Draft Final Report

on

Assessment of Drinking Water Security in the Selected Areas of South-West Coastal Region of Bangladesh






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List of Abbreviations and Acctonyms

AAAQ	Availability, Accessibility, Acceptability and Quality
AHP	Analytic Hierarchy Process
APHA	American Public Health Association
BADC	Bangladesh Agricultural Development Corporation
BBS	Bangladesh Bureau of Statistics
BCCSAP	Bangladesh Climate Change Strategy and Action Plan
BDP	Bangladesh Delta Plan
BMDA	Barind Multipurpose Development Authority
BUET	Bangladesh University of Engineering and Technology
BWA	Bangladesh Water Act
BWDB	Bangladesh Water Development Board
CDS	Coastal Development Strategy
CZPo	Coastal Zone Policy
DGPS	Digital Global Positioning System
DO	Dissolved Oxygen
DPHE	Department of Public Health Engineering
EC	Electric Conductivity
FC	Fecal Coliform
FGD	Focus Group Discussions
GIS	Geographic Information System
GOB	Government of Bangladesh
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IDM	Institute of Disaster Management
IDW	Inverse Distance Weighting
IWFM	Institute of Water and Flood Management
IWRM	Integrated Water Resource Management
KII	Key Informant Interview
KUET	Khulna University of Engineering & Technology
LGED	Local Government Engineering Department
ME	Mean Error
MoEFCC	Ministry of Environment, Forest and Climate Change
NAPA	National Adaptation Programme of Action
NGO	Non-Government Organization
NSDS	National Sustainable Development Strategy
PSF	Pond Sand Filtering
RMSS	
RO	Reverse Osmosis
RWHS	Rain Water Harvesting System
SDG	Sustainable Development Goals
TDS	Total Dissolved Solid
USGS	U.S. Geological Survey's

WARPO	Water Resources and Planning Organization
WASH	Water and Sanitation Hygiene
WHO	World Health Organization
WQI	Water quality index

Execute Summary

Increasing population and human activities along with global climate change have enormously increased the vulnerability of the water system. Considering the existing situations of water security, a good number of initiatives are taken from different bodies and at different levels like the Government of Bangladesh (through different relevant departments), research organizations, national and international NGOs etc. A wide variety of initiatives is taken into consideration along with subsequent actions. However, a great deal is yet to be done for assuring the water security. A little endeavour is taken by the 'Institute of Disaster Management (IDM)' of Khulna University of Engineering & Technology (KUET) to contribute at national level for minimizing the challenges to ensure the 'water security' through this research project. Primarily, the research is for piloting the main concept at a small scale and after a productive outcome from the project and successful implementation of this outcome, there will be a great chance to go for a large scale which may cover the whole country. Considering the immense importance of water related challenges, specifically in the south-west coastal region of Bangladesh, the research team has designed the joint research project titled "Drinking water security Assessment in South-West Coastal Region of Bangladesh".

The current research project identified the drinking water security challenges in southwestern coastal zone of Bangladesh. To evaluate the overall water security, the study determined the availability of drinking water, analyzed its accessibility, and assessed its quality separately by indexing method at the union, upazila, and district levels. Spatial analyses were also completed in order to create drinking water availability, accessibility, quality and overall water security map. And at the final stage of the project work a water app (WATAPP) for Android mobile devices is produced depending on water security index of Khulna, Satkhira and Bagerhat districts of southwestern coastal zone of Bangladesh. In the aspect of availability, result shows that majority of the households collect water from private sources followed by the Government and non-government sources. Overall water availability condition seems to be better in Khulna than Bagerhat and Satkhira District. In terms of accessibility, the findings indicate that the majority of families gather water from sources more than 100 meters away, which is twice the national standard for Bangladesh. Overall water accessibility condition seems households of Satkhira district have higher access to the source than Khulna and Bagerhat district. According to the findings of drinking water quality, only 1% water sources were of good quality and other 99% not good with a significant portion of water sources poor or very poor for drinking purpose during dry season due to occurrence of extremely higher values of E.Coli in the source. Over all water quality shows that Bagerhat district was relatively better than Khulna and Satkhira during dry season. The Overall water security condition in 18 disaster hotspots in the South-west coastal region in poor to very poor. However, in comparison, Satkhira has better water security with an average score of 2.82 whereas Khulna and Bagerhat have scores of 2.55 and 2.48 respectively.

The application (WATAPP) is designed as a decision making tool that will provide an instant overview of the water security situation of Khulna, Satkhira and Bagerhat districts of south-western Bangladesh. The output of the project work will help the policy makers and they can obtain a baseline for effective planning and execution with priority-based planning.

New policy interventions should emphasize on implementation of some new sources of potable water because 42% households claimed that they faces water scarcity for 3 to 4 months in dry season and 33% household's houses located more than 500m far from the

water collection sources and 55% household require more than 15 minutes for travelling to collect water. Road condition needs to be taken care of in order to insure water accessibility because 50% household use fully kutcha road for fetching water.

For the future course of action, some adaptation and transformation mechanisms could be under taken based on the outputs of the research. For this purpose, all the rest of the unions should be taken under consideration of these three districts for analysis. In addition, to have a dynamic baseline of drinking water, the study could be replicated for all over the country. Through the mobile application all the data and information could be utilized by the policy makers and marginal people. The database can also be used as a baseline for any future study related to drinking water. The 1st version of the mobile application should be further developed to make it more user friendly.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Water security is one of the increasingly recognised challenges worldwide. Human livelihood requires consistent availability and continuous accessibility to an acceptable quality of water. The scarcity of safe drinking water is increasing due to an increase in population, changing lifestyles and urbanization (Abedin and Shaw, 2013). Increasing population and human activities along with global climate change have enormously increased the vulnerability of the water system. Around 13 percent of the total world urban population lives in coastal zones and of these, more than 75 percent lives in Asia (ADB, 2013). The effect of this is more adverse in developing countries like Bangladesh. Specifically, the southwest coastal region, being under tidal influence and dependent on fresh water supplies from upstream, that has a unique brackish water ecosystem. Scarcity of safe drinking water is an acute problem in the coastal regions which is mainly caused by seasonal drought, coastal flood, cyclone, and salinity intrusion. The context is also severely affecting agriculture, health, fisheries, and the ecosystem of the region (Rahman et al., 2017). Therefore, water security assessment can be perceived in terms of availability, accessibility, and quality. Water availability encompasses the quantity of water that can be used for human purposes without significant harm to ecosystems or other users, whereas accessibility is the availability within a reasonable distance and time, and which is affordable and free of gender and class discrimination, and the quality embodies that the commodity is safe for consumption and aesthetically acceptable. So, it is important not only to address the importance of water security but also to measure its intensity to deal with this challenge. Since, water security varies based on locality, appropriate indicators are needed to measures the level of water security that can reflect changes at the local level. Addressing such vulnerabilities and challenges is a high priority as this will help to stimulate and implement policy actions.

Considering the existing situations of water security, a good number of initiatives are taken from different bodies and at different levels like the Government of Bangladesh (through different relevant departments), research organizations, national and international NGOs etc. A wide variety of initiatives is taken into consideration along with subsequent actions. However, a great deal is yet to be done for assuring the water security. A little endeavour is taken by the ‘Institute of Disaster Management (IDM)’ of Khulna University of Engineering & Technology (KUET) to contribute at national level for minimizing the challenges to ensure the ‘water security’ through this research project. Primarily, the research is for piloting the main concept at a small scale and after a productive outcome from the project and successful implementation of this outcome, there will be a great chance to go for a large scale which may cover the whole country. Considering the immense importance of water related challenges, specifically in the south-west coastal region of Bangladesh, the research team has designed the joint research project titled “Drinking water security Assessment in South-West Coastal Region of Bangladesh”. The specific objectives of the project are as follows:

- To identify the availability of water in local level and delineate the factors affecting.
- To analyze the accessibility of water and its consequences on the coastal residents.
- To assess the water quality and its spatial and seasonal distribution/trends.

There are some organizations,which are directly dealing with water issues and are involved in the different research initiatives related to water in Bangladesh. Water Resources and Planning Organization (WARPO) is one of them. The objectives of the research and the existing different Government Policies match deeply with each other. Moreover, the relevant policies are also related to WARPO. In National Water Policy (1999) governs the availability of safe and affordable drinking water supplies through various means, including rainwater harvesting and conservation at clause 4.6 a. Water resources virtually depend on the equitable sharing and management of transboundary rivers in the context of Bangladesh. The Southwest region of Bangladesh, in particular, suffers from a serious safe drinking water crisis (Akber, 2010). There are several reasons that make safe water unavailable for the people of Bangladesh. One is water related problems in the extremes such as flood, storm surge, cyclones etc. during monsoon and water scarcity during dry season (Rahman and Rahman, 2015; Rahaman, 2005).

Although, according to the literature, a few studies have been conducted in the assessment of drinking water quality of south west coastal region of Bangladesh, assessment of drinking water insecurity (Benneyworth et al., 2016; Rahman et al., 2016; Hossain et al., 2021), drinking water quality, exposure and health risk assessment for the school-going children at school time (Rahman et al., 2021) revealed that the water quality of this area is highly impaired due to anthropogenic activities. These studies were conducted using traditional monitoring methods which do not calculate water quality index or do not show any marked seasonal variations of drinking water quality.

Hence, to overcome these limitations, this study intended to map the drinking water quality coupled with water quality indexing related to of disaster hot spots of south west coastal region of Bangladesh by applying ArcGIS based on the spatial interpolation analysis IDW and in accordance with the tested water quality data obtained during two seasons (dry and wet) in the study period. The main objectives of this study are to assess the physicochemical and microbiological properties of drinking water by sampling and testing of the significant water quality parameters and calculation of water quality index and represent their spatio-temporal distribution by using GIS-based tools of interpolation along the study area. This integrated approach has the most promising outlook for solving the problem of drinking water insecurity in coastal Bangladesh.

The Coastal Zone Policy (2005) emphasises the intensity of coverage of safe drinking water facilities (clause 4.2 b), encouraging rainwater harvesting and water conservation (clause 4.2.2) which are directly related to water security. The action plan proposed by the Government of Bangladesh regarding Sustainable Development Goals (SDG)-6 includes access to safe, adequate and equitable water supply for all with a target of improving 100% water supply coverage in urban and rural area by 2020. Another important target is ensuring safe yield from ground water sources of water and their preservation and conservation by 2020 through appropriate actions and continuous monitoring up to 2030. Equitable access to safe and affordable drinking water for all is one of the goals of Sustainable Development Goals (SDGs) which is cited at Goal 6.1. Again, the goal 2 of Delta Plan Specific Goals aims to ensure reliable and adequate provision of freshwater to support equitable and sustainable economic development, environmental sustainability and livelihood security. This includes: i) sufficient and timely provision of safe surface and groundwater for drinking, agriculture, fisheries, environment, navigation, industry, etc.; and ii) controlling pollution, ensuring water quality and providing sanitation at acceptable levels in relation to defined standards as well as environmental, health, agricultural and industrial needs.

However, there are a number of challenges for achieving these targets including protecting water sources and introducing sustainable management of groundwater and surface water will be a priority given Bangladesh’s extreme reliance on limited groundwater sources. Considering all those things for achieving SDG 6, the water security analysis and preparation of digital water security map for southwest coastal region of Bangladesh are more rational.

The project covers the interest of the all the said policies which are very important for the sustainable development of Bangladesh.

Research works of different organizations also endeavored to address the water security issue in the coastal Bangladesh. Study conducted by the Institute of Water and Flood Management (IWFM), Bangladesh University of Engineering and Technology (BUET), the University of Dhaka and the University of Oxford found substantial low coverage of safe drinking water, despite exponential growth of privately installed tube-wells in the past decades (Discussion Paper, 2018). Vanderbilt University, USA and Khulna University, Bangladesh investigated drinking water insecurity in respect to water access and quality in the south-western coastal Bangladesh in 2012-2013. According to the authors, residents of the Dacope Upazilla use far less groundwater than the national average due to its unacceptable quality. Moreover, salinity and rainwater scarcity force them to use multiple water sources with questionable quality throughout the year (Benneyworth et al., 2016). Rahman and Islam (2018) from Patuakhali Science and Technology University and Pabna University of Science and Technology, Bangladesh conducted study in Kamarkhola of Dacope Upazilla under Khulna District, Bangladesh on safe drinking water scarcity. They have pointed out saline water intrusion, reduction of upstream flow, sea level rise, disasters, polder, arsenic contamination, shrimp cultivation in brackish water, excessive use of underground water and lack of appropriate aquifer are the constraints of potable water supply in the coastal area of Bangladesh. Islam et al. (2013) studied the perceptions of the communities exposed to severe water scarcity in the coastal regions. The perceptions indicate that the local people might not have the knowledge to understand the changing phenomenon regarding water security, but they do have the experience to cope against such adversities. They have their own adaptation measures e.g. rainwater harvesting, pond water conservation etc. Rahman et al. (2017) assessed fresh water security in coastal Bangladesh from the perspective of salinity, community perception & adaptation and concluded that a well-coordinated approach from local and central government, NGOs and community people will be effective in reducing the scarcity of safe drinking water in coastal Bangladesh. Chan et al. (2016) studied water governance in Bangladesh from institutional and political context and drew policy insights for implementing Integrated Water Resource Management (IWRM) approach to achieve SDGs.

1.1.1 Policies for Safe Drinking Water

1.1.1.1 Global Perspective

About 71% of our globe is covered with water (The U.S. Geological Survey's (USGS) Water Science School 2019) where only 3% is fresh water and two-thirds of it is frozen in glaciers or unavailable to us. In consequence, 1.1 billion people around the globe do not have access to clean water, and a total of 2.7 billion people face water scarcity for at least one month of the year (World Wildlife Fund 2022).

In the light of achieving a better and more sustainable future for all, the United Nations General Assembly set up 17 interlinked SDGs in 2015, which are intended to be attained by 2030. Specifically, SDG 6 depicts clean water and sanitation, which will ensure the availability and sustainable management of water and sanitation for all by 2030 with having 8 targets and 11 indicators (United Nations 2021). Except Target 2, all others are directly related to water and water management which are as follows:

Target 6.1: By 2030, achieve universal and equitable access to safe and affordable drinking water for all

Target 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

Target 6.4: By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity

Target 6.5: By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate

Target 6.6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes

Target 6.a: By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies

Target 6.b: Support and strengthen the participation of local communities in improving water and sanitation management

Despite progress, considerable hurdles remain in achieving Sustainable Development Goal 6 and resolving large disparities in access to basic water and sanitation services across and within nations. To address the SDG 6 obstacles, a paradigm shift is required: water should be viewed as a fundamental human right to which all people are entitled beyond discrimination, rather than just a natural resource to be managed and consumed, which is from the right to an adequate standard of living under Article 11(1) of the International Covenant on Economic, Social and Cultural Rights. The key elements of the water right are availability; accessibility; affordability; quality and safety; and acceptability (United Nations 2022) are given in the Table 1.

Table 1: Definition of the key elements of water right.

Key Elements of Water Right	Definition
Availability	The water supply for each person must be sufficient and continuous to cover personal and domestic uses, which comprise water for drinking, washing clothes, food preparation and personal and household hygiene. There must be a sufficient number of sanitation facilities within or in the immediate vicinity of each household, and all health or educational institutions, workplaces and other public places to ensure that all the needs of each person are met.
Accessibility	Water and sanitation facilities must be physically accessible and within safe reach for all sections of the population, taking into account the needs of particular groups, including persons with disabilities, women, children and older persons.
Affordability	Water services must be affordable to all. No individual or group should be denied access to safe drinking water because they cannot afford to pay.

Quality and safety	Water for personal and domestic use must be safe and free from micro-organisms, chemical substances and radiological hazards that constitute a threat to a person's health. Sanitation facilities must be hygienically safe to use and prevent human, animal and insect contact with human excreta.
Acceptability	All water and sanitation facilities must be culturally acceptable and appropriate, and sensitive to gender, life-cycle and privacy requirements.

Source: (United Nations 2022)

The Danish Institute for Human Rights (2014) developed an AAAQ framework based on AAAQ (Availability, Accessibility, Acceptability and Quality) criteria that consist of specific standards, generic indicators and generic benchmarks (Table 2) . This framework acts as a tool for assessing the safe drinking water scenario in a specific geographical area. The following table shows the AAAQ water – standards and generic indicators for assessing safe drinking water.

Table 2: AAAQ water – Standards and Generic Indicators

Criteria		Human Rights Standard (Adequacy)	Generic Indicator
Availability		Sufficient water	Quantity of water used per person per day
		Regularity of water	Number of disconnections Period of unavailability of water Incidents of unavailability of water over time
Accessibility	Physical accessibility	Reasonable distance/number of outlets / waiting time	Total collection time, including waiting time
		Security	% of rights holders report that they have not experienced threats/assaults
		Equitable distribution	Number of people per water outlet
	Economic accessibility	Affordability	Total (direct + indirect) costs as the proportion of income and as the proportion of the total cost of fulfilling basic needs/right
	Non-discrimination	Non-discrimination	% of rights holders report they have not been subjected to discrimination % of individuals belonging to vulnerable groups report they have not been subjected to discrimination % of other AAAQ indicators where no discrimination is detected
	Access to information	Information access	% of rights holders with access to information about water-related issues % of disconnections/changes in water delivery advised to the public with adequate notice

Acceptability	Consumer acceptability: odour, colour, taste	% of rights holders who are satisfied with odour, colour and taste Number of complaints about odour, colour and taste
	Cultural acceptability: gender, life-cycle, privacy	Adaptions to cultural, gender, life-cycle and privacy considerations
Quality	Safe water / sufficient quality	% of water is compliant with WHO quality standards
		% of rights holders use improved water sources
	Prevent, treat, control water-related disease	Prevalence of waterborne disease

Source: (The Danish Institute for Human Rights 2014)

1.1.1.2 Policies for Safe Drinking Water: National Perspective

Following sustainable development goals, Bangladesh has made remarkable progress in advancing access to water services by increasing access to drinking water to 98% (Bangladesh Bureau of Statistics (BBS) and UNICEF Bangladesh 2019). It turns out that Bangladesh has made significant strides in achieving universal access to improved water sources where 95% population meet the basic water supply criteria (available within thirty minutes). having said that water quality and equitable access in hard to reach areas remain the main challenge nationwide (UNICEF Bangladesh 2018). However, Bangladesh has taken many initiatives through the formulation of policy, strategy, plans, etc. with times for striving the situation. A few of the relevant initiatives are discussed below.

1.1.1.2.1 National Policy for Safe Water Supply and Sanitation 1998

National Policy for Safe Water Supply and Sanitation 1998 aims to ensure access to safe water and sanitation services for all at an affordable cost. The policy mentioned several steps and strategies for achieving the goal. The issue of physical accessibility and quality of water was given more priority keeping less focus on the availability of water and, acceptability and affordability of the people. Access to a basic level of services in water to all citizens, ensuring proper storage, management and use of surface water without contamination, and measures for storage and use of rainwater are the emphases of the policy. Providing safe drinking water to every family in the urban areas, and increasing current safe drinking water coverage in rural areas by reducing the average number of users per tube-well from 105 to 50 in the near future are major-specific goals. On top of that, the policy highlights ensuring the supply of quality water through observance of accepted quality standards. However, several strategies for implementing the policy are mentioned to achieve the goal. Major strategies are participation of the users in all phases of the water project, community cost-sharing and introduction of economic pricing for services, more priority to under-served and un-served areas, adoption of appropriate technologies based on specific regions, geological situations and social groups, controlling and preventing contamination of drinking water, etc. Interestingly, the provision of providing credit facilities for the poor to bear the costs of water and sanitation service was made. But equity in getting water quantity and pricing considering the poorest section of the large population is not mentioned (Government of the People's Republic of Bangladesh 1998).

1.1.1.2.2 National Strategy for Water Supply and Sanitation 2014

The goal of the National Strategy for Water Supply and Sanitation 2014 is to provide safe and sustainable water supply, sanitation and hygiene services for all, leading to better health and well-being. The major objective of the strategy sets to provide a uniform strategic guideline to the sector stakeholders, including the government institutions, private sector and NGOs, for achieving the sector goal. 17 strategies were made under their themes viz. WASH interventions, emerging challenges, and Sector governance to achieve the goal. Major WASH intervention strategies are ensuring safe drinking water, giving priority to arsenic mitigation, adopting specific approaches for hard to reach areas and vulnerable people, mainstreaming gender, etc. It is mentionable that recovering the cost of services while keeping a safety net for the poor is the key strategy that will ensure the equity and affordability of the poor people. Under each strategy there are a set of directions was made to reach the goal. An implementation plan of the National Strategy for Water Supply and Sanitation for each strategy was made mentioning the lead, partners and milestones at the end (Government of the People's Republic of Bangladesh 2014).

1.1.1.2.3 National Water Policy, 1999

National Water Policy 1999 emphasizes managing the water resources of the country in a comprehensive, integrated and equitable manner and acts towards fulfilling the national goals of economic development, poverty alleviation, food security, public health and safety, decent standard of living for the people and protection of the natural environment. The policy ensured the availability of water to all users of society, particularly the poor, and considered the particular needs of women and children. Besides, stressed enhancing the role of women in water management as they have a significant role in this manner. In the case of supplying drinking water, the policy will facilitate the availability of safe and affordable drinking water supplies through various means, including rainwater harvesting and conservation. Besides, it accentuates preserving natural depressions and water bodies in major urban areas for recharge of underground aquifers and rainwater management and creating awareness in checking pollution and waste (Government of the People's Republic of Bangladesh 1999).

1.1.1.2.4 National Policy for Arsenic Mitigation and Implementation Plan, 2004

The policy provides a guideline for reducing the impact of arsenic on people and the environment comprehensively and sustainably. It highlights the arsenic aspect of the quality of safe drinking water which supplements the National Water Policy 1998, National Policy for Safe Water Supply and Sanitation 1998 in fulfilling the national goals of poverty alleviation, public health and food security. In the arsenic affected areas, the policy facilitates access to safe water for drinking and cooking through the implementation of alternative water supply options with maintaining Bangladesh Standards for drinking water as defined in 'Environmental Conservation Act 1995 and Rules 1997, Schedule - 3'. It also ensured the physical accessibility of providing a safe source of drinking water at a reasonable distance on an emergency basis. In addition, in case of availability of drinking water, 8 litres of water per capita per day will be ensured for piped water supply in the rural areas where the supply will be mainly for drinking and cooking (Government of the People's Republic of Bangladesh 2004).

1.1.1.2.5 Coastal Zone Policy 2005

Coastal Zone Policy 2005 provides broad direction to all parties involved in the administration and development of the coastal zone in such a way that coastal residents may live and work in a safe and pleasant environment without impairing the integrity of the natural environment. The policy adopts a set of associated actions which leads to increasing the intensity of coverage of safe drinking water facilities. It encourages the establishment of appropriate infrastructures within the polders for freshwater storage and other water utilization and promoted rainwater harvesting and conservation. Furthermore, It spotlights the excavation of the existing ponds and tanks for the conservation of water and promotes the local technology for water treatment (such as pond sand filtering - P.S.F.) for the supply of safe water. On top of that, it emphasizes the management of groundwater and its sustainable use. It is acknowledged that gender disparities and gaps exist in the coastal zone, particularly in the areas of livelihoods, assets, and resources, as inadequate safe drinking water for household purposes adds to a heavy burden for poor women. Zoning regulations for the establishment of new industries and their effluent discharge possibilities are a focus in this policy document for ensuring fresh and safe water availability in the coastal zone (Government of the People’s Republic of Bangladesh 2005a).

1.1.1.2.6 Coastal Development Strategy, 2006

The Coastal Development Strategy (CDS) 2006 followed the Coastal Zone Policy (CZPo) 2005, which prepares for coordinated priority actions and arrangements for their implementation through selecting strategic priorities and setting targets. The strategy document identified nine strategic priorities based on targeting areas viz. regions (islands and chars, exposed coastal zone/districts; high tsunami risk area; South-West region); disadvantaged groups (erosion victims, women and children, fisher and small farmers); issues (shrimp culture, land zoning; groundwater management, climate change); and opportunities (tourism, renewable energy, marine fisheries). Among them, the first one is ensuring fresh and safe water availability as lack of availability and access to safe drinking water is a major issue, reaching a crisis level in the southwest. The government of Bangladesh has already taken several initiatives where some are ongoing and others will be implemented in future (Government of the People’s Republic of Bangladesh 2006).

1.1.1.2.7 Bangladesh Delta Plan 2100

The Bangladesh Delta Plan (BDP) 2100 is a long-term water-centric integrated techno-economic mega plan that encompasses a delta vision and strategies that allow for the long-term integration of sector plans and policies and the presentation of actionable interventions with a roadmap for implementation. Delta Plan sets the vision to achieve a safe, climate-resilient and prosperous delta and keeps the mission to ensure long term water and food security, economic growth and environmental sustainability while effectively reducing vulnerability to natural disasters and building resilience to climate change and other delta challenges through robust, adaptive and integrated strategies and equitable water governance. BDP 2100 has six specific goals where Goal 2 depicts enhancing water security and efficiency of water usage. All strategies including freshwater, drinking water and water management issues are discussed hereunder national level, hotspot level, and cross-cutting issues. at the hotspot level, water-stressed zones are identified and the necessary initiatives to be taken to tackle the problems are mentioned (Government of the People’s Republic of Bangladesh 2018).

1.1.1.2.8 Bangladesh Water Act 2013

The Bangladesh Water Act 2013 (BWA) is a framework law that aims to integrate and coordinate the country's water resource management through establishing a new, integrated approach to the protection, improvement and sustainable use of the country's rivers, lakes, estuaries, coastal waters and groundwater. This act will ensure the best use of water resources, legitimate the water rights of the poor and disadvantaged, an optimal and efficient way of using scarce water resources, etc. To do so, several key measures were taken viz. water rights, Adoption of the National Water Policy and National Water Resources Plan, Water resource protection/pollution control and water quality standards and most importantly Water Stressed Areas and Safe Yield. The act acknowledged access to drinking water and water for domestic usage as a basic right along with the affordability for the poor and disadvantaged for water. In addition, the act defined the water-stressed areas based on certain issues and put restrictions on water abstraction and usage. It also emphasizes the water quality to certain standards. In the water-stressed areas drinking water gets the highest priority followed by domestic usage (Government of the People's Republic of Bangladesh 2013a)**.**

1.1.1.2.9 Bangladesh Climate Change Strategy and Action Plan 2009

Bangladesh Climate Change Strategy and Action Plan (BCCSAP) 2009 is considered a living document to tackle climate change based on COP 2009, which targets the Vision 2021 and includes the ambition for a substantial eradication of poverty by 2021. The Plan will be a living document that will be updated and modified as needed in the future. BCCSAP 2009 has two parts where part one describes the background issues based on physical and climatic contexts, socio-economic realiteis, policies, etc. and the consequent rationale of the strategies on climate change based on the vision of future development, and the second part elaborates a set of programmes based on six pillars or broader areas of interventions viz. (a) food security, social protection and health (b) Comprehensive disaster management (c) Infrastructure (d) Research and knowledge management (e) Mitigation and low carbon management (f) Capacity building and institutional strengthening. under each theme, several programmes are mentioned along with the rationale, justificaiton, and facilitating agencies. A couple of water related programmes are mentioned in the plan especially adaptation against draught, water and sanitation programmes in climate-vulnerable areas, etc. (Government of the People's Republic of Bangladesh 2009).

1.1.1.2.10 The National Adaptation Programme of Action 2005

The National Adaptation Programme of Action (NAPA) 2005 aims to develop a countrywide program that encompasses the immediate and urgent adaptation activities that address the current and anticipated adverse effects of climate change, including extreme events. Future coping strategies and mechanisms are proposed based on existing processes and practices, with the major focus of adaptation science to adjust the detrimental effects of climate change. NAPA suggested fifteen future adaptation strategies. Mentionable strategies are (a) Providing drinking water to coastal communities to combat enhanced salinity due to sea-level rise (b) Promotion of research on drought, flood and saline tolerant varieties of crops to facilitate adaptation in the future (c) Reduction of climate change hazards through coastal afforestation with community participation (d) Capacity building for integrating climate change in planning, designing of infrastructure, conflict management and land-water zoning for water management institutions. Finally, NAPA mentioned 15 projects along with their type, primary implementing agency, and total cost. In addition, each project is detailed with the future outcomes, description, rationale, etc. (Government of the People's Republic of Bangladesh 2005b)**.**

1.1.1.2.11 The National Sustainable Development Strategy (2010-2021)

The National Sustainable Development Strategy (NSDS) (2010-2021) sets the objectives to formulate strategies to meet the challenges of economic, social and environmental sustainability faced by the economy and to meet the international obligation of our country to global sustainable development principles and agenda. The NSDS (2010-21) has identified five Strategic Priority Areas areas viz. sustained economic growth, development of priority sectors, social security and protection, environment, natural resources and disaster management along with three cross-cutting issues. Regarding safe drinking water supply under quality health and Sanitation services, the NSDS (2010-21) facilitated ensuring every household's access to safe drinking water by supplying technology for purifying arsenic-contaminated water as well as surface water including desalinization in the coastal areas. Research should be undertaken to develop affordable desalinization techniques. NSDS set an indicator to assess the accesibility to pure drinking water with % of the population with access to pure drinking water (Government of the People's Republic of Bangladesh 2013b)**.**

1.1.1.2.12 Pro Poor Strategy for Water and Sanitation Sector in Bangladesh 2020

The strategy concludes that hardcore poor households need to get 100% subsidies but they must also share 100% of the operation and maintenance costs of water and sanitation facilities. The pro-poor strategy is based on four pillars: (1) an operational definition of hardcore poor households; (2) a definition of a basic minimum service level; (3 identification and organisation of the poor households; and (4) the development of the mechanism for administering subsidies. The basic minimum services for safe water supply will be characterized by (a) For the purpose of drinking, cooking and personal hygiene, the basic minimum level of service is defined as 50 litres per person per day, (b) Collection time of safe drinking water from source should be within 30 minutes of the household premise, and (c) The drinking water must meet the national water quality standards (Government of the People's Republic of Bangladesh 2020)

CHAPTER TWO: MATERIALS AND METHODS

2.1 Study Area

Coastal Bangladesh is separated into three sub-zones (e.g., south-eastern, south-central, and south-western) and consists of 19 districts. The study focused on the south-western coastline zone, which includes the districts of Khulna, Bagerhat, and Satkhira (Figure 1). The study conducted in Five unions named Southkhali, Dhansagar, Khontakata, Rayenda, Khaulia under two upazillas or sub districts (Sarankhola and Morrelganj) of Bagerhat district, nine unions named Deluti, Garuikhali, Sholadana, Lata, Kamarkhola, Sutarkhali, Tildanga, DakshinBedkashi, Uttar Bedkashi under three upazillas (Paikgacha, Dacope and Koyra) of Khulna district and four union named Gabura, Padma Pukur, Pratap Nagar, Sreeula under two upazillas (Shyamnagar, Assasuni) of Satkhira district. Due to its proximity to the Bay of Bengal, low elevation, freshwater scarcity, and salinization, the southwestern coastal region is highly vulnerable (Johnson & Humphreys, 2021). Frequent cyclones and cyclone-induced storm surges put coastal inhabitants in Bangladesh at great risk, causing harm to fresh water sources. Salinity intrusion is one of the major water-related problems in the southwestern coastal region which hampers drinking water availability, accessibility and quality.

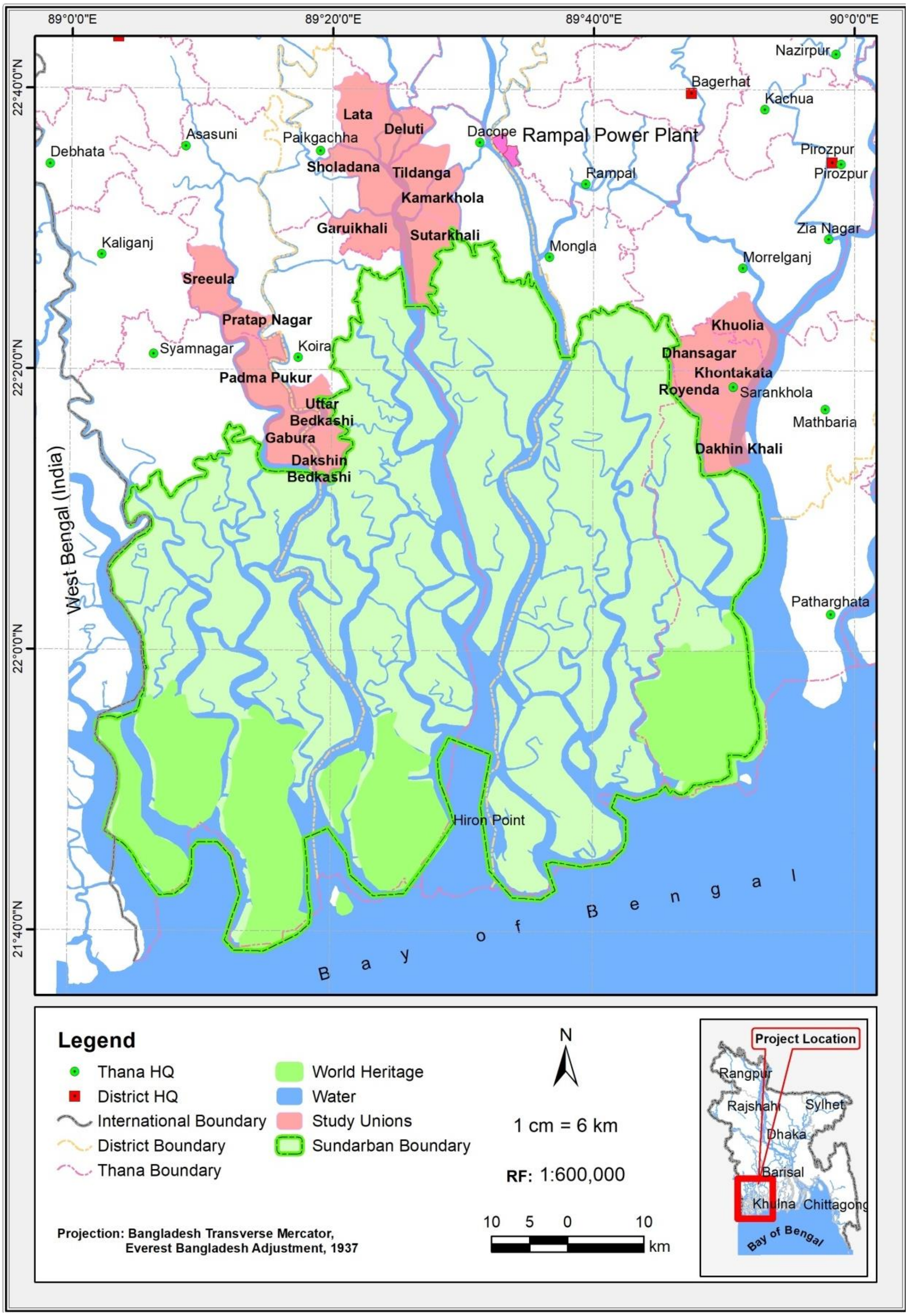

Figure 1: Map of the study area

2.2 Methodologies used for the Assessment of Water Availability and Accessibility

2.2.1 Identification of Indicators

Dimensions of water availability consist of a number of complex or simple variables. These variables are identified through extensive literature review. Ownership of the source, number of available sources in wet and dry season, demand-source ratio and duration of water scarcity have been considered as the variables or indicators of water availability index as shown in Table 3.

Table 3: Indicators of household level water availability index

Indicators	Measurement Unit
Ownership	Qualitative
Number of Available sources in Dry Season	Number of sources
Number of Available sources in Wet Season	Number of sources
Demand-Source Ratio	Lt/number of sources
Duration of Water Scarcity	Month/year

Distance of sources, mode of transport, condition of road, travel time, queuing time, water price-income ratio have been considered as important Accessibility index as shown in Table 4. Other social variables like equality, safety and security also have been considered here.

Table 4: Indicators of household level water accessibility index

Indicators	Measurement Unit	Standard
Distance of source	meter	No more than 500 meter [1,3]
Mode of transport	Qualitative	-
Condition of road	Qualitative	-
Travel Time	minutes	No more than 15 min [1]
Queuing Time	minutes	No more than 15 min [1]
Water price-income ratio	%	No more than 5% of household monthly income [2,4]
Equality	Qualitative	-
Safety	Qualitative	-
Security	Qualitative	-

2.2.2 Survey Design

A solid survey design has been outlined to make the data collection more effective which correspond to the objectives of the research and the frequency at which the data will be collected. The main purpose was to make the data clean and reliable. Total twenty-seven questions were formed to collect the data regarding the indicators of availability (see appendix A). The questionnaire has been developed in both Bangla and English languages. Survey was decided to conduct using Google form and surveyors were trained for using it. It also has been decided on which date and how the survey will be conducted. Beside questionnaire survey, it was decided that at least three focus group discussions (FGDs) will be conducted in each of three union. Location and time of FGDs were also decided at this stage through rapport building and by consultation with Key Informants. A structured format has been developed to collect the experts' opinions through Google Form.

2.2.3 Sample Size Calculation

For calculating the sample size of each study area, population for the year 2021 has been predicted. Population data for the year 2011 and 2014 has been collected from the Bangladesh Bureau of Statistics (BBS 2011, 2014). The population growth rates were computed from these data and the number of households was predicted for the year 2021 based on that growth rate. Sample Size has been decided at 10% error and 90% confidence level. Table 6 shows the sample size and distribution of this samples under different unions, upazillas or districts. Following equations have been used to calculate the sample size-

$$Sample\ Size = \frac{\frac{p(1-p)z^2}{e^2}}{1+\left(\frac{p(1-p)z^2}{Ne^2}\right)} \qquad (1)$$

Where, N means population size, e is margin of error and z means z-score which is the number of standard deviations a given proportion is away from the mean. Table 5 has been used to find the right z-score.

Table 5: Z-value at different confidence level

Desired confidence level	z-score
80%	1.28
85%	1.44
90%	1.65
95%	1.96
99%	2.58

Table 6: Sample size calculation and distribution

District	Upazilla	Union Name	Numbers of household 2011	Predicted Numbers of household 2021	Sample Size
Bagerhat	Sarankhola	Southkhali	6179	7058	68
		Dhansagar	4890	6000	67
		Khontakata	7622	7890	68
		Rayenda	9463	10394	68
	Morrelganj	Khaulia	5568	5702	68
Khulna	Paikgacha	Deluti	5474	7663	68
		Garuikhali	5090	7126	68
		Sholadana	5857	8200	68
		Lata	5729	8020	68
	Dacope	Kamarkhola	3490	4886	67
		Sutarkhali	5667	7933	68
		Tildanga	5288	7403	68
	Koyra	DakshinBedkashi	7452	11178	68
		Uttar Bedkashi	7114	10671	68
Satkhira	Shyamnagar	Gabura	12389	18584	68
		Padma Pukur	12106	18159	68
	Assasuni	Pratap Nagar	9967	14953	68
		Sreeula	13004	19506	68

2.2.4 Data Collection

A detail questionnaire survey has been conducted to collect the data from the households of the study area. Consents of the participants were taken and the purpose of the study were fully described before questioning. In each union, at least three focused group discussions (FGDs) have been carried out to investigate the strength, opportunity, weakness and threat. The information collected from this has helped to verify the data about indicators specially the social indicators. Opinions from ten different key informants and experts i.e academicians, administrative personnel, public representative of the unions etc. have been used for identifying, weighting and ranking the indicators. Key informants also enlightened the overall scenario of the study area.

2.2.5 Secondary Data Collection

Relevant data and previous reports from National Water Resources Database were provided by WARPO at free of cost. Detailed digital layouts or shape files of existing houses and roads have collected from secondary sources like BWDB, BADC, BMDA, DPHE and MoEFCC. The data has been updated and more detailed through digitization. Freely available satellite images on Google earth have been used for this task. After that, location of selected water sources and location of households have been compared and verified using Geographic Information System (GIS). For this research, each indicator of water availability and accessibility has been compared with a standard value for that indicator which was collected from different secondary resources or literatures. Secondary sources include published and unpublished literatures, websites and web pages. Household data from Bangladesh Bureau of Statistics (BBS) has been used for sampling.

2.2.6 Scaling

All raw data values have been converted to comparable scales based on expert opinions and minimum standard found from the literature review. A likert scale has been used to rate each variable where minimum value refers to poor availability and accessibilty, and maximum value refers to high availability (Table 7) and accessibility (Table 8). Measurement unit of each variable is given in the former table.

Table 7: Scaling for household level water availability Index

Indicators	Scale			
	1	**2**	**3**	**4**
Ownership	Govt.	NGO	Community	Private
Available sources in dry season	≤1	2	3	>3
Available sources in wet season	≤1	2	3	>3
Demand-Source Ratio	>21	14.1-21	7.1-14	≤7
Duration of Water Scarcity	5-6 months	3-4 months	1-2 months	0

Table 8: Scaling for household level water accessibility index

Indicators	Scale			
	1	**2**	**3**	**4**
Distance (km)	>0.5	0.301- 0.5	0.101 – 0.3	≤0.1
Mode of transport	Boat, Truck	Van, Rickshaw, Bicycle	Walk	No Transport Required

Condition of road	Kutcha	Kutcha and Pucca	Pucca	No Road Required
Travel Time	>15	11-15	6-10	≤5
Queuing Time	>15	11-15	6-10	≤5
Water price-income ratio	>5%	2.6% - 5%	1.1% - 2.5%	≤1%
Equality	Gender Inequality	Economic and Social Inequality	Racial and Religious Inequality	Equal
Safety	Injury and Accident	Physical Stress	Mental Stress	No Stress
Security	Physical Assault	Thievery	Verbal Assault	No Violence

2.2.7 Correlation and Reliability Analysis

At the very beginning of the study, the variables have been analyzed for significantly high correlations (Pearson's R>0.70) between individual variables. No such high correlations have been found and therefore those variables have been kept from further consideration. The correlations among variables are shown in the Table 9 and 10.

Table 9: Inter-item correlation matrix and significance for availability index

	Ownership	Available Source in Dry Season	Available Source Wet Season	Demand-Source Ratio	Water Scarcity
Ownership	1	-0.011	-0.010	-0.040	-0.033
Available Source in Dry Season	-0.011	1	0.494	0.383	-0.034
Available Source Wet Season	-0.010	0.494	1	0.308	-0.106
Demand-Source Ratio	-0.040	0.383	0.308	1	-0.087
Water Scarcity	-0.033	-0.034	-0.106	-0.087	1

Table 10: Inter-item correlation matrix and significance for accessibility index

	Distance of source	Mode of transport	Condition of road	Travel time	Queuing time	Water price-Income Ratio	Equity	Safety	Security
Distance of source	1	0.229	-.036	0.78	0.195	0.272	0.129	0.132	0.144
Mode of transport	0.229	1	-.094	0.172	0.036	0.471	0.018	0.056	0.053
Condition of road	-00.036	-0.094	1	-0.083	-0.019	-0.074	0.001	0.164	0.054
Travel Time	0.780	0.172	-.083	1	0.218	0.223	0.139	0.202	0.154
Queuing Time	0.195	0.036	-.019	0.218	1	0.037	0.015	-0.087	0.019
Water price-income ratio	0.272	0.471	-.074	0.223	0.037	1	0.043	0.093	0.063
Equity	0.129	0.018	0.001	0.139	0.015	0.043	1	0.224^{**}	0.460

Safety	0.132	0.056	0.164	0.202	-0.087	0.093	0.224	1	0.272
Security	0.144	0.053	0.054	0.154	0.019	0.063	0.460	0.272	1
	0.000	0.069	0.064	0.000	0.523	0.031	0.000	0.000	

2.2.8 Weighting and Aggregating

The weight refers to the relative importance of a certain indicator in the overall evaluation. The greater the weight, the higher the importance of the indicator and the higher the overall impact. For this study, a widely used techniques for deriving weights, known as Analytic Hierarchy Process (AHP) has been applied to determine the weight of indicators. At first, expert's opinions have been systematically collected by means of pairwise comparisons of indicators. Elements of each pair are compared in relation to the objective, and the intensity of their importance is determined by introducing a scale from 1 to 9 (Geopel, 2013). An excel template formulated by Goepel was used for this analysis and the derived weights for the indicators are shown in Table 11 and 12.

Table 11: Data driven weight for availability index

Indicator	Weights (Wi)
Ownership (O)	11.1%
No of Available Source in Dry Season (ASD)	18.7%
No of Available Source Wet Season (ASW)	7.4%
Demand-Source Ratio (DS)	24.8%
Water Scarcity (WS)	38.0%

Table 12: Data driven weight for availability index

Indicator	Weights (Wi)
Distance of source (D)	11.9%
Mode of transport (M)	4.4%
Condition of roI(C)	7.6%
Travel time (T)	14.1%
Queuing time (Q)	6.1%
Water price-income ratio (W)	22.9%
EIty (E)	6.3%
Safety (S_1)	12.6%
Security (S_2)	14.2%

Once the scores of all the variables are derived, the composite drinking water availability (I_{av}) has been calculated by assigning derived weight over the indicators as mentioned in Equation (2).

$$I_{av} = \frac{1}{n} \sum_{1}^{n} W_n I_n \qquad (2)$$

and the composite drinking water accessibility (I_{av}) has been calculated by assigning derived weight over the indicators as mentioned in Equation (3).

$$I_{ac} = \frac{1}{n}\sum_{1}^{n} W_n I_n \qquad (3)$$

2.2.9 Developing Drinking Water Availability and Accessibility Index Map

For developing water availability index five indicators or parameters have been considered. Similarly, nine and sixteen parameters have been considered for developing water accessibility index and water quality index. Finally, the results of the total water security index for drinking water have been calculated by giving equal priority to all three domains of water security- water availability, water accessibility and water quality. The value close to 1 indicates poor water security and the value close to 4 indicates higher water security. Separate maps for water availability, water accessibility and water quality in the union, upazila and district level have been produced using Geographic Information System (GIS). Total water security map for drinking water has been prepared combining these three maps.

2.3 Methodologies used for the Assessment of Water Quality

2.3.1 Water Sampling

Drinking water quality is a vital indicator to determine the water quality index and the adequate treatment procedure. Also water quality varies with geographic location, weather, human activities; site-specific conditions (Halder, Dey, & Bosu, 2020). In the first part of the study, available sources in the study area were assessed. For the selection of the source for water sampling, expert opinion and purposive sampling method were used. Selected sources were then fixed using digital global positioning system (DGPS). Total number of 160 water samples was taken in order to assess the physic-chemical and microbiological characteristics of the study area.

2.3.2 Water Quality Analysis

Water quality assessment was carried out to generate a database of water quality indicators for the study area. Physical, chemical and microbiological parameters were measured to provide baseline information on water quality of study area during dry and wet seasons of study period. In this study situ measurement were adopted to determine unstable parameters including; pH, temperature, electric conductivity (EC) and DO by handheld multi-water quality probe (HANNA HI-9828, USA), and locations ascertained using a Trimble GeoXT 6000. The collected water samples from selected sources were analyzed for Physico-Chemical and microbiological parameters namely; total dissolved solid (TDS), total hardness, arsenic (As), total colirform (TC), fecal coliform (FC), alkalinity, sulphate (SO_4^{2-}), nitrate (NO_3^-), phosphate (PO_4^{3-}), chloride (Cl^-) by Institute of Disaster Management's Environmental Engineering lab and/or other laboratories of KUET using inductively coupled plasma mass spectrometry (ICP-MS) and ion chromatography utilizing these standard techniques represented by “American Public Health Association” (CPCB, 2011; Maiti, 2011; APHA, 1998).

2.3.3 Development of Water Quality Index (WQI) Model

Water quality index (WQI) is an exceptionally valuable tool for evaluating the overall quality of water (Ketata, Gueddari, & Bouhlia, 2011). It reduces the large number of data into single value and facilitates easy understanding of the information. WQI is utilized to determine the suitability of the water for drinking purposes (Ketata, Gueddari, & Bouhlia, 2011)

WQI has been estimated in three steps utilizing weighed arithmetic index approaches (Ramakrishnaiah, Sadashivaiah, & Ranganna, 2009; Patil & Dandge, 2021) Firstly, selected 15 water quality parameters are very important in assessment of drinking water quality as well as has been assigned a wi (weight) shown in Table 13. A weight value ranging from 1 to 5 is assigned to water quality determinants for estimating water quality index. Nitrate, E. Coli, Arsenic, Salinity and Iron are usually assigned with the maximum weight of 5, while 4 is assigned to Sulphate, pH and EC. Bicarbonate, Alkalinity and Cl^- is assigned 3 and 2 is assigned to Ca^{2+} and magnesium and Temperature are assigned a weight of 1 according to Krishna et al (2015) and Vasanthavigar et al., (2010). The maximum weight are generally allocated for those parameters due to their significant role in WQI and the minimum weight are allocated for those parameters that could not be harmful to human health(Patil & Dandge, 2021). In next step, Wi (relative weight) is calculated by using the equation 4.

Here, relative weight is represented by Wi, weight of each selected water quality parameter is described by wi, number of water quality parameters is represented by n. Table 13 represents the calculated Wi (relative weight) values of every water quality parameter.

$$\mathrm{Wi} = \mathrm{wi} / \sum_{i-1}^{n} \mathrm{wi} \ldots\ldots\ldots\ldots\ldots\ldots..(4)$$

Table 13: Assigned weight and calculated relative weight for selected parameters

Parameter	Standards as per GOB (2022)	wi (Weight)	Wi (Relative weight)
Temperature	-	1	0.02
Arsenic	0.05	5	0.1
Nitrate	45	5	0.1
Fecal Coliform	0	5	0.1
Salinity	-	5	0.104
Iron	0.3-1.0	5	0.104
Sulphate	250	4	0.083
pH	6.5-8.5	4	0.083
EC	400	4	0.083
Bicarbonate	125-350	3	0.063
Phosphate	0.1	1	0.021
Cl^-	250	3	0.063
Ca^{2+}	75	2	0.042
DO		1	0.021
Alkalinity		1	0.021
Magnesium	30-35	1	0.021
Total		**50**	**1**

In third stage, using equation 5 qi (quality rating scale) for individual water quality parameter is computed by dividing it's observed value in respective water sample by its corresponding standard as per the drinking water guidelines prescribed by the GOB (2022) and the outcome is multiplied by 100.

$$qi = \frac{Ci}{Si} * 100 \ldots\ldots\ldots\ldots(5)$$

Here, quality rating is defined by qi, concentration of individual chemical (Ci) characteristics in every water sample, as well as Si is the Bangladesh standard of drinking water for individual chemical characteristics as per (GOB, 2022) guidelines.

Firstly, using equation 6 SI is determined for computing WQI for every chemical parameter by multiplying quality rating with relative weight, finally the summation of sub-index is utilized to calculate WQI according to the given equation 7.

$$SIi = \text{Wi} * \text{qi} \ldots\ldots\ldots\ldots\ldots(6)$$

$$\text{WQI} = \sum \ SIi \ldots\ldots\ldots\ldots(7)$$

Here, sub index (SIi) is the ith water quality parameter; the rating qi depends on concentration of ith parameter along with number of water quality parameters (n) undertaken for calculating WQI. WQI values are organized in 5 categories, "Excellent water" to "Water, unsuitable for drinking".

2.3.4 Spatial Modeling and Surface Interpolation through Kriging

To conduct the geostatistical analysis, the "Kriging" interpolation technique was used within the spatial analyst extension module (Matheron, 1962) in ArcGIS 9.3 software. Kriging is a multistep process; it includes exploratory statistical analysis of the data, variogram modeling, creating the surface, and (optionally) exploring a variance surface. Kriging is most appropriate when you know there is a spatially correlated distance or directional bias in the data. The spatial analyses were carried out with prepared maps using this technique The spatial transformation was performed to determine the most appropriate model to use with the parameters of the generated maps (Ryu, Kim, Cha, & Lee, 2002). The ordinary Kriging formula is shown in equation 8.

$$Z(S_0) = \Sigma\lambda_i Z(S_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

where:

Z(si) is the measured value at the location (ith),
λi is the unknown weight for the measured value at the location (ith) and
s_0 is the estimation location.

The unknown weight (λp) depends on the distance to the location of the prediction and the spatial relationships among the measured values. The statistical model estimates the unmeasured values using known values. A small difference occurs between the true value $Z(s_0)$ and the predicted value, ∑λi Z(si). Therefore, the statistical prediction is minimized using the equation 9.

$$[Z(S_0) - \sum\lambda_i Z(S_i)]^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

The Kriging interpolation technique is made possible by transferring data into the GIS environment. In this way, analysis in areas that have no data can be conducted. The following criteria were used to evaluate the model: the average error (ME) must be close to 0 and the square root of the estimated error of the mean standardized (RMSS) must be close to 1 (Johnston, Hoef, & Kriviruchok, 2001).

Parameter	Standards as per GOB (2022)	wi (Weight)	Wi (Relative weight)	Influence% (Weightage Value)
Arsenic	0.05	5	0.11363636	11.36364
Nitrate	45	5	0.11363636	11.36364
Total Coliform	0	5	0.11363636	11.36364
Fecal Coliform	0	5	0.11363636	11.36364
Iron	0.3-1.0	5	0.11363636	11.36364
Sulphate	250	4	0.09090909	9.090909
pH	6.5-8.5	4	0.09090909	9.090909
EC	400	4	0.09090909	9.090909
Phosphate	0.1	1	0.02272727	2.272727
Cl^-	250	3	0.06818182	6.818182
Ca^{2+}	75	2	0.04545455	4.545455
Magnesium	30-35	1	0.02272727	2.272727
Total		**44**	**1**	**100**

Normalization in four defined category

Parameter	Range	Range Value	Category
Arsenic	0-0.03	4	Good
	0.03-0.05	3	Poor
	0.05-0.09	2	Very Poor
	>0.9	1	Unsuitable
Nitrate	0-0.5	4	Good
	0.5-1.5	3	Poor
	1.5-2.5	2	Very Poor
	2.5-7.5	1	Unsuitable
	>7.5	5	Unsuitable
Fecal Coliform	0-100	4	Good
	100-400	3	Poor
	400-700	2	Very Poor
	700-1000	1	Unsuitable
	>1000	1	Unsuitable
Total Coliform	0-200	4	Good
	200-1500	3	Poor
	1500-5000	2	Very Poor
	5000-10000	1	Unsuitable

	>10000	1	Unsuitable
Iron	0-0.3	4	Good
	0.3-0.6	3	Poor
	0.6-0.9	2	Very Poor
	>0.9	1	Unsuitable
Sulfate	0-15	4	Good
	15-30	3	Poor
	30-50	2	Very Poor
	50-70	1	Unsuitable
	70-90	1	Unsuitable
pH	5.9-6.6	1	Unsuitable
	6.6-6.9	2	Very Poor
	6.9-7.2	4	Good
	7.2-8.6	3	Poor
	>8.6	1	Unsuitable
EC	100-200	4	Good
	200-400	3	Poor
	400-700	2	Very Poor
	700-1000	1	Unsuitable
	>1000	1	Unsuitable
Phosphate	<0.1	4	Good
	0.1-0.4	3	Poor
	0.4-0.8	2	Very Poor
	0.8-1.2	2	Very Poor
	>1.2	1	Unsuitable
Cl^-	0-50	1	Unsuitable
	50-100	2	Very Poor
	100-250	4	Good
	250-500	3	Poor
	>500	1	Unsuitable
Ca^{2+}	0-25	2	Very Poor
	25-50	3	Poor
	50-75	4	Good
	75-100	1	Unsuitable
	>100	2	Very Poor
Magnesium	0-10	2	Poor
	10-25	3	Poor
	25-35	4	Good
	35-70	2	Very Poor
	>70	1	Unsuitable

Final Map Preparation

Value	Category
4	Highly secure
3	Moderate secure
2	Slightly secure
1	Not secure

CHAPTER THREE: FINDINGS ON WATER AVAILABILITY

3.1 Water Availabilty Situation at Union Level

The condition of ownership is good in Rayenda and bad in Khontakata compared to other unions of Bagerhat District (Table 14). In Khaulia union, the number of available sources in dry seasons are found to be highest. In wet season, the number of available sources is found to be highest in Khontakata union. On the other hand, Southkhali union has lowest available sources in both dry and wet seasons. The duration of water scarcity is lower in Southkhali union in comparison with other unions and hence get the highest score. The score is lower for Rayenda union. Khaulia union occupies the highest position in terms of demand-source ratio and the lowest position is occupied by Southkhali union. In case of total availability, Khaulia union is ahead of other unions. On the other hand, Southkhali union is lagging behind in terms of total availability.

Table 14: Variable wise water availability condition in different unions of Bagerhat

	Dhansagar	Khontakata	Khaulia	Rayenda	Southkhali
Ownership	2.941	2.818	3.175	3.267	3.186
Available Source in Dry Season	1.118	1.323	1.351	1.133	1.000
Available Source in Wet Season	1.647	1.737	1.684	1.700	1.305
Demand-source Ratio	2.118	2.202	2.667	2.089	1.831
Duration of Water Scarcity	2.324	2.404	2.298	2.267	2.525
Total availability	2.065	2.148	2.264	2.080	2.051

Different forms of water delivery technologies, including as PSF, RO, and RWHS, have been discovered in various locations around the Khaulia union, in addition to pond water. In comparison to other unions of Bagerhat, the Khaulia union has maximum RO in number. People of Khaulia have also habituated of treating raw pond, canal, and river water with potassium alum or lime during periods of water scarcity. As a result, during the dry season, the Khaulia union has the most drinking water available sources. Among other unions, Khaulia union also has the highest demand source ratio. For the reasons stated above, the total water availability in the Khaulia union is better than in other unions. Although there are fewer PSF and RO in Southkhali, the respondents expressed satisfaction with the water quality and availability. Furthermore, many of them have large water storage tanks that they got from regional NGOs. As a result, they store adequate rainwater for the dry season's water scarcity. As a result, it has a shorter term of water scarcity than other unions of Bagerhat. Southkhali union is falling behind other unions in Bagerhat in terms of overall availability due to the lowest available sources in the dry and wet seasons, as well as the lowest demand source ratio.

The condition of ownership is good in Lata and bad in Garuikhali compared to other unions of Khulna District (Table 15). In Tildanga union, the numbers of available sources both in dry season and wet season are found to be highest. In Garuikhali union, the numbers of available sources in dry season and in Sholadana unions the numbers of available sources in wet season are found to be lowest. The duration of water scarcity is lower in Uttar Bedkashi union in comparison with other union and hence gets the highest score. The score is lower for Deluti and Kamarkhola unions. Tildanga union occupies the highest position in terms demand-source ration and the lowest position is occupied by Uttar Bedkashi union. In case of total availability, Tildanga union is ahead of other unions. On the other hand, Garuikhali union is lagging behind in terms of total availability.

Tildanga has the most available drinking water sources for dry and wet seasons among the investigated unions in Khulna, with eleven ROs in addition to PSF and RWHS. Tildanga also has the highest demand source ratio of all the unions. That is why, when compared to other unions, Tildanga has the highest total drinking water availability.In Uttar Bedkashi, the duration of water scarcity is the shortest among the union of Khulna due to huge number of hand pumps are available there. Aside from that, Garuikhali has a limited amount of water sources, with only four PSF and one RO. As a result, the Garuikhali union has the lowest total availability of drinking water.

Table 15: Variable wise water availability condition in different unions of Khulna

	Dakshin Bedkashi	Deluti	Garuik hali	Kamar khola	Lata	Sholad ana	Sutarka hli	Tildan ga	Uttar Bedkas hi
Ownership	2.782	2.781	1.529	2.825	3.517	2.677	2.952	3.429	2.361
Available Source in Dry Season	1.350	1.547	1.086	1.238	1.418	1.154	1.556	1.732	1.194
Available Source in Wet Season	2.028	2.063	1.986	2.079	2.088	1.585	2.143	2.339	1.972
Demand-source Ratio	2.860	3.016	2.871	2.889	2.890	2.692	3.175	3.482	2.389
Duration of Water Scarcity	2.430	2.000	2.114	2.000	2.517	2.615	2.302	2.625	2.667
Total availability	2.344	2.258	2.035	2.175	2.483	2.483	2.439	2.739	2.237

The condition of ownership is good in Pratap Nagar and bad in Gabura compared to other unions (Table 16). In Satkhira district, the number of available sources in dry seasons are found to be highest in Padma Pukur whereas in wet season, highest available source is found in Gabura. Pratap Nagar union has lowest available sources both in dry and wet seasons. The duration of water scarcity is lower in Sreeula union in comparison with other unions, hence it gets the highest score. The score is lower for Padma Pukur union. Padma Pukur union occupies the highest position in terms demand-source ratio and the lowest position is occupied by Pratap Nagar union. In case of total availability, Sreeula union is ahead of other unions. On the other hand, Gabura union is lagging behind in terms of total availability. Figure 2 shows the union level water availability map for three districts.

Table 16: Variable wise water availability condition in different unions of Satkhira

	Gabura	Padma Pukur	Pratap Nagar	Sreeula
Ownership	2.090	2.509	2.857	2.646
Available Source in Dry Season	1.141	1.491	1.114	1.481
Available Source in Wet Season	1.962	1.877	1.171	1.658
Demand-Source Ratio	2.769	3.175	2.543	2.949
Duration of Water Scarcity	2.590	3.246	3.514	3.658
Total availability	2.261	2.717	2.578	2.815

Sreeula union has the highest drinking water availability among the several unions in Satkhira, due to the union's ninety hand pumps and four RO. As a result, the duration of water scarcity in Sreeula is also lowest. Gabura has 38 PSF, which work effectively during the rainy season, but the rain-fed ponds dry up during the dry season and become inoperable due to poor maintenance. Gabura also has the longest period of water shortage compared to other unions due to its lack of hand pumps and RO, and as a result, it has the lowest overall drinking water availability among the Shatkhira unions.

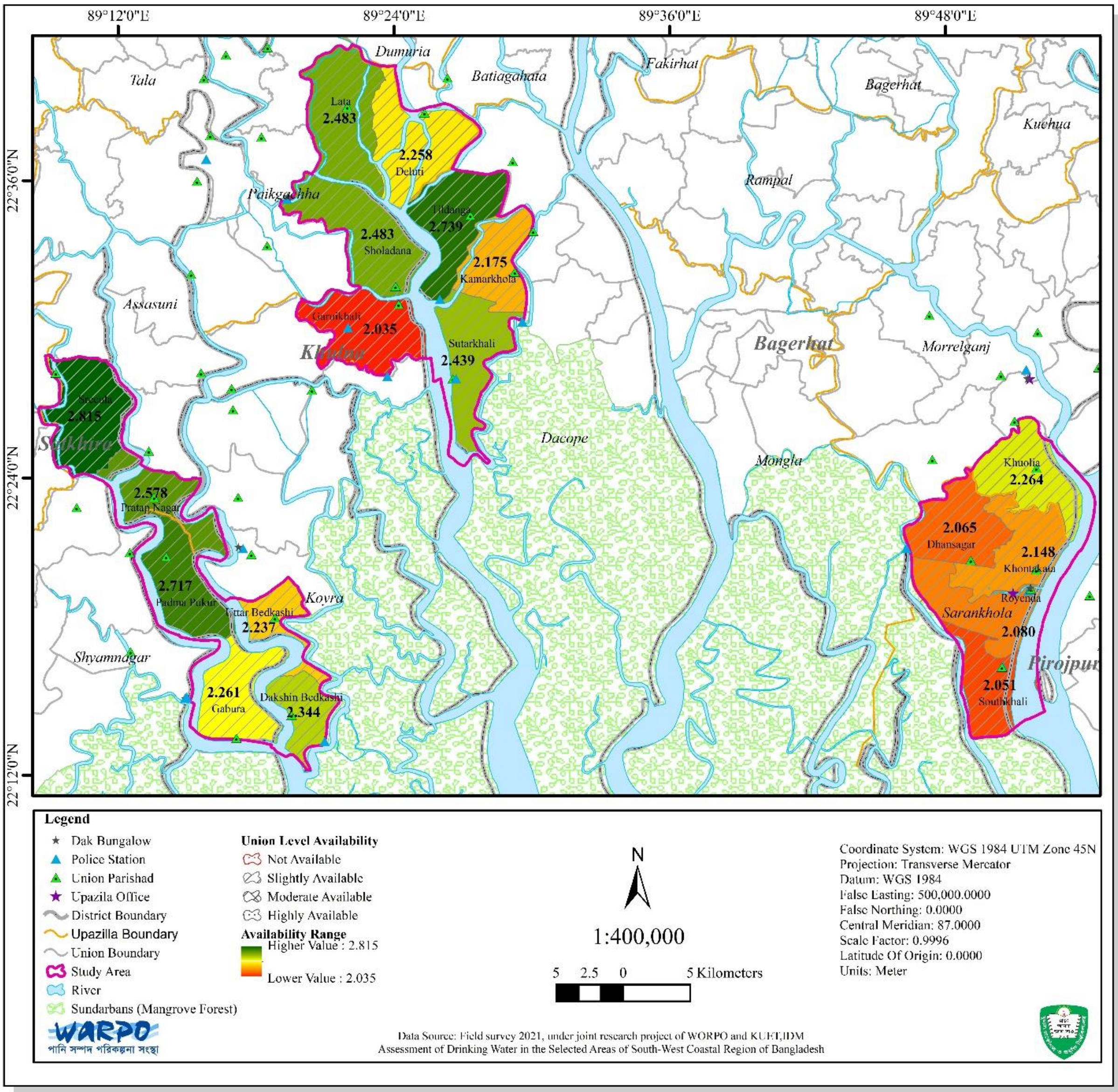

Figure 1: Union level water availability map for three districts.

3.2 Water Availabilty Situation at Upazilla Level

Among seven study upazillas, Morrelganj and Sarankhola upazilla belongs to Bagerhat district. Assasuni and Shyamnagar upazilla belongs to Satkhira district. Rest of the upazillas namely Dacope and Paikgacha fall under Khulna district.

Main sources of drinking water in all upazillas are Pond Sand Filter (PSF), community based Rainwater Harvesting System (RWHS), household based RWHS, shallow tube well, deep tube well etc (Shaibur et al. 2019). In Shyamnagar upazilla 39.1% household uses sources owned by government whereas in Dacope upazilla, only 8.3 % household uses sources provided by government. The percentage of NGO and community provided sources are highest in Dacope which are consecutively 28.6% and 37.5%. According to a research Sarankhola and Paikgacha have very few sources provided by NGOs where the percentages are below 10%. Besides, Sarankhola and Koyra upazailla have lowest percentges of community sources. Sarankhola upazilla has the highest percentage of private sources which is about 63.4% of the total sources in that upazilla. According to a research, shallow tube well and PSF are least successful options in Sarankhola in terms of safe drinking water. RWH is the least used source due to higher cost though can be a potential safe source (Sultana et al. 2013). Figure 3(a) shows the percentage distribution of household as per ownership condition for different upazillas.

Sarankhola upazilla has the highest percentange in terms of only one available sources in dry season. About 82.2% househols in that upazilla can use only one source in dry season . It is found from FGDs that during dry season, RWH is not possible and in shallow tubewell water goes below the water table. Therefore, only few options remain for the houholds to collect water. On the other hand, Morrelganj upazilla has the lowest percentage (52.4%) of housholds who use only single source. Surprisingly, about 47.6% of people in Morrelganj upazilla uses two sources even in the dry season. According to a research, lost of pond were excaveted in Morrelganj for shrimp culture and people often use water from those pond though they are not safe for drinking (Munirul et al. 2010, Mahmud et al. 2014). Figure 3(b) shows the percentage distribution of households as per source availabilty in dry season for different upazillas.

In wet season, the percentage (52.4%) of housholds depends on only one source is high for Morrelganj upazilla and low for Dacope and Koyra Upazilla. However, in Koyra upazilla, more than 97% of housholds depend on two sources during wet season. In Shyamnagar, Sarankhola and Dacope, significant amount households uses more than two sources during wet season. Different types of drinking sources like Pond Sand Filter (PSF), community based Rainwater Harvesting System (RWHS), household based RWHS, shallow tube well, deep tube well etc becomes available in wet season (Shaibur et al. 2019). Specially. RWH is a potential safe source though it is the least used source due to higher cost though (Sultana et al. 2013). Notably, only 19% households in Morrelganj use two sources for collecting drinking water in wet season. Figure 3(c) shows the percentage distribution of households as per source availabilty in wet season for different upazillas.

In Sarankhola Upazilla, maximum household (52.2%) has high demand for drinking water with few sources available according to decided scale. In Dacope Upazilla, only 9.9% household have condition like this. About 42.9% households in Morrelganj have low demand for drinking water in proportion with the available source. From this research it has been found that households in Morrelganj have household member no more than 6 which might be reason for lower demand for water. On the other hand, in Ssarankhola, households have no more than 5 member on an average. So, the main reason for higher demand-source ratio in Sarankhola district is fewer available sources. Households of Koyra Upazilla has stayed behind in terms of low demand. Figure 3(d) shows the percentage distribution of households as per demand-source ratio for different upazillas.

About 76.2% households of Morrelganj Upzilla suffer from three to four months of water scarcity which is the highest among all upazillas. Climate change, seasonal cultivation of shrimp, fewer available sources are the main reasons for prolonged water scarcity (Munirul et al. 2010, Mahmud et al. 2014). In Assasuni upazilla, only 0.9% of hoodhoods face this type of extreme condition. About 63.4% households of this upazilla have no water scarcity over the year which is the maximum among all upazillas. In Sornkhola, more than 36% households suffers from water scarcity for at least one to two months. About 35,7% and 30.4% households of consecutive Assasuni and Sarankhola upazillas faces one to two months of water scarcity. Local people of these upazilla have reported that, people suffer from a short duration of water scarcity due to ground water depletion specially in the dry season. Figure 3(e) shows the percentage distribution of households as per duration of water scarcity for different upazillas.

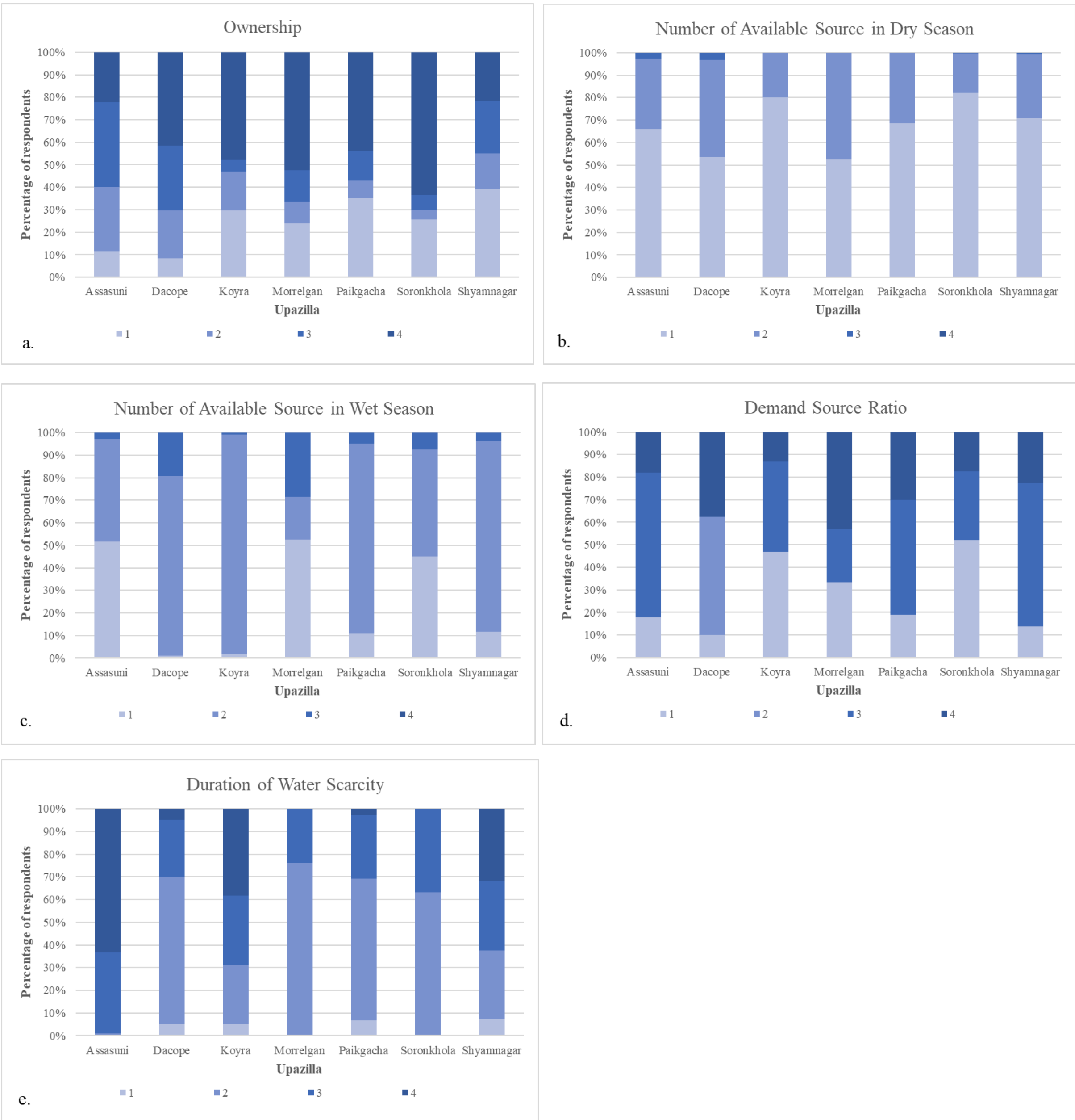

Figure 3: Upazilla wise percentage distribution of households as per different indicators

From Table 17, it is seen that the condition of ownership is comparatively good in Sarankhola Upazilla and worst in Shyamnagar Upazilla. In terms of available sources in dry season, the average condition is comparatively good in Dacope and Morrelganj. On the other hand, this condition is worst in Sarankhola Upazilla. However, in wet season, the average condition is good in Dacope and bad in Assasuni Upazilla. Average score for demand-source ratio is found to be highest in Dacope and lowest in Sarankhola. As per duration of water scarcity, the condition of Assasuni Upazilla is good and bad in Paikgacha Upazilla. Figure 4 shows upazila level water availability map for three districts.

Table 17: Variable-wise water availability condition in different upazillas

	Assasuni	Dacope	Koyra	Morrelganj	Paikgaacha	Sarankhola	Shyamnagar
Ownership	2.705	3.033	2.713	2.952	2.655	3.078	2.275
Available Source in Dry Season	1.366	1.497	1.200	1.476	1.313	1.181	1.297
Available Source in Wet Season	1.509	2.182	1.991	1.762	1.943	1.625	1.920
Demand-source Ratio	2.821	3.177	2.191	2.762	2.925	2.131	2.949
Duration of Water Scarcity	3.625	2.298	3.017	2.238	2.271	2.369	2.870
Total availability	2.745	2.439	2.363	2.270	2.272	2.111	2.459

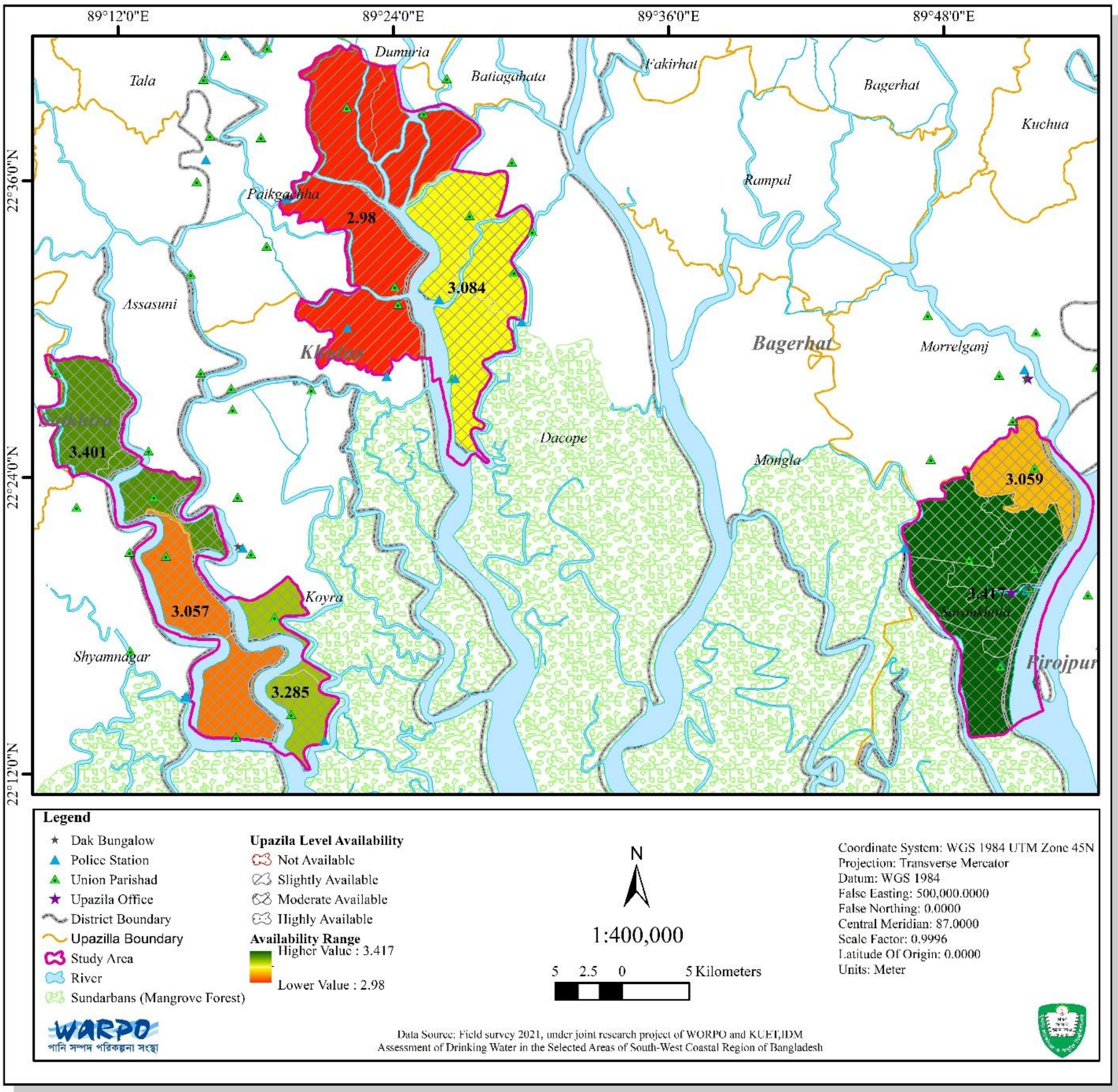

Figure 4: Upazila level water availability map

3.3 Water Availabilty Situation At District Level

According to the surveys in Bagerhat district, 62.9% households collect water from private sources. 25.4% households depend on the sources provided by the government or non-government organization. In dry season, number of available sources are less than 1 according to the 80.4% of households. In wet season, as more sources are available for drinking water, only 45.3% household use less than 1 source. Besides, 45.9% households use more than 2 sources for collecting drinking water. According to research, tubewells are not that popular and very rarely used in Bagerhat district due to lack of fresh water aquifer in suitable depth and highly saline ground water. Due to these conditions of existing water sources, people are forced to depend on pond, PSF or RWH (Hossain et al. 2017). According to the FGDs, local people can harvest rain water during wet season which works as a potential source for drinking water. Therefore, during wet season the number of available sources seems to increase in different regions of Bagerhat district. Demand-source ration is lower than 7 by the 50.9% of households which means 50.9% of the surveyed household in Bagerhat district has admissible amount of water sources to fulfill their demand for drinking water. Oppositely, demand-source ratio is and higher than 21 by the 19% of households which means 19% households has fewer sources in comparison to their demand. According to 64% of the households, duration of water scarcity is within 1 to 2 months. Another 36% households said that, duration of water scarcity is within 3 to 4 months (Appendix B1).

In Khulna district, it is found that 43.7% households collect water from private sources. 25.6% households depend on the sources provided by the government or non-government organization. A group of researchers has found that, water sources in Khulna district are owned by community people whom don't have financial capability to own a source (Benneyworth et al. 2016). Another study indicates that ownership of tubewells and privately funded RWH storage tank depends on the wealth differences (Ferdous Hoque 2021). In dry season, number of available sources are less than 1 according to the 66% of households whereas 32.9% households can use two sources. In wet season, as more sources are available for drinking water, 85.4% households use more than 2 sources for collecting drinking water. Rainwater is used extensively in the monsoon season, but not available year-round because lack of storage (Benneyworth et al. 2016). Therefore, during wet season the number of available sources seems to increase than during dry season in different regions of Khulna district. Another study shows increasing dependence on vendor for getting water during dry season specially by rich people (Ferdous Hoque 2021). Demand-source ratio is lower than 7 by the 21.7% of households which means 21.7% of the surveyed household in Khulna district has admissible amount of water sources to fulfill their demand for drinking water. Oppositely, demand-source ratio is higher than 21 by the 21.3% of households which means 21.3% households has fewer sources in comparison to their demand. It According to 27.7% of the households, duration of water scarcity is within 1 to 2 months. Another 55.8% households said that, duration of water scarcity is within 3 to 4 months (Appendix B2).

According to research, Shatkhira district is subject to different disasters like floods, tidal surge, erosion and cyclones with added effect of climate change. River water in the area is saline and thus availability of potable water for drinking purpose is already a big challenge (Farhana 2011). Installed PSFs by government or local NGOs are also vulnerable to different hazards. Local people consider RWH as the potential sources for drinking water. From this research it has been found that, 22.1% households collect water from private sources. On the other hand, 26.9% households depend on the sources provided by the government or non-government organization. In dry season, number of available sources are less than 1 according to the 69.1% of households whereas only 29.3% households can use two sources. In wet season, a completely opposite scenario has been found. As more sources are available for drinking water, 67.1% households use more than 2 sources for collecting drinking water. Besides, 29.7% households depend on 1 source for collecting drinking water. According to the FGDs, local people can harvest rain water during wet season which works as a potential source for drinking water. Therefore, during wet season the number of available sources seems to increase in different regions of Satkhira district. Demand-source ratio is lower than 7 by the 24.6% of households which means 24.6% of surveyed households in Satkhira district has admissible amount of water sources t fulfill their demand for drinking water. Oppositely, demand-source ratio is higher than 21 by the 11.6% of households which means that the said households has fewer sources in comparison to their demand. . According to 27.6% of the households, duration of water scarcity is within 1 to 2 months. Another 56.0% households commented to have water scarcity for 3 to 4 months (Appendix B3).

The condition of ownership is good in Bagerhat and bad in Khulna compared to other districts. In Khulna, the number of available sources in dry seasons are found to be highest whereas Bagerhat shows the lowest available source in the same season. In case of number of available sources in wet season, Satkhira occupies the best position and Khulna occupies the lowest. The duration of water scarcity is lower in Satkhira in comparison with other districts and hence get the highest score. The score is lower for Khulna. Besides, Khulna occupies the highest position in terms demand-source ration and the lowest position is occupied by Bagerhat.

3.4 Overall Scenario of Water Availability

According to the surveys in all three districts, 44.7% households collect water from private sources, 14.5% households use community source and 36.4% households depend on the sources provided by the government or non-government organization. Number of available sources in both wet and dry season does not exceed 3 in any of the three districts. According to 70.8% households, they can use less than 1 source in dry season. On the other hand, 63% households agreed that same is true for wet season as well. Demand-source ratio is lower than 7 by the 21.4% of households and higher than 21 by 9.7% of households. According to 18.3% of the households, there is no water scarcity whereas 36.1% household said that the duration of water scarcity is within 1 to 2 months. Another 41.6% households claimed that, the duration is 3 to 4 months. According to only 4% households, duration of water scarcity is 5 to 6 months (Appendix C). Figure 5 shows district level water availability map for three districts.

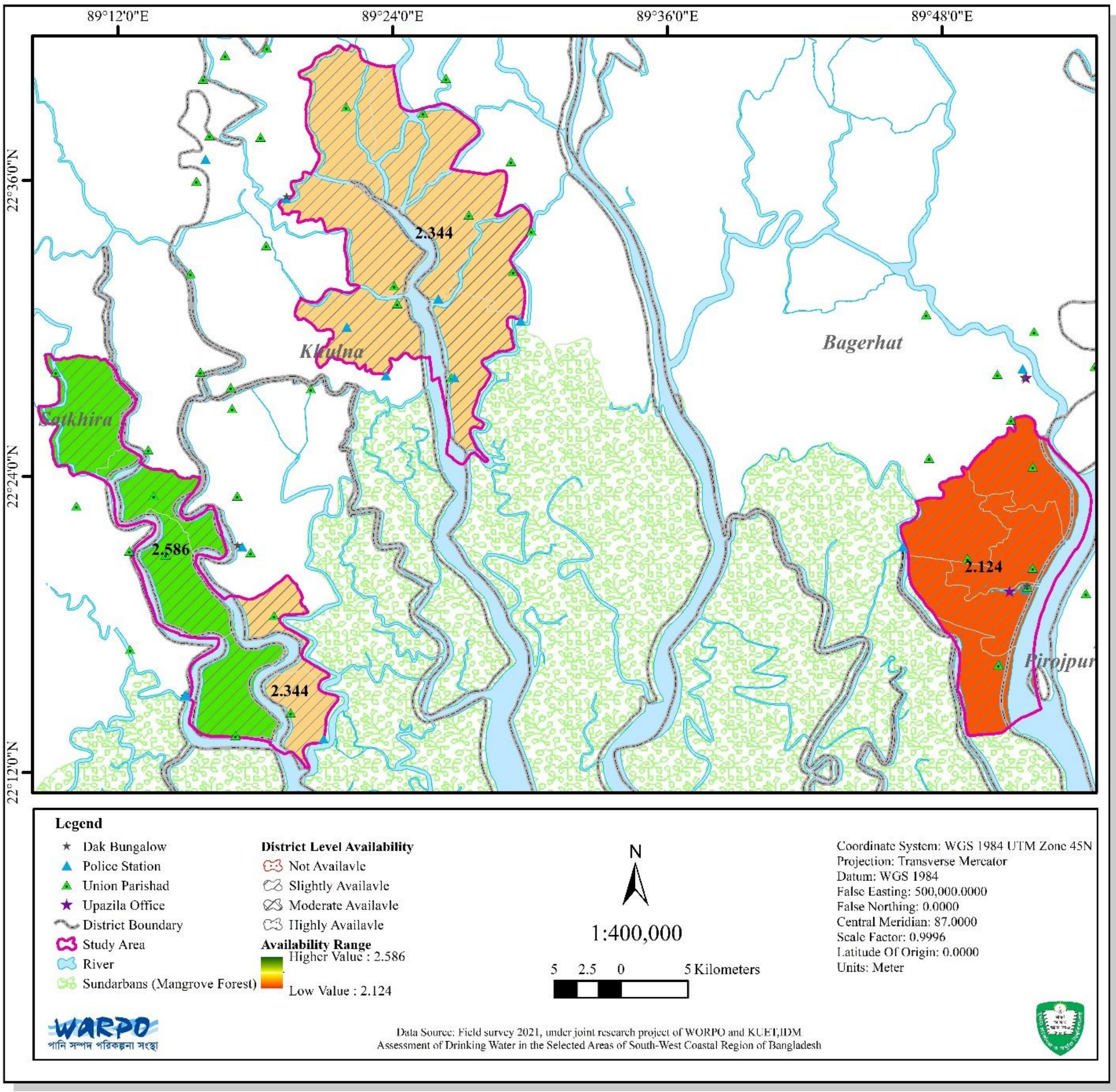

Figure 5: District level water availability map

CHAPTER FOUR: FINDINGS ON WATER ACCESSIBILITY

4.1 Water Accessibility Situation at Union Level

From the following table 18, it is seen that in people of Dhansagar union of Bagerhat district have to travel shorter distance to collect water on an average whereas Rayenda union households have to travel far on an average in comparison with other unions. Water price income ratio is also lower for this union. In terms of transport, Southkhali anad Dhansager union produces the best result among all unions and Khontakata union suffers most. The condition of road is found to be worst in Dhansagar union. This condition is better in Khontakata union compared to other unions. Southkhali is occupying a good position in terms of travel time. On the other hand, Rayenda is occupying the worst condition under same indicator. All unions are showing equally good results in terms of queuing time. The worst condition in terms of road condition, equity, safety and security are found in Rayenda union. Cost-income ratio is comparatively high in Khontakata union whereas the ratio is comparatively low in Southkhali union. In terms of equity, safety and security, consecutively Southkhali, Dhansagar and Khaulia union are lagging behind but in case of total accessibility, Southkhali union is ahead of others. On the other hand, Khaulia union is lagging behind in terms of total accessibility.

Table 18: Variable-wise water accessibility condition in different unions of Bagerhat

	Dhansagar	Khontakata	Khaulia	Rayenda	Southkhali
Distance from source	2.971	2.020	2.333	1.933	2.729
Mode of transport	3.000	2.737	2.947	2.789	3.034
Road condition	1.500	2.172	1.597	2.056	1.881
Travel time	2.677	1.859	2.228	1.744	2.780
Queuing time	4.000	4.000	4.000	4.000	4.000
Cost -Income ratio	3.706	3.556	3.579	3.622	3.814
Equity	3.941	3.838	3.895	3.856	3.542
Safety	2.735	3.253	2.614	3.256	3.119
Security	3.765	3.737	3.579	3.811	3.814
Total accessibility	3.197	3.029	2.989	3.023	3.268

From table 19, it is seen that among all the unions of Khulna District, residents of Garuikhali union have to travel shorter distance while the residents of Deluti Union have to travel longer distance to collect water. Among all unions, Tildanga union is staying ahead in terms of transport mode whereas Sholadana union is lagging behind. All the unions under study have poor road condition on an average. Among this, Sholadana is in slightly better condition. The households in Lata union need less travel time for collecting water whereas the other Unions need more time to travel to the source and come back to house. In Guruikhali, people do not have to wait at the source while collecting water. In Southkhali union, people are waiting more in comparison with other unions. Cost income ratio is low in Deluti union and high in Sholadana union. water collection. In terms of both safety and security Sholadana union is lagging behind. The condition of equity is worser in Tildanga union. In case of total accessibility, Lata union is ahead of other unions. On the other hand, Sholadana union is lagging behind in terms of total accessibility.

Table 19: Variable wise water accessibility condition in different unions of Khulna

	Dakshin Bedkashi	Deluti	Garuikhali	Kama rkhola	Lata	Sholada na	Sutarkh ali	Tildan ga	Uttar Bedkas hi
Distance from source	1.972	1.094	2.200	1.810	2.088	1.646	1.952	2.089	2.028
Mode of transport	3.087	2.828	2.957	3.302	3.308	2.662	3.095	3.393	3.083
Road condition	1.756	1.391	2.300	1.064	2.033	2.308	1.127	1.911	1.694
Travel time	1.953	1.031	1.900	1.778	2.363	1.523	2.016	1.821	1.861
Queuing time	3.539	3.438	4.000	3.079	3.934	3.554	3.460	3.321	3.139
Cost - Income ratio	3.494	3.797	3.200	3.635	3.418	2.939	3.508	3.750	3.528
Equity	3.950	4.000	3.957	4.000	3.978	3.908	3.905	3.857	4.000
Safety	3.718	3.219	3.814	3.984	3.868	3.108	3.714	3.964	3.833
Security	3.936	4.000	3.986	4.000	3.956	3.754	3.937	3.946	3.944
Total accessibility	3.071	2.810	3.107	3.034	3.204	2.764	3.026	3.164	3.063

From the following table 20 and figure 6, it is seen that among all the unions of Satkhira District, residents of Sreeula union travels shorter distance while the residents of Gabura union travels longer distance to collect water. In most unions, residents use van, rickshaw and bicycle except in Sreeula Union where they mostly walk to collect water from the source. All the unions under study have poor road condition. The road condition of Pratap Nagar in comparatively better than other unions. In terms of travel time, people from Pratap Nagar union suffer least whereas people form Gabura suffers most. In all union except in Gabura, people need to wait less than 5 minutes to collect water. Cost-income ratio is low in Pratap Nagar union whereas the ratio is high in Gabura union. Respondents from all unions of Satkhira District reported to get equal treatment during water collection with a minor exception of Gabura Union. Households of Gabura Union reported to feel no stress while the households of other Unions reported to feel mental stress during water collection. In terms of security, no violence has been reported by the respondents of the Pratap Nagar union. In case of total accessibility, Sreeula union is ahead of other unions. On the other hand, Gabura union is lagging behind in terms of total accessibility.

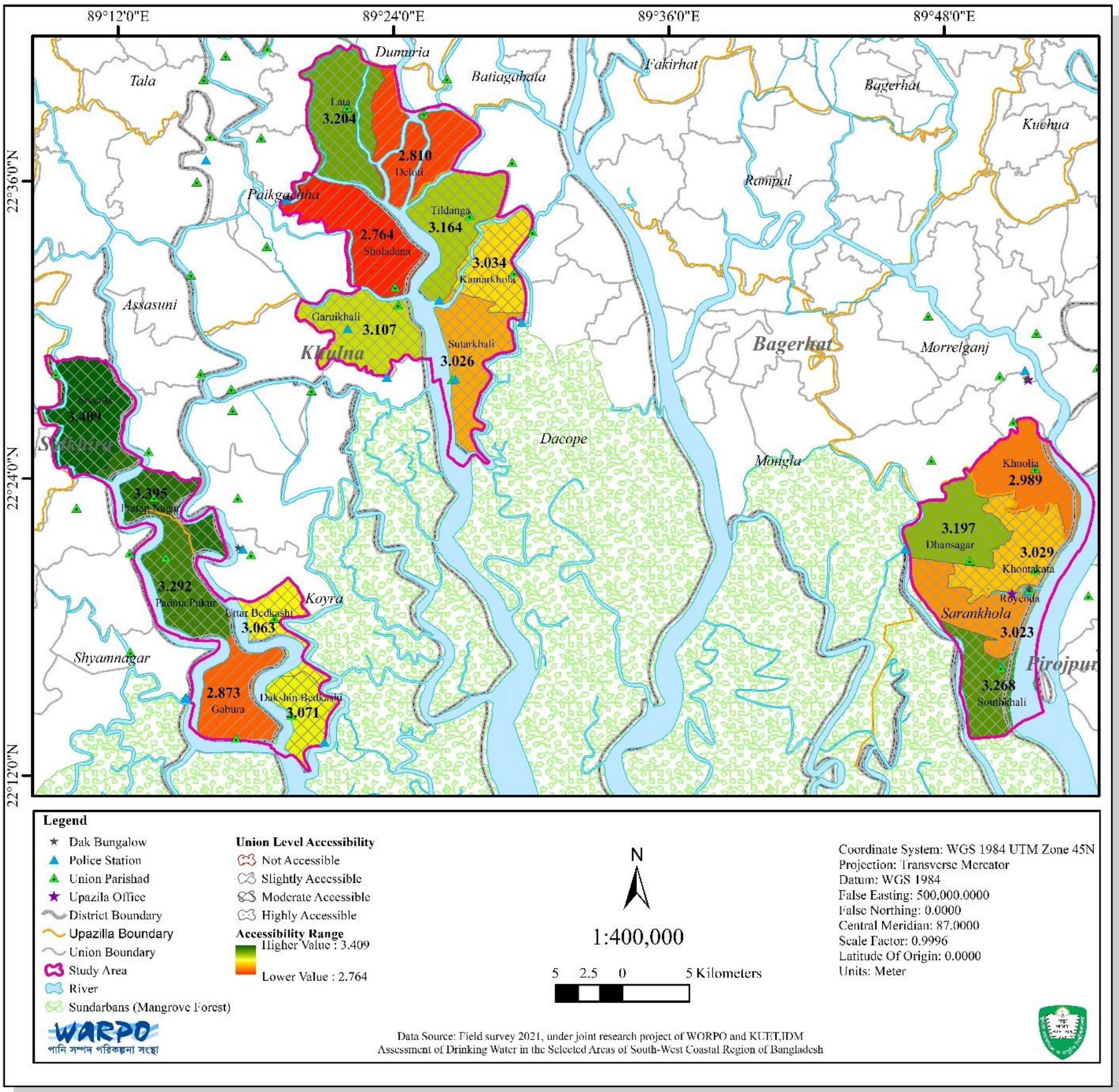

Figure 6: Union level water accessibility map

Table 20: Variable wise water accessibility condition in different unions of Satkhira

	Gabura	Padma Pukur	Pratap Nagar	Sreeula
Distance from source	1.923	2.579	2.886	3.038
Mode of transport	2.910	2.930	2.857	3.101
Road condition	1.192	1.421	1.857	1.595
Travel time	1.885	3.263	2.971	2.987
Queuing time	3.872	4.000	4.000	4.000
Cost -Income ratio	3.346	3.491	3.800	3.760
Equity	3.962	4.000	4.000	4.000
Safety	2.872	3.386	3.429	3.532
Security	3.846	3.983	4.000	3.987
Total accessibility	2.873	3.292	3.395	3.409

4.2 Water Accessibility Situation at Upazila Level

Among seven study upazillas, Morrelganj and Sarankhola upazilla belongs to Bagerhat district. Assasuni and Shyamnagar upazilla belongs to Satkhira district. Rest of the upazillas namely Dacope and Paikgacha fall under Khulna distrcit.

In Paikgacha upazilla, more than 65% household travel at least 500m to reach to the source which is very concerning. This percentage is 22.3% for Assasuni upzallia which is very low in comparison with other upazillas. According to the 54.5% household of Assasuni, the distance to the source is less than 100m. Besides, in Morrelganj upazilla, about 47.6% households travel less than 100m. Only 15.3% households of Paikgacha upazilla agreed that the source is within 100m. From FGDs it is found that, most of the people in Paikgacha use tubewell for the purpose of drinking which are very far from their house rather than ponds most of which are located besides their house. According to FGDs, Assasuni upazilla have more than 800 deep and shallow tubewells which makes the sources within colse reach of the households. From a research it is found that, Assasuni Upazilla has better road network which might also be the reason for lesser travel distance to the sources (Amin et al. 2016). Figure 7(a) shows the percentage distribution of household as per distance to source for different upazillas.

Less than 5% households from Dacope, Koyra, Paikgacha and Sarankhola upazilla use truck or boat to travel to source or to transport water. In Assasuni and Paikgacha, more than 26% households use van, rickshaw or bicycle to transport water from source. Most of the people from all upazilla have to walk to collect and transport water. This percentage is high for Shyamnagar upazilla which is about 73.2%. Local people reported that a considerable amount of people do not need to transport water as they have their own sources within their house. As per this research 39.1% surveyed households in Shyamnagar have their own sources which is the highest among other upazillas. This is one of the main the reason people walk to the sources instead of using other trasnports. Figure 7(b) shows the percentage distribution of household as per the mode of transport for different upazillas.

According to less than 5% households in all upazillas, no road is required to go to the source. Maximum people in all upazillas uses kutcha road to collect water except in Paikgacha upazilla. In Paikgacha upazilla, maximum people (39.5%) uses mixed road. In Morrelganj, Sarankhola and Paikgacha, a certain percentages of people use pucca road. It is found from another research that Paikgacha has good connectivity of pucca roads which are mainly constructed by Local Government Engineering Department (LGED) and Roads & Highway Department. In Shyamnagar upazilla, no surveyed people use pucca road to collect water (Shama et al., 2020). About 73.5% people from Dacope anad 71.2% people from Shyamnagar upazilla use kutcha road. According to a study, lots of rural roads were rebuild under the food/cash-for-work programs by local government and NGOs in Shyamnagar upazilla which might be the reason for high percentage of katcha road as well as their usage (Masud-All-Kamal and Hassan 2018). Fiure 7(c) shows the percentage distribution of household as per road condition for different upazillas.

About 66.9% household of Paikgacha upazilla travel more than 15 minutes to go to and come back from the source. On the other hand, only 24.1% people of Assasuni upazilla travel more than 15 minutes. In Assasuni, 48.2% households requires less than 5 minutes to travel. This percentage is also considerably high and above 40% in Shyamnagar and Morrelganj upazilla. From FGDs it is found that few existing RO are the main sources of drinking water in Paikgacha union. The location and distance of these sources are main reason for higher travel time. There are several other RO plant in Paikgacha but most of those are used by few welthy people as the cost is too high for general people to bear. On the other hand, Assasuni and Shyamnagar upazilla have many available water sources and good road condition which are causing lower travel time for water collection in these two upazillas (Amin et al. 2016, Masud-All-Kamal and Hassan 2018). Figure 7(d) shows the percentage distribution of household as per travel time for different upazillas.

In Sarankhola, Morrelganj and Assasuni, 100% people do not have to wait or queue for collecting water. Also, maximum households in other upazillas do not need to wait or queue for collecting water though in Dacope and Koyra, these amounts are compartively lower than other upazillas. In Dacope and Koyra Upazilla, consecutively 12.7% and 10.4% households requires queuing for more than 15 minutes. The Dacope and Koyra Upazila has scarcity of safe drinking water due to increasing salinity (Shaibur et al. 2021) which is creating pressure deep tubewell. According to FGDs, rapid depletion of ground water by extensive extraction and fast growing population are also responsible for extra queuing time during water collection in tubewell. Iure 8(e) shows the percentage distribution of households as per queuing time for different upazillas.

Cost-income ratio is low according to the maximum households of all upazillas. More than 80% people in Assasuni, Dacope, Koyra and Morrelganj upazilla agreed that cost-income ratio is very low and negligible. According to this research, in Assasuni and Morrelganj upazilla people have an average income of more that 14000 Taka. Besides, in Dacope and Koyra, people have an avarage income of more than 10000 Taka. Higher income are mainly the reason for lower cost-icome ratio comared to other upazillas. Still, a certain percentages of people in Paikgacha and Shyamnagar claimed to have a considerably high cost income ratio. Accrding to the local people of Shyamnagar, the cost they bear are mainly for transporting water, purifying water and maintaining sources. Sometimes they use tablet and most people can’t afford to purify water stuff so they drink what they get. Figure 7(f) shows tIe percentage distribution of household as per queuing time for different upazillas.

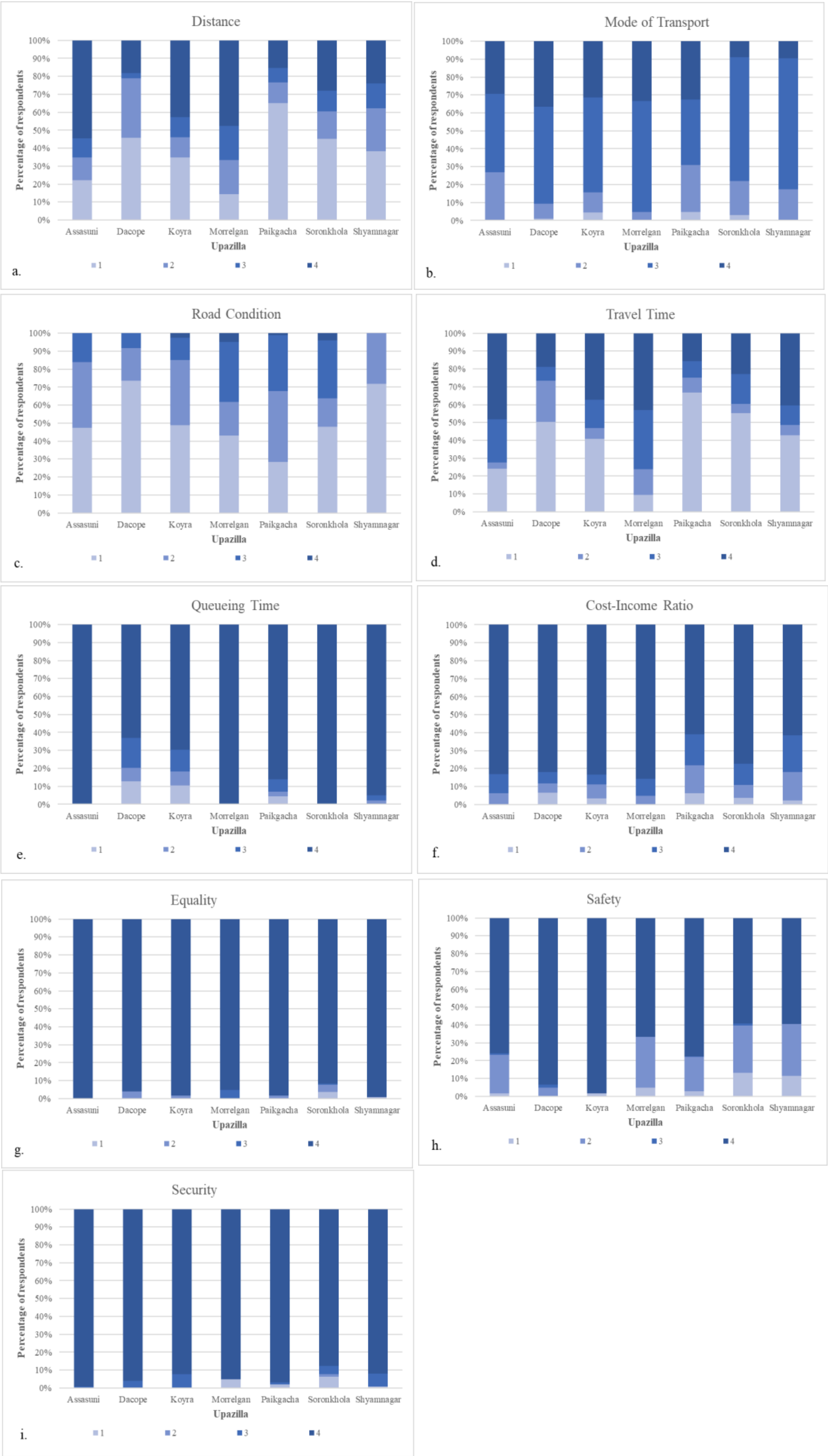

Figure 7: Upazilla-wise percentage distribution of households as per different indicators.

More than 90% people in all upazillas are glad in terms of equality. In Morrelganj, 4.8% households face religious inequality. Few people in Sarankhola and Dacope faces socio-economic inequality. About 3.8% people in Sarankhola faces gender inequality. In terms of safety, more than 95% people in Dacope and Koyra were pleased as they face no stress while collecting water. Very negligible amount of people is worried about mental stress. About 29% people in Shyamnagar and 28.6% people in Morrelganj suffers from physical stresses during water collection. About 13.1% households in Sarankhola upazilla and 11.6% households in Shyamnagar upazilla have faced injuries or accidents while collecting drinking water. More than 90% people in all upazillas except in Sarankhola are satisfied in terms of security. In Koyra and Shyamnagar, consecutively 7.8% and 7.2% households have faced verbal assaults. Very few people (1.3%), only from Sarankhola upazillas, has faced the act of thievery sometimes. Some people from Sarankhola, Paikgacha and Morrelganj upazillas have suffered from physical assaults which are very concerning. It is found from a study that social capital in coastal areas of Bangladesh are relative rich which is responsible for their strong community bondage. This is the main reason for higher equality, safety and security in this region (Masud-All-Kamal and Hassan 2018, Kadir 2021). Figure 7(g), 7(h), 7(i) show the percentage distribution of household as per equality, safety and security for different upazillas. Figure 8 shows upazila level water accessibility map for three districts.

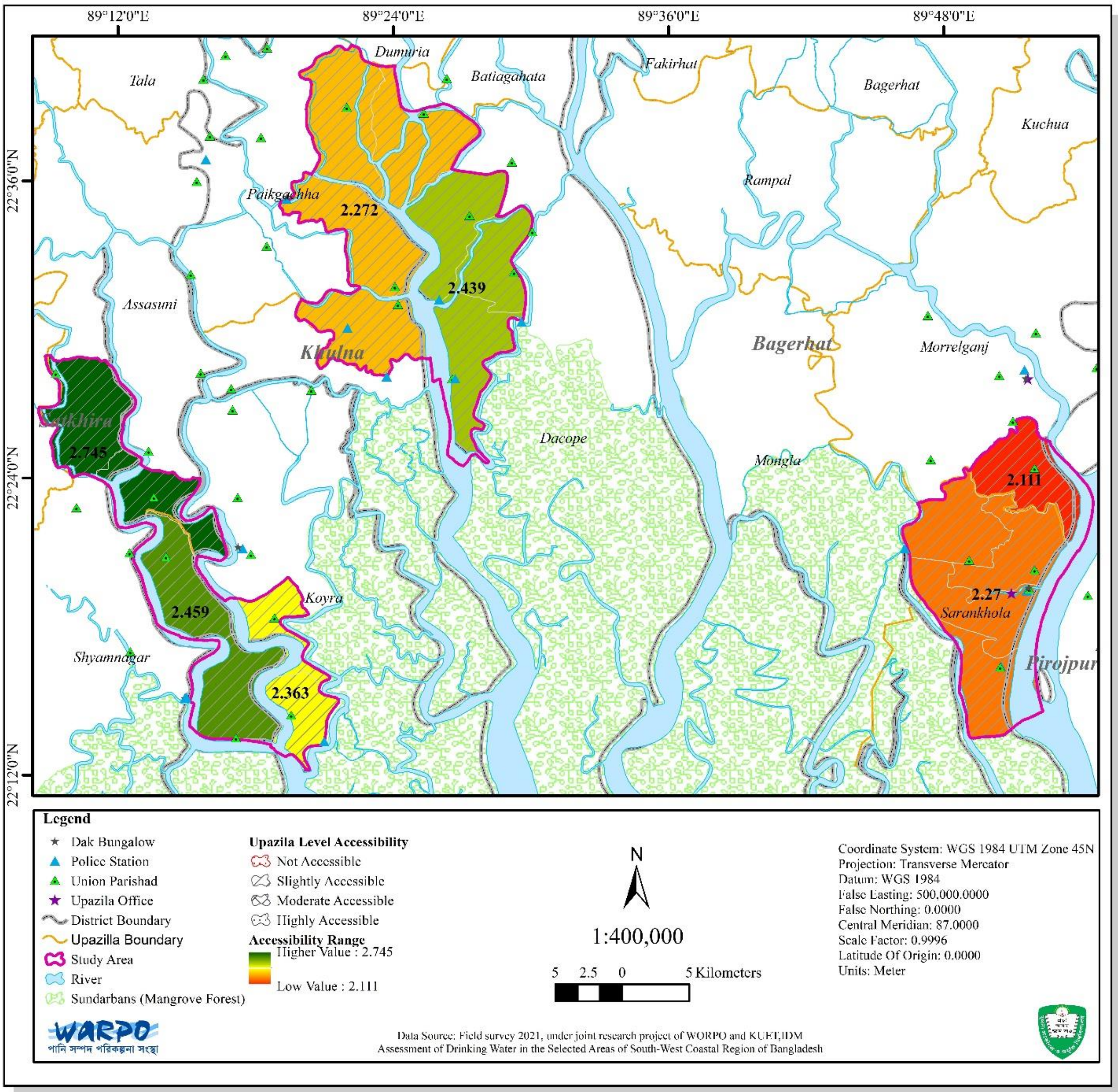

Figure 8: Upazila level accessibility map

From table 21 it is seen that, in terms of distance, Morrelganj upazilla is in good condition whereas Paikgacha upazilla is in worst condition. As per transport mode, the condition of Morrelganj is good but the condition of Sarankhola is bad in comparison with other upazillas. The average condition of road is found to be good comparatively in Paikgacha upazilla and very bad in Shyamnagar upazilla. In terms of travel time, Morrelganj upazilla has got the highest score whereas Paikgacha upazilla has got the lowest score. In the question of queuing time, all upazillas are in good condition but Assasuni, Morrelganj and Sarankhola upazillas score highest. Average condition of cost-income ratio are found to be good in Morrelganj and bad in Paikgacha. In terms of equality and security, the average score Assasuni upazilla is highest among all upazillas. Koyra Upazilla has got the highest score in terms of safety.

Table 21: Variable wise water accessibility condition in different upazillas

	Assasuni	Dacope	Koyra	Morrelganj	Paikgaacha	Sarankhola	Shyamnagar
Distance from source	2.973	1.934	2.617	3.000	1.737	2.222	2.232
Mode of transport	3.027	3.260	3.113	3.286	2.968	2.838	2.920
Road condition	1.688	1.348	1.687	2.000	2.046	1.925	1.283
Travel time	2.964	1.950	2.496	3.095	1.737	2.072	2.493
Queuing time	4.000	3.298	3.409	4.000	3.747	4.000	3.928
Cost -income ratio	3.768	3.635	3.687	3.810	3.327	3.628	3.413
Equality	4.000	3.923	3.965	3.952	3.961	3.803	3.978
Safety	3.509	3.884	3.948	3.286	3.527	3.063	3.073
Security	3.991	3.961	3.922	3.857	3.925	3.741	3.906
Total Accessibility	3.401	3.084	3.285	3.417	2.980	3.059	3.057

4.3 Water Accessibility Situation at District Level

As per the national standard of Bangladesh, a source should be within 50m of the household premise (GoB, 2005). According to the survey in Bagerhat district, 29.5% households have water sources within 100m of their house and 43.3% households have houses located more than 500m far from the sources. 10.5% household requires no transport to collect water while 17.8% uses rickshaw and van to reach the sources and for transporting water. Majority of the people, about 68.7% walks to the source for collecting water. As per FGDs, people are willing to carry heavier loads instead of using other transport because of higher transportation cost. 47.7% household use fully kutcha road to go to the source and 32.2% household use fully pucca roads. Only 4.1% households require no road because they have their own source close to their house. 24.3% household requires less than 5 minutes to travel to the source and come back to the house whereas 52.3% households require more than 15 minutes for travelling. Beside this, 100% households do not have to wait for more than 5 minutes. A study indicated that PSFs in the Bagerhat district have been installed randomly based on the availability of rain fed ponds. Therefore, users have to travel several distances to collect water. Moreover, lower cost of PSF are causing substantial queuing time (Hossain 2017). People from FGDs also told that these sources are also frequently damaged by natural disaster, lack of regular cleaning and proper maintenance. They often become dysfunctional within a short time after installation. Water price – income ratio is less than 0.01 for 78.1% household which means price of water is not burden for them. Still, this ratio is more than 0.05 is for 3.5% household. A study shows that women and girls are generally responsible for water collection (Hossain 2017). About 92.1% households get equal treatment and 59.6% households feel no stress during water collection. However, 26.6% households which is a considerable amount, faces physical stress and 12.6% people have suffered from injuries and accidents. On the other hand, 88.3% household faces no violence during water collection (Appendix E1).

The field survey in Khulna District reveals 21.5% households have water sources within 100m of their house whereas 53% households use sources that are located at least 500m distant to their houses. This distance creates a huge mental burden to the women of the house as they are solely responsible for collecting drinking water. Field survey suggests 33.3% households require no transport to collect water since the sources are within very close distance to the house while 45.6% needs to walk to reach the sources and for transporting water. Only 17.7% uses van, rickshaw and bicycle for collecting water as those sources situated far away from their household. 46.6% households use fully kutcha road, 20.1% households use fully pucca roads and 32.2% households use mixed road to go to the source. According to a study, road networks in coastal part of Khulna district often are damaged by cyclone, storm surge and floods which causes a hindrance for collecting potable water (Kumar et al. 2010). Consequently, 56.5% households of the study area require more than 15 minutes traveling to the source and coming back to the house. Households that are situated close to the source (20.8%) require less than 5 minutes traveling to the source. Interestingly, 75.6% households do not need to wait for more than 5 minutes. As most of the people uses ponds and PSF (Benneyworth et al. 2016), they do not have to wait unlike collecting water from tubewell. 8.1% people wait for more than 15 minutes in queue for collecting water as the source is tube-well and it takes time to pump water. Water price – income ratio is less than 0.01 for 71.8% household which means price of water is not burden for them. The main reason for lower cost-income ratio is higher average income of the people from Khulna District. Still, this ratio is more than 0.05 is for 5.9% household. About 97.6% households get equal treatment and about 86.5% people feel no stress during water collection. In addition, 95.7% households never face violence during water collection (Appendix E2).

According to the survey in Satkhira District, 37.8% households have water sources within 100m of their house whereas 31.3% households located more than 500m of the sources. Due to popularity of shrimp culture in Satkhira district, most of the available ponds are not safe for collecting drinking water (Farhana 2011). Therefore, people who wants to collect safe drinking water have to travel far. About 59.8% of the households walk to reach the sources of the water while 18.5% require no transport to collect water. Only 21.7% uses van, rickshaw and bicycle for collecting water. According to FGDs, people prefer to walk to the source to save money and for that they are even willing to carray heavier loads. 60.6% households use fully kutcha road, only 7.2% households use fully pucca roads and 32.1% households use both kutcha and pucca to go to the source. Consequently, 34.5% households of the study area require more than 15 minutes to travel to the source and come back to the house whereas 44.2% households require less than 5 minutes. Remarkably, 97.2% households of Satkhira District do not need to wait for more than 5 minutes in queue for collecting water. Water price – income ratio is less than 0.01 for 71.5% household which means price of water is not burden for them. Higher average income of the people of Satkhira district and comparatively lower water price is the main reason for this lower ratio. Local people reported that, they pay little mainly for water purification and transportation. In case of sources owned by community they have to pay an yearly maintenance cost which is very negligible as per them. Still, this ratio is more than 0.05 is for 1.2% household. About 99.6% households get equal treatment. On the other hand, 95.2% households never face no violence during water collection. About 67.1% households feel no stress during collecting water. In contrast, 25.7% respondents feel physical stress during water collection from the source (Appendix E3).

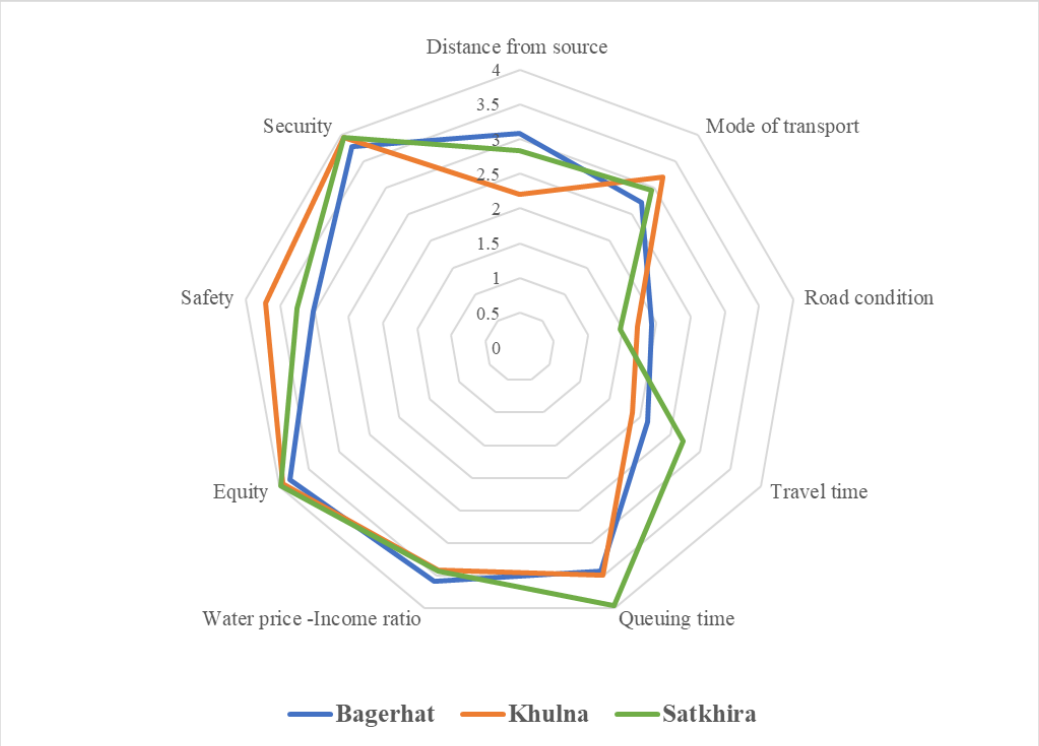

Figure 9: Overall Scenario of Drinking Water Accessibility in three Districts

From the figure 9, it is seen that in Bagerhat, people have to travel shorter distance within short period of time to collect water. In Khulna, people have to travel on an average a long distance from their home to the source of water to collect water. In terms of mode of transport, Khulna produces the best result among all districts and Bagerhat is in worst condition. Condition of road is best in Khulna. On the other hand, condition of road in Satkhira is bad compared to other two districts. People in Satkhira suffers less in terms of travel time and queuing time. People in Khulna suffers most in terms of travel time. Water price income ratio is higher for Bagerhat district and lower for Khulna district. Satkhira is also in good position in terms of equality and security whereas Khulna is in good position in terms of safety. Bagerhat district is in the lowest position in terms of equality, safety and security. Figure 10 shows district level water accessibility map for three districts.

4.4 Overall Scenario of Water Accessibility

According to the survey, overall 40.7% households have water sources within 100m of their house and 32.8% households have houses located more than 500m far from the sources. 25.1% household requires no transport to collect water while 22.5% uses rickshaw and van to reach the sources and for transporting water. Majority (51.5%) people walk to the source for collecting water. 50.4% household use fully kutcha road to go to the source and 20.9% household use fully pucca roads. Only 1.3% households require no road. 26.8% household requires less than 5 minutes to travel to the source and come back to the house whereas 54.8% households require more than 15 minutes for travelling. Beside this, maximum (79%) households do not have to wait for more than 5 minutes. Only 9.8% people waits for more than 15 minutes in the source for collecting water. Water price – income ratio is less than 0.01 for 73.3% household which means price of water is not burden for them. Still, this ratio is more than 0.05 is for 9.2% household. 96.2% households get equal treatment and 74.5% household feel no physical or mental stress during water collection. On the other hand, 90.3% household faces no violence during water collection (see Appendix F).

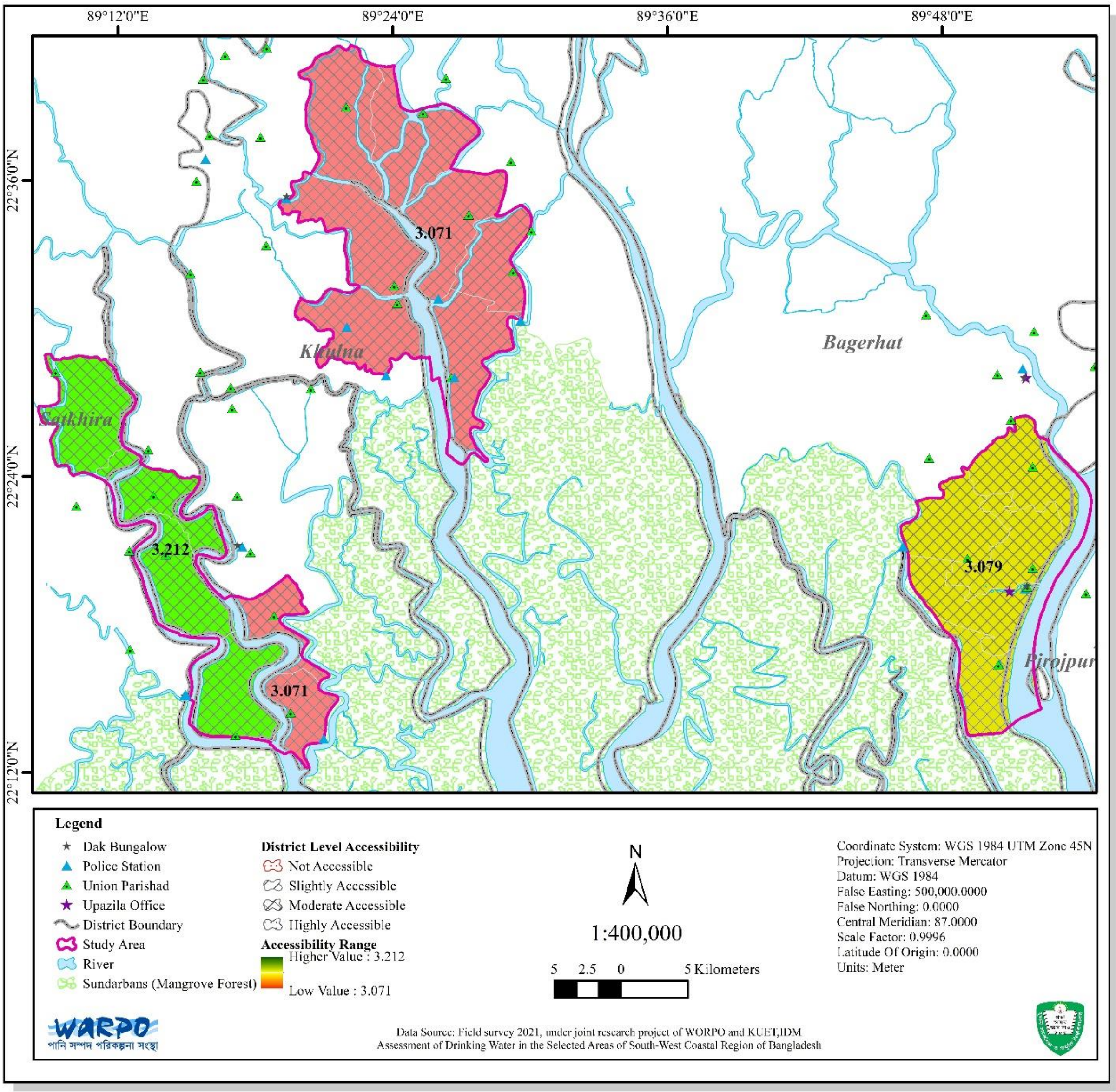

Figure 10: District level water accessibility map

CHAPTER FIVE: FINDINGS ON WATER QUALITY

5.1 Results and Discussion

A total of 91 numbers samples during dry season of 2022 were collected from various locations of the study area as per the standard protocol prescribed by (APHA, 1998). Significant physicochemical characteristics of collected water samples in study area has been examined statistically as well as outcomes like standard deviation, mean, minimum, and maximum parameters are depicted in Table 22. Also the correlation matrix between water quality parameters is given in Table 23. The chemical, physical and biological parameters of the analytical outcomes of water sample have been compared to GOB guideline Standards for public health as well as drinking standards (GOB, 2020).

Table 22: Statistical analysis of physico-chemical water quality parameters

Parameter	Standards GOB (2022)	Maximum			Minimum			Mean			Standard deviation		
		Bagerhat	Khulna	Satkhira	Bagerhat	Khulna	Satkhira	Bagerhat	Khulna	Satkhira	Bagerhat	Khulna	Satkhira
pH	6.5-8.5	7.88	8.23	9.12	6.57	5.44	6.34	7.07	7.26	7.59	0.32	0.68	0.53
EC (mS/cm)	0.4	1.15	15.02	7.07	0.11	0.1	0.33	0.29	3.03	3.22	0.22	4.08	2.27
Total Coli (cfu/100ml)	0	570000	19800	45530	45	40	279	4223	1408	10546	11228	3610.2	15992
Fical Coli (cfu/100ml)	0	1005	1954	3540	27	10	30	474	631	1123	262.74	533.80	802.14
Sulfate (mg/L)	250	83.57	97.23	98.94	10.62	5.03	5.88	27.80	18.03	26.34	16.35	15.54	26.29
Chloride (mg/L)	250	241.06	1382.55	1276.6	21.27	10.64	31.90	43.09	220.74	249.21	43.35	299.64	270.85
Nitrate (mg/L)	45	3.48	35.33	25.47	0.07	0.10	0.06	0.92	3.35	3.13	0.78	7.42	5.96
Calcium (mg/L)	75	60.12	130.26	68.14	10.02	8.02	10.02	24.63	39.55	31.96	12.99	28.21	18.50
Magnesium (mg/L)	30-35	30.38	132.46	82.64	3.65	2.43	2.43	10.78	29.84	33.78	7.19	26.47	25.24
Iron (mg/L)	0.3-1.0	0.44	0.80	0.68	0	0	0	0.02	0.13	0.26	0.09	0.20	0.20
Phosphate (mg/L)	0.1	0.89	31.06	4.58	0.06	0.12	0.30	0.35	2.82	0.58	0.25	6.02	0.96
Arsenic (mg/L)	0.05	0	0.1	0	0	0	0	0	0.003	0	0	0.02	0

Table 23(a): Correlation matrix between water quality parameters for Bagerhat area

	pH	EC	TC	FC	PO_4^{3-}	SO_4^{2-}	Cl^-	Calcium	Magnesium	Iron	Nitrate	Arsenic
pH	1											
EC	0.523663	1										
TC	0.013676	0.039052	1									
FC	-0.05631	-0.30251	0.154214	1								
PO_4^{3-}	0.41004	-0.15683	0.237704	0.346757	1							
SO_4^{2-}	0.127891	0.616483	-0.1275	-0.28924	0.001092	1						
Cl^-	0.484097	0.932864	0.072919	-0.25562	-0.19703	0.479392	1					
Calcium	0.429838	0.749618	-0.02451	-0.34781	-0.20595	0.557373	0.560652	1				
Magnesium	0.525825	0.883282	-0.05973	-0.33205	0.035489	0.71718	0.745803	0.793277	1			
Iron	-0.16759	-0.07302	-0.07442	-0.28668	-0.11333	0.097354	-0.06793	-0.03975	0.004414	1		
Nitrate	0.205537	-0.32521	0.243587	0.395821	0.576237	-0.36267	-0.19805	-0.46281	-0.23751	-0.17712	1	
Arsenic	0	0	0	0	0	0	0	0	0	0	0	1

Table 23(b): Correlation matrix between water quality parameters for Khulna area

	pH	EC	TC	FC	PO_4^{3-}	SO_4^{2-}	Cl^-	Calcium	Magnesium	Iron	Nitrate	Arsenic
pH	1											
EC	0.087223	1										
TC	0.083443	0.26934	1									
FC	0.014528	0.063851	0.286936	1								
PO_4^{3-}	0.008079	0.614595	0.296672	0.167547	1							
SO_4^{2-}	-0.17063	0.166215	-0.01746	-0.10511	-0.12212	1						
Cl^-	0.272954	0.747423	0.093592	-0.06954	0.403878	-0.12127	1					
Calcium	0.129883	0.556883	0.268865	-0.03355	0.292711	0.40894	0.412129	1				
Magnesium	0.098653	0.65284	0.050081	0.062915	0.235168	0.320267	0.519215	0.624737	1			
Iron	-0.0722	0.475787	0.219534	0.242579	0.701974	-0.21357	0.393282	0.131401	0.230507	1		
Nitrate	-0.11229	0.444447	0.492461	0.458019	0.661007	-0.11124	0.197999	0.242547	0.165719	0.65762	1	

Arsenic	0.144133	0.344593	0.151904	-0.02949	0.081211	-0.05566	0.370399	-0.04352	-0.0435	0.147327	0.109164	1

Table 23(c): Correlation matrix between water quality parameters for Satkhira area

	pH	EC	TC	FC	PO_4^{3-}	SO_4^{2-}	Cl^-	Calcium	Magnesium	Iron	Nitrate	Arsenic
pH	1											
EC	-0.09463	1										
TC	0.017377	-0.31771	1									
FC	-0.19491	0.204269	0.133062	1								
PO_4^{3-}	0.264474	0.177266	-0.19655	0.0616	1							
SO_4^{2-}	0.520924	-0.58689	0.532556	-0.27369	-0.18286	1						
Cl^-	-0.06433	0.375888	-0.13753	-0.14296	-0.09655	-0.18788	1					
Calcium	-0.13173	0.453432	0.015399	0.152633	-0.17663	-0.11743	0.570746	1				
Magnesium	-0.16725	0.646139	-0.19507	0.006569	-0.15346	-0.15029	0.565762	0.692476	1			
Iron	-0.10442	0.591439	-0.32852	0.101706	0.110958	-0.45783	0.256295	0.31961	0.391487	1		
Nitrate	0.176821	-0.01698	-0.25322	-0.29484	-0.03014	-0.25043	0.151254	0.018862	-0.14928	-0.04392	1	
Arsenic	0	0	0	0	0	0	0	0	0	0	0	1

5.1.1 pH

pH is the measure of hydrogen ion concentration value in water which indicates whether a solution is acidic, neutral or basic(Khan & Jhariya, 2017). The pH required has to be in the range of 6.5–8.5 for the drinking purpose (GOB, 2020). In present study although the pH concentration is ranges from 5.44 to 9.12, however the pH value of majority water samples are within the permissible limit as prescribed by(GOB, 2020).

5.1.2 Electrical conductivity (EC)

Conductance is a calculation of the electric flow capability of water that is specifically related to ion concentration in the water (EPA, 2012). The greater the salinity amount, the less the oxygen absorbed. An abrupt rise or decline in conductivity in the water body may indicate pollution (Dandge and Patil, 2021). In the present investigation values observed for conductivity during dry season ranged from 0.1-15.02 mS/cm, the minimum conductivity values were observed at Lata union of Paikgachaupazila under Khulna district with 0.1 mS/cm. Conductivity of the water sample for the entire study area stands at an average of 2.18 mS/cm. This data reveals that, there is high solute dissolution in collected water sample, slow ion-exchange between soil as well as water, or basically soluble geologic rock and mineral forms in the area.

5.1.3 Escherichia coli

E. coli is present in large numbers in the normal intestinal flora of humans and animals, where it normally causes no harm. Though, in other parts of the body, E. coli can be responsible for serious illness, such as urinary tract infections, bacteraemia and meningitis(Patil & Dandge, 2021) Total coliforms can also live and grow in water distribution systems, mostly in the presence of biofilms (WHO, 2011). It was significantly detected in all collected water samples in study area. This significant presence of E. coli may be attributed to the bacteriological water in these areas was not safe and required treatment before drinking.

5.1.4 Sulphate

Sulphate occur naturally in several minerals and are used commercially, mainly in the various chemical industries. They are discharged into water by industrial wastes and through atmospheric deposition; though, the highest levels generally occur in water mostly are from natural sources. In present study the Sulphate concentration is ranges from 5.03 to 98.94 which show that it is within the permissible limit as prescribed by (GOB, 2020).

5.1.5 Chloride

The salts such as NaCl (sodium), KCl (potassium) and $CaCl_2$ (calcium), are chloride containing and commonly spread in nature. The weathering cycle absorbs chlorides from several rocks into the water and soil (WHO, 1996). Based on the following, cation is the sensation of taste threshold of chloride anion in water. Sense of perception thresholds for sodium and calcium chloride in water are in the array 200–300 mg/L (Zoeteman, 1990).The anthropogenic sources of chlorides in water sources is inorganic fertilizer made with potash, sewage contamination and industrial effluents landfill leachates, animal fodders, irrigation drainage. In the study area chloride concentration ranges from 10.64 mg/l to 1382.55 mg/l with the maximum value of 1382.55 mg/L has been observed in few number of villages. The presence of chloride in slightly higher amounts at some sites can be because of both natural as well as anthropogenic procedures such as shrimp and curb farming.

5.1.6 Nitrate

Nitrate concentration above 45 mg/l (GOB, 2020), causes methemoglobinemia (blue baby syndrome), gastric cancer, thyroid disease and diabetes (Kumar, 2014). Hence, increasing nitrate contamination seriously threatens public drinking water supply and human health (Kumar, 2014). The main source of nitrate concentration in drinking water is anthropogenic activity. Nitrate concentration ranges from 0.07 mg/l to 35.33 mg/l in the study area. Higher level of nitrate at some sites might have been either due to overuse of fertilizers or due to leaching.

5.1.7 Calcium

The high concentration of calcium ions can cause abdominal ailments and is undesirable for domestic use as it causes encrustation and scaling (Kumar, 2014). In the present study area calcium concentration ranges from 8.02 to 130.26 mg/l.

5.1.8 Magnesium

Magnesium is an essential element for human being, it is important for normal bone structure in the body. Water with high levels of magnesium or calcium is considered as hard and is undesirable for domestic purposes. In the study area magnesium concentration ranges from 2.43 mg/l to 132.46 mg/l. Both the highest calcium and magnesium concentrations exceed the permissible limit as prescribed by GOB 2022 for the same water sample in the study area.

5.1.9 Phosphate

Phosphate is a common constituent of agricultural fertilizers, manure, and organic wastes in sewage and industrial effluent. It is an essential element for plant life, but when there is too much of it in water, it can speed up eutrophication (a reduction in dissolved oxygen in water bodies caused by an increase of mineral and organic nutrients) of rivers and lakes. Soil erosion is a major contributor of Phosphate to streams. Bank erosion occurring during floods can transport a lot of Phosphate from the river banks and adjacent land into a stream, lake, or other water body. In the study area magnesium concentration ranges from 0.06 mg/l to 31.06 mg/l.

5.1.10 Iron

Iron can be a troublesome chemical in water supplies. Making up at least 5 percent of the earth’s crust, iron is one of the earth’s most plentiful resources. Rainwater as it infiltrates the soil and underlying geologic formations dissolves iron, causing it to seep into aquifers that serve as sources of groundwater for wells. In present study calcium concentration is ranges from 0 to 0.80 which shows that it is within the permissible limit as prescribed by GOB 2022.

5.1.11 Arsenic

Arsenic occurs naturally as a trace component in many rocks and sediments. Whether the arsenic is released from these geologic sources into groundwater depends on the chemical form of the arsenic, the geochemical conditions in the aquifer, and the biogeochemical processes that occur. Arsenic also can be released into groundwater as a result of human activities, such as mining, and from its various uses in industry, in animal feed, as a wood preservative, and as a pesticide. In drinking-water supplies, arsenic poses a problem because it is toxic at low levels and is a known carcinogen. In present study arsenic concentration has been found in two water samples with one sample (0.1 mg/L) cross the permissible limit as prescribed by GOB 2022 and the other collected water samples show zero concentration of arsenic.

5.2 Water Quality Index (WQI)

Water quality index is one of the most successful tools to represent information on the quality of streams, lakes or any water body (Patil & Dandge, 2021). WQI is a scientific equation used to transform large number of water quality data into a single number which is easily understandable to lay man (Tyagi & Sharma, 2014). It serves the understanding of water quality issues by integrating complex data and generating a score that describes water quality status (Reza & Singh, 2010) WQI value is computed for the suitability of surface and groundwater for domestic uses human (Ravikumar, 2011).

To evaluate water suitability for drinking purposes water quality index of the study area was calculated using different water quality parameters during dry season of 2022. For the present investigation, calculated WQI values are classified into four types as shown in Table 24. Also the water quality index range of the study area is shown in Table 25.

The water quality index data of the present study revealed that, only 1% water sources were of good quality and other 99% not good with a significant portion of water sources poor or very poor for drinking purpose during dry season as given in Table 26. The high WQI values in water samples were principally due to the occurrence of extremely higher values of E.Coli which is very alarming. The higher concentration of water quality parameters like nitrate, electrical conductivity and chloride also accountable for high WQI values in the study area.

Table 24: Water classification based on Water Quality Index

WQI Value	Category	Water Quality
<2000	4	Good water
2000-4000	3	Poor water
4000-6000	2	Very poor water
>6000	1	Water unsuitable for drinking

Table 25: Water quality index range of the study area

	Area (Sq.km)			Area (%)		
Water Quality	Khulna	Bagerhat	Satkhira	Khulna	Bagerhat	Satkhira
Good water	0.00	0.04	0.00	0.00	0.005	0.00
Poor water	275.97	188.44	90.98	39.14	26.73	12.90
Very poor water	80.18	2.25	67.87	11.37	0.32	9.63
Total	**356.15**	**190.73**	**158.85**	**50.51**	**27.06**	**22.53**

Table 26: Percentage of water sources based on water quality

	% of Water Sources		
Water Quality	Khulna	Bagerhat	Satkhira
Good water	0	1	0
Poor water	43	24	13
Very poor water	7	3	9
Total	**50**	**28**	**22**

Figures 11, 12 and 13 shows the spatial distribution of WQI in the study area, based on Kriging interpolation technique. The spatial maps depicted that all part of the study area falls under the category of “Poor water” and “Very poor water” except few villages of Bagerhat district which falls under the category of “Good water” during dry season. These are due to the sources situated very close to latrine or directly connected to on site sanitation systems. Also some ponds in Bagerhat district were found very much unprotected due to daily activities of surrounding population and animals. Figure 14 shows the overall water security for study area at a glance.

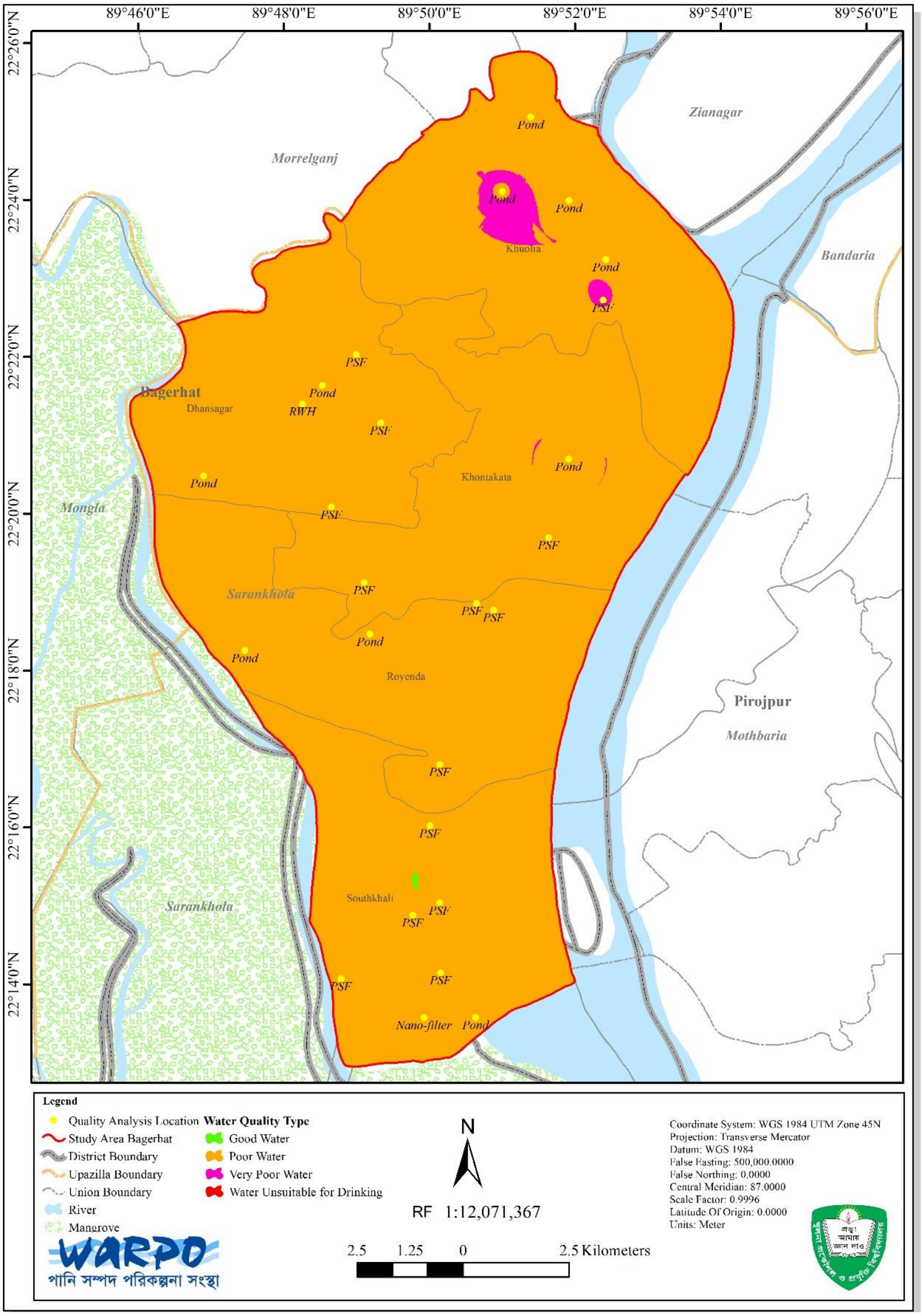

Figure 11: Spatial distribution of WQI during dry season for Bagerhat area

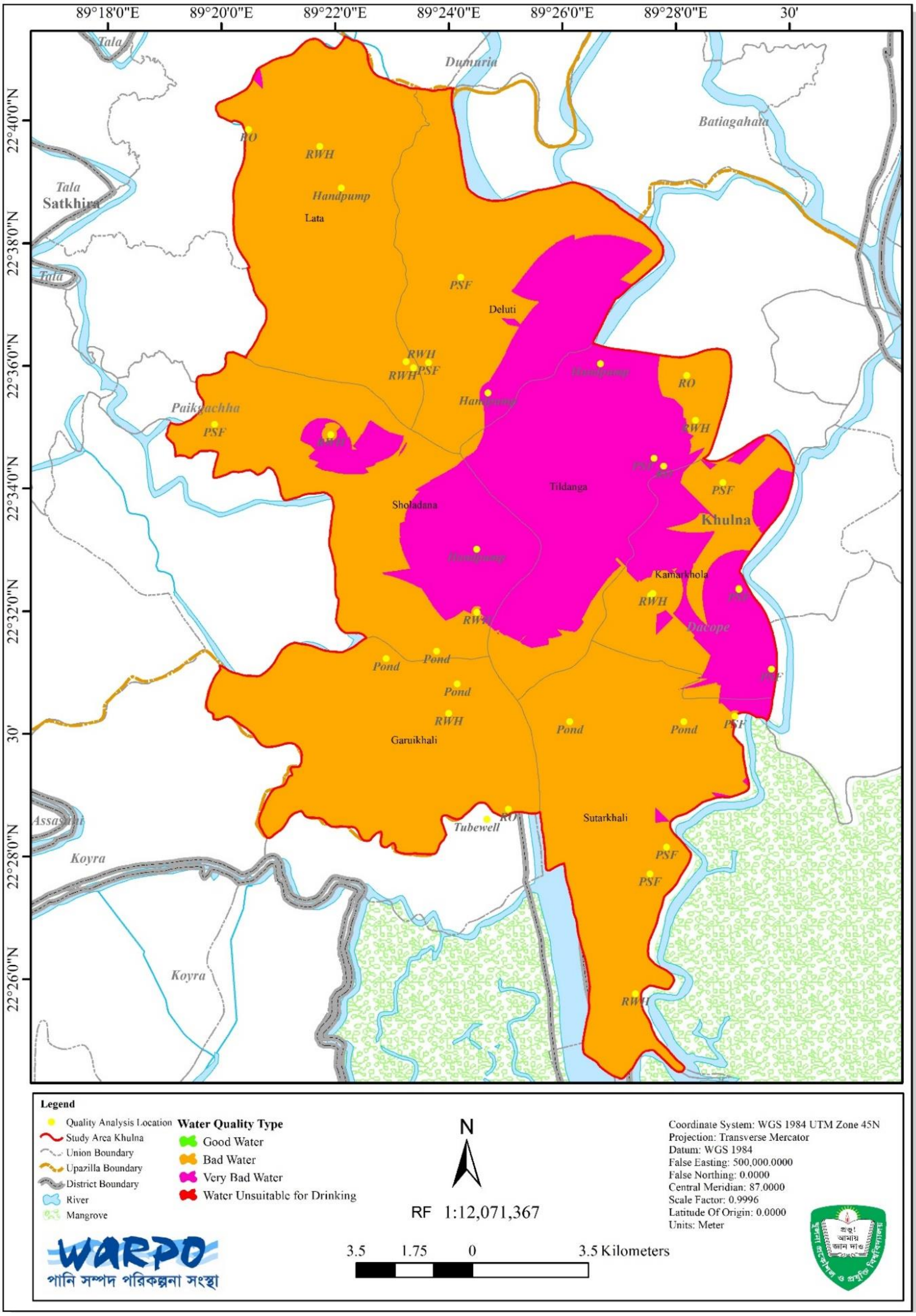

Figure 12: Spatial distribution of WQI during dry season for Khulna area

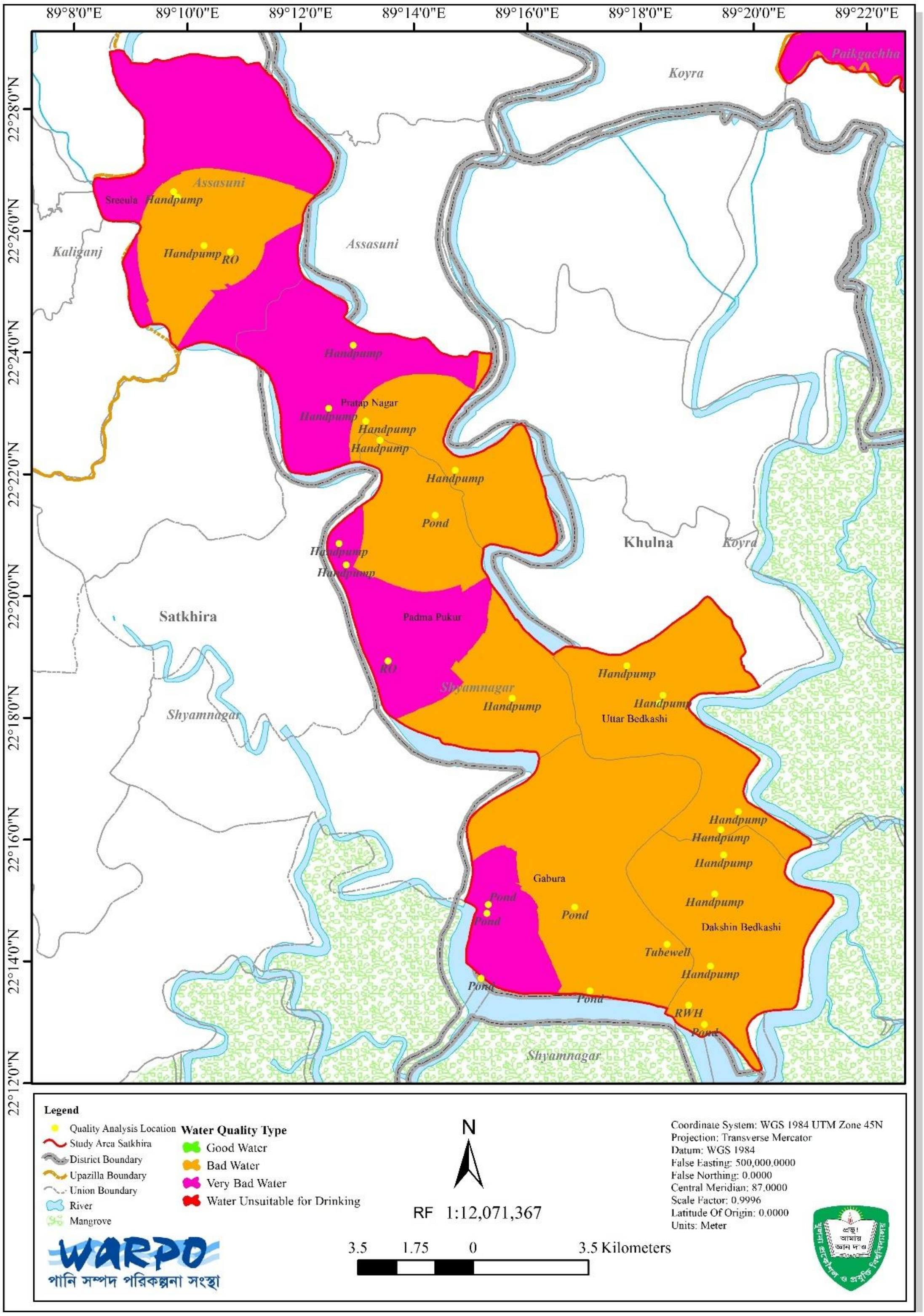

Figure 12: Spatial distribution of WQI during dry season for Satkhira area

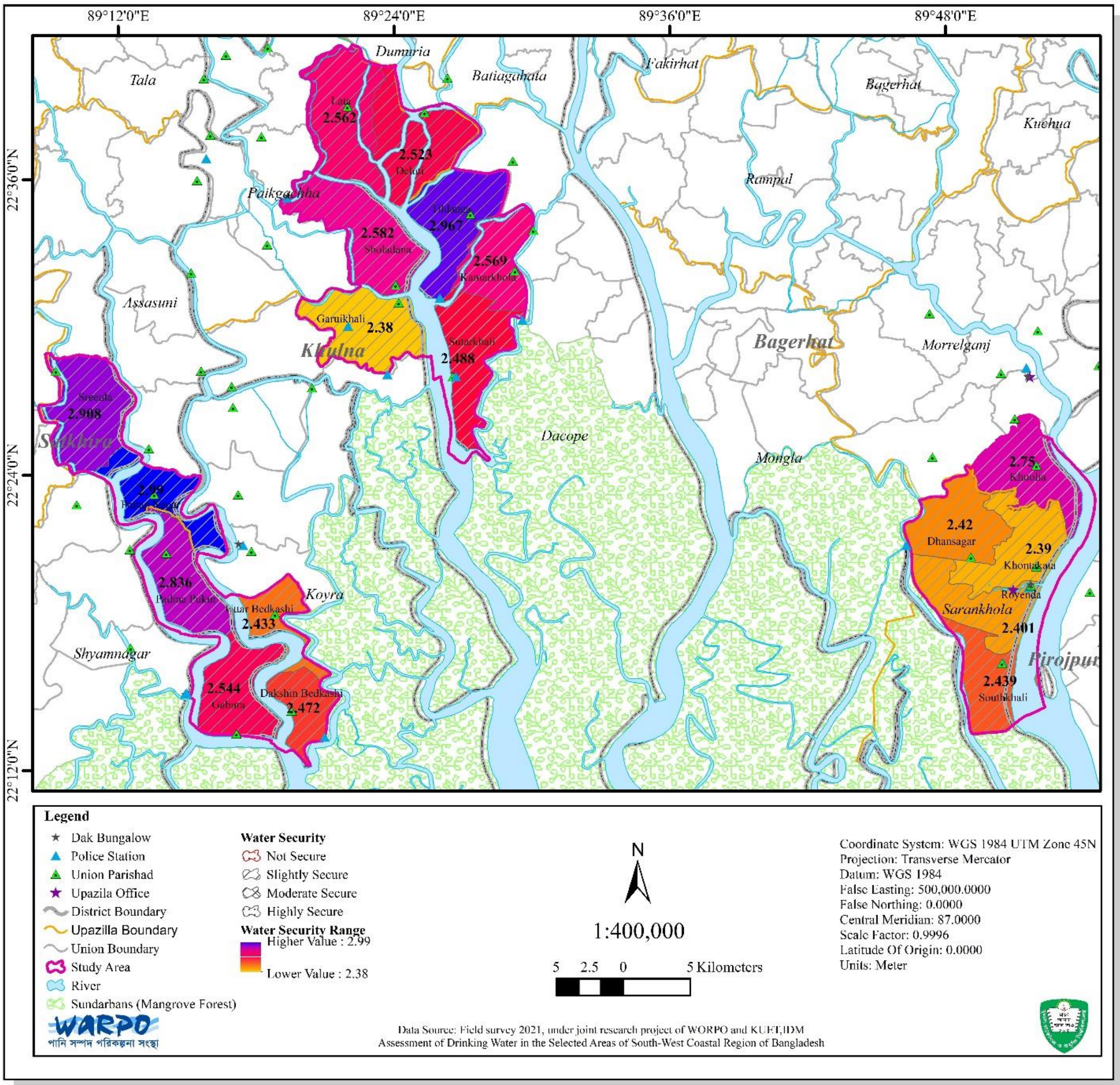

Figure 14: Overall water security for study area

- Overall water security condition in 18 disaster hotspots in the South-west coastal region in poor to very poor.
- However, in comparison, Satkhira has better water security with an average score of 2.82 whereas Khulna and Bagerhat have scores of 2.55 and 2.48 respectively.

4 Action Plan and Present Status of Research Work

Table 27: Action plan versus completion of research work

Activities	Months																		Comment	% of Completion
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
Approval of the Project																			Done	100%
Staff and Expert recruitment																			Done	100%
Staff orientation and deployment																			Done	100%
Inception meeting																			Done	100%
Reconnaissance survey																			Done.	100%
Activities # 01																				
Types and numbers of sources, ownership of the source, and continuity of services																			Done	100%
Fixing the drinking water source location																			Done	100%
Developing source location map																			Under	100%
Developing availability index map																			Under	100%
Activities # 02																				
Develop Indicators																			done	100%
Questionnaire Survey																			Done	100%
Focus Group Discussion																			Done	100%
Key Informant Interview																			Done	100%
Collection of Secondary Data																			On going	100%
Activities # 03																				
Selection of sources for water sampling																			Almost done	100%
Water sample collection																			Not yet	100%
Water quality analysis																			Not yet	100%
Water quality mapping																			Not yet	100%
Spatial distribution of water quality parameters																			Not yet started	100%
Development of water quality index model																			Not yet started	100%
Data Analysis																			Under	100%

Activities	Months																		Comment	% of Completion
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
Mobile App Preparation																			Not yet	95%
Report Writing																			Under	95%
Dissemination and Reporting																				
Initial Workshop in Khulna																			Done	100%
Yearly progress report																			Done	100%
Final Project Report																			Stipulated time is not begun.	100%
Final Workshop in Dhaka																			Stipulated time is not begun.	0%

CHAPTER SIX: DEVELOPMENT OF ANDROID MOBILE APPLICATION-WATAPP

6.0 General Information

WATAPP is a water related mobile application and could be found in Play Store. It contains the outputs of the current study. The application is designed as a decision making tool that will provide an instant overview of the water security situation of Khulna, Satkhira and Bagerhat Districts of south-western Bangladesh.

6.1 Developing Components of the Application

The user manual consists of the following three sections

- 6.1.1 Geo Processing Tools
- 6.1.2 Hosting Technologies
- 6.1.3 Application Development Tools and Technologies

Geo Processing Tools will discuss the tools used to create maps from collected data.

Hosting Technologies section will provide a short overview of every technology used to host our database and other servers.

Application Development Tools and Technologies section will provide a short introduction of those languages and tools what we used to create our app.

6.2 Geo Processing Tools

Geoprocessing is a framework and collection of tools used to handle geographical and related data. The entire array of geoprocessing tools may be used to undertake spatial analysis or automate the management of GIS data. In our application we used different tools for process our data.

6.2.1 GIS Mapping Software

GIS software lets us produce maps and other graphic displays of geographic information for analysis and presentation. With these capabilities a GIS is a valuable tool to visualize spatial data.

A GIS stores data on geographical features and their characteristics. Geographic Information Systems store information using spatial indices that make it possible to identify the features located in any arbitrary region of a map

6.2.2 PostgreSQL

PostgreSQL is a robust, open-source object-relational database system that uses and extends the SQL language and has several capabilities for safely storing and scaling the most complex data demands.

PostgreSQL includes several capabilities designed to assist developers in building applications, and administrators in protecting data integrity and building fault-tolerant settings, and we can manage our data regardless of how large or small the dataset. PostgreSQL is very extendable in addition to being free and open source.

6.2.3 PostGIS

PostGIS is a PostgreSQL object-relational database system plugin that supports the storage of

GIS (Geographic Information Systems) objects in the database. PostGIS contains utilities for analyzing and processing GIS objects, as well as support for GiST-based R-Tree spatial indexes.

6.2.4 Geo-Server

GeoServer is a Java-based server for viewing and editing geographical data. GeoServer provides tremendous freedom in map generation and data sharing by utilizing open standards established by the Open Geospatial Consortium (OGC).

GeoServer data may be seen in a variety of popular mapping apps, including Google Maps, Google Earth, Microsoft Bing Maps, and MapBox. GeoServer may also communicate with standard GIS systems such as ESRI ArcGIS.is a PostgreSQL object-relational database system plugin that supports the storage of GIS (Geographic Information Systems) objects in the database. PostGIS contains utilities for analyzing and processing GIS objects, as well as support for GiST-based R-Tree spatial indexes.

6.3 Hosting Technologies

Following Technology is used to host our PostgreSQL database and Geo Server in online.

- ➢ Virtual Private Server (VPS)

6.3.1 Virtual Private Server (VPS)

A virtual private server (VPS), also called a virtual dedicated server (VDS), is a virtual server that appears to the user as a dedicated server, but that is actually installed on a virtual computer here for our application we used Linux CentOS 7 VPS server.

6.4 Development Tools and Technologies

The following technologies are used to develop our application.

- JAVA
- JavaScript
- Openlayers

6.4.1 JAVA

Java is a high-level, class-based, object-oriented programming language with a low number of implementation dependencies. It is a general-purpose programming language designed to allow programmers to write once and execute anywhere, which means that generated Java code may run on any platform that supports Java without the need for recompilation. The Android platform enables developers to manage and control Android devices by writing managed programs in Java.

6.4.2 JavaScript

JavaScript (JS) is a lightweight, interpreted, object-oriented programming language with first-class functions. It is best known as a scripting language for Web pages, although it is also used in many non-browser applications. It is a multi-paradigm, prototype-based scripting language that supports object-oriented, imperative, and functional programming techniques.

6.4.3 OpenLayers

OpenLayers is an open-source JavaScript toolkit for presenting map data in web browsers as slippy maps. It provides an API for developing powerful web-based geospatial apps akin to Google Maps and Bing Maps.

OpenLayers supports GeoRSS, KML (Keyhole Markup Language), Geography Markup Language (GML), GeoJSON, and map data from any source utilizing OGC-standards such as Web Map Service (WMS) or Web Feature Service (WFS).

CHAPTER SEVEN: CONCLUSION

The current research project identified the drinking water security challenges in southwestern coastal zone of Bangladesh. To evaluate the overall water security, the study determined the availability of drinking water, analyzed its accessibility, and assessed its quality separately by indexing method at the union, upazila, and district levels. Spatial analyses were also completed in order to create drinking water availability, accessibility, quality and overall water security map. And at the final stage of the project work a water app (WATAPP) for Android mobile devices is produced depending on water security index of Khulna, Satkhira and Bagerhat districts of southwestern coastal zone of Bangladesh. In the aspect of availability, result shows that majority of the households collect water from private sources followed by the Government and non-government sources. Overall water availability condition seems to be better in Khulna than Bagerhat and Satkhira District. In terms of accessibility, the findings indicate that the majority of families gather water from sources more than 100 meters away, which is twice the national standard for Bangladesh. Overall water accessibility condition seems households of Satkhira district have higher access to the source than Khulna and Bagerhat district. According to the findings of drinking water quality, only 1% water sources were of good quality and other 99% not good with a significant portion of water sources poor or very poor for drinking purpose during dry season due to occurrence of extremely higher values of E.Coli in the source. Over all water quality shows that Bagerhat district was relatively better than Khulna and Satkhira during dry season. The Overall water security condition in 18 disaster hotspots in the South-west coastal region in poor to very poor. However, in comparison, Satkhira has better water security with an average score of 2.82 whereas Khulna and Bagerhat have scores of 2.55 and 2.48 respectively.

The application (WATAPP) is designed as a decision making tool that will provide an instant overview of the water security situation of Khulna, Satkhira and Bagerhat districts of south-western Bangladesh. The output of the project work will help the policy makers and they can obtain a baseline for effective planning and execution with priority-based planning.

New policy interventions should emphasize on implementation of some new sources of potable water because 42% households claimed that they faces water scarcity for 3 to 4 months in dry season and 33% household's houses located more than 500m far from the water collection sources and 55% household require more than 15 minutes for travelling to collect water. Road condition needs to be taken care of in order to insure water accessibility because 50% household use fully kutcha road for fetching water.

For the future course of action, some adaptation and transformation mechanisms could be under taken based on the outputs of the research. For this purpose, all the rest of the unions should be taken under consideration of these three districts for analysis. In addition, to have a dynamic baseline of drinking water, the study could be replicated for all over the country. Through the mobile application all the data and information could be utilized by the policy makers and marginal people. The database can also be used as a baseline for any future study related to drinking water. The 1st version of the mobile application should be further developed to make it more user friendly.

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Appendices

APPENDIX-A: Questionnaire

Questionnaire Survey

(For research purpose only)

"Water Security Assessment in South-West Coastal Region of Bangladesh"

Institute of Disaster Management (IDM)

Khulna University of Engineering & Technology (KUET)

Surveyor will introduce himself/herself and communicate the following message before the survey to get informed consent of the respondent.

Hello! My name is ______________________________ and I am currently working for IDM-KUET to conduct this survey. The purpose of this survey is to analyse the present situation of the water security in the south-west coastal region.The information will be used by IDM-KUET and WARPO for research purposes only. You have been selected by chance to participate in this survey. Your participation is completely voluntary and your response will be kept completely confidential. Anytime you may discontinue the survey if you want so.

IDENTIFICATION INFORMATION

Questionnaire ID:

Latitude	**Longitude**

Village	Union	Thana	District

SECTION 01: DEMOGRAPHIC AND SOCIO-ECONOMIC INFORMATION

101. Name of the respondent	**102.** Sex[1]	**103.**Age	**104.**Religion[2]	**105.**No. of family member	106. No. of earning member	**107.**Occupation: Main Earning Member	**108.**Occupation: 2nd earning member	**109.**Occupation: 3rd earning member

110. Average monthly household income	**111.**Total owned land	**112.**Total leased (taken) land

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[1] Sex 1=Male, 2=Female

[2] Religion 1= Islam, 2= Hindu, 3= Christian, 4= Buddhist, 5= Others

SECTION 02: WATER AVAILABLITY

[Code: 1= Hand Pump, 2= Pond, 3= River, 4= Rain Water Harvesting (RWH), 5= Reverse Osmosis (RO), 6= Managed Aquifer Recharge (MAR), 7= Pond Sand Filter (PSF), 8= Others]

113.	Which of the above sources of drinking water are available in your locality? (use code) (***Multiple responses are possible***)		
114.	Who is the owner of the Source? ***(Multiple responses are possible***) (Code: 1=Private, 2= Government, 3=NGO)	Hand Pump	
		Pond	
		River	
		RWH	
		RO	
		MAR	
		PSF	
		Others	

115.	Which of the above sources of drinking water does your household use? (***Multiple responses are possible***)		
116.	What is your main source of water in Dry Season **(Oct-Mar)**? ***(Multiple responses)***		
117.	What is your main source of water in Wet Season **(April -September)**?		
118.	Which months do you face scarcity?	Dry Season	Wet Season
119.	Who fetches water most often? (***Multiple Response are possible)*** [Code: 1= Adult male, 2= Adult Female, 3= Male child, 4= Female child, 5=Elderly, 6=Outside the family, 7= Others]		

120.	In which time of the day drinking water is collected? **(Multiple Response are possible)** [Code= Early Morning, 2= Noon, 3= Afternoon, 4= Evening, 5=Night, 6=Others]	

121.	How much drinking water your family members collect/ purchase?	½ Pot (< 5 Litre)	Per day		Per week	
		1 Pot (< 10 Litre)	Per day		Per week	
		2 Pot (< 20 Litre)	Per day		Per week	
		3 pot (<30 Litre)	Per day		Per week	
		4 Pot (<40 Litre)	Per day		Per week	
		Others( )	Per day		Per week	

122.	In which mode you received/ Intake water? (×/√)	No transportation needed	
		Purchased from supplier ***(****Escape Q.* ***123,124)***	
		Transported from cost-free source ***(****Escape Q***. 125, 126)**	

123.	What is the mode of transporting water (if applicable) from the main source to the house? **(*Multiple Response are possible)*** [Code: 1= Walk, 2= Bicycle, 3= Rickshaw, 4=Van, 5=Truck, 6= Boat, 7=Others]				
124.	What is the cost for transporting from source?	Per Day		Perweek	
125.	What is the purchase cost?	Per Day		Per week	
126.	What is the cost for purifying?	Per Day		Per week	
127.	What is the cost for maintaining source?	Per Day		Per week	

SECTION 03: WATER ACCESSIBILITY

128.	What yourfamily members think about their ability to bear the cost of drinking water?	Capable	
		Notcapable	
129.	What is the distance (in Kilometer) of the main source from the house?		

130.	A) What is the pathway (if applicable) to go to the main source of drinking water?	Formal Road	Kutcha	
			Pucca	
		No pathway		
	B) What is the condition of the pathway (if applicable) used for transporting water? (use code) [Code: 1=Very Bad, 2= Bad, 3= Moderate, 4= Good, 5= Very Good]			

131.	A) Time required to go to the source (in minute)	
	B) Queuing/ Waiting time(in minute)	
	C) Time required to come back from the source(in minute)	

132.	A) Is there any time restriction for collecting water? [Code: 1=Yes, 0= No]	
	B) If yes, which time (range) of the day is restricted?	
133.	Do the household member(s) ever face any problem* while collecting water? ***(Multiple Response are possible)*** [Code: 1= Never, 2=Injury, 3=Physical stress, 4=Mental stress, 5=Other (specify)] *Resulting from carrying heavy loads or bad condition of pathway	

134.	Do the household member(s) face any kind of violence while collecting water? **(*Multiple Response are possible)*** [Code: 1= No Violence, 2= Sexual Harassment, 3= Physical Assault, 4= Verbal Violence, 5= Thievery, 6=Other (specify)]	
135.	A) Do the household member(s) face any unjust or prejudicial treatment [3]especially on the grounds of religion, race, sex, occupation, social status, or economic status while collecting water? **(*Multiple Response are possible)***	

[3] Treatment 1=Equal treatment, 2=Gender discrimination, 3= Religious discrimination, 4= Racial discrimination, 5= Occupational discrimination, 6= Economic discrimination, 7= Discrimination due to unequal social status

SECTION 04: WATER QUALITY

136.	Are you satisfied with the quality of drinking water? [Code: 1=Yes, 0= No]	
137.	A) Have you or members of your household suffered (or suffering) from bad water quality? [Code: 1=Yes, 0= No]	
	B) If yes, what diseases[4] have you suffered from?	
138.	Where, do you think, highest drinking water quality is found? [Code: 1= Hand Pump, 2= Pond, 3= River, 4= Rain Water Harvesting (RWH), 5= Reverse Osmosis (RO), 6= Managed Aquifer Recharge (MAR), 7= Pond Sand Filter (PSF), 8= Others]	

139.	Which months do you think maximum water quality found? ***(Multiple Response are possible)***	Dry Season (Oct-Mar)	Wet Season (Apr-Sep)

140.	A) Do your drinking water sources have the following? [Code: 1=Yes, 0=No]	Bad Taste	Odour	Color
	B) If yes, what are the sources? [Code: 1= Hand Pump, 2= Pond, 3= River, 4= Rain Water Harvesting (RWH), 5= Reverse Osmosis (RO), 6= Managed Aquifer Recharge (MAR), 7= Pond Sand Filter (PSF), 8= Others]			
	C) If yes, what is the level? [Code: 1=Acceptable limit, 2=Slightly extreme, 3=Extreme, 4=Very extreme, 5=Unacceptable			

141.	If drinking water quality is not acceptable, what is the main cause? ***(Multiple Response are possible)*** [Code: 1=Bathing, 2=Washing, 3=Cattle bathing, 4=Fishing, 5=Outlet of toilet/latrine, 6=Other (specify)]	
142.	How would you grade the quality of your drinking water from the main source? [Code: 1= Good, 2= Moderately Good, 3= Moderately Bad, 4= Bad, 5=Unacceptable]	

143.	Compared to 15 years ago, have there been any changes in the quality of your drinking water from the SAME source? (use ×/√)		2005	2010	2020
		1=Improved to a Great Extent			
		2=Improved to Some Extent			
		3=Stayed the Same			
		4=Worsened to Some Extent			
		5=Worsened to a Great Extent			
		6=Didn't use this Source Before			

144.	A) Does your household treat drinking water to make it safer to drink? [Code: 1=Yes, 0=No]		
	B) If no, why don't you treat water?	1=Water is Safe to Drink	
		2=Water is Unsafe, but I Don't Think It	

[4] Diseases 1=Cholera, 2=Dysentery, 3= Typhoid, 4=Hypertension, 5=Skin rash, 6=Other (specify)

	(use ×/√)	3=Too Expensive	
		4=No Knowledge of Treatment Options	
		5=Not Enough Time	
		6=Unavailability of Treatment Technologies	
		7=Other (Specify)	
	C) If yes, what does your household do to make water safer to drink? (use ×/√)	1=Boil the Water	
		2=Add Bleach/Chlorine	
		3=Sieve It Through Cloth	
		4=Water Filtering Device	
		5=Other Filter (Ceramic, Sand, Composite)	
		6=Let It Stand And Settle	
		7=Other (Specify)	
145.	Does your household have a water storage container for storing drinking water? [Code: 1=Yes, 0=No]		
	B) If yes, what is the capacity of storage container? [Code: 1=< 5 Litre, 2= <10 Litre, 3=<20 Litre, 4=<30 Litre, 5=<40 Litre, 6=Others (specify)]		
146.	How often does your household usually clean the drinking water storage container? [Code: 1=Several times per week, 2=Once a week, 3=Once a month, 4=Once every three months, 5=Once every six months, 6=Less often than half yearly		

147.	Do your source of drinking water are saline?[Code: 1=Yes, 0=No]	
148.	What do you think about the source of saline water? ***(Multiple Response are possible)*** [Code: 1= Cyclone, 2= Natural flood, 3= Embankment failure, 4= Excessive extraction of ground water, 5=Shrimp/Crab farming, 6=Other(specify)]	
149.	**Phone Number:**	

Name and Signature of the Surveyor:

Date:

Thank you very much

APPENDIX-B1: Scale Wise Distribution (Bagerhat)

Scale wise distribution of households under different indicators of availability for Bagerhat District

Scale	Frequency	Percent	Valid Percent	Cumulative Percent
Ownership				
1.00	87	25.4	25.4	25.4
2.00	16	4.7	4.7	30.1
3.00	24	7.0	7.0	37.1
4.00	215	62.9	62.9	100.0
Available Source in Dry Season				
1.00	275	80.4	80.4	80.4
2.00	66	19.3	19.3	99.7
3.00	1	.3	.3	100.0
4.00	0	0	0	100.0
Available Source in Wet Season				
1.00	155	45.3	45.3	45.3
2.00	157	45.9	45.9	91.2
3.00	30	8.8	8.8	100.0
4.00	0	0	0	100.0
Demand Source Ratio				
1.00	174	50.9	50.9	50.9
2.00	0	0.0	0.0	50.9
3.00	103	30.1	30.1	81.0
4.00	65	19.0	19.0	100.0
Duration of Water Scarcity				
1.00	0	0.0	0.0	0.0
2.00	219	64.0	64.0	64.0
3.00	123	36.0	36.0	100.0
4.00	0	0.0	0.0	100.0

APPENDIX-B2: Scale Wise Distribution (Khulna)

Scale wise distribution of households under different indicators of availability for Khulna District

Scale	Frequency	Percent	Valid Percent	Cumulative Percent
Ownership				
1.00	148	25.6	25.6	25.6
2.00	82	14.2	14.2	39.9
3.00	95	16.5	16.5	56.3
4.00	252	43.7	43.7	100.0
Available Source in Dry Season				
1.00	381	66.0	66.0	66.0
2.00	190	32.9	32.9	99.0
3.00	6	1.0	1.0	100.0
4.00	0	0	0	100.0
Available Source in Wet Season				
1.00	125	21.7	21.7	21.7
2.00	0	0.0	0.0	21.7
3.00	283	49.0	49.0	70.7
4.00	169	29.3	29.3	100.0
Demand Source Ratio				
1.00	34	5.9	5.9	5.9
2.00	322	55.8	55.8	61.7
3.00	160	27.7	27.7	89.4
4.00	61	10.6	10.6	100.0
Duration of Water Scarcity				
1.00	306	53.0	53.0	53.0
2.00	105	18.2	18.2	71.2
3.00	42	7.3	7.3	78.5
4.00	124	21.5	21.5	100.0

APPENDIX-B3: Scale Wise Distribution (Shatkhira)

Scale wise distribution of households under different indicators of availability for Satkhira District

Scale	Frequency	Percent	Valid Percent	Cumulative Percent
Ownership				
1.00	302	25.9	25.9	25.9
2.00	151	12.9	12.9	38.8
3.00	193	16.5	16.5	55.3
4.00	522	44.7	44.7	100.0
Available Source in Dry Season				
1.00	828	70.9	70.9	70.9
2.00	329	28.2	28.2	99.1
3.00	11	0.9	0.9	100.0
4.00	0	0	0	100.0
Available Source in Wet Season				
1.00	263	22.5	22.5	22.5
2.00	817	69.9	69.9	92.5
3.00	88	7.5	7.5	100.0
4.00	0	0	0	100.0
Demand Source Ratio				
1.00	338	28.9	28.9	28.9
3.00	0	0.0	0.0	28.9
3.00	546	46.7	46.7	75.7
4.00	284	24.3	24.3	100.0
Duration of Water Scarcity				
1.00	44	3.8	3.8	3.8
2.00	584	50.0	50.0	53.8
3.00	364	31.2	31.2	84.9
4.00	176	15.1	15.1	100.0

APPENDIX-C: Scale Wise Distribution (Availability)

Scale wise distribution of all households under different indicators of availability

Scale	Frequency	Percent	Valid Percent	Cumulative Percent
Ownership				
1.00	67	26.9	26.9	26.9
2.00	53	21.3	21.3	48.2
3.00	74	29.7	29.7	77.9
4.00	55	22.1	22.1	100.0
Available Source in Dry Season				
1.00	172	69.1	69.1	69.1
2.00	73	29.3	29.3	98.4
3.00	4	1.6	1.6	100.0
4.00	0	0	0	100.0
Available Source in Wet Season				
1.00	74	29.7	29.7	29.7
2.00	167	67.1	67.1	96.8
3.00	8	3.2	3.2	100.0
4.00	0	0	0	100.0
Demand Source Ratio				
1.00	39	15.7	15.7	15.7
2.00	0	0.0	0.0	15.7
3.00	160	64.3	64.3	79.9
4.00	50	20.1	20.1	100.0
Duration of Water Scarcity				
1.00	10	4.0	4.0	4.0
2.00	43	17.3	17.3	21.3
3.00	81	32.5	32.5	53.8
4.00	115	46.2	46.2	100.0

APPENDIX-D1: Scale Wise Distribution in Bagerhat (Accessecibility)

Scale wise Distribution of households under different indicators of Accessibility for Bagerhat District

Scale	Frequency	Percent	Valid Percent	Cumulative Percent
Distance				
1.00	148	43.3	43.3	43.3
2.00	53	15.5	15.5	58.8
3.00	40	11.7	11.7	70.5
4.00	101	29.5	29.5	100.0
Mode of Transport				
1.00	10	2.9	2.9	2.9
2.00	61	17.8	17.8	20.8
3.00	235	68.7	68.7	89.5
4.00	36	10.5	10.5	100.0
Condition of Road				
1.00	163	47.7	47.7	47.7
2.00	55	16.1	16.1	63.7
3.00	110	32.2	32.2	95.9
4.00	14	4.1	4.1	100.0
Travel Time				
1.00	179	52.3	52.3	52.3
2.00	19	5.6	5.6	57.9
3.00	61	17.8	17.8	75.7
4.00	83	24.3	24.3	100.0
Queuing Time				
1.00	0	0.0	0.0	0.0
2.00	0	0.0	0.0	0.0
3.00	0	0.0	0.0	0.0
4.00	342	100.0	100.0	100.0
Cost-Income Ratio				
1.00	12	3.5	3.5	3.5
2.00	24	7.0	7.0	10.5
3.00	39	11.4	11.4	21.9
4.00	267	78.1	78.1	100.0
Equality				
1.00	12	3.5	3.5	3.5
2.00	13	3.8	3.8	7.3
3.00	2	.6	.6	7.9
4.00	315	92.1	92.1	100.0
Safety				
1.00	43	12.6	12.6	12.6
2.00	91	26.6	26.6	39.2
3.00	4	1.2	1.2	40.4
4.00	204	59.6	59.6	100.0
Security				
1.00	21	6.1	6.1	6.1
2.00	4	1.2	1.2	7.3
3.00	15	4.4	4.4	11.7
4.00	302	88.3	88.3	100.0

APPENDIX-D2: Scale Wise Distribution in Khulna (Accessecibility)

Scale wise Distribution of households under different indicators of Accessibility for Khulna District

Scale	Frequency	Percent	Valid Percent	Cumulative Percent
Distance				
1.00	306	53.0	53.0	53.0
2.00	105	18.2	18.2	71.2
3.00	42	7.3	7.3	78.5
4.00	124	21.5	21.5	100.0
Mode of Transport				
1.00	20	3.5	3.5	3.5
2.00	102	17.7	17.7	21.1
3.00	263	45.6	45.6	66.7
4.00	192	33.3	33.3	100.0
Condition of Road				
1.00	269	46.6	46.6	46.6
2.00	186	32.2	32.2	78.9
3.00	116	20.1	20.1	99.0
4.00	6	1.0	1.0	100.0
Travel Time				
1.00	326	56.5	56.5	56.5
2.00	72	12.5	12.5	69.0
3.00	59	10.2	10.2	79.2
4.00	120	20.8	20.8	100.0
Queuing Time				
1.00	47	8.1	8.1	8.1
2.00	31	5.4	5.4	13.5
3.00	63	10.9	10.9	24.4
4.00	436	75.6	75.6	100.0
Cost-Income Ratio				
1.00	34	5.9	5.9	5.9
2.00	61	10.6	10.6	16.5
3.00	68	11.8	11.8	28.2
4.00	414	71.8	71.8	100.0
Equality				
1.00	1	.2	.2	.2
2.00	13	2.3	2.3	2.4
4.00	0	0.0	0.0	2.4
4.00	563	97.6	97.6	100.0
Safety				
1.00	11	1.9	1.9	1.9
2.00	63	10.9	10.9	12.8
3.00	4	.7	.7	13.5
4.00	499	86.5	86.5	100.0
Security				
1.00	6	1.0	1.0	1.0
2.00	0	0.0	0.0	1.0
3.00	19	3.3	3.3	4.3
4.00	552	95.7	95.7	100.0

APPENDIX-D3: Scale Wise Distribution in Satkhira (Accessecibility)

Scale wise Distribution of households under different indicators of Accessibility for Satkhira District

Scale	Frequency	Percent	Valid Percent	Cumulative Percent
Distance				
1.00	78	31.3	31.3	31.3
2.00	47	18.9	18.9	50.2
3.00	30	12.0	12.0	62.2
4.00	94	37.8	37.8	100.0
Mode of Transport				
1.00	0	0.0	0.0	0.0
2.00	54	21.7	21.7	21.7
3.00	149	59.8	59.8	81.5
4.00	46	18.5	18.5	100.0
Condition of Road				
1.00	151	60.6	60.6	60.6
2.00	80	32.1	32.1	92.8
3.00	18	7.2	7.2	100.0
4.00	0	0.0	0.0	100.0
Travel Time				
1.00	86	34.5	34.5	34.5
2.00	12	4.8	4.8	39.4
3.00	41	16.5	16.5	55.8
4.00	110	44.2	44.2	100.0
Queuing Time				
1.00	0	0.0	0.0	0.0
2.00	3	1.2	1.2	1.2
3.00	4	1.6	1.6	2.8
4.00	242	97.2	97.2	100.0
Cost-Income Ratio				
1.00	3	1.2	1.2	1.2
2.00	29	11.6	11.6	12.9
3.00	39	15.7	15.7	28.5
4.00	178	71.5	71.5	100.0
Equality				
1.00	1	0.4	0.4	0.4
2.00	0	0.0	0.0	0.4
3.00	0	0.0	0.0	0.4
4.00	248	99.6	99.6	100.0
Safety				
1.00	17	6.8	6.8	6.8
2.00	64	25.7	25.7	32.5
3.00	1	0.4	0.4	32.9
4.00	167	67.1	67.1	100.0
Security				
1.00	1	0.4	0.4	0.4
2.00	0	0.0	0.0	0.4
3.00	11	4.4	4.4	4.8
4.00	237	95.2	95.2	100.0

APPENDIX-E: Scale Wise Distribution (Accessecibility)

Scale wise distribution of all households under different indicators of Accessibility

Scale	Frequency	Percent	Valid Percent	Cumulative Percent
Distance				
1.00	532	45.5	45.5	45.5
2.00	205	17.6	17.6	63.1
3.00	112	9.6	9.6	72.7
4.00	319	27.3	27.3	100.0
Mode of Transport				
1.00	30	2.6	2.6	2.6
2.00	217	18.6	18.6	21.1
3.00	647	55.4	55.4	76.5
4.00	274	23.5	23.5	100.0
Condition of Road				
1.00	583	49.9	49.9	49.9
2.00	321	27.5	27.5	77.4
3.00	244	20.9	20.9	98.3
4.00	20	1.7	1.7	100.0
Travel Time				
1.00	591	50.6	50.6	50.6
2.00	103	8.8	8.8	59.4
3.00	161	13.8	13.8	73.2
4.00	313	26.8	26.8	100.0
Queuing Time				
1.00	47	4.0	4.0	4.0
2.00	34	2.9	2.9	6.9
3.00	67	5.7	5.7	12.7
4.00	1020	87.3	87.3	100.0
Cost-Income Ratio				
1.00	49	4.2	4.2	4.2
2.00	114	9.8	9.8	14.0
3.00	146	12.5	12.5	26.5
4.00	859	73.5	73.5	100.0
Equality				
1.00	14	1.2	1.2	1.2
2.00	26	2.2	2.2	3.4
3.00	2	0.2	0.2	3.6
4.00	1126	96.4	96.4	100.0
Safety				
1.00	71	6.1	6.1	6.1
2.00	218	18.7	18.7	24.7
3.00	9	0.8	0.8	25.5
4.00	870	74.5	74.5	100.0
Security				
1.00	28	2.4	2.4	2.4
2.00	4	0.3	0.3	2.7
3.00	45	3.9	3.9	6.6
4.00	1091	93.4	93.4	100.0

APPENDIX-E: USER MANUAL OF ADROID MOBILE APPLICATION- WATAPP

6.0 General Information

General information section explains in general terms the WATAPP application overview and the sections of the user manual.

6.1 Application Overview

The application is designed as a decision making tool that will provide an instant overview of the water security situation of Khulna, Satkhira and Bagerhat Districts of south-western Bangladesh.

6.2 Organization of the Manual

The user manual consists of the following four sections

6.2.1 General information
6.2.2 System Summary
6.2.3 How to download the application
6.2.4 User–Privileges

6.2.1 General Information

General information section explains in general terms the application overview and the sections of the user manual.

System Summary sectionexplainsaboutthehardwareandsoftwarerequirementsforaccessing WATAPP application and user access levels.

How to download the application section explains the options available to download thee WATAPP Android application on your mobile.

Using the Application section provides a detailed description of the functionalities of the WATAPP application

6.2.2 System Summary

System Summary section explains about the hardware and software requirements for accessing WATAPP application and user accesslevels.

6.2.1.1 Hardware and Software Requirements

Requires a smart phone with Android operating system (OS)
The minimum Android version should be 6.0.3 and up to avail all the features in the application.
To download and use the functionalities of WATAPP mobile app, you require an Internet connection in your mobile.

6.2.1.2 User Access Levels

Any user can access and uses the WATAPP application without registering in the application and any kind of hassle.

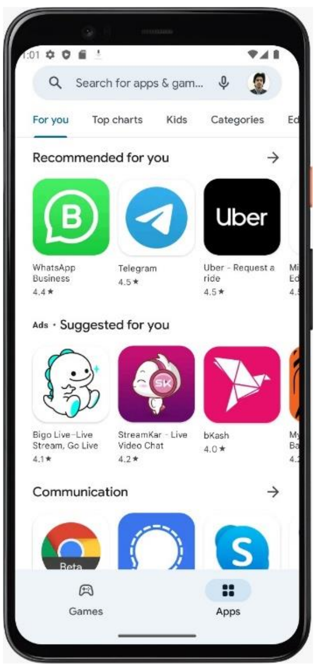
6.2.3 How to download the application

WATAPP application can be downloaded through the following way

- Google PlayStore

6.2.3.1 Google Play Store

Open **Play Store** application on your mobile by clicking on the Play Store icon as shown in the image below.



Click on the Google Play text at the top and enter the text "WATAPP" in the search bar. Click on the WATAPP application icon from the search result. Now below page will open which asks to install the application. Click on the "INSTALL" button to install the application.

6.2.4 User-PRIVILEGES

Following features can be availed by the user.

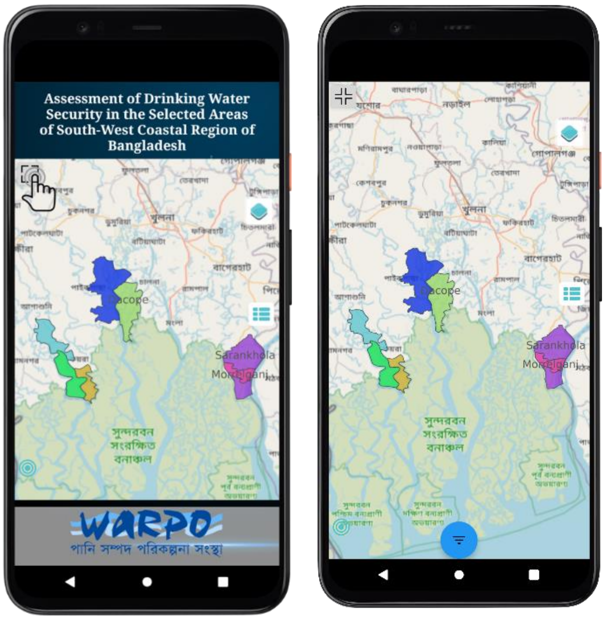
- Home Screen Overview
- Full Screen Button
- Layer Switcher
- Legend
- Area Selection
- Basic Information
- Map Information & Result
- Current Location

6.2.4.1 Home Screen Overview

Launch the application by clicking on the WATAPP icon on your mobile as shown in the image below.

As soon as WATAPP application is launched, homepage will be displayed which shows the main window of the application as shown in the image. There are three components to this window. A title portion is at the top, and a logo section is at the bottom. And the heart of our app is in the center. This is the section for the map. There are a few action buttons in the map area.

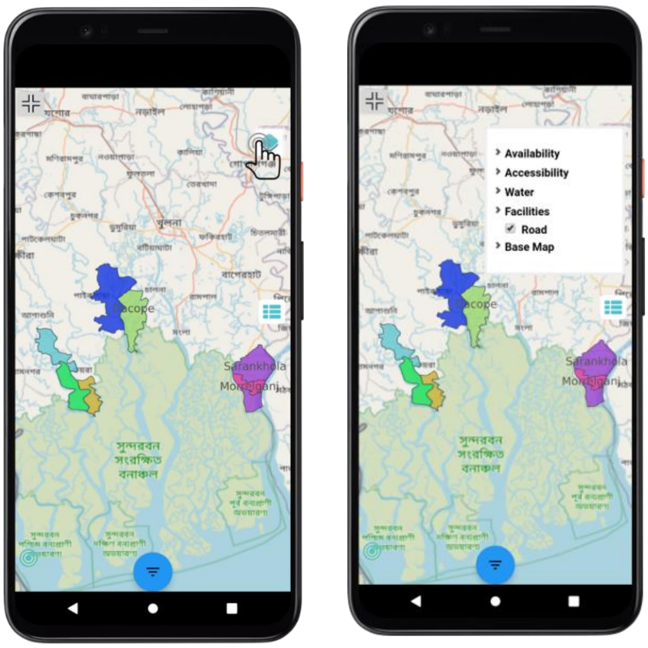
6.2.4.2 Full Screen Button



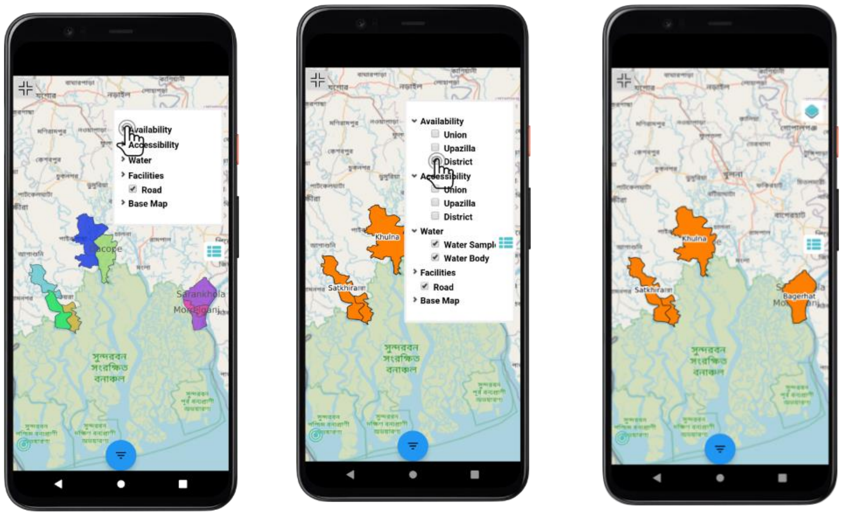
The full-screen button is found in the upper-left corner of the map area. When user click on it, the map will expand to fill the entire screen. And then another button will appear at the bottom.

6.2.4.3 Layer Switcher

The layer switcher button is positioned in the upper right corner of the map. When you click on it, a panel appears that displays all layers of the map, for example water availability, accessibility, and quality.

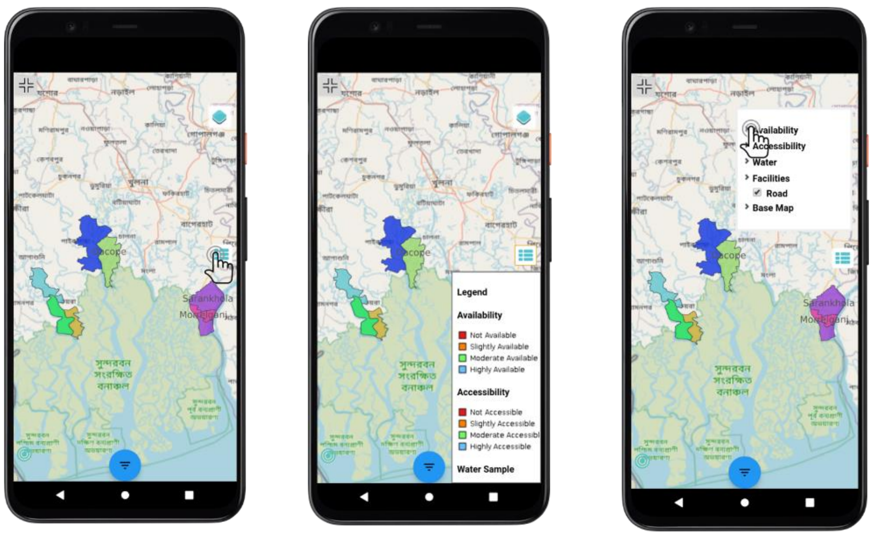


When a user clicks on one of the layers, it expands. And display several types of that layer. If the user chooses one of these, the map will be colored accordingly. The legend explains the significance of the colors.



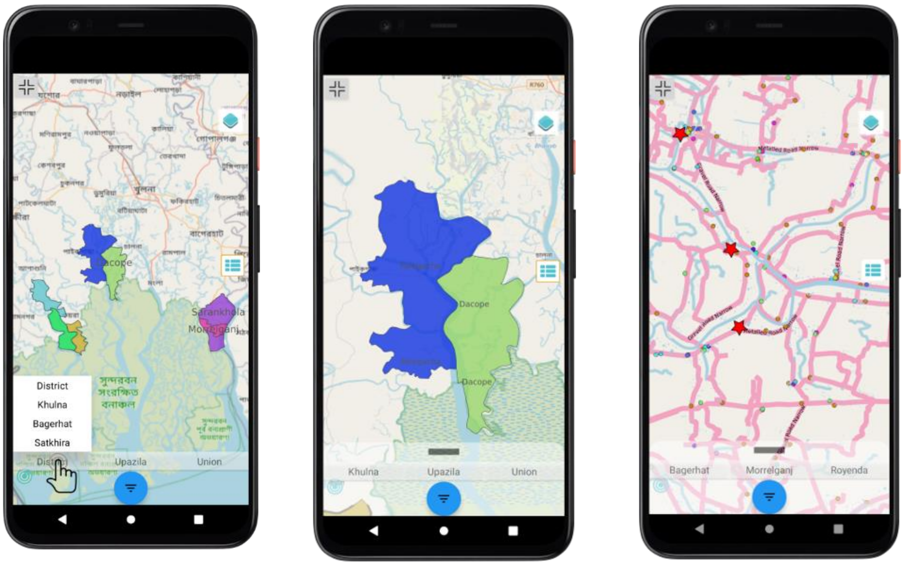
6.2.4.4 Legend

When we look at the map, we can see a button in the right-middle of the map. Which is the legend button. And clicking on it will bring up a panel. This panel displays the legend for all of the layers on the map.



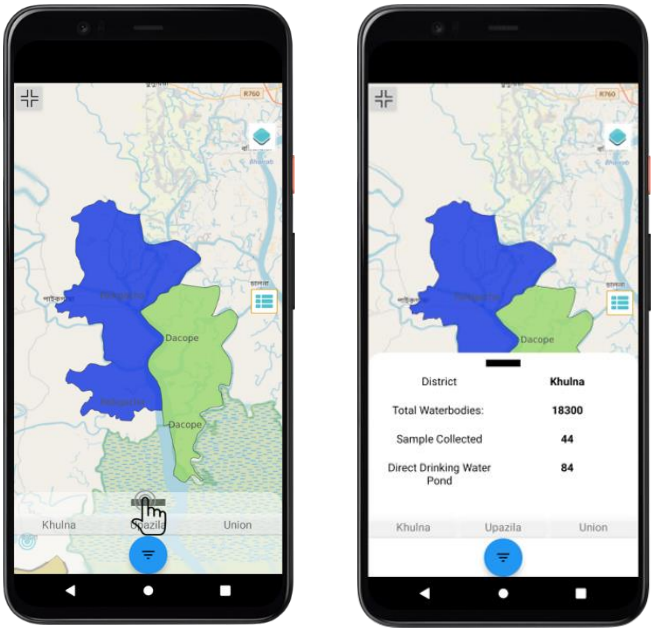
6.2.4.5 Area Selection

The search button / area selection button is located at the bottom of the map. Users may simply choose a district, then an upazila within that district, and finally a union inside that upazila. When he picks a spot, the map zooms in on that specific region. The detailed data will then be visualized.

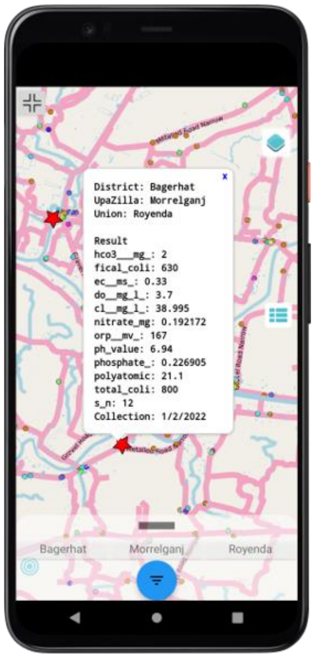


6.2.4.6 Basic Information

The essential information for each selected location can also be seen in numerical figures. As shown in the images.



6.2.4.7 Map Information & Result



Detail information will be shown at the final zoom scale. A user may view all of the layers of that place, including the road layer, building layer, waterbodies layer, and other utilities. All colors and symbols are explained in the Legend section. The waterbodies highlighted with a star are where water samples were collected and analyzed in the lab. If user click on it, they will view the laboratory findings.

6.2.4.8 Current Location

When a user selects the Current Location button, the application zooms in on its current location. Then he'll be able to observe the circumstances around him on the map.