ASSESSMENT OF AQUACULTURE HABITAT SUITABILITY OF GAZIPUR DISTRICT USING GEO-SPATIAL TECHNOLOGY BASED MULTI-CRITERIA MODELING

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of MS in Fisheries

Submitted by

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Department of Fisheries

University of Dhaka

CERTIFICATE

This is to certify that Susmita Das Rimi bearing Examination Roll No: Curzon-4213, Session-2013-2014, Registration No: Ha-2153; has successfully completed the M.S thesis entitled "Assessment of Aquaculture Suitability of Gazipur District using Geo-spatial Technology based Multi-Criteria Modeling" under our supervision. It is also certify that, this is an original thesis work and suitable for the partial fulfillment of the degree of Master of Science in Fisheries.

Supervisor	Co-supervisor
Dr. Md. Monirul Islam	Mr.Hasan Faruque
Associate Professor	Assistant Professor
Department of Fisheries	Department of Fisheries
University of Dhaka	University of Dhaka

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LIST OF ACRONYMS AND ABBREVIATIONS

GIS	*Geographic Information System*
CEGIS	*Center for Environmental and Geographic Information Services*
BFRI	*Bangladesh Fisheries Research Institute*
DoF	*Department of Fisheries*

BBS	*Bangladesh Bureau Statistics*
SPARSO	*Space Research and Remote Sensing Organization*
MCE	*Multi-Criteria Evaluation*
LGED	*Local Government Engineering Department*
DO	*Dissolved oxygen*
BOD	*Biological oxygen demand*
P	*Phosphorus*
N	*Nitrogen*
C	*Carbon*
Pb	*Lead*
Cd	*Cadmium*
Cu	*Copper*
CO_2	*Carbon di-oxide*
%	*Percentage*
°C	*Degree of Celcius*
mg/l	*Milligram per Liter*
mt	*Metric Ton*
ppm	*Parts per milligram*
km^2	*Square kilometer*
ppt	*Parts per thousand*
mm	*Millimeter*
ha	*Hecter*
Sd	*Standard deviation*
Tk	*Taka*
HSI	*Habitat Suitability Index*
USFWS	*US fish wild life service*

ABSTRACT

The aim of this study wasto develop a method using integrated habitat suitability index approach to produce geo-referenced ecological information about the habitat requirements of different species. A habitat suitability framework has been developed for cultured species of Gazipur districtcomprising five (5) upazilas, named- GazipurSadar, Kalikair, Kaliganj, Kapasia and Sreepur. The degree or magnitude of habitat suitability depends on different parameters such as (i) river connectivity (ii) good spawning ground (iii) water quality (temperature, pH, DO, BOD) (iv) soil pH (v) water pollution (vi) food availability (vii) livelihood status of fishermen, etc. Both the primary and secondary data are used for this study. Primary data were collected through semi-closed questionnaire interview, key informant interview and cross-check interviews.

Gazipur Sadar and Kapasia Upazilas have been identified as the highest and lowest habitat suitability for beel and floodplain respectively. In case of KaliakairUpazila, highest habitat suitability has been identified for beel and lowest for pond habitat; in KaliganjUpazila highest suitability for pond and lowest for floodplain; in Sreepur Upazila highest suitability for pond and lowest for beel fish habitat. The present study using multiple regression model has revealed that habitat characteristics, regarding connectivity among existing water bodies, water availability and spawning ground condition, are moderately correlated with habitat suitability at 95% significant level. The present condition of water depth indicates that it is not the major cause for maintaining habitat suitability for culture fish production in the study area. Phytoplankton availability may not play more important role in maintaining habitat suitability due to using artificial feeding for culture fish production in the selected upazilas of Gazipur district. The present condition of water quality is the major causes for maintaining habitat suitability for both the capture and culture fish production in the study area. The present condition of soil quality indicates that it is one of the major causes for habitat suitability for both the capture and culture fish production in the study area. However, water pollution has not been identified as the major causes for regulating habitat suitability Furthermore, increasing indiscriminate fishing activities, like brood and fry fishing and unregulated use of gears, with increasing standard livelihood pattern of full time commercial fishermen resulting in decreased habitat suitability particularly for the capture fish habitats (beel and floodplain).

CHAPTER 1: INTRODUCTION

1.1 Background

In recent years, aquaculture has become the world's largest growing food industry with an annual growth of 10% compared to 2–3% of other major food sectors (Karthik et al., 2005). Remarkably Bangladesh is ranked as fifth largest aquaculture producing country with its estimated production of 1956925 MT and 55.15% sharing to the national total fish production of the country (FRSS 2013-14). The socio-economic benefits derived from aquaculture expansion provide the provision of nutritive foods contributing improved life style to the poor, income generation and employment opportunity, diversification of fish production and create scope for foreign exchange earnings through export of high-valued products. Aquaculture is also treated as potential input to compensate for the low growth rate of capture fisheries (Naylor *et a*l. 2000).

Suitable site selection is a key factor and fundamental of planning for any aquaculture operation, affecting both success and sustainability and can solve conflicts between different activities, making a rational use of the physical space (Pérez *et a*l., 2005). The main problem in the selection of suitable sites for culture fisheries is the lack of baseline information on the physico-chemical and topographic conditions as well as existing land use patterns. Moreover site selection is essential for aquaculture development, incorporating water quality, soil characteristics and infrastructure facilities that influence the suitability for the intended purpose. Without considering the above factors can lead to misuse of natural resources and degradation of the environment, breeding poverty and other social conflicts (Hossain and Das 2010). Applying multi-criteria approach including both the environmental and socio-economic criteria can do potential sites for various types of aquaculture developments. Appropriate socio-economic factors will ensure the profitability of the industry, while environmental factors will maximize production and prevent adverse impacts on the environment (Jarayabhand,1997).

Therefore this study presents a GIS-based multi-criteria Evaluation to identify the most suitable sites for culture fishes in context of Gazipur district in Bangladesh.

1.2 Prospect of culture fisheries in Bangladesh

Fish is the second most valuable agricultural crop in Bangladesh and its production contributes to the livelihoods and employment of millions of people. The culture and consumption of fish therefore has important implications for national income and food security. Bangladeshi people are popularly referred to as "Mache Bhate Bangali" or "fish and rice makes a Bengali".

The fisheries sector in Bangladesh is broadly divided into four sub-sectors- inland capture, inland culture, mariculture (artisanal fisheries) and marine industrial fisheries. However, Bangladesh has a high potential for aquaculture development due to the favorable conditions of natural habitats such as ponds, floodplains, beels, rivers, lakes, estuaries and coastal areas (Hossain and Das 2010). Inland pond culture represents the most important part of aquaculture in Bangladesh contributing to around 86% of total production (Ghose 2014). Aquaculture accounted for about 55.15 percent of the total fish production during 2013–14 (FRSS 2014).

1.3 Fisheries *culture* habitat trend*:*

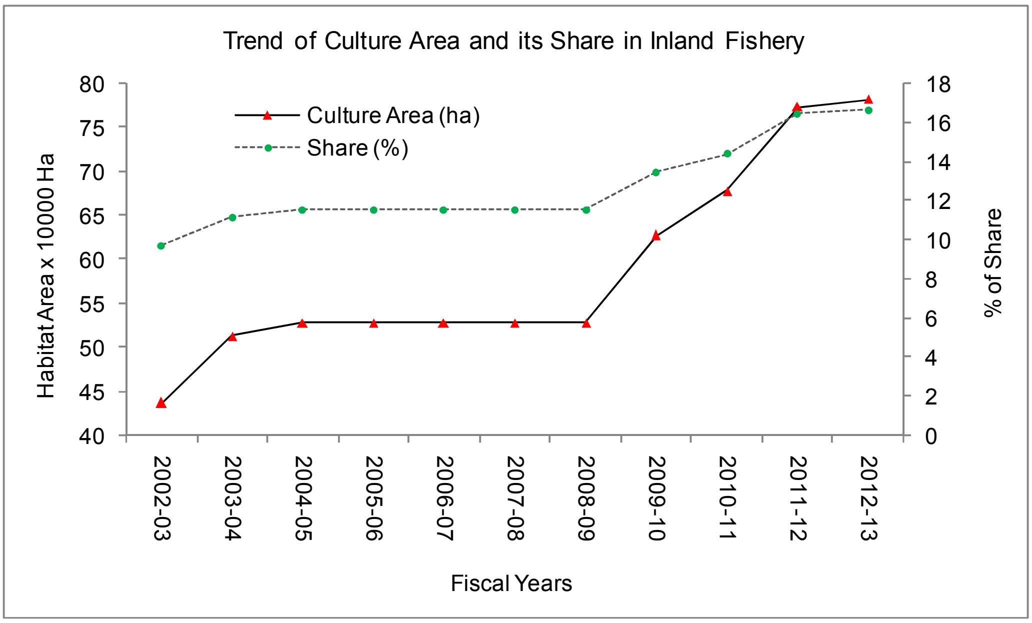

Figure 1: Trend of capture area and its share in inland fishery

Analysis of time series data for 11 years (2003-2013) on inland culture fishery habitats is showing the increasing trend. Culture fishery area has increased by 3.45 lakh hectare from 4.37 lakh hectare in 2003 to 7.83 hectare in 2013. In accordance with such upturn of capture fishery habitat, its contribution to the inland fishery has been increasing at higher rate as people are moving towards creating more aquaculture area by converting capture habitat area, agriculture field and other types of lands. The Figure xx portrays the trend of culture fishery and its share in inland fishery.

1.4 Fisheries production trend

It appears from the production data analysis that overall production increased at an average rate of 6.35% during last 20 years, but the production in inland open water gradually declined at a very low rate with a slow upward trend since 1991-1992 to 2008-09 (Figure 2). The production trend of the capture fishery is found steady from 2011-12 to 2012-13 after fluctuations within the time period of 2009-10 to 2010-11. The reasons of increasing production from the open water sources are include the followings: floodplain stocking with carp fingerlings, Beel nursery programme, and the strengthening of conservation measures. On the contrary, for the last five years the capture fishery production is decreasing at the average rate of 1.7%. This means increase of fisheries interventions and management induced production cannot outweigh the loss of capture habitat induced production.

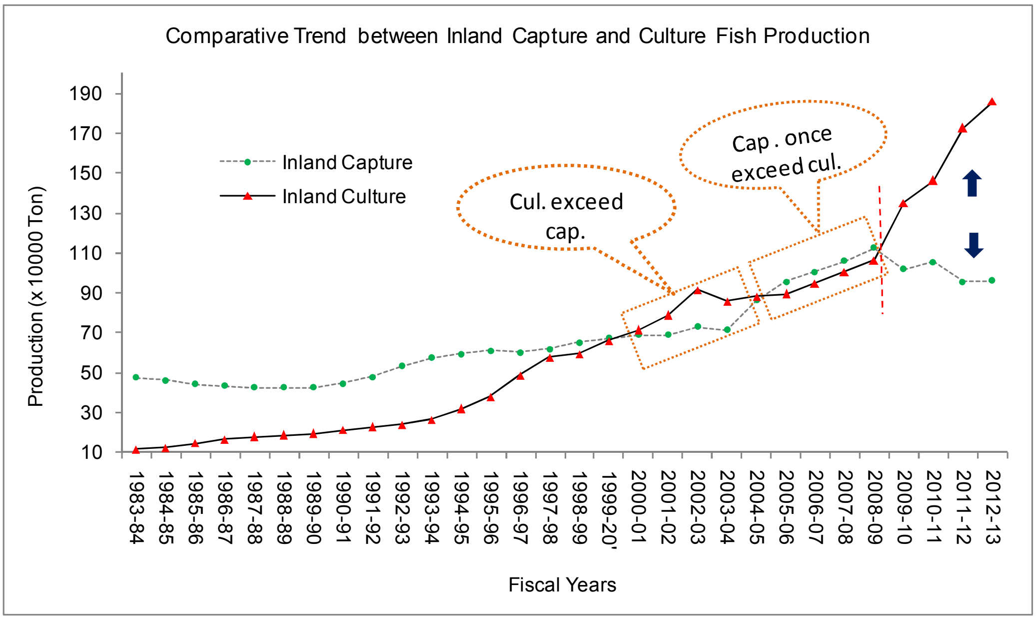

Figure 2: Fish production trends of the inland capture and culture fishery

1.5 Fish habitat suitability aspect and HSI Modelling

According to the NSW Fisheries Management Act 1994 fish habitat means: any area occupied, or periodically or occasionally occupied, by fish or marine vegetation (or both), and includes any biotic (living) or abiotic (non-living) component. Loss of habitat is a major factor contributing to the decline of fisheries in both marine and freshwater systems around the world (Langton et al., 1996). A suitability study is a preliminary step when assessing whether land or any other area is likely to be practical and successful for sustainable development of an intended venture. In many instances aquaculture has been promoted in regions which are unsuitable in terms of climatic conditions, water and soil quality, and other facilities. A suitable site is a prerequisite for successful aquaculture. Appropriate location of aquaculture development will minimize the risk of environmental impact, maximize the overall economic return and minimize conflict between aquaculture and other resource uses (GESAMP, 2001).

A tool to aid in the delineation of important habitat areas and to facilitate the decision making process for environmental management and ecosystem restoration is habitat suitability index (HSI) modeling. Habitat suitability index models were originally developed in the 1970s by the US Fish and Wildlife Service (USFWS) as a part of their Habitat Evaluation Procedures (HEP). The HEP system was developed to determine the quality and quantity of habitat for a given species to assess the impacts of human activities on fish and wildlife populations (USFWS, 1980). Brown et al. (2000) describe some of the various management applications of HSI modeling as: (1) evaluating the impacts of regulatory alternatives, specifically for EFH studies, (2) identifying and prioritizing areas for conservation actions, and (3) ascertaining the potential impacts of environmental change. HSI models may also be used to guide ecosystem restoration activities by indicating the physical habitat conditions that should be created to benefit target organisms. The HSI itself is a value derived from key habitat components of a selected species or life history stage (USFWS, 1980). The key habitat components are described by suitability curves on a scale from 0 to 1 over a range of values for the habitat variable. The composite HSI value for a given area is obtained by mathematically combining the individual suitability values of the habitat components to give an overall index of habitat suitability on a scale of 0–1.

One of the original HSI models is the Physical Habitat Simulation System (PHABSIM), which was developed by the US Geological Survey (USGS) as part of the Instream Flow Incremental Methodology (Bovee et al.,1998). PHABSIM consists of a suite of computer programs to: (1) model the spatial distribution of hydraulic variables, such as depth and velocity, throughout the study reach, (2) determine the spatial distribution of habitat suitability, and (3) relate the overall suitability of the study reach to discharge (Waddle, 2001). PHABSIM is a very specialized software package that contains its own hydraulic modeling software, HSI calculation routines, and mapping software.

In recent years, several new developments in HSI modeling in rivers have emerged that improved upon the original PHABSIM design for use in ecological engineering and restoration studies (Spence and Hickley, 2000; Bockelmann et al., 2004). Probably the most notable advance has been the coupling of two-dimensional hydraulic river models with HSI models to simulate depth and velocity (Ghanem et al., 1996; Leclerc et al., 1996; Tiffan et al., 2002; Bockelmann et al., 2004; Korman et al., 2004). These models have the advantage of not needing empirical data on water velocity distributions to calculate bed roughness for velocity simulations at different discharges. Also, since two-dimensional hydraulic models simulate velocity distributions throughout a reach via a series of cells, the practice of modeling long lengths of a stream reach as a single cross section can be avoided. One-dimensional hydraulic models have several advantages including: (1) the need of only two boundary conditions (upstream discharge, downstream water level), (2) they are simple to calibrate compared to two dimensional models, and (3) they are commonly used commercially for other river applications.

HSI modeling has also become common in other aquatic ecosystems. Several investigators have used HSI modeling to determine areas of optimal fish habitat in oceans, bays, estuaries, and lakes to support essential fish habitat decision making (Rubec et al., 1998; Brown et al., 2000; Eastwood et al., 2001; Rowe et al., 2002). In all of these situations, the entire HSI modeling process takes place using a commercially available geographic information system (GIS). GIS has been used for many different tasks in fishery biology that involve a spatial dimension, including mapping fish habitats and fish distributions, determining the effects of land use on fish populations, and analyzing spatial and temporal changes in fish distribution (Fisher and Rahel, 2004). HSI modeling is one of the newer fields to use GIS (Gillenwater et al. 2006).

1.6 GIS-based multi-criteria Evaluation

Multi-criteria decision-making is the concepts, approaches, models and methods that aid in evaluation expressing by weights, values or intensities of preference (Barredo, 1996) which ultimately lead to better decisions. The main purpose of the multi-criteria evaluation (MCE) techniques is to investigate a number of alternatives in the light of multiple criteria and conflicting objectives (Voogd, 1983). In order to carry out the idea, it is necessary to generate compromise alternatives and a ranking of alternatives according to their degree of attractiveness (Janssen and Rietveld, 1990). The integration of analytical techniques designed to work with MCE problems within GIS could give more functionality to the user (Carver, 1991).

GIS are very useful for storing, processing and manipulating spatial databases (Aronoff, 1989). Consequently, the integration of MCE within a GIS context could help users to improve decision-making processes. In the last decade MCE has received renewed attention in the context of a GIS-based decision-making (Pereira and Duckstein, 1993; Heywood et al., 1995; Malczewski, 1996) which could be useful in solving conflictive situations for individual or groups interested in spatial context. It is also a powerful approach to land suitability assessments (Joerin et al., 2001).

1.7 Food availability

1.7.1 Phytoplankton

Those aquatic pelagic organisms, which are carried about by the movement of the water rather than their own ability to swim are called planktons. The plant components are called as phytoplankton and animal components as zooplanktons and they serve as fish food organisms. There is a close relationship between plankton abundance and fish production (Smith and Swingle, 1938).

Fertilization may not be the only reason for eutrophication or excessive growth of planktons in pond water surface. The growth of certain species of blue green algae forms dense scums in surface waters, cause shallow thermal stratification. Exploiting primary production is a cheap method of producing fish. Planktons also prevent the development of macrophytes that are undesirable for fish.

1.8 Hydrological characteristics

1.8.1 Water depth

Water depth is very important for fish culture. It can be varied from season to season. In the summer season the water depth of pond, beel and floodplain is increased. Besides, in the winter season the water depth is decreased. Mostly the depth of various waterbodies are highest in rainy season. Various fish can survive in different depth.

1.9 Water quality

1.9.1 Water temperature

Water temperature exerts a major influence on biological activity and growth. Temperature governs the kinds of organisms that can live in rivers and lakes. Fish, insects, zooplankton, phytoplankton, and other aquatic species all have a preferred temperature range. As temperatures get too far above or below this preferred range, the number of individuals of the species decreases until finally there are none. Temperature is also important because of its influence on water chemistry. It is the opposite when considering a gas, such as oxygen, dissolved in the water. Warm water holds less dissolved oxygen than cool water.

1.9.2 Water pH

pH is an important indicator of water that is changing chemically. pH is a measure of how acidic/basic water is. The range goes from 0 - 14, with 7 being neutral. pH of less than 7 indicates acidity, whereas a pH of greater than 7 indicates a base. pH is really a measure of the relative amount of free hydrogen and hydroxyl ions in the water. The pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (P, N, C) and heavy metals (Pb, Cu, Cd etc.). Pollution can change water’s pH, which in turn can harm animals and plants living in the water. Emissions of organic water pollutants are measured by biochemical oxygen demand, which refers to the amount of oxygen that bacteria in water will consume in breaking down waste. This is a standard water-treatment test for the presence of organic pollutants.

1.9.3 Dissolved oxygen (DO)

Dissolved oxygen is what makes aquatic life possible. Changes in oxygen concentration may affect species dependent on oxygen-rich water, like many macro invertebrate species. Without sufficient oxygen they may die, disrupting the food chain. All aquatic animals need oxygen to survive. Many aquatic macro invertebrate species depend on oxygen-rich water. Without sufficient oxygen they may disappear. Even a small change in dissolved oxygen concentration can affect the composition of aquatic communities. Many fish require a certain dissolved oxygen range in order to survive.

1.9.4 Biological oxygen demand (BOD)

Biochemical oxygen demand is the amount of oxygen required for microbial metabolism of organic compounds in water. This demand occurs over some variable period of time depending on temperature, nutrient concentrations, and the enzymes available to indigenous microbial populations. The amount of oxygen required to completely oxidize the organic compounds to CO_2 and water through generations of microbial growth, death, decay, and cannibalism is total BOD. Total BOD is of more significance to food webs than to water quality. If the microbial population deoxygenates the water, however, that lack of oxygen imposes a limit on population growth of aerobic aquatic microbial organisms resulting in a longer term food surplus and oxygen deficit.

1.10 Soil quality

1.10.1 Soil pH

pH is considered as most important factor for fish culture. Most of the nutrients in the pond water are directly influenced by the soil pH. If the pH is too high or too low, nutrients become insoluble, limiting the availability of nutrients to the organisms. It indicates the acidity and alkalinity of water body. Besides indicating hydrozen ion concentration, pH acts as a index of several environmental conditions such as (i) free CO2 concentration (ii) DO content (iii) concentration of nutrients (iv) acidity or alkalinity etc. the circum neutral pH or slightly alkaline pH is most suitable for fish culture (Rahman, 1992).

pH 6.5 to 9 is suitable for fish culture and pH more than 9.5 is unsuitable because CO2 is not available in this situation (Swingle, 1967). Fish dies at pH 11 and pH less than 6.5 reduce fish growth, physiological activities, and tolerance to toxic substances.

1.11 Water pollution

The fish production is badly hampered by pollution. Different kinds of pollution are responsible for decreasing fish production. For example, agricultural effluents, industrial effluents, sewage problems, poultry wastes are important factor for destroying fish survival rate, fish growth, reproduction etc. For these pollution fish can be death.

1.12 Research gap

Vasilis, D. et al., (2004) used a GIS environmental modelling approach to designe essential fish habitat. They propsed a multi-parameter model that includes processing and integration of EFH environmental and biological descriptors under a Geographic Information System. However, the model did not extended to include more variables depending on the available life history information of the targeted species. The proposed EFH model more emphasized on fisheries management efforts by contributing as part of GIS-based decision support systems, especially in the identification of species seasonal aggregation regions, the monitoring of the variability of catch in these regions and ultimately, the design of marine protected areas or seasonally closure areas.

GIS-based multi-criteria evaluation models have been used by Nyoman Radiarta, et al., (2008) for identifying suitable sites for Japanese scallop (*Mizuhopecten yessoensis*) aquaculture in Funka Bay, southwestern Hokkaido, Japan. This study was conducted to identify the most suitable sites for hanging culture of Japanese scallop using geographic information system (GIS)-based multi-criteria evaluation models. This study mainly focused on the selection of the most suitable sites for hanging culture of Japanese scallop which cannot be considered as a holistic approach for integrated fisheries management.

Walke ,N. *et al.,* (2012) has been conducted GIS-based multi-criteria overlay analysis in soil-suitability evaluation for cotton (*Gossypium* spp.) which only considered the soil characteristic for assessing habitat suitability. This study has revealed that the soil associations E–F, F–G, G–H, and H–G are ‘‘moderately suitable’’ (S2), D–E were ‘‘marginally to moderately suitable,’’ and C–D were marginally (S3) suitable.

Rajitha, K. *et al.,* (2006) applied the remote sensing and GIS for sustainable management of shrimp culture in India. This paper addressesd the potential capabilities of evolving satellite remote sensing technology and GIS for the sustainable management of shrimp culture through the analysis of various dataset depicting the criteria of sustainability.

Mark, B. Bain *et al.,* (2012) had been developed a Habitat Model for Fish Communities in Large Streams and Small Rivers. They reported on synthesis of 30 habitat models for fish species that inhabit large streams and small rivers. Eleven habitat variables were most commonly used in habitat models, and they were grouped by water quality, reproduction, and food and cover. The developed relations defined acceptable and optimal conditions for each habitat variable. Water quality variables were mid-summer water temperature, dissolved oxygen, pH, and turbidity. Other structural habitat variables were identified: riffle and pool velocity, riffle depth, and percent of the stream area with cover and pools. However, there are some constraints in practical decisionmaking in aquaculture provided through using GIS modeling: (1) a lack of appreciation of the benefits of such systems on the part of key decision-makers; (2) limited understanding about GIS principles and associated methodology; (3) inadequate administrative support to ensure GIS continuity among organizations; and (4) poor levels of interaction among GIS analysts, subject matter specialists and end users of the technology (Kapetsky and Travaglia, 1995).

Kapetsky *et al.,* (1995) had provided An overview of their present and potential applications of geographical information systems and remote sensing in aquaculture**.** They pointed out that the individual investor interested in aquaculture development requires spatial information particularly at the time of site selection among a range of alternative locations with different biophysical and socio-economic characteristics. However, climatic variability is one of the prime predictors for biophysical and socio-economic characteristics which were not considered in this study.

Scott, P.C. and Ross, L.G. (1999) conducted a study on GIS based environmental modeling for management of coastal aquaculture and natural resources in Sepetiba, Brazil. In this study a Landsat TM imagery was used coupled with ground information on land use and water quality parameters to allow the construction of a GIS database from which management strategies were proposed. In this study result validation process through analyzing peoples' perception and expert opinion was more or less weak to seek a integrated information management system.

Sa´nchez, P.E. ***et al.,*** **(2003)** conducted a study on changes in natural cover and land use within the Ceuta coastal lagoon system, Mexico, using multi-temporal analysis of Landsat imagery. Global trends of change and the effects of the recent establishment of the shrimp aquaculture industry on the natural cover were examined. On two images from 1984 and 1999, nine information categories (secondary succession, mangrove, irrigated and temporary agriculture, dry forest, bare substratum, lagoons, shrimp ponds, and villages) were evaluated.

Jayanthi, M. and Rekha, P.N. (2004) conducted a study in the Krishna district of Andhra Pradesh, India for identifying the potential brackish water area through remote sensing and GIS. According to this study, the brackish water area developed in this district is 28,205 ha.

Ron Store and Jukka Jokimäki, (2003) has develop a method by means of which it was possible to produce geo-referenced ecological information about the habitat requirements of different species. The integrated habitat suitability index approach includes the steps of constructing habitat suitability models, producing data needed in models, evaluating of target areas based on habitat factors, and combining various suitability indices.

Littleboy, M., et al., (1996) used GIS-based spatial modeling to extrapolate point basic models to form spatial models. In their work, the study area was evaluated according to soil, slope, and rainfall classes and GIS was used to produce a suitability class for each polygon.

Giap and Yang Yi, (2005) has used GIS for land evaluation for shrimp farming in Haiphong of Vietnam. It was estimated that about 31% (2604 ha) of the total land area (8281 ha) in Haiphong was highly suitable for shrimp farming.

William, S. Arnold and Mary, W. White, (2000) had identified a 6,321 ha subset of the estuary that appears suited for hard clam aquaculture .

Pe´rez, O.M. ***et al.,*** **(2003)** used GIS and related technology. Most areas of the coastline of Tenerife were identified as being suitable or very suitable, and none was identified as totally unsuitable

Salam, M.A. and Khatun, N.A. (2005) used Multi Criteria Evaluation (MCE) with Weighted Linear Combination (WLC) where 58% of the area was very and moderately suitable for carp culture.

Karthika, M. et al., (2005) delineate the potential area for brackish water aquaculture using the techniques of remote sensing an geographical information system. The total study area of 20431.034 ha, 0.377% is highly suitable, 9.873% was suitable, 1.772% was moderately suitable, 85.027% was unsuitable, and 2.951% was under aqua farms.

Silva, C. et al., (2011) has been conducted an integrative methodology for site selection of shellfish aquaculture that combines geographical information systems and dynamic farm-scale carrying capacity modeling was developed. The identification of 3 km2 (7.6%) of suitable sites in the study area using a GIS approach indicates that Tornagaleones was the most promising area for shellfish aquaculture and Valdivia was satisfactory.

Rida Al-Adamat, et al., (2010) used both the Weighted Linear Combination (combining GIS with multi-criteria decision making) and the Boolean techniques within GIS environment to select suitable areas in Northern Jordan for establishing water harvesting ponds where 25% of the study area (64,184.8 ha) with high potential for constructing water harvesting ponds.

Nayak, et al., (2014) use GIS-based multi-criteria evaluation approach fo aquaculture site suitability identification. The total area suitable for aquaculture development was computed as most suitable (8,426 ha forming 27%) moderately suitable (5,623 ha forming 18%) and not suitable (198 ha forming 1%) with constraints of forest cover an infrastructure facilities of around 16617 ha (54%) of the total landings area. In context of Bangladesh, Salam Dr.M.A. has only identified the potential site for sustainable aquaculture development in Mymensing district using GIS as a tools and MCE modelling. Six main categories of criteria were considered to locate areas suitable for aquaculture potential followed by the approach of Kapetsky 1994. They were water sources, soil characteristics, infrastructure, market potential, agricultural input, and extension support facilities.

Hence, the attempt for this study is the first approach to identify the habitat suitability for aquaculture in case of Gazipur district and second approach in consideration of whole Bangladesh.

1.13 Study objectives

The main objective of this research is to delineate the suitable water bodies in Gazipur districts for culture fishes through the MCE technique within a GIS context, using habitat characteristics, food availability, water depth, water quality, soil quality, industrial and agricultural pollution, as well as socio-economic factors.

The specific objectives are:

- To assess connectivity, water availability, spawning ground condition of fish habitat
- To assess phytoplankton amount for understanding food availability
- To monitor prevailing condition of phisico-chemical parameters (e.g. water temperature, DO, BOD, pH
- To assess soil quality and its relation to habitat productivity
- To assess industrial and agricultural effluents
- To assess the livelihood status of existing fishermen and fish farmer
- To assess of habitat suitability for culture species
- To create suitability index/priority map using GIS.

CHAPTER 2: MATERIALS AND METHODS

2.1 Conceptualization of aquaculture suitability assessment framework

It is crucially important to develop a habitat suitability framework for cultured species of Gazipur district. The important factors associated in this are (i) prioritizing habitat type (ii) monitoring water depth and water quality through water sampling (iii) observing phytoplankton availability. The degree or magnitude of habitat suitability depends on different parameters such as (i) river connectivity (ii) good spawning ground (iii) water quality (temperature, pH, DO, BOD) (iv) soil pH (v) water pollution (vi) food availability (vii) livelihood status of fishermen etc (CEGIS, 2008). All these above factors were taken into consideration in conceptualizing the habitat suitability (Figure 3)

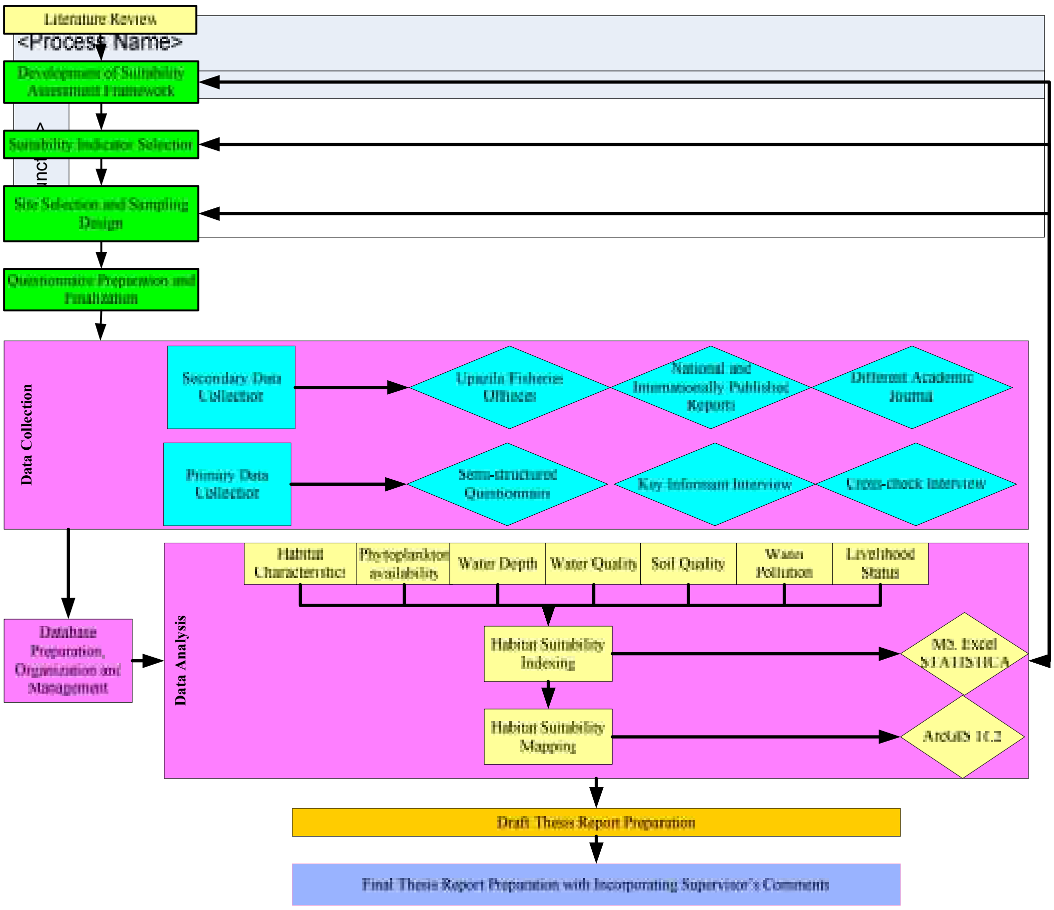

Figure 3: Suitability assessment framework

2.2 Study Design for Habitat Suitability Index

In the present study, various steps were taken under several layers. They are briefly described below.

2.2.1 Literature Review

Literature review has been made to understand the basic theories, concepts and present liquidity of information on fisheries habitat and its suitability indicators, sensitivity of fish abundance, richness and fish production of various capture and culture fish habitats. Literatures have been collected from different nationally and internationally published reports, scientific journals and online sources.

2.2.2 Site Selection

Rationalization of selection of study site

The water bodies (pond, beel, and floodplain) of Gazipur district are enriched with a plenty of fisheries resources from the primordial stretch, but with time passing by the deleterious human conduct alongside the environmental anomalies synergistically affecting the habitat of fishes. In the recent past there were plenty of the indigenous species but ironically, they are now awfully in perilous circumstances, many of them is going to be extinct and the rests are endangered. The Gazipur district is considered as study site based on following facts: (i) It is a floodplain area (ii) It is one of the most industrial zones in Bangladesh (iii) It is most suitable district for fisheries resources of Bangladesh (iv) It has lot of fishing area.

Physical characteristics of study area

Gazipur district is a district of Dhaka division in Bangladesh. The Geo position of Gazipur district is between 23˚53' to 24˚20' North latitudes and between 90˚09' to 90˚42' East longitude. The total area of the district is 1806.36 km^2 of which 17.53 km^2 is riverine and 273.42 km^2 is forest area. The main rivers of Gazipur district are - old Brahmaputra, Shitalakshya, Turag, Bangshi, Balu and Banar. Belai, Mokesshor, Labolong and Dakurai are main beel[1] of Gazipur district. Besides Gazipur district has 12195 pond and its area is 9051

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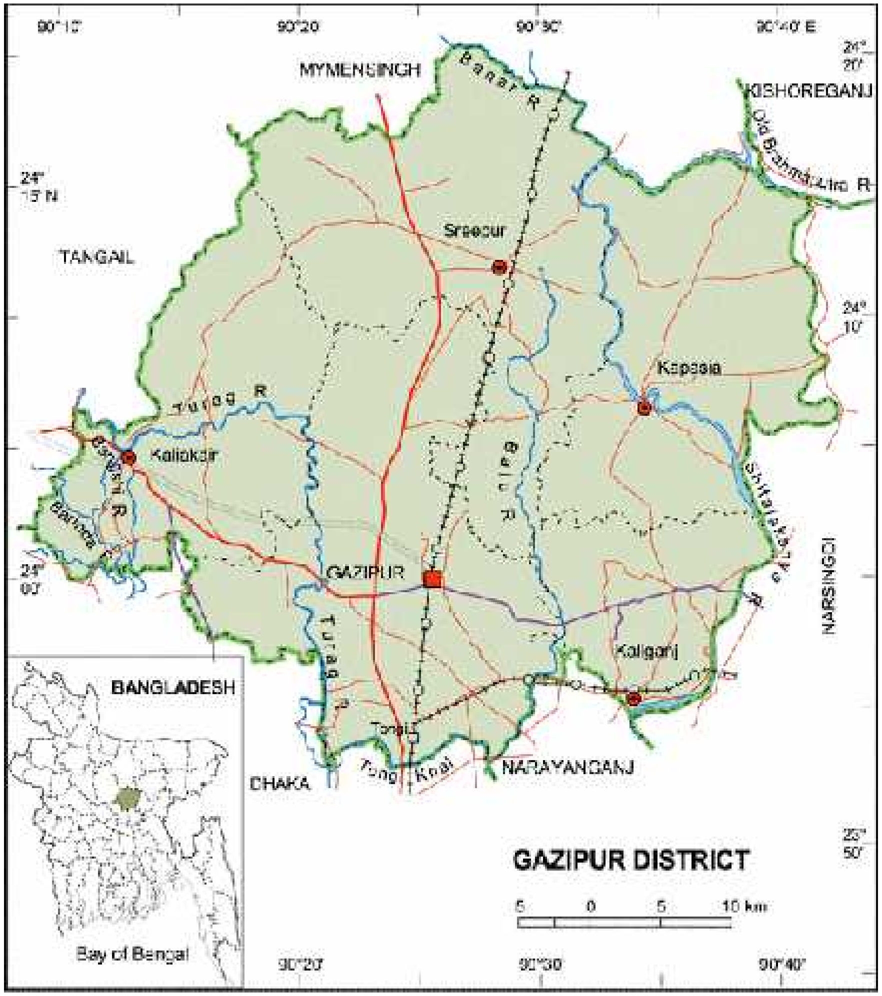
[1] Beel is the large depression that contain water whole the year around and where it is connected with river (Islam, 2006).

ha. Various water bodies of the district constitute habitats for fish population. The number of upazilla in Gazipur district is 05, named- Gazipur Sadar, Kalikair, Kaliganj, Kapasia and Sreepur (BBS, 2011).



Map 01: Study Area

2.2.3 Sampling design

The study sites were selected using purposive-cum-snowball2 sampling method. The sites were chosen in such a way that those sites cover all habitat types and major areas in Gazipur districta. Thus, three types of habitat were selected according to respondents' importance.

2.2.4 Data Collection

In order to address the objectives of the study, both secondary and primary data were used. Both qualitative and quantitative data were considered while conducting data collection.

Secondary and Institutional data

***GIS Data*:** Space technology including GIS was used extensively for analysis and preparation of spatial maps of the study areas. Based on available baseline data (administrative boundary, and water bodies, etc.), base map was prepared under the study using ArcGIS software and updated GIS data of the National Water Resource Database (NWRD).

***Hydrological and Drainage Network*:** connectivity, surface water availability, historical trend of water level, etc. were considered to assess the hydrological variability of the study.

***Fisheries Data*:** Historical trend of capture and culture fish production were assessed using FRSS data book and Upazila Fisheries Offices (2009-2014).

Several sorts of data, historical maps, thematic indication and secondary data on the study were collected from following ways:

Table 01: Various collected information from organizations

Secondary data	Source of data	Use of data
Upazila agricultural census report (2011)	BBS (Bangladesh Bureau of Statistics)	For livelihood status
Upazila map of Gazipur District	LGED (Local government engineering department)	For suitability analysis

[2] In snowball sampling, a technique of non-probability sampling, one or more key individuals are located and they are asked to name others who would be likely candidates for the study. Snowball sampling is an effective way to build an exhaustive sampling frame of displaced populations.

Data of fish production of previous year (2010-2014)	BFRI (Bangladesh Fisheries Research Institute)	For analysis of production trend
Data of fish production of previous year (2010-2014)	DoF(Department of Fisheries	Fish production trend analysis
Data collection related to fish production of every upazila	Upazila office of Gazipur	For identification of habitat suitability
Livelihood status of fishermen	Bangladesh population and housing census,2011	For analysis of livelihood trend

Primary Data

Primary data were collected through semi-structured questionnaire interview and cross-check interviews.

Design and formulation of questionnaire

Survey questionnaire is an important part for collecting data through survey. The draft questionnaire was pre-tested using elicit responses from interviewing several fishermen. Then the draft questionnaire was improved, rearranged as well as modified in the light of actual and practical experiences.

Questionnaire interview

For questionnaire interview, random sampling method was followed from five upazilas of Gazipur. Fishers were interviewed near pond, beel when fishing.

Cross-check interviews

After collecting the data through questionnaire interviews, it is necessary to check the information for justification of the collection data. Cross-check interviews were conducted with key person such as SUO (Senior Upazila Officer, DFO (District Fisheries Officer). The interviews of the respondents were conducted in their office during office hour.

Situational Observation

The overall condition of habitat suitability of the study area was observed to evaluate the entire changing indicator in respect of fish habitat.

Key Informants Interviews (KII)

After collecting the data, it was crosschecked with the following one hundred knowledgeable persons (key informants):

a. Upazila Fisheries Officers (UFO and NGOs' officers): 3 N × 5 UP = 15
b. Knowledgeable Fishermen including women = 15 N × 5 UP = 75
c. Other Local Experience Person non-Fishermen = 50

Total = 140

2.2.5 Data Processing and Database Preparation

After collecting data, database was developed using Microsoft Excel Spreadsheet. Finally, after entering all the primary collected data, quality of the data was ensured by an expert.

2.2.6 Data Analysis and Interpretation

Quantification

MS. Excel Spreadsheet has been used for analyzing discreate statistics, such as average, standard deviation, etc. Furthermore, correlation coefficient, multiple regression model have been conducted through using STATISTICA-8.0.550 software package.

Content analysis

Qualitative information was analyzed through content analysis by the associate experts of the team. Pressure-state-response model was used for qualitative impact analysis. Moreover, the interpretation was also done by the experts.

Mathematical Modeling for Analyzing Abitat Suitability Index

A formula was developed to calculate the habitat suitability index following systematic steps i.e., (i) formulae development for different indicator calculation, (ii) formulae and lookup table development to calculate the scores of different indicators/parameters and (iii) habitat suitability index computation.

Determinants /Indicators and Suitability Index

The habitat suitability was computed based on several determinants or indicators. The indicators were calculated based on some parameters e.g., indicator parameters. The indicator and indicator parameters are given Table 02. Using these parameters the suitability index score for individual parameters were calculated.

Choice of indicators

A number of indicators against habitat suitability determinants of corresponding criteria were chosen. The indicators are presented in Table 4. The Table 4 explains the relationship between the indicators and the habitat suitability.

Table 02: Indicator use for habitat suitability computation (CEGIS, 2008)

Indicators	Indicator parameter	Hypothesis of the indicator	Hypothesized functional relationship
Habitat characteristics	Habitat type	Perennial	If the habitat type is perennial, the habitat will be suitable.
		Seasonal	If the habitat type is seasonal, the habitat will be moderately suitable.
	Spawning ground	Good/Poor/Very poor	If there is good spawning ground, it will be suitable; otherwise it will be moderately suitable.
Food availability	Phytoplankton	Good	If there is good amount of phytoplankton, habitat will be suitable.
		Poor/Very poor	If there is very poor amount of phytoplankton, it will be moderately suitable.
Hydrological characteristics	Water depth	>7 feet <5 feet	The water depth is >7 feet, it will be suitable and the <5 feet is moderately suitable.
Water quality	Temperature	29-30℃	The lower the temperature water quality will deteriorate cause moderately suitable.
	DO	5ppt	The lower DO the water will be moderately suitable.
	pH	6.5-9	The higher and lower pH, water quality will deteriorate cause moderately suitable.
	BOD	1-2	The higher BOD cause moderately suitable.
Soil quality	pH	6.5-9.5	The lower the soil pH will be

Indicators	Indicator parameter	Hypothesis of the indicator	Hypothesized functional relationship
			moderately suitable.
Water pollution	Agricultural land and Industrial effluents	Harmful	If agricultural and industrial effluents are harmful, habitat will be moderately suitable.
		Moderate harmful/Not harmful	If agricultural and industrial effluents are not harmful, habitat will be suitable.
Livelihood status	Number of fish farmer and fishermen	>3000	The higher number of fish farmers and fishermen indicates good locality for aquaculture.
Economic condition	Fish production	>4300 mt	If higher fish production , habitat is considered suitable.

Calculation of Habitat Suitability Index

The chosen indicators then were calculated through applying the following formula given in the following table (Table 03)

Table 03: Habitat suitability index calculation

Sl	Indicators	Weight	Criteria	Score
1	Habitat type (H_t)	0.03	Perennial	1.0
2			Seasonal	0.5
3	Spawning ground (S_g)		Very good	1.0
4			Good	0.6
5			Moderate	0.4
Habitat Characteristics (I_1), = Value of H_t+Value of S_g				
6	Phytoplankton availability	0.1	Very good	1.0
7			Good	0.6
8			Moderate	0.4
Phytoplankton availability, I_2 = Value of I_2				
9	Water depth (feet)	0.3	>7	1.0
10			5-7	0.6
11			4-5	0.4
12			<4	0
Water depth (feet), I_3 = Value of I_3				

Sl	Indicators	Weight	Criteria	Score
13	Temperature (°C)	0.3	29-30	1.0
14			25-28	0.6
15			<25	0.4
16			<10	0
17	DO(mg/l)		>5	1.0
18			5	0.6
19			<5	0.4
			<1	0
20	pH		6.5-9	1.0
21			4-6.5	0.6
22			4-5	0.3
23			Less than 4	0
24	BOD		1-2	1.0
25			3-5	0.6
26			6-9	0.2
Water quality (I_4) =Value of W_t+Value of W_{DO}+Value of W_{pH}+Value of W_{BOD}				
27	Soil pH	0.2	6.5-8.5	1.0
28			<6.5	0.6
29			>9.5	0
Soil pH (I_5) =Value of S_p				
30	Agricultural pollution (A_p)	0.04	Not harmful	1
31			Moderate harmful	0.5
32			Harmful	0
33	Industrial pollution (I_p)		Not harmful	1
34			Moderate harmful	0.5
35			Harmful	0
Water pollution (I_6) = Value of A_p+Value of I_p				
	No of Fish Farmer (F_f)	0.02	2500-3000	1.0
			2000-2500	0.6
			<2000	0.4
	No of Fishermen (F_m)		>3000	1.0
			2500-3000	0.6
			2000-2500	0.4
			1500-2000	0.2
			<1500	0
Livelihood status (I_7) = Value of F_f +Value of F_m				
	Fish Production (F_p)	0.01	>4300	1.0

Sl	Indicators	Weight	Criteria	Score
			3600-4300	0.6
			2900-3600	0.4
			2200-2900	0.2
			1500-2200	0.1
			<1500	0
Fish Production (I_7) = Value of F_p				
HS= $I_1 \times 0.03 + I_2 \times 0.1 + I_3 \times 0.3 + I_4 \times 0.3 + I_5 \times 0.2 + I_6 \times 0.04 + I_7 \times 0.02 + I_8 \times 0.01$				

CHAPTER 3- RESULTS

In the present study, fish habitat has been classified based on physical existence. Fisheries resources primarily based on the study area, five (5) upazilas under Gazipur district, comprising capture (river, beel and floodplain) and culture (pond) fisheries. A diversified capture and culture fish habitats exist in the study area with showing two quite different scenarios during two hydrological seasons (wet and dry seasons). Open water fish habitat of the study area includes surrounding external river, internal khal, seasonalbeel and seasonal floodplain. Moreover, due to locating in Brahmaputra-Jamuna floodplain and Madhupur Sal Tract there are a number of deep portions of floodplains (koles) in the study area which have used as the breeding and spawning ground, especially for *Anabas testudineus*, *Channastriatus*, *Channa punctatus*, *Puntius ticto*, etc. Moreover, a number of semi-intensive and intensive fish aquaculture practices are dominant in the study area. In addition to both of these capture and culture fisheries resources fishing activities, fish demand, access to the market, etc are playing vital role in maintaining fisheries productivity in the study area. Moreover, a significant number of existing settlement, infrastructures (like road), and different industries play an important role to maintain the productivity of the study area which increasingly causes the loss of connectivity, reduction of breeding, spawning, nursing and feeding ground and the presence of viral diseases especially, in dry season.

3.1 Habitat Distribution

Total fish habitat area in Gazipur district is about 44,580 ha of which culture fisheries covers about 7.5% (3,362ha) and capture fisheries about 92.5% (41,218ha). Among capture fisheries resources floodplain attains the maximum habitat area in Gazipur district (Table 04).

Table 04: Habitat area of upazilas of Gazipur district

Upazila	Capture Fisheries					Culture Fisheries		Grand Total
	River	Khal	Beel	Floodplain	Sub-Total	Pond	Sub-Total	
SadarUpazilla	158	529	668	10,270	11,625	1,204	1,204	12,829
Kaliakair	2,824	-	2,401	3,109	8,334	620	620	8,954
Kaliganj	302	11	400	5,600	6,313	624	624	6,937
Kapasia	1,200	167	1,115	5,263	7,744	329	329	8,073
Sreepur	150	117	6,534	400	7,201	585	585	7,787

Source: Upazila Fisheries Office (2015)

It has been found that SadarUpazila covers highest fish habitat (about 29%) among the five (5) upazilas of Gazipur district, whereas, lowest fish habitat has been found in Kaliganjupazilas (Figure 04 and Map 2-4).

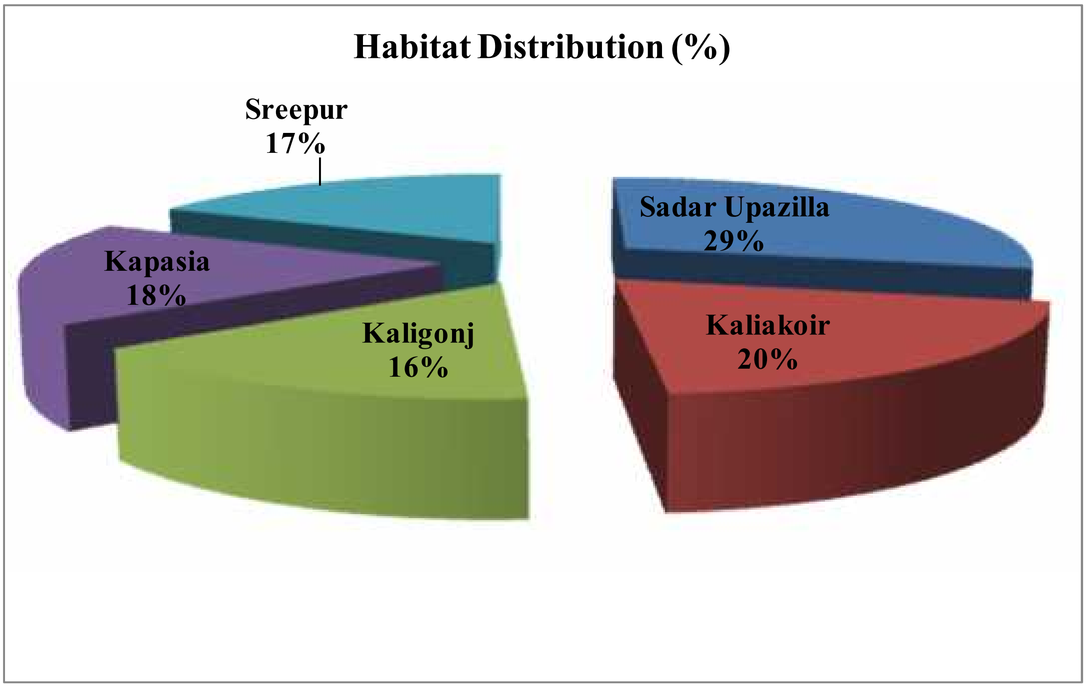
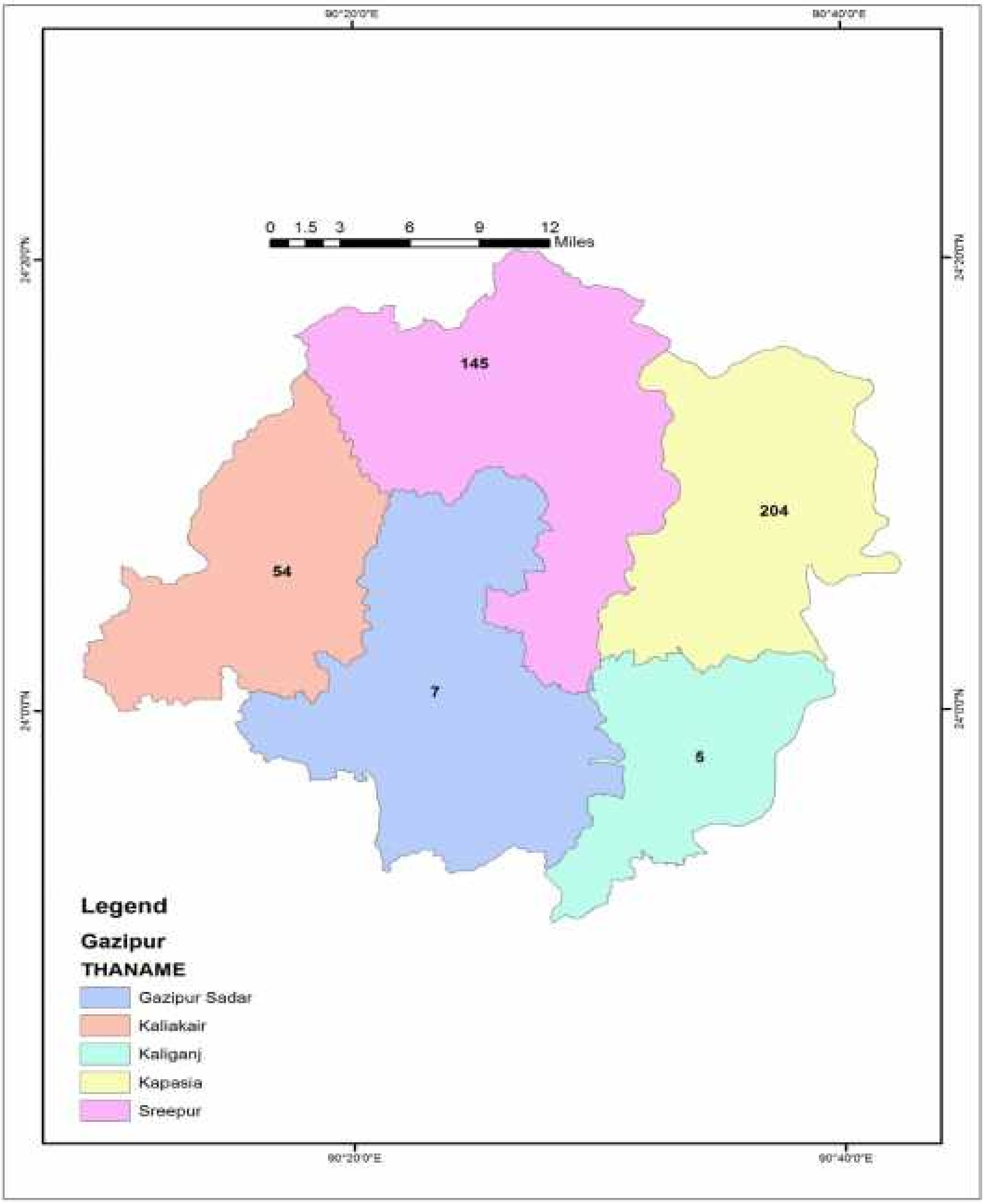


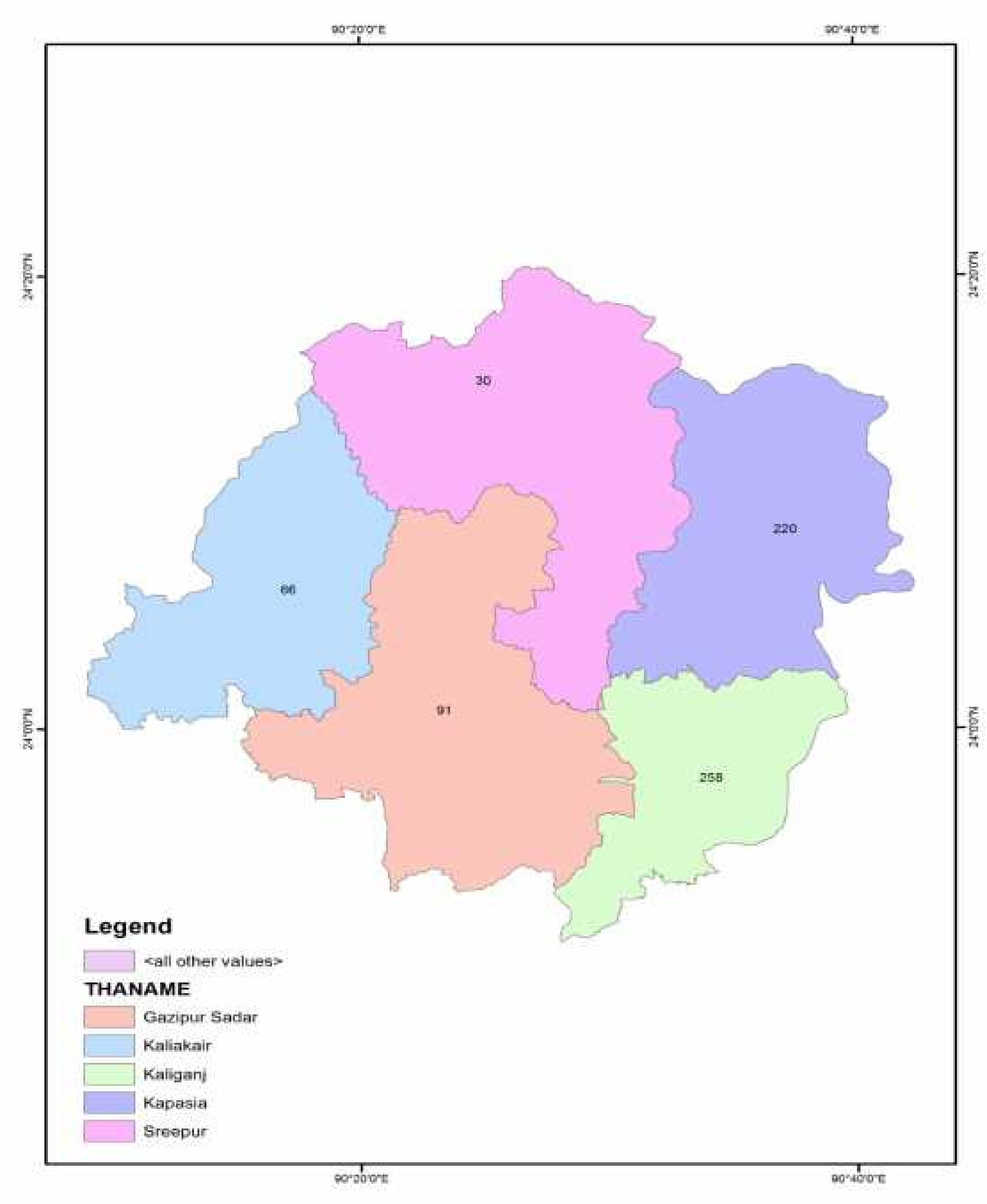
Figure 04: Habitat distribution in GazipurDistrict

Source: The diagram created by the author using data fromUpazila Fisheries Office (2015)



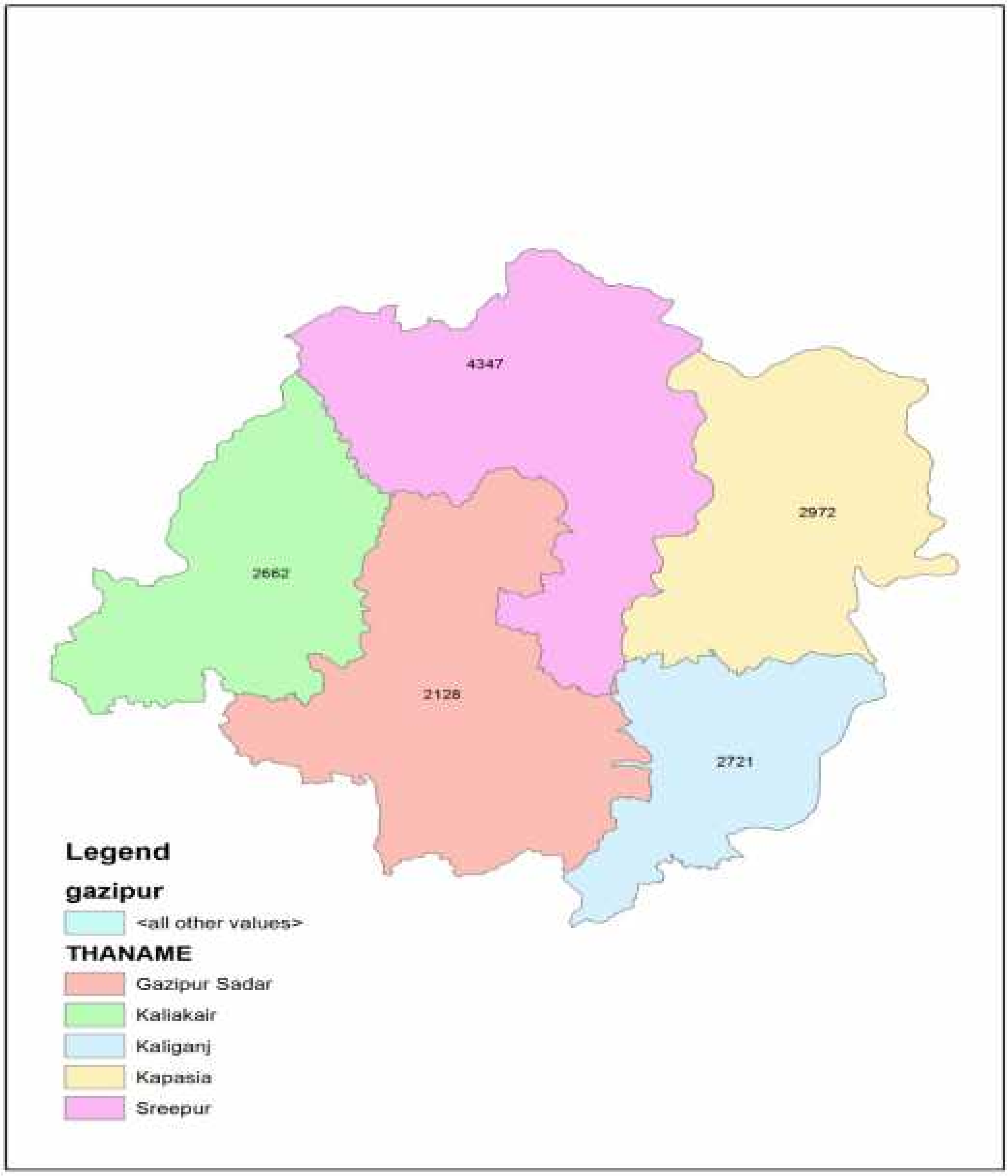
Map 02: Beel habitat distribution in GazipurDistrict

Source: The diagram created by the author using data from fishermen's interview



Map 03: Floodplain habitat distribution in GazipurDistrict

Source: The diagram created by the author using data from fishermen's interview



Map 04: Culture fish habitat (including Pond) distribution in GazipurDistrict

Source: The diagram created by the author using data from fishermen's interview

Various historical trends in fish habitat area have been found in the present study. In case of Kaliakair and Sadarupazilas, culture fish habitat areas have been increased from the year of 2011. However, in all the cases floodplain attains increasing trend. Moreover, other capture fish habitat shows a continuous trend for habitat area (Figure 5).

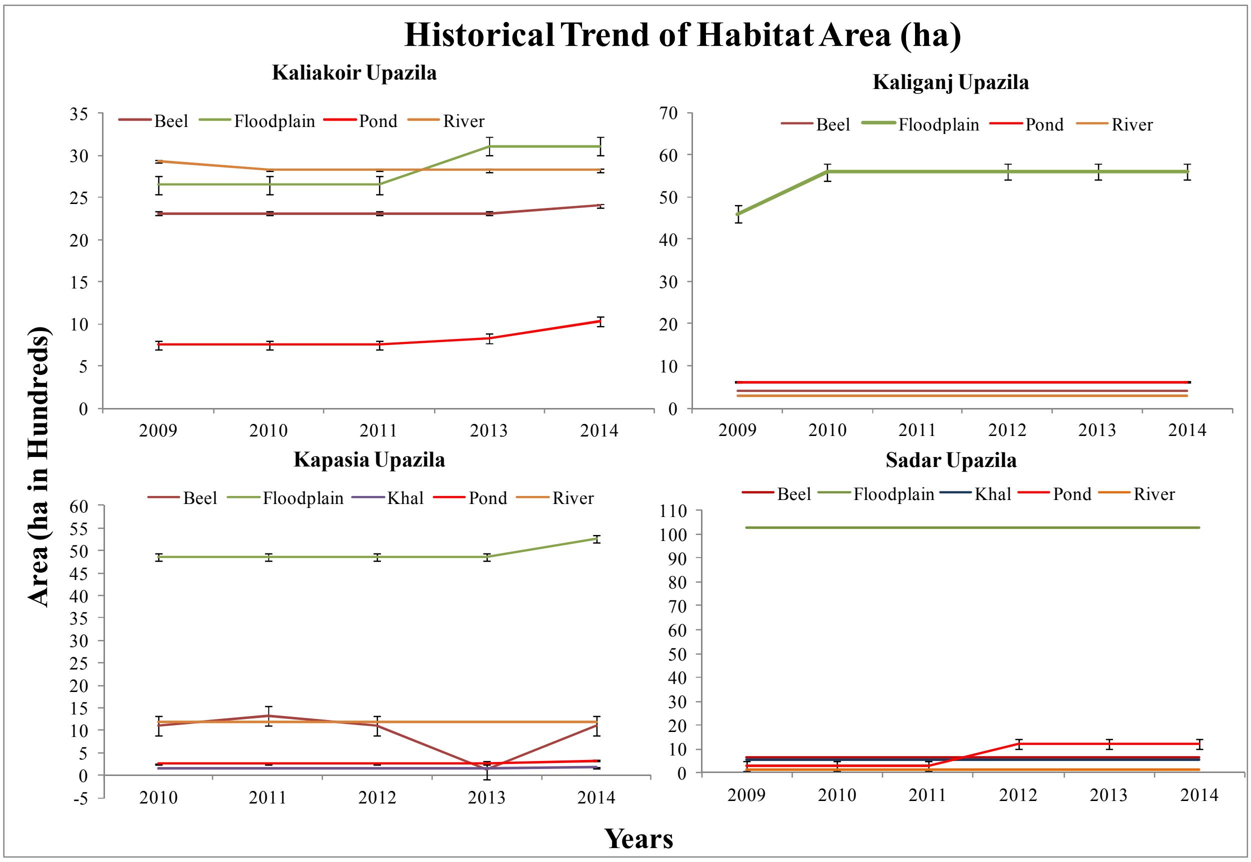


Figure 05: Historical trend of fish habitat area for the study area

Source: The diagram created by the author using data fromUpazila Fisheries Office, 2015

Fish habitat condition in the study area shows that connectivity among the fish habitats, mainly among capture fish habitats, was strong in case of Sadar and Kaliakairupazilas, while in other upazilas fish habitats were weakly or not connected (Table 05). This results in lower depth and moderate to poor food availability for the fish habitats in the respective upazilas.

Table 05: Habitat condition of different fish habitats in the upazilas

Upazilla	Connectivity	Depth(ft)				Food availability (Phytoplankton)
		Pond	Beel	River	Floodplain	
Sadar	Yes	6-8	5-8	25-30	15-20	Good
Kaliakair	Yes	8-9	8-10	25-30	10-12	Good
Kaliganj	No	7-8	6-8	25-30	10-12	Moderate
Kapasia	No	5-6	5-8	25-30	5-10	Poor
Sreepur	No	7-8	6-8	25-30	5-10	Poor

Source: Key Informant Interviews, 2015

Water quality is more or less similar in pond, beel and floodplain fish habitat in case of studied upazilas. However, the pH level for beel habitat has been reported to be higher than other fish habitats (Table 06). Moreover, the soil quality is ranged from 5 to 7 which are considered as the moderate suitability for high value fish species.

Table 06: Water quality of different fish habitats in the upazilas

Upazilas	Water quality									Soil pH
	Pond			Beel			Floodplain			
	DO	pH	BOD	DO	pH	BOD	DO	pH	BOD	
GazipurSadar	5-6	6-9	6-9	4-6	8-9	7-9	6-8	7-8	7-8	5-6
Kaliakair	4-6	7-8	3-5	5-6	6-8	6-7	5-7	5-6	6-8	5-7
Kaliganj	4-5	7-9	3-5	4-6	6-8	4-5	5-7	6-7	4-6	5-6
Kapashia	5-6	8-9	1-2	5-7	7-8	1-3	4-6	6-8	1-3	5-7
Sreepur	6-7	6-9	3-5	6-8	7-8	5-7	5-7	7-8	2-4	6-7

Source: The Table created by the author using data fromUpazila Fisheries Office (2015)

3.2 Pollution Proximity

It has been found in the present study that in all the upazilas, except Kaliakairupazila, agricultural land is near the fish habitat which is supposed to moderate to very harmful to fish habitat (Table 07). Moreover, highest number of industries has been observed in SadarUpazila which poses very harmful to fish habitat.

Table 07: Pollution severity in different upazilas of Gazipur district

Upazila	No of Waterbody	Pollution Proximity		Pollution Severity	
		Agricultural land	Industry	Agricultural	Industrial
GazipurSadar	2,226	Near	Near	Moderate harmful	Very harmful
Kaliakair	2,782	Far away	Very far away	Not harmful	Not harmful
Kaliganj	2,984	Near	Very far away	Moderate harmful	Not harmful
Kapasia	3,396	Near	Far away	Very harmful	Moderate harmful
Sreepur	4,522	Near	Far away	Moderate harmful	Not harmful

Source: Key Informant Interview, 2015

Historical productivity scenario of different fish habitat in case of GazipurSadarupazila shows that although the productivity of capture fisheries has been increasing, but pond productivity has been decreasing, particularly from the year of 2012 to 2014 (Table 08). However, in case of Kaliakair, Kaliganj and Kapasiaupazilas, productivity has been increasing.

Table 08: Historical productivity scenarios of different fish habitat in upazilas of Gazipur districts

Upazila	Year	Beel	Floodplain	Khal	Pond	River	Average Productivity	Sd
SadarUpazilla	2009	389	320	7	14,519	247	3,096	6,387
	2010	397	330	7	11,704	251	2,538	5,126
	2011	397	347	7	14,970	373	3,219	6,571
	2012	397	350	7	3,367	373	899	1,389
	2013	758	350	8	3,376	380	974	1,369
	2014	816	421	9	3,613	386	1,049	1,461
Kaliakair	2009	450	717	-	1,717	2	577	707
	2010	498	800	-	1,707	233	648	663
	2011	528	868	-	1,885	237	704	736
	2013	615	1,078	-	2,994	462	1,030	1,164
	2014	638	1,066	-	4,174	538	1,283	1,660
Kaliganj	2009	123	150	131	3,064	151	724	1,308
	2010	123	124	131	1,525	161	413	622
	2012	661	699	263	3,470	819	1,182	1,296
	2013	712	697	263	3,525	819	1,203	1,315
	2014	712	697	263	3,841	819	1,266	1,455
Kapasia	2010	724	200	1,024	1,988	321	851	715
	2011	1,045	784	1,084	2,750	296	1,192	926
	2012	1,275	807	1,117	2,833	309	1,268	949
	2013	12,294	795	1,057	2,738	301	3,437	5,035
	2014	2,663	499	899	2,553	304	1,384	1,139

**Sd: Standard Deviation*

Source: The Table created by the author using data fromUpazila Fisheries Office, 2015

3.3 Fish Diversity

Fish diversity in the study area is moderate and highly seasonal which drastically decreased during the dry season and has the declining trend over the years. Industrial pollutants, agrochemicals and pesticides coming from paddy fields, obstruction in fish migration routes, anthropogenic obstructions (unplanned housing projects) of internal khals, squeezing of spawning and feeding grounds due to unmanaged indiscriminate fishing (unrestricted fry and brood fishing from deep portions of the floodplain during dry season) in the study area. It has been reported that *Puntius puntio Mystus vittatus*, *Anabas testudineus*, *Oreochromis mossambicus* and *Cirrhinus cirrrhosus* in GazipurSadar; *Wallago attu*,*Pangasiushypophthalmus, Amblypharyngodonmola*, and *Notopteru snotopterus* in Kaliakair; *Mastacembelus armatus* in Kaliganj; *Puntius puntio, Amblypharyngodon microlepis*, *Mystus tengara* and Meni in Kapasia and *Oreochromis mossambicus*, *Labeorohita, Catlacatla* and *Pangasius hypophthalmus,* in Sreepur upazila are abundant (Table 9-10).

Table 09: Species diversity in the study area

Upazila	Trend in Species no±StDev.						Abundant fish	Less abundant fish
	2009	2010	2011	2012	2013	2014		
Gazipur Sadar	11±1	9±1	11±2	11±1	11±2	9±2	*Puntius puntio*,*Mystustengara*, *Anabas testudineus*,*Oreochromismossambicus* ,*Cirrhinuscirrrhosus*	*Catlacatla,LabeocalbasuHypophthalmit hys molitrix*
Kaliakair	9±1	11±2	10-12	10±3	9±1	11±1	*Wallago attu*,,*Pangasiushypophthalmus*,Nala,Small Fish*Notopterusnotopterus*	*Mastacembelusarmatus*,*Mystustengara*
Kaliganj	7±2	7±2	9±1	10±1	11±1	11±1	*Mastacembelusarmatus*	*Ailiacoila*
Kapasia	7±1	7±1	7±1	8±2	10±2	11±1	*Puntius puntio*, *AmblypharyngodonmicrolepisMystustengara*,	*Botia Dario*
Sreepur	12±2	12±1	11±1	9±1	11±1	11±1	*Oreochromismossambicus*,*Labeorohita*,*CatlacatlaPangasiushypo phthalmus*,	*Puntius sarana*, *Channamarulius*

**StDev: Standard Deviation*

Source: Key Informant Interview, 2015

Table 10: Monthly species variation in different upazilas

Upazila	April –September	October –March
GazipurSadar	*Wallago attu*, *Notopterusnotopterus*, *Labeorohita*, *Catlacatla*, *Oreochromismossambicus*, *Hypophthalmicthys molitrix*, *Cteopharyngodonidella*, *Channapunctata*	*Amblypharyn godonmicrolepis, Puntius puntio*, Dhela, *Palaemonmalcolmsonic*, , *Menemuculata*, salmostomaacinaces
Kaliakair	*Channastriatus* ,*Channapunctata* *Wallago*	*Puntius puntio*,*Amblypharyngodon microlepis*, *Lepidcephalichthy guntea, Botia*

	attu,*Pangasiushypophthalmus*,Chitol,*ChannapunctataClariasbatrachusNotopterusnotopterus*	*DarioMastacembelusarmatusAiliacoila*,*Salmostomaacinaces*
Kaliganj	*Oreochromismossambicus*,,*LabeorohitaCatlacatla*,*MacrobrachiumrosenbergiiPangasiushypophthalmus*,*ClariasbatrachusHeteropneustesfossilis*,*Mastacembelusarmatus*	*Ailiacoila*,Meni,*Mystustengara*,*PalaemonmalcolmsonicAmblypharyngodonmicrolepis*
Kapasia	*Hypophthalmicthys molitrix*, *CteopharyngodonidellaChannapunctataBagariusbagarius*,*Pangasiushypophthalmus*, *Oreochromismossambicus*,	*Botia Dario*,Meni,*Puntiussarana*, Coricasoborna,*Anabas testudineus,Mystustengara,Amblypharyngodon, Ailiacoila*
Sreepur	*Labeorohita*, *CatlacatlaClariasbatrachusHeteropneustesfossilisChannastriatus* ,*Channapunctata Labeocalbasu*	*Amblypharyn godonmicrolepi,* microlepis, *Anabas testudineus, Palaemon malcolmsonic*, *Menemuculata*

Source: Key Informant Interview, 2015

3.4 Fish Production

Total fish production in Gazipur district is about 38,763 metric ton (mt) of which culture fisheries covers about 39.5 % (15,319mt) and capture fisheries about 60.5% (23,444mt) (Table 11).

Table 11: Fish production of upazilas of Gazipur district

Upazila	Capture Fisheries					Culture Fisheries		Grand Total
	River	Khal	Beel	Floodplain	Sub-Total	Pond	Sub-Total	
GazipurSadar	61	5	545	4,327	4,938	4,350	4,350	9,288
Kaliakair	1,520	0	1,533	3,314	6,367	2,588	2,588	8,955
Kaliganj	247	3	285	3,901	4,436	2,396	2,396	6,832
Kapasia	365	150	2,969	2,625	6,109	840	840	6,949
Sreepur	30	205	790	570	1,595	5,145	5,145	6,740

Source: The Table created by the author using data fromUpazila Fisheries Office(2015)

The present investigation has found that highest culture fish production comes from Sreepurupazila and lowest from Kapasia of Gazipur district (Figure 06). Highest river fish production has been found in case of Kaliakairupazila. Highest and lowest fish production from beel habitat come from Kapasia and Kaliganjupazila respectively. Moreover, highest fish production from floodplain habitat has been found in case of Kaliganjupazila.

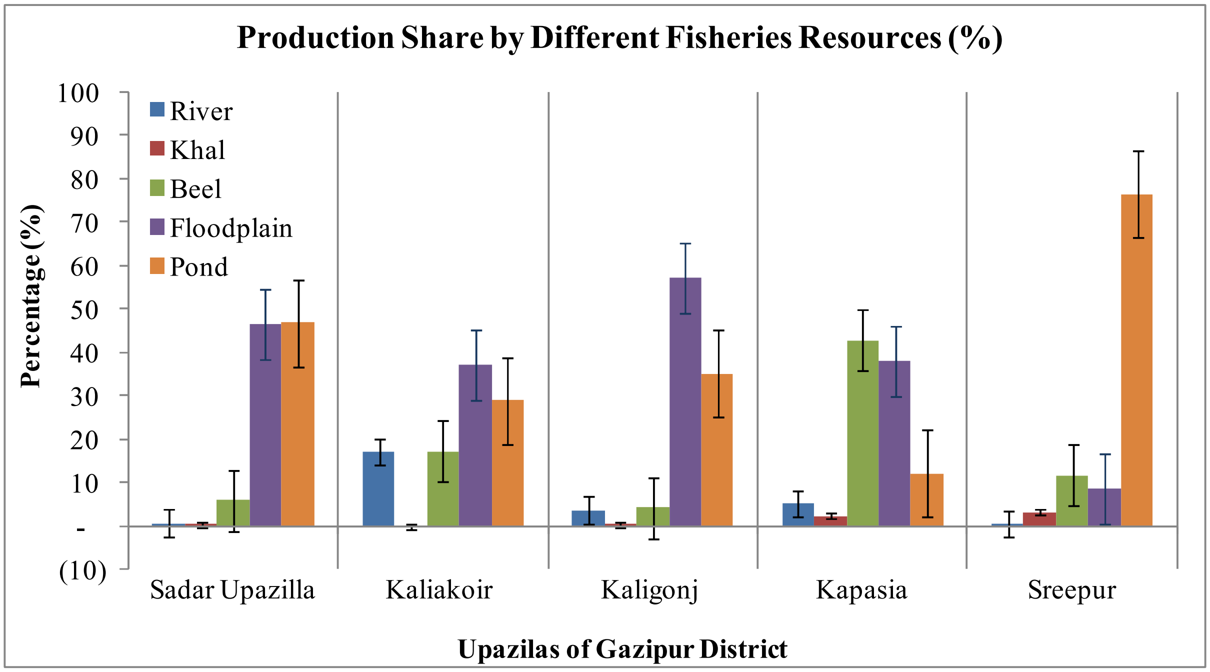


Figure 06: Production share by culture fisheries in Gazipur district

Source: The diagram created by the author using data fromUpazila Fisheries Office(2015)

A diversified trend in fish production has been observed in case of river, khal, beel, floodplain and pond fish habitat (Figure 07). Highest diversity has been found in case of KaliakairUpazila. However, fish production trend shows an increasing line up to the year of 2014.

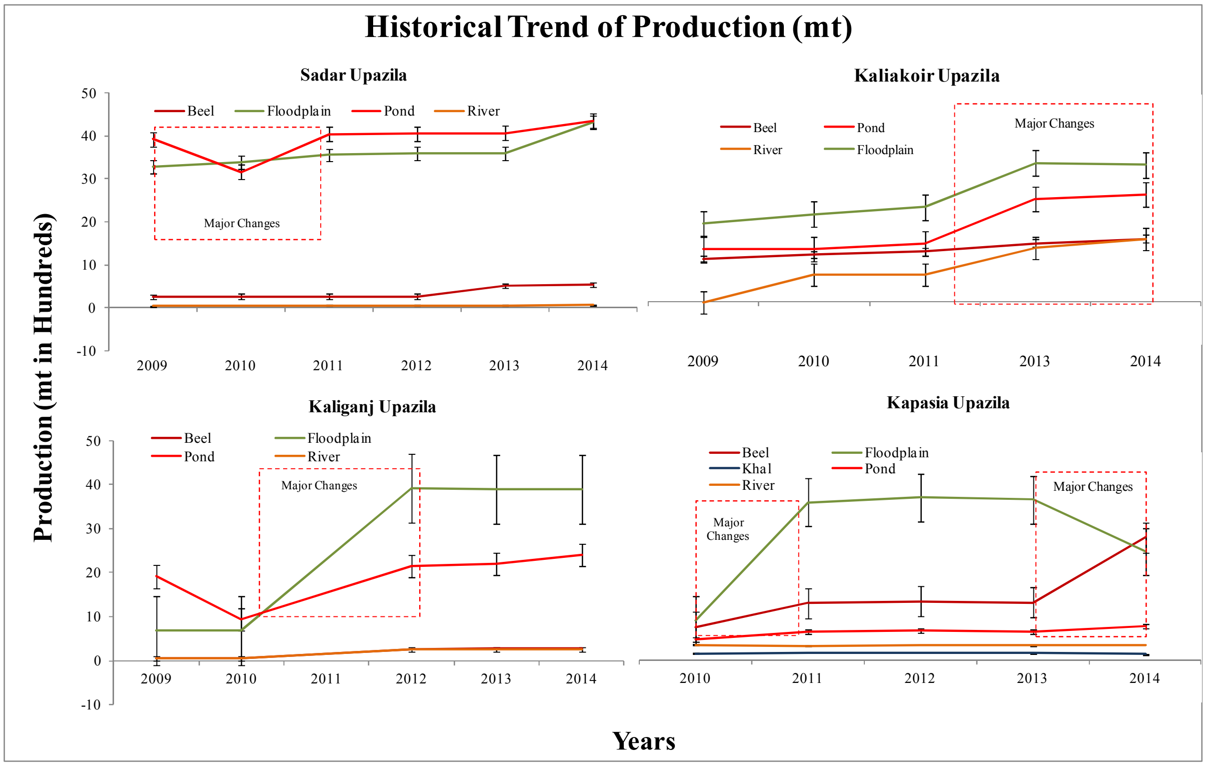


Figure 07: Historical habitat wise production trend in upazilas of Gazipur district

Source: The diagram created by the author using data fromUpazila Fisheries Office(2015)

3.5 Fishermen Livelihood Pattern

3.5.1 Human Capital

Fishermen Number

About 4,789 fishermen has been found in the study area including full time commercial fishermen and part time fish farmers most of which come from the Muslim community (85%) (Table 12). They usually catch fish in the nearby river, khals and floodplain using country boat and dingi boats.

Table 12: Fishermen number of different upazilas in Gazipur district

Name of upazillas	No of Fishermen	No of fish farmer	Total
Sadarupazillas	2,083	2,575	**4,658**
Kaliakair	1,514	2,935	**4,449**

Kaliganj	1,666	2,250	**3,916**
Kapasia	2,021	2,000	**4,021**
Sreepur	3,104	1,685	**4,789**
Total	**10,388**	**11,445**	**21,833**

Source: The Table created by the author using data from Upazila Fisheries Office (2015)

Household Information

In the present study, high age group has been found in Kaliakair and Kapasiaupazilas of Gazipur district (Table 13). Moreover, highest number of fishermen has been reported to be under primary in Kaliganjupazila and lowest in Kapasiaupazila.

Table 13: Household information (Education, Age etc) of 20 fishermen in different upazilas

Name of upazila	Age (years)	Educational status	
		Under primary	Five-ten
GazipurSadar	25-50	15	5
Kaliakair	20-60	17	3
Kaliganj	20-45	18	2
Kapasia	25-60	13	7
Sreepur	28-55	16	4

Source: Key Informant Interviews, 2015

Financial Capital

Maximum solvent fishermen has been found in GazipurSadarupazila and minimum in Kaliganjupazila (Table 14). However, maximum fishermen in Kaliakairupazila have been found to income above 60,000 Tk annually.

Table 14: Financial information of 20 fishermen in different upazila

Name of upazila	Financial status		Income (annual) tk		
	Solvent	Poor	10000-30000	30000-60000	Above 60000
GazipurSadar	20	0	2	16	2
Kaliakair	18	2	3	10	7
Kaliganj	12	8	5	12	3
Kapashia	17	3	3	14	3

Sreepur	15	5	5	13	2

Source: Key Informant Interview, 2015

Fishing Technology and Effort

Fishing Technology: Gear and Crafts

The commercial fishermen usually catch fish in the nearby river and connecting khals using country boat and dingi boats. Five major types of nets/gears have been observed to be used for fishing in the polder area (Table 17). These are: (1) Jhakijal, (2) Current jal, (3) Muiajal, (4) Thelajal and (5) Badha/Sluice jal. Only 20 to 25% of fishermen have fishing boats and around 70% fishermen have fishing gears/nets. Among these gears, Thelajal is the mostly used especially for fishing in the intervention location. The following table shows the fishing practice of some major used fishing gears (Table 15).

Table 15: Major gears used in the intervention specific fish habitat in the project area

Name of Gears	Haul Duration (hr)	Haul No	Operated Person (N)
Jhaki Jal	2.5	69.5	1.5
Spear	7.5	8	1
Thela Jal	1	11	1
Vesal	5.5	440	1
Chai (Fishing Trap)	10	1	1

Source: Author's field investigation, 2015

Fishing Season

Capture fishing is the major fishery of the polder area. Fishing in khals starts in May and continues up to October especially by the use of Jhaki Jal and Thela Jal. Rest of the time they are mainly engaged in other fisheries activities (like fish traders). The seasonality of major fishing is furnished in the table 16.

Table 16: Fishing seasonality of the project area

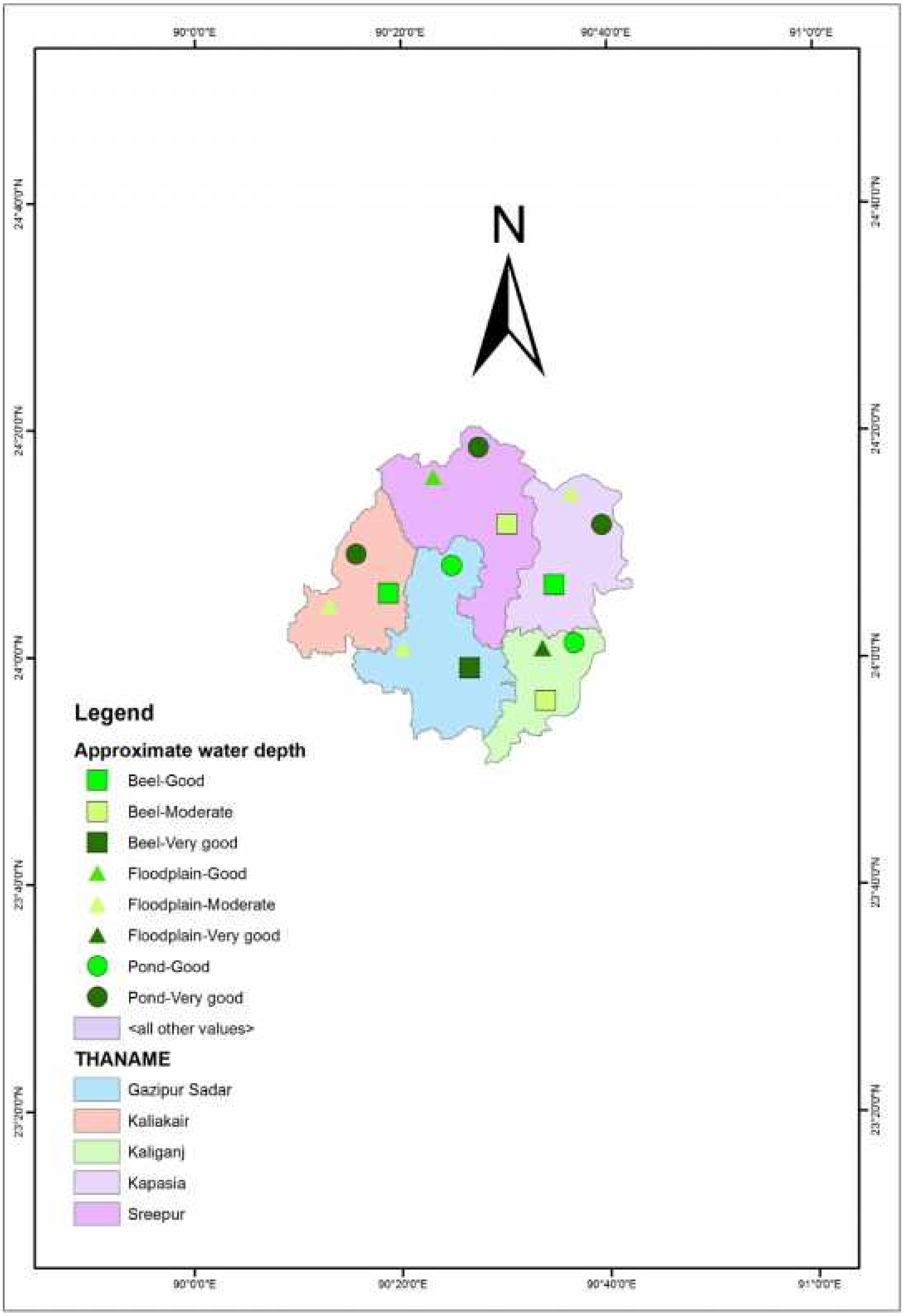
Type of gear	Seasons												
	Pre-monsoon			Monsoon flood season			Post-monsoon		Dry Season				
	Months												
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
	Boishakh	Jaishtha	Ashar	Srabon	Bhadra	Ashyin	Kartik	Agrahayan	Pause	Magh	Falgun	Chatra	
Jhaki Jal													
Thela Jal													
Vesal Jal													
Spear													
Fishing Trap (Chai)													

High | Medium | Low | No occurrence

Source: Author's field investigation, 2015

Habitat Suitability for Fisheries

Habitat Characteristics, Phytoplankton Availability, Water Depth, Water Quality, pH of Soil, Water Pollution, Fish Production and Livelihood Status has been assessed for defining habitat suitability for beel, floodplain and pond fish habitatin case of GazipurSadar, Kaliakair, Kaliganj, Kapashia and SreepurUpazilas of Gazipur District. The following maps shows the sensitivity of fisheries resource of these Upazilas against above mentioned suitability indicators (Map 05-14).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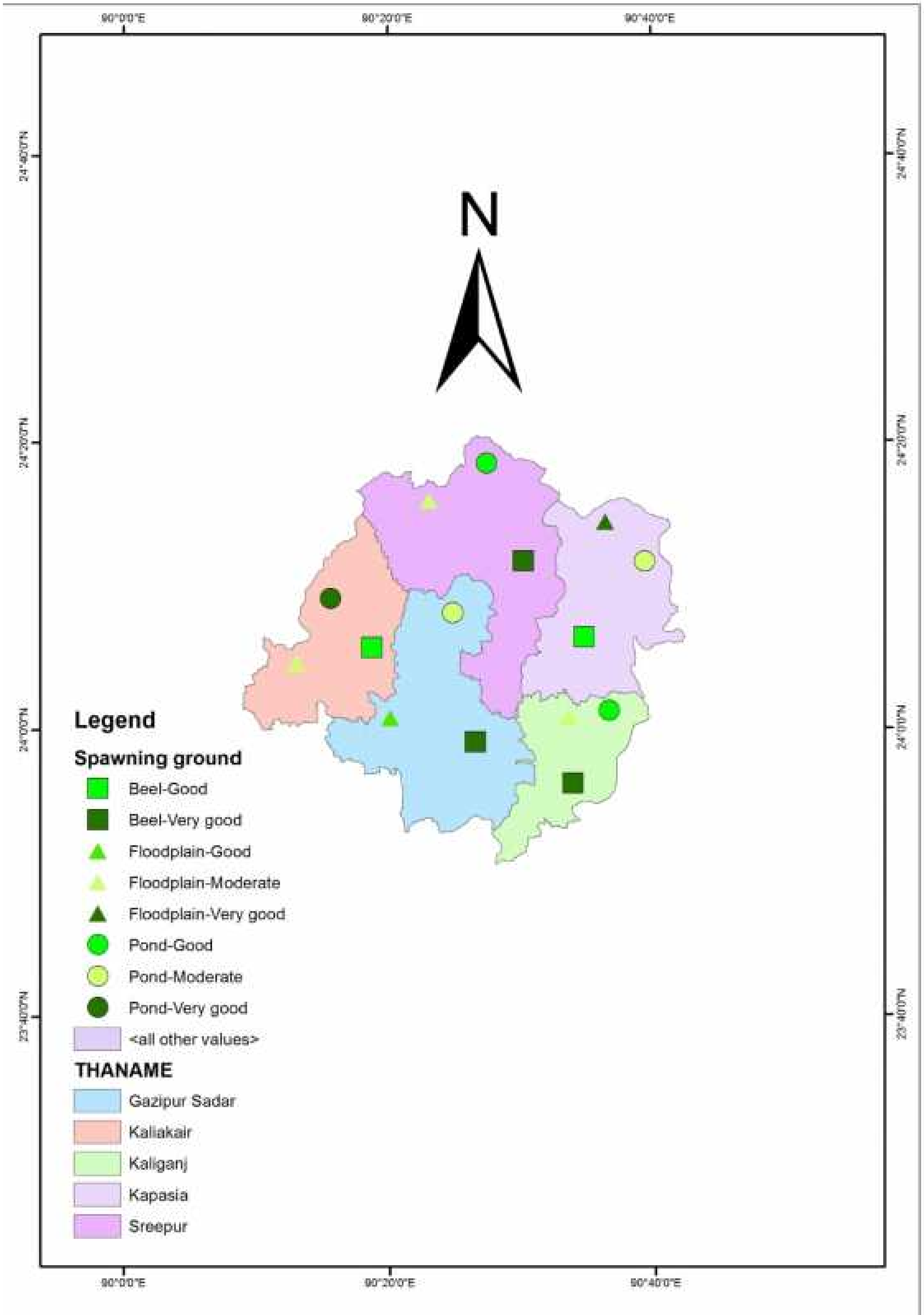
90°40'0"E
91°0'0"E
24°40'0"N
24°20'0"N
24°0'0"N
23°40'0"N
23°20'0"N
N
Legend
Approximate water depth
Beel-Good
Beel-Moderate
Beel-Very good
Floodplain-Good
Floodplain-Moderate
Floodplain-Very good
Pond-Good
Pond-Very good
<all other values>
THANAME
Gazipur Sadar
Kaliakair
Kaliganj
Kapasia
Sreepur

Map 05: Habitat suitability based on water depth

Source: Upazila Fisheries Office, 2015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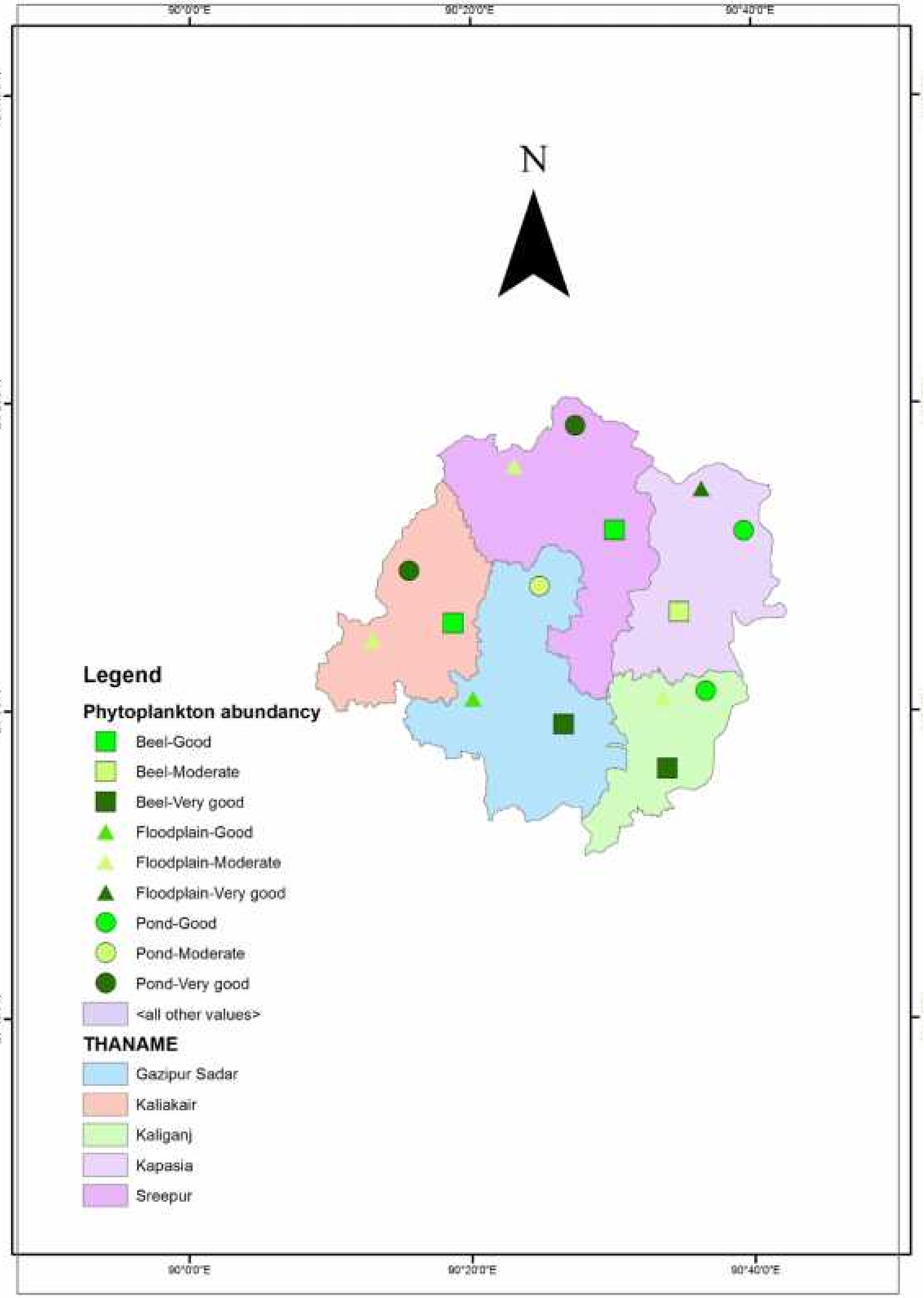
90°20'0"E
90°40'0"E
24°40'0"N
24°20'0"N
24°0'0"N
23°40'0"N
N
Legend
Spawning ground
Beel-Good
Beel-Very good
Floodplain-Good
Floodplain-Moderate
Floodplain-Very good
Pond-Good
Pond-Moderate
Pond-Very good
<all other values>
THANAME
Gazipur Sadar
Kaliakair
Kaliganj
Kapasia
Sreepur

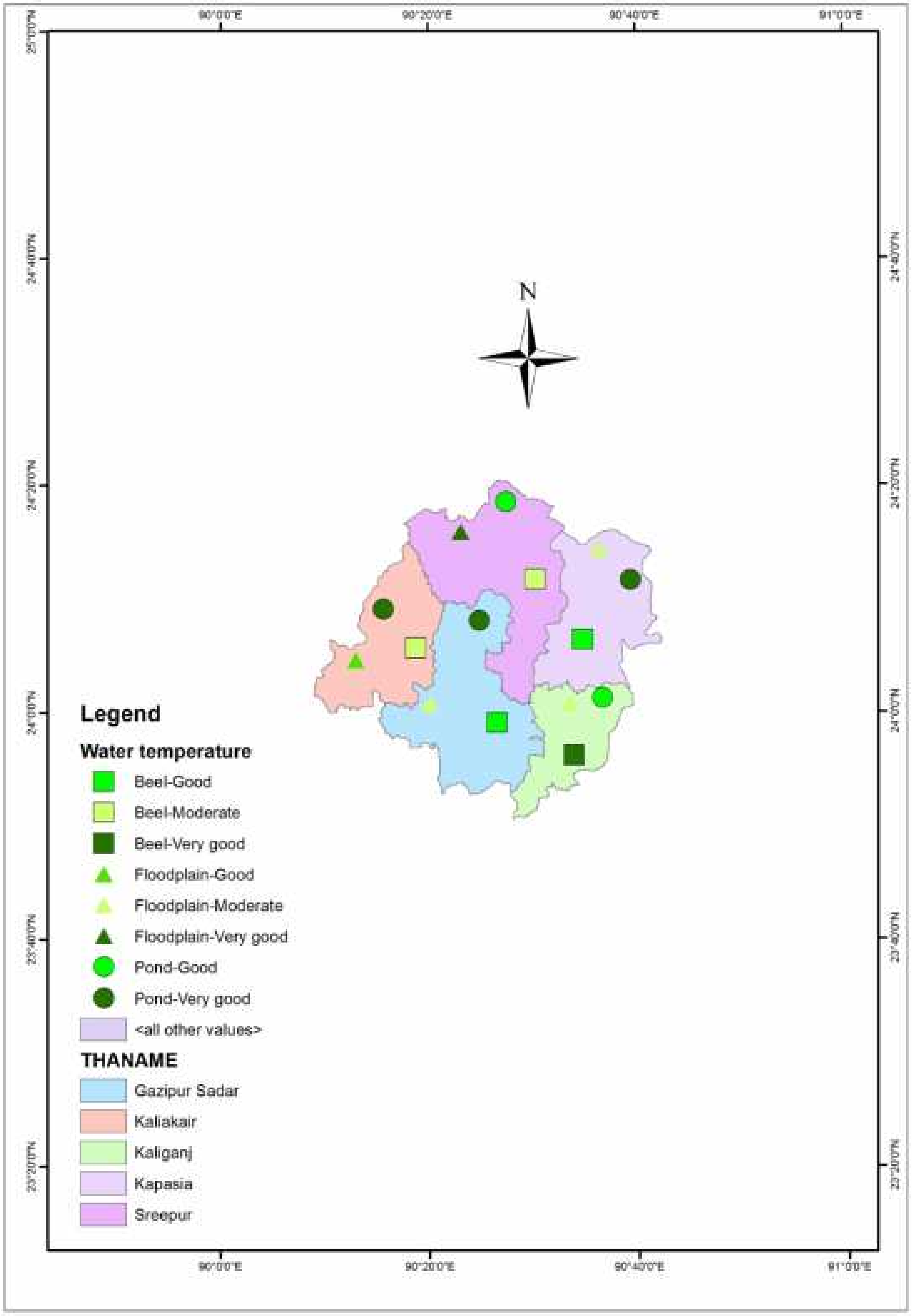
Map 06: Habitat suitability based on for spawning ground

Source: Upazila Fisheries Office, 2015


90°0'0"E
90°20'0"E
90°40'0"E
24°40'0"N
24°20'0"N
24°0'0"N
23°40'0"N
N
Legend
Phytoplankton abundancy
Beel-Good
Beel-Moderate
Beel-Very good
Floodplain-Good
Floodplain-Moderate
Floodplain-Very good
Pond-Good
Pond-Moderate
Pond-Very good
<all other values>
THANAME
Gazipur Sadar
Kaliakair
Kaliganj
Kapasia
Sreepur

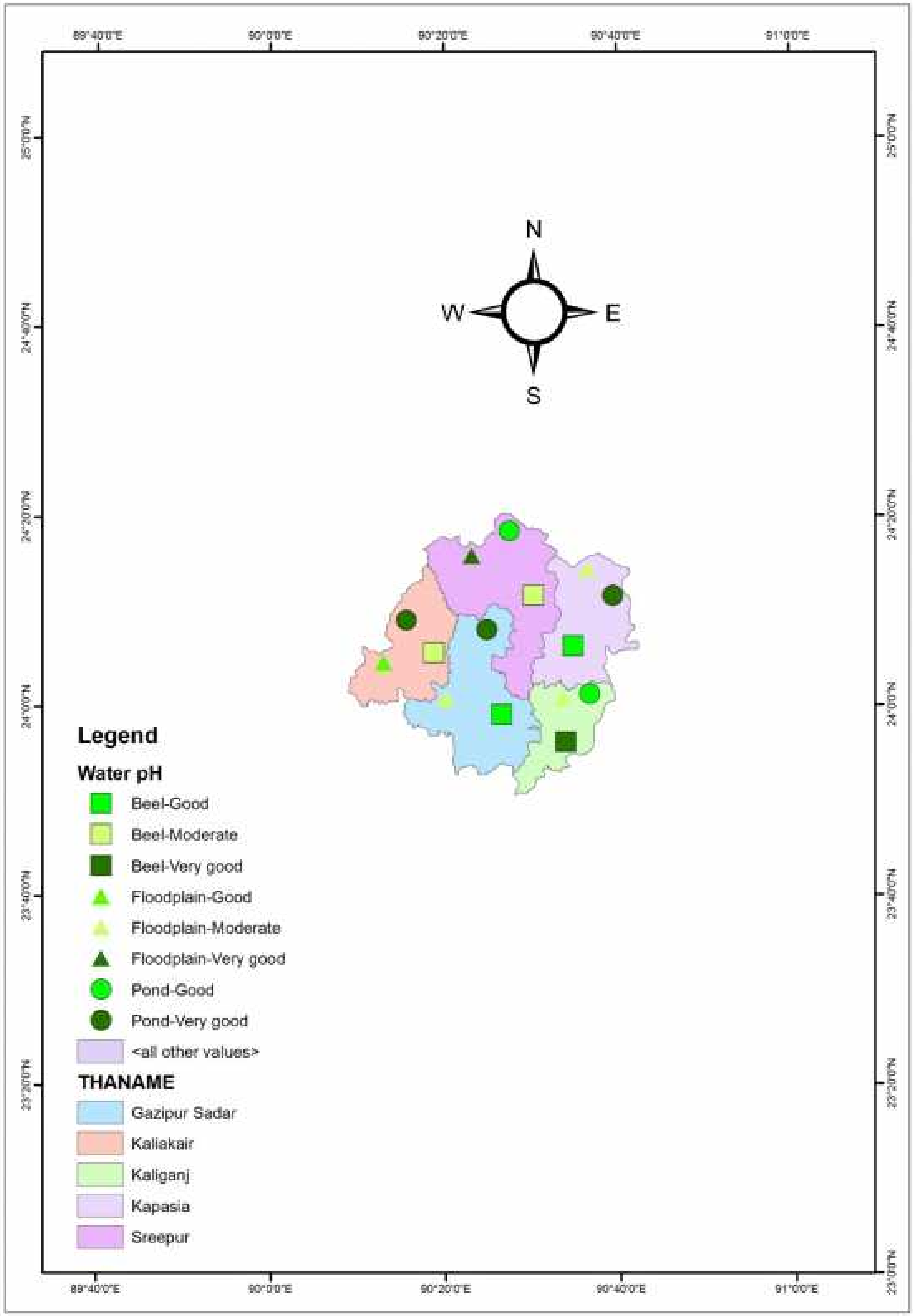
Map 07: Habitat suitability based on to phytoplankton availability

Source: Upazila Fisheries Office, 2015



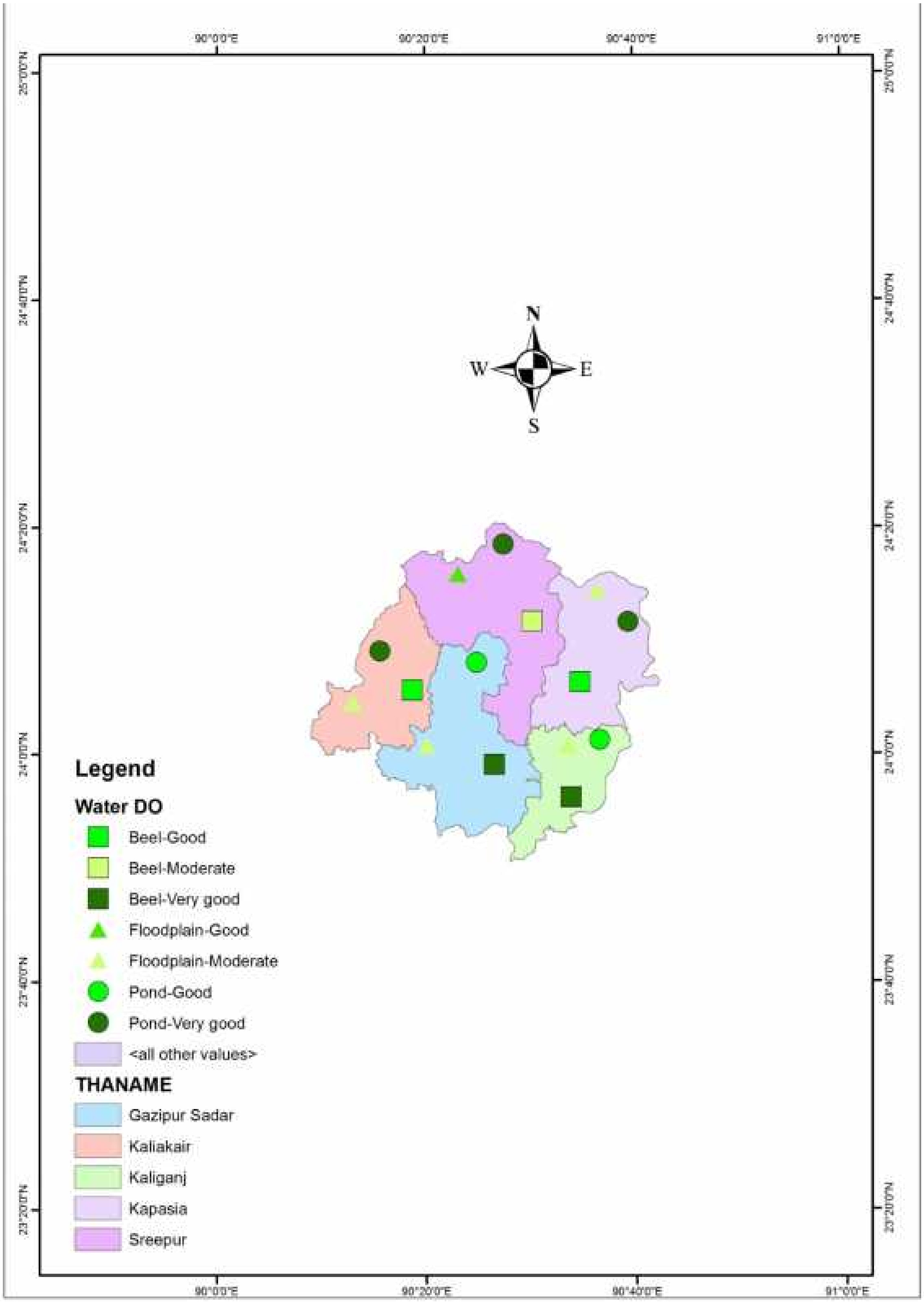
Map 08: Habitat suitability based on water temperature

Source: Upazila Fisheries Office, 2015


89°40'0"E
90°0'0"E
90°20'0"E
90°40'0"E
91°0'0"E
25°0'0"N
24°40'0"N
24°20'0"N
24°0'0"N
23°40'0"N
23°20'0"N
23°0'0"N
N
W
E
S
Legend
Water pH
Beel-Good
Beel-Moderate
Beel-Very good
Floodplain-Good
Floodplain-Moderate
Floodplain-Very good
Pond-Good
Pond-Very good
<all other values>
THANAME
Gazipur Sadar
Kaliakair
Kaliganj
Kapasia
Sreepur

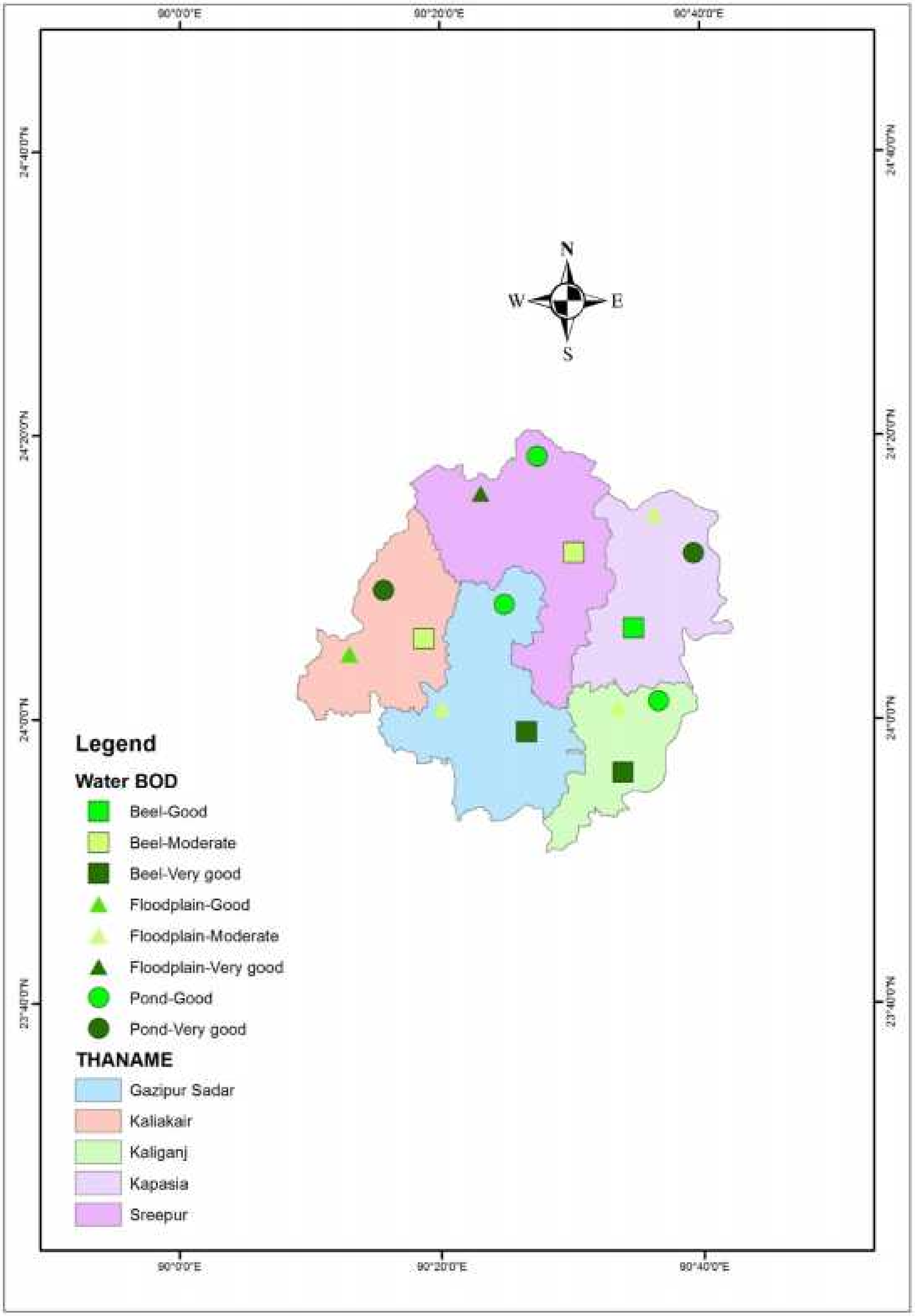
Map 09: Habitat suitability based on water pH

Source: Upazila Fisheries Office, 2015



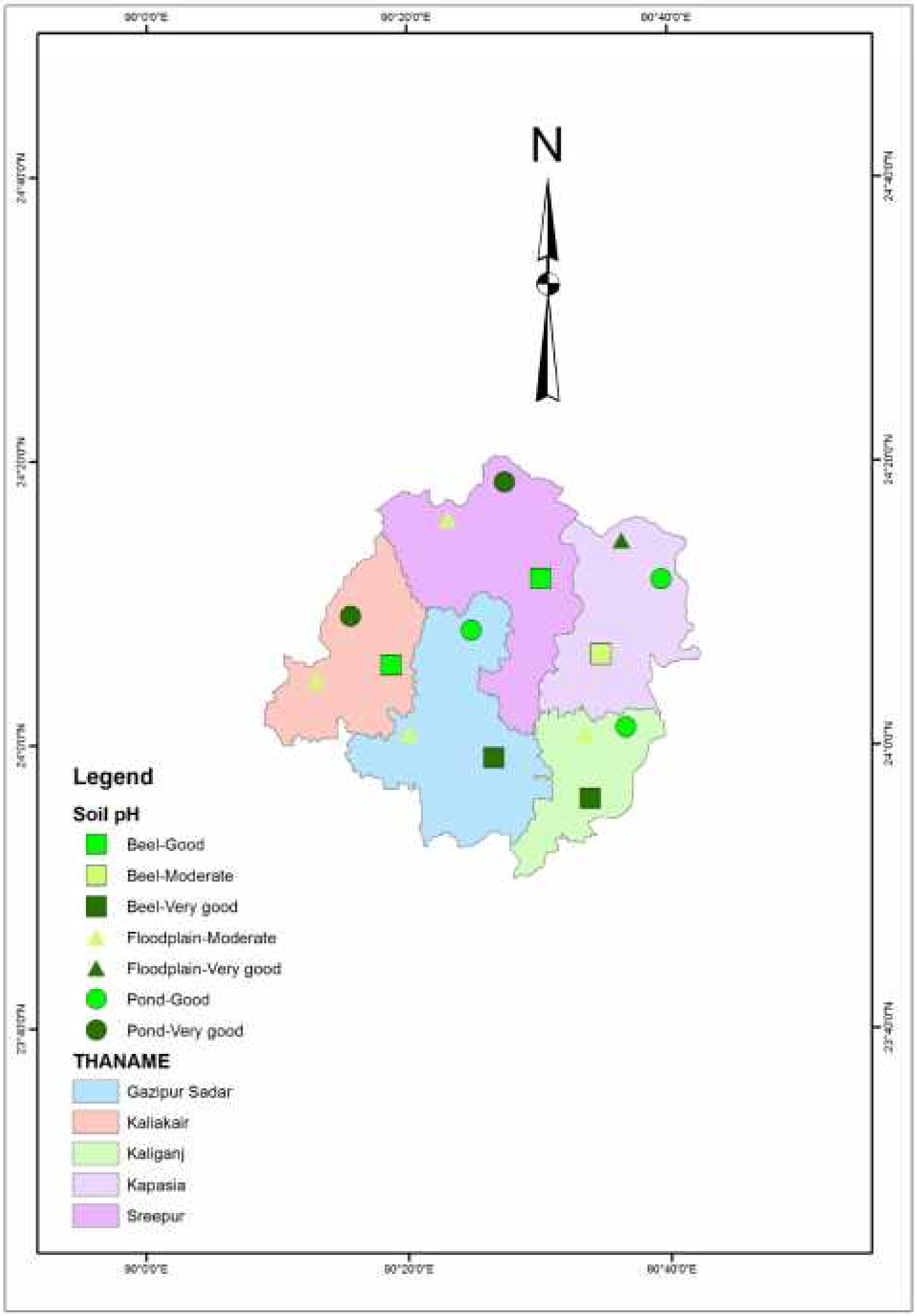
Map 10: Habitat suitability based o*n* dissolved oxygen (DO) of water

Source: Upazila Fisheries Office, 2015



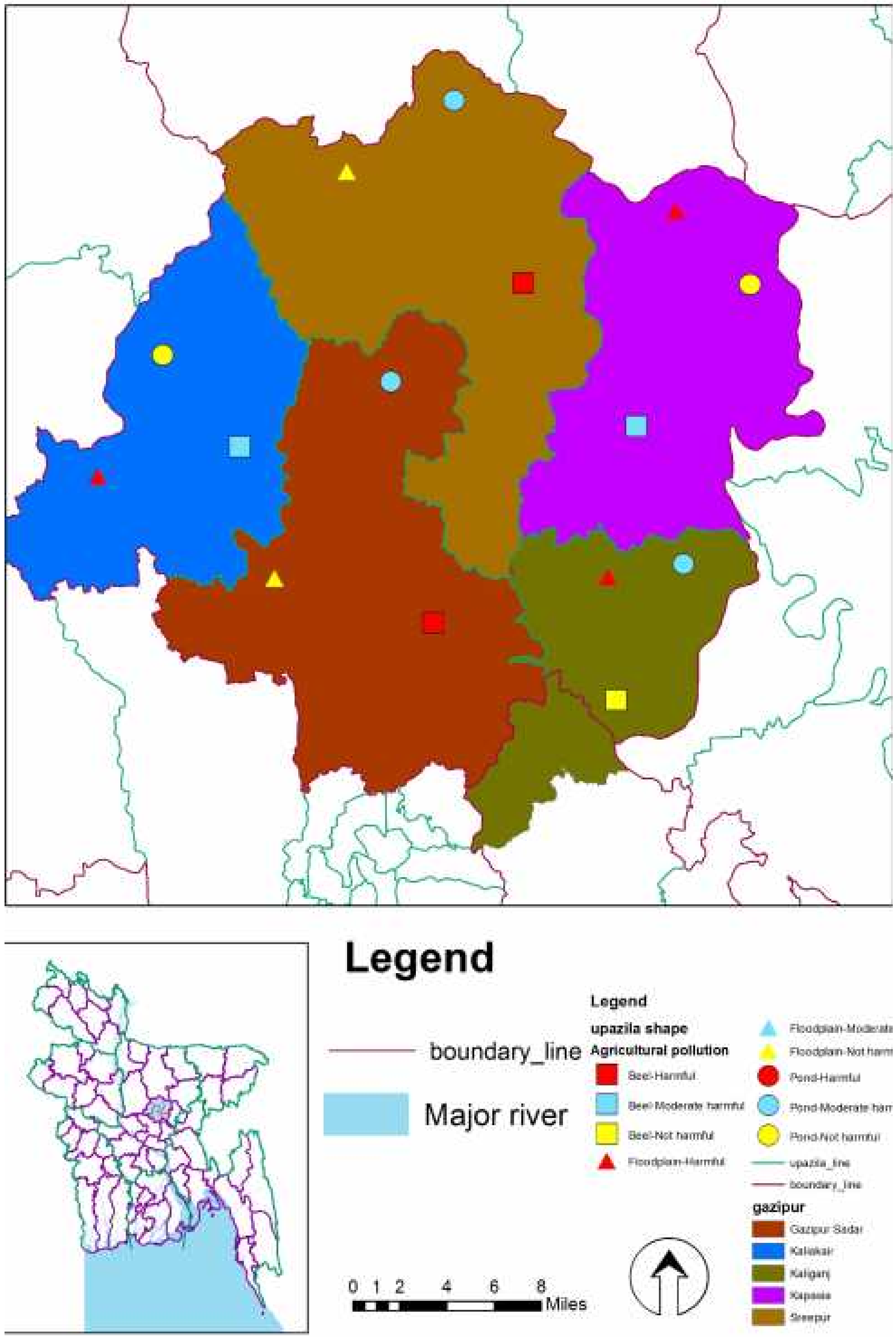
Map 11: Habitat suitability based on biological oxygen demand (BOD)

Source: Upazila Fisheries Office, 2015



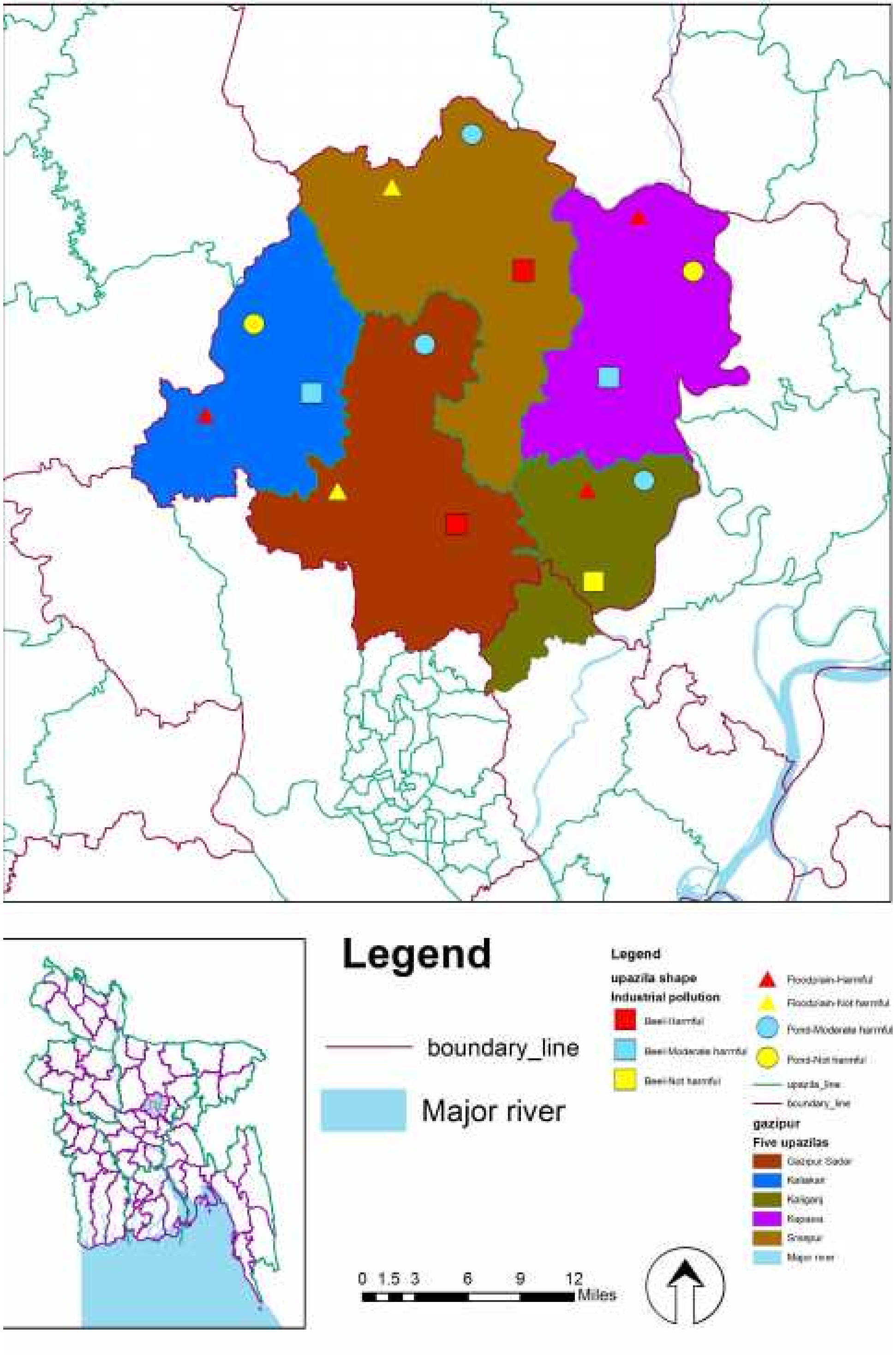
Map 12: Habitat suitability based on soil pH

Source: Upazila Fisheries Office, 2015



Map 13: Habitat suitability based on agricultural effluent

Source: Upazila Fisheries Office, 2015



Map 14: Habitat suitability based on industrial effluents

Source: Upazila Fisheries Office, 2015

Finally, the present study has identified highest habitat suitability for beel habitat and lowest for floodplain habitat in case of Gazipur and Kapasia Upazila. In case of Kaliakoir Upazila, highest habitat suitability has been identified for beel and lowest for pond habitat; in Kaliganj Upazila highest suitability for pond and lowest for floodplain; in Sreepur Upazila highest suitability for pond and lowest for beel fish habitat (Table 17).

Table 17: Habitat suitability index for five (5) Upazilas of Gazipur District

Upazilas	**Suitability Indicators**	**Suitability Score**		
		Beel	**Floodplain**	**Pond**
Gazipur Sadar	Habitat Characteristics	0.048	0.048	0.042
	Phytoplankton Availability	0.1	0.06	0.04
	Water Depth	0.3	0.12	0.18
	Water Quality	0.96	0.72	0.96
	pH of Soil	0.2	0.12	0.2
	Water Pollution	0	0.08	0.04
	Fish Production	0.032	0.032	0.032
	Livelihood Status	0	0.01	0.01
	HSI Values	**1.64**	**1.19**	**1.504**
Kaliakoir	Habitat Characteristics	0.06	0.048	0.042
	Phytoplankton Availability	0.1	0.06	0.04
	Water Depth	0.3	0.18	0.12
	Water Quality	0.96	0.96	0.72
	pH of Soil	0.2	0.12	0.12
	Water Pollution	0.08	0.04	0
	Fish Production	0.024	0.024	0.024
	Livelihood Status	0.002	0.001	0.004
	HSI Values	**1.726**	**1.433**	**1.07**
Kaliganj	Habitat Characteristics	0.048	0.018	0.032
	Phytoplankton Availability	0.1	0.04	0.06
	Water Depth	0.12	0.3	0.18
	Water Quality	0.78	0.24	0.96

Upazilas	Suitability Indicators	Suitability Score		
		Beel	Floodplain	Pond
	pH of Soil	0.2	0.12	0.12
	Water Pollution	0.04	0.04	0.04
	Fish Production	0.016	0.016	0.016
	Livelihood Status	0	0.006	0
	HSI Values	**1.304**	**0.78**	**1.408**
Kapasia	Habitat Characteristics	0.048	0.036	0.042
	Phytoplankton Availability	0.04	0.1	0.06
	Water Depth	0.18	0.12	0.3
	Water Quality	1.08	0.78	1.08
	pH of Soil	0.12	0.2	0.2
	Water Pollution	0.04	0.04	0.04
	Fish Production	0.4	0.02	0.02
	Livelihood Status	0.004	0.002	0
	HSI Values	**1.912**	**1.298**	**1.742**
Sreepur	Habitat Characteristics	0.048	0.03	0.045
	Phytoplankton Availability	0.06	0.04	0.1
	Water Depth	0.12	0.18	0.3
	Water Quality	0.72	0.9	0.96
	pH of Soil	0.12	0.12	0.2
	Water Pollution	0.04	0.06	0.02
	Fish Production	0.028	0.028	0.028
	Livelihood Status	0	0	0.01
	HSI Values	**1.136**	**1.358**	**1.663**

HS> 1.5: High; HS = 1.0-1.5: Medium; HS< 1.0: Low/ Less

3.6 DISCUSSION

Proper designation of essential fish habitat (EFH) is a highly important spatial measure in any management of fishery resources.EFH is characterised by an aggregation of abiotic and biotic parameters that are suitable for supporting and sustaining fishpopulations during all stages of their life cycle (Valavanis et al., 2004). The present study has revealed that habitat characteristics considering connectivity among water bodies in the study area, water availability and spawning ground condition; food availability considering phytoplankton availability; water quality considering water temperature, water pH, DO and BOD; soil quality considering pH; water pollution regarding agricultural and industrial effluents and livelihood status are the major regulating factors for maintaining habitat suitability of five upazilas under Gazipur district.

3.6.1 Habitat Suitability Sensitivity

Deacon and Mize (1997) stated that differences in fish communities reflect their habitat that characterizes the physiographic provinces. Frequency of invertivore, omnivore,herbivore and even piscivore species, like suckers, carps, barbs minnows andsunfish, depends oncharacteristics of habitat (Deacon and Mize, 1997). Similar findings have also been found through using the analysis of similarity (ANOSIM) showing significant dissimilarity in assemblage structure among study stations which were defined by different habitat characteristics (M. S. Hossain et al., 2012). It has also been reported that the main causes of the differences occurring in the biodiversity indexes are seasonal variations of nutrients at habitat affecting the coexistence of many fish species (Huh and Kitting, 1985), atmospheric air currents and environmental conditions (Keskin and Ünsal, 1998).A simple habitat assessment score (HAS) using multiple regression models has shown that habitat type and complexity based on the water availabilityare the most important predictors of observed species richness, variety of growth forms and total fish abundance (B. Gratwicke and M. R. Speight, 2005). The present study revealed that habitat characteristics, regarding connectivity among existing water bodies, water availability and spawning ground condition, are moderately correlated with habitat suitability at 95% significant level ($F = 6.2$; $p<0.05$) (Figure 08). It has also been revealed that thewater depth isweakly correlated with habitat suitability at 95% significant level ($F = 2.19$; $p<0.001$) (Figure 09). It indicates that the present condition of water depth is not the major cause for maintaining habitat suitability for culture fish production in the study area.

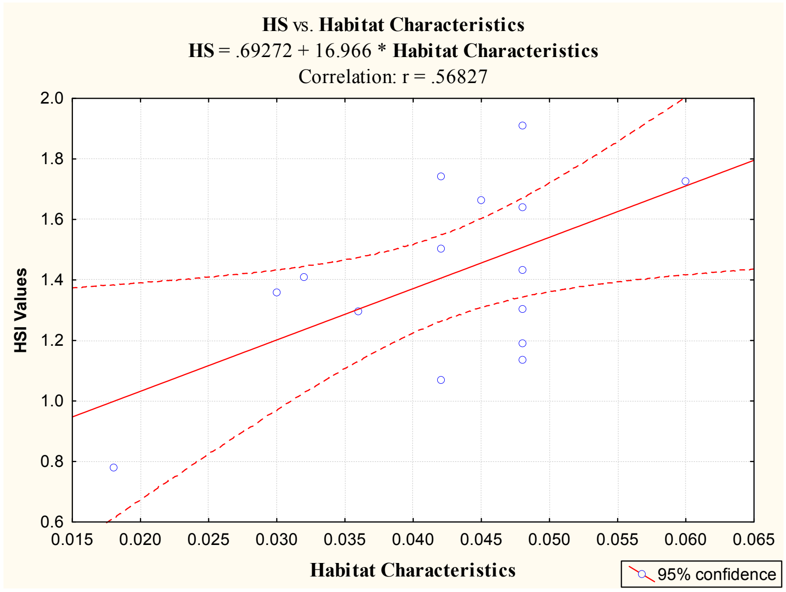


Figure 08: Correlation co-efficient between habitat suitability and habitat characteristics

Source: Author's calculation

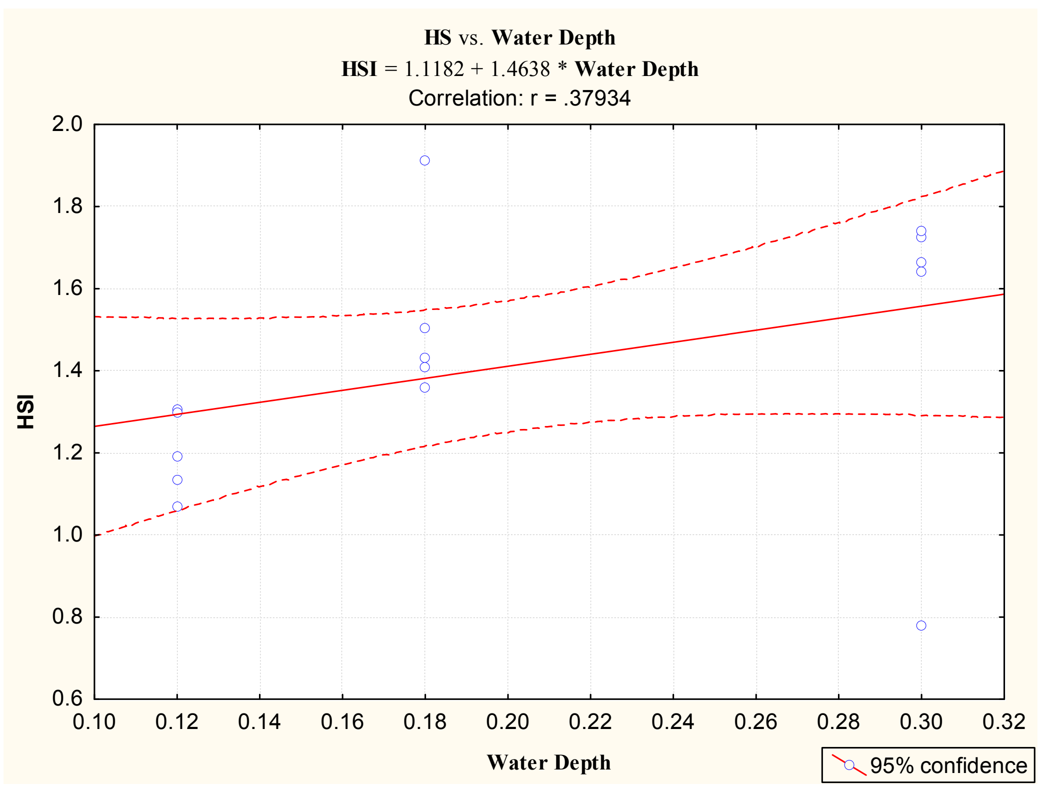


Figure 09: Correlation co-efficient between habitat suitability and water depth

Source: Author's calculation

Abundance of phytoplankton maintains the primary productivity for fish habitat (Doering et al. 1989). Various morphological changes of the fish habitat due to land use pattern and nutrient agents results in distribution of different flagellate and diatom like phytoplankton (*Chlamydomonas, Volvox, Nephroselmis*, etc.) which form a group of dominant food-web factors for habitat suitability (Schelske and Stoermer, 1971, 1972, Doering et al. 1989, Verity, 1998). However, in the present study, phytoplankton availability has been found to beweakly correlated with habitat suitability at 95% significant level ($F = 1.22$; $p<0.001$) (Figure 10). It is supposed that because of using artificial feeding for culture fish production in the selected upazilas of Gazipur district other regulating factors may play more important role than done by phytoplankton availability in maintaining habitat suitability.

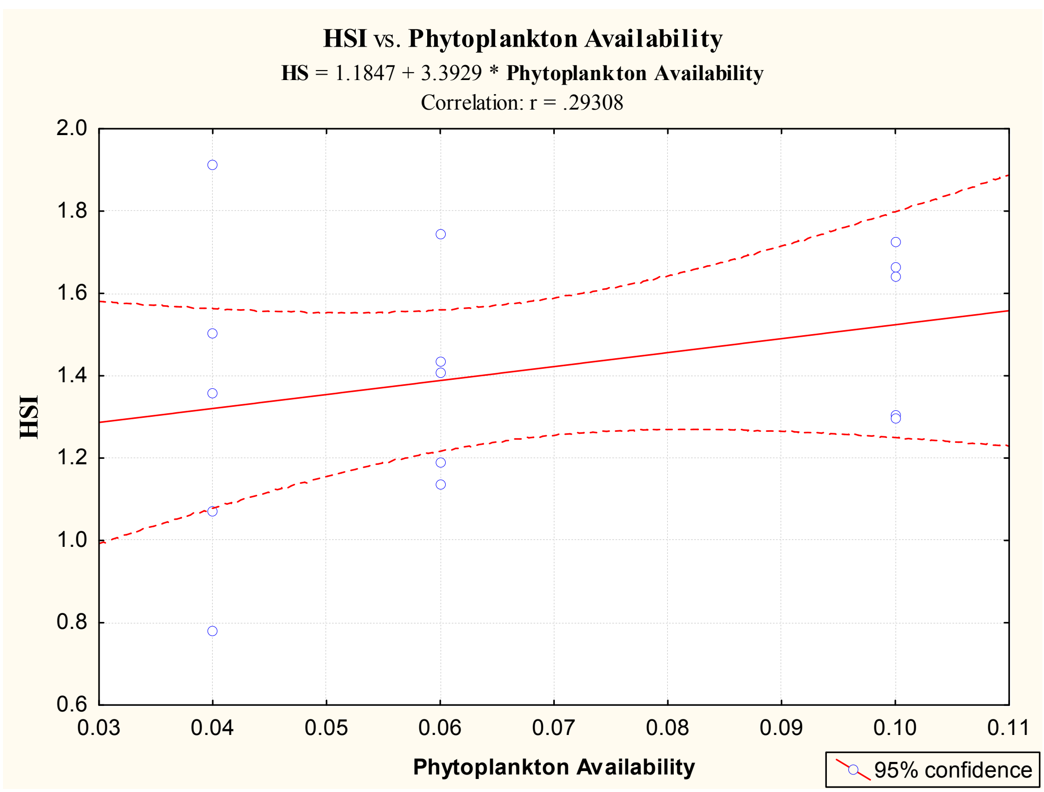


Figure 10: Correlation co-efficient between habitat suitability and phytoplankton availability

Source: Author's calculation

The water quality characterizes the physiographic provinces which results in differences in fish communities (J. R. Deacon and S. V. Mize, 1997).Maintenance of a healthy aquatic environment and production of sufficientfish food organisms in ponds are two factors of primary importance for successfulpond cultural operations.To keep the aquatic habitat favorable for existence,physical and chemical factors like temperature, pH, dissolvedoxygen, influence individuallyor synergisticallyand play the most importantrole in governing the production of plankton organisms or primary productionin fish ponds (S. M. Banerjea, 1965).

S. M. Banerjea (1965) stated that of the physical factors, heat and lightdepending upon climate, sunlight and depth are essential in all waters for photosyntheticactivity, which in turn is basic to productivity. Probst (1950) found an average increase in carp yield of 22 kg per hectarefor 1˚C rise of temperature. Moreover, water temperature plays a very important role in some physiological processeslike release of stimulii for breeding mechanisms in fish, both under natural andartificial conditions (Hora, 1945; Chaudhuri, 1964). In the present study, 29-30˚C has been identified as the very suitable, 25-28˚C suitable and below 25˚C unsuitable water temperature for productivity of fish habitat.

Among the physico-chemical factors regulating aquatic productivity, pH,dissolved oxygen and dissolved inorganicnutrients like nitrogen and phosphorus are considered to be important (S. M. Banerjea, 1965).According to Roule (1930) the largest fish crops are usually produced inwater which is just on the alkaline side of neutrality between pH 7.0 and 8.0 thelimit above or below which pH has a harmful effect is given by Ohle (1938) as 4.8and 10.8. Nees (1946), while reviewing the work of German scientist's remarks thatcategorically it can be said that a weak alkaline reaction (pH 7.0 to 8.0) has beenfound in most productive fish ponds and that very acid waters are distinctlyundesirable.S. M. Banerjea (1965) had found that water with an almost neutral reaction withpH 6.5 - 7.5 is best suited for a fish pond and average production is expected in therange of 7.5 - 8.5. In the present study, 6.5-9 has been identified as the very suitable, 4-6.5 moderate and 4-5 unsuitable water pH for productivity of fish habitat.

Among the chemical substances in natural waters, oxygen is probably oneof primary importance both as a regulator of metabolic processes of plant andanimal community and as an indicator of water condition (S. M. Banerjea, 1965).Hutchinson (1957)had aptly remarked that a series of oxygen determinations along with knowledgeof turbidity and color of water could provide more information about thenature of water than any other chemical data. Ellis (1937) from a study of thousandsof samples over a period of 5 years observed that below 3.0 ppm of dissolvedoxygen asphyxia from low oxygen can be expected and to maintain a favorablecondition for a varied fish fauna 5.0 ppm of dissolved oxygen is required.S. M. Banerjea (1965) had found that dissolved oxygen ranged from a minimum value of4.4 ppm to a maximum value of 10.8 ppm which represents near about the meanvalue for the day. In the present study, >5ppm has been identified as the very suitable, 5 moderate and <5 unsuitable water DO for productivity of fish habitat.

It has been revealed that thewater quality, regarding water temperature, water pH, DO and BOD, isvery highly correlated with habitat suitability at 95% significant level (F = 63.17; $p<0.05$) (Figure 11). It indicates that the present condition of water quality is one of the major causes for maintaining habitat suitability for both the capture and culture fish production in the study area.

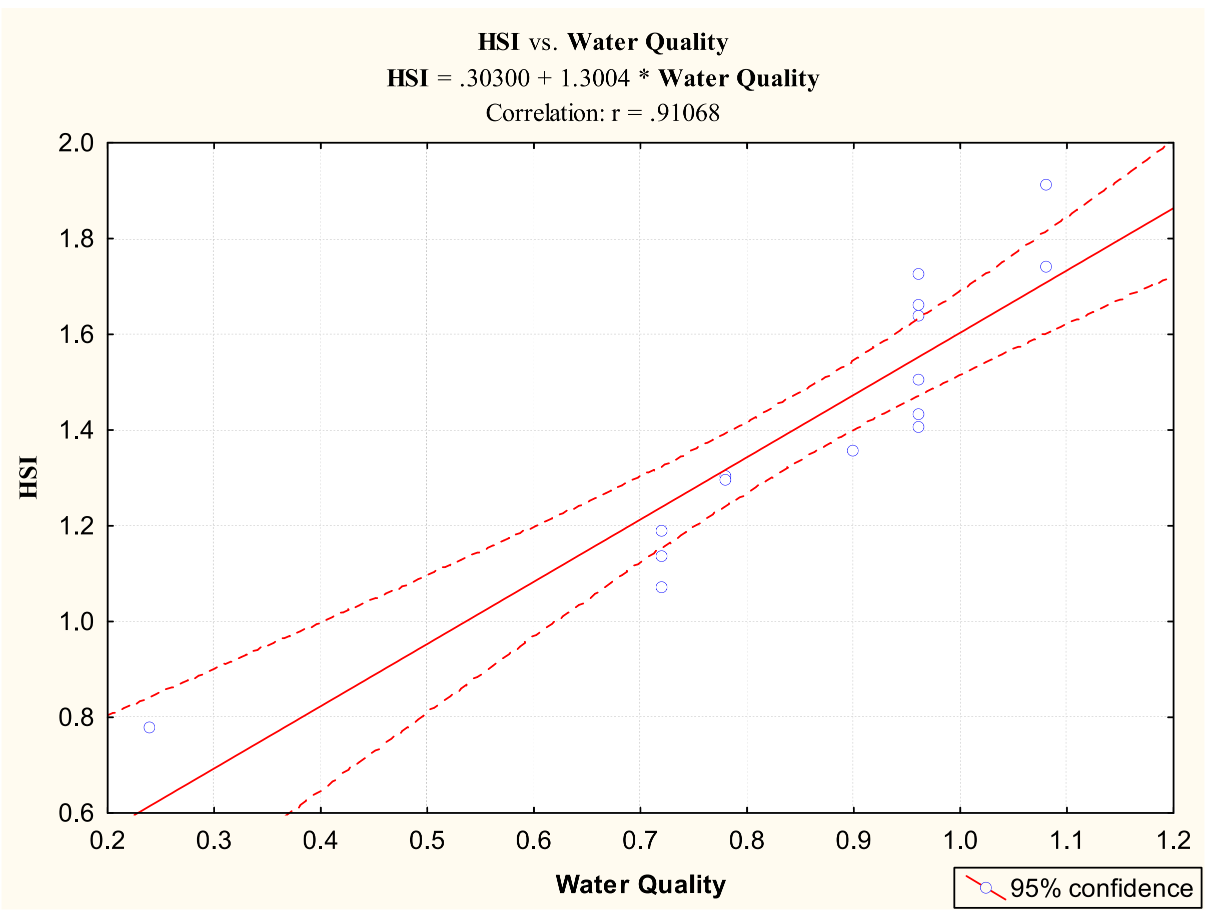


Figure 11: Correlation co-efficient between habitat suitability and water quality

Source: Author's calculation

The physical and chemicalproperties of water influencing both the capture and culture fish habitats are more or less a reflection of the properties of the bottomsoil. In this respect the major chemical factors of importance are pH, total nitrogen,organic carbon, C/N ratio, available nitrogen, available phosphorus and exchangeablecalcium (S. M. Banerjea, 1965).

pH of soil also is dependent on various factors. Because of oxygen depletion in mudlayers, not well aerated, the decompositionof organic matter becomes slow and produces mainly reducedor partially oxidised compounds like HjS, CH_4, and short chain fatty acids. These compounds in turn make the soilstrongly acidic and, unless it is naturally buffered, reduce the rate of bacterialaction, ultimately leading to less productivity.pH of a soil also influencesinorganic transformation of soluble phosphate and control the adsorption and releaseof ions of essential nutrients at soil-water interface. Both for soil and for water aslightly alkaline pH has been considered favourable for fish pond (Schaeperclaus,1933).S. M. Banerjea (1965) hadgroups soil pH into five ranges as (1) <5.5 (2) 5.5-6.5 (3) 6.5-7.5 (4) 7.5-8.5 (5) >8.5. From various observations he concluded that both highly acidicand highly alkaline condition of the soil (pH <5.5 and >8.5) maybe considered undesirablefor a fish pond andthe optimal soil reaction may be taken as almost neutral(pH 6.5-7.5) while moderately acid (pH 5.5-6.5) and moderately alkaline reaction(pH 7.5-8.5) are likely to produce average yield of fish. In the present study, 6.5-8.5 has been identified as the very suitable, 6.5-4 moderate and >9.5 and <4 unsuitable soil pH for productivity of fish habitat.

It has been revealed that thesoil quality, regarding pH of soil, ismoderately correlated with habitat suitability at 95% significant level ($F = 3.55$; $p<0.01$) (Figure 12). It indicates that the present condition of soil quality is one of the major causes for habitat suitability for both the capture and culture fish production in the study area.

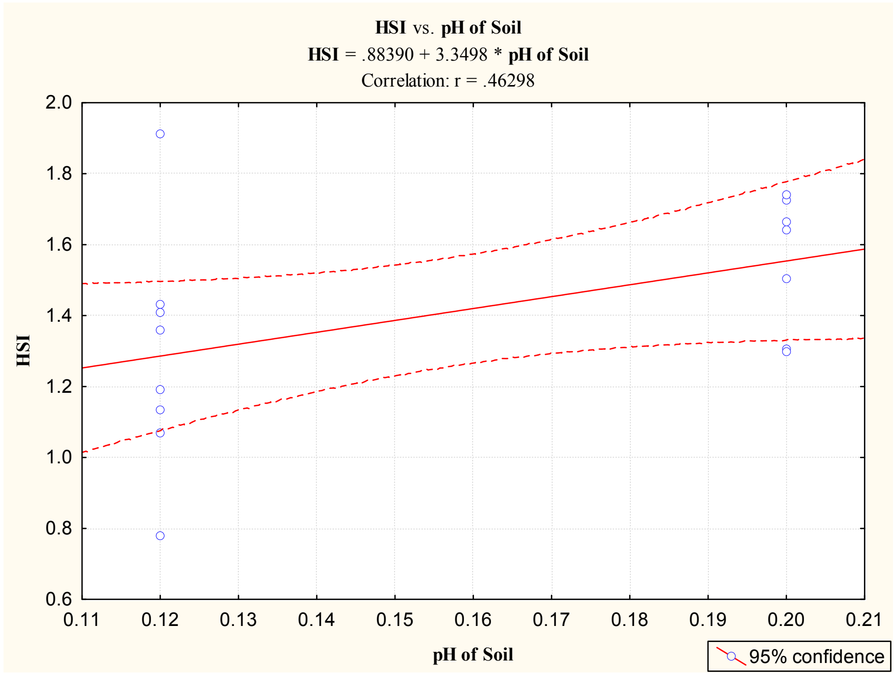


Figure 12: Correlation co-efficient between habitat suitability and soil quality

Source: Author's calculation

It has been revealed that thewater pollution resulting from the agricultural and industrial effluents isvery weakly correlated with habitat suitability at 95% significant level ($F = 0.01$; $p<0.0001$)for all selected fish habitats in all the Upazilas of Gazipur District (Figure 13). It indicates that the present condition of water pollution is not the major causes for regulating habitat suitability for both the capture and culture fish production in the study area. It has been reported from the local fishermen and Upazila Fisheries Offices that the maximum industries are located far away to very far away from the culture fish habitats which suggested that industrial effluents do not causes highly harm to culture fisheries practices.

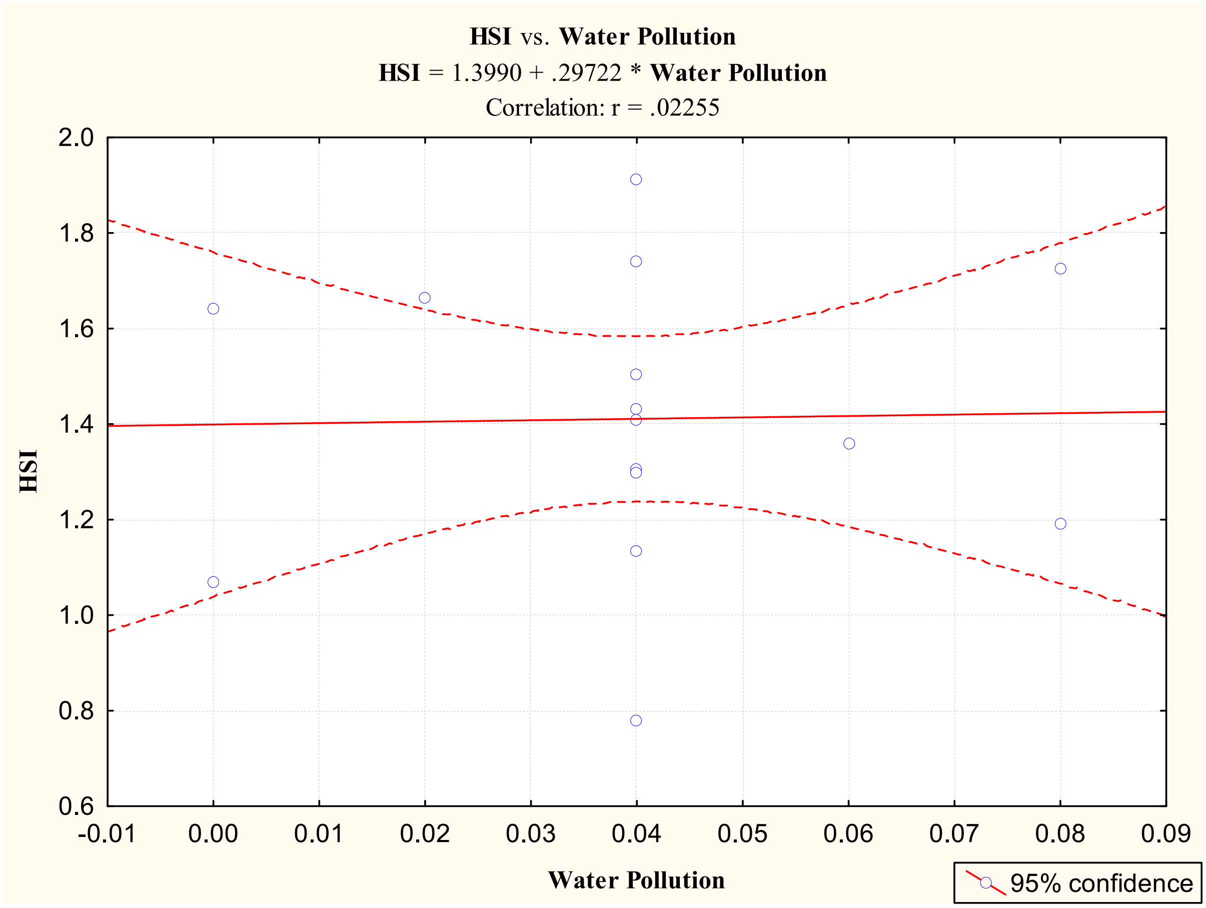


Figure 13: Correlation co-efficient between habitat suitability and water pollution

Source: Author's calculation

Thelivelihood status resulting from demographic, household pattern and fishing activities shows very weaklyand negatively correlation with habitat suitability at 95% significant level ($F = 0.11$; $p<0.0001$) for all the Upazilas of Gazipur District (Figure 14). It indicates that the increasing standard livelihood status is one of the causes for regulating habitat suitability for fish production in the study area. It has been reported from the local fishermen and Upazila Fisheries Offices that indiscriminate fishing activities, like brood and fry fishing and unregulated use of gears, has been increasing with increasing standard livelihood pattern of full time commercial fishermen which in turn resulting in decreased habitat suitability particularly for the capture fish habitats (beel and floodplain).

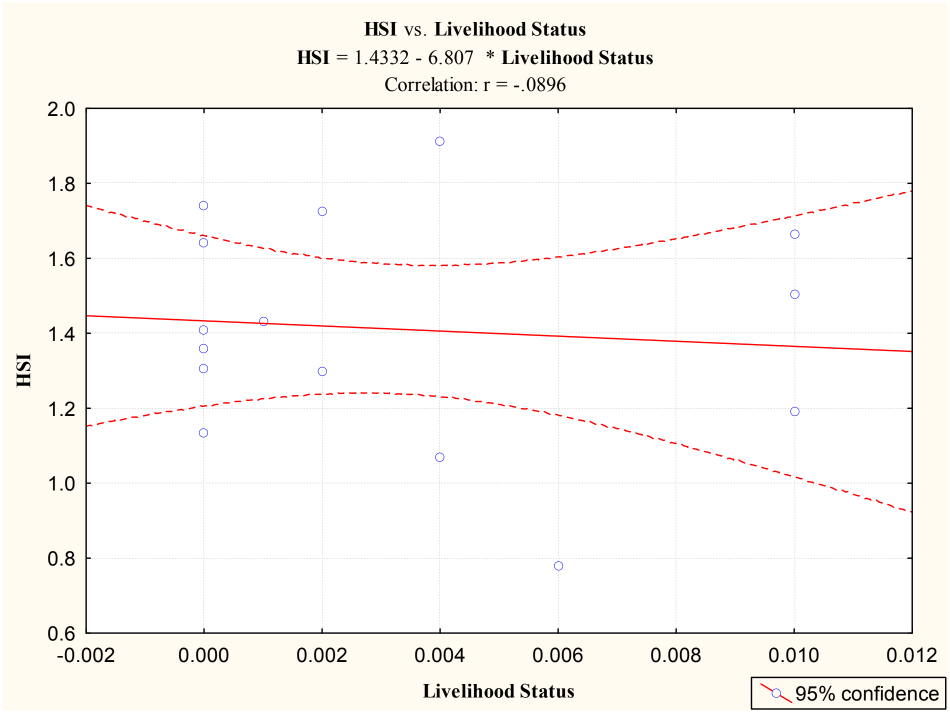


Figure 14: Correlation co-efficient between habitat suitability and livelihood status

Source: Author's calculation

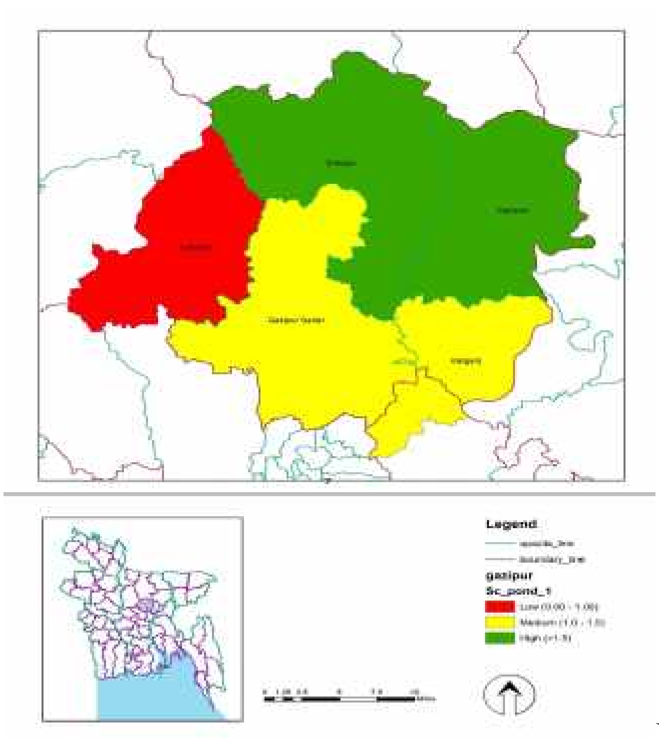


Figure 15: Habitat suitability map of pond

CHAPTER 4: CONCLUSION

Selection of suitable sites is the main problem for *aquaculture* because of lacking of baseline information on the physico-chemical and topographic conditions as well as existing land use patterns. The aim of this study was, thus, to use integrated habitat suitability index approach to produce geo-referenced ecological information about the habitat requirements of different species. In the present study a habitat suitability framework has been used for cultured species of Gazipur districtcomprising five (5) upazilas, named- GazipurSadar, Kalikair, Kaliganj, Kapasia and Sreepur. Various water quality data were the primary data functional for the present study. Various secondary data are also used for this study. Primary data were collected through semi-closed questionnaire interview, key informant interview and cross-check interviews. Several sorts of data, historical maps, thematic indication and secondary data on the study were collected.

Total fish habitat area in Gazipur district is about 44,580 ha of which culture fisheries covers about 7.5% (3,362ha) and capture fisheries about 92.5% (41,218ha). Various historical trends in fish habitat area have shown that in case of Kaliakair and Sadarupazilas, culture fish habitat areas have been increased from the year of 2011. However, in all the cases floodplain attains increasing trend. Connectivity among the fish habitats, mainly among capture fish habitats, was strong in case of Sadar and Kaliakairupazilas, while in other upazilas fish habitats were weakly or not connected. Water quality is more or less similar in pond, beel and floodplain fish habitat in case of studied upazilas. It has been found in the present study that in all the upazilas, except Kaliakairupazila, agricultural land is near the fish habitat which is supposed to moderate to very harmful to fish habitat. Historical productivity scenario of different fish habitat in case of GazipurSadarupazila shows that although the productivity of capture fisheries has been increasing, but pond productivity has been decreasing, particularly from the year of 2012 to 2014.

Fish diversity in the study area is moderate and highly seasonal which drastically decreased during the dry season and has the declining trend over the years. It has been reported that *Puntius ticto*, *Mystusvittatus*, *Anabas testudineus*, *Oreochromis mossambicus* and *Cirrhinus cirrrhosus* in

Gazipur Sadar; *Wallago attu*, *Pangasius hypophthalmus, Amblypharyngodon mola*, *Notopterus notopterus* in Kaliakair; *Mastacem belusarmatus* in Kaliganj; *Puntius ticto, Amblypharyngodon mola* and *Mystus vittatus* in Kapasia and *Oreochromis mossambicus*, Rui, *Catla catla* and *Pangasius hypophthalmus,* inSreepur Upazila are abundant. Total fish production in Gazipur District is about 38,763 metric ton (mt) of which culture fisheries covers about 39.5 % (15,319mt) and capture fisheries about 60.5% (23,444mt). The present investigation has found that highest culture fish production comes from Sreepur Upazila and lowest from Kapasia of Gazipur District. Moreover, a diversified trend in fish production has been observed in case of river, canal, beel, floodplain and pond fish habitats. It has been found that about 4,789 fishermen has been found in the study area including full time commercial fishermen and part time fish farmers most of which come from the Muslim community (85%).

GazipurSadar and KapasiaUpazilas have been identified as the highest and lowest habitat suitability for beel and floodplain respectively. In case of KaliakairUpazila, highest habitat suitability has been identified for beel and lowest for pond habitat; in KaliganjUpazila highest suitability for pond and lowest for floodplain; in SreepurUpazila highest suitability for pond and lowest for beel fish habitat. The present study using multiple regression model has revealed that habitat characteristics, regarding connectivity among existing water bodies, water availability and spawning ground condition, are moderately correlated with habitat suitability at 95% significant level. The present condition of water depth indicates that it is not the major cause for maintaining habitat suitability for culture fish production in the study area. Phytoplankton availability may not play more important role in maintaining habitat suitability due to using artificial feeding for culture fish production in the selected upazilas of Gazipur district. The present condition of water quality is the major causes for maintaining habitat suitability for both the capture and culture fish production in the study area. The present condition of soil quality indicates that it is one of the major causes for habitat suitability for both the capture and culture fish production in the study area. However, water pollution has not been identified as the major causes for regulating habitat suitability Furthermore, increasing indiscriminate fishing activities, like brood and fry fishing and unregulated use of gears, with increasing standard livelihood pattern of full time commercial fishermen resulting in decreased habitat suitability particularly for the capture fish habitats (beel and floodplain).

Recommendations/Implications

From the above discussions, some recommendations have been proposed in the present study as follows:

- Development of connectivity between river and beel or beel to beel through re-excavation for smoothness of fish migration around the year
- Re-excavation of khas land in the beel and keeping the water depth (1-1.5) m in dry season to protect the brood stocks of beel resident fish species
- Protect the Doho / Kums (deep pool in the river) in the river adjacent to the Beel as overwintering place of fish species
- Recommended dose of fertilizers and pesticides use in agriculture should be ensured by local institutional body for rescue of fish habitat
- For recovery of fish biodiversity illegal fishing, overfishing activities, destructive gear and nets like Badai jal, current jal and other fine mesh net should be banned around the year
- Development of numbers of fish sanctuary in adjacent river (Deep Pool / Doho / Kum area with 100 m both side of upstream and downstream as buffer zone) and beel (One in each beel and area about 50 decimal or more with buffer zone) and protect the area for future recruitment of riverine and beel fish species
- Water pollution related acts should be strictly implemented by institutional bodies in case of agricultural and industrial affluent discharge
- Regular monitoring program by GOs and NGOs should be maintained for better suitable fish habitats in the study area.
- To avoid indiscriminate fishing and to save open water fisheries and the beel basin may be well-managed by organizing the present fishers, through conservation and harvesting fishes in a sustainable manner.
- More HYV crops may be introduced and instead of pesticide ICM may be practiced otherwise fisheries resources will gradually be destroyed.
- For resolution of conflict, the khas lands should be recovered by the relevant government body and be demarcated by concrete pillars and flags.
- The fish sanctuary should be guarded by guard and managed by the local management committee.
- Awareness development at the community level and dissemination of the knowledge on how the natural resources play a vital role in various ways in our daily life.
- Creation of Alternate Income scope (AIG) for the poor fishers and providing need-based training including nursery development and pond culture, and sanctioning loan with minimum interest by the Government organization.
- Management committee (Village Conservation Group (VCG) or Resource Management Committee / Group (RMC/G) should be formed by the representatives of fishers, land owners

/ agriculturist, teachers, local elites, representative of related union parisad and professionals from the Department of Fisheries (DoF) and Agriculture. The committee will be headed by fisherman.

- Management committee's responsibilities are protection of fish sanctuary and other aquatic resources and disseminate the findings to the local community
- Exchange of knowledge on fisheries with other fisheries groups in the country should be a regular practice
- A separate policy on the Management of capture and culture fisheries is strictly needed for appropriate and sustainable fisheries management and implementation of the policy
- Local community participation should be ensured in all decision making at management level
- Fisheries related laws and regulations; acts should be implemented strictly to protect the fisheries resources around the year through local administration
- Awareness development to the local fisher community on wetland resources, conservation and sustainable management of fish production need to be conducted by the local government authority.

Limitations and future research

It is the duty of the scientists to make the people and communities aware of the potential role in ensuring nutritional security and poverty alleviation of the rural poor in Bangladesh through protecting and conserving of capture and culture fisheries. The present study tries to cover a variety of suitability indicators for assessing habitat suitability mainly for culture fisheries in Gazipur district. However, the present study cannot cover some major indicators due to having very limited time. Among them, one of the major indicators is climatic variability which is considered as the primary regulatory predictor of habitat characteristics. Various organic and inorganic trace elements, such as pb, Ag, etc cannot be considered in this study. Among physical characteristics, like turbidity, TDS, etc., only water temperature has been considered which makes limitation for this study. In recent times, various Geo-referenced model based software package have been developed for assessing habitat suitability. However, the present study uses a traditional multivariate index method. Nevertheless, the present study is the first initiative to assess habitat suitability for Gazipur district. It is, therefore, suggested that further research should continue in Gazipur and other districts of Bangladesh for need based fisheries conservation as well as protection of the largest wetland of the country.

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Appendices-1

Calculation of indicator parameter for indicator 1(habitat characteristics) of pond of Gazipur Sadar

Look up table1: Criteria for habitat type of the pond (H_t)

Pond	Score
Perennial	1.0
Seasonal	0.5

Look up table 2: Criteria for spawning ground of the pond (S_g)

Spawning ground (S_g)	Score
Very good	1.0
Good	0.6
Moderate	0.4

Equation for calculation of habitat characteristics (I_1) of pond for Gazipur Sadar

I_1=Value of H_t+Value of S_g

=1+0.4

=1.4

Calculation of indicator parameter for indicator 2(phytoplankton availability) of pond

Look up table 3: Criteria for phytoplankton availability of the pond

Phytoplankton availability	Score
Very good	1.0
Good	0.6
Moderate	0.4

Calculation of indicator parameter for indicator 3 (water depth) of pond

Water depth (feet)	Score
>7	1.0
5-7	0.6

4-5	0.4
<4	0

Look up table 4: Criteria for water depth of the pond

Calculation of indicator parameter for indicator 4 (water quality) of pond

Look up table 5: Criteria for temperature (°C) of the pond

Temperature (°C)	Score
29-30	1.0
25-28	0.6
<25	0.4
<10	0

Look up table 6: Criteria for DO (mg/l) of the pond

DO(mg/l)	Score
>5	1.0
5	0.6
<5	0.4
<1	0

Look up table 7: Criteria for pH of the pond

pH	Score
2.2 6.5-9	1.0
2.3 4-6.5	0.6
2.4 4-5	0.3
2.5 Less than 4	0

Look up table 8: Criteria for BOD (mg/l) of the pond

BOD	Score
1-2	1.0
3-5	0.6
6-9	0.2

Equation for calculation of water quality (I_4) of pond for Gazipur Sadar

I_4=Value of W_t+Value of W_{DO}+Value of W_{pH}+Value of W_{BOD}

=1.0+0.6+1+0.6

=3.2

Calculation of indicator parameter for indicator 5(soil pH) of pond

Look up table 9: Criteria for soil pH of the pond

Soil pH	Score
6.5-8.5	1.0
<6.5	0.6
>9.5	0

Calculation of indicator parameter for indicator 6(water pollution) of pond

Look up table 10: Criteria for agricultural pollution (A_p) of the pond

Agricultural pollution	Score
Not harmful	1
Moderate harmful	0.5
Harmful	0

Look up table 11: Criteria for industrial pollution (I_p) of the pond

Industrial pollution	Score
Not harmful	1
Moderate harmful	0.5
Harmful	0

Equation for calculation of water pollution (I_6) of pond of Gazipur Sadar

I_6=Value of A_p+Value of I_p

=0.5+0.5

=1.0

Calculation of indicator parameter for indicator 7(livelihood status) of Gazipur Sadar

Look up table 12: Criteria for no of fish farmer (F_f)

No of fish farmer	Score

2500-3000	1.0
2000-2500	0.6
<2000	0.4

Look up table 13: Criteria for no of fishermen (F_m)

No of fishermen	Score
>3000	1.0
2500-3000	0.6
2000-2500	0.4
1500-2000	0.2
<1500	0

Equation for calculation of livelihood status (I_7) of Gazipur Sadar

I_7=Value of F_f +Value of F_m

=1.0+0.6

=1.6

Calculation of indicator parameter for indicator 8(fish production) of pond

Look up table 14: Criteria for fish production (F_p) of pond

Fish production	Score
>4300	1.0
3600-4300	0.6
2900-3600	0.4
2200-2900	0.2
1500-2200	0.1
<1500	0

$HS = I_1 \times 0.03 + I_2 \times 0.1 + I_3 \times 0.3 + I_4 \times 0.3 + I_5 \times 0.2 + I_6 \times 0.04 + I_7 \times 0.02 + I_8 \times 0.01$

$= 1.4 \times 0.03 + 0.4 \times 0.1 + 0.6 \times 0.3 + 3.2 \times 0.3 + 1.0 \times 0.2 + 1.0 \times 0.04 + 1.6 \times 0.02 + 1.0 \times 0.01$

= 0.042+0.04+0.18+0.96+0.2+0.04+0.032+0.01

=1.504

Where,

HS = Final potential score

Lookup Table 15: Weights of different indicators

Indicator Parameter	**Weights**
I_1	0.03
I_2	0.1
I_3	0.3
I_4	0.3
I_5	0.2
I_6	0.04
I_7	0.02
I_8	0.01

Lookup Table 16: Potentiality class of the pond

Potential score	Potential class
HS> 1.5	High
HS = 1.0-1.5	Medium
HS< 1.0	Low/ Less

Calculation of indicator parameter for indicator 1(habitat charecteristics) of beel

Look up table 17: Criteria for habitat status of beel

Beel	Score
Perennial	1.0
Seasonal (months)	
>6	1.0
5-6	0.6
<5	0.2

Look up table 18: Criteria for spawning ground (S_g) of beel

Spawning ground (S_g)	Score
Very good	1.0
Good	0.6
Moderate	0.4

Equation for calculation of habitat characteristics indicator 1(I_1) of beel of Gazipur Sadar

I_1=Value of H_t+Value of S_g

=0.6+1.0

=1.6

Calculation of indicator parameter for indicator 2(phytoplankton availability) of beel

Look up table 19: Criteria for phytoplankton availability of beel

Phytoplankton availability	Score
Very good	1.0
Good	0.6
Moderate	0.4

Calculation of indicator parameter for indicator 3 (water depth) of beel

Look up table 20: Criteria for water depth of beel

Water depth (feet)	Score
>7	1.0
5-7	0.6
4-5	0.4
<4	0

Calculation of indicator parameter for indicator 4 (water quality) of beel

Look up table 21: Criteria for temperature (℃)of beel

Temperature (℃)	Score
29-30	1.0
25-28	0.6
<25	0.4
<10	0

Look up table 22: Criteria for DO (mg/l) of beel

DO(mg/l)	Score
>5	1.0
5	0.6
<5	0.4

<1	0

Look up table 23: Criteria for pH of beel

pH	Score
2.6 6.5-9	1.0
2.7 4-6.5	0.6
2.8 4-5	0.3
2.9 Less than 4	0

Look up table 24: Criteria for BOD (mg/l) of the pond

BOD	Score
1-2	1.0
3-5	0.6
of pond 6-9	0.2

Equation for calculation of water quality (I_4) of beel of Gazipur Sadar

I_4=Value of W_t+Value of W_{DO}+Value of W_{pH}+Value of W_{BOD}

=0.6+1.0+0.6+1.0

=3.2

Calculation of indicator parameter for indicator 5(soil pH) of beel

Look up table 25: Criteria for soil pH of beel

Soil pH	Score
6.5-8.5	1.0
<6.5	0.6
>9	0

Calculation of indicator parameter for indicator 6(water pollution) of beel

Look up table 26: Criteria for agricultural pollution (A_p) of beel

Agricultural pollution	Score
Not harmful	1
Moderate harmful	0.5
Harmful	0

Look up table 27: Criteria for industrial pollution (I_p) of beel

Industrial pollution	Score
Not harmful	1
Moderate harmful	0.5
Harmful	0

Equation for calculation of water pollution (I_6) of beel of Gazipur Sadar

I_6=Value of A_p+Value of I_p

=0.0+0.0

=0.0

Calculation of indicator parameter for indicator 7(livelihood status) of Gazipur Sadar

Look up table 28: Criteria for no of fish farmer (F_f)

No of fish farmer	Score
2500-3000	1.0
2000-2500	0.6
<2000	0.4

Look up table 29: Criteria for no of fishermen (F_m)

No of fishermen	Score
>3000	1.0
2500-3000	0.6
2000-2500	0.4
1500-2000	0.2
<1500	0

Equation for calculation of livelihood status (I_7) of Gazipur Sadar

I_7=Value of F_f +Value of F_m

=1.0+0.6

=1.6

Calculation of indicator parameter for indicator 8(fish production) of beel

Look up table 30: Criteria for fish production (F_p) of beel

Fish production	Score

>4300	1.0
3600-4300	0.6
2900-3600	0.4
2200-2900	0.2
1500-2200	0.1
<1500	0

$HS = I_1 \times 0.03 + I_2 \times 0.1 + I_3 \times 0.3 + I_4 \times 0.3 + I_5 \times 0.2 + I_6 \times 0.04 + I_7 \times 0.02 + I_8 \times 0.01$

$= 1.6 \times 0.03 + 1.0 \times 0.1 + 1.0 \times 0.3 + 3.2 \times 0.3 + 1.0 \times 0.2 + 0 \times 0.04 + 1.6 \times 0.02 +$

0×0.01

$= 0.048 + 0.1 + 0.3 + 0.96 + 0.2 + 0 + 0.032 + 0$

$= 1.64$

Where,

HS = Final potential score

Lookup Table 31: Weights of different indicators

Indicator Parameter	Weights
I_1	0.03
I_2	0.1
I_3	0.3
I_4	0.3
I_5	0.2
I_6	0.04
I_7	0.02

Lookup Table 32: Potentiality class of beel

Potential score	Potential class
HS> 1.5	High
HS = 1.0-1.5	Medium
HS< 1.0	Low/ Less

Calculation of indicator parameter for indicator 1(habitat characteristics) of floodplain of Gazipur Sadar

Look up table 33: Criteria for habitat type of floodplain (H_t)

Beel	Score
Perennial	1.0
Seasonal (months)	
>6	1.0
5-6	0.6
<5	0.2

Look up table 34: Criteria for spawning ground of floodplain (S_g)

Spawning ground (S_g)	Score
Very good	1.0
Good	0.6
Moderate	0.4

Equation for calculation of habitat characteristics indicator 1(I_1) of floodplain of Gazipur Sadar

I_1=Value of H_t+Value of S_g

=1+0.6

=1.6

Calculation of indicator parameter for indicator 2(phytoplankton availability) of floodplain

Look up table 35: Criteria for phytoplankton availability of beel

Phytoplankton availability	Score
Very good	1.0
Good	0.6
Moderate	0.4

Calculation of indicator parameter for indicator 3 (water depth) of floodplain

Water depth (feet)	Score
>7	1.0
5-7	0.6
4-5	0.4
<4	0

Calculation of indicator parameter for indicator 4 (water quality) of floodplain

Look up table 37: Criteria for temperature (℃)of floodplain

Temperature (℃)	Score
29-30	1.0
25-28	0.6
<25	0.4
<10	0

Look up table 38: Criteria for DO(mg/l) of floodplain

DO(mg/l)	Score
>5	1.0
5	0.6
<5	0.4
<1	0

Look up table 39: Criteria for pH of floodplain

pH	Score
2.10 6.5-9	1.0
2.11 4-6.5	0.6
2.12 4-5	0.3
2.13 Less than 4	0

Look up table 40: Criteria for BOD (mg/l) of floodplain

BOD	Score
1-2	1.0

3-5	0.6
of pond 6-9	0.2

Equation for calculation of water quality (I_4) of floodplain of Gazipur Sadar

I_4=Value of W_t+Value of W_{DO}+Value of W_{pH}+Value of W_{BOD}

=0.4+0.4+0.6+1.0

=2.4

Calculation of indicator parameter for indicator 5(soil pH) of floodplain

Look up table 41: Criteria for soil pH of beel

Soil pH	Score
6.5-8.5	1.0
<6.5	0.6
>9	0

Calculation of indicator parameter for indicator 6(water pollution) of floodplain

Look up table 42: Criteria for agricultural pollution (A_p) of floodplain

Agricultural pollution	Score
Not harmful	1
Moderate harmful	0.5
Harmful	0

Look up table 43: Criteria for industrial pollution (I_p) of floodplain

Industrial pollution	Score
Not harmful	1
Moderate harmful	0.5
Harmful	0

Equation for calculation of water pollution (I_6) of floodplain of Gazipur Sadar

I_6=Value of A_p+Value of I_p

=1.0+1.0

=2.0

Calculation of indicator parameter for indicator 7(livelihood status) of Gazipur Sadar

Look up table 44: Criteria for no of fish farmer (F_f)

No of fish farmer	Score
2500-3000	1.0
2000-2500	0.6
<2000	0.4

Look up table 45: Criteria for no of fishermen (F_m)

No of fishermen	Score
>3000	1.0
2500-3000	0.6
2000-2500	0.4
1500-2000	0.2
<1500	0

Equation for calculation of livelihood status (I_7) of Gazipur Sadar

I_7=Value of F_f +Value of F_m

=1.0+0.6

=1.6

Calculation of indicator parameter for indicator 8(fish production) of floodplain

Look up table 46: Criteria for fish production (F_p) of floodplain

Fish production	Score
>4300	1.0
3600-4300	0.6
2900-3600	0.4
2200-2900	0.2
1500-2200	0.1
<1500	0

$HS= I_1 \times 0.03 + I_2 \times 0.1 + I_3 \times 0.3 + I_4 \times 0.3 + I_5 \times 0.2 + I_6 \times 0.04 + I_7 \times 0.02 + I_8 \times 0.01$

$=1.6 \times 0.03 + 0.6 \times 0.1 + 0.4 \times 0.3 + 2.4 \times 0.3 + 0.6 \times 0.2 + 2.0 \times 0.04 + 1.6 \times 0.02$

$+1.0 \times 0.01$

=0.048+0.06+0.12+0.72+0.12+0.08+0.032+0.01

=1.19

Where,

HS = Final potential score

Lookup Table 47: Weights of different indicators

Indicator Parameter	Weights
I_1	0.03
I_2	0.1
I_3	0.3
I_4	0.3
I_5	0.2
I_6	0.04
I_7	0.02
I_8	0.01

Calculation of indicator parameter for indicator 1(habitat characteristics) of pond of Kaliakair

I_1=Value of H_t+Value of S_g

=1.0+1.0

=2.0

Calculation of indicator parameter for indicator 2(phytoplankton availability) of pond

Look up table 51: Criteria for phytoplankton availability of the pond

Phytoplankton availability	Score
Very good	1.0
Good	0.6
Moderate	0.4

Calculation of indicator parameter for indicator 3 (water depth) of pond

Water depth (feet)	Score
>7	1.0

5-7	0.6
4-5	0.4
<4	0

Look up table 52: Criteria for water depth of the pond

Calculation of indicator parameter for indicator 4 (water quality) of pond

I_4=Value of W_t+Value of W_{DO}+Value of W_{pH}+Value of W_{BOD}

=0.6+1.0+1.0+0.6

=3.2

Calculation of indicator parameter for indicator 5(soil pH) of pond

Look up table 57: Criteria for soil pH of pond

Soil pH	Score
6.5-8.5	1.0
<6.5	0.6
>9	0

Calculation of indicator parameter for indicator 6 (water pollution) of pond

Equation for calculation of water pollution (I_6) of pond of Kaliakair

I_6=Value of A_p+Value of I_p

=1.0+1.0

=2.0

Calculation of indicator parameter for indicator 7(livelihood status) of Kaliakair

I_7=Value of F_f +Value of F_m

=1.0+0.2

=1.2

Calculation of indicator parameter for indicator 8 (fish production) of pond

Look up table 62: Criteria for fish production (F_p) of pond

Fish production	Score
>4300	1.0
3600-4300	0.6
2900-3600	0.4

2200-2900	0.2
1500-2200	0.1
<1500	0

HS= $I_1 \times 0.03 + I_2 \times 0.1 + I_3 \times 0.3 + I_4 \times 0.3 + I_5 \times 0.2 + I_6 \times 0.04 + I_7 \times 0.02 + I_8 \times 0.01$

$= 2.0 \times 0.03 + 1.0 \times 0.1 + 1.0 \times 0.3 + 3.2 \times 0.3 + 1.0 \times 0.2 + 2.0 \times 0.04 + 1.2 \times 0.02 + 0.2 \times 0.01$

$= 0.06+0.1+0.3+0.96+0.2+0.08+0.024+0.002$

$= 1.726$

Habitat suitability calculation of beel of Kaliakair

HS= $I_1 \times 0.03 + I_2 \times 0.1 + I_3 \times 0.3 + I_4 \times 0.3 + I_5 \times 0.2 + I_6 \times 0.04 + I_7 \times 0.02 + I_8 \times 0.01$

$= 1.6 \times 0.03 + 0.6 \times 0.1 + 0.6 \times 0.3 + 3.2 \times 0.3 + 0.6 \times 0.2 + 1.0 \times 0.04 + 1.2 \times 0.02 + 0.1 \times 0.01$

$= 0.048+0.06+0.18+0.96+0.12+0.04+0.024+0.001$

$= 1.433$

Habitat suitability calculation of floodplain of Kaliakair

HS= $I_1 \times 0.03 + I_2 \times 0.1 + I_3 \times 0.3 + I_4 \times 0.3 + I_5 \times 0.2 + I_6 \times 0.04 + I_7 \times 0.02 + I_8 \times 0.01$

$= 1.4 \times 0.03 + 0.4 \times 0.1 + 0.4 \times 0.3 + 2.4 \times 0.3 + 0.6 \times 0.2 + 0 \times 0.04 + 1.2 \times 0.02 + 0.4 \times 0.01$

$= 0.042+0.04+0.12+0.72+0.12+0+0.024+0.004$

$= 1.07$

Habitat suitability calculation of pond of Kaliganj

HS= $I_1 \times 0.03 + I_2 \times 0.1 + I_3 \times 0.3 + I_4 \times 0.3 + I_5 \times 0.2 + I_6 \times 0.04 + I_7 \times 0.02 + I_8 \times 0.01$

$= 1.06 \times 0.03 + 0.6 \times 0.1 + 0.6 \times 0.3 + 3.2 \times 0.3 + 0.6 \times 0.2 + 1.0 \times 0.04 + 0.8 \times 0.02 + 0.2 \times 0.01$

$= 0.032+0.06+0.18+0.96+0.12+0.04+0.016+0.00$

$= 1.41$

Habitat suitability calculation of beel of Kaliganj

$HS = I_1 \times 0.03 + I_2 \times 0.1 + I_3 \times 0.3 + I_4 \times 0.3 + I_5 \times 0.2 + I_6 \times 0.04 + I_7 \times 0.02 + I_8 \times 0.01$

$= 1.6 \times 0.03 + 1.0 \times 0.1 + 0.4 \times 0.3 + 2.6 \times 0.3 + 1.0 \times 0.2 + 1.0 \times 0.04 + 0.8 \times 0.02$

$+ 0 \times 0.01$

$= 0.048 + 0.1 + 0.12 + 0.78 + 0.2 + 0.04 + 0.016 + 0$

$= 1.304$

Habitat suitability calculation of floodplain of Kaliganj

$HS = I_1 \times 0.03 + I_2 \times 0.1 + I_3 \times 0.3 + I_4 \times 0.3 + I_5 \times 0.2 + I_6 \times 0.04 + I_7 \times 0.02 + I_8 \times 0.01$

$= 0.6 \times 0.03 + 0.4 \times 0.1 + 1.0 \times 0.3 + 0.8 \times 0.3 + 0.6 \times 0.2 + 1.0 \times 0.04 + 0.8 \times 0.02$

$+ 0.6 \times 0.01$

$= 0.018 + 0.04 + 0.3 + 0.24 + 0.12 + 0.04 + 0.016 + 0.006$

$= 0.78$

Habitat suitability calculation of pond of Kapasia

$HS = I_1 \times 0.03 + I_2 \times 0.1 + I_3 \times 0.3 + I_4 \times 0.3 + I_5 \times 0.2 + I_6 \times 0.04 + I_7 \times 0.02 + I_8 \times 0.01$

$= 1.4 \times 0.03 + 0.6 \times 0.1 + 1.0 \times 0.3 + 3.6 \times 0.3 + 1.0 \times 0.2 + 1.0 \times 0.04 + 1.0 \times 0.02$

$+ 0 \times 0.01$

$= 0.042 + 0.06 + 0.3 + 1.08 + 0.2 + 0.04 + 0.02 + 0$

$= 1.742$

Habitat suitability calculation of beel

$HS = I_1 \times 0.03 + I_2 \times 0.1 + I_3 \times 0.3 + I_4 \times 0.3 + I_5 \times 0.2 + I_6 \times 0.04 + I_7 \times 0.02 + I_8 \times 0.01$

$= 1.6 \times 0.03 + 0.4 \times 0.1 + 0.6 \times 0.3 + 3.6 \times 0.3 + 0.6 \times 0.2 + 1.0 \times 0.04 + 1.0 \times 0.4 +$

0.4×0.01

$= 0.048 + 0.04 + 0.18 + 1.08 + 0.12 + 0.04 + 0.4 + 0.004$

$= 1.512$

Habitat suitability calculation of floodplain of Kapasia

$HS = I_1 \times 0.03 + I_2 \times 0.1 + I_3 \times 0.3 + I_4 \times 0.3 + I_5 \times 0.2 + I_6 \times 0.04 + I_7 \times 0.02 + I_8 \times 0.01$

$= 1.2 \times 0.03 + 1.0 \times 0.1 + 0.4 \times 0.3 + 2.6 \times 0.3 + 1.0 \times 0.2 + 1.0 \times 0.04 + 1.0 \times 0.02$

$+ 0.2 \times 0.01$

=0.036+0.1+0.12+0.78+0.2+0.04+0.02+0.002

=1.298

Habitat suitability calculation of pond of Sreepur

$HS= I_1 \times 0.03 + I_2 \times 0.1 + I_3 \times 0.3 + I_4 \times 0.3 + I_5 \times 0.2 + I_6 \times 0.04 + I_7 \times 0.02 + I_8 \times 0.01$

$=1.5 \times 0.03 + 1.0 \times 0.1 + 1.0 \times 0.3 + 3.2 \times 0.3 + 1.0 \times 0.2 + 0.5 \times 0.04 + 1.4 \times 0.02 + 1.0 \times 0.01$

=0.045+0.1+0.3+0.96+0.2+0.02+0.028+0.01

=1.663

Habitat suitability calculation of beel

HS= I1 $\times$ 0.03 + I2 $\times$ 0.1 + I3 $\times$ 0.3 + I4 $\times$ 0.3 + I5 $\times$ 0.2 + I6 $\times$ 0.04 +I7 $\times$ 0.02 + I8 $\times$ 0.01

$=1.6 \times 0.03 + 0.6 \times 0.1 + 0.4 \times 0.3 + 2.4 \times 0.3 + 0.6 \times 0.2 + 1.0 \times 0.04 + 1.4 \times 0.02 + 0 \times 0.01$

=0.048+0.06+0.12+0.72+0.12+0.04+0.028+0

=1.136

Habitat suitability calculation of floodplain of Sreepur

$HS= I_1 \times 0.03 + I_2 \times 0.1 + I_3 \times 0.3 + I_4 \times 0.3 + I_5 \times 0.2 + I_6 \times 0.04 + I_7 \times 0.02 + I_8 \times 0.01$

$=1.0 \times 0.03 + 0.4 \times 0.1 + 0.6 \times 0.3 + 3.0 \times 0.3 + 0.6 \times 0.2 + 1.5 \times 0.04 + 1.40 \times 0.02 + 0 \times 0.01$

=0.03+0.04+0.18+0.9+0.12+0.06+0.028+0

=1.358

Potential score	Potential class
HS> 1.5	High
HS = 1.0-1.5	Medium
HS< 1.0	Low/ Less

Number of suitable pond	Number of suitable beel	Number of suitable floodplain

High	Medium	low	High	Medium	Low	High	Medium	Low
3	2	0	2	3	0	0	4	1

Name of upazilla	High	Medium	Low
Gazipur Sadar	Beel	Pond ,flooodplain	
Kaliakair	Pond	Beel ,floodplain	
Kaliganj		Pond ,beel	Floodplain
Kapasia	Pond ,beel	Floodplain	
Sreepur	Pond	Beel ,floodplain	

Name of upazilla	Pond	Beel	Floodplain
Gazipur Sadar	1.504	1.64	1.19
Kaliakair	1.726	1.427	1.07
Kaliganj	1.41	1.304	0.78
Kapasia	1.742	1.512	1.298
Sreepur	1.663	1.136	1.358

Appendices-2

Upazilla	Waterbody	Area (ha)	Production (mt)	Year	Total production
Sadar upazilla	Pond	1204	4065	2013	8233.3 mt
	Beel	668.1	506.3		
	River	158	60		
	Khal	529	4		
	Flood plain	10270	3598		

	Waterbody	Area (ha)	Production (mt)	Year	Total production(mt)
Sadar upazilla	Pond	1204	4350	2014	9288
	Beel	668.1	545		
	River	158	61		
	Khal	529	5		
	Floodplain	10270	4327		

	Waterbody	Area (ha)	Production (mt)	Year	Total production (mt)
Sadar	Pond	1204	4054	2012	7976.5
	Beel	668.1	265		
	River	158	59		
	Khal	529	3.5		
	Floodplain	10270	3595		

	Waterbody	Area (ha)	Production (mt)	Year	Total production(mt)
Sadar	Pond		4042	2011	7929.5
	Beel		265		
	River		59		
	Khal		3.5		
	Floodplain		3560		

	Waterbody	Area(ha)	Production (mt)	Year	Total production(mt
Sadar	Pond		3160	2010	6853.6
	Beel		265		
	River		39.7		
	Khal		3.9		
	Floodplain		3385		

	Waterbody	Area (ha)	Production (mt)	Year	Total production(mt)
Sadar	Pond	270	3920	2009	7512.5
	Beel	668.1	260		
	River	158	39		
	Khal	529	3.5		
	Floodplain	10270	3290		

Upazilla	Waterbody	Area (ha)	Production (mt)	Year	Total production
Kaliakoir	Pond	830.11	2485.65	**2013**	8562.65 mt
	Beel	2311	1421		
	River	2824	1305		
	Khal				
	Floodplain	3109	3351		

Upazilla	Waterbody	Area (ha)	Production (mt)	Year	Total production
Kaliakoir	Pond	620	2588	2014	8955.03 mt
	Beel	2401	1533		
	River	2824	1520		
	Khal				
	Floodplain	3109	3314.03		

	Waterbody	Area (ha)	Production (mt)	Year	Total production
Kaliakoir	Pond	750.68	1288.6	2009	4235.1 mt
	Beel	2311	1040		
	River	2929	6.5		
	Khal				
	Floodplain	2650	1900		

	Waterbody	Area (ha)	Production (mt)	Year	Total production
Kaliakoir	Pond	752.01	1284.05	2010	5215.05 mt
	Beel	2311	1151		
	River	2829	660		
	Khal				
	Floodplain	2650	2120		

	Waterbody	Area (ha)	Production (mt)	Year	Total production
Kaliakoir	Pond	752.01	1417.7	2011	5607.7 mt
	Beel	2311	1220		
	River	2829	670		
	Khal				
	Floodplain	2650	2300		

Upazilla	Waterbody	Area (ha)	Production(mt)	Year	Total production
Kapasia	Pond	329	840		
	Beel	1114.57	2968.50		

Upazilla	Waterbody	Area (ha)	Production(mt)	Year	Total production
	River	1200	365	2014	6948.5 mt
	Khal	166.80	150		
	Floodplain	5263	2625		

Upazilla	Waterbody	Area(ha)	Production (mt)	Year	Total production
Sreepur	Pond	585.22	5145	2014	6740 mt
	Beel	6534	790		
	River	150	30		
	Khal	117.41	205		
	Floodplain	400	570		

	Waterbody	Area (ha)	Production (mt)	Year	Total production
Kaligonj	Pond	620.21	2151.91	2012	6578.89 mt
	Beel	400.2	264.45		
	River	301.62	247		
	Khal	11.41	3		
	Floodplain	5599.80	3912.53		

Upazilla	Waterbody	Area (ha)	Production (mt)	Year	Total production
Kaligonj	Pond	622.18	2193.38	2013	6628.91 mt
	Beel	400.2	285		
	River	301.62	247		
	Khal	11.41	3		
	Floodplain	5599.80	3900.53		

	Waterbody	Area (ha)	Production (mt)	Year	Total production
Kaligonj	Pond	615.479	938.79	2010	1729.79 mt
	Beel	400.20	49.42		
	River	301.62	48.50		
	Khal	11.41	1.50		
	Floodplain	5591.80	691.58		

	Waterbody	Area (ha)	Production (mt)	Year	Total production
Kaligonj	Pond	623.72	1911.14	2009	2699.14 mt
	Beel	400.20	49.42		
	River	301.62	45.50		
	Khal	11.41	1.50		
	Floodplain	4599.84	691.58		

	Waterbody	Area (ha)	Production (mt)	Year	Total production
Kaligonj	Pond	623.92	2396.28	2014	6831.81 mt
	Beel	400.2	285		
	River	301.62	247		
	Khal	11.41	3		
	Floodplain	5599.80	3900.53		

Appendices 3: Report of thesis work

A Questionnaire for fishermen of Gazipur district

Responding information:

1. Name of the region:
2. Random number:
3. District:
4. Date:
5. Name of Interviewee:
6. Relation to the household head:
7. Name of Household head (if not the interviewee):
8. Phone (if any):
9. Religion: Islam /Hindu / Others……………………

Livelihood and socioeconomic condition:

- **Composition of household and information about human capital:**

Household member	Gender (male -1, female -2	Age	Marital status (married – 1, unmarried– 2, others	Education level		Health condition	
				Total years of schooling completed	Any other technical knowledge or course	Regular health status	Any severe disease
Household head (HH)							
…..of HH							
…..of HH							
..of HH							
..of HH							
..of HH							

HH size	Observations/notes:	Mean age		Mean education	Mean health condition

8. Which type of chemicals are responsible for water pollution? .... industrial/ non-industrial

Information about financial capital:

1. How is your financial status (you think)?
   I. Rich
   II. Solvent
   III. Poor

2. Do the fishing provide you enough economic solvencies? Yes/no if no, then what do you do to fulfill your basic need? .... 1. When did you start fishing?..

2. How many years are you involve in fishing?..........................

3. Is this your family traditional occupation? Yes/no. if no, then why did you choose to live on fishing? ....

4. Any other household members engage in fishing activities? Yes/No.

If yes, then which types of activities?-
   I. Fisherman
   II. Labour in other fisheries activities
   III. Boat owner/renting
   IV. Fish trading
   V. Net making or mending
   VI. Traps, spears and hooks making
   VII. Others fisheries related activities

5. How many water bodies in this area?

6. How many species do you catch during a normal fishing?

7. Which species do you catch?............................

8. How does the production of fish vary throughout the year?

9. Production variation between last 10 years and existing year……..increasing/decreasing

10. Species variation between last 10 years and existing year……..increasing/decreasing

11. Which type of species are abundantly found in this area?..........

Months of a year when fishing	Fish species	Variation in the quantity of fish (Increasing rapidly, Increasing moderately, Increasing slowly, Constant, Decreasing	Reasons for variations across months in the recent year	Observations/notes

		slowly, Decreasing moderately, Decreasing rapidly)		
January				
February				
March				
April				
May				
June				
July				
August				
September				
October				
November				
December				

Information about natural capital:

1. Do you have any agricultural land? Yes/ no, if yes

Quantity:

2. Do you cultivate any crops in the beel? Yes/ no if yes

I. Which crops?........

3. What do you do with the crops?

I. Sell in market
II. Only for household consumption

4. Do you have any personal pond or water based asset? Yes/ no if yes

5. How do you use this asset?

I. Fish culture for household consumption
II. Fish culture for selling
III. Watering agricultural land
IV. Others

6. Level of water depth to get more species……………..

7. Which chemical are used in this water body? ....

....

3. Do you involve in any other occupation? Yes/no if yes, then mention…………………………………

4. What do you do in the off peak season of fishing?...

Source of income	Income level	Investment of time	Investment of money	Observation/ notes
Fishing				
Agricultural cultivation				
Other activities/profession				

5. What is the trend in income from fisheries sources? :

I. Increasing rapidly
II. Increasing moderately
III. increasing slowly
IV. constant
V. decreasing
VI. slowly
VII. decreasing moderately

6. What are the reasons for this trend?

7. What is the trend in income from non-fisheries sources? :

I. Increasing rapidly
II. Increasing moderately
III. increasing slowly
IV. constant
V. decreasing
VI. slowly
VII. decreasing moderately
VIII. decreasing rapidly

8. What are the reasons for this trend?

9. Do you maintain your livelihood by doing this work? Yes/No......

10. Approximately how much do you income in every year?......................tk

11. Do you have any bank account? Yes/ no if yes…..how many?

11.1 How much have you save in account?...

12. Do you have any loan from any NGO/GO/Bank? Yes/no if yes. If yes, what type of assistance?

I. Get loan
II. Get fishing gear/boat/other instruments as loan
III. Get assistance for rehabilitation as loan

Others (………………………………………………………….)

13. Do you get any types of assistance from Government? Yes/ no

14. If yes, what type of assistance?

I. Financial assistance
II. Get fishing gear/boat/other instruments
III. Get assistance for rehabilitation

Others (………………………………………………………….)

Climate information

1. Do you feel the pattern of weather is generally changing? Yes/ No /Don't know

2. If yes, why do you think this might be? ....

3. Have rainfall patterns changed in your life time? Yes /no. if yes, explain about the changing pattern………

4. Is there more or less rain today than in your childhood? (a) increased (b) reduced (c) same

5. Do the rains fall earlier or later than you remember from your childhood? the rains come (a) earlier (b) later (c) same

6. Have temperature patterns changed in your life time? Yes/no. Temperature in the growing season has become (a) Hotter (b) Cooler.

7. Please rank three disasters which cause most adverse impact on your fishing activities:

I. ………………………
II. ………………………
III. ………………………

8. What are the impacts of natural disaster on fisher's life?

I. Loss of life as a result of fish mortality
II. Sickness of fishermen due to body injuries

9. Level of water depth…………..increasing/decreasing

10. Amount of species because of climate change? decreasing/more decreasing/extinct

11. Which species are not found now?..........

12. What is your opinion for extinction of species?................

- Total annual production of Gazipur region:

	River	Beel	Flood plain	Pond	Seasonal culture water body	Shrimp/prawn farm	Pen culture	Total	Sources

Area		1720 ha	6624 ha	4290 ha	3084 ha		2581 ha		FRSS
Production	167mT	1276mT	16331mT	18451 mT	7534 mT	1 mT	6668 mT	50428 mT	

- Indicator parameter for selected species to identify habitat suitability:
    1. Habitat type
    2. Water depth
    3. Temperature
    4. DO
    5. pH
    6. BOD
    7. Food availability
    8. Industrial pollution
    9. Biodiversity

Appendices: Photo Album