Water Poverty for Different Livelihood Groups in Peri-urban Areas in a Changing Environment

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The thesis titled "**Water Poverty for Different Livelihood Groups in Peri-urban Areas in a Changing Environment**" submitted by Lamiya Sharmeen Jaren, Roll No.: 1017282033, Session: October 2017, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Science in Water Resources Development on 04 January, 2020.

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Lamiya Sharmeen Jaren

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Session: October, 2017

Dedicated

to

My Beloved Parents

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ABSTRACT

Water is one of the most essential elements for human life and survival of our ecosystem. There is a direct relationship between income poverty and water poverty. Water poverty is the situation of not having access to sufficient water of adequate quality or sufficient capacity to meet basic needs. This study assessed water poverty for different livelihood groups of three different types of peri-urban areas (Tetuljhora, Dhalla and Saista unions) by using Water Poverty Index (WPI), an inter-disciplinary tool to measure water stress. Both present and future WPIs were estimated for male and female industrial workers, male large and small farmers, female farmers and economically inactive women group (unemployed women, adolescent girls, physically challenged and elderly women). The WPI is an indicator-based approach and comprised of five components: Resource, Access, Capacity, Use and Environment. Data for the study was collected from 260 respondents, made up of 120 men and 140 women. Principal Component Analysis (PCA) was performed to assign component weights and weighted multiplicative function was used for constructing the final indices. Different aspects of environmental change, such as population growth, land use change and changes in water level, and climatic change, such as changes in rainfall and temperature were also assessed in this study.

Currently, the economically inactive women group (41.46) in Saista is the most water-poor group. But, in future the small male farmers (33.8) will be the most water-poor group. Comparison of the present and future WPIs indicated decreasing values of physical components (Resource and Environment). The future scores showed that better scores in Access, Capacity and Use might help the groups to adapt to the future water poverty. So, in order to be more water-secured, social components must be improved. Role of education and different awareness programs is important to fight against the increased conflicts and violence regarding water use. The climatic and environmental factors indicated adverse effect in near future. Only 31.67% men and 23.57% women had basic knowledge on climate change. Women farmers will be more affected due to high temperature as most of them had to collect water from a distant water source. The farmers will suffer the most for the rainfed crops due to high rainfall variability and decreasing groundwater level. In this case, cultivation of climate-resilient crops are needed for ensuring food security.

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Abbreviations and Acronyms

AIDS	Acquired Immunodeficiency Syndrome
AWPI	Agricultural Water Poverty Index
AWR	Available Water Resources
BBS	Bangladesh Bureau of Statistics
BMD	Bangladesh Meteorological Department
BWDB	Bangladesh Water Development Board
CBN	Cost of Basic Needs
CETP	Common Effluent Treatment Plant
CCC	Committee on Climate Change
CDMP	Comprehensive Disaster Management Program
CV	Coefficient of Variation
CVI	Climate Vulnerability Index
DFID	Department for International Development
DPHE	Department of Public Health Engineering
ECOSOC	The Economic and Social Council
eWPI	Enhanced Water Poverty Index
FGD	Focus Group Discussion
GDP	Gross Domestic Product
GWP	Global Water Partnership
HDI	Human Development Index
HIV	Human Immunodeficiency Virus
HPI	Human Poverty Index
IFAD	International Fund for Agricultural Development
IMF	International Monetary Fund
IPCC	The Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
KII	Key Informant Interview
KMO	Kaiser-Meyer-Olkin
LGED	Local Government Engineering Department

LVI	Livelihood Vulnerability Index
MDG	Millennium Development Goal
MSA	Measure of Sampling Adequacy
OECD	Organisation for Economic Co-operation and Development
PCA	Principal Component Analysis
PPP	Purchasing Power Parity
RWLI	Rural Water Livelihoods Index
SDG	Sustainable Development Goal
SLA	Sustainable Livelihoods Approach
SSWRDSP	Small Scale Water Resources Development Sector Project
SWSI	Social Water Scarcity Index
UN	United Nations
UNESCO	The United Nations Educational, Scientific and Cultural Organization
USGS	United States Geological Survey
WEF	World Economic Forum
WHO	World Health Organization
WPI	Water Poverty Index
WSI	Water Stress Index
WWAP	World Water Assessment Programme

CHAPTER ONE

INTRODUCTION

1.1 Background and Present State of the Problem

Water is an essential element for human life, our economic and social well-being, and life of our ecosystem. As water resources are threatened in so many parts of the world, especially in developing countries, human life is threatened. Water resources management and development are essential for growth of human life and ecosystem and poverty reduction. Proper distribution of water resources can improve well-being of a nation or community or household.

Water is essential for the poor in four key ways: a) for food production, b) for sound health and sanitation, especially for vulnerable groups: children, women and old people, c) for maintaining ecological integrity on which most of the world poor depend for their survival, and d) even when any water related hazard like flood, drought, storm surge or pollution occurs, poor are the most vulnerable to it (Soussan and Arriens, 2004). Millions of people around the world failed to overcome poverty because of the lack of water supply in adequate quantity and quality to sustain their livelihoods. According to UNESCO (2003), better access to better managed water could significantly reduce poverty. Alleviation of income poverty without reducing water poverty is nearly impossible.

The provision of reliable, sustained and safe water to people worldwide became a top priority on the international agenda (Garriga and Foguet, 2010), as evidenced by the UN General Assembly declaring 2008 the international year of sanitation. IMF (2005) highlighted the risk of water poverty due to lack of clean and safe water. This water poverty might occur even when there is an abundance of water, because this water may not be a useful resource due to timing of the availability, lack of socio-economic capacity or access to the resource, or inferior quality for use. Water poverty is the situation of not having access to sufficient water of adequate quality to meet basic needs. Assessment of water poverty required a holistic approach to consider all these characteristics that linked water and poverty (Heidecke, 2006).

A method that was easy to calculate, cost effective to implement, based mostly on existing data, and that used a transparent process (i.e. easy to understand) was needed by policy makers and funding agencies. This could be done by designing Water Poverty Index (WPI), an alternative water situation assessment tool, suggested by Sullivan et al. (2002). The WPI captured the whole range of issues related to water resources availability as well as their impacts on people (Sullivan et al., 2006). Rahman (2004) proposed a set of water poverty indicators for monitoring the performance of macro-scale water sector interventions in Bangladesh. The WPI could be defined as an inter-disciplinary tool that integrated the key issues relating to water resources, combining physical, social, economic and environmental information associated with people's ability to get access to water and to use water for productive purposes (Sullivan and Meigh, 2003). The WPI represented different water management issues integrating assessment of water scarcity and various socio-economic variables related to water availability (Sullivan, 2002). The WPI had the following advantages over conventional methods (Sullivan and Meigh, 2007; Komnenic et al., 2009; Cho et al., 2010):

- It was a mechanism to prioritize water needs.
- It provided a better understanding of the relationship between the physical availability of water, its ease of abstraction, and the level of welfare.
- The WPI was mainly designed to help improve the situation for people facing poor water endowments and poor adaptive capacity.
- It was a tool for monitoring progress in the water sector.

- It provided a reasonably simple process to combine biophysical, social, economic and environmental data to produce a single index value, i.e. it recognized the multidimensional nature of water poverty.

Changes in the global climate over the next hundred years were almost certain (IPCC, 2014), regardless of whether they were human induced or otherwise. Bangladesh had been identified as one amongst 27 countries that are the most vulnerable to the impacts of global warming (Islam, 2004). According to Ahmed (2006), variability in climate system affected six sectors which are found to be the major users of water in Bangladesh. These included agriculture (for irrigation), domestic or municipal use of water, fisheries, navigation, industry and environment (in-stream flow including salinity control). Over the next 25 years, however, with the increase in the absolute size of the population, the per capita water availability in Bangladesh would progressively be reduced (Ahmad et al., 2001). Under general climate variability, the annual per capita water availability in 2025 will become 7,670 cubic meters as against 12,162 cubic meters in 1991 (Ahmed, 2006). However, such reduction in water availability would only affect the country's huge population during the dry season, where the current availability is already very low (Ahsan, 2006). Keeping in view the poor water availability in the dry season, the per capita available supply will be much less, while demand for irrigation and other purposes (i.e., industrial process water, domestic & municipal water supply etc.) will continue to rise. So, the changes in climate would affect the spatial and temporal distributions of surface and groundwater resources which clearly indicated that the freshwater resources availability will need to be more carefully managed in future as the water poverty status depended merely on it.

Impact of climate change and development pressure woule be differently distributed among different regions, generations, classes, income groups and men-women. Socio-economically and physically disadvantaged groups would suffer the most due to climate change induced risks (CCC, 2009). Bangladesh was frequently cited as one of the most vulnerable countries to climate change because of its disadvantageous geographic location; flat and low-lying topography. Many of the anticipated adverse effects of climate change, such as higher temperatures, enhanced monsoon precipitation and an increase in climate variability, would aggravate the existing stresses, particularly by reducing water and food security and consequently livelihood security. Peri-urban areas might face severe consequences of such effects. In the peri-urban areas of Khulna, water availability and access for the communities were adversely affected by rapid urbanization and industrialization, leading to competition and conflict over water (Narain et al., 2013).

Singair upazila of Manikganj district and Savar upazila of Dhaka district have emerged in the suburban areas of Dhaka city. Hence people of different social backgrounds are residing in these areas. Rapid development has accelerated the process of urbanization in recent years. In Manikganj, urban land use has been increased by 4% during 1989 to 1999 and 8% from 1999 to 2009 which leads to a significant decrease in the area of agriculture, water surface, bare land and vegetation cover (Sayed and Haruyama, 2015). All surface and groundwater samples of Singair upazila exceeded Bangladesh standard value for arsenic concentration (0.05 mg/L) (Akter et al., 2015). Severe iron problems in groundwater are also experienced by local people. In Savar upazila, most of the drains at the newly established Savar Tannery Estate are already choked with tannery wastes and chemicals creating drainage congestion. The untreated wastewater is also flowing into the nearby agricultural lands and wetlands, posing health hazards. Currently surface water sources are creating odor problem, aquaculture is hampered and other subsistence use is nearly impossible due to industrial wastewater dumping. In rural periphery, water supply is highly intermittent and the duration of supply is also not adequate. Most of the inhabitants perceive urbanization as a positive feature as livelihood opportunity is increasing due to the presence of tannery and other industries. As a result, migrants are increasing in these areas day by day for employment opportunities. In the study area, climate change perception is not well-conceived by local people.

Previously, different studies were conducted to assess water poverty for different households or communities. But, study on different livelihood groups is totally a new concept. Generally, high-income groups were considered to be the water-secured group as they had better access to water resources and had higher capacity than the low-income group. The hypothesis of this research was that different livelihood groups would get affected differently due to environmental change and different peri-urban settings. Therefore, this study is undertaken to address severe water related issues for different disadvantaged livelihood groups and to assess water poverty in a changing environment.

1.2 Objectives of the Study

The overall objective of the study is to assess water poverty for different livelihood groups in peri-urban areas in a changing environment. The specific objectives of the proposed study are as follows:

- To assess water poverty for different livelihood groups in selected peri-urban areas;
- To identify most water-poor group following a gender inclusive approach; and
- To assess the impact of environmental change on future water poverty for different livelihood groups.

1.3 Importance of the Study

This study provides better understanding of changes in water poverty with environmental changes. It also identifies the water-poor livelihood group and presents a livelihood group inclusive approach for measuring water poverty. The findings are useful to policy and decision makers in devising water management strategies for water-insecure groups in a dynamic setting.

1.4 Structure of the Thesis

The thesis is organized into six chapters including a number of sections and sub-sections in each chapter. Descriptions of the six chapters are given below:

CHAPTER ONE: The chapter discusses the background of study and present state of the problem. It also highlights the objectives and the importance of the study.

CHAPTER TWO: This chapter provides the review of literature on water poverty scenario across the world as well as Bangladesh, water poverty assessment methods and effects of climatic and environmental changes on water poverty.

CHAPTER THREE: This chapter provides a brief description of the study area. It discusses the location of the three selected unions, their climatic, hydrologic, ecological, and socio-economic features.

CHAPTER FOUR: This chapter discusses the methods in details used to analyze present and future water poverty indices for different livelihood groups, trends of hydroclimatic and environmental parameters and their impact on water poverty. The chapter also describes the types of data collected for this study and methods used for collecting the data.

CHAPTER FIVE: This chapter describes the results of water poverty assessment and trend analysis of different hydroclimatic parameters. The chapter also describes the future water poverty scenarios and the changes in water poverty status of existing water-poor groups.

CHPTER SIX: This chapter concludes the findings of the study and provides recommendations for further study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Concept of Water Poverty

Water is increasingly seen as one of the most critically stressed resources. Global water stress and the water needs of the poorest people are now receiving due attention. In fact, poverty itself is now recognized as a lack of access to different livelihood capitals (Sen, 1999), such as water. For the water sector, a number of the UN Millennium Development Goals (MDGs) and targets were relevant and demanding (UN, 2002; UNESCO, 2003). When addressing the problem of global poverty, water allocation was highly relevant as it was impossible to escape extreme poverty without adequate access to water. It could be argued that the reverse was not necessarily true; the availability of safe water did not automatically lead to poverty alleviation. However, given that adequate access to safe water was a necessary condition for an acceptable quality of life. Access to water as a basic human right was recognized by the UN also (UN ECOSOC, 2002). Therefore, water and poverty were intrinsically linked.

By the term 'poverty', the economically and socially disadvantaged groups of people were referred across the world, mainly in Africa and Asia. According to IMF (2009), poverty is a multidimensional concept extending from lower financial capacity such as low level of income and expenditures due to lack of food, water, education and health benefits, lower purchasing power and includes other social dimensions, such as insecurity, vulnerability, social exclusion and gender disparity.

Poverty line may be thought of as the minimum expenditure required by an individual to fulfill his or her basic food and non-food needs. Since 1995-96, Bangladesh Bureau of Statistics (BBS) is using the Cost of Basic Needs (CBN) method as the standard method for estimating the incidence of poverty. It first estimates the cost of acquiring enough food for adequate nutrition – usually 2,100 Calories per person per day – and then adds on the cost of other essentials such as clothing and shelter. In this method, two poverty lines are estimated: Lower poverty line and Upper poverty line. In 2010, using the upper poverty line, per capita expenditure of the poor is BDT 1245.76 at national level, BDT 1200.02 in the rural area and BDT 1457.65 in the urban area. In 2005, it was BDT 656.91 at the national level, BDT 639.82 in rural area and BDT 737.35 in urban area (BBS, 2010). In line with the World Bank (2005) definition, people who live on less than $1.90 a day, are considered as extremely poor.

The relevance of water to different aspects of people's lives and livelihoods in developing countries, especially in rural contexts, and the different ways in which populations in low income countries are affected by, or vulnerable to, poverty which was 'water-related', indicated that water issues were an important entry-point into poverty reduction strategies (Kashyap, 2004). It was thus very important to assess and evaluate the capacity in using water resource properly, climate change induced effects on water resources and water induced effects on livelihoods, and to suggest a way-out and propose some effective water management mechanisms that can be found useful for tackling the water management with changes in climatic conditions for Bangladesh (Chattapadhya and Islam, 2016).

Modern water management was emerged from a background of engineering, rather than social discourse, and it was time for 'soft water paths' (Gleick, 2002). Hence, the concept of water poverty was introduced which was an essential part of Integrated Water Resources Management (IWRM). IWRM is defined as a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP, 2000). IWRM aimed to strike a balance between the use of resources for livelihoods and conservation of the resource to sustain its functions for future generations. The definition of IWRM embraced economic efficiency, environmental sustainability and social equity – the three E's (GWP, 2003).

Water as a resource and its development and management was specific to the geographical, historical, cultural and economic contexts of any country. Hence, IWRM processes differed from country to country. For the poorest countries of the world, the national IWRM planning processes might well focus strongly on how to attain the UN MDGs on reducing poverty and hunger, diseases and environmental degradation, including halving the proportion of people without access to basic drinking water and sanitation services. For the richer countries of the world, progress towards IWRM might be pursued by focusing on environmental maintenance and restoration (Jønch-Clausen, 2004).

At the United Nations Conference on the Environment and Development that was held in 1992 in Rio de Janeiro, IWRM was a major item on the agenda. During this conference the various stakeholders came up with an action plan for the world environmental crisis, called Agenda 21. Under this agenda, the four main objectives of IWRM were (Pallett et al., 1997):

- To plan the sustainable and rational utilization, protection, conservation and management of water resources;

- To identify and strengthen or develop, as required, in particular in developing countries, the appropriate institutional, legal and financial mechanisms to ensure water policy and its implementation are a catalyst for sustainable social progress and economic growth;

- To promote a dynamic, iterative, interactive and multisectoral approach to water resources management; and

- To design, implement and evaluate projects and programs that are both economically efficient and socially appropriate within clearly defined strategies.

Among the four objectives of IWRM, the first three objectives were related to water resources management. The United Nations published 17 Sustainable Development Goals (SDGs) for 15 years (2015-2030). At least six of the 17 goals were directly linked to water, and several others are indirectly affected by water issues (UNESCO, 2016). The SDGs were not separate entities, instead, they were connected to each other in a high degree. This called for integrated approaches in dealing with the issues the SDGs attempt to address. Water was central to achieving the goals. In addition, water-related issues were identified by the World Economic Forum as some of the biggest risks the world was facing in the future (WEF, 2016).

Water occupied a major role in poverty alleviation as access to water and poverty were linked for a long time (Sullivan, 2002; Perez-Foguet and Garriga, 2011). Water and poverty were linked through water management, not water scarcity, which was primarily related to food security due to agriculture being the dominant water user globally. For poverty, water management issues were related to drinking water access, cooking and sanitation through policy failure, lack of infrastructure and low capacity (Perez-Foguet and Garriga, 2011). These factors led to development of indicator approaches in water resource research. To answer the need, WPI was developed as holistic tool to assess water resource in an integrated manner, combining resource availability, social access to water and the environmental water requirements (Sullivan, 2002).

According to Conor (2015), daily struggle for water was one of the terrible burdens of poverty, especially for women and girls who spent endless hours fetching water over long distances. Sources of water were often unclean or unaffordable, or groups were simply cut off from using a particular water source. According to his study, many poor urban dwellers had to pay very high prices for water to informal water vendors or do without water. Not having sufficient and safe water meant constant weakness and pain through recurrent diarrhoea and other debilitating or fatal water related diseases. It led to loss of time, and educational and employment opportunities. Low incomes and limited access to water also meant choosing between paying for water, food, school fees or medicines.

Access to water for household uses was critical for a family's health and social dignity. Access to water for productive uses, such as agriculture and family-run businesses was considered vital to realize livelihood opportunities, generate income and contribute to economic productivity. Access to water was linked to poverty. Reducing poverty through water management was a useful pro-poor framework for action, allowing for the introduction of inter-related issues of governance, water quality, access, livelihood opportunities, capacity-building and empowerment, water-related disaster prevention and management, and ecosystem management.

So, a tool was needed to include all these water-related issues in a holistic way. The WPI, since its main purpose was monitoring, could be used to select the areas where development was urgently needed. Ohlsson (2000) mentioned that WPI demonstrated not only the amount of water resources available but also how effectively the resource was used to require the poverty level of that community. The links between poverty, social deprivation, environmental integrity, water availability and health became clear through the underlying framework of WPI.

Another concept related to poverty assessment was the Human Development Index (HDI) which measured economic and social progress (Lawrence et a1., 2003). HDI is the average of three separate indicators: life expectancy at birth, educational attainment, and Gross Domestic Product (GDP) per capita at Purchasing Power Parity (PPP). However, most of its components were highly correlated with each other. Thus, the usefulness of the separate sub-indices was reduced. Therefore, WPI might provide a better basis for assessing water-related poverty.

2.2 Theoretical Background of Water Poverty: A Chronological Review

Water stress was defined as the number of people that a flow unit of freshwater can sustain (Falkenmark et al., 1989). Considering limited freshwater resources, they asked the question, 'how many people can be supported by each flow unit within given technological and managerial capabilities?' In their visualization of their concept, they assigned a flow unit the arbitrary volume of one million m^3/year. It would appear that linking a volume to the concept of a flow unit would prove to be the unintended precursor of the Water Stress Index (WSI), originally known as the 'Falkenmark Indicator', according to Falkenmark and Rockstrom (2004). Less than 1700 m^3/capita/year for a given region was the conventional threshold used to express water stress whilst less than 1000 m^3/capita/year signified water scarcity where estimates of water resources were typically derived from mean annual river runoff (Arnell, 2004; Falkenmark et al., 1989; Falkenmark and Rockstrom, 2004; Shiklomanov, 2000). Today, the WSI is one of the most widely used indices for measuring water scarcity.

According to Feitelson and Chenoweth (2002), WSI was criticized by Raskin et al. (1997) because of its inability to address different water use patterns. They later criticized a 'use per resource indicator' including a figure to reflect a country's dependence on transboundary water due to their lack of consideration for water quality and a country's economic capacity. Feitelson and Chenoweth (2002) developed a situational definition of water poverty, stating as 'Water poverty is a situation where a nation or region cannot afford the cost of sustainable clean water to all people at all times.' They highlighted two major elements that need attention: cost and affordability. Adapting the Bruntland Commission's definition of sustainable development (Brundtland, 1987) to water resource management suggested that water resources left for future generations should be of similar quantity and quality as those available to current generations. 'Clean water' implied the need to meet basic water quality criteria and thus the cost of such water should include water treatment where necessary. The term 'to all' implied that the cost should include clean water supplies to all sectors of society and sub-regions. The term 'at all times' indicated the costs associated with overcoming the temporal variability of water supply. In essence, these two requirements came to address the intra-generational equity dimension of sustainability notions.

Ohlsson and Turton (1999) expressed first order scarcity as a lack of natural resources (water) and second order scarcity as a lack of adaptive capacity (social resources) such that a society lacked the necessary capacity to deal with first order scarcity. Ohlsson and Turton (1999) proposed combining the widely used WSI with the HDI to arrive at a Social Water Scarcity Index (SWSI). Thus, for the first time, the concept of water scarcity was expanded beyond traditional measures of Available Water Resources (AWR) to include considerations of social and economic capabilities of a population. A number of large-scale models of water resources were developed (Shiklomanov, 1997; Alcamo et al., 1997; Seckler et al., 1998; Meigh et al., 1999), but while these were useful, especially when considering the issue of global change, they provided little insight into the site-specific issues needed for local water management. Further attempts were made to link water availability to food production (Rosegrant et al., 2002), but again that was a broad-brush approach. But WPI provided a solid framework for an integrated water index at the community level (Sullivan and Meigh, 2003).

Salameh (2000) defined WPI as 'the ratio of the amount of available renewable water to the amount required to cover food production and the household uses of one person in one year under the prevailing climate conditions'. Sullivan (2000) suggested an alternative notion of water poverty stating that it should be an aggregate index based upon the percentage of water being used in a region combined with percentage of the population with access to safe water and sanitation, and the percentage of the population with easy access to water for domestic use.

Sullivan (2002) first proposed the WPI as an integrated approach to water poverty (where water poverty was defined as a lack of adequate and efficient water supplies) that 'links physical estimates of water availability with socioeconomic variables.' The development of WPI was intended to help the process of identifying those areas and communities where water was most needed, enabling a more equitable distribution of water to be achieved, one of the most important practical features of any potential water scarcity/poverty indicator. The purpose of the WPI was 'to express an interdisciplinary measure which links household welfare with water availability and indicates the degree to which water scarcity impacts on human populations' (Lawrence et al., 2003). According to the authors, the water-poor could be defined in two ways: those who lacked access to water or had insufficient water available to meet their basic needs, and those with insufficient income to access water even when supplies exist.

Molle and Mollinga (2003) discussed water scarcity in terms of five types of water use (drinking water, domestic water, food security needs, economic production and environmental needs) and their five constraints (physical scarcity, economic scarcity, managerial scarcity, institutional scarcity and political scarcity). In their review of Ohlsson and Turton (1999), they highlighted the tendency of the use of proxy indicators to produce index 'anomalies' necessitating further explanations that were often 'site-specific and qualitative'. They concluded that the main role of indicators was to convey messages, convince the public and decision-makers.

According to Fenwick (2010), many authors acknowledged the need to include social adaptive responses, economic and technological considerations in order to accurately assess the complex dimensions of water poverty. Thus, there was a need for a tool that moved beyond the traditional scope of water scarcity measurements and considered all the dimensions of water poverty in an inclusive, holistic format, such as the WPI. Figure 2.1 represents a timeline view of chronological background of water poverty.

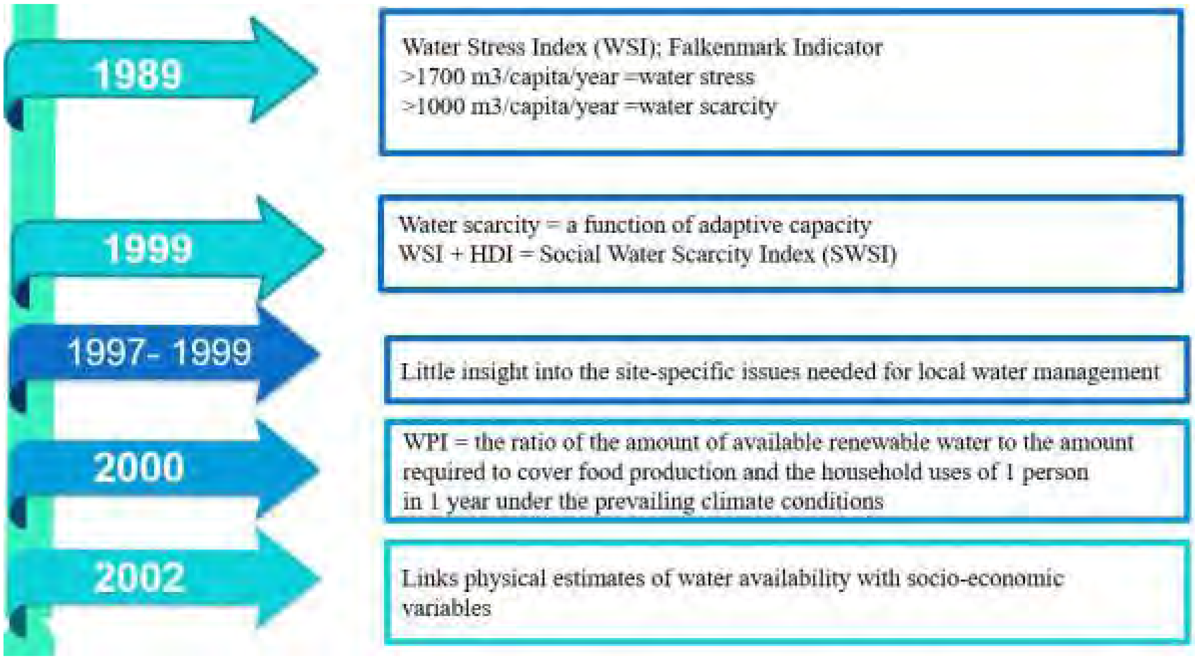

Figure 2.1: A timeline view of chronological background of water poverty

2.3 Framework of Water Poverty Index (WPI)

Most often it is found that countries with high climatic vulnerabilities are also vulnerable to water resources. So, it is very important to understand, assess and evaluate water resource availability, capacity in using them properly and level of threats in the form of water pollution, etc. WPI is an effective water management mechanism which is useful for tackling the water crisis with changes in climatic conditions. Assessing WPI is an interdisciplinary approach to produce an integrated assessment of water stress and scarcity, linking physical estimates of water availability with socioeconomic variables that reflect poverty. It is known that poor households often suffer from poor water provision, and this results in a significant loss of time and effort, especially for women. WPI is a recently developed index which is considered to be very useful for designing an integrated water management system for any country against climate change.

According to Mlote et al. (2002), the development and implementation of WPI will promote:

- Community empowerment, through provision of better information on local water availability and demand;
- Potential for self-calculation of water stress by communities;
- Integrated datasets and a transparent methodology on which water development projects can be prioritized;
- A comprehensive capacity building program to enable calculation of WPI by individual communities and countries;
- More explicit identification of natural capital entitlements of communities; and
- Linkages between cross-sectoral themes such as education, health and ecological demands.

Sullivan (2002) was the first to introduce the concept of WPI. WPI was a number between 0 and 100, where a low score indicated water poverty and a high score indicated good water provision. Traditional water scarcity assessment focused only on the vulnerability of communities and physical water scarcity, whereas WPI attempted to combine social, economic and environmental aspects of water scarcity. WPI was developed to express the complex relationship between sustainable water resource management and poverty at all levels from a community, village, district, region and nation. There were five subcomponents of WPI: resource, access, capacity, use and environment. For each subcomponent, indicators were used to evaluate index values. Indicators must be measurable and the necessary data must be either obtainable through measuring and monitoring, or be readily available (Moldan et al., 1997).

According to Molle and Mollinga (2003), indicators tended to be marred by problems ranging from inadequate quality of data, arbitrariness of weights, incommensurability of values and incorporation of judgments or standpoints, to classical loss of information in the aggregation process as well as in the construction of composite indices. For all these reasons, they were prone to become black boxes, making it difficult for outsiders to unravel calculations, assumptions and meanings. The information was in the components rather than in the final single number. Composite index, that attempted to describe water poverty by simultaneously assessing it as a function of five key indicators: resources, access, capacity, use and environment, in turn comprised of sub-indices made up of several variables. Community scale was considered appropriate where it was possible to generate data for all the communities within a unit, the full complexity of the situation could be represented. This would require a simplified data collection procedure (Sullivan et al., 2003).

According to Sullivan (2002), indices were a statistical concept, providing an indirect way of measuring a given quantity or state, effectively a measure which allowed for comparison over time. Key issues which must be addressed in the construction of any index are:

- choice of components;
- sources of data;
- choice of formula; and
- choice of base period.

Apart from these empirical issues, the main point of an index however was to quantify something which could not be measured directly (e.g., how water stressed a household is) and to measure changes (e.g., the impacts of economic growth). The proposed WPI fitted this concept of an index which measured something indirectly, and which was made up of defined components. Advancing numerous novel ideas surrounding the identification of water poverty, Sullivan (2002) discussed the advantages and disadvantages of four possible approaches to calculate a WPI but refrained from recommending any one methodology. The approaches were:

- **The conventional composite index approach:** This could be done using national scale data (a top-down approach), or at a local level, using locally determined values and parameters (a bottom-up approach).

- **An alternative approach - the gap method:** Another way to develop a WPI measure could be to consider the assessment of by how much water provision and use deviateed from a predetermined standard. This standard could be an assessment made up of considerations of the following:

    - ecosystem health,
    - community well-being,
    - human health,
    - economic welfare

  Using this approach, water stress was considered to be the highest when the water poverty gaps were the largest; if the situation improved, the gaps were smaller.

- **A matrix approach:** In order to keep the WPI simple and easy to understand, the main characteristics of water stress and human welfare could be combined into a two-dimensional matrix. This would involve the identification of key indicators, representing a suite of appropriate characteristics, and these would then be combined on a suitable scale.

- **Simple time-analysis approach:** Another possible way of addressing the methodology of constructing a WPI was to use a time-analysis approach, where time was used as a numeraire for the purpose of assessing water poverty. In this method, the WPI was determined by the time required (per capita) to gain access of a particular quantity of water.

Sullivan et al. (2003) used the following five key components of WPI:

- **Resource:** Physical availability of both surface water and groundwater, taking account of the variability and quality of the resource as well as the total amount of water.

- **Access:** The extent of access to this water for human use accounting for not only the distance to a safe source, but the time needed for collection of a household's water and other significant factors. Access meant not simply safe water for drinking and cooking, but water for irrigating crops or for industrial use.

- **Capacity:** The effectiveness of people's ability to manage water. Capacity was interpreted in the sense of income to allow purchase of improved water, and education and health which linked with income and indicated a capacity to lobby for and manage water.

- **Use:** The ways in which water was used for different purposes: it included domestic, agricultural and industrial use.

- **Environment:** The need to allocate water for ecological services, an evaluation of environmental integrity related to water and of ecosystem goods and services from aquatic habitats in the area.

A composite index approach was used to calculate the WPI (Cullis, 2005). Experts from the World Water Council, calculated the WPI for 147 countries all over the world (World Water Forum, 2003). The traditional method with five components was proven to be successful, Cho et al. (2010) identified the need for a simplified and more cost-effective method for index calculation, as financial and data availability constraints often existed. This motivated them to perform a Principal Component Analysis (PCA) using the same worldwide data mentioned earlier. The PCA was used to transform a large set of correlated variables into a smaller set of uncorrelated variables, called principal components, which account for most of the variation in the original set of variables. PCA was mostly used as a tool in exploratory data analysis, for making predictive models and to visualize relatedness between populations. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. PCA seeks a linear combination of variables such that the maximum variance is extracted from the variables. It then removes this variance and seeks a second linear combination which explains the maximum proportion of the remaining variance, and so on. This is called the principal axis method and results in orthogonal (uncorrelated) factors. PCA analyzes total (common and unique) variance (Morrison, 1967).

2.4 Applications of WPI

The WPI was designed to operate at a number of scales and enable quick and reliable comparisons of water poverty across space and time. By utilizing a set of standard indicators, community or regional performance could be assessed over time and compared to other localities enabling decision-makers to prioritize levels of need. Moreover, the indicators were intended to be flexible and can be modified to meet local needs. WPI had the ability to compare performance across localities, but variables were very location specific.

It was applied at various scales: a grid approach (Meigh et al., 1999), national (Lawrence et al. 2002; Komnenic et al. 2009; Cho et al. 2010), river basin (Pérez-Foguet and Giné, 2011; Manandhar et al., 2012; Pandey et al., 2012; Alcamo, 1997), regional or district or sub-district (Heidecke, 2006; Manandhar et al., 2012) or a mix of basins and administrative units (Amarasinghe et al., 1999) and local (Sullivan et al., 2003; Cullis and O'Regan, 2004; Giné and Pérez-Foguet, 2011; Sullivan and Meigh, 2007; Manandhar et al., 2012). Its methodological structure was also used in a number of WPI based indices e.g. the Climate Vulnerability Index (CVI) (Sullivan and Meigh 2004), the Livelihood Vulnerability Index (LVI) (Hahn et al. 2009), the Water, Economy, Investment and Learning Assessment Indicator (Cohen and Sullivan, 2010) and the Modified Water Poverty Index (van Ty et al., 2010).

OECD (2001) admitted that, 'a national level indicator may hide significant territorial differences and should be complemented with information at subnational level'. Planning, therefore, had to be based on a finer knowledge of local realities and needs, and was considered ill-informed by aggregate indicators. To overcome this difficulty, it was often claimed that indicators could also be calculated at a local scale. The corresponding data collection and situation analysis were then useful (especially if, like for the WPI, they covered a large range of issues).

2.4.1 Application of WPI at the international level

A number of case studies were undertaken since WPI was first introduced and an international comparison of 140 countries was undertaken. In the first major study of its kind, the authors concluded that the WPI produces 'sensible results' although cautioned that the WPI was not 'definitive' and not 'totally accurate' (Lawrence et al., 2003). Each indicator and the variables that comprise it were weighted equally. The WPI compared relative water poverty by assigning the lowest ranking country on any indicator a score of zero and the highest a score of one. It was found that there was a positive correlation between the HPI and WPI and strong positive correlation between the sub-indices of

W'PI and the HDI (Lawrence et al., 2003; Wurtz et al., 2019). Thus, the WPI could be used to establish an international measure comparing performance in the water sector across countries in a holistic way.

Sullivan et al. (2003) subsequently undertook a pilot study that applied the WPI at the community scale in South Africa, Tanzania and Sri Lanka. Disseminating their results with pentagram diagrams (where each point represented the score for one of the five indicators), they allowed users to quickly classify the situation of water poverty in any location without losing its ‘underlying complexities’ appealing especially to policy-makers. They cautioned the need for reliable data and recognized the impact of local politics, which might affect the comparability of results. According to one of the original case studies, Majengo, Tanzania (an urban community) attained an overall WPI score of 43.8, but at the indicator level scored only 10 for Resources, 32.7 for Access and 15.0 for Use. On the other hand, it had the highest indicator score for Environment at 98.4, which served to artificially inflate the overall WPI score. This distortion was a common problem experienced in additional case studies. Finally, it should be noted that the WPI was not intended to replace more comprehensive integrated water resource management tools but instead to provide a needs-based approach to assessing water poverty enabling decision-making.

Cullis and O'Regan (2004) extended the use of the WPI to devise water poverty maps in their case study of a municipal district in South Africa. Data used to calculate a WPI were collected at the lowest level possible and then aggregated at different scales. Although the main objective of this study was the creation of water poverty maps, it nevertheless provided some insight into the WPI. They found that data for Use were the most difficult to obtain. Finally, their results showed that overall WPI results at the macro scale (in their study, the sub-catchment and place name scale) significantly masked results at the local enumerator scale.

As a follow-up to their earlier work, Sullivan et al. (2006) appeared to rebrand the WPI as ‘primarily designed for use at the community level’ though the authors cited its ability to be applied to different scales depending on need. Presenting a selection of case studies at different levels, they cautioned users on the impacts of scale. At the community scale, certain variables having been selected for their theoretical impacts did not translate well into practice. Specifically, variables relating to land use designed to assess environmental integrity did not always apply to each setting especially given the marked difference between rural and urban settings. On the subject of comparisons, the authors concluded: ‘there needs to be consistency of data collection, a synchronized definition of variables and standardized procedures for calculating the final index values.’

Komnenic et al. (2009) interpreted the strong correlation between the WPI and Capacity, and the strong relationship between Access and Capacity, as a reflection of the WPI's position that ‘societies with low income levels and weak health and educational systems are likely to have inhabitants lacking access to safe drinking water.’ In their study, countries with high access rates to safe water and sanitation, for example Serbia and Montenegro with 93% and 87% respectively, being defined as water-poor by the WPI (WPI=25.4). They concluded that the concept of water poverty expressed through the WPI was neither universally applicable nor suitable for making generalizations. The authors founded the data collection process to be slow and painstaking.

In a series of conference papers, Garriga and Pérez-Fouget (2008; 2009) proposed an enhanced Water Poverty Index (eWPI) that emphasized the importance of causality and thus incorporates ‘cause-effect relationships’ whilst including ‘sustainability issues.’ They defined indicators of ‘pressure, state and societal responses’ for each variable used to calculate a WPI thus arriving at what they described as a ‘causality-issue matrix’. In essence, indicator scores for Pressure, State and Response were added to the five existing indicators of Resources, Access, Capacity, Use and Environment to arrive at overall WPI. They first applied their eWPI to the basin scale to a watershed shared between Ecuador and Peru (Garriga and Pérez-Fouget, 2008) then at the community scale in ten communities in Bolivia (Garriga and Pérez-Fouget, 2009). Their brief analysis of results added to the growing body of evidence that suggested overall WPI scores were less meaningful than the individual indicator although they suggested the WPI could be a powerful tool with potential for wider implementation. They highlighted the need for continued research into the issue of indicator weighting and suggested this could be investigated using statistical analyses or participatory methods. The different aggregation methods available in constructing a water poverty index was also discussed.

Expanding specifically upon the issue of weighting, Cho et al. (2009) used PCA in an attempt to address the problem of indicator weighting subsequently resulting in a reduced number of weighted indicators comprising the WPI. They arrived at a modified WPI that comprises indicators of Access, Capacity and Environment, weighted according to the results of their analysis (0.4, 0.4 and 0.2 respectively). They further reduced their model to include equally weighted indicators of Capacity and Environment justified by statistical tests that suggested these two indicators were most strongly correlated to the primary principal components of the WPI. The authors were driven by a desire to find a more cost-effective way of calculating the WPI and although their attempt was admirable, their purely statistical approach to the decision-making process lacked sensitivity towards the realities of water poverty. They failed to address the problem of internal correlation amongst indicators. Furthermore, given the constraints of the WPI, acknowledged by its developers, these analyses might best be undertaken using data derived at the community scale.

Sullivan et al. (2009) introduced a version of the WPI for rural communities called the Rural Water Livelihoods Index (RWLI), which distinguished between urban and rural human-water systems. The RWLI included components accounting for access to water and sanitation, crop and livestock water security, clean and healthy environments, as well as secure and equitable water entitlements. This index also utilized parameters measuring local corruption, agricultural holdings, and water quality (total nitrogen consumed on cultivated land).

Forouzani and Karami (2011) developed an agriculture water resource assessment tool for the first time, an Agricultural Water Poverty Index (AWPI) for assessing the water situation that could have immediate application at the farm and other spatial levels. The AWPI was an attempt to construct a farm-level sustainable water management index. The AWPI could be used to assess the agricultural water poverty among farmers and regions and to provide guidelines for sustainable water management. Linking water management and sustainability analyses of the agricultural system via the agricultural water poverty framework was proved to be an attractive explanation of how water played an important role to achieve sustainability in agriculture. The authors also highlighted that the national analysis of water scarcity was of very limited use in assessing whether individuals or communities were water-poor.

2.4.2 Application of WPI in Bangladesh

Runu (2009) identified the changes of water poverty status in the Small Scale Water Resources Development Sector Project (SSWRDSP) for two different types of subprojects. One relatively successful subproject in Rajbari District and one less successful subproject in Khulna and two control sites having geographical, demographic and hydrological characteristics similar to those of the subproject sites were selected on the basis of accessibility and availability of secondary data. The components were scored based on evaluation of their sub-components from field investigation and secondary data. The WPI in two project sites were higher than the country's overall index (WPI=54) estimated by Sullivan (2002). The WPI was also higher in one control site, possibly because of relatively low level of conflict in water uses, fertile soil, crop diversity, absence of salinity problem, and higher water use for livestock. In this study, the author established that WPI provided a means to identify the areas where more attention is needed from water management perspective and also could be used as an effective tool for evaluation of project intervention. The author suggested that the selection of component or sub-component should be field oriented or participatory.

Mahtab and Khan (2012) also used WPI as a tool to monitor the progress of water sector in a pilot site across the tidal river Bakkhali situated in the southern part of Bangladesh. For this study, primary data were collected from the field through household questionnaire survey and Focus Group Discussion (FGD). Simple random sampling technique was used for household survey. This study assessed the water poverty status for selected small-scale water resources development subprojects of Local Government Engineering Department (LGED) based on a WPI. It also assessed project intervention (dam construction) by comparing WPI values.

Gunda (2014) used the components (Resource, Access, Capacity, Use and Environment) of WPI to determine the relative rankings of Bangladesh and Sri Lanka (Gunda, 2014). The WPI score of Bangladesh (58.1) was slightly lower than that of Sri Lanka (58.5) which indicated that Sri Lanka was more water-secured country than Bangladesh.

2.5 The Relationship between Water Poverty and Changing Environment

Environmental protection as well as the proper management of environmental resources remains the most important driver in relieving water poverty in the developing world and increasing the subjective well-being of rural communities (Nadeem et al., 2018). According to Allen and Bell (2011), WPI would be an improved water management strategy for one country’s economy to face against the climatic wrath in the years to come. They tried to identify the connection between climate change and its effects on water management system in Bangladesh. Providing adequate water supply to growing populations under changing climatic conditions is one of the greatest challenges of the twenty first century. Defining the scale of the challenge is made difficult by the complexities of urbanization.

In case of local scale of WPI, a study by Mlote et al. (2002) in Tanzania, Sri Lanka and South Africa, it was found that the WPI score represented the real picture, but in case of environmental indicator it represented the real picture for rural areas but it did not represent the real picture in urban areas because sub-indicators might be different in rural and urban areas. In case of access component, it was found that the score on access increased in wet season and decreased in dry season (Runu, 2009). The value of the WPI varied seasonally. Seasonal differences in water poverty using WPI as a tool was addressed only by Van Ty et al. (2010), Tang and Feng (2016) and Zhang et al. (2015). These studies showed that, WPI varied considerably between years. The extreme difference between dry and wet seasons was likely to cause large differences in some of the WPI components seasonally as well.

As we progress through the twenty first century, we know already that we will be affected by changes in water resources, and the demands upon them. Changes in the global climate over the next hundred years are almost certain (IPCC, 2014), irrespective of whether they are human induced or otherwise. Such changes will impact on the spatial and temporal distributions of surface water resources, and may well be characterized by a more frequent occurrence of extreme events (Meigh et al., 1998, Arnell and King, 1998). This clearly suggested that the availability of freshwater resources needed to be more carefully managed in future, and the development of the WPI could be seen as a contribution to monitor these resources periodically. The impact of human population growth was also a major issue when considering the future challenges for water management (Falkenmark, 1990).

Assessments were needed to address the problems arising from the increasing likelihood that human vulnerability was increasing as a result of climate change (IPCC, 2014; Lenton, 2002; Adger and Brooks, 2003). Sullivan and Meigh (2005) addressed the issue of assessment of vulnerability to the impacts of climate change through the use of an indicator approach, the CVI. Most existing methods followed Falkenmark (1986) in showing a continuously worsening water situation, as population grew. Although, water is a dynamic and complex resource which is hard to describe with simple indicators (Rijsberman, 2006).

According to Feitelson and Chenoweth (2002), countries will not remain static in terms of their water poverty relative to other nations, as many different inter-related factors will influence whether water poverty will increase or decrease. Figure 2.2 illustrates a few of the factors that may influence water poverty in a country over time. Some of these factors, like climate change or structural change in the economy, may have either positive or negative effects on supply costs depending upon the type of change in the particular locale. If rains increase or the dependence on water dependent economic sectors is reduced, the long-term cost per capita may go down. Other factors such as increasing pollution or population will only increase long-term supply costs. It also illustrates that while a country's level of water poverty can increase, it can also potentially decrease over time as a result of economic growth and pollution control.

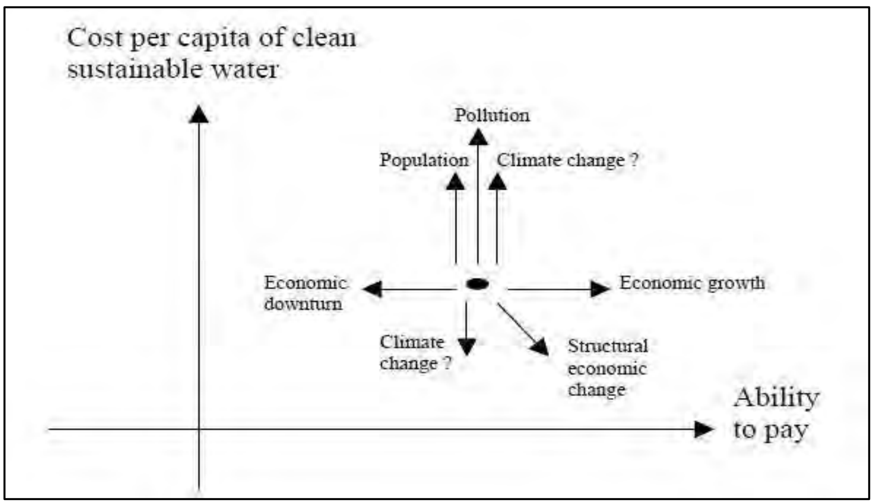

Figure 2.2: Factor influencing water poverty in a country over time. (Source: Feitelson and Chenoweth, 2002)

Climate change, as conceptualized in the physical sciences, is seen as a long-term gradual change in the climatic variables such as annual or seasonal amount of rainfall, annual number of rainy days, or the mean maximum temperature in a given month. Climate variability, which is also an element of change in the climate, is of particular interest when it is important to see the variation in the extremes of certain climatic variables, such as extreme rainfall events or prolonged drought conditions. On the other hand, environmental change is a change or disturbance of the environment most often caused by human influences and natural ecological processes. Rapid urbanization, industrial growth, population growth etc. are the dominant factors behind environmental changes. Climate change will impact agriculture and food production around the world due to the effects of higher temperatures, altered precipitation and transpiration regimes, increased frequency of extreme events, and modified weed, pest, and pathogen pressure. Strategies to address the root causes of anthropogenic climate change, as well as for building resilience for some of the most severe impacts of climate change and environmental degradation must be developed.

2.5.1 Impact of Climate Change and Urbanization on Livelihood Groups

A livelihood may be defined as the sum of ways in which households obtain the things necessary for life, both in good years and in bad. These necessities include food, water, shelter, clothing and health care (with education often included too). Pertinent activities can include crop and livestock production, fishing, hunting, gathering, bartering, and other endeavors and income-generating activities (including off-farm work). Livelihoods vary significantly within a country, from rural to urban areas, and across countries. The household level analysis is preferable for livelihood related analyses as household is the most important institution through which populations anywhere organize production, share income and consumption (Burke et al., 2006). Livelihood conditions of the people largely depend on what resources are available at the household level in terms of ownership and access. Household asset provides the necessary condition for selection of livelihood option, going for gainful activities and coping with all odds.

As poor people lack education and skills, have poor health, inadequate access to water and sanitation services and weak safety nets to ensure basic consumption, they depend more on ecosystem services and products for their livelihoods. As a result, any impacts that climate change has on natural systems threaten the livelihoods, food intake and health of poor people and increase their vulnerability (Chattapadhya and Islam, 2016). To maintain effective livelihood choices, five basic capabilities have been identified by Desai (1995):

- Capability to stay alive/enjoy prolonged life
- Capability to ensure biological reproduction
- Capability for healthy living
- Capability for social interaction
- Capability to have knowledge and freedom of expression and thought.

DFID (1999) explained the in-depth meanings of livelihoods, the objectives of different approaches relating to livelihoods and the objectives and methodology of Sustainable Livelihoods Approach (SLA). The SLA might be used as a checklist or means of structuring ideas or can be applied in the form of a livelihood analysis to assess how development activities 'fit' in the livelihood of the poor. (Kollmair and Gamper, 2002). The livelihood approach is a way of thinking about the objectives, scopes and priorities for development by putting the people at the center of development. The framework is based on the available livelihood assets which are called Livelihood Capitals and the success of this approach depends upon the proper illustration and utilization of the livelihood capitals. SLA identifies five types of assets or capitals upon which livelihoods are built, namely human capital, social capital, natural capital, physical capital and financial capital. Then the vulnerability context and institutional influence is oriented. These two have both way relationship with livelihoods and finally effects the livelihood outcomes significantly. So proper addressing of these two elements is important for the sustainability of the strategy. Livelihoods analysis lays a heavy emphasis on understanding the structures and processes that condition people's access to assets and their choice of livelihood strategies. Figure 2.3 shows the schematic diagram of Sustainable Livelihoods Framework.

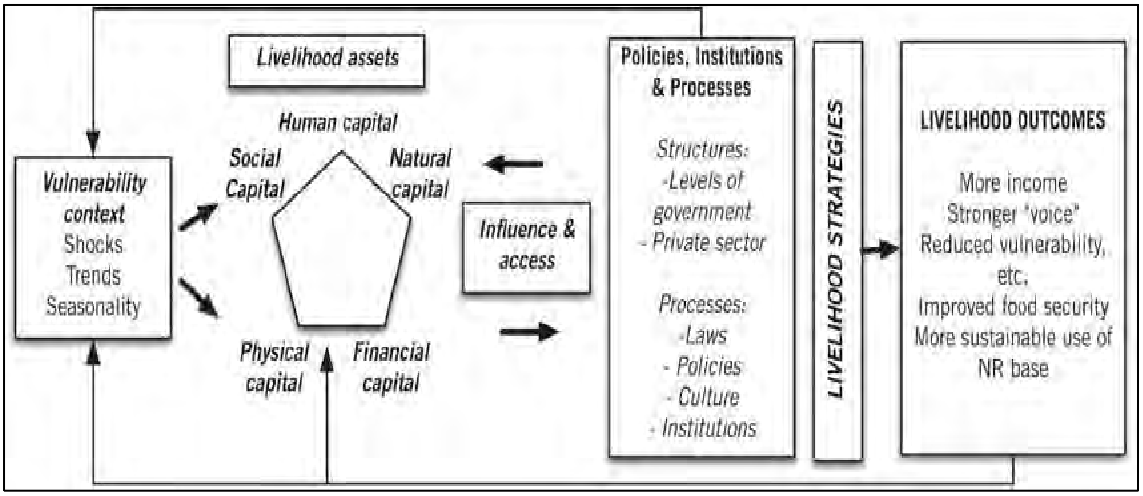

Figure 2.3: The schematic diagram of Sustainable Livelihoods Framework. (Source: DFID, 1999)

According to Scoones (1998), a livelihood comprises of the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks maintain or enhance its capabilities and assets, while not undermining the natural resource base.

According to Vargas-Lundius (2007), the rural poor are usually marginalized smallholders who depend partly on subsistence production (mostly not sufficient to sustain their livelihoods) and partly on cash income from selling surplus, from wage labor (mostly not sufficient and not reliable either), and, increasingly, from remittances. They are also the landless people, relying on seasonal jobs as farm workers and on informal non-farm income sources. Their poverty is usually characterized by a lack of various assets or resources:

- They are often short of land in terms of farm size, quality and security of access.
- They lack access to clean and safe drinking-water.
- They are often short of family labor (owing to migration or HIV/AIDS) and, therefore, suffer from seasonal labor bottlenecks.

Their lack of assets prevents them from accessing the financial resources they need in order to increase their productivity, and they typically live in remote areas with scarce access to markets and services. All these constraints make them highly vulnerable to shocks, in particular those related to climate variability, health risks, natural hazards, and market fluctuations. Accordingly, their strategies are to avoid risks by diversifying their economic activities, by engaging in low-external input or low-capital-investment technologies and by investing in social relations to maintain a social safety network. Low-risk livelihood strategies necessarily yield low returns and represent a severe constraint on poverty reduction. These characteristics are not new, but they continue to be relevant for the majority of rural poor. The new dynamics of rural livelihoods – the new rurality – result predominantly from globalization and deregulation, which create new opportunities but also new threats and limitations. New opportunities for rural smallholders result from access to external markets (niche markets) with increasing demand for new agricultural products, such as fruits, vegetables, nuts, flowers, fish, shrimps and spices. However, these new opportunities are limited. Environmental degradation and the increasing frequency of natural hazards tend to reduce the assets of the rural poor and so make them more vulnerable.

As opportunities and limitations/risks are not equally spread among rural smallholders, there are winners and losers. The winners can usually be found in central locations in proximity to dynamic markets and among resource-rich rural households that can mobilize additional assets. The losers are those in remote places and those with limited resources. Migration has become a predominant survival strategy for the rural poor. As a consequence, rural livelihood systems in many parts of the developing world have become highly diversified and highly mobile, multilocal livelihood systems. A consequence of this is the feminization of the rural economy and of agriculture in particular. In many cases, women have to secure the survival of children and aged family members (Vargas-Lundius, 2007).

Despite the diversification of rural livelihoods and increasing urbanization, at least half of the poor people are expected to remain in rural areas by 2035, and a significant number of them will depend on smallholder farming as their main source of livelihood (IFAD, 2001). Any rural water development strategy will have to deal with multilocal diversified livelihood systems with limited capacities for agricultural investment, a predominance of risk-avoiding strategies (IFAD, 2005), female-headed households, high workloads, and rural people's limited ties to their land. The complexity of the new rural reality reinforces the need for a livelihoods approach to development. In terms of water, this 'means a fundamental shift beyond considering water as a resource for food production to focusing on people and the role water plays in their livelihood strategies' (WWAP, 2006); and implies de facto a multiple-use perspective (Molden, 2007).

Climate change-led shortage in water resources would make a severe impact on the people and their economies. An existing relationship among climate change, impacts on water resources and changes of livelihoods linked. Production of rice, wheat, maize is supposed to be decreased and in certain cases is already decreasing due to increase of water stress and temperature in many areas of the region. This implies that with climate change agriculture and other such rural activities would directly be affected and thus the most vulnerable section of the people too would be affected from climate change and water stress. The impacts of climate change on water availability and water quality will affect many sectors, including energy production, infrastructure, human health, agriculture, and ecosystems.

According to UN Water, 95% of jobs in the agriculture sector, 30% of jobs in the industry sector, and 10% of jobs in the services sector are heavily dependent on water. Additionally, an estimated 5% of jobs in the agriculture sector, 60% of jobs in the industry sector and 30% of jobs in the services sector are moderately dependent on water. An estimated 40% of the global economically active population work in crop and animal production, fisheries or hunting, 20% are employed as waged workers (World Bank, 2005), the remaining are self-employed or contribute family labor to around 570 million farms. Worldwide, some of the most water-intensive industry sectors employ vast numbers of people: 22 million in food and drink (with 40% women), 20 million in chemical, pharmaceutical, and rubber and tires, as well as 18 million in electronics (WWAP, 2016). In Bangladesh, women represent the majority of low-income earners (working in garments, construction, agricultural, domestic sectors, etc.). Crop diversification, livestock varieties, including the replacement of plant types, hybrids and animal breeds with new varieties with higher drought, heat, flood and salinity tolerance, which are recommended as adaptation options to climate change, are rarely available to such women farmers. Naturally and culturally, women in Bangladesh, especially in rural areas, are reluctant to take any decisions on their own. Considering these scenarios, water is considered to be a scarce resource in a changing environment due to urbanization and climate change, especially for the disadvantaged livelihood groups who are depending on water entirely or partially for their livelihoods.

2.5.2 Challenges of Water Management in Peri-urban Areas

The definition of peri-urban goes beyond the definition of a geographic location (Iaquinta and Drescher, 2000; Narain, 2009; Narain and Nischal, 2007; Simon et al., 2006; Dangalle and Narman, 2006). A key feature of peri-urban environments is their dynamic nature, wherein social forms and arrangements are created, modified and discarded (Iaquinta and Drescher, 2000).

Urbanization causes conversion of lowlands, fallow lands and water bodies. While the latter are decreasing, built-up areas are increasing. The peri-urban areas show typical features like multiple institutional arrangements, rural and urban resource-based livelihoods, and hydrological and water pollution linkages. Although peri-urban (fresh)water security is deeply influenced by urbanization, regional development and climate change, it is generally ignored in policies and planning. Because of the fluidity of peri-urban spaces, clear national policies for these spaces and their resources do not exist. While water availability in adequate quantity and quality is important for peri-urban livelihoods, rapid urbanization and land-use changes (often driven by elite interests), climate change, and interventions in natural flows have limited it, especially for the poor who are most vulnerable to these changes. Conversion of lowlands and encroachment of water bodies for urban development continue to reduce peri-urban freshwater availability (Roth et al., 2019).

According to Khan et al. (2013), urbanization has a significant impact on the peri-urban biophysical systems and processes. Urban wastes and wastewater flows to the peri-urban areas degrade the environment and offset the natural balance in the ecosystem or hydrologic cycle. Urban heat island effects spill over to the peri-urban areas and change the local environment and micro-climate. Climate change impacts add to the urbanization effects already in place in peri-urban contexts. For example, excessive groundwater withdrawal for urban water supply may limit water availability in the urban as well as the peri-urban areas. Reduced rainfall due to climate change will reduce groundwater recharge and further limit the water availability. Urban communities are generally more resilient to these compounding stressors than peri-urban communities, primarily because of high-functioning urban service delivery systems, stronger actors and better institutions. The landless, who depend on others for their water sources, often lose access to water sources as the latter sell off their lands. Rural-urban migration, occupational diversification and the acquisition or erosion of common property resources that provide a social glue can erode the bases for social cohesion and weaken social capital. Weakening social capital weakens community resilience.

Peri-urban water security is seen as being shaped by the twin processes of climate change and urbanization. These processes act as multiple stressors on peri-urban water sources and create a situation of uncertain water supply for peri-urban communities. Water sources in peri-urban locations succumb to growing pressures from the cities as new and emerging claimants compete for scarce water; at the same time, the disposal of urban and industrial wastes into peri-urban water sources further compromises peri-urban water security. The effects of these are aggravated by climate variability and change (Prakash and Singh, 2013). It is also recognized that the occurrence of water conflicts is increasing significantly at the local level (Gleick, 2000).

Research by Briscoe et al. (1993) in developing countries relating to rural villagers' willingness to pay for improved water services revealed that the amount people are willing to pay for basic water services varies widely, and is affected by level of income, as well as the characteristics of existing supplies. While in some regions of some developing nations people pay less than 1 percent of incomes, for potable water in other regions in other countries people already pay water vendors 10 percent of their income for water that does not always meet WHO standards.

Another challenge is water pollution due to industrial wastewater. The sources of fresh water are continuously shrinking due to the process of contamination of water bodies. Ecosystem of the Buriganga, Shitalakkha, Dhaleshwari and Balu is literally dead for dumping of industrial garbage into the rivers. Industrial pollutants, such as chromium, lead, cadmium, iron, copper and organic wastes discharged from the industries, can accumulate in rivers. Referred as bioaccumulation, this process can ruthlessly affect water quality and species survival (Al-Salem et al., 2017; Schwarzenbach et al., 2010). More importantly, bioaccumulation of metals in fish, crabs and other edible aquatic species, may cause health problems to enter the food chain. Also, this can destroy the water aeration system, the self-purifying process of rivers (Akter et al., 2019).

Presence of brick kilns decrease land fertility. Bricks are made from top soil, a process, which is said to be aggravating land degradation. The removal of top soil makes the land lose its fertility for a period of between 25 to 30 years. People living within five kilometers of a brick kiln are exposed to various health risks (Islam, 2001).

Hasan et al. (2017) investigated on the peri-urbanization process, as a consequence of urbanization of Khulna, the corresponding impacts on land use changes and groundwater resources over different time scales. This study established that peri-urbanization process involved changes in land use and water demands, thus increasing stress on scarce groundwater resources. From a hydrological point of view, these changes in land use had a direct impact on the water cycle.

Gomes (2019) acknowledged institutional problems for peri-urban areas. During the rural to urban transition, there might be situations where both urban and rural institutions coexist, making it unclear which rules to apply or what the roles and responsibilities were during problem solving. Peri urban areas have a changing and mixed social composition that typically includes farmers, industrial entrepreneurs, informal settlers, and the urban middle class. These actors differ in their lifestyle, economic and educational backgrounds contributing to varying objectives and responses to local problems. Problem solving is affected by this also (Allen, 2003).

CHAPTER THREE

STUDY AREA

3.1 Introduction

Three peri-urban areas have been selected in this study. Two of them (Dhalla and Saista unions) are within Singair upazila of Manikganj district and the other (Tetuljhora union) is within Savar upazila of Dhaka district. The map of the study area is shown in Figure 3.1. A brief description of different features of the study area is given in the following sections.

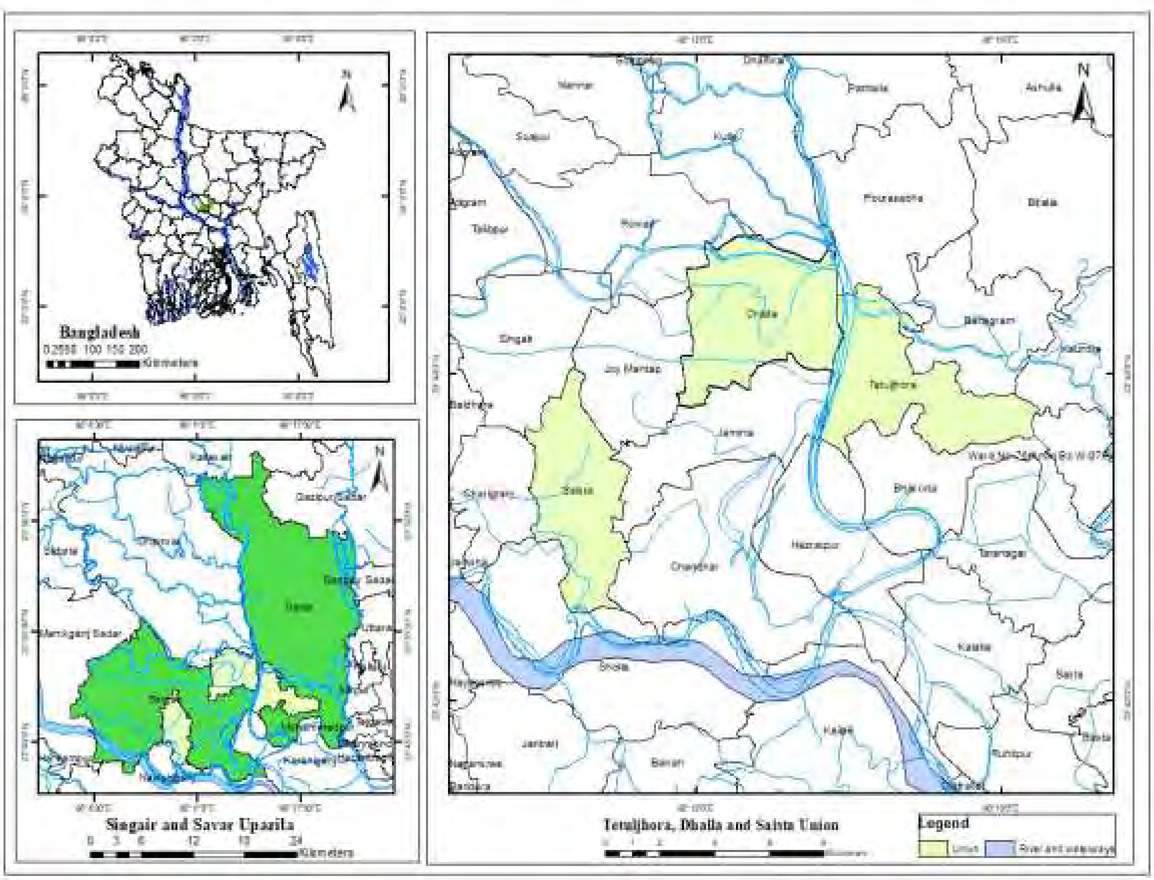

Figure 3.1: Location of the study area (Dhalla and Saista unions in Singair upazila and Tetuljhora union in Savar upazila)

3.2 Location

Dhaka district, located in central Bangladesh is the densest district in the country. Dhaka, the capital of Bangladesh, has a total area of 1463.60 sq. km. The district consists of 5 upazilas. Among them, Savar upazila (Figure 3.2) occupies an area of 280.11 sq. km. It is located between 23°44' and 24°02' north latitudes and between 90°11' and 90°22' east longitudes. The main rivers are Bangshi, Turag, Buriganga, Dhaleshwari and Karnatali. The upazila consists of 1 pauroshova, 9 wards, 12 unions, namely Amin Bazar, Ashulia, Yearpur, Kaundia, Tetuljhora, Dhamsana, Pathalia, Banagram, Birulia, Bhakurta, Shimulia and Savar. The unions are subdivided into 216 populated mouzas and 380 villages.

The Tetuljhora union has a total area of 20.98 sq. km. This union consists of 39 villages, 23 mouzas (BBS, 2012). The area is bounded on the north by Bangram and Savar Unions, on the east by Amin Bazar Union, on the south by Bakurta Union and on the west by Singair upzaila. The "Shahid Rafiq" bridge above the river has eased the transportation system and connected Dhaka to Manikganj perfectly through Savar upazila. Dhalla union is separated from Tetuljhora union by the Dhaleshwari river.

Manikganj, a part of the Dhaka Division, is a district in central Bangladesh. The total area of the district is 1383.66 sq. km. The district consists of 7 upzilas, namely, Manikganj Sadar, Singair, Shibalay, Saturia, Harirampur, Ghior and Daulatpur. Singair upazila (Figure 3.3) occupies an area of 217.55 sq. km. It is located between 23°42' and 23°52' north latitudes and between 90°03' and 90°16' east longitudes. The important rivers in the upazila are the Dhaleshwari river, the Kaliganga river and the Ghazikhali river. The upazila consists of 1 pauroshova, 9 wards and 11 unions, namely, Baldhara, Bayra, Chandhar, Charigram, Dhalla, Joymontop, Jamirta, Jamsha, Saista, Singair and Talibpur. The unions are subdivided into 138 populated mouzas and 241 villages.

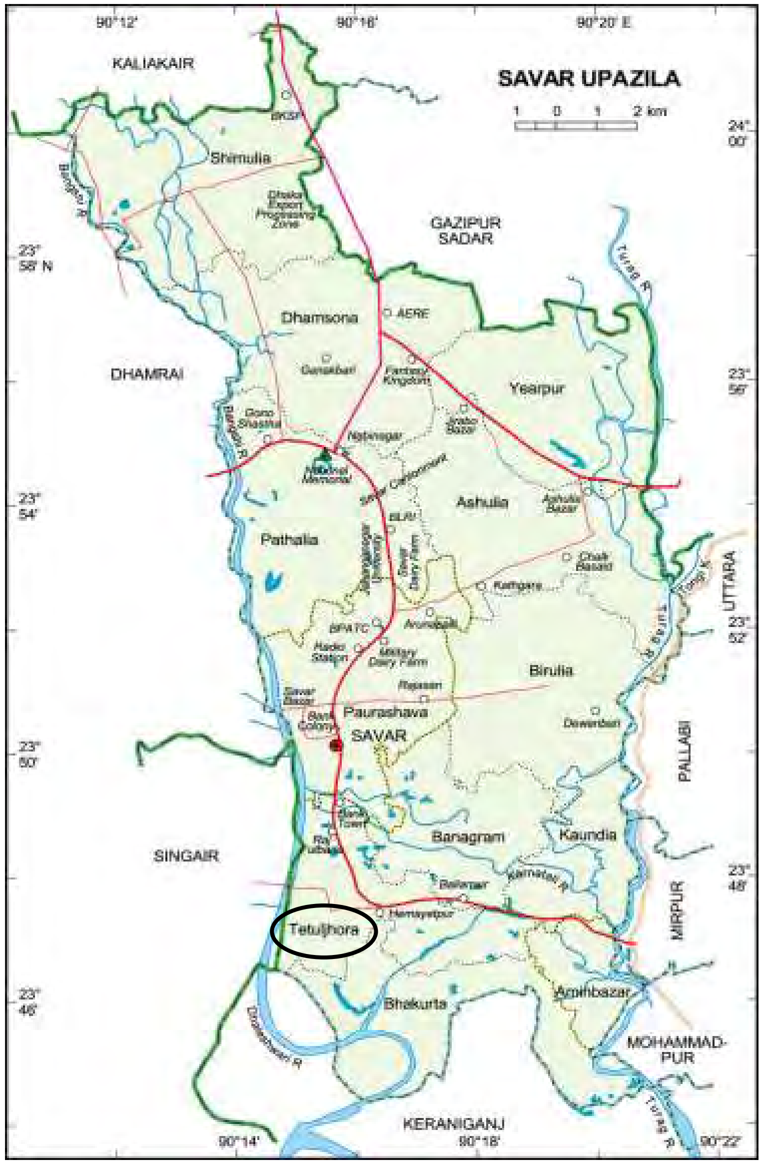

Figure 3.2: Location of Tetuljhora union (Source: Banglapedia, 2014)

Dhalla and Saista unions occupy areas of 22.43 sq. km. and 20.71 sq. km. respectively. Dhalla union is bounded on the north by Dhamrai upazila of Dhaka district, south by Jamirta union, east by the Dhaleshwari river and Savar upazila, and west by Joymontop union. This union consists of 22 villages. Saista union is bounded on the north by Singair and Joymontop union, south by Kaliganga river and Nawabganj upazila of Dhaka district, east by Jamirta and Chandhar unions, and west by Charigram union. This union consists of 44 villages (BBS, 2011).

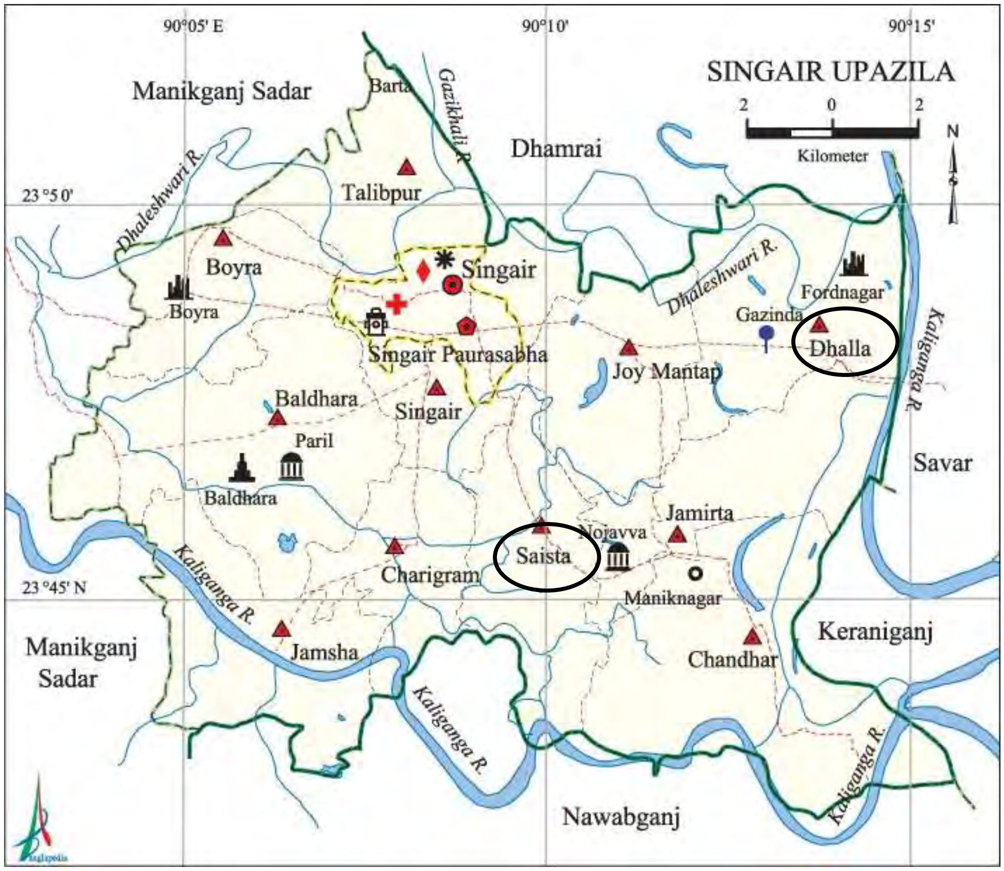

Figure 3.3: Location of Dhalla and Saista unions (Source: Banglapedia, 2014)

3.3 Demography

3.3.1 Population and household

According to Population Census (2011), Tetuljhora union has a total population of about 106929 living in 26287 households. Among them, 54.44% are male and 45.56% are female. The sex ratio (Male: Female) is 119:100. It means that there would be 119 males for every 100 females in the population. The average household size is 4.0 and population density is around 6876 per sq. km.

Dhalla union is the largest union of Manikganj district in terms of population (BBS, 2011). The union has a total population of about 36203 living in 8210 households. Of the total population, 51.11% are male and 48.88% are female. The sex ratio (Male: Female) is 105:100. The average household size is 4.3 and population density is around 1614 per sq. km. Saista union has a total population of about 27188 living in 6153 households. Of the total population, 49.46% are male and 50.54% are female. The sex ratio (Male: Female) is 98:100. The average household size is 4.4 and population density is around 1313 per sq. km. The household and population information are given in Table 3.1.

Table 3.1: Household and population in the study area

Union	HHs	Population		
		Male	Female	Total
Tetuljhora	26287	58214	48715	106929
Dhalla	8210	18506	17697	36203
Saista	6153	13447	13741	27188

On the basis of the above table and using population growth rate, the present and future population (2019 and 2049) in the three unions have been estimated and present population was found to be about 210419, 40590 and 30483 in Tetuljhora, Dhalla and Saista unions respectively.

Table 3.2 shows the percentage distribution of population by age group in the study area. According to Population Census (2011), of the total population in Tetuljhora union, over 60% belongs to age group of 18 years and above. In Dhalla and Saista unions, over 59% and 58% of the total population belongs to age group of 18 years and above. In three unions, the maximum inhabitants are in the age group of 30 years to 49 years. Table 3.3 shows the distribution of population by religion in the study area. It shows that majority of the population is muslim in all the unions.

3.3.2 Literacy rate

The educational institution of the study area involves primary school, high school, college and madrasha. Currently, Bangladesh has, according to UNESCO, an adult literacy rate of 72.89%. While the male literacy rate is 75.7%, for the female, it is 70.09%. According to Population Census (2011), literacy rate in Dhalla union is 42.1%, which is lower than national literacy rate of 72.89%. The literacy rate of male and female in the union is 45.7% and 38.3% respectively. The highest literacy rate is in Tetuljhora union, which is 63.9% (male: 68.1% and female: 58.7%). On the other hand, the lowest rate is found in Saista union, which is 39% only. Table 3.4 shows the literacy rate of the age group 7 years and above in the three unions. Among the three unions, the percentage of disable people is high in Dhalla union.

Table 3.2: Percentage distribution of population by age group in the study area

Age group	% of population in the age group		
	Tetuljhora	Dhalla	Saista
0-4	8.5	9.6	10.0
5-9	9.3	12.1	12.4
10-14	8.4	11.3	11.2
15-19	11.0	7.9	7.6
20-24	15.9	9.0	8.3
25-29	15.3	9.4	9.3
30-49	24.3	25.5	24.1
50-59	3.9	6.8	7.4
60-64	1.6	3.1	3.7
65 and above	1.9	5.4	5.8
% of disable people	0.6	1.8	1.4

Table 3.3: Distribution of population by religion in the study area

Union	Distribution of population by religion				
	Muslim	Hindu	Christian	Buddhist	Others
Tetuljhora	99898	6913	102	11	5
Dhalla	35684	501	16	0	2
Saista	25542	1645	1	0	0

Table 3.4: Literacy rate (7 years and above) in the study area

Union	Literacy rate (7 years and above)		
	Male	Female	Total
Tetuljhora	68.1	58.7	63.9
Dhalla	45.7	38.3	42.1
Saista	41.0	37.1	39.0

3.3.3 Poverty Status

According to BBS (2010), the proportion of the poor population below the upper poverty line, living in Savar and Singair upazila was more than 28% and 16% respectively in 2010. Again, in 2010, the proportion of the poor population below the lower poverty line, living in Savar and Singair upazilas was more than 16% and 7% respectively. The upper poverty line corresponds to the moderate poor households whose food expenditure is at the level of the food poverty line using the cost of basic needs and the lower poverty line corresponds to the extreme poor households whose total expenditures are equal to the food poverty line using the cost of basic needs (BBS, 2010).

According to Household Income and Expenditure Survey (2016), percentage of people living below the national upper and lower poverty lines measured for the year April 2016 to March 2017 are 24.3 and 12.9 accordingly. In Bangladesh, the population living below the national poverty line dropped to 24.3% in 2016 from 31.5% in 2010. So, based on the trend of national poverty rate, the present poverty rate in the study area should be decreased than before.

Table 3.5 shows that, the percentage of well- off inhabitants in Tetuljhora union is more than that of Dhalla and Saista unions in terms of their house structure, toilet facility and electricity connection. Between Dhalla and Saista unions, the percentage of well-off people in Dhalla union is more than that of Saista union.

Table 3.5: Percentage distribution of general household by type of structure, toilet facility and electricity connection

Union	% of type of structure				% of toilet facility				% of electricity connection
	Pucca	Semi-pucca	Kutcha	Jhupri	Sanitary (with water seal)	Sanitary (no water seal)	Non-Sanitary	None	
Tetuljhora	29.6	56.3	13.7	0.4	28.6	65.0	6.2	0.2	97.1
Dhalla	2.7	17.8	77.9	1.7	17.3	69.0	12.7	1.0	48.7
Saista	2.6	13.0	81.4	3.0	7.1	62.2	28.4	2.3	43.6

Table 3.6 shows the distribution of household by tenancy status of house in three unions. In Tetuljhora union, most of the inhabitants are living in rented house and only about 26 percent of the houses are owned by the local people. Because, most of the inhabitants in Tetuljhora union are migrants. They shifted there because of the employment

opportunities in the industries. In Dhalla and Saista unions, most of the houses are owned by local people.

Table 3.6: Percentage distribution of general household by tenancy status of house

Union	% of Tenancy of		
	Owned	Rented	Rent free
Tetuljhora	26.2	72.7	1.1
Dhalla	92.8	4.7	2.5
Saista	96.6	1.8	1.6

3.3.4 Occupation and livelihoods

In the study area, different types of occupations are found such as farmer, fisherman, day laborer, boatman, trader etc. Table 3.7 shows that agriculture farming is the main occupation in Savar and Singair upazilas. Recently, the percentage of industrial workers in Savar upazila has increased to a large extent.

Table 3.8 shows the classification of farmers based on the amount of land. Small cultivated land (0.04 acre or less) is generally used for kitchen garden growing mainly vegetables. So, the minimum cultivated land considered for qualifying to be a farm holding is 0.05 acres. Farmers grow both summer and winter vegetables. Main vegetables are potato, brinjal, raddish, arum, lady's finger, cauliflower, cabbage, bean, tomato, patal, gourd, cucumber, pumpkin, knoll-kal-turnip, dhundal, barbati, khirai, chichinga, carrot, kakrol and sak. Main cash crops are jute, mesta, sunhemp, cotton, sugarcane and tobacco. Dhaincha and other smaller plants used as cooking-fuel.

Table 3.9 shows that the daily average wage rates for agricultural and non-agricultural laborers are higher in Savar upazila than that of Singair upazila. Again, average wage rate for male laborers are higher than that of female laborers. Child laborers (under 15 years old) are the least-paid workers in the study area.

Table 3.7: Percentage distribution of occupation in the study area

Occupation by %	Union	
	Savar	Singair
Industrial worker	1.37	0.98
Farmer	24.34	42.80
Agricultural labor	12.84	14.04
Wage labor	4.44	2.55
Construction	1.66	0.96
Traders	17.35	14.15
Poultry, Fisheries, Dairy	1.90	5.39
Transport (Rickshaw, van puller)	3.96	2.17
Services	20.68	8.39
Remittance and others	11.46	8.57

Source: Banglapedia (2014)

Table 3.8: Farm category by land ownership in Manikganj district

Farm category	Amount of land	Number	% of total population
Landless	0.01-0.04 acre	13163	7.14
Small Farmer	0.05-0.49 acre	40588	22.03
	0.50-0.99 acre	45562	24.73
	1.00-1.49 acre	31207	16.94
	1.50-2.49 acre	30956	16.80
Medium Farmer	2.50-7.49 acre	21244	11.53
Large Farmer	7.50 and above	1511	0.82
Total		184231	100

Source: Agriculture Census-2008, BBS

Table 3.9: Daily average wage rate in the study area

Upazila	Daily average wage rate (Taka)							
	Agricultural laborer			Non-agricultural laborer				
	Male	Female	Child (under 15 years old)	Porter (coolee)	Garden labor male	Garden labor female	Other labor (Adult)	Other labor (Child)
Savar	270	200	150	350	300	0	300	150
Singair	250	200	100	300	250	150	200	100

Source: Yearbook of Agriculture Statistics-2017

3.4 Geology and Soil

Geology of Bangladesh is generally dominated by poorly consolidated sediments deposit over the past 10,000 to 15,000 years (Holocene age). It is mostly characterized by the rapid subsidence and filling of a basin in which a huge thickness of deltaic sediments were deposited as a mega-delta out built and progressed towards the south. The delta building is still continuing into the present Bay of Bengal and a broad fluvial front of the Ganges-Brahmaputra-Meghna river system gradually follows it from behind.

The soil formation of Manikganj district falls under the Brahmaputra alluvium floodplain. The dominant soil texture is sandy loam. The soils are acidic in character and the pH ranges from 5.5 to 6.8. The soils are naturally fertile and are recharged every year by fresh deposition by the floodwaters. The soil formation of Singair upazila falls under the grey floodplain soils which is grey and finely mottled brown in color, seasonally flooded with seasonally acidic top-soil and near neutral subsoils. According to Agricultural Statistics (2017), the soil in Savar upazila is composed of the alluvium soil of the Bangshi and Dhalashwari rivers, soil type is red-brown terrace soils which is well to moderately well-drained, red and brown in color, strongly acidic. The dominant soil texture is clay loams and clays. Modhupur clay is at 0.30-0.91 meter.

3.5 Climate

The Bangladesh Meteorological Department (BMD) monitors different climatic variables from 35 stations in Bangladesh. Among them, the station located at Agargaon, Dhaka is the closest to the site and will best represent the meteorological condition of the site. The climate of the study area is tropical monsoon with hot summer and cool winter. The general pattern follows the monsoon pattern with the cooler, drier months of November to March, increasing rains in April and May. Highest rainfall occurs in the summer months of June to September (about 70% of the annual rainfall) when the prevailing wind direction from the southwest brings moisture-laden air from the Bay of Bengal. The winter period (November to February) is dry with very little rainfall. Table 3.10 shows monthly averages of different climatic variables at the Dhaka station.

Maximum average temperature over the year is usually observed in April (36.7 °C) to September (35 °C) and minimum average temperature in January (10.1 °C). The spatial and temporal variation of relative humidity throughout the year is very low. The relative humidity varies from 59% to 86%. The average incident solar radiation is comparatively higher during the period between February to May than the other months of the year. Consequently, the amount of evaporation is also higher during that period.

3.6 Land Type and Land Use

According to the land classification system of Water Resources Planning Organization (WARPO), land is divided into four types (Table 3.11): high land (F0-type with inundation depth up to 0.3m in average flood), medium highland (F1-type with inundation depth up to 0.3-0.9m in average flood), medium lowland (F2-type with inundation depth up to 0.9-1.8m in average flood) and low land (F3-type with inundation depth >1.8m).

Table 3.10: Monthly averages of climatic variables at the Dhaka station, 2001-2013

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	5	14	29	111	212	326	350	290	316	155	19	11
Mean temp (°C)	18.0	21.9	26.0	28.1	28.5	28.4	28.3	28.5	28.2	27.1	23.7	19.9
Max temp (°C)	28.3	32.3	36.0	36.7	36.5	35.7	34.8	34.8	35.0	34.8	32.3	29.2
Min temp (°C)	10.1	12.4	16.5	19.3	20.6	22.7	23.9	24.0	23.7	20.6	15.8	11.8
Humidity (%)	69	60	59	68	72	80	81	80	80	76	70	71
Sunshine (Hours)	5.7	7.3	7.5	7.7	6.8	3.4	4.0	4.5	4.2	5.7	6.8	5.8
Solar radiation ($Cal/cm^2/min$)	166	207	231	244	229	175	189	192	172	183	174	146
Evaporation (mm/d)	2.6	4.0	5.0	5.5	5.3	4.1	3.8	3.8	3.6	3.5	3.3	2.5

Source: Bangladesh Meteorological Department

Table 3.11: Percentage of land types in Singair upazila

Land types	Percentage of land
High land	18.73
Medium land	66.65
Low land	14.62

The existing scenario at the eastern side of the Dhaleshwari river is significantly different from the western side of this river. Tetuljhora union of Savar upazila is situated at the eastern side of the Dhaleshwari river. The Agriculture Census of 1996 (BBS, 2000) recorded Savar upazila as urban domain. But the area is not completely rural and not a completely urban area. The union is mainly a mixed area comprising both urban and rural characteristics.

Several number of brick kilns are present at the study area which are adjacent to the Dhaleshwari river. A significant number of mosques, temples, residential houses, commercial installations and various types of factories are available in Singair upazila. Construction work of the Tannery Estate Dhaka (a Bangladesh Government project) is going on and all kinds of tannery and leather industries from the Hazaribagh area are relocated here. A central effluent treatment plant will be setup for this Tannery Estate.

3.7 Agricultural Practices

The main crops of the study area are Aman rice, Boro rice, wheat, potato and vegetables. The amount of land used for cultivation of different crops and their total production are shown in Table 3.12. According to Agriculture Census (2008), Aman and Boro rice were the main crops in Savar and Singair upazilas, Aman rice cultivated in rotation with HYV Boro rice is the major cropping pattern in the study area. In recent years, farmers of the area have given more emphasis on wheat cultivation because it requires less irrigation compared to rice cultivation. A very small amount of Aus rice have also been cultivated. But at present, cultivation of Aus rice has almost extinguished in the study area because Aus rice suffers from drought any time from the seedling to reproductive stages, as the crop is direct-seeded and grown under rainfed upland conditions. Table 3.13 shows that most of the land in the study area are temporary cropped area. Among them main exports in the study area are paddy, potato, pulse, oil seed, vegetables, sugarcane molasses, brass and bell metal products, cattle, poultry, milk, papaya, guava and brick.

Table 3.12: Cultivated area and production of different crops in Savar and Singair upazilas

Crops	Savar		Singair	
	Area (acres)	Production (metric ton)	Area (acres)	Production (metric ton)
Aus	173	156	275	188
Aman	4730	4134	17268	5450
Boro	27702	51218	28301	47738
Wheat	86	83	1840	956
Jute	756	564	4811	3309
Sugarcane	34	306	4065	24390
lentil (masur)	42	10	1035	207
maize	38	92	295	508
potato	95	666	447	2860
Rape & mustard	1389	457	5277	1530

Source: Agriculture Census-2008, BBS

Table 3.13: Percentage of operated cropped area based on utilization

Upazila	Permanent cropped area	Temporary cropped area	Permanent fallow area
Savar	3.5	54.85	2.68
Singair	1.64	76.32	0.34

Source: Agriculture Census-2008, BBS

The area under irrigation in the study area is mainly irrigated by low lift pump in traditional method. Table 3.14 shows that low lift pumps and shallow tubewells are the main sources of irrigation in Singair upazila and only thirteen deep tubewells are used for irrigation. There are fewer number of equipment in Savar upazila than that of Singair upazila as Savar upazila has smaller amount of agricultural land for cultivation.

Table 3.14: Number of irrigation equipment and irrigated area of different crops

Mode of irrigation	Number of irrigation equipment		Irrigated area (acres)	
	Savar	Singair	Savar	Singair
Low lift pump	852	5054	12758	27274
Deep tubewell	124	13	7553	1939
Shallow tubewell	495	3745	1425	9379

Source: BADC, 2006

3.8 Resources

The main livestock resources of the study area involve cows, goats, sheep, hens and cocks, and ducks. Table 3.15 provides an account on the livestock resources of the study area. In recent years, the numbers of livestock species have decreased drastically.

Table 3.15: Distribution of livestock species in the study area

Upazila	Cow and buffalo	Goat	Sheep	Hen and cock	Duck
Savar	41613	21768	2411	145664	42425
Singair	480	36	0	101230	0

Source: Agriculture Census-2008, BBS

Table 3.16 shows the distribution of household by source of drinking water in the study area. In all the three unions, the main source of drinking water is tubewells. At present, the use of tubewells has reduced as the use of tap water has increased in Tetuljhora union. In Dhalla union, dependency on tap water connections has increased too.

According to Agriculture Census (2008), the number of ponds, dighees and other wetlands in Savar upazila is more than that of Singair upazila (Table 3.17). At present, many dighees and ponds have dried up entirely. As a result, the production of fish has also decreased and many fishermen have to change their occupation. Table 3.18 shows the number of fisherman and production of fish in the study area.

Table 3.16: Percentage distribution of general household by source of drinking water

Union	Percentage of source of drinking water		
	Tap	Tubewell	Others
Tetuljhora	39.2	60.3	0.5
Dhalla	0.7	98.9	0.4
Saista	0.5	95.3	4.3

Table 3.17: Number and area of pond, dighee and others

	Savar			Singair		
	Number	Area (acres)	% of area	Number	Area (acres)	% of area
Pond	2066	1183	25.8	1217	353	33.24
Dighee	1	11	0.24	7	709	66.76
Other area	-	3392	73.96	-	0	0
Total area	-	4586	100	-	1062	100

Source: Agriculture Census-2008, BBS

Table 3.18: Number of fisherman and production of fish in the study area

Upazila	Number	Production (metric ton)
Savar	7073	1380
Singair	2018	2748

Source: Agriculture Census-2008, BBS

Operationally important NGOs are BRAC, Proshika, ASA, World Vision and Swanirvar Bangladesh.

3.9 Hydrological Features

3.9.1 Surface water

3.9.1.1 River network

The Dhaleshwari River, a distributary of the Jamuna River, takes off in the northwestern part of Tangail district. It is a meandering river having two branches. The main stream flows north of Manikganj and joins the other branch, the Kaliganga River, south of Manikganj. The Kaliganga River again joins the Dhaleshwari River. The Buriganga River was once a distributary of the Dhaleshwari River and used to discharge its flow again into the Dhaleshwari River. The river meets the Shitalakshya River near Narayanganj and flows south to meet the Meghna River near Shaitnol and then loses its separate identity. Total length of the river is about 160 km. Figure 3.4 shows the Dhaleshwari River from the Google Earth image and Figure 3.5 shows the river from Shaheed Rafiq Uddin Ahmad Bridge which connects Tetuljhora and Dhalla unions.

Once the Dhaleshwari River was a lifeline of the study areas. From washing of daily household chores to fishing or farming, everything revolved around the river. It was the main source of water. Since the Savar Tannery Industrial Estate started dumping effluents into the river, the water became highly polluted. The local people cannot not use the water for farming or washing livestock anymore. They cannot bathe in the river in fear of water-borne diseases. Some of the local people in Tetuljhora union reported waterlogging problem during peak monsoon.

Figure 3.4: The Dhaleshwari River along with the study sites

Figure 3.5: The Dhaleshwari River from Shaheed Rafiq Uddin Ahmad Bridge connecting Tetuljhora and Dhalla unions

3.9.1.2 River water level

Annual maximum and minimum water level data of the Dhaleshwari River from the Savar station for the period 1994-2014, collected from Bangladesh Water Development Board (BWDB), is given in Table 3.19. The maximum and minimum water levels were found to be 11.44 m and 0.65 mPWD in 2002 and 2007, respectively. Figure 3.6 shows the station-based water level of the Dhaleshwari River compared to its Danger Level (DL) and Recorded Height Water Level (RHWL) during May to October. It shows that the river water level for monsoon season starts exceeding danger level from end of July to mid-September at the station.

Table 3.19: Year wise water level data of the Dhaleshwari River at Savar (Station ID: SW69)

Year	Maximum level (mPWD)	Minimum level (mPWD)
1994	5.83	1.23
1995	7.29	1.18
1996	6.48	1.25
1997	6.14	0.95
1998	8.63	0.88
1999	6.45	0.97
2000	6.48	1.00
2001	5.91	1.20
2002	11.44	1.24
2003	7.92	1.39
2004	5.96	0.88
2005	5.80	1.26
2006	5.05	0.78
2007	7.30	0.65
2008	4.10	0.97

2009	5.71	0.99
2010	6.15	1.36
2011	6.47	1.68
2012	6.16	1.69
2013	5.38	1.02
2014	5.89	1.09

Source of data: BWDB

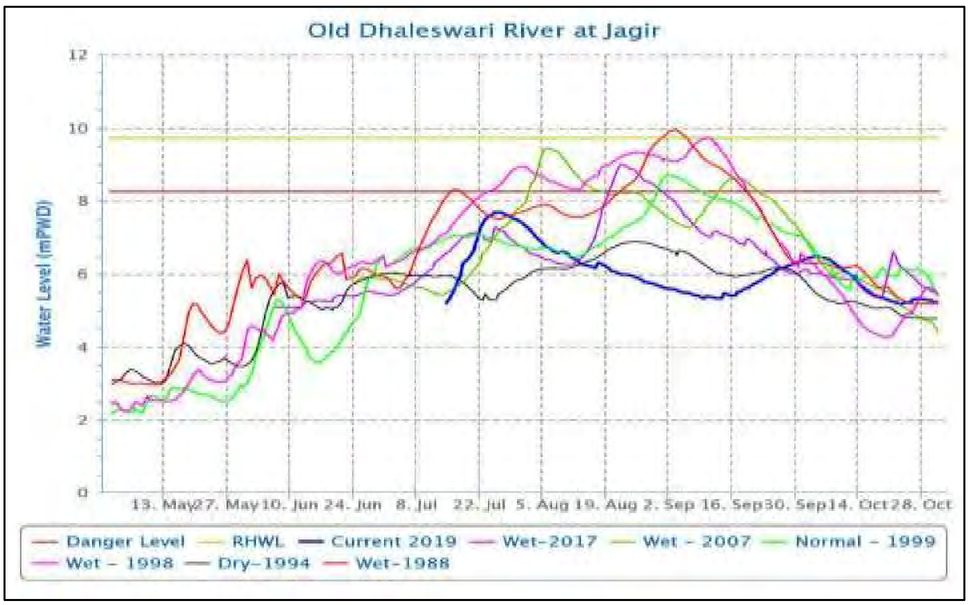

Figure 3.6: Water level of the Dhaleshawari River during May-October along with its danger level

3.9.1.3 River water quality

The main surface water body in the study area is the Dhaleshwari River which serves the purpose of natural drainage of storm water. Several factories are present on the bank of the river which receives their waste streams. The Dhaleshwari River is also the intended recipient of the treated effluent of the Common Effluent Treatment Plant (CETP) of the tannery estate which is under construction.

According to River Water Quality Report (DoE, 2015), the Dhaleshwari river water was almost neutral and pH varied from 6.7 to 8.78 in 2015 which is within the permissible limit for diverse uses like irrigation, according to standard value of DoE (Figure 3.7a). The normal range for pH in surface water systems is 6.5 to 8.5 and for groundwater systems 6 to 8.5 (ECR, 1997).

Dissolved oxygen (DO) is needed for waste degradation and decomposition by microorganism. Fish in water containing excessive dissolved gases may suffer from severe disease. The requirement for DO is 4 to 6 mg/L for fish and livestock (ECR,1997). In 2015, the maximum DO concentration (20.4 mg/l) was at Harindhara in May. The minimum value was (0.0 mg/l) at Muktarpur Ghat in January (Figure 3.7b) and such low value does not support the survival of aquatic life.

The permissible limit for BOD for drinking water is 0.2 mg/L, for recreation 3 mg/L, for fish 6 mg/L and 10 mg/L for irrigation. (Bangladesh standard) (ECR, 1997). In 2015, BOD varied from 0.8 to 17.0 mg/l (Figure 3.7c). So, it does not meet the standard for drinking water.

The maximum COD of the Dhaleshwari River water was 53 mg/l in January at Muktarpur Ghat and the minimum was 24.15 mg/l in July (Figure 3.7d). The permissible limit for drinking water is 4 mg/L (ECR, 1997). The river water has higher COD values because of the industries near the riverbank and their waste materials (organic/inorganic substances).

Considering all measured parameters (especially DO, BOD and COD), it could be concluded that pollution of Dhaleshwari water reached at critical point. So, the water is unable to be used by local people for drinking, bathing and cooking purposes.

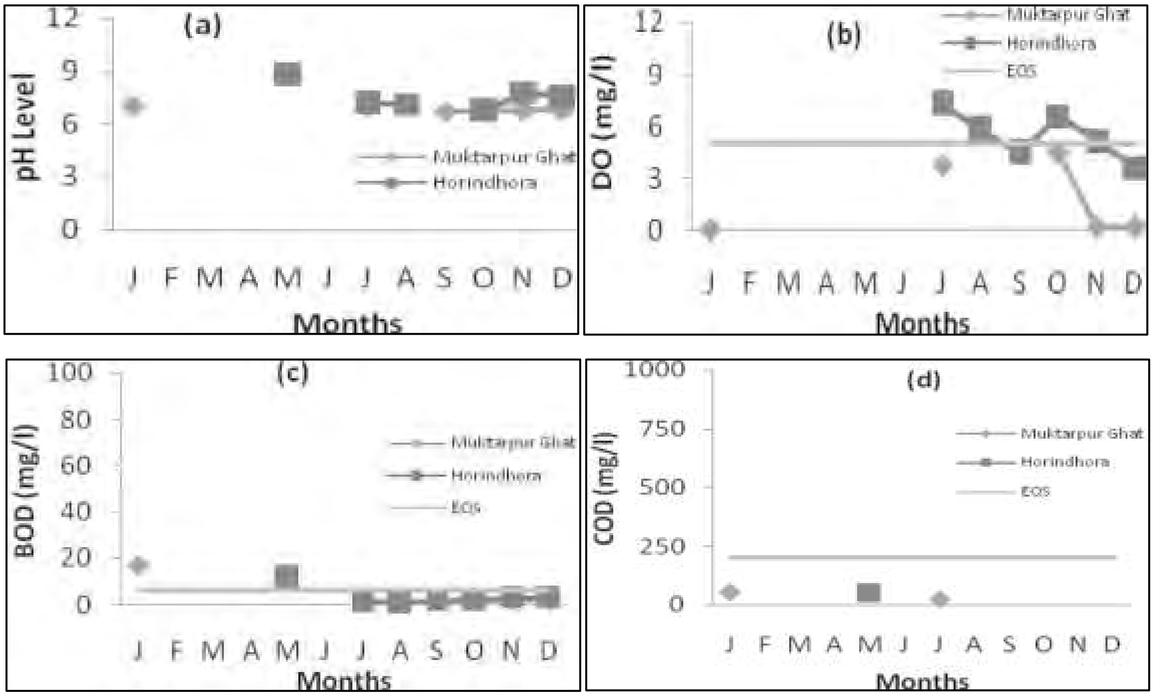

Figure 3.7: pH, DO, BOD and COD of the Dhaleshwari River in 2015

3.9.2 Groundwater

3.9.2.1 Lithology

The aquifer system of Singair upazila can be divided into three divisions: upper aquitard, upper aquifer and lower aquifer. Upper aquitard comprises a mixed sequence of grey colored low permeability clays, silty clays, silts and occasional very fine sand layer. Thickness ranges from 3.05 m to 9.15 m. Upper aquifer is mainly composed of grey to light brown color very fine sand to fine sand and thickness ranges from 39.65 m to 85.41 m. Lower aquifer is composed of medium to coarse sands and gravels. The thickness ranges from 129.2 m to 173.8 m. Most of the deep tubewells, either for irrigation or for domestic and industrial purposes, have been installed in this zone. Absence of lower aquitard indicates that the area is susceptible to contamination (Islam et al., 2018).

Hydro-geologically the aquifer system of Savar upazila is semi-confined to confined in nature and transmissibility of the main aquifer varies from 855 m^2/day to 1259 m^2/day with a storage coefficient ranging from 0.003 to 0.01 (Zahid, 2003). It is quite alarming that there has been a constant decline in the groundwater level since 2005, with the average rate of declination about 0.6 m/year. The groundwater level is relatively higher in the northern and western parts and lower in the southeastern part of the study area due to huge water extraction in Dhaka city (Ahmed et al., 2010). Combining seven hydrogeological attributes, namely depth to aquifer, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity, a vulnerability map has been prepared (Hasan et al., 2019). According to the groundwater vulnerability map of Savar upazila (Figure 3.8), Tetuljhora union falls under moderate vulnerable zone.

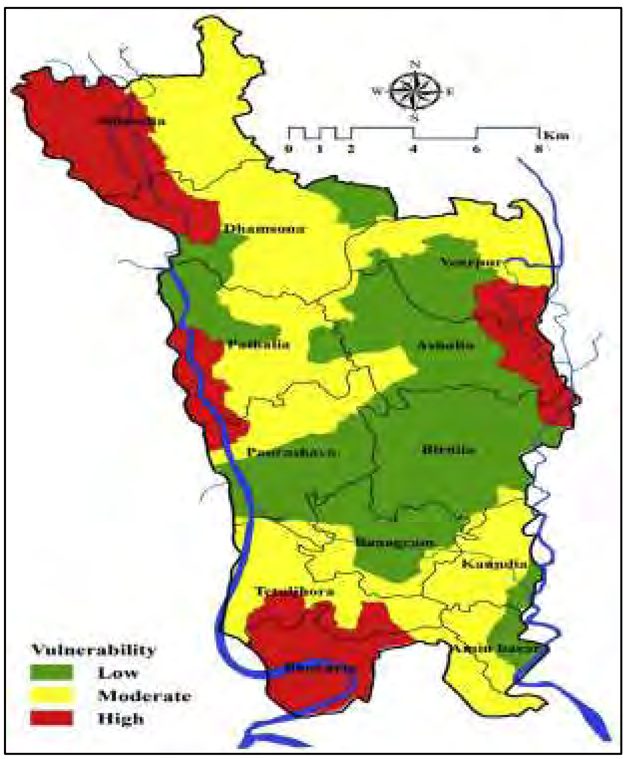

Figure 3.8: Groundwater vulnerability map of Savar upazila (Source: Hasan et al., 2019)

3.9.2.2 Groundwater level

Aquifers are being recharged by the major river systems and by infiltration of rainwater. The groundwater level fluctuates seasonally, approaching the ground surface at some places during the months of July to September. However, the deep aquifer, which is used for supplying water in the study area, lies at a much greater depth (up to about 200m). Strong declining trends (0.5-1.0 m/year) in dry-period groundwater levels are observed in the central part of the country surrounding the Dhaka city (Shamsudduha et al., 2009).

Excess extraction has caused the groundwater level to decline at a rate of more than 1.0 m in the study area. Groundwater is replenished each year during the monsoon season when rain and flood water finds its way into the aquifer slowly percolating down through overlying soils and sediments. The rate of recharge varies depending on the property of soil and geology of the area. Figure 3.9 shows the location of the study area on the groundwater zoning map (BARC, 2015) of Bangladesh. It can be seen from the map that groundwater is available at Dhalla and Saista unions around 5.3 – 7.6 m and at Tetuljhora union around 7.6 – 9.8 m below the ground surface.

3.10 Natural Disaster

The flood inundation map of Bangladesh prepared by Flood Forecasting and Warning Centre (FFWC) shows that the study area is subject to low to moderate river flooding with some flood-free area (flood depth ranging from 0 - 0.1 m) and some area under flood depth of 0.1 – 0.3 m (Figure 3.10).

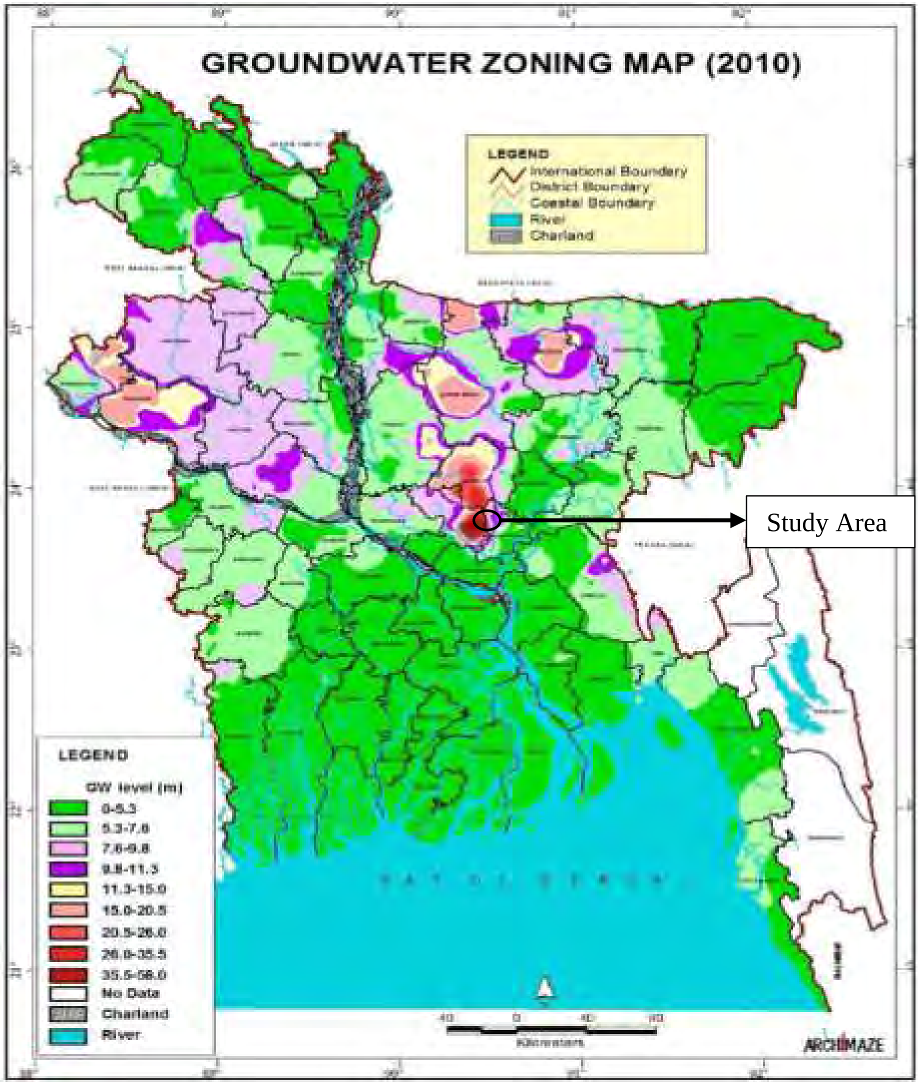

Figure 3.9: Location of the study area on the Groundwater Zoning Map (2010) of Bangladesh (Source: BARC, 2015)

During monsoon, especially in July and August, due to heavy rainfall, crop loss is observed. Table 3.20 shows historical production loss in Manikganj district due to heavy rainfall in financial year 2014 – 15. In this area, Aman rice yields the highest production loss. Table 3.21 shows the occurrence of major tornados in 1973 and 1989 in the study area. Both the tornados were catastrophic, but the tornado in 1989 was the deadliest which strucked into an area that had been suffering from severe drought.

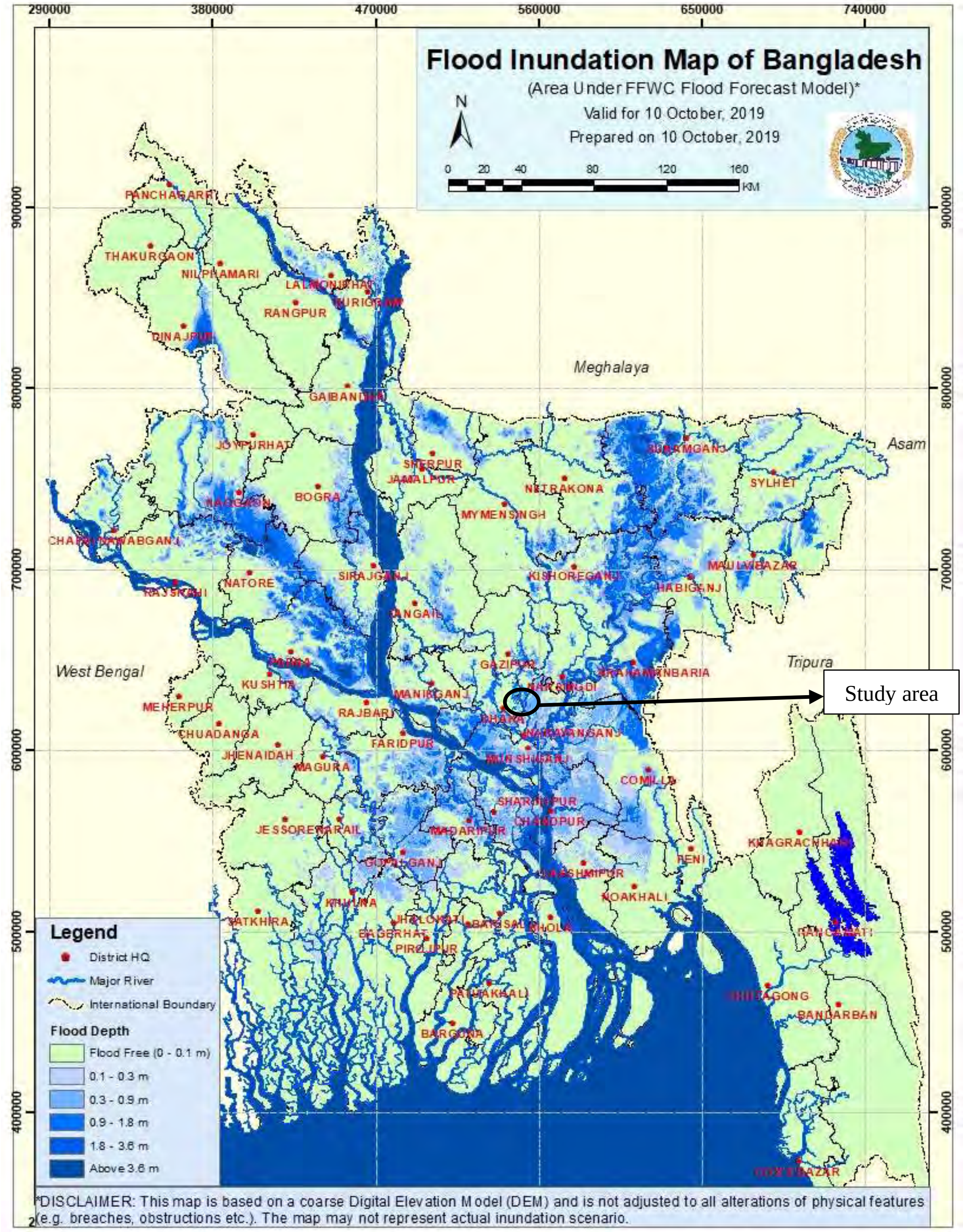

Figure 3.10: Flood inundation map of Bangladesh (Source: FFWC, 2019)

Table 3.20: Damage report for different crops due to flood and excessive rain in the months of July and August (2014-15) in Manikganj district

Name of crop	Area damaged (acres)		% of partial damage	Area in terms of full damage (caused by partial damage)	Total area damaged (Acres) (Col. 2+5)	Yield per acre (kg)	Production Loss in (Metric Ton)
	Fully	Partially					
B. Aman	9141	18553	46.40	8609	17750	18.30	12125
HYV Aman	1227	1680	45.42	763	1990	27.95	2076
Total Aman	4109	12855	20.23	2601	6710	14.63	3665

Source: Yearbook of Agricultural Statistics 2017, BBS

Table 3.21: Major tornados in the study area

Date of occurrence	Place of occurrence	Area of devastation (sq. km.)	Duration of storm (min.)	Maximum wind speed (km/hr.)	People killed	Number of injured	Loss of property (Tk. in millions)
17-04-1973	Manikganj	20.7	8-10	322	100	1000	10
26-04-1989	Manikganj (Saturia)	150.2	Several minutes	388-419	526	Innumerable	Several millions

Source: Agriculture Census-2017, BBS

CHAPTER FOUR

METHODOLOGY

4.1 Introduction

The overall objective of this study was to assess present and future water poverty for different livelihood groups in selected peri-urban areas in a changing environment. At first, the present and future water poverty indices were calculated for selected groups. Then, the impact of environmental changes on different groups had been assessed by analyzing different climatic and environmental factors.

4.2 Selection of the Study Area and Livelihood Groups

To identify the changes in water poverty status, three different types of unions were selected after conducting a detailed Reconnaissance Survey and Focus Group Discussions (FGDs) and Interviews with local stakeholders. The study area offered sufficient existence of both urban and rural characteristics which exhibit the characteristics of peri-urban areas. The other selection criteria were accessibility, availability of different livelihood groups and likely impact of climate change.

Table 4.1 shows a comparative scenario among the three study areas. It shows that all of the unions have different hydrological background and other features. The unions have different water issues too. Tetuljhora union in Savar upazila is an industrial area which is one of the densely populated cities with unplanned land cover. The access to water and availability are highly affected due to the environmental degradation. On the other hand, Dhalla and Saista unions in Singair upazila have more rural characteristics with different livelihood groups than Tetuljhora union. The water supply system also varies among three areas. Most of the inhabitants in Tetuljhora union have piped water connection whereas inhabitants of other two unions are dependent on tubewells. The degree of urbanization also differs from each other. Considering these differential scenarios, these three unions are considered suitable for the study.

Table 4.1: A comparison among three study areas

Features	Tetuljhora	Dhalla	Saista
Area (sq. km)	20.98	22.43	20.71
Villages	39	22	44
Total HH	26287	8210	6153
Population	106929	36203	27188
Average size of HH	4	4.3	4.4
Population density (per sq. km)	6876	1614	1313
Sex ratio (Male:Female)	119:100	105:100	98:100
Literacy rate	63.9%	42.1%	39%
Main source of DW	GW (tap water): 39.2	GW (TW): 98.9%	GW (TW): 95.3%
Hydrological features	on the bank of the Dhaleshwari River	on the bank of the Dhaleshwari River	Nearest river: Kaliganga
Land type and land use	Both urban and rural	Mixed land use	Rural setting
Major livelihood	Industrial workers, day laborers	Farmers, Industrial workers	Farmers, fishermen

In Tetuljhora union, major livelihood groups were industrial workers, day-laborers, small vendors, peddlers and small businessmen. In Dhalla union, major livelihood groups were farmers, industrial workers, small vendors and drivers and rickshaw pullers. In Saista union, majority of the inhabitants were farmers and fishermen. Among these major livelihood groups, the disadvantaged livelihood groups were identified from seven FGDs and eight Key Informant Interviews (KIIs). Only the livelihood groups from lower income groups which were directly involved with water management were selected for the analysis.

From Tetuljhora union, two groups, such as, male and female industrial workers were selected. From Dhalla union, five groups were selected and they were: female industrial workers, large male farmers, small male farmers, women farmers and economically inactive women group (unemployed women, adolescent girls, physically challenged and elderly women). From Saista union, four groups were selected and they were: large male farmers, small male farmers, women farmers and economically inactive women group.

4.3 Data Collection

Both primary and secondary data were used for this analysis. Qualitative data were collected mainly from the field while most of the quantitative data were collected from secondary sources. The following sections will describe the data collection method.

4.3.1 Primary data collection

Primary data were collected using a number of methods like semi-structured questionnaire survey, FGDs, semi-structured interviews with different key informants, and in-depth interviews. Data collection was carried out from October 2018 to April 2019.

4.3.1.1 Reconnaissance survey

At first, field reconnaissance was done three times in the study area to have a clear idea about the location, livelihoods of the local inhabitants and water management system. The information helped in selecting appropriate indicators for WPI components, conducting a questionnaire survey and arranging FGDs and identifying people for KIIs and in-depth interviews.

4.3.1.2 Questionnaire survey

Stratified purposive random sampling technique was adopted for household survey. A set of questionnaires (Appendix A) were prepared before conducting the household questionnaire survey and the questionnaires were pre-tested during reconnaissance visit to the study area. Sample size in each group in the study area is shown in Table 4.2. The total sample size for the household questionnaire survey was 260.

Table 4.2: Distribution of sample size in the study area

Upazila	Union	Livelihood Groups	Sample Size
Savar	Tetuljhora	Industrial workers (Male)	20
		Industrial workers (Female)	15
Singair	Dhalla	Industrial workers (Female)	25
		Large farmers (Male)	25
		Small farmers (Male)	25
		Women farmers	15
		Economically inactive women group	30
	Saista	Large farmers (Male)	25
		Small farmers (Male)	25
		Women farmers	15
		Economically inactive women group	40
Total			260

Semi-structured household questionnaire survey was conducted in the study area to evaluate the present and future WPIs from its five components: Resource, Access, Capacity, Use and Environment. The questionnaire for survey had been classified into two parts. The first part was designed to know the personal information of individual households. The second part of the questionnaire was selected based on the indicators for the components. Each question contained some options. Response against each question was recorded and the response was converted into numeric scores. Following Jemmali (2017), the scores ranged from 0 to 100 and were divided into four scale. The highest score was 100 which was considered as fair and the lowest score was 0 which was considered as risky. The other two scores in between them were 67 (acceptable) and 33 (poor). The values for each response were given on judgment basis.

4.3.1.3 Focus group discussions

A total of seven FGDs were conducted with different livelihood groups such as male and female farmers and economically inactive women groups in Dhalla and Saista unions. Checklists to conduct FGDs were developed on the basis of objectives of the study. The findings from the FGDs were useful in selecting indicators for WPI components and assessing future water poverty indices for the groups. Figure 4.1 shows the view of an FGD with farmer group in a local tea store in Dhalla union.

Figure 4.1: View of an FGD with farmer group in Dhalla union

4.3.1.4 Key informant interviews

Key Informant Interviews (KIIs) were conducted for collection of information. KII is an important method for collection of information on the overall aspects of the study based on observation and experience of the local key people. These semi-structured interviews with different key informants helped to understand the overall situation of the location, occupation, the water sources and their availability, water quality, conflicts regarding water use and other qualitative information. KIIs were conducted with the Assistant and Sub-Assistant Engineers from The Department of Public Health Engineering (DPHE) in Singair upazila, the Sub-Assistant Agriculture Officer of Singair upazila, two local school teachers and three local large educated farmers. Figure 4.2 shows the view of a KII with the Sub-Assistant Agriculture Officer of Singair upazila.

Figure 4.2: View of a KII with the Sub-Assistant Agriculture Officer of Singair upazila

4.3.1.5 In-depth Interviews

Four case studies were conducted on male industrial worker, female industrial worker, male farmer and female farmer in order to differentiate gender roles in their respective workplaces and also in their family life from water management perspective. Table 4.3 shows the list of participants involved in the case studies. Figure 4.3 shows views of male and female farmers engaged in agricultural activities.

Table 4.3: Details of participants involved in the case studies

Participants	Age (years)	Occupation	Location
A	29	Industrial worker	Tetuljhora
B	32	Industrial worker	Tetuljhora
C	44	Farmer	Saista
D	50	Farmer	Saista

Figure 4.3: Views of male and female farmers engaged in agricultural activities

4.3.2 Secondary data collection

Secondary data such as climatic data (daily maximum and minimum temperatures and daily total rainfall) from the year 1953 to 2017 were collected for Dhaka station from Bangladesh Meteorological Department (BMD). Hydrological data such as surface water level of Dhaleshwari river (Station name: Savar; Station ID: SW 69), and groundwater level (Well ID: GT5682014 and GT5682015) from the year 1975 to 2015 were collected and gathered from Bangladesh Water Development Board (BWDB). Data for population growth in the study area were collected from the census reports of Bangladesh Bureau of Statistics (BBS, 2011). Satellite images, i.e. landsat images for 1989 and 2019, were collected to determine land use changes. These landsat images were collected from the

United States Geological Survey (USGS) using the EarthExplorer (https://earthexplorer.usgs.gov/) tool.

4.4 Methods of Evaluating the Water Poverty Index (WPI)

To compute the WPI from a series of variables at a local level, locally determined values and parameters (a bottom-up approach) were used using the composite index approach. A conceptual framework for the index calculation is shown in Figure 4.4. Composite indexing involved two key steps such as selection of indicators and construction of the index. The first three steps in the framework were associated with selection of indicators and the next three steps were associated with construction of the index. The two key steps are described in the following sections.

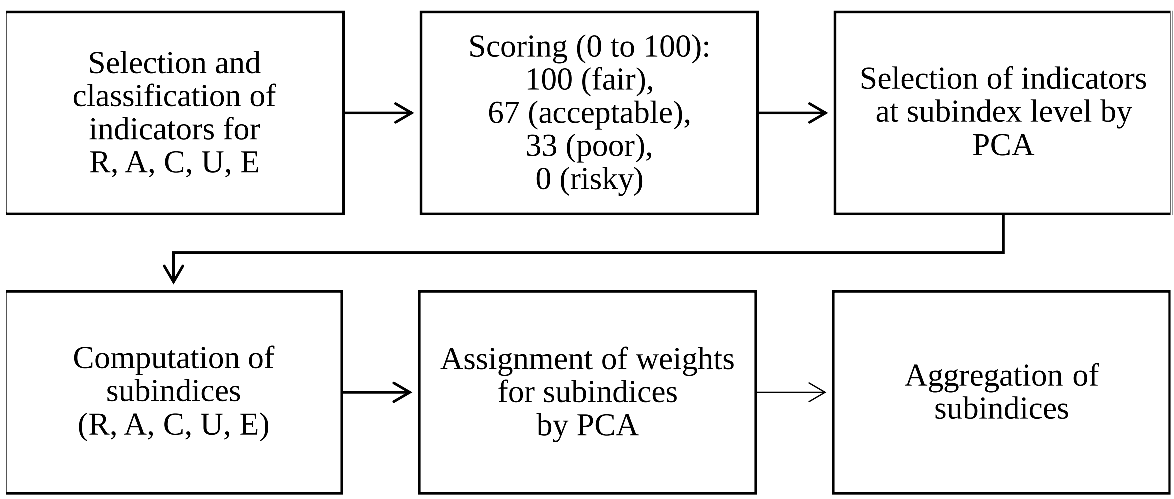

Figure 4.4: Methodological framework for construction of WPI (Note: R, A, C, U and E indicate Resource, Access, Capacity, Use and Environment respectively)

4.4.1 Selection of indicators

As WPI is an indicators-based approach, the first stage consisted of defining a set of relevant indicators for its five components: Resource (R), Access (A), Capacity (C), Use

(U) and Environment (E). For Resource, Capacity and Environment components, indicators would be the same for all the groups. But the indicators for Access and Use slightly varied due to different contexts of different groups. Indicators were selected after reconnaissance survey and FGDs and also through literature review. In a conventional method, following dimensions were covered by the components (Table 4.4).

Table 4.4: Water poverty index structure

Components	Indicator
Resource (R)	Surface water availability
	Groundwater availability
	Variability
Access (A)	Access to safe water
	Access to irrigation
	Access to improved sanitation
Capacity (C)	Economic capacity
	Social capacity
	Operation and management
Use (U)	Water consumption in different sectors
	Conflicts regarding water use
Environment (E)	Pollution and water quality
	River health indicator
	Natural disasters related to water
	Vegetation and land use

Source: Adapted and modified from Sullivan (2002), Van Ty et al. (2010) and Anju et al. (2017).

In this study, indicators were modified as per the present scenario and relevance of the study area (Appendix B). Each component consisted of several indicators to create a context-specific index of water poverty. All data for the indicators were collected through questionnaire survey. The indicators are as follows:

a. Resource (R):

There were eight indicators under Resource component for all groups and they were: perceived changes in surface and groundwater level (R1 and R2 accordingly), degree of rainfall variability (R3), occurrence of illness from using surface and groundwater (R4 and R6 accordingly), odor in surface and groundwater (R5 and R8 accordingly) and groundwater quality (R7).

For R1 and R2, responses from the questionnaires were divided into four categories: No change (100), low decrease (67), medium decrease (33) and high decrease (0). Responses for R3 were segmented as less, moderate, high and very high. R4 and R6 were segmented as no illness, minor illness, moderate illness and major or extreme illness; R5 and R8 as no odor, seasonal mild odor, seasonal extreme odor and odor throughout the year; R7 as no issue, iron, arsenic and presence of both iron and arsenic.

b. Access (A):

The indicators for Access component of female industrial workers were: access to safe drinking water inside the industry (A1), daily water collection time including travel and waiting time (A2), collection of water even when sick (A3), security issue during collection of water (A4), access to improved washroom facilities inside the industry (A5), access to improved sanitation and medication (A6 and A7 accordingly). For male industrial workers, three indicators were selected from the list above and they are: A1, A6 and A7. One additional indicator was selected for them which was access to safe water supply for daily use. For large and small male farmers, there were three indicators: access to irrigation, A6 and A7. For female farmers and economically inactive women group, A2, A3, A4, A6 and A7 were selected.

A1 was divided into four scores based on the distance of drinking water points from the workstation. A2 was evaluated basically by a yes-no question but if any household had piped water connection, then the scores would depend on whether the supply is continuous or intermittent. A3 scores depended on how frequent one had to collect water despite being sick. A3 and A4 were not applicable for Tetuljhora union as they had piped water connection. A5 depended on the adequacy and maintenance of separate washroom facilities for females inside the industry. A6 scores were assigned based on the appearance of the latrines the households have. A7 scores were assigned based on the availability of the emergency doctors and medical facilities. The scores for access to irrigation were assigned based on whether the agriculture water-managed areas were well-equipped for irrigation or not.

c. Capacity (C):

There were nine indicators under Capacity component and they were: affordability (C1), financial help (C2), access to institutional loan (C3), duration of residence (C4), political or NGO linkage (C5), training in water sanitation, and hygiene issues (C6), education ratio (C7), role in operation and maintenance (C8 and C9 accordingly). For women farmer and economically inactive women group, C1 was eliminated from the indicator set because these groups did not have to pay for water.

C1 was measured based on the cost-income ratio in terms of percentage. C2, C3, C4 and C5 were evaluated from yes-no questions. C6 was segmented based on the number of years the households are living in the study area. C7 denoted the ratio of educated person (primary level) to total household number. C8 measured how frequent one operates the water source. The scores of C9 were based on the participation rate in maintenance of the water source.

d. Use (U):

For female industrial workers, four indicators were selected for Use component and they were: daily water requirement inside and outside the industry for domestic use (U1 and U2 accordingly), occurrence of violence (U3) and conflicts regarding water use (U4). For male workers, U3 was eliminated as it was not applicable for them. For male farmers, three indicators such as irrigation water requirement, daily water requirement and conflicts were chosen. For female farmers, U2, U3 and U4 and also water requirement for cooking for laborers and post harvesting were used. For economically inactive women group, U2, U3 and U4 were used.

Water requirements scores were divided based on the level of shortages reported by the households. The scores for occurrence of violence were divided based on the degree of violence when demand was not fulfilled or one could not bring water timely. The reported conflicts were scored based on the degree and level of the conflict.

e. Environment (E):

The Environment component had six indicators in total for all the groups such as consumable fish species in surface water (E1), reduction in fish species (E2), damage and loss due to flood or drought (E3), crop loss (E4), drainage facilities (E5) and reduction in vegetation cover (E6). For E2, E3, E4 and E6, the change was considered for the last 15 years.

E1 was evaluated based on a yes-no question. The scores for E2 was segmented based on the reduced number of fish species. E3 and E4 were scored in terms of the severity of the amount of loss and damage due to flood and/or drought and crop loss accordingly. The scores of E5 were assigned based on the level of water logging due to drainage facilities in the study area. E6 evaluated the level of reduction (low = 100, medium = 67, high = 33, critical = 0) in vegetation cover.

For scoring future responses, existing segmentation of scores was used on the basis of human judgement. After selecting and classifying indicators for R, A, C, U and E, scoring was done for all the indicators and thus they were prepared for further analysis. The next step was selection of indicators at the sub-index level by conducting Principal Component Analysis (PCA).

Before applying PCA to the data set, the Kaiser-Meyer-Olkin (KMO), a Measure of Sampling Adequacy (MSA) test was used to detect multicollinearity in the data so that the appropriateness of carrying out a factor analysis could be detected. Based on correlations and partial correlations, sampling adequacy predicted the factorability of the dataset. It was also recommended that the factorability of all indicators collectively and individually be tested using the KMO test (Hair et al., 2006). The maximum value of KMO can be 1.0, a value of 0.9 is considered as 'marvelous', 0.8 as 'meritorious', 0.7 as 'middling', 0.6 as 'mediocre'and 0.5 as 'miserable' (Antony and Rao, 2007). According to Jemmali and Matoussi (2013), the threshold value was considered as 0.5 in this study. So, if the KMO values exceeded 0.5, it would fall in the acceptable range and it would be allowed to proceed with PCA.

Another test of the strength of the relationship among variables was done using the Bartlett's (1954) Test of Sphericity. The Bartlett's Test of Sphericity tested the null hypothesis that the variables in the population correlation matrix were uncorrelated. The Bartlett's tests for the indicators which indicated that the probability should be less than 0.05 to reject the null hypothesis. It indicated that the strength of the relationship among variables was strong or the correlation matrix was not an identity matrix as was required by factor analysis to be valid. These diagnostic procedures indicated that factor analysis was appropriate for the data. The remaining components which did not satisfy the conditions for factorability tests were calculated by averaging the indicator values without applying PCA.

Next step was performing PCA to explore whether the variables were statistically well balanced at both index and sub-index levels. The main goal of this analytical approach was to reduce a complex set of correlated variables into a set of fewer uncorrelated components. On the issue of how factors should be retained in the analysis without losing too much information, this decision was based on the "variance explained criteria," i.e., to keep enough factors to account for 80% of the variation (Nardo et al., 2005). Jolliffe (1972) suggested that the number of selected variables must be equal to the number of principal components that had characteristic roots in the correlation matrix greater than 0.7. According to this thumb rule, the indicators were retained. After deciding the number of indicators to keep, the combination of the retained indicators was the next step. At this level, since variables in the same indices could compensate each other's performance, an additive aggregation was employed. Moreover, all variables were considered as having the same importance, so no specific weighting was introduced. So, equal weighting scheme was selected for retained variables.

4.4.2 Construction of the index

After calculation of the five sub-indices, again PCA was performed to assign component weights (Cho et al., 2010). Weighting meant the relative importance of criteria or indicators. In this study, weight calculation was used among the components only (R, A, C, U, E). A Varimax orthogonal rotation was applied to each analysis, in order to maximize variance of factor loadings and thus enhance the interpretability of the results. To obtain the final weighting scheme, the principal component retained must be weighted with the proportion of variance calculated by dividing the square root of the eigenvalue of the corresponding principal component by the sum of square root of eigenvalue. After that, calculated weights were normalized in such a way that the sum of the weights equaled to 1. The formula used for weight calculation is given below:

$$w_i = \sum_{k=1}^{n} PC_k \frac{\sqrt{\lambda_k}}{\sum_k \sqrt{\lambda_k}}$$

where, w_i = the weight assigned to the ith component of WPI

PC_k = the value of the characteristic vector associated with the kth principal component

λ_k = eigenvalue

Last step was the aggregation of the sub-indices. The most appropriate aggregation function was the weighted multiplicative function, as it did not allow compensability between the different components (Pérez-Foguet and Garriga, 2011). Numerically, the WPI could be formulated as follows:

$$WPI = \prod_{i=R,A,C,U,E} {X_i}^{w_i}$$

where, WPI = the value of WPI for the corresponding group

X_i = value of component i which can be Resource, Access, Capacity, Use and Environment

w_i = the weight associated with the component

4.5 Methods of Evaluating Environmental Changes

4.5.1 Trend analysis

Temporal trend is the gradual change in a variable at a location with time. The trend can be linear or non-linear. There are two methods of trend analysis- one is the parametric method and the other is the non-parametric method. Parametric method is widely used in hydrology. In the parametric method, a scatter plot of the dependent variable (y) and the independent variable (x) is first made. A least square linear regression line is then superimposed to the plot. Linear change is expressed in the following form:

$$y = a + bx$$

where, *y* is the dependent variable such as temperature, rainfall, surface water level or groundwater level; *x* is the independent variable which is time in this case; a and b are, respectively, the intercept and slope of the linear line. The estimate of b is the change in the variable per unit time, and is the linear trend. The two parameters (a and b) can be estimated by the parametric or non-parametric method. Parametric method is commonly used and is robust in case of normally distributed data. For testing the statistical significance of trend, the most commonly used statistic in parametric method is Pearson's r. Pearson's r measures the linear association between two variables and most widely used (CDMP, 2012).

The Mann-Kendall test is a non-parametric trend test that does not require any particular distribution of data (Gilbert, 1987). If normality is violated, the nonparametric test such as the Mann-Kendall Test (Mann, 1945; Kendall, 1975) is commonly applied to assess the statistical significance of trends. Mann (1945) first suggested using the test for significance of Kendall's tau where the x variable is time as test for trend. This test detects a monotonic trend in the mean or median of a time series. The Mann-Kendall test has been widely used to test for randomness against trends in hydrology (Hirsch et al., 1992). Both parametric and non-parametric methods (Maidment, I992) have been used for testing the significance of trends of two climatic parameters- temperature and rainfall, and two hydrological parameters- surface water level and groundwater level.

4.5.2 Rainfall variability

The reliability or dependability of the rainfall is closely related to its variability. The variability is defined as the ratio of the mean of deviations from the average to the mean itself (Petterssen1956, 1969). In this study, rainfall variability was evaluated using Coefficient of Variation (CV). A higher value of CV implied a higher variability of water resources which may also reflected higher climate induced risks and vulnerability of resources (Alessa et al., 2008; Hamouda et al., 2009). A low ratio indicated a high degree of dependability, and high ratio indicated an erratic behavior. According to Petterssen (1956), when the ratio of variability was less than 15 percent, there was a high degree of dependability. But in the areas with 20 to 25 percent variability, there was a constant fear of prolonged drought, and dependability of rainfall was minimal. According to Hare (2003), CV was used to classify the degree of variability of rainfall events as less (CV< 20), moderate (20 < CV <30), and high (CV >30). In this study, CV was classified according to this and calculated by the following equation:

$$CV = \frac{\sigma}{\mu} * 100$$

where, CV = the coefficient of variation

σ = the standard deviation

μ = mean rainfall over a period of observation

Another analysis of rainfall variability was conducted by determining inter-annual variability. Standardized Rainfall Anomaly (Z) assessed frequency and severity of droughts. The drought severity classes (Agnew and Chappel, 1999) were extreme drought (Z < -1.65), severe drought (-1.28 > Z > -1.65), moderate drought (-0.84 > Z > -1.28 and no drought (Z > -0.84). The following equation was used for the calculation:

$$Z = \frac{(X_i - \overline{X_i})}{s}$$

where, Z = standardized rainfall anomaly

X_i = annual rainfall of a particular year

$\overline{X_i}$ = long term mean annual rainfall over a period of observation

s = standard deviation of annual rainfall over the period of observation

4.5.3 Environmental factors

Two environmental factors- population growth and changes in land use were assessed. As weather threats grew, so had our world population. Rapid population growth and fossil fuel emissions are two leading characteristics of our modern age. Since 1800, world population grew sevenfold. In this study, geometric growth was considered which implied that compounding took place at specified intervals (George et al., 2004). The annual compounding formulae used for present and future population calculation is given below:

$$P_t = P_0 (1+ r)^t$$

where P_0 = initial population

P_t = population t years later

r = annual population growth rate

Land use or land cover dataset was generated from the digital image classification of landsat 5 and landsat 8 satellite images. There were two broad classification procedures: supervised classification and unsupervised classification. The supervised classification is the essential tool used for extracting quantitative information from remotely sensed image data (Richards, 1993). Also, field knowledge was applied for identifying the features from the images.

The supervised image classification process is divided into two phases: a training phase, where the computer is 'trained', by assigning for a limited number of pixels to what classes they belong in this particular image, followed by the decision making phase, where the 'maximum likelihood parametric rule' assigns a class label to all (other) image pixels, by looking for each pixel to which of the trained classes this pixel is most similar. To have training areas, ground truthing points collected from field survey were used for this image classification. For the research purpose four classes were assigned (water body, bare land, settlement and urban development area, and agricultural land and vegetation). Similar studies were followed by Islam and Hasan (2011) and Paul et al.

(2014). Each class's areal percentage were calculated over the years to see the changes of classes, i.e. the decrease or increase of any class's area.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Introduction

To assess Water Poverty Index (WPI) for different groups both present and future situations were considered for each group. Present WPI and future WPI were calculated for industrial workers (male and female), large farmers (male), small farmers (male), women farmers and economically inactive women group (unemployed women, adolescent girls, physically challenged and elderly women). Data for the study were collected from two hundred and sixty respondents, made up of one hundred and twenty men and one hundred and forty women, respectively.

5.2 Evaluation of Present WPI for Livelihood Groups

Households were involved with different agriculture and non-farm activities in Tetuljhora, Dhalla and Saista unions. Table 5.1 shows occupational diversity in the study areas. In addition to industrial workers and farmers there were a few fishermen, day laborers, service holders, businessmen etc. In Tetuljhora union, on an average fifty one percent of the households were dependent on newly transferred tannery, garments and other industries. In Dhalla and Saista unions majority of the households were dependent on agriculture.

Table 5.1: Percentage of households dependent on different occupations

Union	Occupation by %			
	Industrial workers	Farmers	Others	Unemployed
Tetuljhora	51	4	40	5
Dhalla	35	48	7	10
Saista	8	55	19	18

Source: DPHE office, Singair upazila

The WPI was calculated from five components: Resource (R), Access (A), Capacity (C), Use (U) and Environment (E). These components were evaluated for different livelihood groups at the study area from data collected through primary field survey. The following sections discuss different features of the components for different groups.

5.2.1 Industrial workers

As Tetuljhora union became an industrial area after the relocation of tanneries specially after 2017, the majority of the population was involved with industries for their livelihood. A total of 35 workers (15 females and 20 males) in several industries were surveyed from this union. From Dhalla union 25 female workers in several industries were surveyed. Industrial workers were surveyed from two locations only Tetuljhora and Dhalla. From Saista union, no workers were surveyed.

Before applying PCA to the data set and discarding correlated variables, the KMO measure of sampling adequacy (MSA) test and overall significance of the correlation matrix of indicators for each component were analyzed. Table 5.2 shows the result for factorability tests. To proceed with PCA, the Bartlett's tests for the sub-indexes which indicated the presence of non-zero correlations would be significant at the 0.05 level and MSA values would be greater than 0.5. For the remaining components (**Bold** values) which did not satisfy the factorability tests, each of these indices were calculated as average of their indicator values.

Table 5.2: Factorability tests (KMO and Bartlett's Test) for industrial workers

Union	Group	Variable	KMO index	Barlett's test of sphericity		
				Approx. Chi-square	df	p-value
Tetuljhora	Male	R	0.495	59.100	28	0.001
		A	0.559	4.600	6	0.000
		C	**0.306**	60.4	36	0.007
		U	0.553	3.950	3	0.000

		E	0.515	32.544	15	0.001
	Female	R	0.525	43.711	28	0.000
		A	0.515	11.018	15	0.001
		C	**0.423**	43.486	36	0.008
		U	0.504	**4.772**	**3**	**0.189**
		E	0.649	14.788	15	0.047
Dhalla	Female	R	0.544	34.414	28	0.000
		A	0.573	**18.800**	**21**	**0.598**
		C	**0.445**	**38.093**	**36**	**0.374**
		U	0.609	4.406	3	0.001
		E	**0.468**	**11.456**	**15**	**0.720**

Table 5.3 shows the result for the present WPI values for the groups. After conducting factorability tests, principal components associated with eigenvalues greater than 0.7 were selected. For example, four indicators (R2, R3, R5, R8) were retained after discarding the rest for the resource component of the first group, and the cumulative variance explained for the component was about 85%. From the data shown in Table 5.3, it could be said that approximately more than 80% of the data were retained for all the variables after conducting PCA. And then the component values were calculated by applying equal weightage for the retained indicators followed by calculation of weightages by PCA for the components. Thus, the final present WPI for male and female industrial workers in Tetuljhora union were 48.044 and 45.84 accordingly. In Dhalla union, the female industrial workers scored 57.531. For all the three groups, weightage for capacity was the highest. So, it could be said that social components were more dominant than physical components based on the weightage assigned.

Table 5.3: Results of the PCA for industrial workers

Union	Group	Variable	Data retained	Variable equation	Value	Weight (after normalization)	Present WPI
Tetuljhora	Male	R	84.947	0.2*R2 + 0.2*R3 + 0.2*R5 + 0.2*R8	38.725	0.13	48.044
		A	86.741	0.33*A1 + 0.33*A2 + 0.33*A4	65.488	0.21	
		C	-	-	53.36	0.36	
		U	81.902	0.5*U1 + 0.5*U2	68.425	0.17	
		E	91.944	0.25*E2 + 0.25*E4 + 0.25*E5 + 0.25*E6	17.025	0.13	
	Female	R	85.635	0.25*R2 + 0.25*R3 + 0.25*R4 + 0.25*R6	31.633	0.15	45.84
		A	86.178	0.25*A1 + 0.25*A3 + 0.25*A5 + 0.25*A6	73.967	0.14	
		C	-	-	49.8	0.27	
		U	-	-	70.44	0.19	
		E	87.817	0.25*E1 + 0.25*E3 + 0.25*E4 + 0.25*E6	28.9	0.25	
Dhalla	Female	R	84.328	0.2*R2 + 0.2*R3 + 0.2*R5 + 0.2*R6 + 0.2*R7	52.8	0.21	55.853
		A	-	-	65.07	0.09	
		C	-	-	51.342	0.41	
		U	87.168	0.5*U1 + 0.5*U3	84.66	0.12	
		E	-	-	50.44	0.17	

5.2.2 Farmers

A total of 130 farmers (100 males and 30 females) were surveyed from Dhalla and Saista unions. Table 5.4 shows percentage of large and small male farmers who were actively involved in farm activities in the area and the amount of land they owned. Survey data showed that majority of the farmers are small and marginal in both unions owning 1.07 acres and 0.97 acres on average in Dhalla and Saista unions accordingly. Large farmers had approximately 8.023 and 6.77 acres of land in Dhalla and Saista unions respectively. Farmers, not actively engaged in agricultural activities, were not considered for the analysis.

Table 5.4: Percentage of male farmers and amount of own land in Dhalla and Saista

Union	% of active farmers		Amount of land owned on average (acres)	
	Large	Small	Large	Small
Dhalla	15	85	8.023	1.07
Saista	12	88	6.77	0.97

Women farmers participating in any kind of agricultural activities such as cooking and carrying lunch for the workers in the field or post harvesting were also surveyed considering the fact that these activities also required a large portion of water daily. The following sections discuss different features of the components for different farmer groups.

5.2.2.1 Large and small farmers (male)

A total of 50 (25 per location) large farmers were surveyed. Table 5.5 shows results for factorability tests for male large farmers in Dhalla and Saista. For large farmers in Dhalla, PCA was applied on Resource, Capacity and Environment as only these three components satisfied the condition for PCA (KMO index and Barlett’s test). Access and Use components were calculated by taking average value of the indicators (indicated as bold letters). For large farmers in Saista, Capacity and Use components were calculated by taking average value of the indicators as either the KMO index value was lower than 0.5 or significance value exceeds 0.001 in Barlett's test results (indicated as bold letters). The rest of the components (Resource, Access and Environment) were calculated by retaining non-correlated variables by PCA.

Table 5.5: Factorability tests (KMO and Bartlett's Test) for male large farmers

Union	Variable	KMO index	Barlett's test of sphericity (p-value)
Dhalla	R	0.567	0.000
	A	0.541	**0.060**
	C	0.601	0.001
	U	**0.363**	0.000
	E	0.581	0.001
Saista	R	0.516	0.000
	A	0.615	0.001
	C	**0.423**	0.004
	U	**0.354**	**0.089**
	E	0.594	0.000

Table 5.6 shows the results of the present WPI for male large farmers in Dhalla and Saista. In Dhalla union, more than 85% of the data were retained after PCA is applied. The highest weightage (0.34) was given to Capacity and the lowest weightage (0.08) was applied to Access. For this group, social components were dominant than physical components based on the component weights.

In Saista union, more than 80% variance was explained by the retained data for Resource, Access and Environment after conducting PCA. Again, PCA was applied to the 5 components and from the characteristic root or eigenvectors the component values were obtained. The highest weightage (0.27) was applied to Environment and the lowest weightage (0.15) was applied to Capacity. For this group, physical components were dominant than social components based on the component weights. Thus, in Dhalla and Saista large farmers scored 56.659 and 44.802 respectively.

Table 5.6: Results of the PCA for male large farmers

Union	Variable	Data retained	Value	Weight (after normalization)	Present WPI
Dhalla	R	85.947	48.04	0.28	56.659
	A	-	68.78	0.08	
	C	86.674	64.56	0.34	
	U	-	77.4	0.11	
	E	90.241	44.01	0.19	
Saista	R	89.567	39.136	0.20	44.802
	A	80.262	54.186	0.17	
	C	-	60.568	0.15	
	U	-	41.28	0.21	
	E	86.940	39.6	0.27	

A total of 50 (25 per location) small farmers were surveyed. Table 5.7 shows the results for factorability tests for male small farmers. In Dhalla union, for small farmers Resource, Access and Use components did not satisfy the conditions for PCA. So, average value was taken for these three components. For Capacity and Environment, PCA was applied. For Saista union, PCA was applied to Resource, Capacity and Use. Access and Environment components were calculated by taking average value of the indicators.

Table 5.7: Factorability tests (KMO and Bartlett's Test) for male small farmers

Union	Variable	KMO index	Barlett’s test of sphericity (p-value)
Dhalla	**R**	**0.467**	0.005
	A	**0.442**	0.008
	C	0.552	0.001
	U	**0.431**	**0.089**
	E	0.677	0.001

Saista	R	0.502	0.001
	A	**0.311**	**0.201**
	C	0.622	0.000
	U	0.542	0.000
	E	**0.411**	**0.067**

Table 5.8 shows the results for present WPI for small farmers. In Dhalla union, more than 83% of the data were retained after PCA is applied. The highest weightage (0.34) was assigned to Access and the lowest weightage (0.1) was applied to Capacity. For this group, social components were more dominant. In Saista union, more than 87% variance was explained by the retained data for Resource, Capacity and Use after conducting PCA. The highest weightage (0.3) was applied to Environment and the lowest weightage (0.05) was applied to Access. In this case, physical components were more dominant. Thus, in Dhalla and Saista, small farmers scored 55.279 and 41.690 respectively.

Table 5.8: Results of the PCA for male small farmers

Union	Variable	Data retained	Value	Weight (after normalization)	Present WPI
Dhalla	R	-	37.872	0.15	55.279
	A	-	67.5	0.34	
	C	83.399	43.456	0.1	
	U	-	78.804	0.23	
	E	89.092	35.72	0.18	
Saista	R	91.223	36.95	0.22	41.690
	A	-	26.8224	0.05	
	C	87.817	31.448	0.18	
	U	90.330	52.8	0.25	
	E	-	47.68	0.3	

5.2.2.2 Women farmers

A total of 30 (15 per location) women farmers were surveyed who are involved in farm activities directly (post harvesting) or indirectly (cooking lunch or carrying them in the field for the workers). Table 5.9 shows the results for factorability tests for women farmers. In Dhalla union, for women farmers Capacity and Environment components did not satisfy the conditions for PCA. So, average value was taken for these three components. For Resource, Access and Use, PCA was applied. For Saista union, PCA was applied on Resource, Access and Environment components. Capacity and Use components did not satisfy KMO index values and significance values. So, average values of their indicators were taken.

Table 5.9: Factorability tests (KMO and Bartlett's Test) for women farmers

Union	Variable	KMO index	Barlett’s test of sphericity (p-value)
Dhalla	R	0.778	0.001
	A	0.556	0.000
	C	**0.239**	0.009
	U	0.509	0.000
	E	0.557	**0.120**
Saista	R	0.668	0.000
	A	0.509	0.000
	C	0.550	**0.563**
	U	**0.440**	0.001
	E	0.537	0.000

Table 5.10 shows the result for the present WPI values for women farmers in Dhalla and Saista. After conducting factorability tests, it could be said that approximately more than 84% of the data were retained for all the variables after conducting PCA for women farmers in Dhalla union. The highest weightage (0.31) was applied to Capacity and the lowest weightage (0.09) was applied to Environment. Hence, social components were dominant for this group. For women farmers in Saista, more than

82% variance was explained by the retained data for Resource, Access and Environment after conducting PCA. The highest weightage (0.37) was applied to Capacity and the lowest weightage (0.11) was applied to Resource. For this group, social components were carrying more weightage than physical components. Thus, in Dhalla and Saista women farmers scored 49.669 and 42.279 respectively.

Table 5.10: Results of the PCA for women farmers

Union	Variable	Data retained	Value	Weight (after normalization)	Present WPI
Dhalla	R	84.778	40.556	0.2	49.669
	A	89.596	49.557	0.2	
	C	-	50.556	0.31	
	U	-	68.804	0.2	
	E	89.126	35.72	0.09	
Saista	R	82.440	29.88	0.11	42.279
	A	90.457	29.94	0.19	
	C	-	45.958	0.37	
	U	-	57.604	0.12	
	E	89.990	50.13	0.21	

5.2.3 Economically inactive women group

This group included unemployed women, adolescent girls, physically challenged and elderly women. All of them were not engaged with any kind of economic activities. Figure 5.1 shows the employment profile of women in Tetuljhora, Dhalla and Saista unions. In Tetuljhora, 50 percent of the women were economically inactive and 30 percent were employed and rest of the 20 percent were currently unemployed and searching for opportunities for earning livelihoods. In Dhalla, 61 percent of the women were economically inactive and 24 percent were employed and rest of the 15 percent were unemployed. In Saista, 75 percent of the women were not economically active, only 12 percent of women were currently employed and 13 percent of women were unemployed.

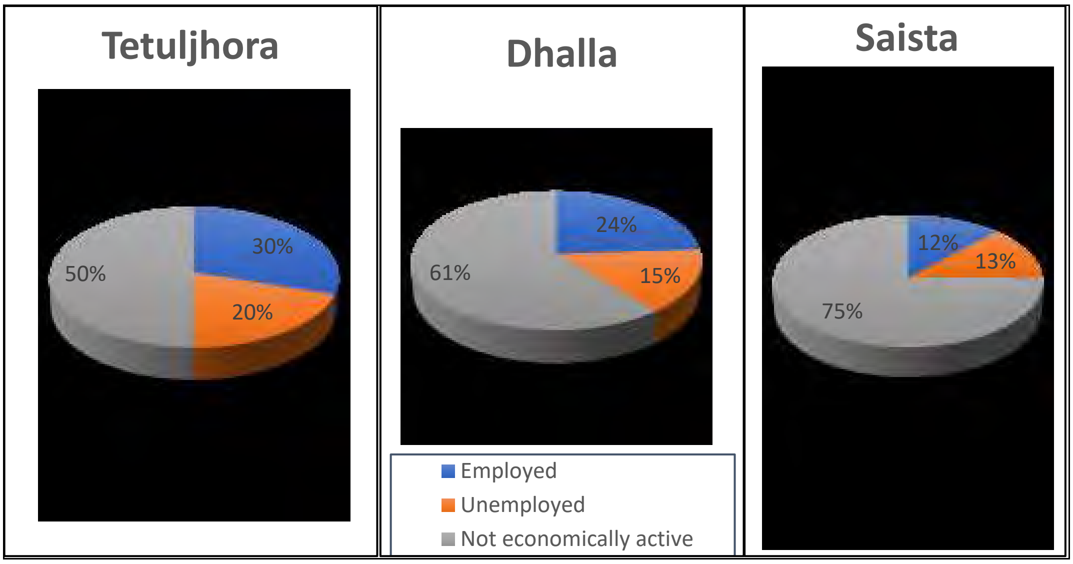

Figure 5.1: Employment profile of women in the study area

A total of 70 responses (30 from Dhalla and 40 from Saista) were included in the analysis. Table 5.11 shows the number of persons surveyed from each group. 12 unemployed women who were involved in only domestic activities, 8 adolescent girls between ages 10 and 19 years, and 10 physically challenged and elderly women above ages of 65 years were surveyed from Dhalla union. 15 unemployed women, 10 adolescent girls and 15 physically challenged and elderly women were surveyed from Saista union. WPI is calculated for each group individually and also combinedly for the entire economically inactive women group.

Table 5.11: Sample size for the economically inactive women group

Union	Number of respondents		
	Unemployed women	Adolescent girls	Physically challenged and elderly women
Dhalla (30)	12	8	10
Saista (40)	15	10	15

Table 5.12 shows the present WPI in Dhalla union for the groups mentioned above. For the adolescent girls group, variables were calculated as average of their indicator

values. As the sample size was very small (8 from Dhalla), PCA could not be applied for this group. Unemployed women group scored 52.513, adolescent girls scored 38.153 and physically challenged and elderly women scored 33.264 individually, whereas when all these three groups were combined and analyzed the present WPI became 49.643.

Table 5.12: Results of the present WPI for economically inactive women group in Dhalla

Group	Variable	Value	Present WPI
Unemployed women	R	42.6	52.513
	A	63.779	
	C	57.991	
	U	50.12	
	E	42.769	
Adolescent girls	R	41.66	38.153
	A	36.009	
	C	35.224	
	U	40.578	
	E	40.976	
Physically challenged and elderly women	R	32.66	33.264
	A	35.009	
	C	29.224	
	U	34.745	
	E	43.847	
Combined	R	41.66	49.643
	A	60.197	
	C	39.776	
	U	71.33	
	E	45.778	

Table 5.13 shows the present WPI in Saista union for the groups mentioned above. For the adolescent girls group, variables were calculated as average of their indicator values as the sample size was very small (10 from Saista). So, PCA was not applied for this group. PCA was applied for the rest of the groups. Unemployed women group scored 42.763, adolescent girls scored 36.825 and physically challenged and elderly women scored 32.466 individually, whereas the combined present WPI score for the unemployed and economically inactive group was 41.460.

Table 5.13: Results of the present WPI for economically inactive women group in Saista

Group	Variable	Value	Present WPI
Unemployed women	R	39.55	42.763
	A	48.57	
	C	40.685	
	U	42.688	
	E	45.689	
Adolescent girls	R	39.68	36.825
	A	32.697	
	C	34.608	
	U	39.705	
	E	42.562	
Physically challenged and elderly women	R	35.22	32.466
	A	30.586	
	C	27.697	
	U	35.988	
	E	42.524	
Combined	R	39.34	41.460
	A	56.777	
	C	35.99	
	U	38.279	
	E	45.032	

Overall values for the present WPI are shown in Table 5.14, while the pentagram plot (Figure 5.2) allows for easy visualization and comparison of present WPI values among the three unions. The result says that, large farmers (male) in Dhalla union had highest value and that was 56.66 and economically inactive women group in Saista union had the lowest score which was 41.46 which meant that large farmers in Dhalla union was the most water-secured group and economically inactive women group in Saista union was the most water-poor group among all. From three industrial workers groups, female industrial workers group in Dhalla union was the most water-secured group and female industrial workers group in Tetuljhora union was the most water-poor group.

Figure 5.2 shows that in Tetuljhora union, Resource and Environment scores were very low. In Dhalla union, male large farmers were the most water-secured group whereas economically inactive women were the most water-poor. Resource, Environment and Capacity scores were comparatively lower than Access and Use. In Saista union, the situation was similar to Dhalla union in case of water-secured and water-poor group. In this union, Resource and Access component scores were lower than the other components. In Dhalla union, scores were more uniformly distributed for all the groups. But in Saista union the scores were scattered irregularly for the groups.

Table 5.14: Overall values of the present WPI for the livelihood groups

Union	Group	R	A	C	U	E	Present WPI
Tetuljhora	Industrial workers (Male)	38.73	65.49	53.36	68.43	17.03	48.04
	Industrial workers (Female)	31.63	73.97	49.8	70.44	28.9	45.84
Dhalla	Industrial workers (Female)	52.8	65.07	51.34	84.66	50.44	55.85
	Large farmers (Male)	48.04	68.78	64.56	77.4	44.01	**56.66**
	Small farmers (Male)	37.87	67.5	43.46	78.80	35.72	55.28
	Women farmers	40.56	49.56	50.56	68.80	35.72	49.67
	Economically inactive women group	41.66	60.2	39.78	71.33	45.78	49.64
Saista	Large farmers (Male)	39.14	54.19	60.57	41.28	39.6	44.80
	Small farmers (Male)	36.95	26.82	31.45	52.8	47.68	41.69
	Women farmers	29.88	29.94	45.96	57.60	50.13	42.28
	Economically inactive women group	39.34	56.78	35.99	38.28	45.03	**41.46**

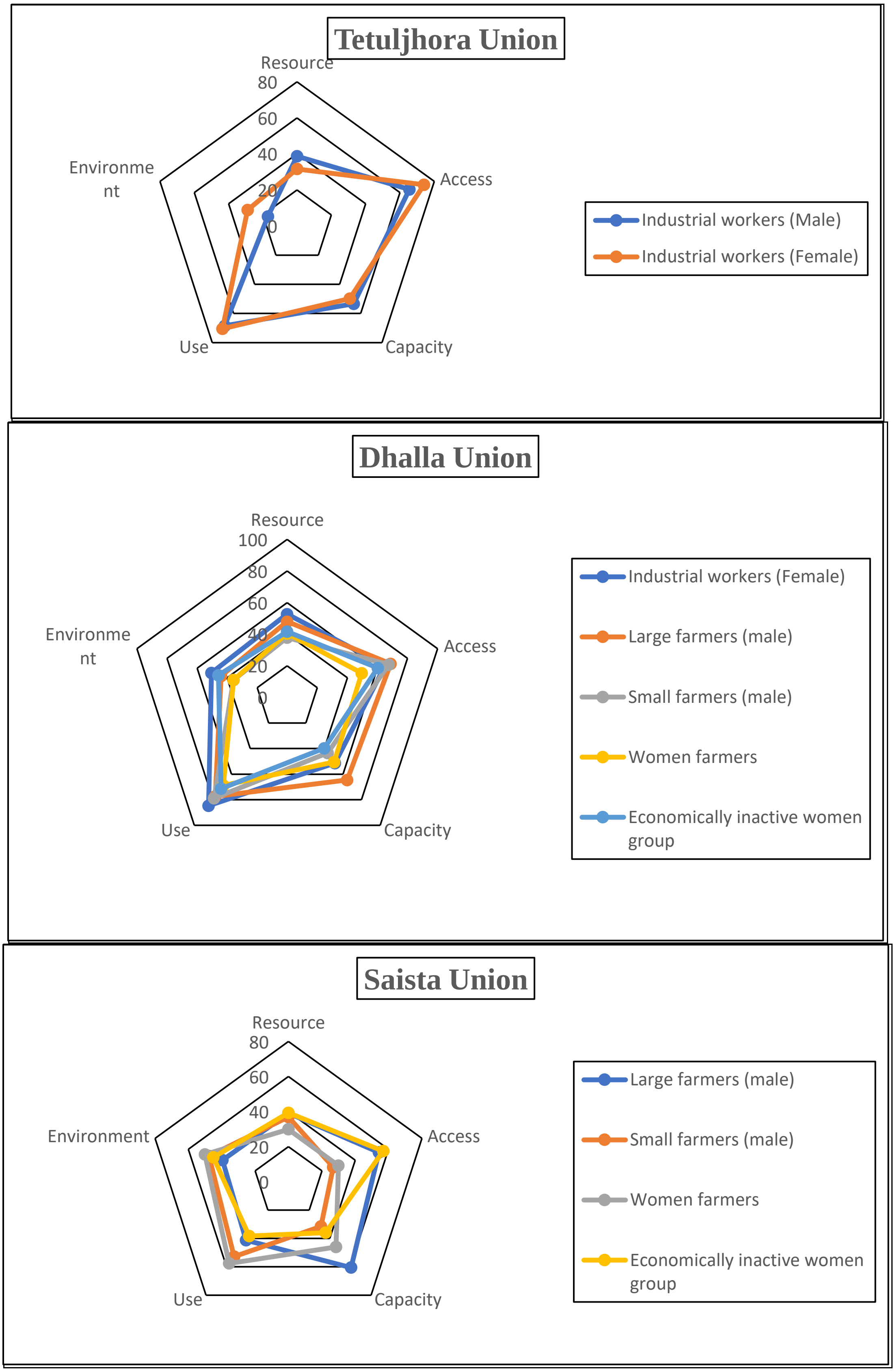

Figure 5.2: Present WPI pentagram for the livelihood groups in Tetuljhora, Dhalla and Saista

5.3 Comparison of WPI Values

The WPI component scores show the underlying reasons for water poverty and their variation within the groups and also locations in the study area. Analyzing the indicator values individually, an insight can be gained about the specific reasons for a specific value in the score. Following sections will describe the reasons of water poverty by analyzing the indicator scores among different groups, locations and also among present and future scores.

5.3.1 Comparison of Present WPI among Different Groups

From Tetuljhora union only two groups were analyzed and they were: male and female industrial workers. Figure 5.3 shows that male industrial workers scored slightly higher than female workers. Both the groups scored poorly in Resource and Environment components as this area had undergone huge environmental degradation due to tanneries and industries near the bank of the Dhaleshwari River. Score of Resource component was higher for male workers than that of female because the rate of occurrence of illness from using surface and groundwater was higher in case of female workers. For Access component, female group scored higher because of the higher access to improved washroom facilities inside the industry and also access to improved sanitation. The Capacity and Use scores were nearly similar. The male group scored poorly in Environment because of the low score for the indicator regarding loss and damage due to severe flood or drought in last 15 years in their area.

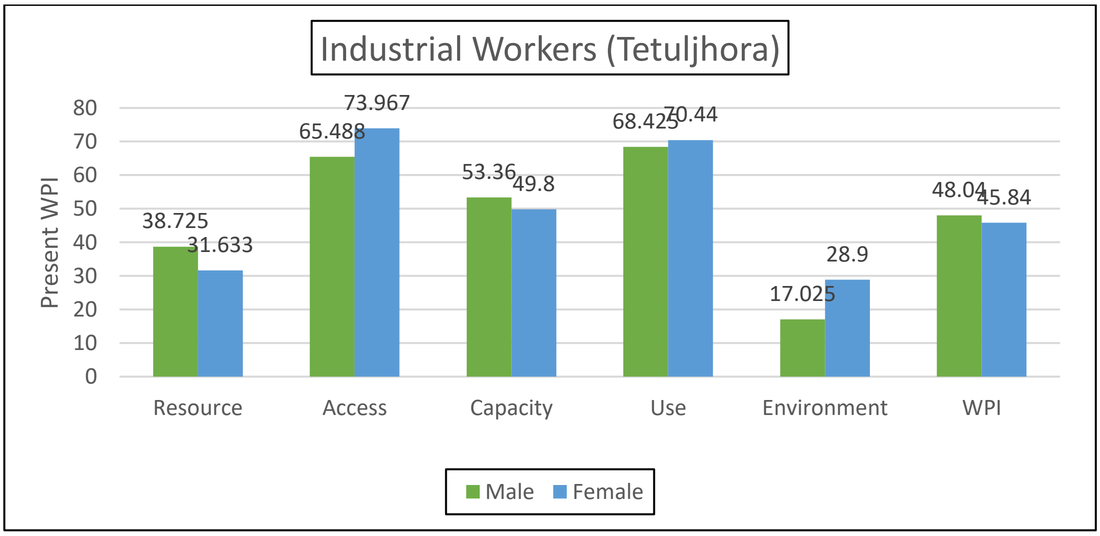

Figure 5.3: Present WPI for industrial workers in Tetuljhora union

From Dhalla union, comparative analyses among large and small male farmers, male and female farmers, female industrial workers, farmers and economically inactive group, and economically inactive groups were conducted to find out the specific scenario behind each score. Another comparative analysis was done combining all the males in one group and all the females in another group. Figure 5.4 shows present WPI for large and small farmers in Dhalla union. The overall present WPI for male large farmers showed slightly high score (56.66) than male small farmers (55.28). Here also Resource and Environment scores were comparatively lower than Access, Capacity and Use. For Resource component, large farmers' score (48.04) was higher than that of small farmers (37.87) because the rate and level of occurrence of illness for using groundwater was higher for small farmers than the large farmers. The reason behind this was small farmers did not practice any treatment method like boiling or filtering water before drinking from the water source. Access score was slightly higher for large farmers because small farmers score poorly in all the three indicators (access to irrigation, sanitation and medication). Large farmers had higher capacity also due to the facilities of getting help from their relatives during disaster and longer duration of residence. For Use component, small farmers scored well than the large farmers because of the higher score for fulfilment of demand for irrigation water.

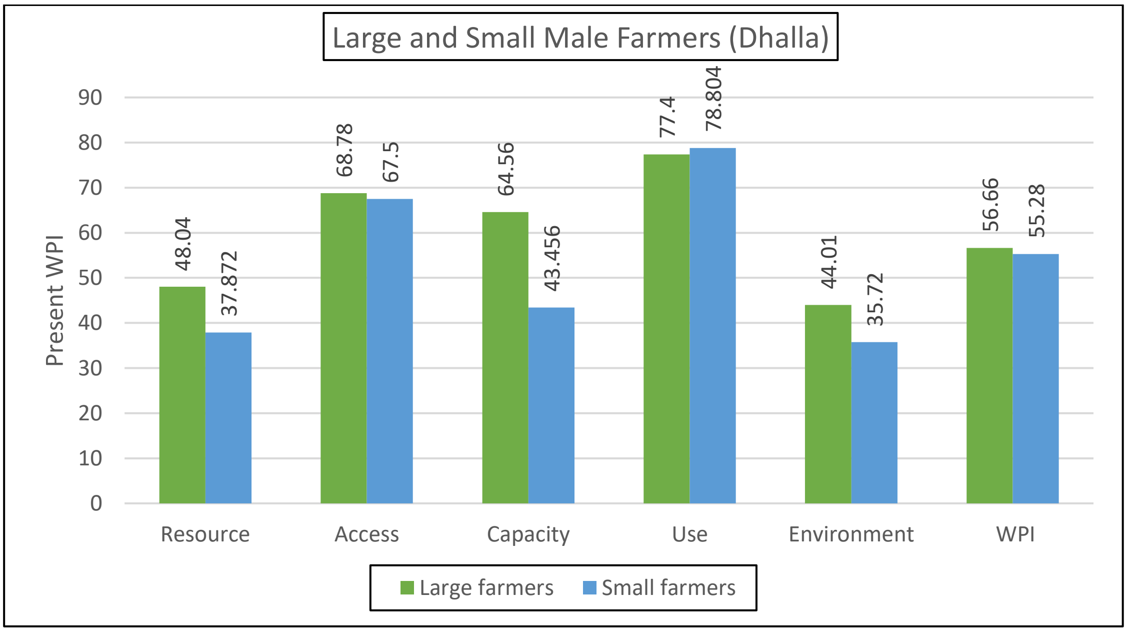

Figure 5.4: Present WPI for large and small farmers in Dhalla union

Figure 5.5 shows the comparison among male farmers and female farmers in Dhalla union. The present WPI of male farmers was calculated by taking average score of present WPIs of large and small farmers. The female farmers scored poorly in all the fields especially in Access and Use than that of male farmers. Female farmers had to spend a considerable amount of time for collection of water daily which male farmers did not deal with. Some women farmers collected water even when she is sick as there was no one to help her. Score for Use component was also low for women farmers due to insufficient water for post harvesting, cooking food and washing dishes.

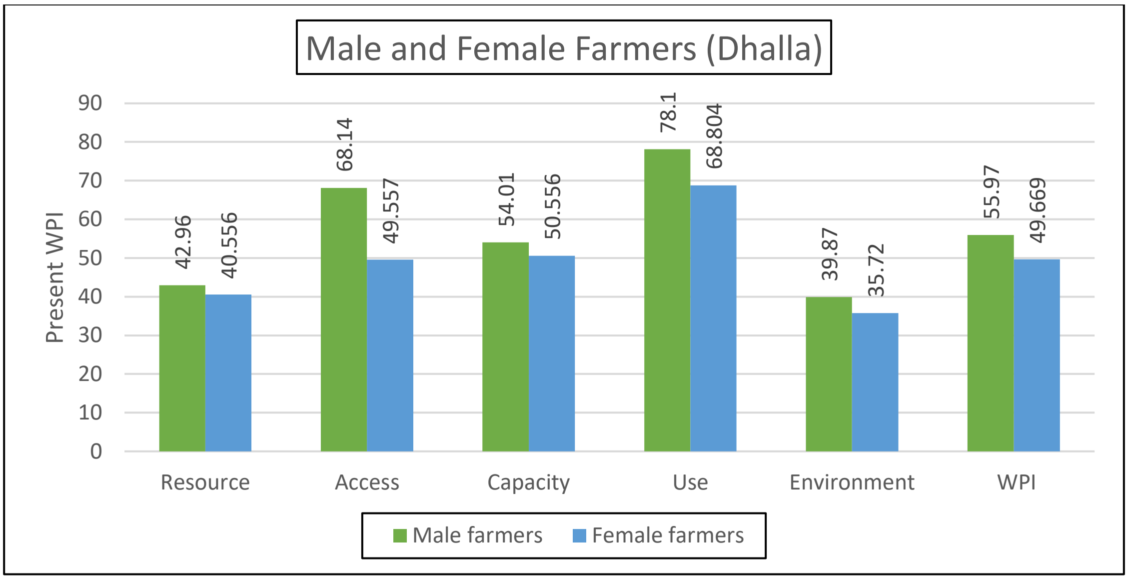

Figure 5.5: Present WPI for male and female farmers in Dhalla union

Figure 5.6 shows comparison among present WPI for all the women groups (female industrial workers, farmers and economically inactive group) in Dhalla union. Among these three groups, economically inactive group (combined) scored the lowest. For Access component this group scored higher than women farmers because of the higher value for the indicator stated ‘collection of water even when she is sick’. The economically inactive group included physically challenged and some elderly women too. They were helped by others during collection of water. The Capacity score for this group was very poor due to poorly scored education ratio than other two groups. Female industrial workers’ scores were high for all the components especially due to higher education ratio, involvement in NGO activities, less amount of time spent in collection of water and less occurrence of violence.

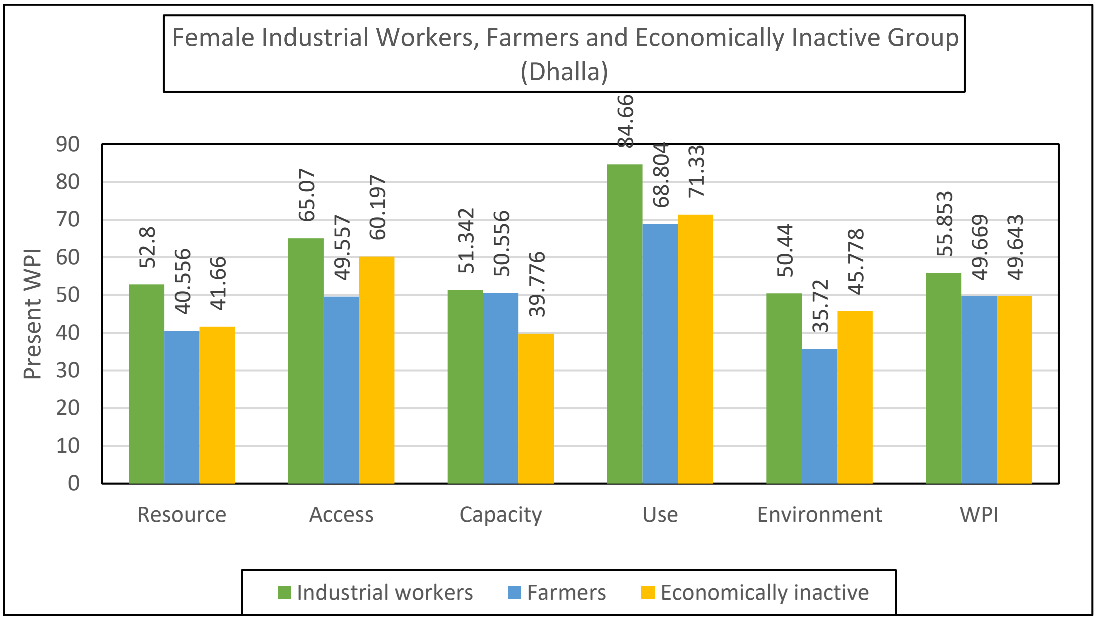

Figure 5.6: Present WPI for female industrial workers, farmers and economically inactive group in Dhalla union

Figure 5.7 shows present WPI for unemployed women, adolescent girls and physically challenged and elderly women in Dhalla union individually. Among these three groups, physically challenged and elderly womens' overall present WPI score (33.26) was the lowest. Resource, Access, Capacity and Use scores showed a gradual decrease among three groups. The indicator which influences the value for Resource component was the occurrence of illness for using surface and groundwater. For Access component, unemployed women scored well than the other two groups due to scores in access to medication. The physically challenged women usually did not prefer to go outside for visiting doctors. For Capacity component, the education ratio and role in operation were much higher for unemployed women than the other two groups. In case of Use component, more reports of occurrence of violence when demand was not fulfilled or due to inability to bring water timely cause the score to decrease for adolescent girls.

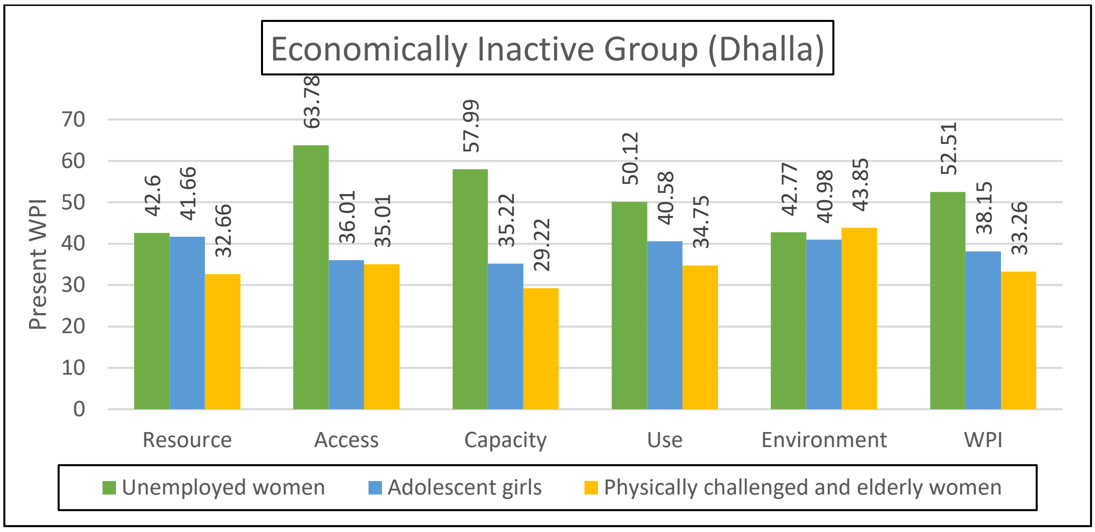

Figure 5.7: Present WPI for economically inactive group in Dhalla union

Figure 5.8 shows a comparative analysis between present WPI for all male group and all female group in Dhalla union. All the scores were low for the female group except for Resouce and Environment. The overall present WPI was 55.97 and 51.72 for male group and female group accordingly. So, there was a lack of access to safe water and sanitation, capacity for water management and using sufficient water for specific needs of women compared to men.

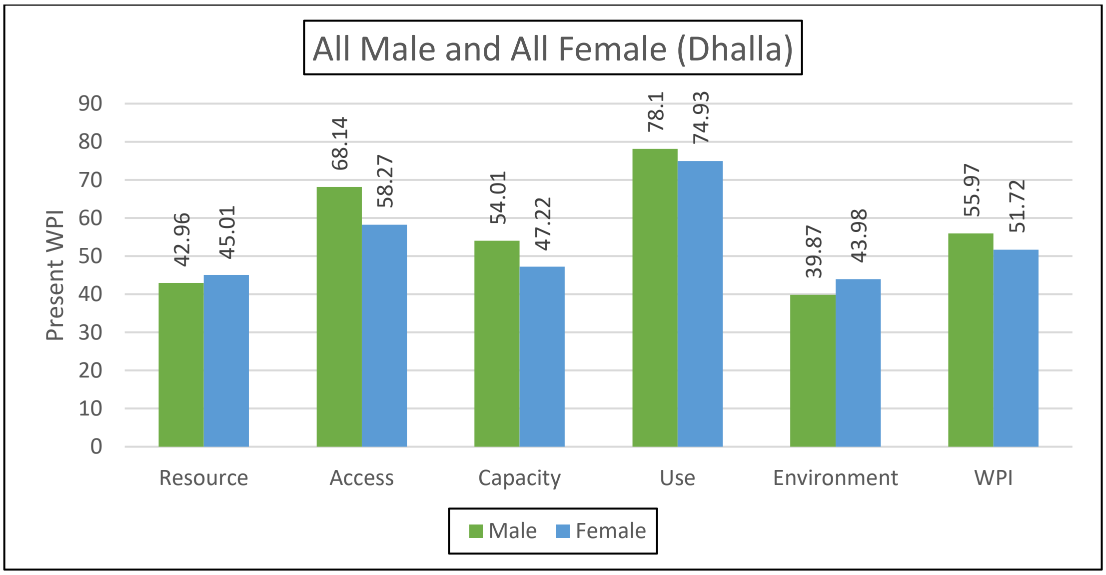

Figure 5.8: Present WPI for all male and all female groups in Dhalla union

In Saista union, Figure 5.9 shows that small farmers' access (26.82) and capacity (31.45) was very low compared to that of large farmers. Small farmers' cost of water compared to their income was very high. These farmers had to pay BDT 600 per month on average or share one fourth amount of the crop for irrigation in the cropping seasons (Rabi and Kharif). Also, the overall cost of production of rice was very high compared to the amounts they have to pay. So, their access to irrigation and affordability was very low. The overall present WPI for large farmers (44.8) was slightly greater than small farmers (41.69).

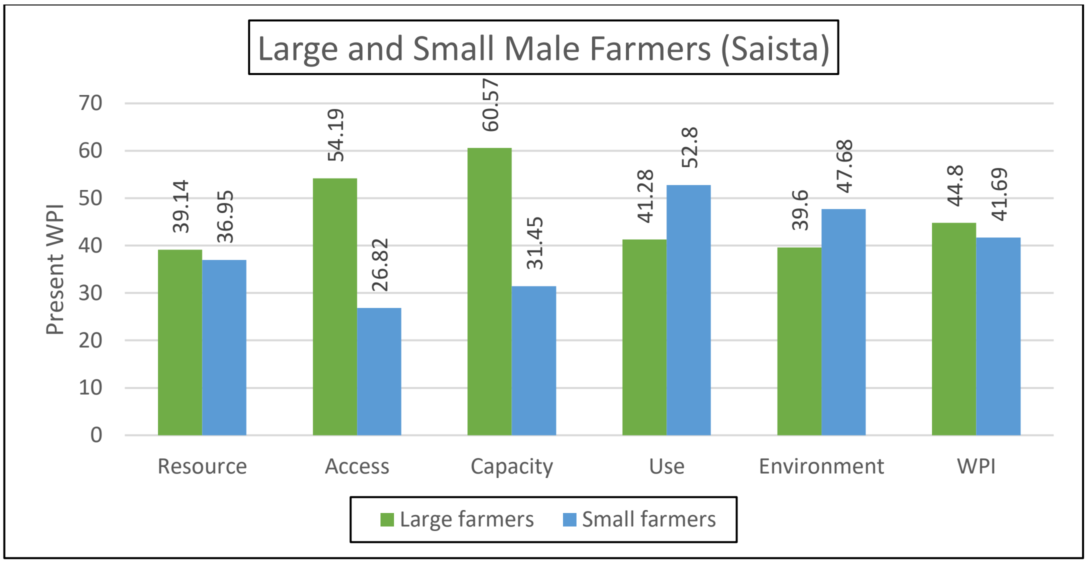

Figure 5.9: Present WPI for large and small farmers in Saista union

Comparison between present WPI for male and female farmers of Saista union (Figure 5.10) shows that female farmers had almost equal value for Capacity component, lower value for Resource and Access components and higher value for Environment component. Resource score was low due to more occurrence of illness from using groundwater for female farmers than for male farmers. Access was also poor for female farmers due to the amount of time they had to spend for collection of water. The overall present WPI scores for male and female farmers in Saista union were 43.25 and 42.28 accordingly which were almost equal.

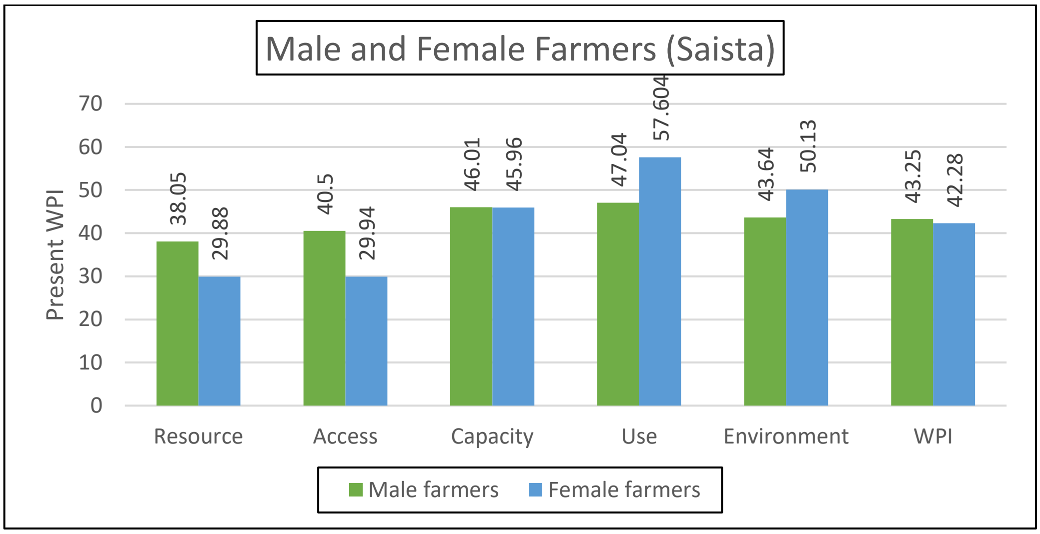

Figure 5.10: Present WPI for male and female farmers in Saista union

In Saista union, present WPI for women farmers was greater than that of economically inactive women group as shown in Figure 5.11 especially for Capacity, Use and Environment components. On the other hand, the Resource and Access scores were higher for the economically inactive group. The Resource component was higher for this group due to the responses regarding rainfall variability. Most of them reported that the rainfall was uniform which was not practically accurate. The lack of perception of the context of climate change and environmental degradation was the reason behind this. They had greater Access value because most of the correspondents did not have to collect water and wait in the queue when they are sick. But they lacked in capacity due to education level, inability to operate water source and less opportunities for training regarding sanitation and hygiene.

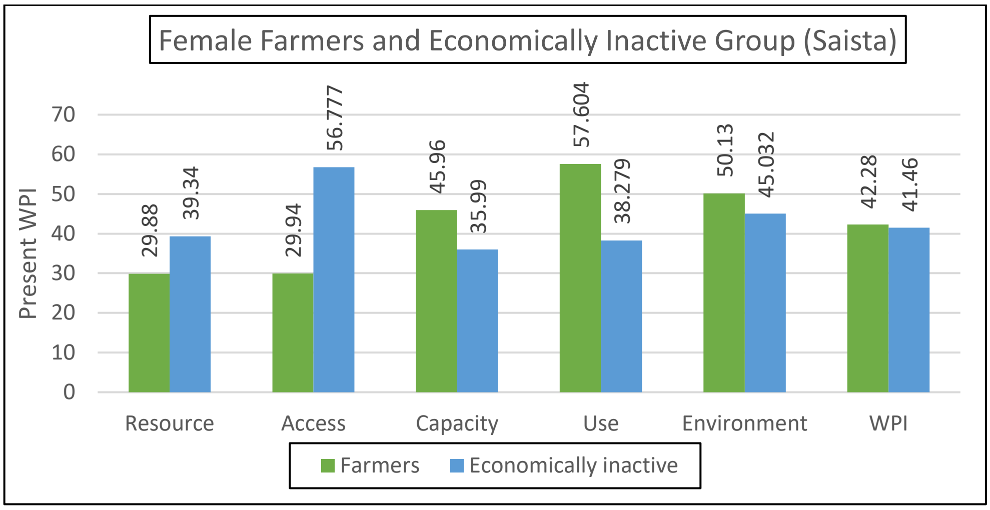

Figure 5.11: Present WPI for female farmers and economically inactive group in Saista union

Figure 5.12 shows a comparison among present WPI for economically inactive group in Saista union. Among them, physically challenged and elderly women were the most water-poor and unemployed women were the most water-secured. Unemployed women showed consistently higher values for all the components because of better access to sanitation and medication and for their role in operating the water source. The score of adolescent girls was the highest of all because of less occurrence of illness.

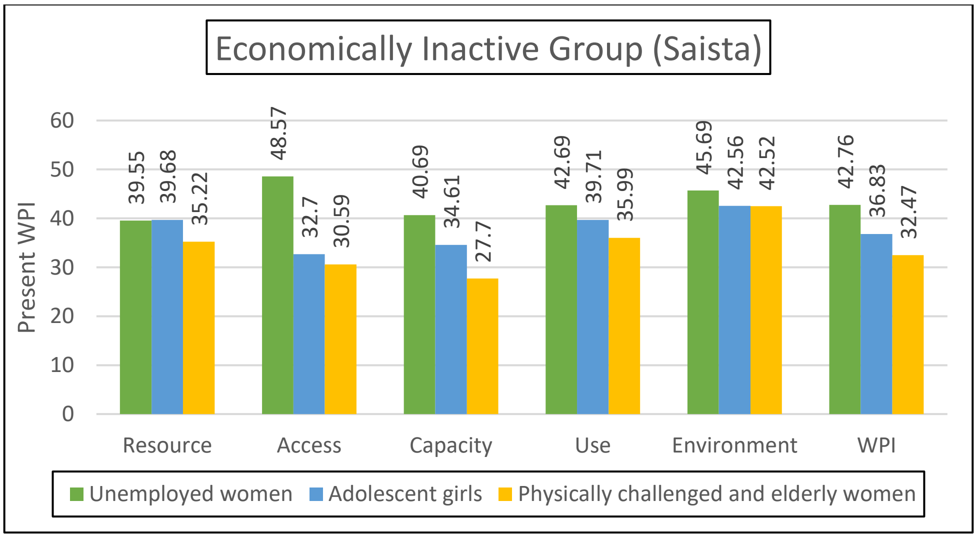

Figure 5.12: Present WPI for economically inactive group in Saista union

From a comparison between present WPI for all male and all female groups in Saista union, it was found that the male group was more water-secured than the female group (Figure 5.13). The combined male group had better score for Resource and Capacity.

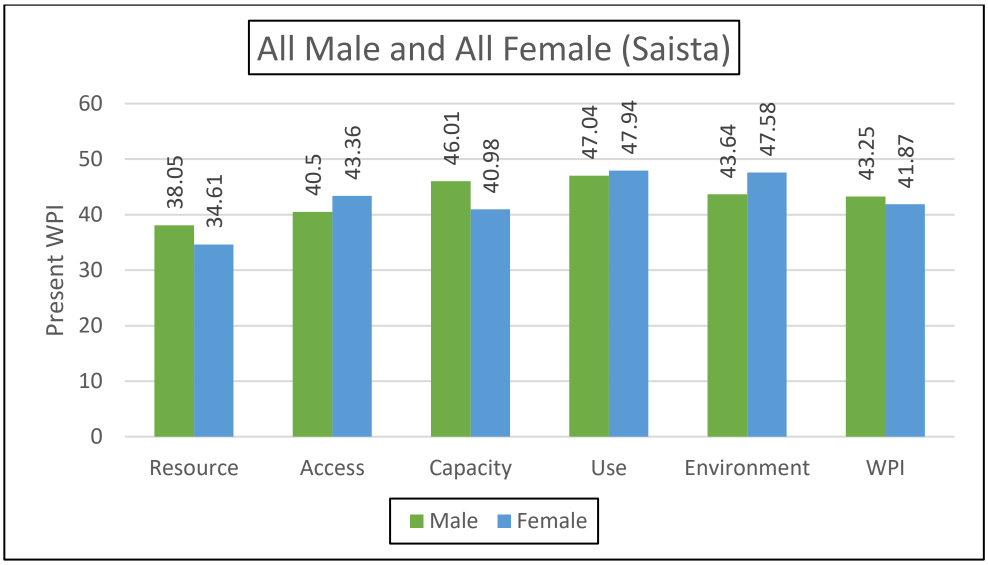

Figure 5.13: Present WPI for all male and all female groups in Saista union

5.3.2 Comparison of Present WPI among Different Unions

Only the present WPIs of female industrial workers of Tetuljhora and Dhalla union were compared as male industrial workers were not considered from Dhalla union. Industrial workers in Dhalla union were more water-secured than that of Tetuljhora union as Tetuljhora union had excessive lower value for Resource and Environment (Figure 5.14). The rate of environmental degradation and pollution from the industries were higher in Tetuljhora union. But, better access to reliable water source, piped water connection and medication caused industrial workers in Tetuljhora to obtain a higher value in Access component. Dhalla industrial workers had slightly better score in Capacity due to lower cost of water than Tetuljhora. For use component, low shortage of water inside and outside the industry caused industrial workers in Dhalla union to score higher.

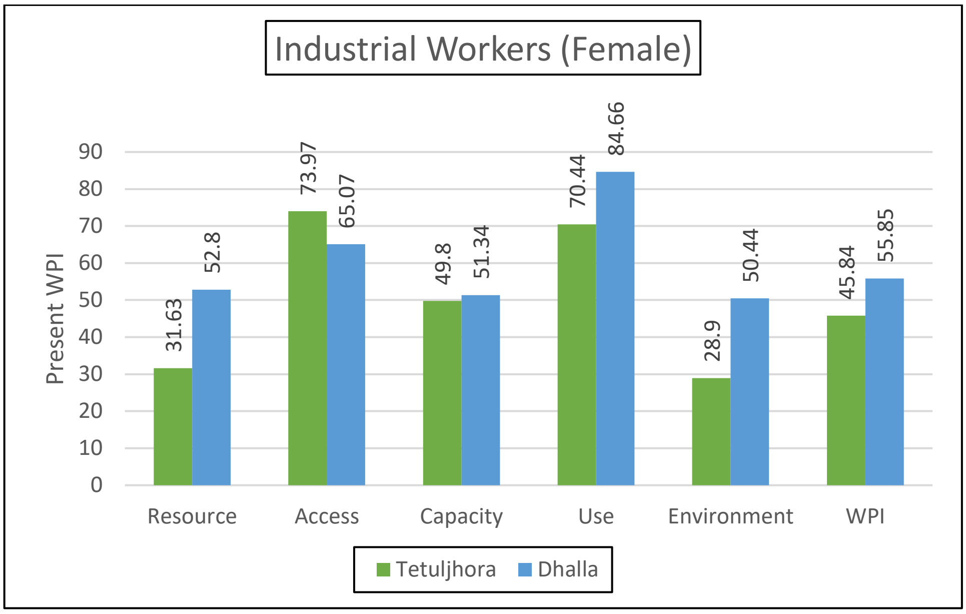

Figure 5.14: Present WPI for female industrial workers in Tetuljhora and Dhalla unions

Comparison between present WPI for large farmers in Dhalla and Saista unions is shown in Figure 5.15. Large farmers in Dhalla union were more water-secured than large farmers in Saista union due to reliable water source, better access to irrigation facilities (access to pump or deep tubewell which is installed in the agricultural land under irrigation) and sanitation, more association with political clans and non-governmental organizations, less scope for conflicts regarding water use and less damage due to seasonal flood. The present WPI scores for large farmers in Dhalla and Saista were 56.66 and 44.8 accordingly.

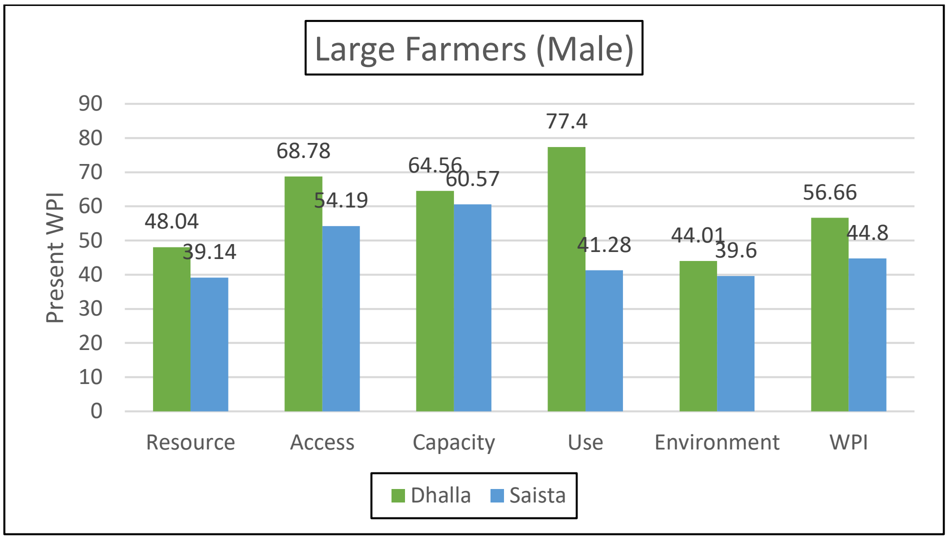

Figure 5.15: Present WPI for large farmers in Dhalla and Saista unions

Figure 5.16 shows comparison between present WPI for small farmers in Dhalla and Saista unions. Small farmers of Saista union had lower access, lower capacity and lower use scores than small farmers in Dhalla union. Because, the irrigation and production costs were higher in Saista union and their affordability was limited. Also, residents of Dhalla union had better access to medication. Only the score of Resource component was close to each other. On the other hand, the environment component was poor in case of small farmers in Dhalla union because of the frequent water logging problem in monsoon season.

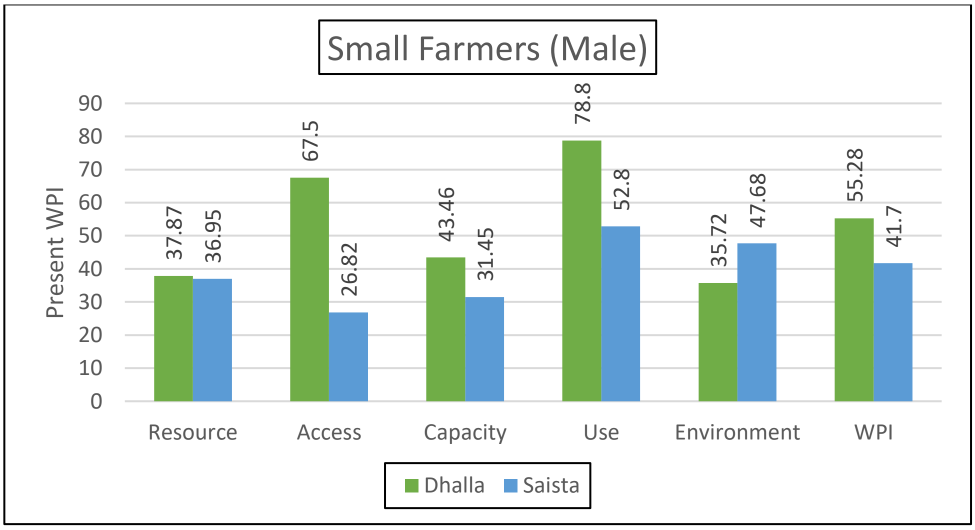

Figure 5.16: Present WPI for small farmers in Dhalla and Saista unions

Present WPI for women farmers in Saista union (42.28) was lower than women farmers in Dhalla union (49.67) as shown in Figure 5.17. For the first four components (Resource, Access, Capacity and Use), women farmers in Saista scored poorly than that of Dhalla union. The rate of occurrence of illness was found to be higher for women farmers in Saista than Dhalla. The collection time for water was also high in Saista union as the water availability was not uniform in that area. Even after owning a tubewell, women could not use water from it due to either unavailability or presence of arsenic or excessive amount of iron. In Dhalla union, women farmers were more educated than in Saista. The conflict regarding water use was also prominent in Saista. But, the loss and damage incurred from seasonal flood was substantial in Dhalla union.

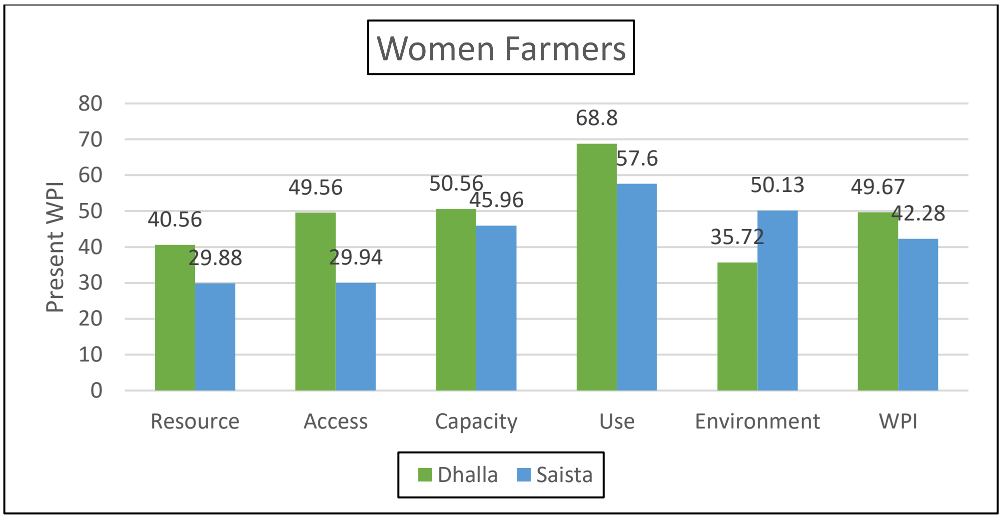

Figure 5.17: Present WPI for women farmers in Dhalla and Saista unions

The economically inactive group in Dhalla union was more water-secured than that of Saista union as shown in Figure 5.18 because of better Access, Capacity and Use scores. The Dhalla group had better access to medication and sanitation than Saista group. Also, the water availability in Dhalla was not irregular as much as in Saista. So, the women had to suffer less regarding water collection in Dhalla. Almost all of the adolescent respondents were enrolled either in school or college. But in Saista, the education ratio was very low. Saista group scored poorly in Use component due to frequent incidents of physical violence which adolescent girls and unemployed women faced if they failed to bring sufficient water from a distant tubewell.

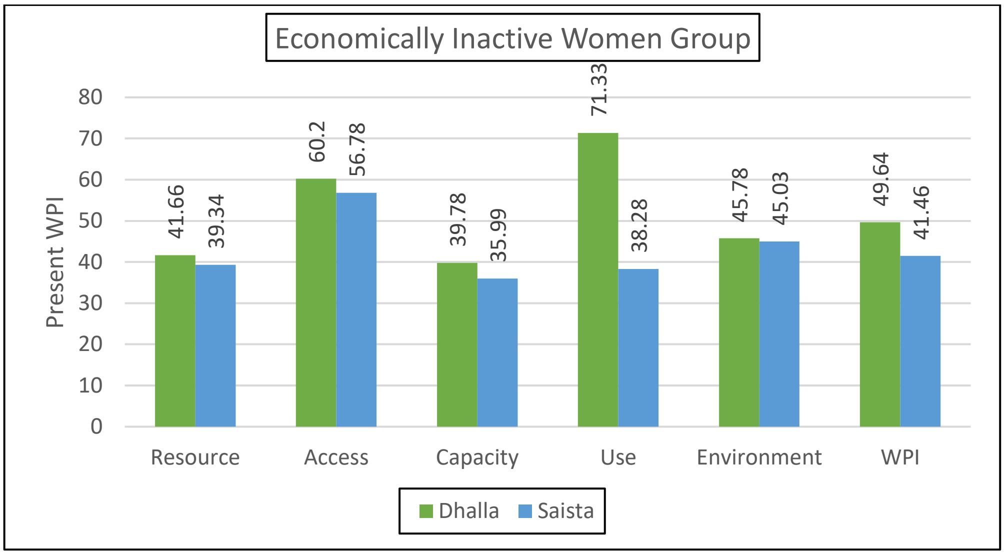

Figure 5.18: Present WPI for economically inactive women group in Dhalla and Saista unions

5.4 Analysis of In-Depth Interviews

Four in-depth interviews (two with industrial workers and two with farmers) were conducted and the results are presented in the following sections.

5.4.1 Industrial workers

In-depth interview -1:

Amina Begum, age 29, who works in a garment factory in Tetuljhora union of Savar Upazila is currently living in the same area. She has been working in that factory for five years in the third floor of the building. She constantly works until the assigned target is fulfilled. When she was pregnant last year, she could not stop working, even though it involved continuous physical activity. A medical officer is in ground floor, but she does not pay a visit even when she is sick as it will affect her productivity. She can not visit a private hospital as it is not affordable and a government hospital for her long working hours.

Inside the industry, only one washroom is in her floor which is used by around 250 female workers and is not well-maintained. There is not any drinking water point near her seat. The water point is almost at the other end of the room (at around 30m distance). She usually avoids drinking water just to avoid walking and wasting time.

Her monthly salary is around BDT 7000 from which she has to pay for her water bill which is around BDT 350 per month (5% of her salary). She has a piped water connection at her home which is highly intermittent. Her husband contributes in paying water and electricity bills in some months. She collects water during the lunch time and stores it for the whole day. No one helps her at her household chores.

According to her statement, 'I have a ten-hour workday with one-hour lunch break with constant pressure of achieving the target on my head though the wage rate is not satisfactory. The wage rate should be fair and free from discrimination. Another obstacle is that the factory does not accommodate the needs of women workers of reproductive age.'

In-depth interview -2:

Hafiz Mia, age 32, who also works in a garment factory in Tetuljhora union of Savar Upazila is currently living in Rajphulbaria, at ten minutes walking distance from the factory. He has been working in that factory for almost eight years in the fifth floor of the building. He is very hard working and currently suffering from severe backpain due to working at the same position for a long time. He visits medical officer of the garment factory whenever needed. There is only one washroom in his floor used by around 300 male workers which is not well-maintained. There is no drinking water point near his seat. But he drinks water whenever he wants.

His monthly salary is around BDT 8500 and water bill for piped water connection is monthly BDT 300 (3.5% of his salary). He pays his rents, water and electricity bills. His wife does not work outside and has no source of income. He does not have to collect water or store it and does not help his wife at her household chores.

5.4.2 Farmers

In-depth interview -1:

Nurjahan Khanom, age 44, currently lives in Saista union. She works both in the field and at her home. She is involved in post-harvesting activities and also, she has to cook for her family member and the laborers who work in the field. Both inside and outside activities need water and she is the only manager of it. She drinks water from the nearest government tubewell as her own tubewell is marked red for the presence of high amount of arsenic. Nobody is there to collect water for her even if she is physically sick. She has to walk for 20 minutes and wait in the queue for several minutes and then come back on foot again. She collects water twice daily.

Her husband is a farmer who works in the field whole day. She has to carry his lunch in the field. As she is living in an area where water availability is highly erratic, sometimes she does not have enough water to store. Her husband often beats her for not having enough water when he comes back home. According to her statement, “Working for both field and home is not an easy task. It gets tougher when there is not clean and safe water in your home.”

In-depth interview -2:

Abul Kashem, age 50, is a farmer by occupation. He has been living in Saista union for almost 30 years. He cultivates rice, mustard and vegetables. He does not have his own land and uses shallow tubewell to irrigate his field. The amount he has to pay for water is very high compared to his income (BDT 600 /month). Profit from rice is very low, but the cost of water and labor is very high.

Quality of his tubewell water is not satisfactory. He and his family do not drink from it but uses to wash clothes and to bathe. His wife collects water from his neighbor’s tubewell and stores it. When she is sick, he manages to go there and collects water.

In dry season, the water level goes down so he finds it difficult to irrigate and also cannot store sufficient amount of drinking water. In March-April, his neighbor sometimes does not want to share water as they also do not get sufficient water for themselves.

5.4.3 Findings from in-depth interviews

From the four in-depth interviews, it is found that women and men have their distinct sets of needs and interests when it comes to water use and access to it. For example, from the case studies with a male and a female industrial worker following conclusions can be drawn out:

- ✓ The female industrial worker is highly concerned about the necessity of a gender friendly workplace especially considering the specific needs during pregnancy such as better washroom facilities, provision of water points which is equally accessible for all. On the other hand, the male industrial worker did not complain about the distant water source. He does not avoid drinking water like the woman does.

- ✓ Discrimination in wage rate of male and female workers is very prominent. As a result, the female workers who pay their water bills or who contributes financially to their family have to struggle a lot to fulfill their daily target.

- ✓ Another insight is that female workers despite of working outside, collects and stores water at their home. But the male workers do not have to manage the water or store it.

From the in-depth interviews with a male and a female farmer, the following conclusions can be drawn:

- ✓ The woman has to work both inside and outside her home which compels her to manage water more carefully as she has to spend the stored water for additional purposes for farm activities. The male farmer is more concerned about the required water for irrigation in summer season and the cost of it.

- ✓ Only the woman farmer in the case study is responsible for collection of water which causes her to spend a considerable amount of time daily. Otherwise, she is physically abused by her husband for not storing enough water. On the other hand, the male farmer collect water only when his wife is sick.

- ✓ A woman farmer finds it hard to perform traditional duties as daughters, housewives and mothers, and to balance their work and family life. In most cases, the women who are participating in any kind of farm activities either cooking or carrying lunch in the field or participating in post harvesting activities are not recognized as working women.

5.5 Assessment of Environmental Change

To assess the impact of climate and environmental change on future water poverty for different groups, trend analysis of two climatic parameters- temperature and rainfall, and four environmental factors- population growth, changes in groundwater level, changes in surface water level and changes in land use were analyzed. A yes-no question to understand the scenario of difference in climate change perception of men and women revealed that only 31.67% of men and 23.57% of women had basic knowledge of climate change phenomenon as shown in Figure 5.19. The result implied that women needed special training or awareness program to clear their perception regarding climate and environmental change which would help them to adapt more quickly to these changes.

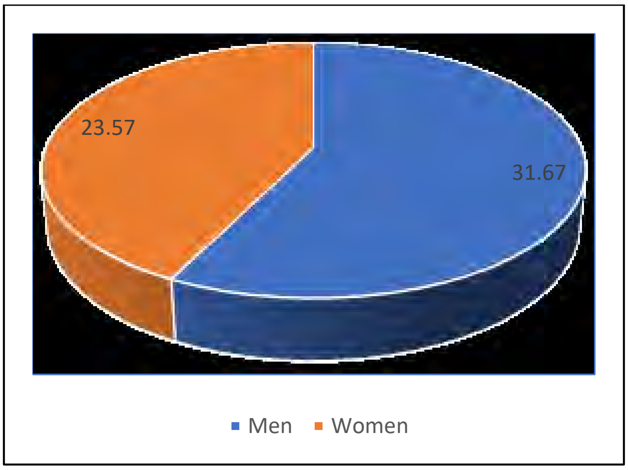

Figure 5.19: Percentages of men and women with climate change perception

5.5.1 Changes in temperature

Trend analysis was carried out for annual average temperature and also for both daily maximum and minimum temperatures. The trends were estimated for BMD station Dhaka as the study area fell under this station. Daily maximum and minimum temperature data were available for Dhaka station for a period of 64 years (1953-

2017). Time series of observed (1953-2017) mean annual temperature is shown in Figure 5.20.

The linear trend line shows that there is an increase in annual average temperature for the station. The increase in temperature in Dhaka is on an average 0.0306ºC per year that is an increase of 3ºC in 100 years. Another trendline (indicated by orange line) is obtained from time series of observed mean annual temperature data for last 28 years (1989-2017) to estimate recent climatic trend. If time series data from 1989 to 2017 is considered only, the increase in annual average temperature is on average 0.0489ºC per year that is an increase of 4.89ºC in 100 years.

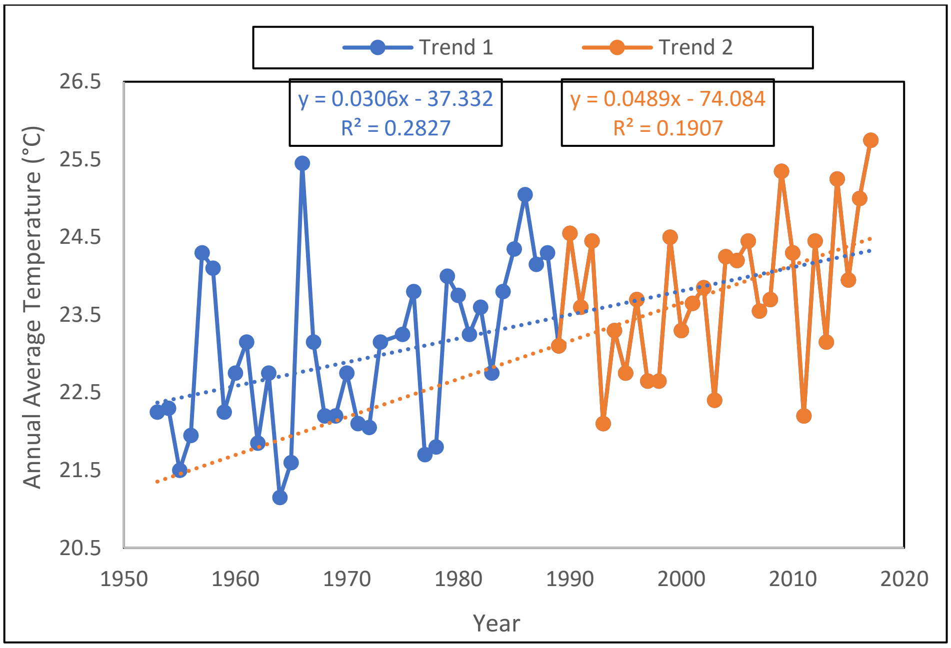

Figure 5.20: Trend in observed annual average temperature

Maximum and minimum temperatures also show an increasing trend of 0.0124ºC and 0.0487ºC per year respectively which means 1.24ºC and 4.87ºC in 100 years respectively. Trends of observed annual maximum and minimum temperatures are shown in Figure 5.21. Trendlines for time series data of last 28 years show an increasing trend of 0.0297ºC and 0.0681ºC per year (2.97ºC and 6.81ºC in 100 years) respectively.

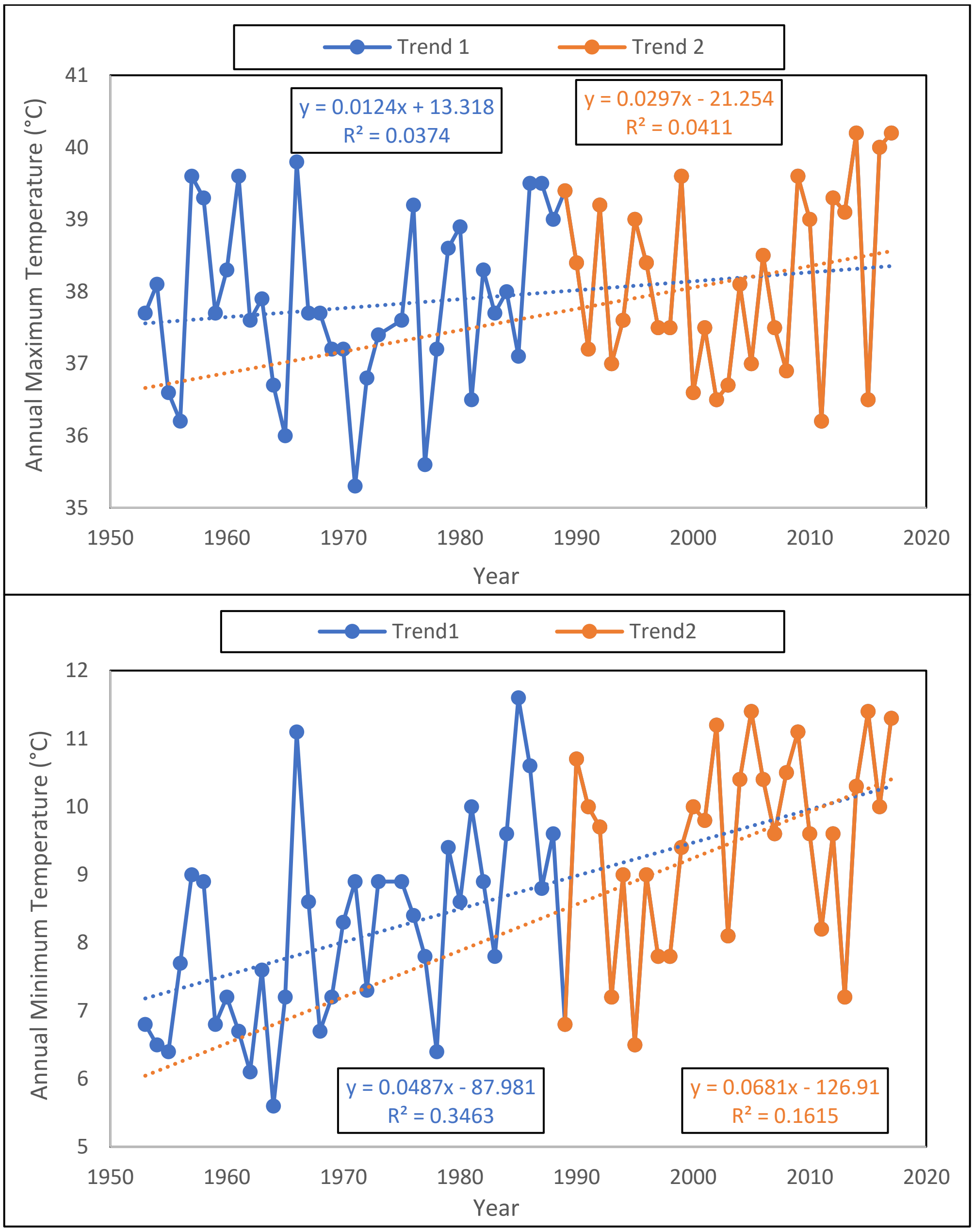

Figure 5.21: Trends in observed annual maximum and minimum temperatures

Table 5.15 shows the summary of the trends from the observed data for both time spans of 1953 to 2017 (Trend[1]) and 1989 to 2017 (Trend[2]). All of the three parameters show an increasing trend. Increasing rate is higher for last 28 years than that of last 64 years.

Table 5.15: Trends (°C/year) in observed temperature data in Dhaka station

Parameters	Trend[1]	Trend[1] (°C/year)	Trend[2]	Trend[2] (°C/year)
Annual average temperature	Increasing	0.0306	Increasing	0.0489
Annual maximum temperature	Increasing	0.0124	Increasing	0.0297
Annual minimum temperature	Increasing	0.0487	Increasing	0.0681

Note: [1]using data from 1953 to 2017; [2]using data from 1989 to 2017.

Both parametric and non-parametric correlations between annual average temperature, annual maximum and minimum temperatures and time (years) were estimated. The parametric correlation coefficient that is Pearson's r, is shown for both Trend[1] and Trend[2] in Table 5.17. For Trend[1], annual average and annual minimum temperature and for Trend[2], annual maximum and minimum temperatures are statistically significant which means there is a significant trend in the time series.

On running the Mann-Kendall test on temperature data, the following results in Table 5.16 were obtained for Dhaka station. If the p value is less than the significance level (α (alpha) = 0.05), H_0 is rejected. Rejecting H_0 indicates that there is a trend in the time series, while accepting H_0 indicates no trend was detected. On rejecting the null hypothesis, the result is said to be statistically significant. The results are statistically significant where the significance value is <0.05.

So, the final result says that the temperature is rising rapidly in the study area. The rate of evaporation of water will increase due to warmer temperatures. As a result, some areas will dry out and other areas will experience severe rainfall.

Table 5.16: The correlation coefficients (parametric and nonparametric) between temperature parameters and times (years) and their significance levels

	Annual average temperature	Annual maximum temperature	Annual minimum temperature
Pearson's r (Trend[1])	0.532	0.193	0.588
Significance (Two tailed Test)	0.000*	0.126 (NS)	0.000*
Pearson's r (Trend[2])	0.203	0.402	0.437
Significance (Two tailed Test)	0.292 (NS)	0.031**	0.018**
Kendall's tau_b (Trend[1])	0.374	0.091	0.438
Significance (Two tailed Test)	0.000*	0.291 (NS)	0.000*
Kendall's tau_b (Trend[2])	0.293	0.100	0.287
Significance (Two tailed Test)	0.027**	0.452 (NS)	0.031**

Note: * Correlation is significant at 0.01 level
** Correlation is significant at 0.05 level
NS = Not significant

5.5.2 Changes in rainfall

From the rainfall analyses done in this study, season wise variation was seen. Seasonal analyses are usually done dividing the rainfall data into four seasons: dry period or winter (December to February), pre-monsoon or summer (March to May), monsoon (June to September) and post-monsoon (October-November). In this study, only pre-monsoon rainfall data were analyzed.

Decadal (10 years) variations of total rainfall of summer or pre-monsoon season (March to May) are shown in Figure 5.22. It is seen from the figure that the rainfalls of the first three decades were gradually increasing. But in the last two decades (1991-2010), the amount of rainfall decreased drastically.

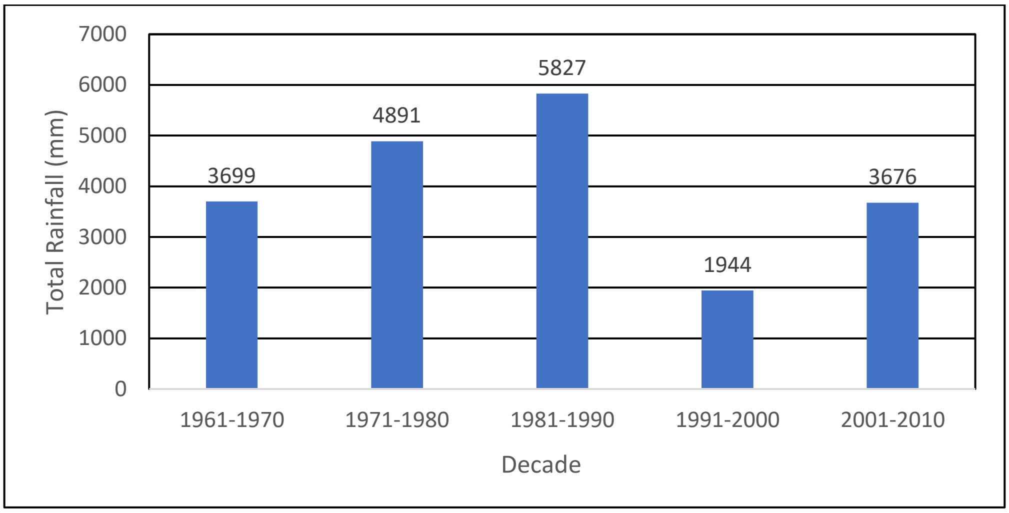

Figure 5.22: Decadal variation of rainfall in pre-monsoon or summer season

A decrease in total annual rainfall is also observed from Figure 5.23. In case of trend analysis for rainfall data, using annual average rainfall is misleading because for many days of some months there is no rainfall at all. The annual total rainfall considering time series data for 64 years is showing an increasing trend at the rate of 0.4445 mm/year that is 4.45 mm per 100 years. But the recent trend shows a decreasing rate of 5.72mm/year.

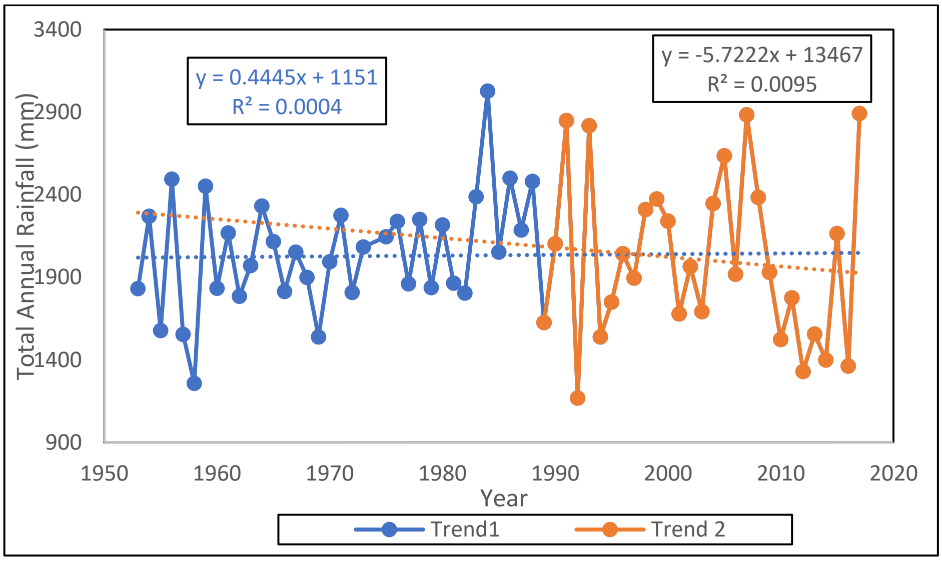

Figure 5.23: Trend in total annual rainfall of Dhaka

Considering average rainfall in March, April and May, another trend analysis is done for average pre-monsoon rainfall also known as summer season is shown in Figure 5.24. This is the most critical season as the groundwater level depletes drastically in this season. Both the trends show a decreasing rate of 0.0135mm and 0.2137mm per year for 64 years and last 28 years data, respectively. The recent decreasing trend is higher than that of the overall trend.

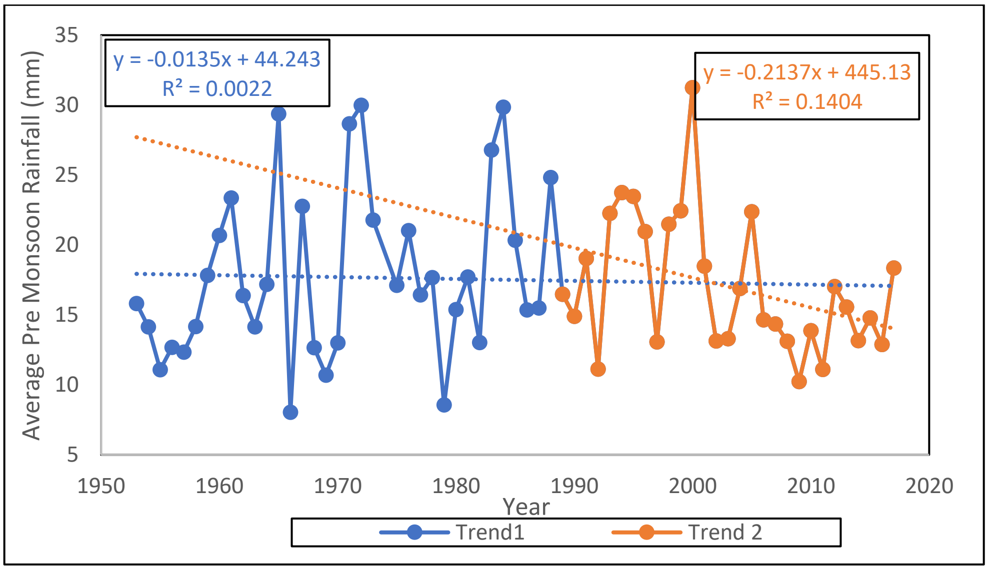

Figure 5.24: Trend in average pre-monsoon (summer) rainfall of Dhaka

Figure 5.25 shows decreasing trend in maximum rainfall in pre-monsoon season for both the time spans. The recent rate of decrease (0.5512 mm/year) is much higher than the long-term rate of decrease (0.1692mm/year).

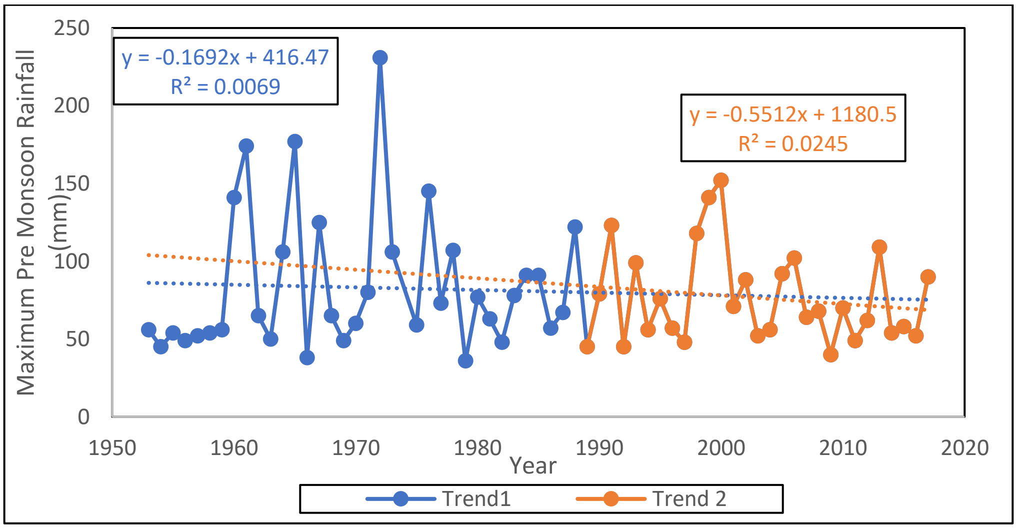

Figure 5.25: Trend in maximum pre-monsoon (summer) rainfall of Dhaka

Table 5.17 shows the summary of the trend from the observed data for both time spans of 1953 to 2017 (Trend[1]) and 1989 to 2017 (Trend[2]). All of the three parameters for recent time span show decreasing trend and the rate is higher for last 28 years than that of last 64 years. Table 5.18 shows the parametric and nonparametric correlations between rainfall parameters and times (years) and their significance levels.

Table 5.17: Trends (mm/year) in observed rainfall data in Dhaka station

Parameters	Trend[1]	Trend[1] (mm/year)	Trend[2]	Trend[2] (mm/year)
Annual total rainfall	Increasing	0.4445	Decreasing	5.7222
Average pre monsoon (summer) rainfall	Decreasing	0.0135	Decreasing	0.2137
Maximum pre monsoon (summer) rainfall	Decreasing	0.1692	Decreasing	0.5512

Table 5.18: The correlation coefficients (parametric and nonparametric) between rainfall parameters and times (years) and their significance levels

	Annual total rainfall	Average pre monsoon rainfall	Maximum pre monsoon rainfall
Pearson's r (Trend[1])	0.020	-0.046	-0.083
Significance (Two tailed Test)	0.874 (NS)	0.716 (NS)	0.516 (NS)
Pearson's r (Trend[2])	-0.097	-0.375	-0.156
Significance (Two tailed Test)	0.615 (NS)	0.045**	0.418 (NS)
Kendall's tau_b (Trend[1])	-0.002	-0.020	0.017
Significance (Two tailed Test)	0.982 (NS)	0.817 (NS)	0.844 (NS)
Kendall's tau_b (Trend[2])	-0.069	-0.251	-0.067

Significance (Two tailed Test)	0.599 (NS)	0.056 (NS)	0.612 (NS)

Note: * Correlation is significant at 0.01 level
** Correlation is significant at 0.05 level
NS = Not significant

Table 5.19 shows that the Coefficient of Variation (CV) of different rainfall parameters of Dhaka varies from 20 to 48 percent. The annual total rainfall shows moderate variability for both long term and recent data. The annual pre-monsoon rainfall for long term data shows erratic behavior as the value is more than 30 percent. The maximum pre-monsoon rainfall in summer season for both long term and recent data shows highly erratic behavior which indicates that there is a constant threat of prolonged drought in dry season.

Table 5.19: Rainfall parameters and their variability

Parameters	Standard Deviation	Coefficient of Variation (%)	Degree of Variability
Annual total rainfall (1953-2017)	418.40935	20.57598	Moderate
Annual total rainfall (1989-2017)	499.89316	24.92247	Moderate
Average pre monsoon rainfall (1953-2017)	5.51395	31.506	**High**
Average pre monsoon rainfall (1989-2017)	4.85662	28.53371	Moderate
Maximum pre monsoon rainfall (1953-2017)	38.83872	48.14407	**High**
Maximum pre monsoon rainfall (1989-2017)	29.99109	39.24827	**High**

On the other hand, standardized anomalies of rainfall were calculated to examine the nature of the trends, enables the determination of the dry and wet years in the record and used to assess frequency and severity of droughts. Figure 5.26 shows a presence of inter-annual variability and the trends below the long-term average (1989 to 2017) that is rainfall anomaly for Dhaka station. Very low values of rainfall anomaly correspond to severe drought periods and the value in this case ranges from +2.04 in 1984 to -1.67 in 1992. There were consecutive dry years from 2009 to 2014 and consecutive wet years from 1983 to 1988.

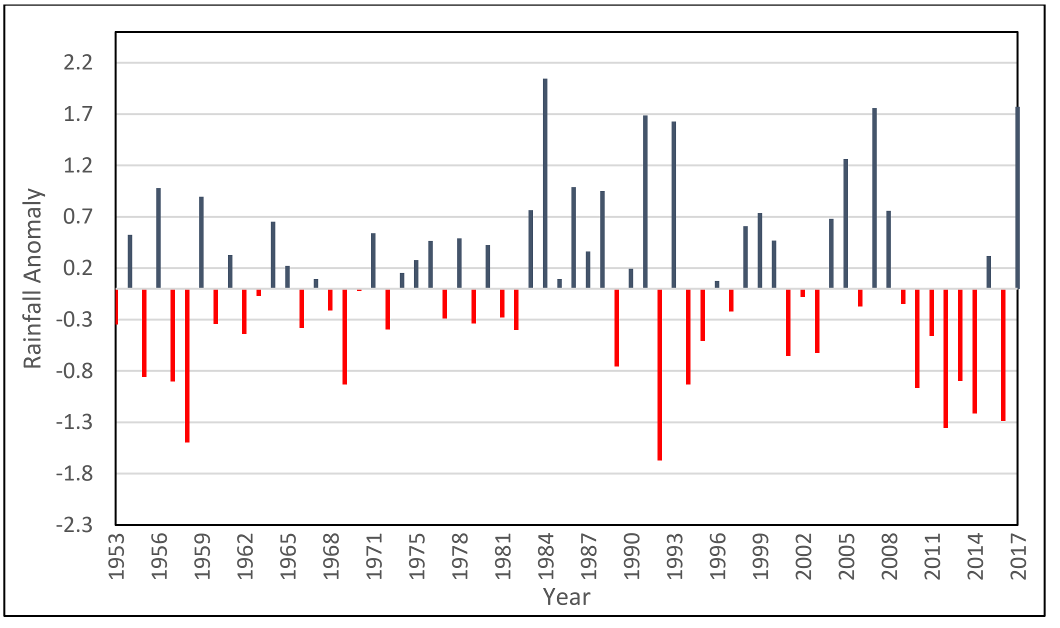

Figure 5.26: Rainfall anomalies of Dhaka (1953-2017) relative to 1989 to 2017 average

5.5.3 Changes in groundwater level

To determine the trend in groundwater level in the study area 40 years (1975-2015) below ground level (bgl) data was considered for two stations situated in Singair and Parilnoadda village. Figure 5.27 shows that groundwater levels for both of the stations are reducing at an alarming rate. The upward trendline indicates the increase in depth of groundwater from ground level. The rate of reduction is 2.82 cm per year at Singair village where bgl data varies from 6.64 m to 4.39 m. At Parilnoadda, the situation is worse. The groundwater level is falling at a higher rate at 7.93 cm per year, where bgl data varies from 4.75 m to 8.19 m. The fluctuation of water levels shows high variability also.

Both parametric and nonparametric correlation analyses show that the trends are statistically significant (Table 5.20). The below ground level (bgl) data of Parilnoadda village is highly correlated (Pearson's r: 0.942 and Kendall's tau_b: 0.812) with year. That means if the year increases the rate of reduction in water level also increases and the reduction rate is very high.

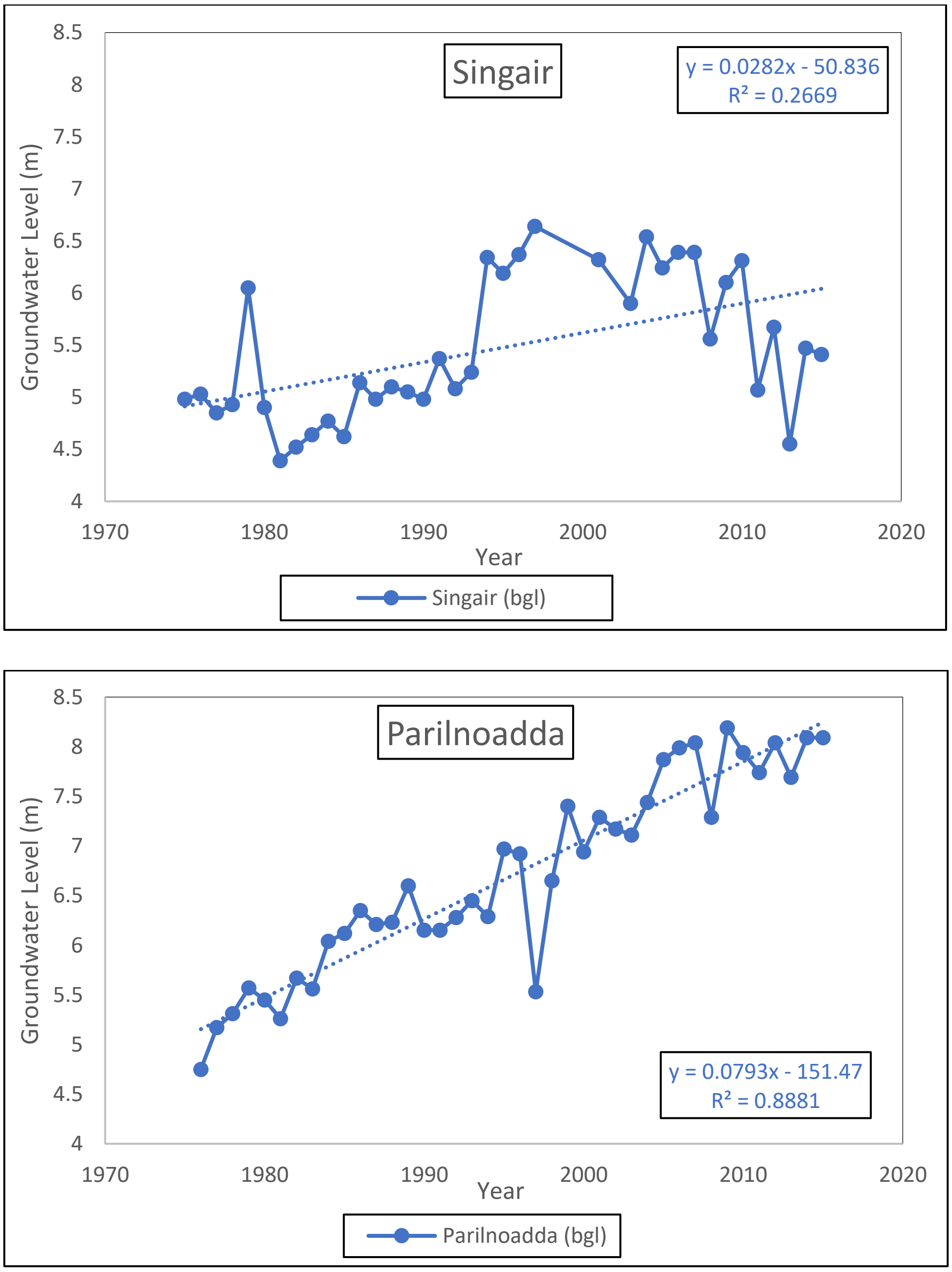

Figure 5.27: Annual maximum falling trend in groundwater level at the study area

Table 5.20: Trends (cm/year) in groundwater level and parametric and nonparametric correlations and their significance level

Well ID	Village Name	Decreasing Trend (cm/year)	Pearson's r	Sig (2-tailed)	Kendall's tau_b	Sig (2-tailed)
GT5682014	Singair	2.82	0.517	0.001*	0.386	0.001*
GT5682015	Parilnoadda	7.93	0.942	0.000*	0.812	0.000*

Note: * Correlation is significant at 0.01 level

5.5.4 Changes in surface water level

Trends in water level of Dhaleshwari River in Savar upazila are determined in order to understand the situation regarding surface water availability by analyzing annual minimum high and low water levels and monthly average water levels in March (Figure 5.28). According to local people's statement, water level reaches the lowest in March. All of the parameters show a decreasing trend. The water level of Dhaleshwari River is going down and the rates are 0.74, 0.69 and 0.33 cm per year for annual minimum high tide, annual minimum low tide and average daily water level (March), respectively, as shown in Table 5.21. Though the decreasing rate is not alarming but the variability in water level is highly prominent. Table 5.22 shows the statistical analyses for the above-mentioned trends which show that none of the trends are statistically significant.

Table 5.21: Trends (cm/year) in water levels of Dhaleshwari River in Savar (Station Name: Savar; Station ID: SW69)

Parameters	Trend	Trend (cm/year)
Annual minimum high tide	Decreasing	0.74
Annual minimum low tide	Decreasing	0.69
Average daily water level (March)	Decreasing	0.33

Table 5.22: The correlation coefficients (parametric and nonparametric) between water level parameters and times (years) and their significance levels

	Annual minimum high tide	Annual minimum low tide	Average daily water level (March)
Pearson’s r	-0.250	-0.238	-0.103
Significance (Two tailed Test)	0.168 (NS)	0.189 (NS)	0.580 (NS)
Kendall’s tau_b	-0.172	-0.164	-0.123
Significance (Two tailed Test)	0.168 (NS)	0.189 (NS)	0.333 (NS)

Note: NS = Not significant

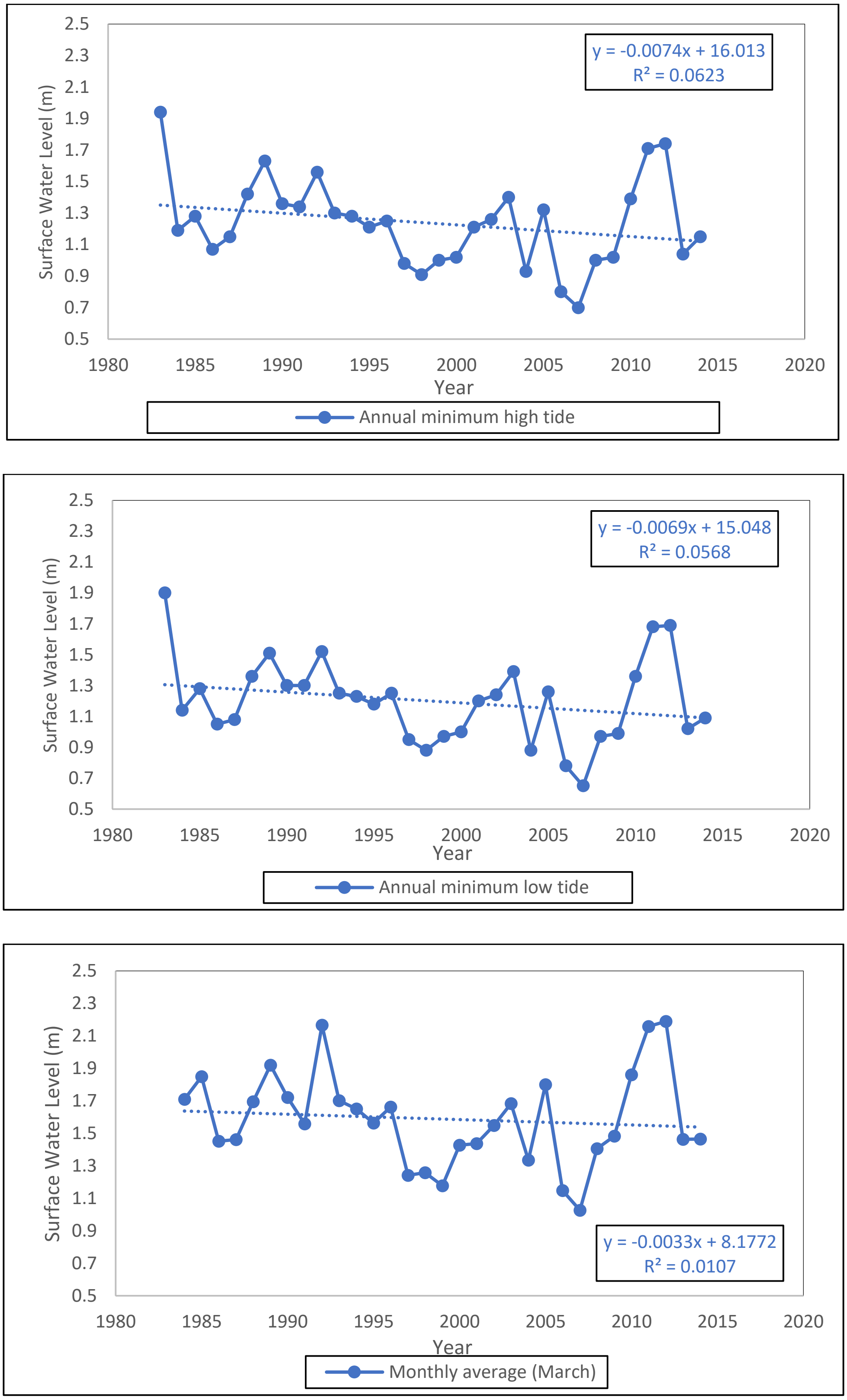

Figure 5.28: Trend in water levels of Dhaleshwari River in Savar

5.5.5 Population growth

Both Singair and Savar upazilas were threatened by excessive population growth. According to Population and Housing Census 2011 (BBS, 2011), the decadal population growth rates for Savar and Singair upazilas were 136.08 and 15.6 percent respectively and the annual compound growth rates were 8.83 and 1.44 percent accordingly. The decadal growth rates for the last six decades of Savar and Singair upazilas are shown in Table 5.23. Based on the data for 1991 to 2011, future decadal growth rates were projected through linear trend relationship as shown in Figure 5.29. Both rates are showing increasing trend. Between these two upazilas, the growth rate of Savar is higher than that of Singair upazila.

Table 5.23: Decadal growth rate of population (1951-2011)

Decades	Growth rate (%)	
	Savar	Singair
1951-1961	27.50	22.8
1961-1974	37.60	30.7
1974-1981	27.80	20.9
1981-1991	44.30	14.6
1991-2001	55.29	7.3
2001-2011	136.08	15.6

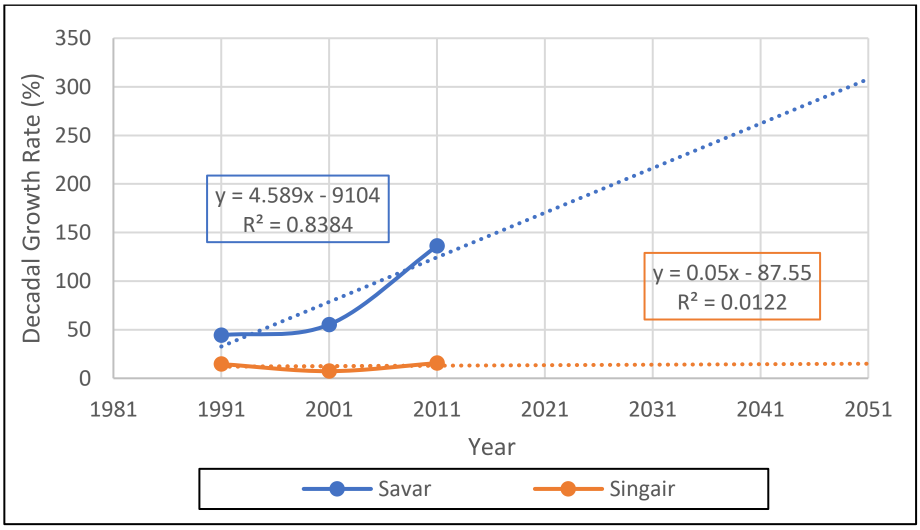

Figure 5.29: Projected future growth rates of population in Savar and Singair upazilas

In Tetuljhora union, population growth rate is very high due to shifting of industries which creates employment opportunities for a large number of lower income group. The rates of inward migration in Tetuljhora and Dhalla are increasing alarmingly. Table 5.24 shows the population in three unions for 2049 by population projection method considering 2011 as the base period. Figure 5.30 shows that future population density is maximum for Tetuljhora union followed by Dhalla and Saista unions.

Table 5.24: Population projection in the study area

Union	Growth rate* (r), %	Total population		
		2011**	2019	2049
Tetuljhora	8.83	106929	210419	2664057
Dhalla	1.44	36203	40590	62330
Saista	1.44	27188	30483	46809

Note: *growth rate is obtained from population data for upazila level, BBS
**base year

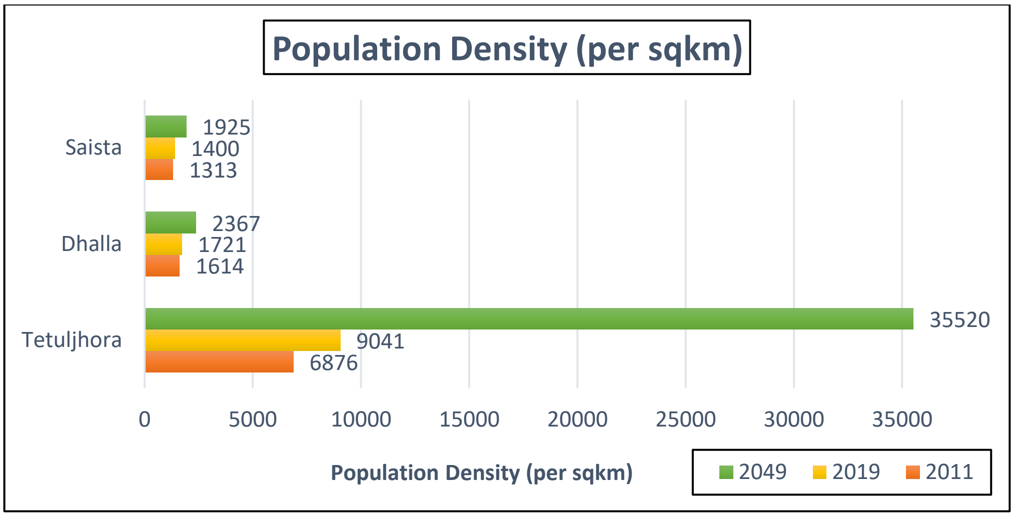

Figure 5.30: Comparison in population density in the study area for 2011, 2019 and 2049

5.5.6 Changes in land use

Landsat images of the year 1989 and 2019 were collected from landsat 5 and landsat 8 accordingly. All the images from February month were used in this study. Four major land use types, agriculture and vegetation, bare land, settlement and urban development area and, water body were calculated. Table 5.25 shows a short description of land use classes used in this study.

Table 5.25: Description of land use classes

Class	Description
Agriculture and Vegetation	This class includes areas under cultivation, the areas which are being used for preparation of the crops, homestead vegetation and other vegetative areas.
Bare Land	This class includes all types of fallow and uncultivable lands.
Settlement and Urban Development Area	This class includes human settlement areas, roads, and all types of urban areas.
Water Body	This class includes all the surface water bodies such as rivers, canals, ponds, etc.

Table 5.26 shows that agriculture and vegetation decreased from 49.28% in 1989 to 28.17% in 2019. Percentage of agriculture and vegetation was the highest in 1989. But, in 2019, percentage of settlement and urban development area (45.01%) is the highest of all the classes. A significant amount of increase in bare land was found. The amount of water body decreased from 4.2% in 1989 to 3.9% in 2019 in Tetuljhora union. Figure 5.31 and Figure 5.32 show the land use maps of Tetuljhora union of the year 1989 and 2019 respectively.

Table 5.27 shows the change of land use in Dhalla union. In this union, percentage of agriculture and vegetation (50.62%) was the highest in 1989 and it decreased to 30.11% in 2019. Percentage of settlement and urban development area increased from 23.38% in 1989 to 44.24% in 2019. The percentage of water body decreased from 13.67% in 1989 to 8.19% in 2019. Most of the canals and ponds dried up in last 30 years. An increase in bare land from 13.67% in 1989 to 8.19% in 2019 was found.

Figure 5.33 and Figure 5.34 show the land use maps of Dhalla union of the year 1989 and 2019 respectively.

Table 5.28 shows change of land classes in Saista union. In this union, the percentage of settlement and urban development area showed the highest amount of increase that is, from 0.57% in 1989 to 33.56% in 2019. The other three classes decreased from 1989 to 2019. Figure 5.35 and Figure 5.36 show the land use maps of Saista union of the year 1989 and 2019 respectively.

Table 5.26: Change of land classes in Tetuljhora union

Class	% of area		Total area (sq km)	
	1989	2019	1989	2019
Agriculture and Vegetation	49.28	28.17	9.87	5.64
Bare Land	12.68	22.88	2.54	4.58
Settlement and Urban Development Area	33.85	45.01	6.78	9.01
Water Body	4.2	3.9	0.84	0.79

Table 5.27: Change of land classes in Dhalla union

Class	% of area		Total area (sq km)	
	1989	2019	1989	2019
Agriculture and Vegetation	50.62	30.11	11	6.54
Bare Land	12.33	17.45	2.68	3.79
Settlement and Urban Development Area	23.38	44.24	5.08	9.61
Water Body	13.67	8.19	2.97	1.78

Table 5.28: Change of land classes in Saista union

Class	% of area		Total area (sq km)	
	1989	2019	1989	2019
Agriculture and Vegetation	36.85	29.38	6.43	5.05
Bare Land	27.85	25.77	4.86	4.43
Settlement and Urban Development Area	0.57	33.56	0.10	5.77
Water Body	34.73	11.28	6.06	1.94

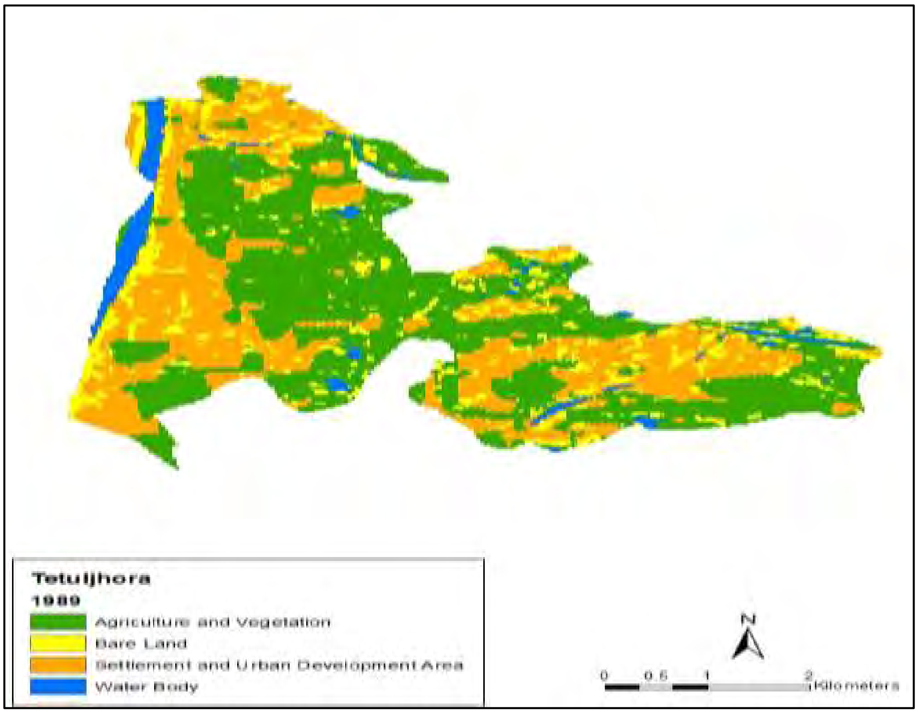

Figure 5.31: Land use map of Tetuljhora union (year: 1989)

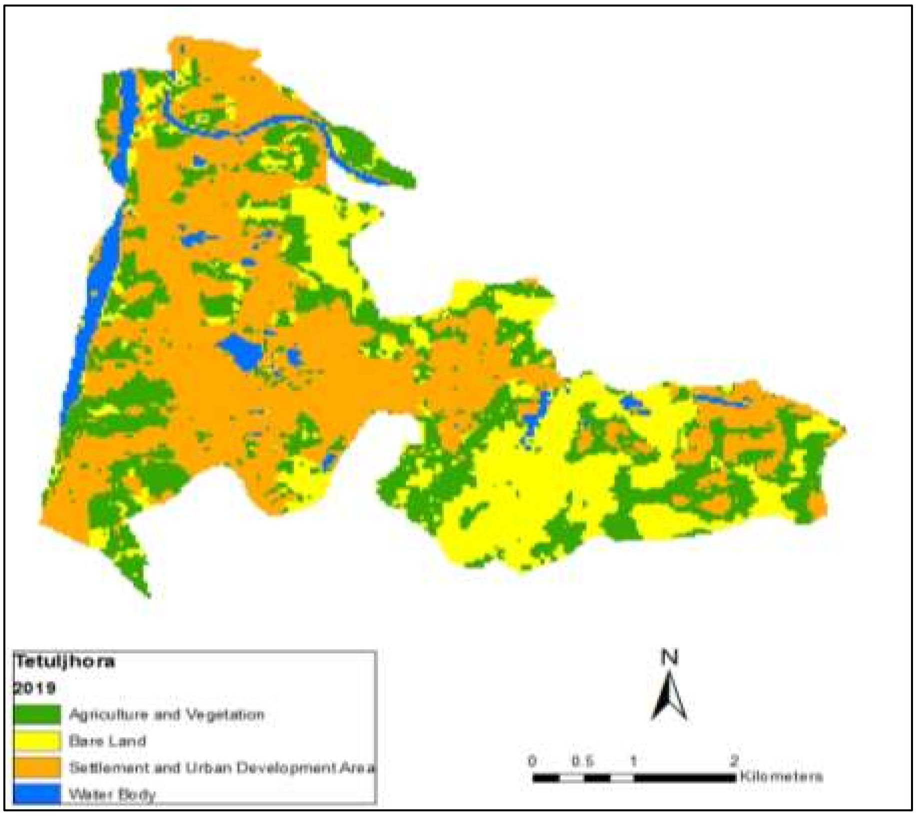

Figure 5.32: Land use map of Tetuljhora union (year: 2019)

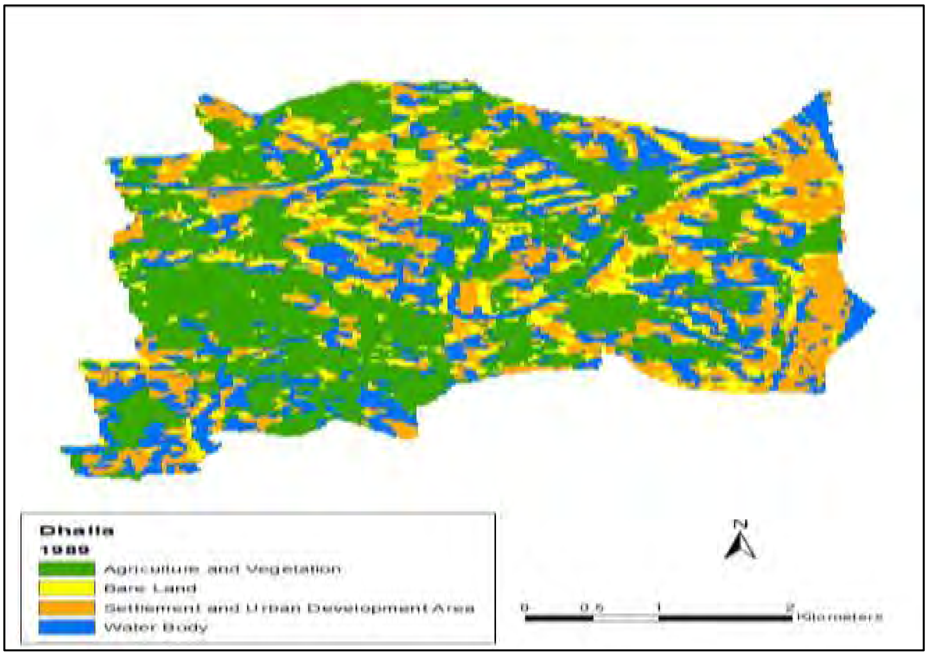

Figure 5.33: Land use map of Dhalla union (year: 1989)

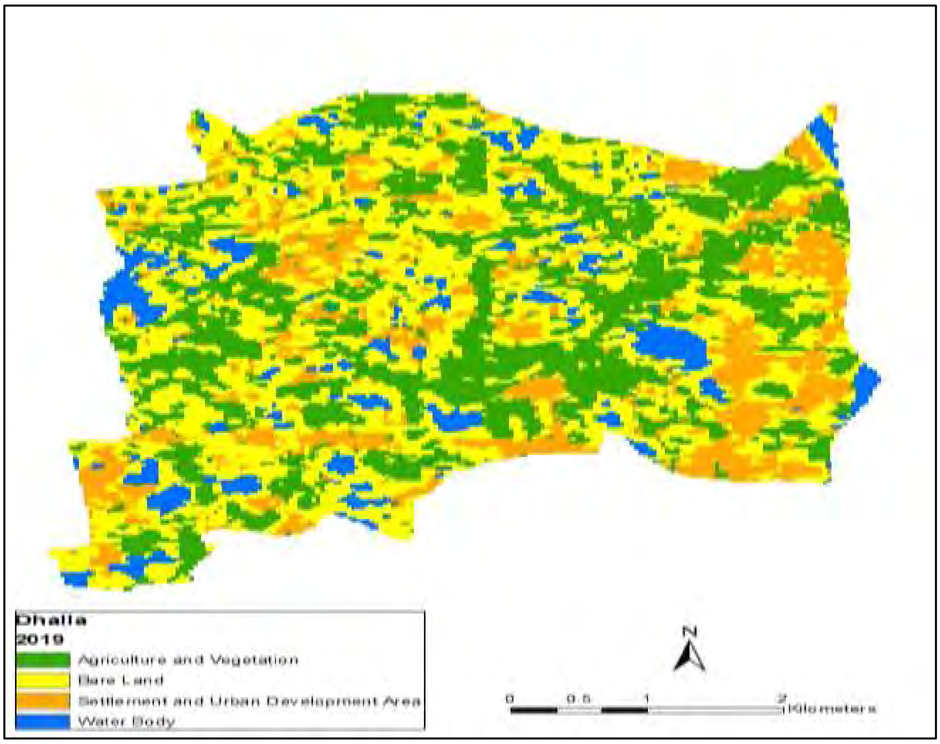

Figure 5.34: Land use map of Dhalla union (year: 2019)

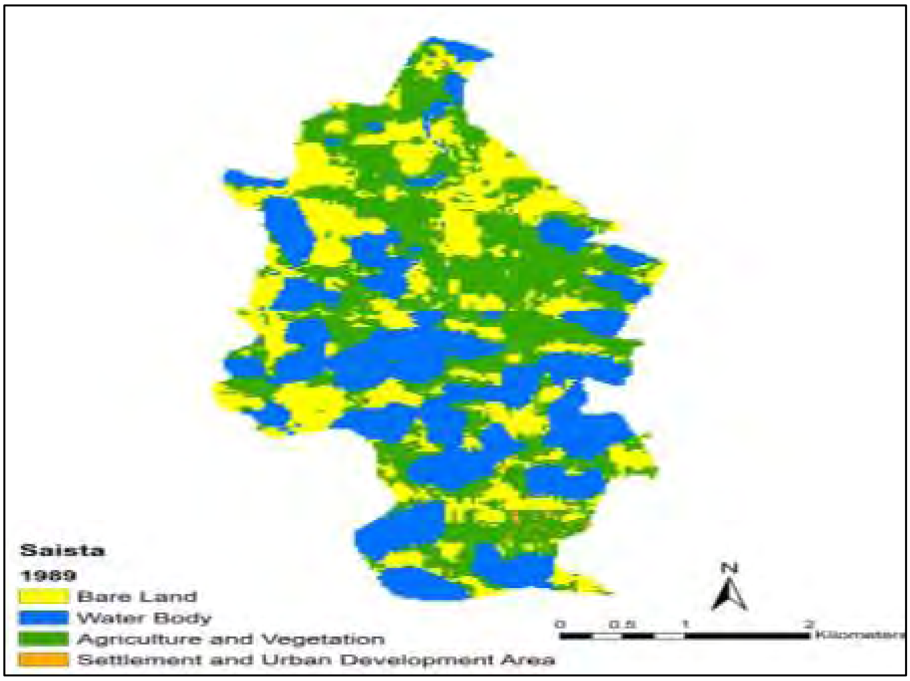

Figure 5.35: Land use map of Saista union (year: 1989)

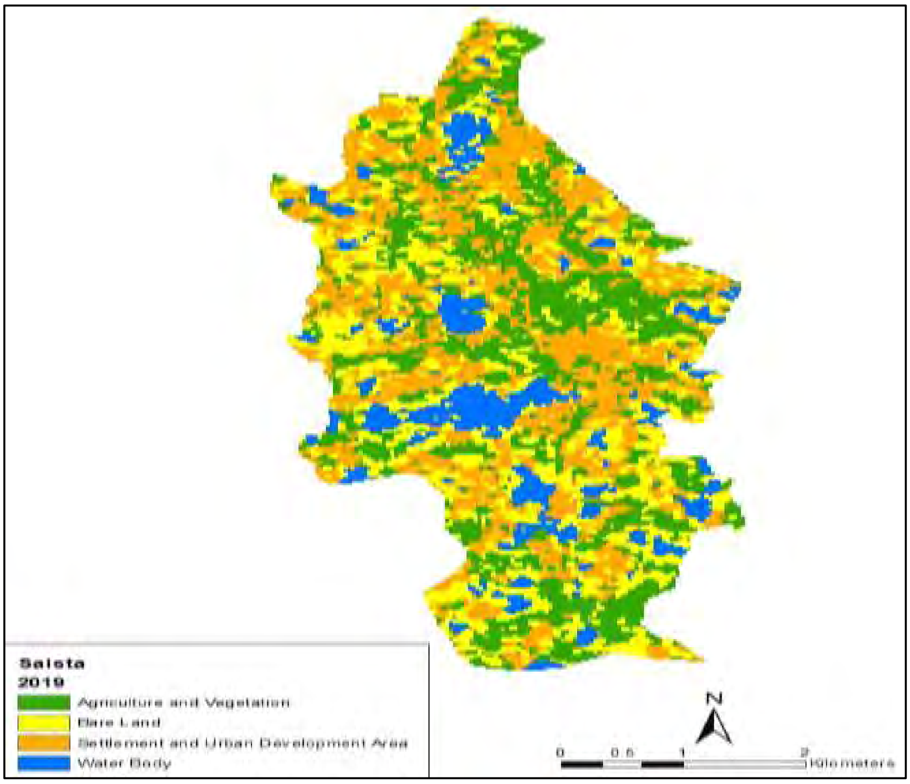

Figure 5.36: Land use map of Saista union (year: 2019)

5.6 Evaluation of Future WPI for Livelihood Groups

From the primary data from field survey, future WPI for each group was calculated. Table 5.29 shows the results of the future WPI for the livelihood groups in the study area. Considering the present situation, future predictions for 2050 were considered for the analysis. As water poverty is dynamic, the hypothesis was that the present WPI will change for all the groups considering environmental and climate change. Figure 5.37 shows the pentagram for future WPI for all the groups in Tetuljhora, Dhalla and Saista. In Tetuljhora union, Resource, Environment and Use scores were very low. In Dhalla and Saista union, Resource and Environment scores were very poor. The prediction says that in future, female industrial workers in Dhalla union were going to be the most water-secured group and male small farmers in Saista union were going to be the most water-poor group.

Table 5.29: Overall values of the future WPI for the livelihood groups

Union	Group	R	A	C	U	E	Future WPI
Tetuljhora	Industrial workers (Male)	16.27	66.05	48.92	45.67	30.84	40.55
	Industrial workers (Female)	23.28	83.69	57.83	64.57	16.97	40.06
Dhalla	Industrial workers (Female)	42.74	54.26	52.33	59.88	39.02	**48.65**
	Large farmers (Male)	45.37	72.1	68.81	64.7	11.86	44.85
	Small farmers (Male)	34.9	44.06	28.8	59.3	25.86	36.46
	Women farmers	37.69	59.31	49.87	61.05	28.49	48.33
	Economically inactive women group	35.09	55.33	40.98	62.78	39.67	46.4
Saista	Large farmers (Male)	31.83	45.47	58.46	36.61	28.89	38.74
	Small farmers (Male)	35.38	24.36	30.15	47.87	40.1	**33.78**
	Women farmers	28.57	31.67	48.77	41.4	39.4	38.16
	Economically inactive women group	25.45	49.02	40.89	31.94	19.09	34.33

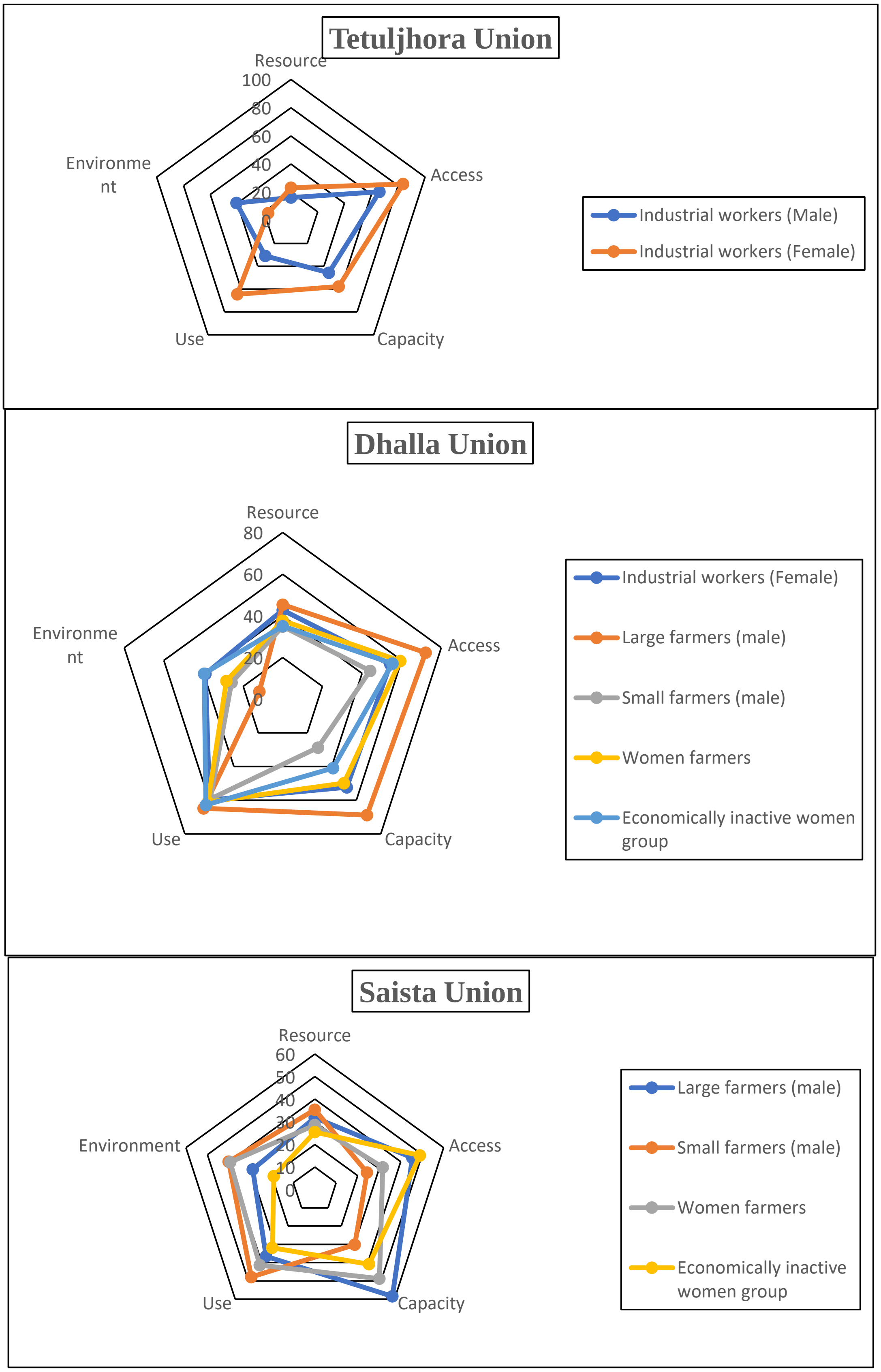

Figure 5.37: Future WPI pentagram for the livelihood groups in Tetuljhora, Dhalla and Saista

5.6.1 Comparison of WPI among Present and Future Scores

Future scores showed a different scenario for a few groups, especially for industrial workers, in Dhalla and small farmers in Saista. Figure 5.38 shows the pentagram representing a comparison between present WPI and future WPI scores for male and female industrial workers in Tetuljhora union. For both male and female, the pentagrams showed a similar pattern for the components. The decrease in future Resource score is extremely large for male industrial workers. The Capacity component will improve for female workers whereas it will degrade for male workers. Because of the increasing role in operating the water source and interest for participation in training in water sanitation, and hygiene issues, the Capacity component will be improved for female workers. Both the groups show lower scores for Use component as the conflicts regarding water use will increase in near future due to excessive water demand. The overall future WPI scores are lower than present WPI scores in both cases.

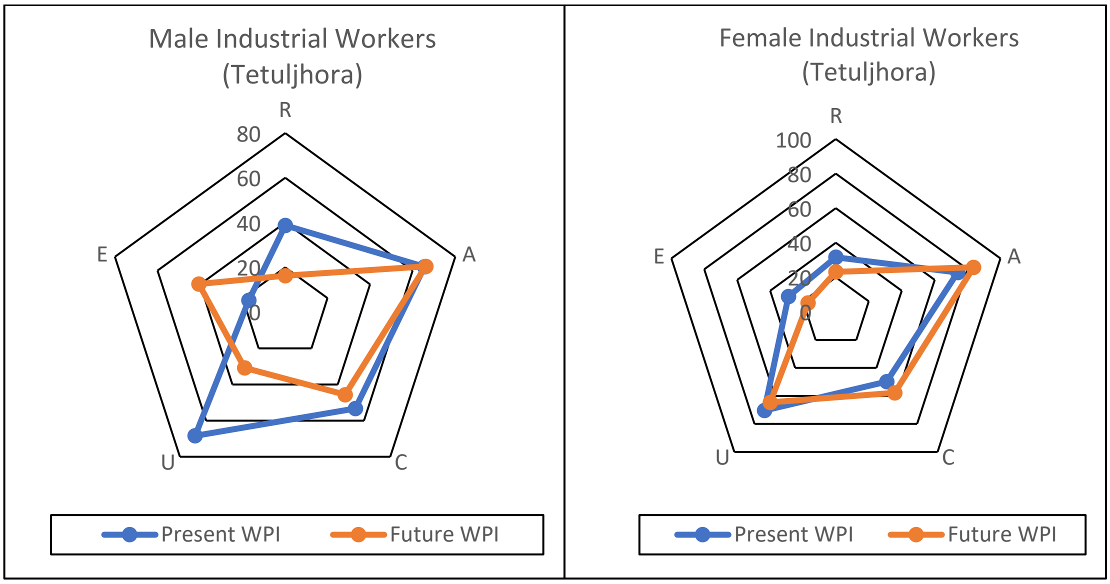

Figure 5.38: Present WPI and future WPI pentagram for industrial workers in Tetuljhora

Female industrial workers in Dhalla union scores the highest among all the groups for future WPI. Figure 5.39 shows the pentagram representing a comparison between present WPI and future WPI scores for female industrial workers in Dhalla union. The overall future WPI score (48.65) is lower than present WPI score (55.85). The Capacity component will be slightly improved for the increasing indicator scores regarding education ratio. The rest of the component scores will be decreased in future.

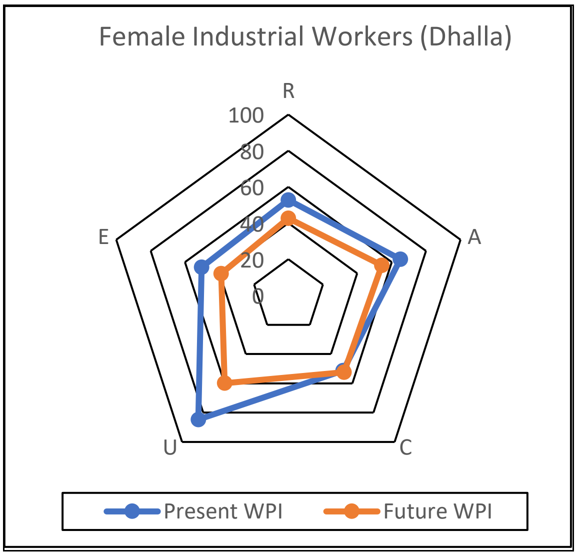

Figure 5.39: Present WPI and future WPI pentagram for female industrial workers in Dhalla

Figure 5.40 shows that for three farmer groups in Dhalla union, Resource, Use and Environment components will decrease due to increase in occurrence of illness from using surface water and excessive reduction in vegetation cover.

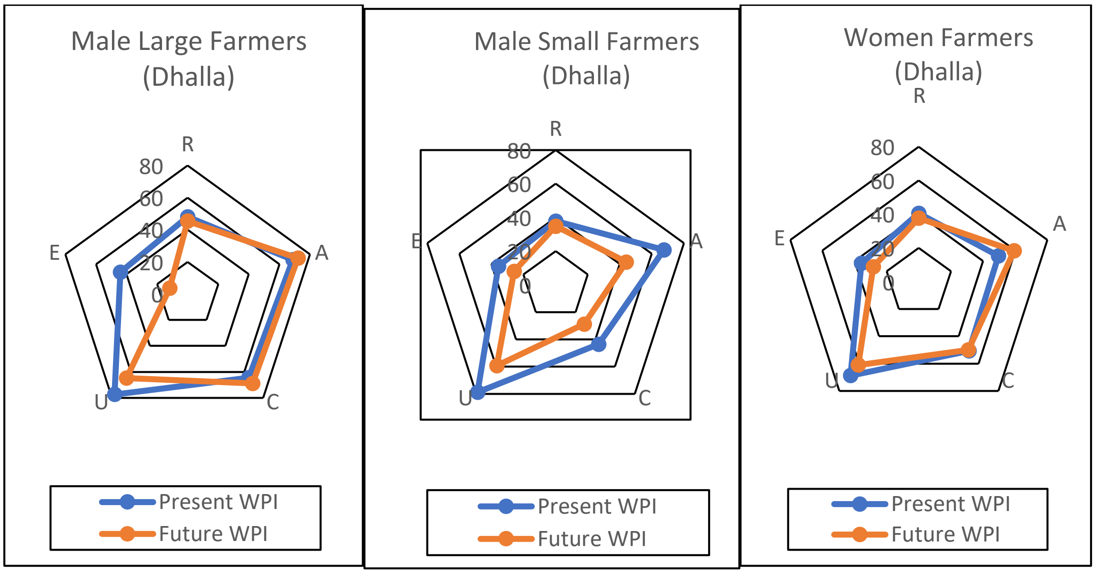

Figure 5.40: Present WPI and future WPI pentagram for farmers in Dhalla

Figure 5.41 shows present WPI and future WPI pentagram for economically inactive women group in Dhalla. It shows a uniform decrease throughout the diagram. All of the component scores will decrease in future because of the decrease in groundwater level in future, the increase in cost income ratio, limited access, lack of sufficient water, reduction in vegetation cover and improper drainage facilities.

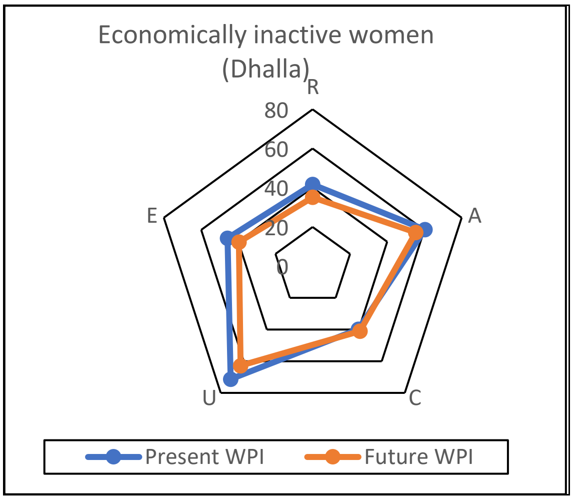

Figure 5.41: Present WPI and future WPI pentagram for economically inactive women group in Dhalla

Figure 5.42 shows that for the three farmer groups in Saista union, Resource, Use and Environment components will decrease in future. For small male farmers, all of the components and their indicators score poorly and that is why this group might be the most water-poor group in future. The Capacity for women farmers will increase slightly due to increased role in operating the water source and NGO activities.

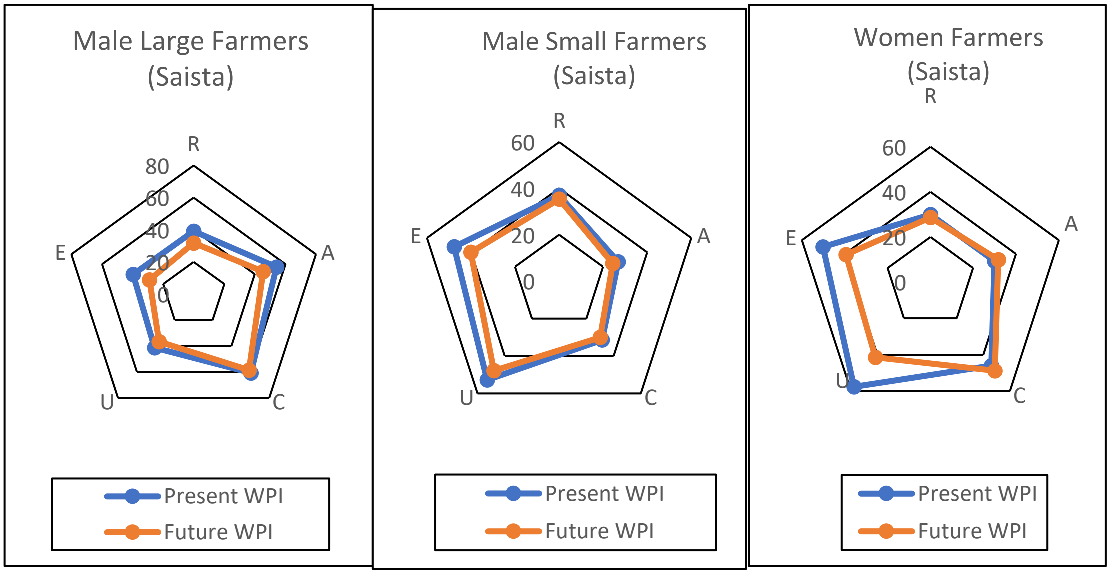

Figure 5.42: Present WPI and future WPI pentagram for farmers in Saista

Figure 5.43 shows present WPI and future WPI pentagram for economically inactive women group in Saista. It shows a uniform decrease in Resource and Environment components because of the decrease in surface and groundwater level in future, increase in arsenic contamination in groundwater and increase in crop loss. But the Capacity of this group will be increased due to increase in duration of residence and increased NGO activities.

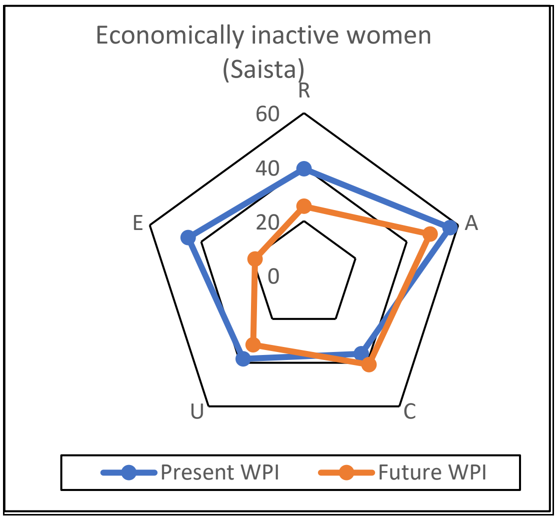

Figure 5.43: Present WPI and future WPI pentagram for economically inactive women group in Saista

5.6.2 Impact of Environmental Change on Future WPI

The fact is, women generally prefer indoor activities due to high temperature than men and thus the productivity of female farmer group will decrease in future, as the women farmers have to work outside their home for a considerable amount of time. Women farmers in Saista union will suffer most as most of them have to collect water from a distant source by walking and they also have to carry lunch in the field. High temperature will worsen the situation in future as the water scarcity will be more prominent in future.

The variability in rainfall will increase and the total amount of rainfall will decrease in future due to climate change and also human activities. In this situation, the farmer groups of Dhalla and Saista unions will suffer the most for the rainfed crops. On the other hand, excessive untimely rainfall will hamper production of rice for which small farmers will suffer most as their income will be affected.

All the three unions are dependent on groundwater. The abstraction rate of groundwater will increase and the recharge rate will decrease due to human developmental activities in future and thus all the marginalized group will suffer heavily. Mostly, the people living in Saista union will be the victim as the scores of present WPI of the livelihood groups of Saista union are very low compared to other unions. Among all the livelihood groups in Saista, small male farmers will suffer the most. Small farmers will suffer because irrigation by shallow tubewells will not be possible and they will not be able to afford deep tubewells as the cost of production will increase also.

The variability in surface water levels will increase in future. In future, if the surface water level increases due to heavy rain, floods might occur. In this case, Tetuljhora union will be damaged more than Dhalla and Saista unions. The odor from surface water is high in Tetuljhora union. And the floodwater will affect both the male and female industrial workers. But, especially the female workers will be highly affected as their rate of occurrence of illness is higher than the male workers.

The future WPI will be highly affected due to the excessive growth of population. Tetuljhora union is already densely populated. The excessive population growth in future will trigger the water demand in the areas and also the access to water will be affected. In Tetuljhora, the female industrial workers will suffer more than the male workers because water will be highly intermittent due to the increasing demand and women workers are responsible for managing and storing water.

All the three unions have an increased rate of urbanization. Tetuljhora union has more industries, schools, colleges and other public facilities. Hence, it is already over-populated. So, people from rural setting will migrate towards this union because of the increased opportunities for employment and better access to modern facilities. This area is expected to be fully urban in upcoming years due to increase in built-up areas. On the other hand, Dhalla union is also a point of attraction for migrants for lower house rent and secured water supply. Saista union is currently considered as a rural area as it is less developed than other two unions and the water supply system is not well-developed. But, the degree of urbanization in last 30 years proves that it is constantly converting into a peri-urban area.

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study identified the present and future water poverty statuses of industrial workers, farmers and economically inactive women group. The applicability and usefulness of the livelihood group inclusive indices were tested throughout the study. The study provided an understanding of how climate and environmental change affected water poverty status. The specific conclusions drawn from this study are summarized below:

- In this study, present WPI and future WPI were calculated for industrial workers (male and female), large farmers (male), small farmers (male), women farmers and economically inactive women group (unemployed women, adolescent girls, physically challenged and elderly women). Among all the groups, currently, the economically inactive women (41.46) in Saista are the most water-poor group. But, in future the small male farmers (33.8) in Saista will be the most water-poor group.

- At present, male group (48.04) is more water-secured than female group (45.84) in Tetuljhora. Female workers have low scores in Resource, and the male workers have low score in Access and Environment. For female workers, the rate of occurrence of illness from using surface and groundwater is the governing indicator for low Resource score. Higher access to improved washroom facilities inside the industry and better access to improved sanitation than that of male workers are the governing indicators for better Access score.

- The capacity of female industrial workers will increase in future because of the increasing role in operating the water source and interest for participation in training in water sanitation and hygiene issues, whereas male workers will suffer for lack of access to water and sanitation inside the industry and lower capacity for water management. Both the groups will suffer for the increasing conflicts regarding water use due to excessive water demand.

- Female industrial workers (55.85) in Dhalla are the most secured group in terms of water poverty. Although they will be slightly water-poor (48.65), this group will be the most water-secured group among all the groups in future. Because their capacity score will increase due to higher score for the indicator 'education ratio'. So, in case of other water-poor groups, this indicator needs to be improved.

- The rate of environmental degradation and pollution from the industries are higher in Tetuljhora. But, better access to reliable water source, piped water connection and medication help industrial workers in Tetuljhora to have better Access scores. In Dhalla, lower cost and less shortage of water inside the industry than Tetuljhora help the workers to afford clean water.

- In Dhalla union, overall present WPI for male large farmers shows slightly high score (56.66) than male small farmers (55.28). Small farmers have greater chances to suffer from water-borne diseases as they do not practice any water treatment before drinking. For all the three farmer groups in Dhalla, Resource, Use and Environment components show decreasing tendency due to increase in occurrence of illness from using surface water. To reduce the occurrence of illness among the water-poor groups, training and awareness programs should be arranged by the government or NGOs.

- In Dhalla, female farmers are poor in all the fields than male farmers, especially in Access and Use. Female farmers have to spend a considerable amount of time for collection of water daily and deal with insufficient water for post harvesting, cooking food and washing dishes.

- For the farmer groups in Saista, Resource, Use and Environment components will decrease in future. Small male farmers will be the most water-poor group in future. At present, small farmers' access (26.82) and capacity (31.45) is very low compared to that of large farmers. Because small farmers have to pay high price for water and high production cost compared to their income, their access to irrigation and affordability is very low. Occurrence of illness from using groundwater and amount of time for collecting water are the reasons for lower Resource and Access scores for female farmers than male farmers in Saista.

- Residents of Dhalla has better access to medication than Saista but Dhalla faces frequent water logging problem. Women farmers in Saista have higher occurrence of illness and collection time for water than women farmers in Dhalla. In Saista, the water availability is not uniform and they suffer due to presence of arsenic or excessive amount of iron. So, they face water scarcity even after having their own tubewells. As a result, the conflict regarding water use is also prominent in Saista. Women farmers are more educated in Dhalla than in Saista.

- For economically inactive women group in Dhalla, there is a uniform decrease in all of the components. In this group, physically challenged and elderly women are the most water-poor (33.26) at present. Unemployed women are the most water-secured because of better access to medication, better education ratio and role in operation. Occurrence of violence when demand is not fulfilled is the reason behind adolescent girls' water poverty.

- Decrease in groundwater level in future, increase in arsenic contamination in groundwater and increase in crop loss in Saista cause a uniform decrease in present values of the adolescent girls group in Saista. In Saista, the physical water resources need more attention.

- Almost all of the adolescent respondents are enrolled either in school or college. But in Saista, the education ratio is very low and there are frequent incidents of physical violence which adolescent girls and unemployed women face if they fail to bring sufficient water from a distant tubewell. The increase in education ratio might improve the situation.

- Female industrial workers need a gender friendly workplace which meets the specific needs during pregnancy such as better washroom facilities, provision of water points at all sides. For a woman farmer it is hard to perform multiple roles and balance their work and family life and the women farmers need to be recognized as working women. On the other hand, for the male farmers, water pricing should be fixed in all the unions so that they do not feel discriminated.

- To assess the impact of climate and environmental change on future water poverty for different groups, trend analysis of two climatic parameters-temperature and rainfall, and four environmental factors- population growth, changes in groundwater level, changes in surface water level and changes in land use are analyzed. The study reveals that only 31.67% of men and 23.57% of women have basic knowledge of climate change phenomenon and they are not aware of the negative impacts of urbanization. They consider peri-urbanization as a positive phenomenon as it creates employment opportunity.

- The annual average temperature, annual maximum and annual minimum temperatures have increasing trend considering a period of 64 years (1953-2017) and 28 years (1989-2017). The increasing trends are 3ºC, 1.24ºC and 4.87ºC per century, respectively, in case of 64 years data and 4.89ºC, 2.97ºC and 6.81ºC per century, respectively, in case of 28 years data. The temperature is rising rapidly in recent years. Due to high temperature, the productivity of female farmer group will decrease in future. Women farmers in Saista will suffer most as most of them have to collect water from a distant source.

- An analysis on decadal (10 years) variations of total rainfall of summer (March to May) show that in the last two decades (1991-2010), the amount of rainfall has decreased drastically. The recent rate of decrease (0.5512 mm/year) in maximum pre-monsoon rainfall is much higher than the long-term rate of decrease (0.1692mm/year). The annual pre-monsoon rainfall for long term data shows erratic behavior as CV is more than 30%. The maximum pre-monsoon rainfall in summer season indicates that there is a constant threat of prolonged drought in dry season. The variability in rainfall will increase and the total amount of rainfall will decrease in future due to climate change and also human activities. The farmer groups of Dhalla and Saista unions will suffer the most in this case.

- The rates of reduction in groundwater level are 2.82cm and 7.93cm per year at Singair village and Parilnoadda, respectively. The fluctuation of water levels shows high variability also. Mostly, the people living in Saista will be the victim of groundwater depletion. Small farmers in Saista will suffer because irrigation by shallow tubewells will not be possible and they will not be able to afford deep tubewells as the cost of production will increase also.

- The water level of Dhaleshwari River is going down and the rates are 0.74, 0.69 and 0.33cm per year for annual minimum high tide, annual minimum low tide and average daily water level (March), respectively. Though the decreasing rate is not alarming but the variability in water level is highly prominent. In future, if the surface water level increases due to heavy rain, floods might occur. In this case, Tetuljhora union will be damaged more than Dhalla and Saista unions. And the floodwater will affect especially the female workers as their rate of occurrence of illness is higher than the male workers. The encroachment on the river needs government's attention.

- The rates of inward migration in Tetuljhora and Dhalla are increasing alarmingly. The growth rate in Tetuljhora is 8.83%. Future population density is also the highest for Tetuljhora (35520/sqkm) followed by Dhalla (2367/sqkm) and Saista (1925/sqkm). In Tetuljhora, the female industrial workers will suffer more due to highly intermittent water supply.

- Agriculture and vegetation has decreased from 49.28% in 1989 to 28.17% in 2019 in Tetuljhora, from 50.62% in 1989 to 30.11% in 2019 in Dhalla and from 36.85% in 1989 to 29.38% in 2019 in Saista. Percentage of settlement and urban development area has increased from 33.85% in 1989 to 45.01% in 2019 in Tetuljhora, from 23.38% in 1989 to 44.24% in 2019 in Dhalla and from 0.57% in 1989 to 33.56% in 2019 in Saista. The amount of water body has decreased from 4.2% in 1989 to 3.9% in 2019 in Tetuljhora, from 13.67% in 1989 to 8.19% in 2019 in Dhalla and from 34.73% in 1989 to 11.28% in 2019. So, the rate of urbanization is prominent in all the unions. The existing water bodies need to be carefully managed in these areas.

6.2 Recommendations for Further Study

Based on the present study, the following recommendations are made:

- Further study should be conducted on different time scales to determine temporal variation in water poverty.

- The result from the analysis would be more accurate if the sample size would have been larger.

- Research can be conducted to determine the ways in which the WPI components can be improved. Future research should focus on refining the available methods and on developing guidelines for which method is most suited to which scenario.

- Component or sub-component selection should be field oriented or participatory. Future study could be undertaken using weights from expert opinion or FGD other than using PCA.

- Careful consideration should be given to indicator selection. Throughout the calculation process there are various options for construction of the index that can influence the accuracy of the chosen method.

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APPENDIX-A: SURVEY QUESTIONNAIRES

Questionnaire A1: Present WPI

General Information:

Name of the respondent				
Age				
Duration of residence (year)				
Total HH member				
No. of HH member completing primary level education				
Land ownership (acre)	Own land		Borrowed land	
Tubewell	Owned	Jointly owned	Not owned but used	
Sanitation facility	Pucca	Semi-pucca	Kutcha	Field or open space

1.Which sources of water do you use for different purposes?

Purpose	Source			
	River	Pond	TW	Piped water
Drinking				
Cooking				
Bathing				
Washing/Cleaning				
Irrigation				

2. Surface water:

a. How water availability from surface water is changing over the years?	Decrease	Same		Increase
b. If decreased, how severe is the decrease?	High	Medium		Low
c. Has the quality of SW changed over the years?	Decrease	Same		Increase
d. If it has decreased, why?				
e. Do you face odor problem?	No odor	Seasonal		Throughout the years
		mild	extreme	
f. If SW is used for drinking/cooking, has any illness occurred?	Yes		No	
g. If yes, what kind of illness do you suffer from usually?	Minor illness (skin irritation)	Moderate illness (skin disease, allergy, Malaria)	Major or extreme illness (Cholera, Typhoid, Dysentery)	

3. River water:

a. Is the river water polluted?	Yes		No
b. Are the fish species consumable?	Yes		No
c. Have the number of fish species in the river reduced over the years?	Yes		No
d. If yes, how many species are reduced?	10-20	20-30	>30

4. Groundwater:

a. How water availability from groundwater is changing over the years?	Decrease	Same		Increase
b. If decreased, how severe is the decrease?	High	Medium		Low
c. Has the quality of GW changed over the years?	Decrease	Same		Increase
d. If it has decreased, why?				
e. Which problem is severe at present?	Iron (Fe)	Arsenic (As)		Both Fe & As
f. Do you face odor problem?	No odor	Seasonal		Throughout the years
		mild	extreme	
g. If GW is used for drinking/cooking, has any illness occurred?	Yes		No	
h. If yes, what kind of illness do you suffer from usually?	Minor illness	Moderate illness	Major or extreme illness	

5. Rainfall:

a. Do you see any variability in rainfall pattern in recent years compared to the past?	Yes		No	
b. If yes, rank the variability.	Less	Moderate	High	Very high

6. Capacity:

Do you	a. have any political/NGO linkage?	Yes	No
	b. get any financial help from your relatives/ NGO during disaster?	Yes	No
	c. have any role in operating the source from which you use water?	Yes	No
	d. pay the repair cost if the TW or other sources are damaged?	Yes	No
	e. have training in water sanitation and hygiene issues?	Yes	No
	f. have access to institutional loan/credit?	Yes	No

7a. What percentage of your income you spend on water bill?

3	4	5	>5

7b. Do you think the water bill is much higher compared to your income?

Yes	No

8. If any water related disease occurs, how much time would it take to reach nearest hospital (doctors and medicine points)?

<30 minutes	30 minutes	60 minutes	>60 minutes

9. Do you have proper drainage facilities in your locality?

Yes	No

10. Loss and damage:

a. Have you faced any loss and damage due to flood or drought during last 10 years?	Yes		No
b. If yes, rate the severity of the loss and damage.	Light	Moderate	Severe
c. Have you faced any crop loss during last 10 years (due to insect attack, changes in the pattern and intensity of rainfall, groundwater depletion etc.)?	Yes		No
d. If yes, rate the severity of the loss.	Mild	Moderate	Severe

11. Environment:

a. Do you have any knowledge on climate change?	Yes		No	
b. Has the vegetation cover/greenery changed in your area over the past 15 years?	Decrease	Same		Increase
c. If decreased, how severe is the decrease?	Critical	High	Medium	Low
d. Are the proportions of land cover balanced or not?	Yes		No	
e. If no, then which part has larger proportion and which part needs to be increased?				

12. Access (male industrial workers):

a. How far the drinking water point is from your seat?	Within 10 meters	Within 20 meters	Within 30 meters	>30 meters
b. What is the condition of piped water supply?	Continuous	Intermittent but reliable timing of supply	Intermittent and irregular timing	Intermittent and insufficient supply

12. Access (female industrial workers in Tetuljhora):

a. How far the drinking water point is from your seat?	Within 10 meters	Within 20 meters	Within 30 meters	>30 meters
b. What is the condition of piped water supply?	Continuous	Intermittent but reliable timing of supply	Intermittent and irregular timing	Intermittent and insufficient supply
c. Do you have separate washroom	Yes		No	

facilities for female workers inside the industry?				
d. Are they adequate for all the work well maintained?	Well maintained and adequate	Well maintained but not adequate	Not well maintained but adequate	Not well maintained and not adequate

12. Access (female industrial workers in Dhalla):

a. How far the drinking water point is from your seat?	Within 10 meters	Within 20 meters	Within 30 meters		>30 meters
b. Who collects water from the source?	Yourself	Husband	Son	Daughter	Others
c. When you are physically sick, do you still have to collect water?	Yes		No		
d. How much time does it take to collect water daily (including travel and waiting time)?	<30minutes	30-60 minutes	60-90 minutes		>120 minutes
e. Do you face any security issue during collection of water?	Yes……………………..		No		
f. Do you have separate washroom facilities for female workers inside the industry?	Yes		No		
g. Are they adequate for all the work well-maintained?	Well-maintained and adequate	Well-maintained but not adequate	Not well-maintained but adequate		Not well-maintained and not adequate

12. Access (male farmers):

a. What crops do you cultivate in your land?				
b. Are the agriculture water-managed area well-equipped for irrigation?	Well-equipped	Remote but accessible source	Remote and inaccessible source	Not well-equipped

12. Access (female farmers and economically inactive women group):

a. Who collects water from the source?	Yourself	Husband	Son	Daughter	Others
b. When you are physically sick, do you still have to collect water?	Yes		No		
c. How much time does it take to collect water daily (including travel	<30minutes	30-60 minutes	60-90 minutes		>120 minutes

and waiting time)?				
d. Do you face any security issue during collection of water?	Yes………………………		No	

13. Use (male industrial workers):

a. Do you have to carry water from your home when you go to work?	Yes	No
b. Does the water that you get inside the industry meet your daily requirement during dry season?	Yes	No and high shortage
		No and medium shortage
		No and low shortage
c. Does the water that you get for domestic use meet your daily requirement during dry season?	Yes	No and high shortage
		No and medium shortage
		No and low shortage

13. Use (female industrial workers):

a. Do you have to carry water from your home when you go to work?	Yes		No	
b. Does the water that you get for domestic use meet your daily requirement during dry season?	Yes	No and high shortage		
		No and medium shortage		
		No and low shortage		
c. Do you face any occurrence of violence when demand for water is not fulfilled or you can't bring water timely?	Never	Blamed only	Pressurized to bring water immediately	Occurrence of physical violence

13. Use (female farmers):

a. Does the water that you get daily for farm activities (including cooking for labors and for post harvesting) meet your daily requirement during dry season?	Yes	No and high shortage		
		No and medium shortage		
		No and low shortage		
b. Does the water that you get for domestic use meet your daily requirement during dry season?	Yes	No and high shortage		
		No and medium shortage		
		No and low shortage		
c. Do you face any occurrence of violence when demand for water is not fulfilled or you can't bring water timely?	Never	Blamed only	Pressurized to bring water immediately	Occurrence of physical violence

13. Use (economically inactive women group):

a. Does the water that you get for domestic use meet your daily requirement during dry season?	Yes	No and high shortage		
		No and medium shortage		
		No and low shortage		
b. Do you face any occurrence of violence when demand for water is not fulfilled or you	Never	Blamed only	Pressurized to bring water	Occurrence of physical

can't bring water timely?			immediately	violence

14. Conflict:

a. Is there any conflict regarding water use?	Yes		No
b. If yes, then what is the degree of the conflict?	High	Moderate	Low

Questionnaire A2: Future WPI

1.Which sources of water will you prefer for different purposes?

Purpose	Source			
	River	Pond	TW	Piped water
Drinking				
Cooking				
Bathing				
Washing/Cleaning				
Irrigation				

2. Surface water:

a. How water availability from surface water will be changing over the next 15 years?	Decrease	Same		Increase
b. If it will decrease, how severe it will be?	High	Medium		Low
c. Will the quality of SW change over the next 15 years?	Decrease	Same		Increase
d. If it will decrease, why?				
e. How will be the situation of odor problem?	No odor	Seasonal		Throughout the years
		mild	extreme	
f. What kind of illness you might suffer from for using SW for drinking/cooking?	Minor illness (skin irritation)	Moderate illness (skin disease, allergy, Malaria)	Major or extreme illness (Cholera, Typhoid, Dysentery)	

3. River water:

a. Will the river water be polluted after 15 years?	Yes	No
b. Will the fish species be consumable after 15 years?	Yes	No
c. Will the number of fish species in the river reduce over the years?	Yes	No

d. If yes, how many species can be reduced?	10-20	20-30	>30

4. Groundwater:

a. How water availability from groundwater will be changing over the years?	Decrease	Same		Increase
b. If it will decrease, how severe it might be?	High	Medium		Low
c. Will the quality of GW change over the years?	Decrease	Same		Increase
d. If it will decrease, why?				
e. Which problem will be severe in future?	Iron (Fe)	Arsenic (As)		Both Fe & As
f. How will be the situation of odor problem?	No odor	Seasonal		Throughout the years
		mild	extreme	
g. What kind of illness you might suffer from for using GW for drinking/cooking?	Minor illness	Moderate illness	Major or extreme illness	

5. Rainfall:

a. Do you think there will be any variability in rainfall pattern in future compared to present?	Yes		No	
b. If yes, rank the variability.	Less	Moderate	High	Very high

6. Capacity:

Will you	a. have any political/NGO linkage?	Yes	No
	b. get any financial help from your relatives/ NGO during disaster?	Yes	No
	c. have any role in operating the source from which you use water?	Yes	No
	d. pay the repair cost if the TW or other sources are damaged?	Yes	No
	e. have training in water sanitation and hygiene issues?	Yes	No
	f. have access to institutional loan/credit?	Yes	No

7a. What percentage of your income you might spend on water bill?

3	4	5	>5

7b. Do you think the water bill will be much higher compared to your income?

Yes	No

8. If any water related disease will occur, how much time would it take to reach nearest hospital (doctors and medicine points)?

<30 minutes	30 minutes	60 minutes	>60 minutes

9. Will you have proper drainage facilities in your locality after 15 years?

Yes	No

10. Loss and damage:

a. Will you face any loss and damage due to flood or drought during last 10 years?	Yes		No
b. If yes, rate the severity of the loss and damage.	Light	Moderate	Severe
c. Will you face any crop loss during last 10 years (due to insect attack, changes in the pattern and intensity of rainfall, groundwater depletion etc.)?	Yes		No
d. If yes, rate the severity of the loss.	Mild	Moderate	Severe

11. Environment:

a. Will the vegetation cover/greenery change in your area over the past 15 years	Decrease	Same		Increase
b. If it will decrease, how severe is the decrease?	Critical	High	Medium	Low
c. Will the proportions of land cover be balanced or not?	Yes		No	
d. If no, then which part might have larger proportion and which part will need to be increased?				

12. Access (male industrial workers):

a. How far the drinking water point is from your seat?	Within 10 meters	Within 20 meters	Within 30 meters	>30 meters
b. What will be the condition of piped water supply?	Continuous	Intermittent but reliable timing of supply	Intermittent and irregular timing	Intermittent and insufficient supply

12. Access (female industrial workers in Tetuljhora):

a. What is the condition of piped water supply?	Continuous	Intermittent but reliable timing of supply	Intermittent and irregular timing	Intermittent and insufficient supply
b. Will the washrooms be adequate for all the workers and well maintained inside the industry?	Well maintained and adequate	Well maintained but not adequate	Not well maintained but adequate	Not well maintained and not adequate

12. Access (female industrial workers in Dhalla):

a. How much time will it take to collect water daily (including travel and waiting time) after 15 years?	<30minutes	30-60 minutes	60-90 minutes	>120 minutes
b. Will you face any security issue during collection of water?	Yes………………………		No	
c. Will the washrooms be adequate	Well	Well	Not well	Not well

for all the workers and well maintained inside the industry?	maintained and adequate	maintained but not adequate	maintained but adequate	maintained and not adequate

12. Access (male farmers):

a. What crops you might cultivate in your land considering the climate change-induced crop loss?				
b. Will the agriculture water-managed area be well-equipped for irrigation?	Well-equipped	Remote but accessible source	Remote and inaccessible source	Not well-equipped

12. Access (female farmers and economically inactive women group):

a. How much time will it take to collect water daily (including travel and waiting time) after 15 years?	<30minutes	30-60 minutes	60-90 minutes	>120 minutes
b. Will you face any security issue during collection of water?	Yes………………………		No	

13. Use (male industrial workers):

a. Will the water that you will get inside the industry meet your daily requirement during dry season?	Yes	No and high shortage
		No and medium shortage
		No and low shortage
b. Will the water that you will get for domestic use meet your daily requirement during dry season?	Yes	No and high shortage
		No and medium shortage
		No and low shortage

13. Use (female industrial workers):

a. Will the water that you will get for domestic use meet your daily requirement during dry season?	Yes	No and high shortage		
		No and medium shortage		
		No and low shortage		
b. Do you think the occurrence of violence when demand for water is not fulfilled or you can't bring water timely will increase in future?	Never	Blamed only	Pressurized to bring water immediately	Occurrence of physical violence

13. Use (female farmers):

a. Will the water that you will get daily for farm activities (including cooking for labors and for post harvesting) meet your daily requirement during dry season?	Yes	No and high shortage
		No and medium shortage
		No and low shortage
b. Will the water that you will get for domestic use meet your daily requirement during dry season?	Yes	No and high shortage
		No and medium shortage
		No and low shortage

c. Do you think the occurrence of violence when demand for water is not fulfilled or you can't bring water timely will increase in future?	Never	Blamed only	Pressurized to bring water immediately	Occurrence of physical violence

13. Use (economically inactive women group):

a. Will the water that you will get for domestic use meet your daily requirement during dry season?	Yes	No and high shortage		
		No and medium shortage		
		No and low shortage		
b. Do you think the occurrence of violence when demand for water is not fulfilled or you can't bring water timely will increase in future?	Never	Blamed only	Pressurized to bring water immediately	Occurrence of physical violence

14. Conflict:

a. Will there be any conflict regarding water use?	Yes		No
b. If yes, then what will be the degree of the conflict?	High	Moderate	Low

APPENDIX-B: INDICATORS AND SCORES

Table B1: Indicator and scores for male industrial workers

Components	Indicators	Scores Assigned (0 – 100)			
		Fair (100)	**Acceptable (67)**	**Poor (33)**	**Risky (0)**
Resource (R)	R1: Perceived changes in SWL	No change	Low Decrease	Medium Decrease	High Decrease
	R2: Perceived changes in GWL	No change	Low decrease	Medium decrease	High decrease
	R3: Rainfall variability	Less	Moderate	High	Very high
	R4: Occurrence of illness from using SW	No Illness	Minor illness (skin irritation)	Moderate illness (skin disease, allergy, Malaria)	Major or extreme illness (Cholera, Typhoid, Dysentery)
	R5: Odor in SW	No odor	Seasonal odor but mild	Seasonal extreme odor	Throughout the years
	R6: Occurrence of illness from using GW	No Illness	Minor illness	Moderate illness	Major or extreme illness
	R7: GW quality	None	Iron (Fe)	Arsenic (As)	Both As & Fe
	R8: Odor in GW	No odor	Mild odor due to Iron	Seasonal extreme odor	Throughout the years
Access (A)	A1: Access to safe drinking water inside the industry	Water point is within 10m distance	Water point is within 20m distance	Water point is within 30m distance	Water point is within >30m distance
	A2: Access to safe water supply for daily use	Yes =100		No =0	
	For pipe water connection	Continuous supply	Intermittent but reliable timing of supply	Intermittent and irregular timing of supply	Intermittent and insufficient supply
	A3: Access to improved sanitation	Pucca latrine	Semi pucca latrine	Kutcha latrine	Field/open space
	A4: Access to medication	Emergency doctor and medicines available nearby	Emergency doctor and medicines available at 30 min distance	Emergency doctor and medicines available at 1hour distance	Emergency doctor and medicines available at more than 1hour distance
Capacity (C)	C1: Affordability (Cost/income ratio)	≤ 3%	3 < C/I ≤ 4%	4 < C/I ≤ 5%	>5%
	C2: Financial help from their relatives/ NGO during disaster	Yes=100		No=0	
	C3: Access to institutional loan	Yes=100		No=0	
	C4: Duration of residence	>30 years	20-30 years	10-20 years	<10 years
	C5: Political/NGO linkage	Yes=100		No=0	

Table B1: (continued)

Components	Indicators	Scores Assigned (0 – 100)			
		Fair (100)	**Acceptable (67)**	**Poor (33)**	**Risky (0)**
Capacity (C)	C6: Training in water sanitation, and hygiene issues	Yes=100		No=0	
	C7: Educated ratio	Ratio equals to 100	0.33 to 0.67	0 to 0.33	None
	C8: Role in operation	Always	Frequently	Only when asked to do	Never
	C9: Role in maintenance	Always	Frequently	Only when asked to do	Never
Use (U)	U1: Daily water requirement inside the industry	No shortage	Low shortage	Medium shortage	High shortage
	U2: Daily water requirement for domestic use	No shortage	Low shortage	Medium shortage	High shortage
	U3: Reported conflicts regarding water use	No conflict	Low degree of conflict	Moderate degree of conflict	High degree of conflict
Environment (E)	E1: Consumable fish species in SW sources	Yes= 100		No= 0	
	E2: Reduction in fish species in last 15 years	No reduction	Few no. of species reduced (10-20)	Extinction of several species (20-30)	Extinction of several species (>30)
	E3: Damage and loss due to flood/drought in last 15 years	No loss and damage	No loss and light damage	Moderate loss and damage	Severe loss and damage
	E4: Crop loss in last 15 years	No loss	Mild loss	Moderate loss	Severe loss
	E5: Drainage facilities	Proper drainage and no water logging	Slight water logging during monsoon only	Moderate water logging after rainfall	Improper and severe water logging
	E6: Reduction in vegetation cover in last 15 years	Low Decrease	Medium Decrease	High Decrease	Critical Decrease

Table B2: Indicator and scores for female industrial workers

Components	Indicators	Scores Assigned (0 – 100)			
		Fair (100)	**Acceptable (67)**	**Poor (33)**	**Risky (0)**
Resource (R)	R1: Perceived changes in SWL	No change	Low Decrease	Medium Decrease	High Decrease
	R2: Perceived changes in GWL	No change	Low Decrease	Medium Decrease	High Decrease
	R3: Rainfall variability	Less	Moderate	High	Very high
	R4: Occurrence of illness from using SW	No Illness	Minor illness (skin irritation)	Moderate illness (skin disease, allergy, Malaria)	Major or extreme illness (Cholera, Typhoid, Dysentery)
	R5: Odor in SW	No odor	Seasonal odor but mild	Seasonal extreme odor	Throughout the years
	R6: Occurrence of illness from using GW	No Illness	Minor illness	Moderate illness	Major or extreme illness
	R7: GW quality	None	Iron (Fe)	Arsenic (As)	Both As & Fe
	R8: Odor in GW	No odor	Mild odor due to Iron	Seasonal extreme odor	Throughout the years
Access (A)	A1: Access to safe drinking water inside the industry	Water point is within 10m distance	Water point is within 20m distance	Water point is within 30m distance	Water point is within >30m distance
	A2: Daily water collection time including travel and waiting time	<30m	30-60 m	60-90 m	>120 m
	Tetuljhora: For pipe water connection	Continuous supply	Intermittent but reliable timing of supply	Intermittent and irregular timing of supply	Intermittent and insufficient supply
	*A3: Collection of water even she is sick	Never	Sometimes	Frequently	Always
	*A4: Security issue during collection of water	No risk	Does not feel comfortable but safe	Does not feel comfortable and not safe	Lack of security (Risk of serious harm)
	A5: Access to improved washroom facilities inside the industry (separate for female)	Well maintained and adequate	Well maintained but not adequate	Not well maintained but adequate	Not well maintained & not adequate for all workers
	A6: Access to improved sanitation	Pucca latrine	Semi pucca latrine	Kutcha latrine	Field/open space
	A7: Access to medication	Emergency doctor and medicines available nearby	Emergency doctor and medicines available at 30 min distance	Emergency doctor and medicines available at 1hour distance	Emergency doctor and medicines available at more than 1hour distance

Table B2: (continued)

Components	Indicators	Scores Assigned (0 – 100)			
		Fair (100)	**Acceptable (67)**	**Poor (33)**	**Risky (0)**
Capacity (C)	C1: Affordability (Cost/income ratio)	≤ 3%	3 < C/I ≤ 4%	4 < C/I ≤ 5%	>5%
	C2: Financial help from their relatives/ NGO during disaster	Yes=100		No=0	
	C3: Access to institutional loan/credit	Yes=100		No=0	
	C4: Duration of residence	>30 years	20-30 years	10-20 years	<10 years
	C5: Political/NGO linkage	Yes=100		No=0	
	C6: Training in water sanitation, and hygiene issues	Yes=100		No=0	
	C7: Educated ratio	Ratio equals to 100	0.33 to 0.67	0 to 0.33	None
	C8: Role in operation	Always	Frequently	Only when asked to do	Never
	C9: Role in maintenance	Always	Frequently	Only when asked to do	Never
Use (U)	U1: Daily water requirement outside the industry	No shortage	Low shortage	Medium shortage	High shortage
	U2: Occurrence of violence when demand is not fulfilled or can't bring water timely	Never	Blamed only	Pressurized to bring water immediately	Occurrence of physical violence
	U3: Reporting conflicts regarding water use	No conflict	Low degree of conflict	Moderate degree of conflict	High degree of conflict
Environment (E)	E1: Consumable fish species in SW sources	Yes= 100		No= 0	
	E2: Reduction in fish species in last 15 years	No reduction	Few no. of species reduced (10-20)	Extinction of several species (20-30)	Extinction of several species (>30)
	E3: Damage and loss due to flood/drought in last 15 years	No loss and damage	No loss and light damage	Moderate loss and damage	Severe loss and damage
	E4: Crop loss in last 15 years	No loss	Mild loss	Moderate loss	Severe loss
	E5: Drainage facilities	Proper drainage and no water logging	Slight water logging during monsoon only	Moderate water logging after rainfall	Improper and severe water logging
	E6: Reduction in vegetation cover in last 15 years	Low Decrease	Medium Decrease	High Decrease	Critical Decrease

*Not for Tetuljhora

Table B3: Indicator and scores for male farmers

Components	Indicators	Scores Assigned (0 – 100)			
		Fair (100)	**Acceptable (67)**	**Poor (33)**	**Risky (0)**
Resource (R)	R1: Perceived changes in SWL	No change	Low Decrease	Medium Decrease	High Decrease
	R2: Perceived changes in GWL	No change	Low decrease	Medium decrease	High decrease
	R3: Rainfall variability	Less	Moderate	High	Very high
	R4: Occurrence of illness from using SW	No Illness	Minor illness (skin irritation)	Moderate illness (skin disease, allergy, Malaria)	Major or extreme illness (Cholera, Typhoid, Dysentery)
	R5: Odor in SW	No odor	Seasonal odor but mild	Seasonal extreme odor	Throughout the years
	R6: Occurrence of illness from using GW	No Illness	Minor illness	Moderate illness	Major or extreme illness
	R7: GW quality	None	Iron (Fe)	Arsenic (As)	Both As & Fe
	R8: Odor in GW	No odor	Mild odor due to Iron	Seasonal extreme odor	Throughout the years
Access (A)	A1: Access to irrigation	Well-equipped	Remote but accessible source	Remote and inaccessible source	Not well-equipped
	A2: Access to improved sanitation	Pucca latrine	Semi pucca latrine	Kutcha latrine	Field/open space
	A3: Access to medication	Emergency doctor and medicines available nearby	Emergency doctor and medicines available at 30 min distance	Emergency doctor and medicines available at 1hour distance	Emergency doctor and medicines available at more than 1hour distance
Capacity (C)	C1: Affordability (Cost/income ratio)	$\leq 3\%$	$3 < C/I \leq 4\%$	$4 < C/I \leq 5\%$	>5%
	C2: Financial help from their relatives/ NGO during disaster	Yes=100		No=0	
	C3: Access to institutional loan	Yes=100		No=0	
	C4: Duration of residence	>30 years	20-30 years	10-20 years	<10 years
	C5: Political/NGO linkage	Yes=100		No=0	
	C6: Training in water sanitation, and hygiene issues	Yes=100		No=0	
	C7: Educated ratio	Ratio equals to 100	0.33 to 0.67	0 to 0.33	None
	C8: Role in operation	Always	Frequently	Only when asked to do	Never
	C9: Role in maintenance	Always	Frequently	Only when asked to do	Never

Table B3: (continued)

Components	Indicators	Scores Assigned (0 – 100)			
		Fair (100)	**Acceptable (67)**	**Poor (33)**	**Risky (0)**
Use (U)	U1: Irrigation water requirement	No shortage	Low shortage	Medium shortage	High shortage
	U2: Daily water requirement	No shortage	Low shortage	Medium shortage	High shortage
	U3: HH reporting conflicts regarding water use	No conflict	Low degree of conflict	Moderate degree of conflict	High degree of conflict
Environment (E)	E1: Consumable fish species in SW sources	Yes= 100		No= 0	
	E2: Reduction in fish species in last 15 years	No reduction	Few no. of species reduced (10-20)	Extinction of several species (20-30)	Extinction of several species (>30)
	E3: Damage and loss due to flood/drought in last 15 years	No loss and damage	No loss and light damage	Moderate loss and damage	Severe loss and damage
	E4: Crop loss in last 15 years	No loss	Mild loss	Moderate loss	Severe loss
	E5: Drainage facilities	Proper drainage and no water logging	Slight water logging during monsoon only	Moderate water logging after rainfall	Improper and severe water logging
	E6: Reduction in vegetation cover in last 15 years	Low Decrease	Medium Decrease	High Decrease	Critical Decrease

Table B4: Indicator and scores for female farmers

Components	Indicators	Scores Assigned (0 – 100)			
		Fair (100)	**Acceptable (67)**	**Poor (33)**	**Risky (0)**
Resource (R)	R1: Perceived changes in SWL	No change	Low Decrease	Medium Decrease	High Decrease
	R2: Perceived changes in GWL	No change	Low decrease	Medium decrease	High decrease
	R3: Rainfall variability	Less	Moderate	High	Very high
	R4: Occurrence of illness from using SW	No Illness	Minor illness (skin irritation)	Moderate illness (skin disease, allergy, Malaria)	Major or extreme illness (Cholera, Typhoid, Dysentery)
	R5: Odor in SW	No odor	Seasonal odor but mild	Seasonal extreme odor	Throughout the years
	R6: Occurrence of illness from using GW	No Illness	Minor illness	Moderate illness	Major or extreme illness
	R7: GW quality	None	Iron (Fe)	Arsenic (As)	Both As & Fe
	R8: Odor in GW	No odor	Mild odor due to Iron	Seasonal extreme odor	Throughout the years
Access (A)	A1: Daily water collection time including travel and waiting time	<30m	30-60 m	60-90 m	>120 m
	For pipe water connection	Continuous supply	Intermittent but reliable timing of supply	Intermittent and irregular timing of supply	Intermittent and insufficient supply
	A2: Collection of water even she is sick	Never	Sometimes	Frequently	Always
	A3: Security issue during collection of water	No risk	Does not feel comfortable but safe	Does not feel comfortable and not safe	Lack of security (Risk of serious harm)
	A4: Access to improved sanitation	Pucca latrine	Semi pucca latrine	Kutcha latrine	Field/open space
	A5: Access to medication	Emergency doctor and medicines available nearby	Emergency doctor and medicines available at 30 min distance	Emergency doctor and medicines available at 1hour distance	Emergency doctor and medicines available at more than 1hour distance
Capacity (C)	C1: Financial help from their relatives/ NGO during disaster	Yes=100		No=0	
	C2: Access to institutional loan/credit	Yes=100		No=0	
	C3: Duration of residence	>30 years	20-30 years	10-20 years	<10 years

Table B4: (continued)

Components	Indicators	Scores Assigned (0 – 100)			
		Fair (100)	**Acceptable (67)**	**Poor (33)**	**Risky (0)**
Capacity (C)	C4: Political/NGO linkage	Yes=100		No=0	
	C5: Training in water sanitation, and hygiene issues	Yes=100		No=0	
	C6: Educated ratio	Ratio equals to 100	0.33 to 0.67	0 to 0.33	None
	C7: Role in operation	Always	Frequently	Only when asked to do	Never
	C8: Role in maintenance	Always	Frequently	Only when asked to do	Never
Use (U)	U1: Daily water requirement in farm activities including cooking for labors and for post harvesting	No shortage	Low shortage	Medium shortage	High shortage
	U2: Daily water requirement for domestic use	No shortage	Low shortage	Medium shortage	High shortage
	U3: Occurrence of violence when demand is not fulfilled or can't bring water timely	Never	Blamed only	Pressurized to bring water immediately	Occurrence of physical violence
	U4: Reported conflicts regarding water use	No conflict	Low degree of conflict	Moderate degree of conflict	High degree of conflict
Environment (E)	E1: Consumable fish species in SW sources	Yes= 100		No= 0	
	E2: Reduction in fish species in last 15 years	No reduction	Few no. of species reduced (10-20)	Extinction of several species (20-30)	Extinction of several species (>30)
	E3: Damage and loss due to flood/drought in last 15 years	No loss and damage	No loss and light damage	Moderate loss and damage	Severe loss and damage
	E4: Crop loss in last 15 years	No loss	Mild loss	Moderate loss	Severe loss
	E5: Drainage facilities	Proper drainage and no water logging	Slight water logging during monsoon only	Moderate water logging after rainfall	Improper and severe water logging
	E6: Reduction in vegetation cover in last 15 years	Low Decrease	Medium Decrease	High Decrease	Critical Decrease

Table B5: Indicator and scores for economically inactive women group

Components	Indicators	Scores Assigned (0 – 100)			
		Fair (100)	**Acceptable (67)**	**Poor (33)**	**Risky (0)**
Resource (R)	R1: Perceived changes in SWL	No change	Low Decrease	Medium Decrease	High Decrease
	R2: Perceived changes in GWL	No change	Low decrease	Medium decrease	High decrease
	R3: Rainfall variability	Less	Moderate	High	Very high
	R4: Occurrence of illness from using SW	No Illness	Minor illness (skin irritation)	Moderate illness (skin disease, allergy, Malaria)	Major or extreme illness (Cholera, Typhoid, Dysentery)
	R5: Odor in SW	No odor	Seasonal odor but mild	Seasonal extreme odor	Throughout the years
	R6: Occurrence of illness from using GW	No Illness	Minor illness	Moderate illness	Major or extreme illness
	R7: GW quality	None	Iron (Fe)	Arsenic (As)	Both As & Fe
	R8: Odor in GW	No odor	Mild odor due to Iron	Seasonal extreme odor	Throughout the years
Access (A)	A1: Daily water collection time including travel and waiting time	<30m	30-60 m	60-90 m	>120 m
	For pipe water connection	Continuous supply	Intermittent but reliable timing of supply	Intermittent and irregular timing of supply	Intermittent and insufficient supply
	A2: Collection of water even she is sick	Never	Sometimes	Frequently	Always
	A3: Security issue during collection of water	No risk	Does not feel comfortable but safe	Does not feel comfortable and not safe	Lack of security (Risk of serious harm)
	A4: Access to improved sanitation	Pucca latrine	Semi pucca latrine	Kutcha latrine	Field/open space
	A5: Access to medication	Emergency doctor and medicines available nearby	Emergency doctor and medicines available at 30 min distance	Emergency doctor and medicines available at 1hour distance	Emergency doctor and medicines available at more than 1hour distance
Capacity (C)	C1: Financial help from their relatives/ NGO during disaster	Yes=100		No=0	
	C2: Access to institutional loan/credit	Yes=100		No=0	
	C3: Duration of residence	>30 years	20-30 years	10-20 years	<10 years

Table B5: (continued)

Components	Indicators	Scores Assigned (0 – 100)			
		Fair (100)	**Acceptable (67)**	**Poor (33)**	**Risky (0)**
Capacity (C)	C4: Political/NGO linkage	Yes=100		No=0	
	C5: Training in water sanitation, and hygiene issues	Yes=100		No=0	
	C6: Educated ratio	Ratio equals to 100	0.33 to 0.67	0 to 0.33	None
	C7: Role in operation	Always	Frequently	Only when asked to do	Never
	C8: Role in maintenance	Always	Frequently	Only when asked to do	Never
Use (U)	U1: Daily water requirement	No shortage	Low shortage	Medium shortage	High shortage
	U2: Occurrence of violence when demand is not fulfilled or can't bring water timely	Never	Blamed only	Pressurized to bring water immediately	Occurrence of physical violence
	U3: Reported conflicts regarding water use	No conflict	Low degree of conflict	Moderate degree of conflict	High degree of conflict
Environment (E)	E1: Consumable fish species in SW sources	Yes= 100		No= 0	
	E2: Reduction in fish species in last 15 years	No reduction	Few no. of species reduced (10-20)	Extinction of several species (20-30)	Extinction of several species (>30)
	E3: Damage and loss due to flood/drought in last 15 years	No loss and damage	No loss and light damage	Moderate loss and damage	Severe loss and damage
	E4: Crop loss in last 15 years	No loss	Mild loss	Moderate loss	Severe loss
	E5: Drainage facilities	Proper drainage and no water logging	Slight water logging during monsoon only	Moderate water logging after rainfall	Improper and severe water logging
	E6: Reduction in vegetation cover in last 15 years	Low Decrease	Medium Decrease	High Decrease	Critical Decrease