south-western coastal region of Bangladesh was also studied by Awal (2014). It was found that the water logging had impacted the local economy over the last three decades. Several projects were implemented to improve the drainage situation in the area, including the Khulna Coastal Embankment Project from 1985 until 1990 and the Second Coastal Embankment Rehabilitation Project that started in 1990 and lasted until 1994 (GoB et al., 1993). The latest project to improve the drainage in the area was the Asian Development Bank funded Khulna-Jessore Drainage Rehabilitation Project (KJDRP). The KJDRP aimed to improve drainage in 100,000 hectares of lands that were worst affected by the drainage congestion in the southwest delta, by improving infrastructure and community participation in water management (ADB, 2007). During the KJDRP, 106 formal Water Management Groups (WMGs) and 9 Associations (WMAs) were established and one overarching Water Management Federation (WMF). The KJDRP covered approximately 25% of the CEP area with a population of 800,000 people, ran from 1994 to 2002 and was implemented by the Bangladesh Water Development Board.

The KJDRP is well-known in the study area, and its outcome is the topic of heated debate among locals, NGOs and the government. Initially, there were 9 options considered to improve drainage of the study area, which included the construction of large-scale infrastructure and the development of tidal basins (SMEC, 2002). In contrast to the local population, the BWDB favored the construction of large scale infrastructural solutions to counter drainage congestion in the area (ADB, 2007). During the initial phase of the KJDRP, several regulators were constructed (i.e. at Sholmari and Ramdia), the Hari and the upper Sholmari rivers were dredged, and a large embankment was built between Bhabadaha and Teka (ADB, 2007). On October 29th, 1997, the local people at Beel Bhaina cut their embankment turning the 1000 hectares of beel into a tidal basin (ADB, 2007).

The study by Awal (2014) identified the local adaptation and policy options to respond to the water logging. For mitigating the water logging effect, plinth raising and elevating the local habitats and physical infrastructures were suggested to be as an immediate and short-term measure, whereas the operation of Tidal River Management (TRM) was suggested to be as long-term or permanent solution. The dead or silted-up rivers, canals, ponds and irrigation channels were suggested to be excavated or re-excavated by operating the major welfare social safety net programs of the government like Food-for-Work (FFW) or

Cash-for-Work (CFW) and the excavated soil was to be utilized for creating, maintaining or raising the rural roads, polders/embankments and related other infrastructures which were quite crucial for mitigating the flood or water logging problem in the region. Rahman and Rahman (2011) also identified the indigenous coping capacities due to water logging in the Kobodak river basin.

2.4 Tidal River Management

Under the Coastal Embankment Project (CEP), which started in the late 1950s and continued until the early 1980s, the USAID and the BWDB constructed polders in the south-west deltaic part of the country in order to decrease saline water intrusion in the flood plains and to increase agricultural production. Initially, the latter was achieved, as 3 harvests per year were possible instead of 1 (Ibid, 2012). However, in the late 1980s, the south-west delta started to experience severe problems related to drainage congestion and water logging, and consequently agricultural production went down and some areas became permanently waterlogged, which led to increased poverty (ADB, 2007). Part of the cause of this rapid sedimentation is the lack of upstream flow that flushes out sediment from these rivers. The other causes are due to vulnerable climate and stumpy terrain.

The construction of embankments decreased the tidal prism - the volume of water entering the river during high and low tides - and thereby the flow velocity of the water in the tidal rivers in the southwest delta. Consequently, sediment started settling down in the rivers that were essential for draining the polders made under the CEP. Drainage congestion and water logging were detrimental for agricultural production and the local economy (Rahman, 1995).

From 1994 to 2004, the Khulna-Jessore Drainage Rehabilitation Project (KJDRP) was implemented with financial support from the Asian Development Bank (ADB, 2007), aiming to decrease drainage congestion in the area to allow for agricultural production. Initially, the project proposed to close off the entire area of tidal influence by constructing a huge barrier in the Gangrail River. However, this was considered too risky as social and environmental consequences of this intervention could not be overseen.

During the course of the KJDRP, local inhabitants of Beel Bhaina cut an embankment in their polder which created a tidal basin. Upon return to the sea during low tide, the water stored in these tidal basins pushed its way through the narrow rivers with increased flow velocity, which caused erosion of the riverbed and increased the size of the rivers (Wester and Bron, 1997). Thus, the introduction of TRM at some places of the coastal zone has substantially improved the water logging circumstance.

Khadim et al. (2013) assessed the benefits achieved due to implementation of IWRM in parts of Khulna and Jessore districts and investigated some technical aspects evolved from TRM. Analyses were carried out using satellite images, RS and GIS technology, Digital Elevation Model (DEM) and field investigations. A mathematical formulation was also made to assess the rate of tidal sedimentation due to TRM and select the strategies for tidal basin operation. The study came up with evidences of considerable advancements in regional livelihood, i.e. flood resistance, cultivated lands, cultivable area, cropping intensities and food security due to implementation of TRM.

2.5 Water Security and Its Dimensions

Water security is an emerging concept, and there is not yet an agreed on definition. Instead, there are various definitions which often invite debates and hence the concept is evolving (Norman *et al.,* 2010; Grey and Sadoff, 2007; GWP, 2012; Cook and Bakker, 2012). According to Cook and Bakker (2012), the framings of water security are not consistent and tend to vary with context and disciplinary perspectives on water use. Water security is a situation where “every person has access to enough safe water at affordable cost to lead a clean, healthy and productive life, while ensuring that the natural environment is protected and enhanced”. This integrative definition considers access and affordability as well as environmental health as important dimensions of water security.

Framings of water security that focus on quantity and availability of water are often linked to water security assessment tools. Perhaps the most well-known assessment tool to date combines two indices—water stress and water shortage—in the measurement of water scarcity (Falkenmark *et al*, 2007; Falkenmark and Molden, 2008). The first index of water stress evaluates the ratio of water use to availability and estimates demand-driven apparent scarcity by measuring how much water is withdrawn from rivers and aquifers. The second index of water shortage estimates population driven real water shortages by measuring the number of people that have to share each unit of blue water resource (Falkenmark *et al.*, 2007; Falkenmark and Molden, 2008). From this perspective, sufficiency of water supply for humans is the primary gauge of water security. For an individual, water security exists when she has access to sufficient safe and affordable water to satisfy her needs for drinking, washing, and livelihood (Rijsberman, 2006).

An important theme of water security is the issue of accessibility, water-related hazards and vulnerability. For example, the UNESCO – Institute for Water Education advocates an infrastructure and systems approach to water security which involves protection of vulnerable water systems, protection against water related hazards such as floods and droughts, sustainable development of water resources and safeguarding access to water functions and services (UNESCO-IHE, 2009). The U.S. Environmental Protection Agency defines water security as prevention and protection against contamination (Crisologo, 2008; Minamyer, 2008; Morley *et al*, 2007).

A third dimension of water security is 'human needs, which covers a broad range of issues, including access, food security, and human development-related concerns. For example, one framing of water security from the 1990s focuses on the human need for water: Water security is a condition where there is a sufficient quantity of water at a quality necessary, at an affordable price, to meet both the short-term and long-term needs to protect the health, safety, welfare and productive capacity of position (households, communities, neighborhoods or nation) (Witter and Whiteford, 1999). The United Nations Development Program's approach to human security underpins many of these definitions (UNDP, 1994); for example, Janksy et al. (2008) defined water security as all aspects of human security pertaining to the use and management of water.

Within the human needs approach, there is a tendency to frame water security as a component or subset of food security (Biswas, 1999; FAO, 2000; White *et al.,* 2007). The Food and Agricultural Organization (FAO) linked the concept of water security to food security, in which water security was the ability to provide adequate and reliable water supplies for populations living in the world's drier areas to meet agricultural production needs (Clarke, 1993). The FAO has maintained an agricultural focus of water security—crop water security—where water quantity is highly relevant (FAO Land Division Water

Development, 2000). In many countries, reservoir storage for the purposes of irrigation is the salient feature of water security (Saliby et al., 2009). This focus on water quantity also holds true for framings that widen concern from reservoir storage to consider the entire hydrological cycle (Johansson *et al.*, 1999; Oki and Kanae, 2006; Tuinhof *et al.*, 2005).

The GWP framings of water security include human and ecosystem needs, accessibility, continuity and affordability. Water security is seen as a multi-dimensional concept that recognizes that sufficient good quality water is needed for social, economic and cultural uses, while, at the same time, adequate water is required to sustain and enhance important ecosystem functions (Loe *et al.*, 2007). It is also seen as sustainable access to adequate quantities of water, of acceptable quality, to ensure human and ecosystem health (Dunn and Bakker, 2009; Norman *et al.*, 2010). Another framing that draws on GWP involves the availability of water in adequate quantity and quality in perpetuity to meet domestic, agricultural, industrial and ecosystem needs (Swaminathan, 2001).

Water security research in China often has a combined focus on water availability, water quality and capacity to use water, drawing on definitions from the World Water Forum 2000, either the Global Water Partnership (Zhao *et al.*, 2009) or the Ministerial Declaration (Dong *et al.*, 2010; Zhou *et al.*, 2007). Water security is used there as the ability to supply water, according to a specified quality, to homes and industry under conditions satisfactory to the environment and at an acceptable price (Xia *et al.*, 2007). Another alternative way to look at water security has been based on an analysis of the relationship between environmental changes and security issues considering not only the situation of water resources but also the related factors of environment, ecology, society, politics and economy (Ma *et al.*, 2010). In China, the industrial and populous north is considered highly water insecure (Xia *et al.*, 2007). Thus, the concepts of water security in the context of China have been variable, and most of the studies are engineering, focused on building models to assess water security at the urban (Tong and Dong, 2009; Zhao *et al.*, 2009) or regional scale (Huang *et al.*, 2009; Ren and Dong, 2009).

There is relatively little emphasis in the water security literature on the concept of environmental security, which emerged in the 1990s to refer to the links between water security and environmental degradation (Kaplan, 1994; Homer-Dixon, 1999; Stern, 1999). However, these issues have received significant scrutiny from academics (Giordano *et al.*, 2002; Gleick, 1993; Wolf, 1999). But these scholars do not appear to have adopted the term ‘water security’, even where their nuanced approach to the integrative nature of environmental issues leads them to voice parallel issues, such as the links between multiple scales, or the importance of good governance (Dalby, 2002). The one exception is the Middle East and North Africa, where early uses of the term water security explicitly focused on geopolitical security concerns (Anderson, 1992; Savage, 1991; Shuval, 1992; Starr, 1991).

Following the above review, we can conceptualize the agricultural water security as the reliable availability and accessibility of water for agricultural production.

2.6 Analytic Hierarchy Process in Water Security Analysis

Analytic Hierarchy Process is a multiple criteria decision-making tool. This is an Eigen value approach to the pair-wise comparisons. It also provides a methodology to calibrate the numeric scale for the measurement of quantitative as well as qualitative performances. The scale ranges from 1 to 9 as 1 for equal and 9 for absolutely more important than covering the entire spectrum of the comparison.

A standard feature of multi-criteria analysis (MCA) is a performance matrix or consequence table, in which each row describes an option and each column describes the performance of the options against each criterion. The individual performance assessments are expressed with numerical value. In a basic form of MCA, this performance matrix may be the final product of the analysis. The decision makers are then left with the task of assessing the extent to which their objectives are met by the entries in the matrix. MCA techniques commonly apply numerical analysis to a performance matrix in two stages. Scoring the expected consequences of options is assigned a numerical score on strength of preference scale for each option for each criterion. More preferred options score higher on the scale, and less preferred options score lower. Numerical weights are assigned to define, for each criterion, the relative valuations of a shift between the top and bottom of the chosen scale. Mathematical routines combine these two components to give an overall assessment of each option being appraised (MCA manual, 2009).

By using the performance matrix, Shikder and Salehin (2014) show that the ranking from highest to lowest of drinking water technologies based on the scores of alternatives are:

RWHS, DTW, PSF, STW and natural ponds. Participants also agreed that RWHS was the best option as a source of drinking water supply for their study area. As the groundwater is saline and PSF requires sophisticated maintenance, such as changing the filter materials and replacing them after a certain period, RWHS was viewed as the best choice.

A study by Raju *et al.* (2000) used AHP for freshwater resources planning for Malnichara channel improvement in the Huesca Province of Spain. The relative performances of alternatives were evaluated using the weighted sum technique of multi-criteria decision analysis. A similar study using multi-criteria analysis was conducted in Borguna district, another part of the coastal zone of Bangladesh. The rainwater harvesting was found to be the most suitable option for the area. Moreover, the final result was shared with the users to obtain their feedback to ensure sustainability of the water source (Shikder, 2010).

Multi-criteria decision analysis tool is used in many water resources and environmental management projects. The Malnichara is one of the natural channels in Sylhet city of Bangladesh responsible for storm-water runoff conveyance to the downstream Surma river. The channel was found to be encroached at many locations of the city and found to be very vulnerable. The city corporation authority took a decision to improve the natural channels by using a traditional approach, e.g. constructing box culvert. In most cases, stakeholders' participation was ignored in such type of decision making. Hence, efforts were made to evaluate three common alternatives viz. sodding natural channel, lined natural channel and box culvert for the channel improvement (Chowdhury and Rahman, 2008). The channel is hydrologically divided into two parts: the upper portion (Choukidekhi-Kanishail) and the lower portion (Kanishail-Topoban). Both parts were separately analyzed. Small groups of stakeholders were interviewed for the selection of criteria and for the assignment of weighed factors and scores. Experts' opinions were also taken through consultation. Nine criteria from four categories such as technical, economic, environment and social aspects were selected. The relative performances of alternatives were evaluated using the weighed sum technique of multi-criteria decision analysis. It was found that the sodding natural channel was the best alternative for both portions of the channel. However, the choice was very sensitive to the social criteria (Chowdhury and Rahman, 2008).

The study by Herath (2004) used AHP for wetland management. Wetlands in Australia provide considerable ecological, economic, environmental and social benefits. However, the use of wetlands had been indiscriminate and significant damages to many Australian wetlands had been occurred. During the last 150 years, one-third of the wetlands in Victoria had been lost. A conspicuous problem in wetland management was the paucity of involvement by stakeholders. The study used AHP to incorporate stakeholder objectives in the Wonga Wetlands on the Murray River. The study showed that the AHP could explicitly incorporate stakeholder preferences and multiple objectives to evaluate management options. The AHP also provided several approaches for policy makers to arrive at policy decisions.

A study by Ko *et al.* (1994) used AHP for reservoir operational planning in the Han River Basin in Korea. Reservoir system operators must consider multiple quantitative and qualitative operational objectives with varying degrees of importance. A two-stage procedure combining multi-objective optimization and multi-criterion decision analysis techniques was presented for reservoir system operational planning. Objectives were divided into primary and secondary groups. In the first stage of the procedure, primary quantitative operational objectives were used to generate non-dominated alternatives via multi-objective optimization using successive linear programming and the ε-constraint method. In the second stage, primary and secondary operation objectives were combined within multi-criterion decision techniques to select the most preferred alternatives from the generated set. Four multi-criterion decision analysis techniques were evaluated in that study.

Apart from water sector, AHP has been used in the field of project management (Arbues *et al,* 2009), warehouse site selection process (Komnecric *et al,* 2009), selection of car (Byun, 2001), selecting quality-based programs (Chowdhury, 2010), selecting software product (Jung and Choi, 2012), analyzing a firm's investment justification problem (Mohonty and Deshmukh, 2009), selecting the most appropriate flexible manufacturing system (Shang *et al,* 2000), etc.

CHAPTER THREE
METHODOLOGY AND DATA COLLECTION

3.1 Introduction

In this study, different methods were used to assess agricultural water security at Tala Upazila. Participatory approaches, conventional approach and analytic hierarchy process have been used in the study. Primary data was collected during several field visits to the study area and secondary literatures including reports of Bangladesh Bureau of Statistics (BBS) and reports of Bangladesh Water Development Board (BWDB) were also reviewed. All the collected information was analyzed to calculate and compare water security indices at different agro-ecosystems and to propose suitable strategies to improve agricultural water security at the selected locations.

3.2 Study Area

The study area is located in the south-western coastal region of Bangladesh (Figure 3.1). The study was conducted in three different sites of Tala Upazila (Figure 3.2). One site is located in Khanpur, another is in Kheshra and the rest is in Bhorot Bhaena. These three agro-ecosystems represent major agricultural activity of Tala Upazila. This is the reason for taking these three sites as study area.

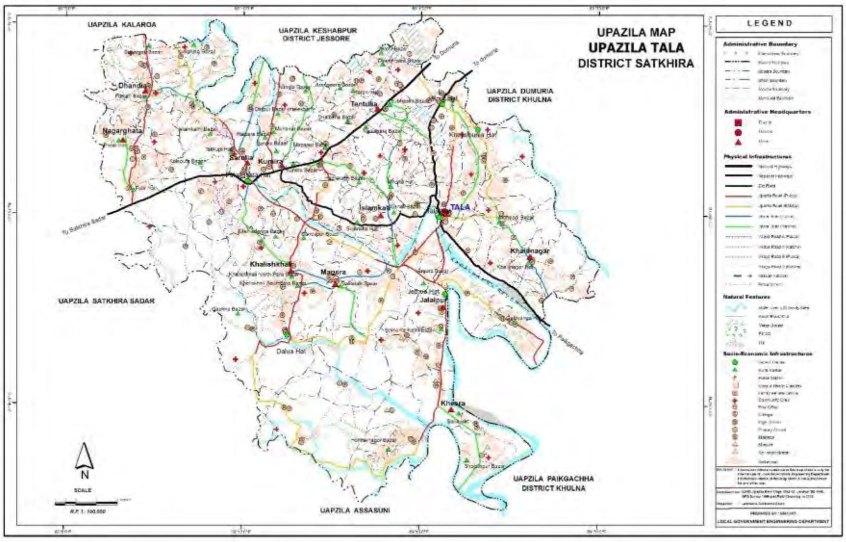

Figure 3.1 Upazila Map of Tala Upazila, Satkhira District

As a flood plain area, most of the land of Tala Upazila is used for cultivation. Due to water logging and salinity in water from the last few decades, people started to cultivate shrimp. People in the study area also cultivate several types of crops like paddy, wheat, potato, jute, sugarcane and other type of crops and fruits.

Most of the agricultural land is used for cultivation of paddy. Here mainly three types of paddy are cultivated like Aus, Aman and Boro. In the year of 2010-2011, paddy production from Tala Upazila was 21768 M.ton of Aus, 271130 M.ton of Aman and 263377 M.ton of Boro. Several types of fruits and vegetables like mango, litchi, blackberry, jackfruit, banana, guava, pineapple, lime and lemon are cultivated. Vegetables are cauliflower, cucumber, brinjal, lady's finger, arum, pumpkin, parble, cabbage, tomato, radish, bean, turmeric and ginger. But most of them are cultivated for the family purpose. Some are also cultivated for the economic purpose. They also cultivate some spices (pepper, onion, and garlic), oilseed (rape, mustard, groundnut and sesame) and pulse (gram, motor, khesari, mash-kalai).

About 70% of our total fish and 90% of export earnings come from frozen foods from Satkhira and this is the place where the bread basket of Bangladesh is situated. Unfortunately, this potential and important area has been experiencing changes in environment and socio- economic phenomena with the expansion of shrimp culture. Embankment was erected in 1960s, before that sea water flows were open. In 1980s, shrimp cultivation started. Since 1994, fish fry has become scarce. Import of fish started at that time. Once there was plenty of production at Tala Upazila. But due to climate change effects, the production has been reduced with time.

3.2.1 Site 1: Khanpur

The site is located at Khanpur of Tala Upazila. There is water logging problem in the area. A significant time of the year, Khanpur remains inundated. During that time, no rice and other productions are continued in the area. In the dry season, various crops like rice, tomato, potato, sesame and different vegetables are produced in the area. The major problem of the area is water logging and this is the reason for which the area is not secured for agricultural production.

At Khanpur, in the rainy season the river water became high and this high water inundated the river floodplain. There was huge damage of agricultural crops in the rainy season which also caused a heavy destruction of the local economy. Thus the government solved the problem and made an embankment (1960) under coastal embankment project (CEP). The embankment was made for the solution of the problem but now it has created a big problem like water logging. Gradually silt has deposited in the river bed and its elevation has become high. There are some polders which are connecting to the river with a channel. But over the time, there have not been proper maintenance of the connecting channels and as a consequence the channels have been silted up. Now the river water cannot enter into this polder and the rain water cannot drain out. The polder (no. 16) is generally lower than the river bed. In the rainy season, the water cannot drain out from this polder which creates water logging. This situation stays at least six months (June – mid November).

3.2.2 Site 2: Khesra

Kashimnogor is located in Khesra Union of Tala Upazilla. The area has salinity problem. The water used for agricultural purpose in the area is saline. Farmers cannot produce plenty of crops because of salinity problem. Few farmers produce saline resistant crops but they do not have enough knowledge about it. Shrimp is cultured throughout the area. People consider it highly beneficial and economically viable. Here, at some places, shrimp fields are operated in dry months while the same land is used for paddy cultivation in wet months. However, it is almost universally felt that shrimp culture by intruding saline water is degrading the soil quality and poor paddy production. Electrical Conductivity of agricultural water in the area is 683-9810 µS/cm, Cl is 0.3-0.68 ppt and TDS is 0.34-3.98 ppt (Somanathan and Ravindranath, 2006). In Khesra area, salinity starts from deep aquifer and increases with the increased depth. In some places in the area, suitable deep aquifer is not available. In these places people use shallow tube well for domestic purpose. Local people suffer from many diseases like diarrhea, dysentery and skin diseases because of consuming saline water.

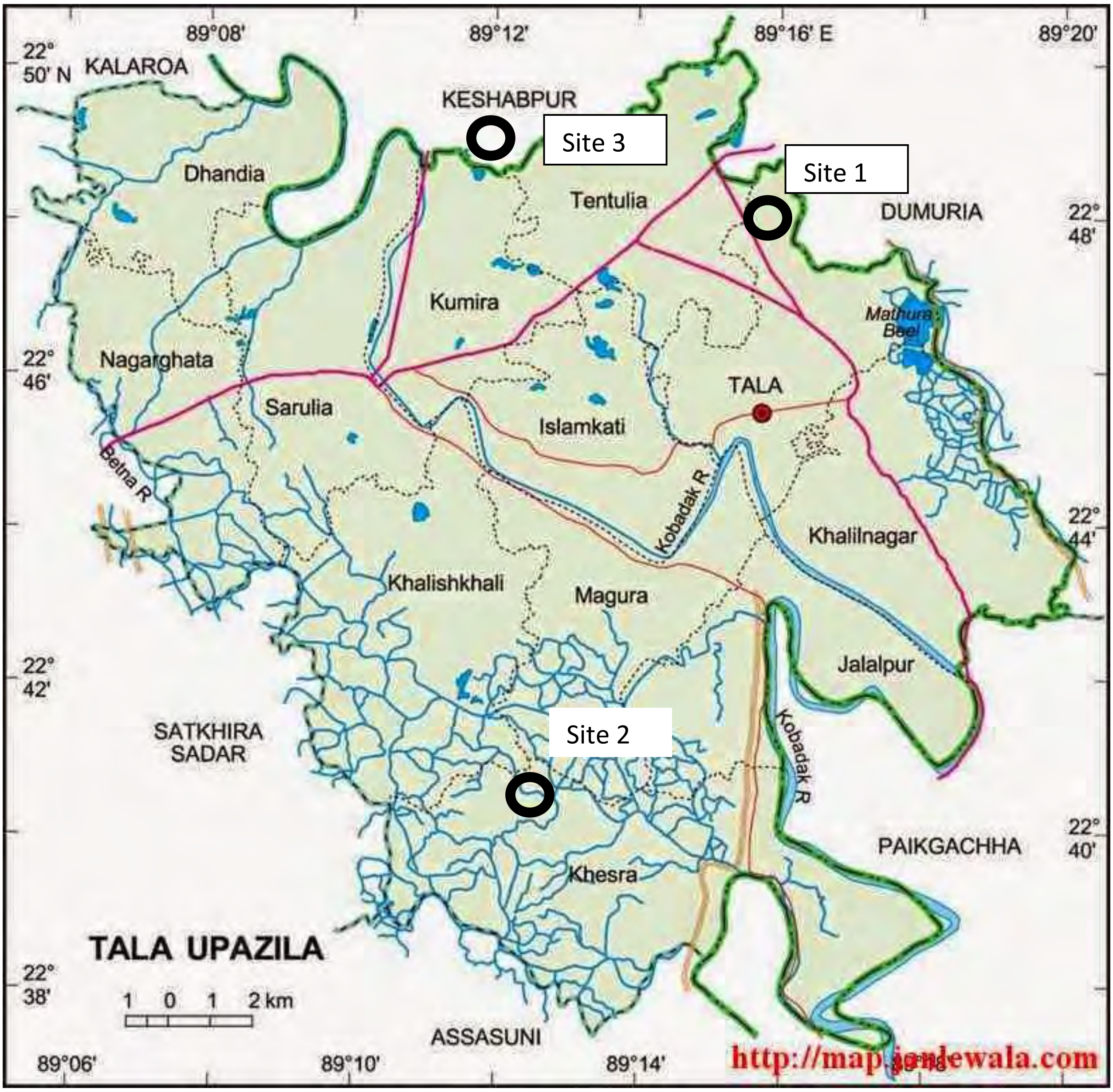

Figure 3.2 Location of Three Different Study Sites

3.2.3 Site 3: Bhorot Bhaena

At Bhorot Bhaena area of Kashimnogor Union of Tala Upazila, Tidal River Management (TRM) is implemented by local people. After implementation of TRM, there was plenty of production of different crops in the area. Farmers are producing various crops like rice, potato, mustard and vegetables at the silted land. Also shrimp cultivation is practiced in the area. Apparently, the area was agriculturally water secured. The major purpose of TRM was to get suspended sediment deposits gradually under a controlled system and sediment management is the most challenging aspect of it. It is a tool under IWRM which involves peripheral breaching at a polder to allow tidal in-flow and hence accumulate deposited sediments inside the polders to raise land elevations. This eventually improves river navigability, making the enclosed lands free from water logging. From 1994 to 2004, the Khulna Jessore Drainage Rehabilitation Project was implemented with financial support of the Asian Development Bank aiming to decrease drainage congestion in the area to allow for agricultural production. During the course of the KJDRP, local inhabitants of Beel Bhaina cut an embankment in their polder which created a "tidal basin" in the area and consequently agricultural production has been increased in the area.

3.3 Conceptual Framework of the Study

The study develops an agricultural water security index for each agro-ecosystem. Important indicators for developing agricultural water security index like water availability, access to water, water use, capacity to use water and disaster management have been considered. The indicators and sub-indicators are given in Figure 3.3. With the help of experts and general people living in the locality, indices of agricultural water security have been generated and then compared among different agro-ecosystems. These revealed the regional differences in water security in coastal areas of Bangladesh. To propose suitable strategies for improvement of agricultural water security at the selected areas of Tala Upazila, Analytic Hierarchy Process (AHP) has been used. Possible strategies have been identified through focus group discussions (FGDs) and key informant interviews (KIIs). The FGDs were structured based on the reconnaissance field visit findings. Priority matrix of the strategies including different criteria to improve the agricultural water security has been generated. With the help of random index and consistency index, the strategies have been ranked.

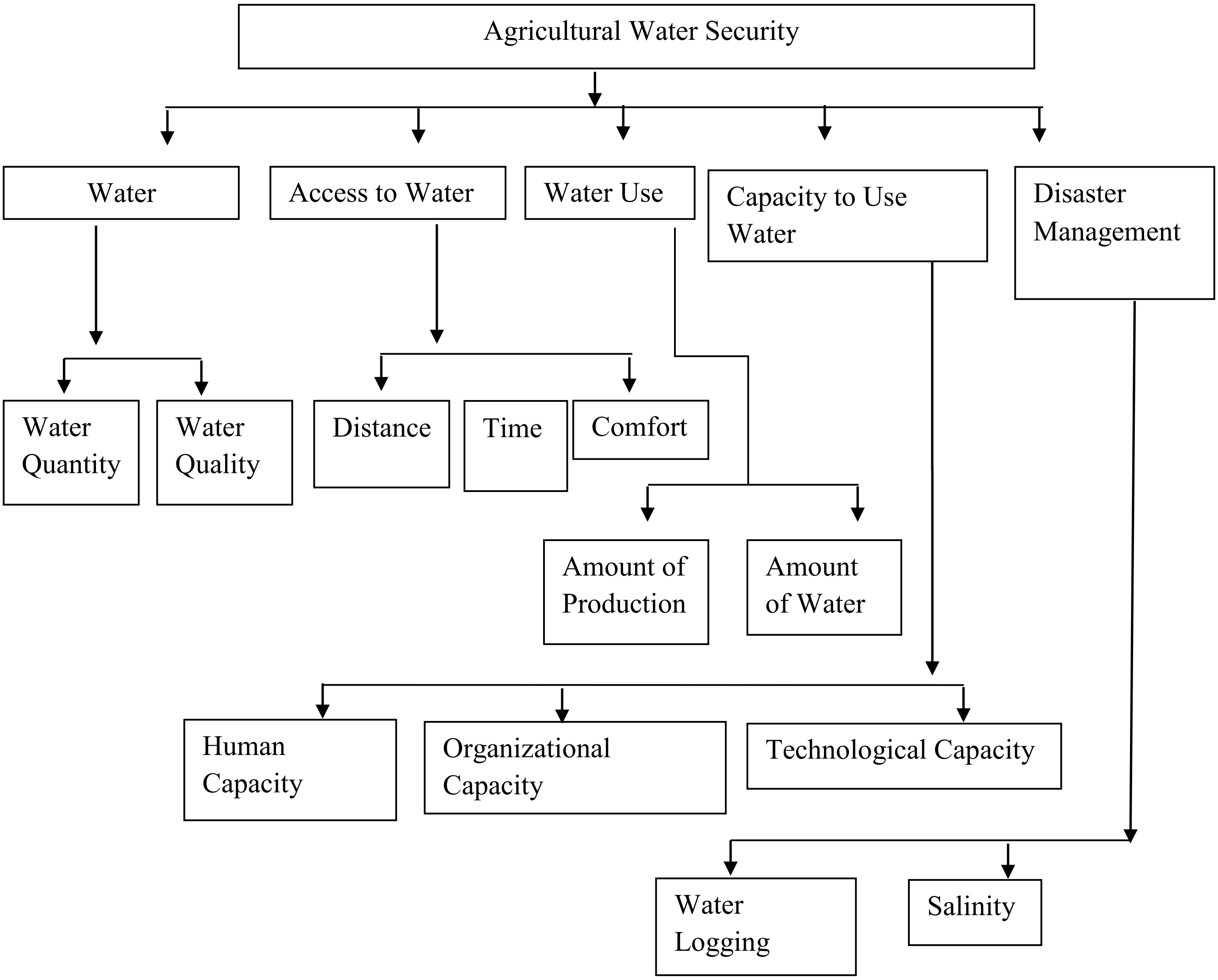

Figure 3.3 Different indicators of agricultural water security at Tala Upazila

3.4 Calculation and Comparison of Agricultural Water Security Indices

Water security indices for agriculture at different agro-ecosystems have been calculated and compared using the following equation:

$$AWSI = \sum W_i F_i X_i / \sum F_i \quad (3.1)$$

where,

AWSI= Agricultural water security index

Wi= weight of a particular indicator of agricultural water security calculated from AHP

Xi= value of level of satisfaction for that indicator

Fi= number of respondents giving that value (Xi)

3.5 Calculation of Weights of Indicators of Agricultural Water Security using AHP

Comparative matrix of different indicators of water security for agriculture like water availability, access to water, water use, capacity to use water and disaster management has been developed through expert opinion. The table of Saaty (Saaty, 2008) was used to prepare the comparative matrix. Weights of different indicators of agricultural water security were calculated using AHP. After calculation of weights, consistencies of the matrices have been checked through dividing consistency index (CI) by random index (RI). To calculate the consistency ratio (CR), the table of RI developed by Saaty (Saaty, 2008) was used.

AHP was operated by prioritizing competing alternatives as well as the criteria used to judge the alternatives. This prioritization procedure places weights on the influential selection criteria, thus accommodating the varying scales and units exhibited by these criteria (Saaty, 2008). AHP was operated at three different stages which are described below:

3.5.1 Construction of pair wise comparison matrices

The first step in performing the AHP was to identify all possible alternatives from which a single alternative was selected. In the study, water security indices and possible strategies to improve water security were developed through pairwise comparison matrices. Next, it was necessary to identify all relevant criteria influencing the selection of a single alternative from the pool of feasible alternatives. Criteria of assessing water security index were water availability, access to water, water use, and capacity to use water and disaster management. Because the numerous selection criteria exhibit varying units (or in some cases no unit at all), mathematical evaluation of the criteria required the researcher to determine the relative scale, or weight, of the alternatives in terms of each criterion. This task was accomplished by employing Table 3.1. This table was first proposed by Saaty (Saaty, 2008) for determining the dimensionless scale of relative importance. This table and others developed since Saaty's initial work, permitted pairwise comparisons within the AHP. In AHP approach, the decision-maker has to express his opinion about the value of one single pairwise comparison at a time (Triantaphyllou and Mann, 1995). In other words, within every hierarchal comparison matrix, each competing alternative was compared against every other competing alternative employing a scale of relative importance. This type of comparison was executed for each influential criterion, and ultimately the influential criteria were compared and ranked against themselves.

Employing the scale of relative importance, judgment matrices for each selection criterion was constructed. This step evaluated the performance of each possible alternative against the other alternatives in terms of the various selection criteria. These judgment matrices were of dimensions $M \times M$, *"M"* being the total number of alternatives considered. The final judgment matrix is termed the criteria judgment matrix and evaluated and ranked the importance of each of the influential criterion when compared against the other criteria. The criteria judgment matrix was of dimension $N \times N$, *"N"* being the total number of influential criteria. In this study, the value of N was 3. It was during the construction of the criteria judgment matrix that the researcher was able to prioritize the criteria influencing the selection of the competing alternatives.

Table 3.1 Scale of Relative Importance (Saaty, 2008)

Intensity of Importance	**Definition**
1	Equal Importance
3	Weak importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2,4,6,8	Intermediate values between the two adjacent judgments

Entries into the judgment and criteria judgment matrices were expressed in terms of the importance intensities illustrated in Table 3.1. For instance, let consider a judgment matrix comparing alternatives *A, B* and *C* in terms of criterion *N.* By convention, the comparison of strength is always of an activity appearing in the column on the left against an activity appearing in the row on the top (Saaty, 2008). An element in the matrix is equally important when compared with itself, and thus the main diagonal of all judgment matrices must be 1. Employing Table 3.1, the following scenario can be considered:

- In terms of criterion *N*, *A* is demonstrably more important than *B*. In practice, such a comparison would indicate that, in terms of satisfying criterion N, alternative *A* strongly outperforms alternative *B*.
- In terms of criterion *N*, *C* is weakly more important than *A*. In practice, this comparison expresses that, in terms of criterion *N*, alternative *C* is slightly superior to alternative *A*.

At this point, the judgment matrix of criterion N appears as follows:

Table 3.2 Preliminary Construction of Judgment Matrix (Criterion "N")

N	A	B	C
A	1	7	1/3
B	1/7		
C	3		

The relative importance from Figure 3.1 are found in row one, while their reciprocal values are found in column one. It is to be noted that, it is not mandatory to enter a reciprocal value, but it is generally rational to do so (Saaty, 2008). Furthermore, intuitively, alternative A is equally important when compared to itself. Now, consider the following additional constraint in the completion of the criterion N judgment matrix:

In terms of criterion *N*, *C* is absolutely more important than *B*. Such a ranking indicates that, in practice, alternative *C* is absolutely superior to alternative *B* in satisfying criterion *N.*

Table 3.3 Completed Judgment Matrix (Criterion N)

N	A	B	C
A	1	7	1/3
B	1/7	1	1/9
C	3	9	1

This step in the AHP was repeated until judgment matrices were constructed for each selection criterion. As presented in Tables 3.1 and 3.2, the competing alternatives, in this example *A, B* and *C* must be compared in terms of each criterion. The final task in this step was the construction of a judgment matrix that prioritizes each selection criterion by comparing one against all other selection criteria.

3.5.2 Extraction of priority vectors

The second step of AHP was the extraction of priority vectors. Upon creating alternative judgment matrices for each selection criterion as well as the criteria judgment matrix, we then proceed to the next step in the AHP, which was to extract the relative importance implied by each matrix. This task was accomplished by employing matrix algebra to determine the right principal eigenvector of each judgment matrix. Mathematically, the principal eigenvector for each matrix, when normalized, becomes the vector of priorities for that matrix (Saaty, 2008). As matrix size grows, the task of computing this principal eigenvector became increasingly complex, particularly in the absence of computing software specifically designed for such a task. However, two computationally accessible methods exist to facilitate extraction of the priority vectors. These methods are illustrated as follows.

3.5.2.1 Method one

The crudest method of principal eigenvector attainment is to simply sum the elements in each row of the matrix and then normalize them by dividing each sum by the total of all row sums. This will result in a vector whose sum is unity and whose first entry is the priority of the first activity, the second of the second activity, and so on (Saaty, 2008). This approach is now applied to the matrix presented in Table 3.2.

Table 3.4 Priority Vector Extractions – Method 1

N	A	B	C	***Row Sum***
A	1	7	1/3	***8.333***
B	1/7	1	1/9	***1.254***
C	3	9	1	***13***

$$\begin{Bmatrix} 0.396 \\ 0.056 \\ 0.576 \end{Bmatrix} \qquad (3.2)$$

The resulting priority equation (3.2) indicates that in terms of criterion *N,* alternative *C* is prioritized, with alternatives *A* and *B* ranking second and third, respectively.

3.5.2.2 Method two

The widely used method of priority vector extraction is an accurate, yet computationally simple method. This approach for obtaining the principal eigenvector is to divide the elements of each column by the sum of that column. This step effectively normalizes the elements of that column such that their sum is unity. Then, the elements in each row are summed and divided by the total number of elements in the row. This step averages the normalized columns to yield the estimated principal eigenvector (Saaty, 2008). This method is used to calculate water security indices in this study. This method is illustrated as follows.

Table 3.5 Priority Vector Extractions – Method 2

N	A	B	C
A	1	7	1/3
B	1/7	1	1/9
C	3	9	1
Column Sum	***4.143***	***17***	***1.444***

Table 3.6 Normalized Column Values and Resulting Row Sums

N	A	B	C	***Row Sum***
A	0.241	0.412	0.231	***0.884***
B	0.034	0.059	0.077	***0.170***
C	0.724	0.529	0.693	***1.946***

$$\left\{ \begin{matrix} 0.295 \\ 0.057 \\ 0.649 \end{matrix} \right\} \qquad (3.3)$$

The results of priority vector extraction method 2 reveal that all methods rank the competing alternatives similarly. Each priority vector extraction method clearly shows alternative *C* as the superior option in terms of criterion *"N."*

3.5.3 Consistency evaluation

The last step of performing AHP in the study was to evaluate consistency of the matrices. There were three sub-steps of consistency evaluation. The first step in the consistency evaluation was to multiply the original judgment matrix by the estimated, normalized priority vector (termed A_{VE}) obtained by one of the previously described extraction methods. The resulting vector was termed A_W. Next, the first component of the A_W vector was divided by the first component of the estimated solution vector. This process was continued, dividing each entry of vector A_W by the corresponding entry of the estimated solution vector, A_{VE}. Upon completing this step, the maximum or principal eigen value (λ_{Max}) was estimated as the average of the entries in vector $\{A_W / A_{VE}\}$. This maximum eigen value was then used to compute the matrix's consistency index (C.I.) using:

$$C.I = (\lambda_{Max} - n) / (n-1) \qquad (3.4)$$

Where *n* was the total number of activities in the matrix. The final step in the consistency evaluation was to examine the ratio of the calculated consistency index and the random index (R.I.) derived from the number of matrix activities. Random indices for varying matrix sizes are shown in Table 3.7.

Table 3.7 Random Indices (Saaty, 2008)

Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The ratio of C.I. to R.I. is called the consistency ratio (C*.R.)*. Generally, a consistency ratio of 0.10 or less is acceptable (Saaty, 2008). In the event that the consistency ratio is greater than 0.10, the operator must re-evaluate the weight assignments within the matrix violating the consistency limits.

3.6 Collection of Data from Different Agro-ecosystems of Southwest Bangladesh

The required data had been collected through several field visits to Tala Upazilla of Satkhira district. Data from three different agro-ecosystems was collected through Focus Group Discussions (FGDs) (Photos 3.1 and 3.2) and Key Informant Interviews (KIIs). Farmer's levels of satisfaction on water availability, access to water, water use, capacity to use water and disaster management have been collected from three different agro-ecosystems. Three field visits were done in the study area along with a reconnaissance field visit. One was done in the dry season and another two were done in the winter season. Two KIIs were also done: one was with the Director of Uttaran and another one was with an elderly inhabitant of the area.

Farmers were found to be highly satisfied with agricultural water at Bhorot Bhaena as production is increased after implementation of TRM (Photo 3.1). At Khanpur, apparently water was available and also accessible but farmers were unable to manage the water in the rainy season. Agricultural production normally reduces in the rainy season because of water logging and this inundation remains almost half of the year in the area. But water seems to be available and accessible at Kheshra area.

Photo 3.1: Focus Group Discussion with farmers at Kheshra

Photo 3.2: Focus Group Discussion with farmers at Khanpur

Photo 3.3: Agricultural production at Bhorot Bhaena after implementation of TRM

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, all the collected information was analyzed to calculate and compare water security indices at different agro-ecosystems and to propose suitable strategies to improve agricultural water security at the selected locations. Analytic Hierarchy Process was used to calculate water security index and also to recommend strategies to improve agricultural water security at the selected sites. Detailed descriptions of different indicators of water security are given in the chapter. Also, comparison between agricultural water securities at three different study sites was done using the analysis of variance (ANOVA) technique and significance of the variation was also tested. The reasons of low and high water security indices are described in this chapter.

4.2 Assessment of Indicators of Agricultural Water Security

4.2.1 Agricultural water availability

4.2.1.1 Agricultural water availability at Khanpur

At Khanpur, the major cropping pattern is shown in Figure 4.1. Farmers produce different crops like aus, aman, boro, wheat, potato, mustard and pulse (Figure 4.2). Farmers mainly produce boro crop in the area during the dry season. But in the rainy season, they cannot produce any crop due to water logging problem. During that time, they remain without any agricultural production at all. The predominant rice crops in Khanpur were the rainfed aman (60%) followed by the boro rice (35%) and aus rice (5%). During the flood of 2015, the majority of the agricultural lands in the affected areas either had an aus rice in the field to be harvested in June/July or recently planted aman seed beds. The rainfall induced water logging usually submerges the agricultural fields with 1.2m to 1.8m of water for over 20 days. This is sufficient time to damage the standing aus crops as well as the aman seed beds. The yield of different crops at the agro-ecosystem is given in Figure 4.2. Usually the district Satkhira has a surplus in vegetables production. During the monsoon season, the majority of the households produce summer vegetables in homestead gardens. However, the homestead vegetables are damaged due to the deep and prolonged water logging.

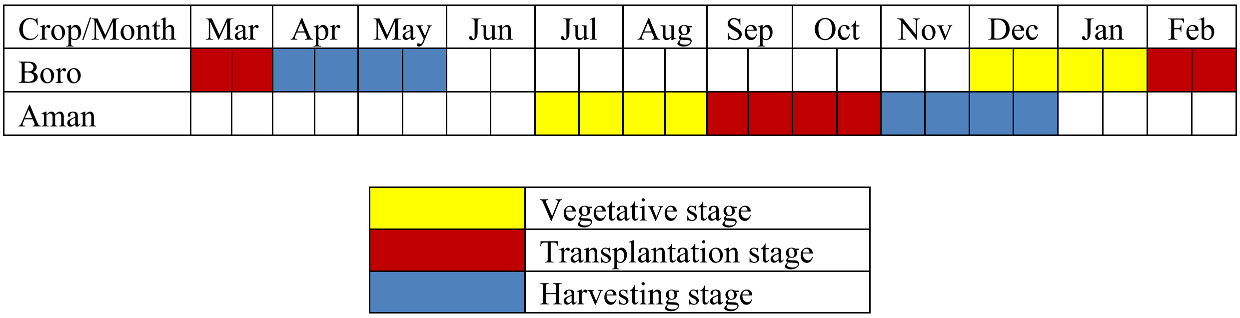

Figure 4.1 Major Cropping Pattern at Khanpur

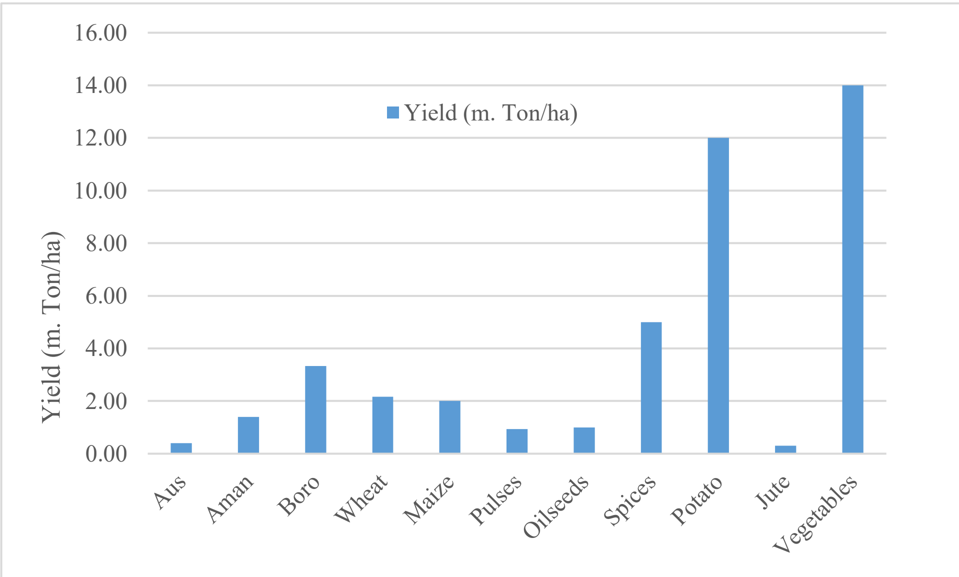

Figure 4.2: Agricultural Production of Different Crops at Khanpur

The main source of irrigation water at the Khanpur area was shallow tube well (STW). About 80% of the farmers are using STW for agricultural production. They use groundwater for irrigation. Some farmers use deep tube well (DTW) for producing different crops. Very few farmers use rainwater for production. Water quantity and water quality were the two sub-indicators considered under water availability. Average satisfaction level of water quantity was found to be good (3) at the area. Average value of farmers' satisfaction level for water quality was also found to be good (3) at the agro-ecosystem.

4.2.1.2 Agricultural water availability at Kheshra

Kheshra area is burdened with salinity in water. Farmers cannot produce plenty of production here. The major cropping pattern at the agro-ecosystem is shown in Figure 4.3. Farmers produce aus, aman, boro, wheat, jute and mustard in the area at different times of the year (Figure 4.4). Though they produce mustard, jute and onion, but the yield is very low which is clear from Figure 4.4. The minimum salinity varied from 300–700 ppm for shallow aquifer and was around 300 ppm for deep aquifer in different locations of the area. The maximum value in different locations varied from 800–4200 ppm and 500–7800 ppm for shallow and deep aquifers, respectively (Rahman and Rahman, 2011). On the other hand, the minimum salinity for each location in shallow aquifer assessed in the form of chloride varied from 51-338 ppm, while the maximum value varied from 294-375 ppm. Similarly, the minimum value in deep aquifer ranged from 43-124 ppm, while the maximum value ranged from 166–4309 ppm. The salinity in the deep tube wells was mostly within 1000 ppm. Only 5.6% of the deep hand tube wells (DHTWs) had salinity exceeding 1000 ppm. In Paikgacha almost all DHTWs had salinity exceeding 1000 ppm (Rahman and Rahman, 2011).

At Kheshra, farmers use both STW and LLP (Low Lift Pump). About 60% of the farmers use STW and rest 40% use LLP (field survey, 2016) for cultivation of different crops. Again some farmers produce saline tolerant rice but the practice is not wide because of not getting enough support and also their lack of knowledge.

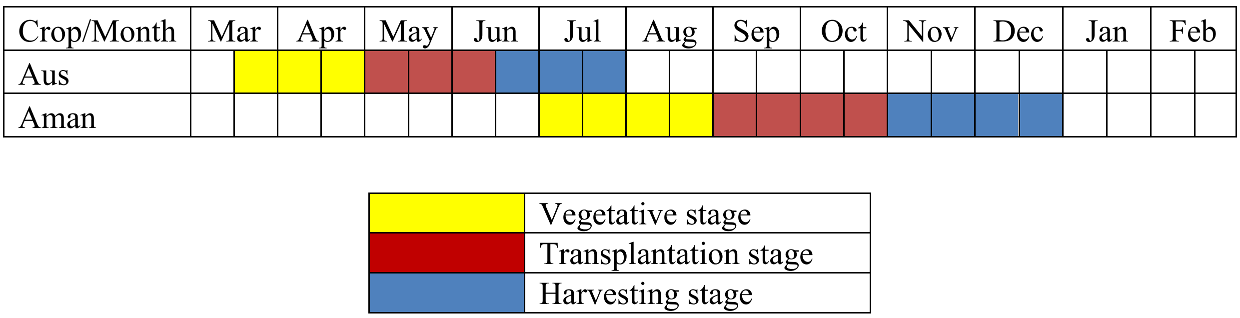

Figure 4.3 Major Cropping Pattern at Kheshra

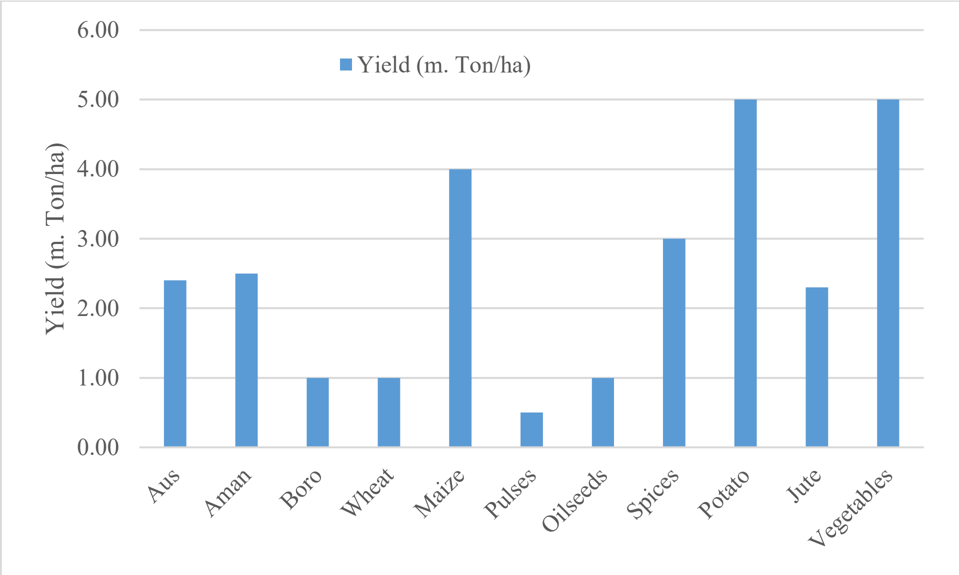

Figure 4.4 Agricultural Production of Different Crops at Kheshra

4.2.1.3 Agricultural Water Availability at Bhorot Bhaena

The process of temporarily inundating Beels in order to prevent drainage congestion is now often referred to as "Tidal River Management" or TRM. On October 29th 1997, people in Beel Bhaina cut their embankment with the Hari River, as they hoped that the sediment-laden water would raise the land of their beel and thereby improve drainage (SMEC, 2003). While the Bangladesh Water Development Board was implementing the Khulna-Jessore-Drainage Rehabilitation Project, Beel Bhaina was turned into a tidal basin which inundated the entire 900 hectares of the beel. Initially, the BWDB's response was to take legal action against the people who cut the embankments, because the embankments (property of the BWDB) were destroyed. Under pressure from ADB consultants for the KJDRP, no legal action was taken. After the cut, cross sections and sediment deposition in Beel Bhaina were monitored by the implementing authorities of the KJDRP; the BWDB, SMEC engineers and ADB consultants (SMEC, 2007). As the tidal prism increased, the cross section of the Hari River downstream of Beel Bhaina increased considerably and during the entire period, the beel functioned as a tidal basin (SMEC, 2002). Additionally, sediment was deposited in Beel Bhaina, raising its land level by an average of 78 cm (SMEC, 2007). As the tidal basin increased the cross section of the Hari River downstream of Beel Bhaina, drainage improved considerably. Beel Bhaina remained functional as a tidal basin until December 8th, 2001. When the cut was closed, the bed level of the Hari River rose by more than 6 m in the next 8 months (SMEC, 2007).

Major cropping pattern at Bhorot Bhaena is given in Figure 4.5. Farmers are producing plenty of production at Bhorot Bhaena after implementation of TRM (Figure 4.6). During TRM operation in Bhorot Bhaina tidal basin, the average discharges entering the basin during dry, pre monsoon, monsoon and post monsoon seasons were measured as around 160, 230, 400, 260 m^3/s respectively [20]. At present, farmers grow more than one crop every year. Single cropped lands occupy around 0.4% to 14% of the entire study area. Double cropped lands occupy about 50% - 98% of the study area and triple cropped lands occupy about 25% - 49% of the area.

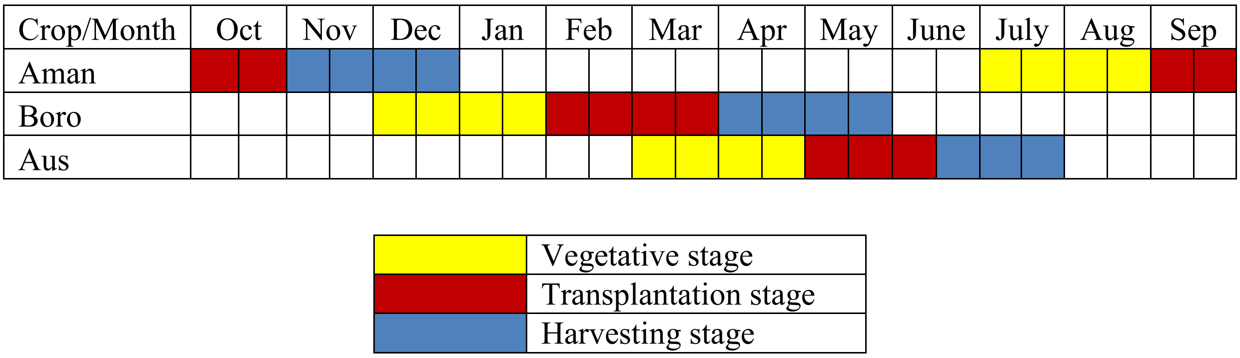

Figure 4.5 Major Cropping Pattern at Bhorot Bhaena

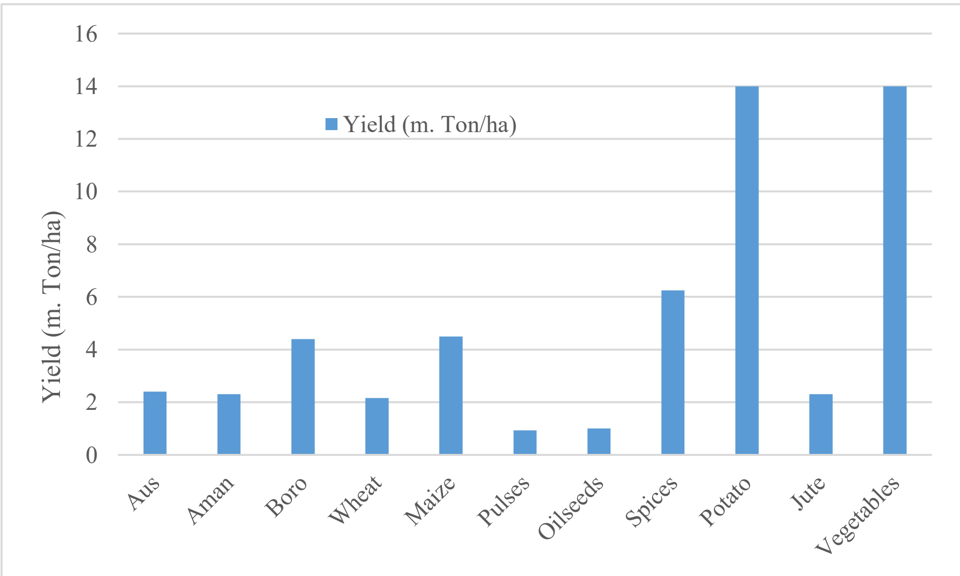

Figure 4.6 Agricultural Production of Different Crops at Bhorot Bhaena

Two different sub-indicators were considered to assess agricultural water availability at different agro-ecosystems. These were water quality and water quantity. There was no major problem with water quality at Khanpur and Bhorot Bhaena. Satisfaction values of farmers were given based on a scale of 5 where 1 indicates dissatisfaction and 5 indicates high satisfaction. Satisfaction value of farmers for water quality was very low (1) at Kheshra area. Most of the farmers were very dissatisfied with the water quality at Kheshra area. There was no problem with water quantity in three different study sites. But water logging was a major problem at Khanpur. People were unable to manage the water at Khanpur area. In the rainy season, the area (Khanpur) gets water logged because of drainage congestion and farmers become unable to continue any production at the area. The satisfaction level for water availability is overall good at Khanpur and Bhorort Bhaena, but low at Kheshra area of Tala Upazila.

4.2.3 Water accessibility at three different agro-ecosystems

Three sub-indicators were considered to measure access to water at different agro-ecosystems. These were distance, time and comfort. Farmers' satisfaction levels were measured based on a scale of one to five where 1 indicated dissatisfaction and 5 indicated high satisfaction. The average values for satisfaction level of the farmers for distance and time were good (3) at Khanpur, Kheshra and Bhorot Bhaena areas. But the level of comfort varied at different study sites. The average value of comfort was very good (4) at Beel Bhaena area and low (3) at Khanpur and Kheshra areas. Hence, it appears that the farmers were getting and using water more comfortably for agricultural production at Bhorot Bhaena area than at Khanpur and Kheshra areas.

4.2.4 Water use at three different agro-ecosystems

Two sub-indicators, amount of production and amount of water, were used to identify satisfaction level for water use at Khanpur , Kheshra and Bhorot Bhaena. Average amount of water use at Khanpur was found to be good (3) but the amount of production is not proportionally good because of water logging. Farmers' level of satisfaction for water use was good at Khanpur and Bhorot Bhaena as the production to water ratio was high in these agro-ecosystems. But farmers' satisfaction level for water use was low (2) at Kheshra area. Because of salinity problem at the area, farmers were not getting enough production though they used enough water in the land. At Bhorot Bhaena the condition is comparatively better but still agricultural productivity can be increased with proper management of land and water.

4.2.4 Capacity to use water at three agro-ecosystems

Three types of capacities were considered to assess overall capacities of different agro-ecosystems. These were human, organizational and technological capacities. Human capacities include farmers' knowledge, skill for agricultural production. As coastal areas are prone to natural disasters, farmers' knowledge and skill to deal with and mitigate hazard is very important for agricultural production. Again organizational capacity includes capacity of different organizations like Water Users Association (WUA), Water Management Committee (WMC), etc. to increase agricultural production and also to deal with hazards to continue production. Technological capacity includes capacity to use different technologies for improvement of agricultural production.

At Khanpur, farmers lack in adequate knowledge to deal with water logging problem. Even there was no WUA in the area to improve farmers' capacity to deal with excessive water. Farmers were not working cohesively to deal with hazards. They were not given proper training to deal with hazards and continue agricultural production. Even there was no government intervention in the area to solve the problems. No training and capacity building programs by BWDB or LGED were found in Khanpur and Kheshra areas. Farmers' level of satisfaction for capacity to use water was found to be very low in Khanpur area.

The value of farmers' satisfaction level was also low (2) at Kheshra area. Farmers had no knowledge to deal with salinity problem. They did not have enough knowledge to produce saline tolerant crops. They did not even get any governmental support for capacity improvement.

The level of satisfaction for capacity to use water was high at Bhorot Bhaena area. Farmers had regular meeting with water user association to deal with any problem related to agricultural production. But they also did not get government support for training and capacity building.

4.2.5 Hazard management at three agro-ecosystems

The major problems of the study area were water logging and salinity. Water logging in Khanpur area was not just related to heavy rainfall and extreme climatic events; it was also related to changes in the built-up areas themselves. The southwest coastal area is part of the tidal floodplain bounded in the north by the Ganges floodplain and in the south by the Sundarbans mangrove tidal forest. The tidal floodplain is strongly influenced by tide, salinity and rainfall. This plain is also crisscrossed by numerous tidal creeks or channels and has high drainage density. Through natural process the rivers carry both sweet water from upstream and tides from the sea. The major portion of the floodplain is low-lying, barely one meter above mean sea level and below high tide level. Homesteads, roads, vegetable gardens and orchards were developed on areas artificially raised by digging ponds and ditches. Daily tides used to inundate the lowlands twice a day. The Sundarbans mangrove forest drops an average of 3.5 million tons of waste per year. This is carried by the tides throughout the floodplain.

According to the focus group discussion (FGD) at Khanpur, during the 17th century, the Jamindar used to create low earthen dykes around the tidal flats to prevent tidal intrusion and wooden sluices to drain off surplus rainwater. Once the Zaminder system was abolished, the maintenance of the system was hampered. Therefore, crop failure became acute and more frequent. To solve this problem, during 1960s a series of polders was built by the Bangladesh government in the area. Although these polders provided some protection from cyclones, they contributed to the water-logging in most parts of the south west coast to varying degrees. On top, expansion of commercial shrimp farming meant that numerous structures were built to keep the saline water which contributed to congestion of the natural drainage and runoff of water. Over the period, the major rivers got silted up and navigation was reduced.

In summary, water logging at Khanpur was a result of a combination of factors that include excessive monsoon rains; inadequate drainage; mismanagement and a lack of maintenance of embankments; increased sediment and siltation of rivers; restricted river flows due to embankments built for shrimp farming; and the release of water from barrages in India especially Farakka Barrage and Durgapur / Damodar Barrage.

Poverty incidence was already high in Khanpur area (55%) and the water-logging hit the poor people most severely in 2011. The affected people were already vulnerable due to repeated water-logging over the last 10 years. Both household and local economies were not able to generate enough surpluses to recover from the cumulative impacts of past water-logging. The major livelihoods of the people were dependent on natural resources and climatic conditions. In general, 60% HHs were dependent on agriculture. However, there was a major variation when it comes to the livelihood of the poorest HHs. The analysis indicated that 60% of the poorest HHs lives on agriculture. The impact of the water-logging was not only massive but also wide-spread. This destroyed significant parts of the private and public physical infrastructure such as houses, homesteads, water and sanitation, roads, market places and embankments. The impact on the household and local economy was also significantly high. People had already lost their existing crops and agricultural equipment, business capital and other livelihood tools. This also caused immense sufferings for the people in accessing food, clean water as well as overall secured environment.

Salinity exists in the surface water of the study area since long as the area is linked with the sea through estuaries. But reduction of upland fresh water flow has increased since commissioning of Farakka Barrage as well as sedimentation has increased in the river system of the region. Salinity in Keshabpur was increasing from detachment of the Kobadak River from the Ganges River via the Mathabhanga River. Change in groundwater salinity was not prominently perceived but there was apprehension of increase. It was perceived that salinity was increasing in groundwater in the areas namely Kheshra, Paikgachha, Abaynagar, Manirampur, Batiaghata, etc., according to KIIs and FGDs. In Kheshra area, salinity starts from deep aquifer and increases with the increased depth. In some places in the area, suitable deep aquifer was not available. In these places people used shallow tube well for domestic purpose. Shrimp was cultured throughout the area. People considered it highly beneficial and economically viable. Here, at some places, shrimp fields were operated in dry months while the same land was used for paddy in wet months. However, it was almost universally felt that shrimp culture by intruding saline water was degrading the soil quality and poor paddy production. With recent outbreak of virus infection in shrimp, people had started shrimp culture with STWs with low saline water. This had done away with the problem of virus infection and paddy production was less affected by low saline water of STWs.

These two sub-indicators (water logging and salinity) were considered under the indicator hazard management. At Khanpur, water logging problem was severe and salinity problem was very high at Kheshra area. Satisfaction value for disaster management was very low in these two (Khanpur and Kheshra) agro-ecosystems. But after implementation of TRM at Bhorot Bhaena, there was no water logging problem and farmers were able to produce plenty of production of different crops. Satisfaction level of farmers was high at Bhorot Bhaena area.

4.3 Ownership of Agricultural Land at Three Agro-ecosystems

There were three types of ownership of agricultural lands at the study sites. At Khanpur, about 80% of the agricultural lands were owned and 20% lands were shared cropped (Figure 4.7). About 50% of the agricultural lands were leased in, 30% were owned and 20% were shared cropped at Bhorot Bhaena. In Kheshra, both shared and owned lands were found for agricultural production. But few amount of shared cropped land was found in Kheshra area. Only 30% of lands were shared cropped and 70% were owned at Kheshra area.

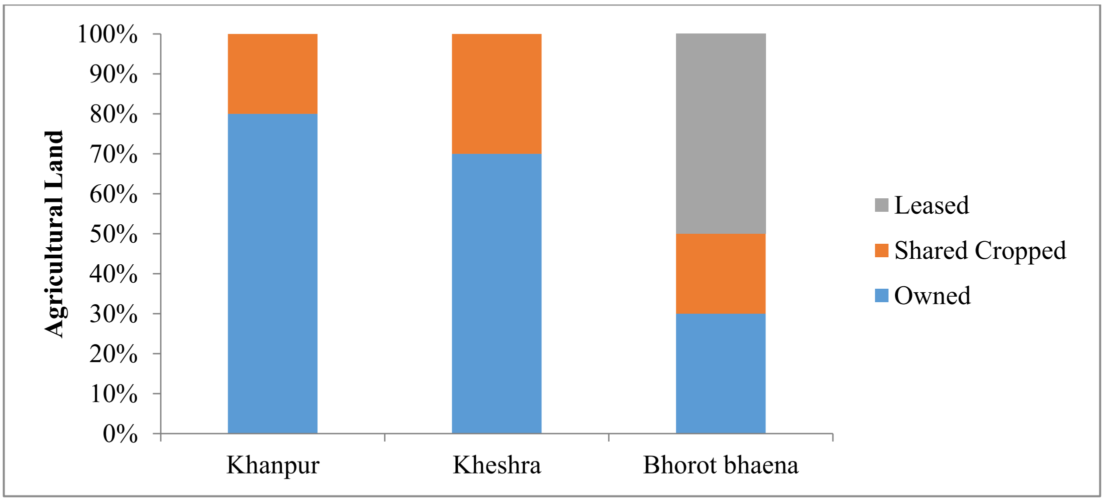

Figure 4.7 Ownership of Agricultural Land at Three Agro-ecosystems

4.4 Agricultural Water Security Index at Three Agro-ecosystems

To calculate agricultural water security index, satisfaction level of five different indicators (water availability, access to water, water use, capacity to use water and disaster management) for three different agro-ecosystems was collected through KIIs. Based on the collected information preliminary judgment matrix of different indicators was formed (Table 4.1).

Table 4.1: Judgment Matrix of Different Indicators of Water Security

	Water Availability	Access to Water	Water Use	Capacity to use	Disaster Management
Water Availability	1	3	4	1/5	7
Access to Water	1/3	1	7	1/5	7
Water Use	1/4	1/7	1	1/9	1/7
Capacity to use	5	5	9	1	7
Disaster Management	1/7	1/7	7	1/7	1

Based on Table 4.1, weights of different indicators of agricultural water security were calculated using AHP (Table 4.2). The detailed calculations on consistency evaluation are given in Table 4.3. At Khanpur, weight of water availability was found to be 0.18, access to water was 0.17, water use was 0.16, capacity to use water was 0.25 and disaster management was 0.23. Value of agricultural water security index was 2.3 (on a scale of 5) and according to the value of security index, Khanpur was not water secured for agricultural production mainly due to water logging problem.

Table 4.2: Weight of Different Indicators of Agricultural Water Security

	Water Availability	Water Accessibility	Water Use	Capacity to Use Water	Disaster Management	Row Sum	Weight
Water Availability	0.15	0.45	0.6	0.02	1.04	2.26	0.45
Water Accessibility	0.05	0.15	1.04	0.03	1.04	2.31	0.46
Water Use	0.04	0.02	0.15	0.02	0.02	0.25	0.05
Capacity to Use Water	0.74	0.74	1.34	0.15	1.04	4.01	0.8
Disaster Management	0.02	0.02	1.04	0.02	0.15	1.25	0.25

Table 4.3: Consistency Evaluation of the Weights

Column Sum	Weight	λmax	CI	RI	CR
6.72	0.2	1.35			
9.28	0.17	1.57			
28	0.03	0.92	0.38	1.12	0.08
1.57	0.51	0.81			
22.14	0.08	1.87			

The value of CR is calculated dividing CI by RI. Consistency ratio is less than 0.1. So, the given weights are acceptable. Calculation of weights of sub-indicators are given in Appendix A.

Table 4.4 Agricultural Water Security Index at Three Agro-ecosystems

	Khanpur	Kheshra	Bhorot Bhaena
Water Availability	0.18	0.16	0.18
Access to Water	0.17	0.18	0.23
Water Use	0.16	0.14	0.17
Capacity to use	0.25	0.27	0.20
Disaster Management	0.23	0.25	0.22
Water Security Index	**2.30**	**2.00**	**4.20**

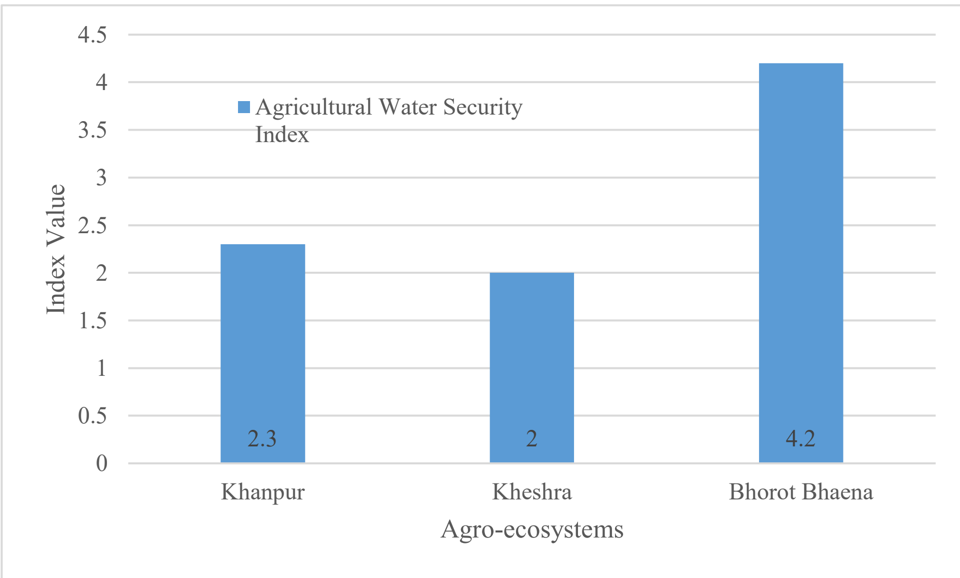

Figure 4.8 Value of Agricultural Water Security Indices at Three Agro-ecosystems

At Kheshra, weight of water availability was found to be 0.16, access to water was 0.18, water use was 0.14, capacity to use water was 0.27 and disaster management was 0.25 (Table 4.4). Agricultural water security index value was 2.00 (Figure 4.8) which indicated water insecurity at the area. Due to salinity problem, agricultural productivity was low in the area.

Agricultural water security index value was high at Beel Bhaena area which was 4.2. Weight of water availability was 0.18, access to water was 0.23, water use was 0.17, capacity to use water was 0.20 and disaster management was 0.22. Because of the implementation of TRM, farmers were producing plenty of production in the area. According to the result, the area was water secured for agriculture.

4.5 Comparison between agricultural water security indices with ANOVA

ANOVA test has been used to decide whether there is any statistically significant variation between agricultural water security indices at three different study sites. The results of analysis are given in Table 4.5. Two hypotheses were considered:

Null hypothesis: There is no significant variation between agricultural water security indices of three different locations.

$H_o: \mu_1 = \mu_2 = \mu_3$

Alternate hypothesis: There is significant variation between agricultural water security indices of three different locations.

$H_a: \mu_1 \neq \mu_2 \neq \mu_3$

F value, which is a ratio of between column variance and within column variance, is found to be 4.467 (Table 4.6). The F statistics suggested a rejection of the null hypothesis which indicates that there is a significant variation between agricultural water security indices at three different study sites. The value is found to be high at Beel Bhaena area and low at Khanpur and Kheshra areas.

Table 4.5: Index Value of Different Indicators at Three Agro-ecosystems

	Khanpur	Kheshra	Bhorot Bhaena
Water Availability	18.25	5	20.5
Access to Water	6.45	5.1	7.5
Water Use	5.4	4.2	8.6
Capacity to use	5.8	11.6	37.7
Disaster Management	4.4	2.2	16.28

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Table 4.6: ANOVA Table

	Sum of Squares	df	Mean Square	F	Sig
Between Groups	91.467	2	45.733	4.467	0.021
Within Groups	276.4	14	10.237		
Total	367.867	16			

Table 4.6 represents results of the ANOVA analysis and whether there is a statistically significant difference between the group means. We can see that the significance value is 0.021, which is below 0.05. Therefore, there is a statistically significant difference between the index values of water security indicators at three different study sites.

4.6 Suitable Strategies to Improve Agricultural Water Security

Weight of different indicators to propose suitable strategies at different study sites have been calculated using AHP. The indicators considered to propose suitable strategies were environmental feasibility, financial feasibility, operational feasibility and technical feasibility. Weight of environmental feasibility was 0.22, financial feasibility was 0.33, operational feasibility was 0.35 and technical feasibility was 0.10. According to the weight, financial and operational feasibility were the most important factors for proposing suitable strategies to improve agricultural water security.

4.6.1 Suitable strategies for Khanpur

4.6.1.1 Tidal river management (TRM)

The southwest area is blessed with upstream flow through the Gorai River, a major tributary of the Ganges and historically bringing huge fresh water and silt. During the last few decades, upstream water flow has been reduced significantly due to withdrawal of the Ganges water by the upstream country. Historically when there were no polders, tidal waters used to inundate the tidal floodplain and the silts were deposited into the tidal plains raising the elevation which again were adjusted mostly due to subsidence maintaining the topography. While the polders were obstructing this natural flow, the sediment load started depositing in the channel and the river bed was silting up the water courses. This has been fostered by significant reduction of water flow during the dry season from the upstream. The combined effect of these resulted into serious congestions and turned entire area into water world. In 1984, Dakatia beel, a part of one polder became water logged for the first time, due to rapid siltation of the Solmari, Hamkura and Hari rivers. Later this problem spread to even more polders. Moreover, lands outside the polders in the greater Jessore district went under water. This problem is gradually creeping to the northern part as well as in the southern part of the embankment area. Fifteen years after the construction of the coastal embankments, water logging began to emerge in the polders. Historically, people cultivated rice in the area putting temporary embankment for eight months of the year and removed the embankment after harvesting allowing the natural flow of the system. People realized from experience and observation, people identified the polders as the main cause of water logging and in October 1997, the people to get rid of the problem wanted to bring back old good days in their mind. They breached the right embankment along the Hari River to allow free access of tides to

Bhaina beel. People were successful in reducing water logging in that specific area and the Bangladesh Water Development Board also realized the old good and natural system of trapping silts into the tidal plain and allowing the channels to drain water. So the concept of Tidal River Management (TRM) emerged accommodating the indigenous process. The high tides bring in muddy water flow with a thick concentration of sediments and allow them to enter a tidal plain, leaves a part of the sediment to be deposited on the tidal plain and the rest goes back to the ocean through the channels. Over time the deposition of sediments raises land level in the tidal plain and enriches the soil. Since this process does not allow sediments to be deposited on river bed, the depth of the river bed also increases due to water velocity and makes the river congestion free. Bangladesh Water Development Board with the financial assistance from ADB also demonstrated this indigenous knowledge based tidal river management (TRM) approach in 1993, which was later found as technically feasible, economically viable, and socially acceptable. The water management groups at the village level were formed at a much later stage and had little contribution to project design and implementation.

National level scientific and knowledge institutions like Institute of Water Modeling (IWM), Centre for Environmental and Geographical Information Services (CEGIS), and multilateral development finance agency Asian Development Bank (ADB) have acknowledged the concept to be an effective way to mitigate the water logging crisis that has been plaguing the region since the 1980s (ADB 2007; CEGIS 1998; IWM 2007, 2008). Local communities, national and regional NGOs and scientific institutions think that planned management of sediment carried by the river is possible through Tidal River Management (TRM). Studies and community consultation has shown that Tidal River Management (TRM) can be scaled up and replicated on river basins throughout the southwest coastal region. It is the most effective method to raise land and make it cultivable, mitigate water logging crisis, increase navigability of rivers, reduce salinity and is used as the most effective climate change adaptation strategy to protect the region from sea level rise (Uttaran, 2011). According to the residents and farmers of Khanpur area, TRM is the most effective way to improve agricultural water security in Khanpur area.

4.6.1.2 Mixed cropping system

Rice as a mixed cropping system could be a better option for flood-prone conditions. Rice is usually broadcast with mungbean, sesame, fodder, sorghum, jute, etc. in summer. Mixed cropping induces a fair degree of sustainability in the system even if the rice crop fails. The mixed crops are harvested before the floods in June-July. Yields as high as 4 t/ha could be achieved with rice, mung, bean and jute in the study areas of Khanpur.

4.6.1.3 Flood tolerant rice varieties

Flood-tolerant rice varieties like scuba rice, swarna-sub, samba mahsuri-sub and IR64-sub can be grown in areas which are frequently affected by floods causing inundation. According to the FGDs, flood-tolerant rice variety can be a suitable strategy for increasing agricultural water security in Khanpur area. Some integrated farming system like rice-fish-azolla, rice-fish-pig, rice-poultry-duck, rice-fish-goat and rice-fish-cattle/buffalo can also be suitable for flood prone areas like Khanpur.

4.6.1.4 Zero-tillage technology

In the rabi season, sowing of wheat or lentil in the low lying areas may be taken up with the help of zero tillage technology. Zero tillage machine of wheat sowing is a special technique of establishing crops without tillage and seedbed preparation. Wheat is sown through zero tillage drills in the residual moisture to avoid the late sowing and save land preparation cost in rice fields. In uplands with irrigation facilities, crops like winter maize, potato, onion, sweet potato and vegetables can also be sown with zero tillage.

4.6.2 Suitable strategies for Kheshra

At Kashimnogor, Kheshra, suitable strategies to improve agricultural water security were found to be saline tolerant rice varieties, short duration rice varieties, rice-prawn farming and rainwater harvesting.

4.6.2.1 Saline resistant crop varieties

Saline tolerant rice varieties which can be cultivated in Kheshra area of the southwest coastal region are BRRI dhan 47 (Boro), BRRI dhan 41 and BINA 8.

BRRI dhan 41 – an Aman variety – has been developed to resist salinity. It can sustain salinity up to 8 to 10 dS/m. The yield per decimal of BRRI dhan 41 is 14.1 kg. It is identified that this variety can be cultivated in Kheshra areas, especially where salinity levels are constantly rising.

BRRI dhan 47 is another widely popular saline-resistant rice crop. This variety can tolerate 8 to 10 dS/m of saline levels. The life of the plant is 152 days. BRRI dhan 47 yields 15 kg per decimal.

BINA 8 has been developed by BINA using gamma radiation. It can resist higher levels of salinity and yield 24.2 kg per decimal. It is farmed in both Boro and Aman seasons.

Very recently, government agricultural agencies (including BRRI, BINA and BARI) have developed rice, maize and vegetable cultivars to address the salinity issue, though these cultivars are not yet available at the community level. Some demonstration plots have been established in the study area by the DAE in collaboration with on-farm research divisions of BRRI, BARI and BINA, to demonstrate results and to motivate farmers to cultivate these salt resistant cultivars. The Bangladesh Agriculture Development Corporation (BADC) was continuing its seed multiplication program to ensure quality seeds and to make them available to the farming community during the production period, thus encouraging them to cultivate saline-resistant cultivars as well as harvesting more crops.

Although the uptake of saline-resistant varieties has been reasonably high, there are several barriers to this. In this context, a common problem is the lack of freshwater due to the lack of khals. Fertilizer and pesticide costs are too high; thus some adaptation mechanisms cannot be realized. Removing salinity is also expensive, which is another obstacle to adaptation. Another pressing issue is that there is a lack of capacity or training. About 20 percent of the respondents of the study area faced this problem. The lack of quality seeds was also a problem faced by 16 percent of the respondents surveyed. However, households had attempted to overcome these barriers in different ways. Although saline tolerant varieties were a good adaptation option for the farmers for higher productivity and economic gain, these seeds were not usually available in the market place. Only the BRAC center provided saline tolerant varieties at the farmer level in the Kheshra area. Thus, supply chain development along with ensuring availability and accessibility can boost the cultivation practice of this variety as an adaption option.

Since Kheshra was the most affected region by salinity, action to train the affected farmers was more critical there and accounted for the higher levels of trainings. Overall, however, fewer people had received training in the study area (45 per cent). Though only 35 percent of the respondents were trained on saline-resistant cropping systems, 97 percent of all respondents wished that there were training programs on saline-resistant agriculture. At a stakeholder workshop it was mentioned that some areas were inaccessible by any kind of transportation. Such areas lack infrastructural facilities, as a result of which training was scarce, despite the fact that it was much needed in those areas.

4.6.2.2 Rice-prawn farming

Rice-prawn farming was a widely practiced adaption option against flood and salinity in the southwest region. In the same unit of land, a canal was excavated surrounding the rice field to cultivate the prawn, and the rest of the areas were used for rice cultivation. The rainwater could also be stored in the canal and used for irrigation purpose later. Integrating rice-prawn farming can effectively compensate the loss and generate net revenue. The average productivity of rice-prawn farming is notably higher than any kind of rice cultivation in Bangladesh. The BCR of such adaption option is about 3.2, according to a key informant. This signifies that any spending on rice-prawn farming as an adaptation option can provide more than triple financial benefit to the farmers.

As an adaptation option, rice-prawn farming offers more benefits to society as a whole. It helps to decrease the seasonal food shortage in the saline and flood prone areas. Since rice-prawn farming is more profitable than rice farming, the economic status as well as the well-being of the farmer increases. Simultaneously, rice-prawn farming can contribute to the prawn export earnings for Bangladesh. Some problems were also involved with this adaptation option. The juvenile prawn was not available all the times in the study area. There was also a question of quality juvenile prawn. Hence, emphasis was needed to be given to extensively produce the juvenile prawn locally to diminish the seasonal crisis and ensure the quality. Some institutional support may be useful in this regard.

4.6.2.3 Rainwater harvesting

At the community level, the farmers of the study area were practicing excavation and re-excavation of mini-ponds on their lands to store water during the monsoon season and to irrigate their crop fields during the dry period. In addition, they were also using fresh surface water from excavated and re-excavated khals and other sources that were available near their fields to irrigate them during the dry period – but these sources were not sufficient. People in the communities of the study area mentioned that a huge area of canal had been excavated once, but it has not been re-excavated for a long time. The canal had silted up, thus constraining the sources of irrigation. Initiatives taken to re-excavate the canal will allow more water to be stored during the monsoon season, which could be used in the dry period for irrigation purposes to increase the cultivation area and raise the production.

4.6.3 Suitable strategies for Bhorot Bhaena

Agricultural production at Bhorot Bhaena is found to be better compared to that at Khanpur and Kheshra. The production increased significantly after implementation of TRM since the year of 2014. Still there is scope for increased agricultural productivity through improvement in strategies like rainwater harvesting and rice-prawn farming.

One way to increase agricultural productivity is to provide more irrigation facilities. Crop productivity depends not only on the quality of inputs but also on the irrigation facilities. Therefore, more canals should be re-excavated to provide better irrigation facilities for the security of crops.

Marketing infrastructure at Bhorot Bhaena should be widened and strengthened to help the farmers to sell their products at better prices. There should be proper arrangements for unloading of the produce in the markets. Besides, price support policy must be adopted and minimum prices should be guaranteed to the peasants.

To advise the farmers regarding the adoption of new technology, arrangements should be made in the area for agricultural education and extension services. It would assist the farmers to take proper crop-care leading to increase in crop productivity.

To check the sub-division and fragmentation of holding, the program of co-operative farming can be launched at Bhorot Bhaena. Co-operative farming would result in the adoption of modern technology on so-called big farms. In this way, agriculture will become lucrative occupation through economies of large-scale farming.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study analyzed agricultural water security and formulated suitable adaptation strategies for three different agro-ecosystems of Tala Upazila, Satkhira district. AHP was used to calculate agricultural water security indices at three study sites. At Khanpur, weight of water availability was found to be 0.18, access to water was 0.17, water use was 0.16, capacity to use water was 0.25 and disaster management was 0.23. Value of agricultural water security index was 2.3 (on a scale of 5.0) and according to the index value, Khanpur was not water secured for agricultural production mainly due to water logging problem. At Kheshra, weight of water availability was found to be 0.16, access to water was 0.18, water use was 0.14, capacity to use water was 0.27 and disaster management was 0.25. Agricultural water security index value was 2.00, which indicated water insecurity at the area. Mainly because of the salinity problem, the area was not secured for agricultural production. At Bhorot Bhaena, the value of agricultural water security index was found to be 4.2. Weight of water availability was 0.18, access to water was 0.23, water use was 0.17, capacity to use water was 0.20 and disaster management was 0.22. The index value was high in this area because of the implementation of TRM. Finally, it can be said that agricultural water security indices at Khanpur and Kheshra were found to be very low which indicated agricultural water insecurity in both these areas. As the result indicated, Bhorot Bhaena area was water secured for agricultural production.

Weight of different indicators to propose suitable strategies at different study sites have been calculated using AHP. The indicators considered to propose suitable strategies were environmental feasibility, financial feasibility, operational feasibility and technical feasibility. Weight of environmental feasibility was 0.22, financial feasibility was 0.33, operational feasibility was 0.35 and technical feasibility was 0.10. According to the weight, financial and operational feasibility were the most important factors for proposing suitable strategies to improve agricultural water security. At Khanpur, suitable strategies were tidal river management, flood tolerant rice variety and mixed cropping system. At Kashimnogor, suitable strategies to improve agricultural water security were found to be saline tolerant rice varieties, short-duration rice varieties, rice-prawn farming and rainwater harvesting. Though agricultural production at Bhorot Bhaena was found to be good but still the productivity can be increased using strategies like land reforms, co-operative farming, irrigation facilities and proper marketing facilities.

5.2 Recommendations

The following recommendations were made based on the findings of this study and the experiences gained during this study:

- It is found both from field visits and literature reviews that, the implementation of TRM has a positive effect on agricultural water security. Hence, it is recommended that the TRM should be implemented, where feasible, to improve agricultural water security. But before taking any TRM project, other relevant factors like impacts on settlements and displacement issues, water logging, salinity, river erosion, drought, income, shrimp sector and agriculture sector should be considered.
- A similar study should be undertaken to assess agricultural water security in other areas of the south-western coastal region of Bangladesh. This will provide a more general picture of agricultural water security in the region and further confirm the suitability of the approach.
- In this study, only agricultural water security indices for different areas of a single upazila were analyzed. Such securities for other water uses like household water security and environmental water security can be studied to generate complete water security scenarios for the upazila. Consequently, it will help manage water resources in a more sustainable manner.

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APPENDIX A

CALCULATION OF WEIGHTS OF SUB-INDICATORS OF WATER SECURITY

Table A1: Priority Vector Matrix of Water Availability

	Water Quantity	Water Quality
Water Quantity	1	1/7
Water Quality	7	1

Table A2: Weight of Sub-Indicators of Water Availability

	Water Quantity	Water Quality	Row Sum	Weight
Water Quantity	0.13	0.02	0.15	0.08
Water Quality	0.88	0.13	1.01	0.51

Table A3: Consistency Evaluation of the Weights

Column Sum	Weight	λ max	CI	RI	CR
6.72	0.2	1.35	0.38	1.12	0.08
9.28	0.17	1.57			

Table A4: Priority Vector Matrix of Water Use

	Amount of Production	Amount of Water
Amount of Production	1	0.14
Amount of Water	7	1

Table A5: Weight of Sub Indicators of Water Use

	Amount of Production	Amount of Water	Row Sum	Weight
Amount of Production	0.13	0.12	0.25	0.13
Amount of Water	0.88	0.88	1.76	0.88

Table A6: Consistency Evaluation of the Weights

Column Sum	Weight	λ max	CI	RI	CR
6.72	0.2	1.35	0.54	0.58	0.09
9.29	0.17	1.57			

Table A7: Priority Matrix of Sub Indicators of Capacity to Use Water

	Human Capacity	Organizational Capacity	Technological Capacity
Human Capacity	1	2	1/5
Organizational Capacity	1/2	1	1/7
Technological Capacity	5	7	1

Table A8: Weight of Sub Indicators of Capacity to Use Water

	Human Capacity	Organizational Capacity	Technological Capacity	Row Sum	Weight
Human Capacity	0.15	0.31	0.03	0.49	0.16
Organizational Capacity	0.08	0.10	0.02	0.20	0.07
Technological Capacity	0.77	0.70	0.15	1.62	0.54

Table A9: Consistency Evaluation of the Weights

<table>
<tr><th>Column Sum</th><th>Weight</th><th>λ max</th><th>CI</th><th>RI</th><th>CR</th></tr>
<tr><td>5.72</td><td>0.16</td><td>1.35</td><td rowspan="3">0.38</td><td rowspan="3">1.12</td><td rowspan="3">0.08</td></tr>
<tr><td>10.24</td><td>0.07</td><td>1.57</td></tr>
<tr><td>25</td><td>0.54</td><td>0.92</td></tr>
</table>

Table A10: Priority Matrix of Sub Indicators of Water Accessibility

	Distance	Time	Comfort
Distance	1	0.20	7
Time	5	1	9
Comfort	0.14	0.14	1

Table A11: Weight of Sub Indicators of Water Accessibility

	Distance	Time	Comfort	Row Sum	Weight
Distance	0.16	0.03	1.14	1.33	0.44
Time	0.81	0.16	1.47	2.44	0.81
Comfort	0.02	0.02	0.16	0.20	0.07

Table A12: Consistency Evaluation of the Weights

<table>
<tr><th>Column Sum</th><th>Weight</th><th>λ max</th><th>CI</th><th>RI</th><th>CR</th></tr>
<tr><td>7.72</td><td>0.44</td><td>2.35</td><td rowspan="3">0.45</td><td rowspan="3">0.58</td><td rowspan="3">0.07</td></tr>
<tr><td>11.24</td><td>0.81</td><td>2.57</td></tr>
<tr><td>29</td><td>0.07</td><td>0.82</td></tr>
</table>

Table A13: Priority Matrix of Sub Indicators of Disaster Management

	Water Logging	Salinity
Water Logging	1	3
Salinity	0.33	1

Table A14: Weight of Sub Indicators of Disaster Management

	Water Logging	Salinity	Row Sum	Weight
Water Logging	0.75	0.75	1.5	0.75
Salinity	0.25	0.25	0.5	0.25

Table A15: Consistency Evaluation of the Weights

Column Sum	Weight	λ max	CI	RI	CR
9.52	0.75	2.35	0.54	0.58	0.089
13.24	0.25	2.57			