Changing Ecosystem Health of Wetlands of Ichhamati Floodplains in North 24 Parganas, West Bengal

Thesis submitted for the award of the degree

of

Doctor of Philosophy

of

Jadavpur University

by

Jibananda Gayen

Under the supervision of

Dr. Debajit Datta

Department of Geography

Faculty of Science

Jadavpur University, Kolkata-700032

November 2022

Dedicated to my parents

Late Provaboti Gayen & Late Basudev Gayen

&

To my spring of inspiration

My wife Smt. Soma Gayen, my beloved sons, Master. Sreejit Gayen and Master. Sounak Gayen

যাদবপুর বিশ্ববিদ্যালয়
JADAVPUR UNIVERSITY
DEPARTMENT OF GEOGRAPHY
FACULTY OF SCIENCE □ KOLKATA 700032 □ WEST BENGAL □ INDIA
Telephone: 033 2457- 3008, , email: debajit.datta.geog@jadavpuruniversity.in, debajit.geo@gmail.com, Mob: 9836112953

CERTIFICATE FROM THE SUPERVISOR

This is to certify that the thesis titled '***Changing Ecosystem Health of Wetlands of Ichhamati Floodplains in North 24 Parganas, West Bengal***' submitted by Mr. Jibananda Gayen, who got his name registered on 2nd November, 2016, for the award of Ph.D. (Science) degree of Jadavpur University, is a bona fide research work and absolutely based upon his own contribution under my supervision and that neither this thesis nor any part of it has been submitted for either any degree/diploma or any other academic award anywhere before.

Debajit Datta
01.11.2022

(Dr. Debajit Datta)
Assistant Professor
Department of Geography
Faculty of Science
Jadavpur University
Kolkata-700032

ASSISTANT PROFESSOR
DEPARTMENT OF GEOGRAPHY
JADAVPUR UNIVERSITY
KOLKATA-700032

Acknowledgements

At the very beginning, I express my deep gratitude to my Ph.D. supervisor, Dr. Debajit Datta, Assistant Professor, Department of Geography, Faculty of Science, Jadavpur University, for his constant supervision, guidance, support and valuable advice throughout the course of my Ph.D. works.

I also express my profound gratitude to Prof. Lakshmi Sivaramakrishnan and Dr. Arijit Majumder, faculties of the Department of Geography, Faculty of Science, Jadavpur University, for their inspiration during the course of my research. I convey my gratefulness to all the board members of the Ph.D. committee whose relevant suggestions helped me enormous to improve the quality of my thesis.

My heartfelt thanks to Mr. Gouranga Nandi, Dr. Proshanta Kumar Ghosh, Dr. Shrabana Sengupta, Dr. Chandreyee Sengupta, Dr. Asit Kumar Roy, Ms. Mrinmayee Naskar, Ms. Sohini Neogy, Mr. Mansa Dey, Mr. Argha Pratim Pal, and Ms. Baidik Sinha Roy of Jadavpur University for providing me information, technical support and emotional support throughout the entire course of my research work.

I am especially thankful to University Grants Commission, New Delhi, for financial support through the minor research project F.NO. F.PHW-209/15-16(ERO) by which some logistics was purchased for in-situ measurements of soil and water parameters.

I am greatful to the Landscape Ecology Laboratory and the Environment Laboratory of Jadavpur University; Vivekananda Institute of Bio Technology, Soil, Water & Manure Testing Laboratory, Nimpith, South 24-Parganas, West Bengal; Scientific Research Laboratory, Santoshpur, Kolkata; and Qualissure Laboratory Services for assisting in carrying out some analysis in their laboratory.

I am really thankful to Mr. Anupam Das, Mr. Amjed Mandal, Ms. Susmita Ghosh, Mr. Samir Kumar Sardar, Mr. Mohan Sarkar, Mr. Suman Mondal, Mr. Roni Paul, Mr. Sudip

Debnath, Mr. Rajesh Sarkar, Mr. Kunal Mallick, Nur Selim Mondal and Mr. Suvojit Halder for their active participation and contribution in data collection during field visits.

I convey my honest thanks to all authors of books and peer reviewed journal articles cited in this research work. Their knowledge helped me to execute my research work with deep understanding.

Last but not the least, this thesis could not have been completed without the constant support and encouragement of my family members who have always stood by me at various critical junctures of my Ph.D. work. I am deeply indebted to my father Late Basudeb Gayen, my father-in-law, Mr. Dulal Krishna Das and my mother-in-law Mrs. Ila Das for constant moral and physical support and encouragement in my research work. Above all, I express my eternal debt to three very special persons, my wife Mrs. Soma Gayen, my elder son Master Sreejit Gayen and my younger son Master Sounak Gayen, who have always given me their encouraging emotional support, cooperation, empathy and compassion.

Jibananda Gayen

Date: 1st November 2022 (Mr. Jibananda Gayen)

Curriculum Vitae

The researcher was born in Jogeshgunj village of North 24 Parganas District, West Bengal, India on 17th September 1979. He obtained his graduate degree with a Bachelor of Science in Geography from the University of Calcutta in 2000. He also obtained his Master of Science degree in Geography with a specialization in Cartography from the University of Calcutta in 2002. He qualified NET examination in June 2008. He joined the Sree Chaitanya College, Habra as an Assistant Professor in 2010. He joined the Department of Geography, Faculty of Science, Jadavpur University on 2nd November 2016 and started his doctoral research on '*Changing Ecosystem Health of Wetlands of Ichhamati Floodplains in North 24 Parganas, West Bengal'*. His research interests include community ecology, wetland ecological health wetland management and restoration. He has published several research papers in peer reviewed journals.

Publications related to Doctoral Research

In Peer-reviewed Journal

Gayen, J., Ghosh, P. K., & Datta, D. (2020). Avifauna habitability of wetlands in an intensive cultural landscape: Insights from the Ichhamati floodplains, India. *Environmental Monitoring and Assessment*, *192*(6):1-16.

Gayen, J., & Datta, D. (2022). Application of pressure-state-response approach for developing criteria and indicators of ecological health assessment of wetlands: A multi-temporal study in Ichhamati floodplains, India. *Ecological Processes.* (Communicated).

In Conference/Seminar:

Presented a paper titled 'Assessment of wetland ecological health through Pressure-State-Response (PSR) model: A study of Ichhamati Floodplains in West Bengal, India' at the 1st Symposium on *Landscape Health and Resilience* organized by IRALE (Indian Regional Association for Landscape Ecology), India on October 3-5th 2021.

Presented a paper titled 'Monitoring and Mapping of Avifauna diversity towards Assessment of Wetland Ecosystem Health: A Study of Ichhamati Floodplains in West Bengal, India' at the 10th IALE World Congress on 'Nature and society facing the Anthropocene challenges and perspectives for landscape ecology' organized by Italian Society of Landscape Ecology (SIEP) and International Association for Landscape Ecology (IALE), Milan, Italy on 1-5th July, 2019.

Presented a paper titled 'Evaluating water quality using water quality index at wetlands in Ichhamati floodplains, Bongaon Block, West Bengal' at the 'International Conference on Global Water Crisis: Agriculture and Food Security in the era of Climate Change' organized by Department of Geography, Faculty of Science Aligarh Muslim University, Aligarh on 1-3rd December, 2018.

Presented a paper titled **'**Evaluating Ecological Health of Wetlands at Human Environment Interface in Ichhamati Floodplains' at the XIII DGSI International Geography Conference on Sustainable Rural Development-Geospatial Solutions organized by Bangalore University, Department of Geography & Geoinformatics on 20-22nd September, 2018.

Jibananda Gayen

Date: 1st November 2022 (Mr. Jibananda Gayen)

Abstract

Index No. 172/16/Geo./25

Title: ***Changing Ecosystem Health of Wetlands of Ichhamati Floodplains in North 24 Parganas, West Bengal***

Along with biological productivity, wetlands of Ichhamati floodplains, North 24 Parganas, West Bengal also contribute substantially towards livelihood provisioning of millions. Subsistence-based faming and traditional fishing activities are intensively practiced in these wetlands. Therefore, exploitative anthropogenic activities have resulted into continuous fragmentation and degradation of these landscape units thereby deteriorating their ecological health throughout the region. Consequently, water quality deterioration, biodiversity loss, and diminishing ecosystem services are some persistent issues generally observed in the wetlands owing to aquatic pollution, landscape fragmentation, and microclimatic changes. Hence, assessment of wetland ecological health is crucial and necessary today considering their rapid disappearance and degradation rates in recent times. In this study, the pressure-state-response model encompassing all the physical, ecological and socioeconomic variables along with Shannon entropy method and the technique for order of preference by similarity to ideal solution (TOPSIS) were used to comprehend wetland ecosystem health in the intensely humanized floodplains of Ichhamati River of West Bengal. Remote sensing-based data, rigorous field investigation and socioeconomic appraisals were used to develop a wetland ecosystem health evaluation index for understanding condition of selected seven floodplain wetlands of River Ichhamati from 2016 to 2020. Wetland ecosystem health is actually an outcome of synthesizing criteria and indicators (C&Is) of pressure system, state system, and response system. Moreover, the values of pressure, state and response were classified with the ideal values and grade values. Thereafter, the health status of wetland ecosystems was assessed and influencing factors of wetland health were identified. Finally, a total of 5-evaluation grades was determined as: Excellent health (1.0-0.8), Good health (0.8-0.6), Moderate health (0.6-0.4), Weak health (0.4-0.2), and Morbid (0.2-0.0) based on the values of ideal alternatives for each assessment year. Results indicated that health of pressure, state and response system of Panchpota, Panchita, Aromdanga wetlands was found to be Weak to Morbid health status (≤ 40%) in both 2016 and 2020; health of state and response system of Berkrishnapur wetland and pressure health of Gopalnagar wetland was also indicated Weak to Morbid health (≤ 40%) in both years. However, Manigram wetland exhibited Moderate health (60% to 40%) in PSR system in 2016 and PS system in 2020 with little bit improvement in health response system *i.e*., Good health (80% to 60%) in 2020 due to several focus group discussions with wetland stakeholders. Only, Madhabpur wetland have shown Excellent to good health in both years with good community practices. It was keenly observed that if jute retting, agricultural washouts and wastewater from various sources, weed infestation and its decomposition and eutrophication are prevailed in these wetlands at the same pace, waning of wetland ecological health (WEH) will drastically increase in imminent years. Therefore, few relevant management measures at regional level, wetland complex specific and wetland specific were inferred for sustainable restoration and protection of these fragile wetlands.

Keywords: *Anthropogenic stress, Criteria and Indicators, Entropy, Wetland Ecological Health, Habitat fragmentation, Landscape ecology, PSR model, TOPSIS*

Contents

List of Abbreviations

AHP	Analytical Hierarchical Process
AK	Available Potassium
AN	Available Nitrogen
AP	Available Phosphorus
BOD	Biological Oxygen Demand
BOA	Bottom of Atmosphere
BWQC	Biological Water Quality Criteria
C	Carbon
CBD	Convention on Biodiversity
CBO	Community Based Organization
C&I	Criteria and Indicators
COD	Chemical Oxygen Demand
CONTAG	Contagion Index
CPCB	Central Pollution Control Board
CPR	Common Property Resource
CWEHI	Comprehensive Wetland Ecological Health Index
DO	Dissolved Oxygen
EC	Electrical Conductivity
EH	Ecosystem Health
EHA	Ecosystem Health Assessment
ENVI	Environment for Visualizing Image
EWM	Entropy Weighting Method
FAO	Food and Agriculture Organization
FCO_2	Free Carbon Dioxide
FGD	Focus Group Discussion
GCP	Ground Control Point
GHG	Greenhouse Gas
GIS	Geographical Information System
GoI	Government of India
GoWB	Government of West Bengal
IAPS	Invasive Alien Plants Species
K	Potassium
LPI	Largest Patch index
LULC	Land Use and Land Cover
MCDM	Multi Criteria Decision Making
MCWD	Minnehaha Creek Watershed District
MEA	Millennium Ecosystem Assessment
MOP	Multiple Objective Programming
MSI	Multi Spectral Instrument
N	Nitrogen
Na	Sodium
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Infrared Index
NGO	Non-Governmental Organizations
NIS	Negative Ideal Solution
NRBE	Natural Resource Based Economy
OECD	Organisation for Economic Co-operation and Development

OWSA	Open Water Surface Area
PCA	Principal Component Analysis
PD	Patch Density
PIS	Positive Ideal Solution
PSR	Pressure State Response
RMSE	Root Mean Standard Error
RS	Remote Sensing
S	Sulphur
SAC	Space Application Centre
SDGs	Sustainable Development Goals
SHDI	Shannon Diversity Index
SNAP	Sentinel Application Platform
SOC	Soil Organic Carbon
TDS	Total Dissolved Solid
TOA	Top of the Atmosphere
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TSS	Total Suspended Solid
UNDP	Unite Nations Development Programme
VA	Vegetated Area
WCS	Wetland Complex Specific
WEH	Wetland Ecosystem Health
WIZ	Wetland Influence Zone
WPZ	Wetland Perennial Zone

List of Symbols

a_{ij}	Area under i^{th} patch j^{th} wetland
A	Total Landscape Area
A_{AF}	Area under Agricultural fallow
A_{AL}	Area under Agricultural land
A_b	Best alternative
A_{BL}	Area under built up land
As	Arsenic
A_w	Worst alternative
Cd	Cadmium
Cr	Chromium
d_j	degree of variation of vital information for the j^{th} indicator
Ed_b^+	Euclidean distance of the i^{th} target alternative from the best alternative
Ed_w^-	Euclidean distance of the i^{th} target alternative from the worst alternative
F	Fluoride
g_{ik}	The number of adjacencies between pixels of patch types *i* and *k*
Hg	Mercury
J_+	Indicator having positive impact
J_-	Indicator having negative impact
m	Number of patch types present in the landscape
n_i	Number of patches of i^{th} class
NIR	Near infrared band
NO_3	Nitrate
P	Phosphorus
Pb	Lead
p_i	The proportion of the landscape occupied by each patch type *i*
pH	Potential Hydrogen
r_{ij}	the normalized score of j^{th} indicator for i^{th} wetland
SD	Standard Deviation
w_j	final entropy weight for each indicator
WP	Wetted perimeter
WS_{ij}	final normalized weighted score of an indicator
$\overline{x}$	Arithmetic Mean
x_{ij}	Standardized score of the j^{th} indicator for the i^{th} wetland

List of Tables

List of Figures

List of Photographs

Chapter 1: Introduction

1.1 Background of the study

The wetland is one of the prime biodiversity-enriched ecosystems globally and ensures a sustained flow of various natural products, goods, and services to mankind (Prasad et al., 2002; Jogo and Hassan, 2010; Datta and Ghosh, 2015; Gayen et al., 2020). They are a ‘transitional zone’, or ‘ecotone’ or ‘interconnecting ecosystems’ between the dry terrestrial and wet aquatic ecosystems (Cowardin and Golet, 1995; Mitsch and Gosselink, 2007). As natural sinks in the landscape, wetlands play a crucial role in cleaning wastewater, absorbing and converting human wastes to resources through their auto-green technology (Mitsch and Gosselink, 2007). Therefore, scientists used many nicknames for wetlands, such as "kidneys of the landscape," "biological supermarkets," and "repository of resources," to describe the wide variety of ecosystem goods, products, and services it provides. (Mitsch and Gosselink, 2007). Although, wetlands were once underrated as unproductive lands and seen as mosquito breeding grounds (Das et al., 2000; Tockner and Stanford, 2002). However, with the continued endeavours of the scientific community and academia, wetlands were proved to be the most productive lands in terms of the variety of food and services for human civilization (MEA, 2005; Mitsch and Gosselink, 2007; Ghosh, 2005; Das et al., 2000). Millennium Ecosystem Assessment (MEA, 2005) classified ecosystem services into provisioning services, regulating services, supporting services, and cultural services. Of these four, provisioning services are tangible and direct services provided by wetlands. Provisioning services are very important for the human population because it provides the vital necessities of human sustenance and livelihoods. Provisioning services provide biomass in terms of food and fiber; food products such as rice, fish, fruits, and corn; supply of medicinal plants for medicinal purposes; navigation services through ford and ferry; grain and livestock products, freshwater use, fuel supply such as wood and peat (MEA, 2005). Wetlands potentially recharge groundwater and thereby provide drinking water and pump irrigation during dry months (Harbor, 1994; Gross et al., 2007). Wetland supports the physiological and biological activities of a wide gamut of wetland flora and fauna (Mitsch and Gosselink, 2007). It consumes extreme heat during heat waves and provides comfortable weather to the community populace living beside it (Wong et al., 2017). It contains a wide mix of vegetation stands, bushes, shrubs, herbs, weeds, and grasses associated with rich benthos communities, avifauna, and fish stocks, thereby becoming biodiversity abodes and providing unique habitats for many distinct species of plants and animals (Mitsch and Gosselink, 2007; Hossain and Wahab, 2010). Wetland offers resting, foraging, nesting, and breeding ground to various waterfowl, including migratory ones (Gayen et al., 2020). In good condition, wetland flowering macrophytes attract various pollinating insects and can yield a decent amount of ecosystem food production (Foley et al., 2005). Various highly important and demandable medicinal plants, naturally grown in wetlands, are used to make life-saving drugs. Wetland, a natural carbon reservoir, significantly mitigates global warming and climate change through the carbon sequestration process more efficiently than any other ecosystems (Bernal, 2008; IPCC, 2021).

In spite of many beneficial effects, 70% of wetlands of the world had been depleted by 1970, and especially inland wetlands were mainly targeted due to its easy access, (Das et al., 2000; Junk, 2002; Kingsford et al., 2016; Yu et al., 2018). Hence, inland wetlands are becoming dysfunctional and rapidly disappearing (61%) in contrast to others (Davidson, 2014). A survey report by the Wildlife Institute of India found that 70% to 80% of inland wetlands (*i.e.*, individual freshwater marshes, oxbow lakes, rivers, paddy fields, and swamps) in the Gangetic floodplains had disappeared in the last five decades (Ramachandra, 2001). They also reported that these valuable resources are disappearing at a rate of 2% to 3% each year, which is a great cause of concern in terms of the socio-economic and ecological sustainability of the wetland environment (Ramachandra, 2001). Therefore, inland wetlands are generally degraded by human-induced socio-economic and unplanned developmental activities, siltation, floods, and droughts. These unplanned developmental activities and resultant wetland conversion, declining water quality, wetland filling, aquaculture farming, and impairing wetland functions have changed wetland landscapes rapidly and accelerated wetland transformation rate, particularly in the last century (Kennedy and Mayer, 2005; Zedler and Kercher, 2005). Consequently, the efficiency of wetlands in producing ecosystem goods and services has also been drastically reduced (Shine and Klemm, 1999). Instead of its healing mechanisms, the major aspects that particularly affect wetland ecosystems include loss of wetland areas, changes in water regime, changes in water quality, overexploitation of wetland products, and introduction of alien species (Shine and Klemm, 1999). Ultimately, such aspects cause irreparable damage to wetland ecology and habitat (Kingsford et al., 2016). Nevertheless, wetland conversion ultimately causes damage to the environment by diffusing carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (NO_2) into the atmosphere, where these become powerful GHGs. As a result, wetlands conversion augments huge carbon emissions (C) (estimated to be 5.8 to

14 million) into the atmosphere rather than sequestration (Sidik and Lovelock, 2013). According a report, 40 tons ha^{-1} yr^{-1} of carbon will also be emitted by the drainage and conversion of various inland wetlands (Paris et al., 2012; Cooper et al., 2020).

Among inland wetlands, floodplain wetlands are in a critical situation in terms of wetland degradation and wetland loss (Junk, 2002; Kingsford et al., 2016; Yu et al., 2018). Therefore, rapid landscape transformation has become a foreseeable consequence to meet the growing needs of the increasing rural population in densely populated floodplains. Indeed, floodplain wetlands, whose economy is natural resource-based economy (NRBE), are thus intensively used for fishing, aquaculture farming, paddy cultivation, jute farming and retting, vegetable farming, livestock rearing, and human habitation (Das et al., 2012; Mukherjee and Kumar, 2012; Reis et al., 2017; Gayen et al., 2020). Although, floodplain wetlands maintain their dynamicity even under constant natural and anthropogenic pressures (Shine and Klemm, 1999). However, natural stressors that greatly affect wetland conditions include subsidence, flooding, sea level rise, drought, erosion, siltation, etc. Besides, episodic events like flooding, river migration, and channel cut-offs in the floodplains largely determine wetland's future (Mukherjee and Pal, 2021). In addition to these, intensive human use patterns accompanied with episodic events have deteriorated and degraded wetland ecosystem health (WEH) considerably over the last few decades in the floodplain's wetlands in general and Ichhamati floodplains in particular. Although, well-being of people and societies largely depends upon wetland health (Finlayson et al., 2015). However, no comprehensive assessment and monitoring of WEH encompassing edaphic, aquatic, biotic, and socio-cultural indicators have been estimated to date (Mondal et al., 2010; Datta and Ghosh, 2015; Gayen et al., 2020). Hence, assessment of WEH is highly essential and also a prerequisite for understanding the existing ecological health and formulating wetland-specific sustainable management guidelines and restoration policies to restore such fragile ecosystems.

1.2 Importance of inland wetland systems

Inland wetlands occupy 92.8% of the world's total wetland area (Davidson et al., 2018). Whereas, inland wetland sites account for 23, 444 (85.55%) of the total 27,403 wetland sites in India (MoEF, 1990). This 85.55% of inland wetlands contribute significantly to the world's biological productivity and ecosystem services (Das et al., 2000; Tockner and Stanford, 2002). Three dominant but distinct aspects of inland wetlands, regulating wetland characteristics and habitat conditions, are wetland hydrology, wetland hydric soils, and wetland vegetation (Mitsch and Gosselink, 2007; Brinson, 1993). Out of these three dominant forces, hydrology is a primary and key determining factor for identifying or delineating wetlands (Braddock and Berntsen, 2007). Because, shallow wetlands usually dry up in the summer months (March to May) every year and sometimes it becomes difficult to identify them as wetlands (Reiss, 2006; Tockner and Stanford, 2002). Therefore, wetland hydrology became an extremely important factor in defining wetlands (Gosh, 2005). Hydrology of wetlands also largely controls biogeochemical processes and supports the biological activities of aquatic life in a wetland environment (Mitsch and Gosselink, 2007). Hence, the hydrology of inland wetlands, along with hydro periods and water chemistry, gives birth to a unique wetland soil type, *i.e.*, the hydric soil developed in anaerobic conditions (Gosh, 2005; Mitsch and Gosselink, 2007). This hydric soil is an important indicator for delineating inland wetland boundaries. The synergetic interplay of water regime and biogeochemical reactions creates a unique wetland environment that supports the prevalence of vegetation with typical adaptation power (Mitsch and Gosselink, 2007; Keddy, 2010). These hydrophytes or water-loving plants normally adapt to a wide range of wetland environmental conditions *i.e.*, perennial or seasonality of wetlands which are pronouncedly reflected in their species composition, richness, and diversities (Mitsch and Gosselink, 2007; Keddy, 2010). Inland wetlands also play a key role in accommodating flood water and saving people from huge losses. However, with the progress of time, people have come to know about the various types of indispensable uses of wetlands empirically. Hence, interactions between people and wetlands changed meaningfully and increased over time, particularly in floodplain wetlands which have been discussed in the next section.

1.3 Importance of floodplain wetlands

Floodplain wetlands, a major part of inland wetland systems, provides nutrition and habitat conditions for native and migratory waterbirds (Halls, 1997; Deepa and Ramachandra, 1999; Thompson and Abraham, 2001; Aarif et al., 2014; Mazumdar, 2017; Mukhopadhyay and Mazumdar, 2019). These wetlands are a stock house of native and exotic fishes and finfish (Mondal et al., 2010). These wetlands also upkeep many benthos communities, invertebrates’ reptiles, etc. (Gayen et al., 2020). Floodplain wetlands also host numerous insects and microorganisms which have a significant role in maintaining the food chains of the wetland ecosystem. Various macrophytes grow in this wetland environment supplying habitation, resting, roosting, and nesting opportunities to numerous faunal species (Chapman and Reiss, 1999). These macrophytes also supply food, fodder, and house making articles to wetland people and thereby empower communities economically. Floodplain wetlands have a carbon sequestration potential estimated to be 400 kg C/ha/year over 50 years (Minasny et al., 2017; Sarkar and Borah, 2017). It is also increasingly being used as an eco-tourism site to bolster the country's economy and consequently, amplify its non-economic use value. Therefore, floodplain wetlands have potentials to be the best ecotourism sites if proper environmental care is undertaken. Traditionally, floodplains communities use these wetlands for subsistence agricultural farming, animal husbandry, house and road construction, ritual activities, idol immersion, water sports, and fishing (Balasubramaniam et al., 2007; Bhattacharya et al., 2013; Roy et al., 2018). However, floodplain wetlands are also used for commercial fishing, jute-retting, and live-stock rearing (McCartney and Acreman, 2009). These wetlands provide water for irrigation during the dry season (Russi et al., 2013). Moreover, floodplain wetlands act as prime areas of livelihood generation and habitation for most of the local human populace (Tockner and Stanford, 2002; Bassi et al., 2014; Mohd-Taib and Kamaruddin, 2018; Luo et al., 2019). Therefore, floodplains wetland has had vital socioeconomic and cultural influences on most of the local human populace for centuries (Prasad et al., 2002; Akwetaireho and Getzner, 2010; Bassi et al., 2014; Lamsal et al., 2015). Therefore, floodplain wetlands are rapidly degraded at the human-environment interface due to their unsustainable and greed-based use. Instead of quality degradation and habitat shrinking, floodplain wetlands still contribute considerable earnings to the lives and livelihoods of these floodplain dwellers. Hence, these natural resources are highly indispensable for promoting rural health, welfare, and resilience in backward communities.

1.4 Meaning of wetland ecosystem health

The term 'health' has been borrowed from medical science and added to the wetland ecosystem, leading to the origin of the term WEH. In medical science, physicians diagnose human health through pathological analysis using sophisticated instruments to understand the overall health of humans (Rapport et al., 2001). Since the 70s of the twentieth century, this idea had been employed by a group of researchers in the domain of wetland ecosystems to understand the health of the ecosystem with the help of a set of standard criteria and indicators of wetland ecosystems (Rapport et al., 1985; Rapport, 1989; Jackson et al., 1990; Cairns et al., 1993; Jorgensen et al., 2013). A healthy wetland turns into unhealthy due to unremitting stress from human-induced developmental activities (Rapport et al., 2001). Human-induced pressures include the release of solid wastes and wastewater mixed with contaminants from various sources, overuse and extraction of natural resources, encroachment through the construction of houses and roads, the introduction of exotic species and habitat fragmentation (Rapport et al., 2001). In addition to these, hydrological stress comes from climate change in terms of quantity and quality of water supply and consequently has a pronounced impact on the wetland systems, species survival, and ecosystem integrity (Horwitz et al., 2012). These pressures affect wetland health badly and lead to various signs of pathology such as algal blooms, loss of fish species, fish death, and lesser attendance of migratory avifauna. Indeed, wetland ecosystems are highly sensitive to any kind of changes in the environment (Horwitz et al., 2012). Therefore, healthy wetlands refer to systems having no distress syndrome and that are capable of achieving reasonable and sustainable goals as well as maintaining biological and social organization (Rapport et al., 2001).

1.5 Necessity of assessing wetland ecosystem health

The primary reason for assessing wetland ecosystem health is to understand how human economic activities and their well-being can affect the state of the wetland ecosystem (Cairns et al., 1993). A healthy natural ecosystem becomes unhealthy mainly due to changes in land use, habitat modification, biodiversity loss, and other environmental degradations. Rapport et al. (1985) measured ecosystem responses to stressors following stress physiology. Furthermore, Rapport et al. (1989) again assessed ecosystem health in an unhealthy environment using ecosystem distress syndrome (EDS). After that, Jackson et al. (1990) analyzed ecosystem health using "stress, exposure and response". Then, Cairns et al. (1993) proposed five groups of indicators for assessing the health of ecosystems. Jorgensen et al. (2013) used eight levels of indicators for measuring wetland ecosystem health. Thereafter, Weiguo et al. (2005), Minghao et al. (2009), Jia et al. (2015), Mao et al., (2014), Ren et al. (2014), Lu et al. (2015) Sun et al. (2016) and Yu et al. () Li and Hao (2016), Sun et al. (2017) and Sun et al. (2019) had tried to quantify wetland ecosystem health internationally mainly based on remote sensing (RS) and geographic information system (GIS) based variables.

Moreover, one of the major geo-environmental issues related to the wetlands in is the propagation of pollution (Das et al., 2000; Gayen et al., 2020). Habitat shrinking and encroachment through landfills, over-fishing, uncontrolled siltation, jute retting, weed infestation, and eutrophication due to excessive use of fertilizers and pesticides. These are causing immense pressure and damage to the wetland ecosystem by deteriorating the quality of wetlands' health (Balasubramaniam et al., 2007). Therefore, assessment of WEH is of utmost necessity as water quality and quantity, fish production, and other wetland resources are diminishing at a faster rate.

1.6 Need of the assessment of WEH in Ichhamati floodplains wetland

Although a substantial number of works on the ecosystem health of wetlands have been published internationally, however, there are a few studies carried out in India and only one study was done in Murshidabad District in WB. Moreover, most of the research articles on WEH published internationally or nationally were based on RS and GIS-derived variables (Minghao et al., 2009; Jia et al., 2015; Mao et al., 2014; Ren et al., 2014; Das et al., 2020). Therefore, a proper quantitative assessment of WEH encompassing edaphic, aquatic, biotic, and socioeconomic criteria and indicators (C&I) has not been conducted in West Bengal, particularly in the wetland complex of the Ichhamati floodplain (Datta and Ghosh, 2015; Gayen et al., 2020). Consequently, a comprehensive ecological assessment of wetland health is absolutely essential for understanding the present status of wetland ecological health and formulating a framework of necessary management guidelines for the respective wetlands under consideration. This type of comprehensive quantitative assessment is conspicuously absent in the case of the wetland-complex of the Ichhamati floodplains. All of these factors invoke the need for the present study.

1.7 Objectives of the study

Considering the existing research gaps in the study of changing ecosystem health of wetlands with special reference to Ichhamati floodplains in North 24 Parganas, WB, the following objectives were set by the researcher

i. Understanding the geomorphic and ecological conditions of selected wetlands and surrounding areas within Ichhamati floodplains of North 24 Parganas
ii. Detection of Spatio-temporal transformation of the selected wetlands
iii. Development of a comprehensive environmental health index and associated

framework of indicators with respect to wetlands of Ichhamati floodplains

iv. Evaluation of the status of ecosystem health conditions of selected wetlands based on the developed comprehensive environmental health index

v. Identification of relevant wise uses and necessary management guidelines for ecological sustenance of the selected wetlands

1.8 Research design

The present study aimed to assess and address the changing ecosystem health of selected wetlands in the Ichhamati floodplain. To comprehend this objective, it was necessary to create an appropriate, scientifically justifiable, environmentally robust, and socio-economically relevant general C&I framework that would facilitate the assessment of wetland ecosystem health in a comprehensive way. Therefore, this research methodology was coherently designed to address research objectives appropriately. To meet this need, the research work was designed in five interconnected stages. An appropriate model, relevant methods and techniques, and different approaches were also adopted to achieve these five interconnected stages and have been outlined and described in the following sections. Several focus group discussions and meetings with stakeholders were also conducted. Also, these five stages are discussed in detail in the respective chapters of this thesis.

Stage I: Analysis of the physical attributes of the selected wetlands

A comprehensive inventory of wetlands was made based on information regarding spatial location, morphometry, use pattern, and evolution of these wetlands, primarily hitherto published books, newspapers, reports, governmental and non-governmental reports, journal articles and papers, etc. Several kinds of literature were also reviewed to understand and identify the biophysical attributes of wetlands under study. Environmental attributes such as geomorphology, hydrology, ecology, and anthropogenic uses of each wetland were studied in terms of effective and relevant sub-component under each environmental attribute. Based on the primary field survey, information was collected through focus group discussions (FGD) and interactions with major stakeholders in each wetland. Repetitive field visits were made to the selected seven wetlands of the study region to understand existing physical attributes. Field-level measurements and seasonal verifications were carried out in this regard.

Stage II: Detection of Spatio-temporal transformation of the selected wetlands

Spatio-temporal transformation of selected wetlands was carried out using high-resolution (with 10 m) Sentinel-2A multi-temporal satellite images. Wetlands were divided into wetland perineal zone (WPZ) and wetland influence zone (WIZ). This WIZ around seven selected wetlands would help to understand the nature of human pressure on these precious natural ecosystems (Datta et al., 2021). Two land use and land cover (LULC) maps include the LULC map of 2016 and 2020 (*i.e.*, 2016 as the base year and 2020 as the final year within five years span of this study) and two normalized difference vegetation index (NDVI) maps (NDVI 2016 and 2020) were prepared. Based on the raster maps, the LULC transformation matrix shows class-wise LULC change dynamics of the considered wetlands in the region. FGDs with the local knowledge persons and major stakeholders were also conducted to understand the changes that had taken place in the wetland area and LULC patterns and to validate RS and GIS-based LULC transformation.

Stage III: Monitoring of ecosystem health parameters

A hybrid methodology combined with relevant quantitative and qualitative analysis was adopted for a comprehensive assessment of the effect of each system under the PSR model. A structured questionnaire-based survey of major stakeholders, namely fishers, farmers, livestock rearers, and indirect users of all wetlands was carried out to understand the intensiveness of uses of these natural systems. This would assist in analysing WEH and how existing uses deteriorate the wetland environment. Valuable information on biodiversity loss and ecological character change was measured using relevant ecological indicators that had been collected during interviews with major wetland users, and key resource persons as well as through FGDs. Several well-recognized geo-environmental parameters (comprising soil, water, flora, and fauna-based indicators) were measured in the field and laboratory and fitted within the pressure-state-response (PSR) model.

Stage IV: Development of a comprehensive Wetland Ecosystem Health Index (CWEHI) and zonal mapping

A comprehensive wetland ecosystem health index (CWEHI) was constructed by merging all these C&Is through the Shannon EWM and Techniques of Order of Preferences Similar to Ideal Solution (TOPSIS) method. The relevant spatial distribution pattern of the CWEHI values across the wetlands was mapped under the PSR model. Landscape metrics indicating changing wetland ecological health were also mapped in the GIS environment.

Stage V: Prescribing wetland-specific management guidelines

Broad guidelines for wise uses and management of wetlands for ecological sustenance were formulated. Potential threats to wetland ecosystem health were considered while formulating these guidelines.

1.9 Scope and limitations of the study

The foremost aim of this research work was a comprehensive assessment of the changing ecosystem health of the floodplain wetland ecosystems with the help of an advanced and robust C&I framework. Hence, the primary aim of this research was to develop a comprehensive C&I framework for the assessment of WEH inclusively for inland floodplain wetlands which can be operative anywhere with site-specific modifications. For this, the PSR model was adopted in this study to identify specific drivers which exert pressure on wetland ecosystems; exhibit the current environmental conditions and how much the system is being disrupted and destroyed; want feedback from both the institutional and environmental, community and individual levels. A typical hybrid system has been used in this study by integrating both the "top-down approach" and "bottom-up approach". In this study, while the "top-down approach" (from the point of view of the Organisation for Economic Co-operation and Development (OECD), ecologists, botanists, geographers, and researchers) was used to determine the evaluation criteria, the "bottom-up approach" (from the point of view of primary stakeholders such as fishermen, farmers, livestock rearers and indirect users) was employed to identify site-specific relevant socio-economic and environmental indicators for the development of the C&I framework. Both general to specific (*i.e.,* "top-down approach") and specific to general (*i.e.,* "bottom-up approach") were synthesized for establishing the C&I structure. Indeed, these techniques supported and integrated the views of stakeholders regarding the development of socio-economic and environmental C&I frameworks for WEH assessment. This advanced, scientifically relevant, and robust C&I framework, incorporating edaphic, aquatic, biotic, and socio-economic aspects, will enable the researcher to quantify and map the ecological conditions of floodplain wetlands which is certainly a significant opportunity and scope of this research study. This C&I framework was designed in such a way that it would be understandable among wetland practitioners, researchers, academia, and community resource persons concerned with WEH assessments.

However, this study has some limitations. Firstly, the proposed comprehensive C&I framework is only suitable for the assessment of WEH in the Ichhamati floodplains and, therefore, this framework must be modified accordingly whenever it is applied in other areas. Furthermore, floodplain wetlands in other countries can be assessed using this C&I framework only after a few site-specific adjustments to the basic framework. Also, the results and findings of this framework may not necessarily apply to other floodplain wetlands as only the opinions and suggestions of Indian experts and scientists were sought during the study. Moreover, the key principles of the current C&I framework regarding appropriate wetland management were selected based on experts' and stakeholders' opinions which only reflects their views at the time the research was conducted and may not be consistent in the future.

1.10 Definition of key terms

Wetland: The Ramsar Convention on wetlands delivers a comprehensive definition of wetlands that includes '*all lakes and rivers, underground aquifers, swamps and marshes, wet grasslands, peatlands, oases, estuaries, deltas, and tidal flats, mangroves, coral reefs, and all man-made sites such as fish ponds, paddy fields, reservoirs and salt pans*' (Ramsar Convention on Wetlands, 2015a).

Inland wetland: Ramsar Convention on Wetlands defined inland wetland as "*Inland wetlands mean an area that is inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and that under normal conditions does support, a prevalence of vegetation typically adapted for life in saturated soil conditions"* (Ramsar Convention Secretariat, 2013; Reis et al., 2017).

Floodplain wetland: It includes paddy fields, marshy lands, swamps, river cut-offs as paleochannels, oxbow lakes locally known as *Beel*, *Baor*, *Daha,* and *Jheel* (Pandey et al., 2005; Datta and Ghosh, 2015) and artificial fish ponds (> 0.25 ha area).

Wetland perennial zone (WPZ): It indicates the part of wetlands that have water even during the driest months (March to May).

Wetland influence zone (WIZ): The wetland influence zone extends from the boundary of WPZ to the maximum limit of water spread during the monsoon months. However, this study also considers the area bounded by a 90-meter buffer around the

WIZ as a wetland influence zone.

Ecosystem health (EH): Ecosystem health is derived from two self-explanatory terms-"ecosystem" and "health". An ecosystem is a landscape unit where plants, animals, and other organisms interact with each other and their abiotic environment (*i.e.*, weather and habitat conditions) in a very complex way. Health denotes the absence of signs of illness or absence of symptoms of ecosystem dysfunction (Rapport et al., 2001; Lu et al., 2015). Thus, a wetland should be considered healthy if it does not exhibit water pollution, fish death, algal blooms, etc. Ecosystem health exhibits good "vigor" or productivity, "organization" (diversity of biota and their interactions), and "resilience" of ecosystem.

Wetland ecosystem health (WEH): The concept of "ecosystem health" has been borrowed from medical science, specifically from the term "human health" and has been suffixed with wetland as "wetland ecosystem health" (WEH) (Rapport et al., 2001). WEH is an outcome of interactions between many complex systems and is highly essential for wetland sustainability and human health.

Pressure-State-Response (PSR): The PSR model consists of three systems: pressure, state, and response. The pressure indicates human activities such as population growth, economic activity, use of environmental resources, and emissions of GHGs which stress wetland ecosystems. The state of the wetland ecosystem reflects its environmental condition such as water contamination, algal bloom, the death of fish and other animals, declining attendance of migratory birds, etc. The state exhibits the sufferings of environmental settings or the physical environment through human-induced activities. Finally, the response defines the initiative, role, or effort of an institution, community, and individual to protect the system from further deterioration or degradation and achieve sustainable environmental conditions.

Criteria and indicators (C&I): Criteria and Indicators are sets of measures and conditions which are integrative and holistic, clearly defined, easy to measure and record, and acceptable to all stakeholders. C&I has been used here to monitor the wetland's ecological health and address the amount of degradation already incurred to achieve wetland ecosystem sustainability and human well-being.

Focus group discussions (FGDs): Focus group discussions are often used as a qualitative approach for a deeper understanding of socio-economic, ecological, and environmental issues**.** The technique involves obtaining information on a specific ecological or environmental issue from a particular group of purposefully selected indivi

-duals who have some knowledge regarding that problem.

The entropy weighing method (EWM): It is a frequently used weighing method that assigns weights according to the discriminating power of indicators. The biggest advantage of EWM is to create reliable weights for both qualitative and quantitative indicators and ensure the objectivity of evaluation results by avoiding the interference of human factors in weight determination (Lotfi and Fallahnejad, 2010; Zhu et al., 2020).

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS): TOPSIS is a multi-criteria decision-making (MCDM) method. It is based on the principle that the preferred alternative has the least geometric distance from the positive ideal solution and the most from the negative ideal solution.

Positive Ideal Solution (PIS): The positive ideal solution maximizes the benefit criteria and minimizes the cost criteria.

Negative Ideal Solution (NIS): The negative ideal solution maximizes the cost criteria and minimizes the benefit criteria.

1.11 Outline of the study

This doctoral thesis was sub-divided into seven interconnected but distinct chapters, explaining the research problems, development of C&I framework for assessing WEH addressing wetland-specific problems, and their management guidelines.

The *first chapter* contains the scientific background and theoretical connections of the study. It also deals with some definitions, terminologies, scope, and objectives of the research, the present-day relevance of the study, and identified research gaps.

The *second chapter* deals with the detailed surveys of literature relating to various sub-components of this study. Review works include the study area, various aspects of wetlands, wetland ecosystem health, the PSR model, Shannon entropy, and the TOPSIS method at national and international levels.

The *third chapter* describes the geographical location, bio-physical settings, physical environment, human environment, anthropogenic use patterns, and potential threats to the floodplain wetlands.

The *fourth chapter* elaborates upon the Spatio-temporal changes of wetlands and their LULCs, the criteria of wetlands selection adopted in this study for identifying representative wetlands, identification of major actors of wetland degradation and conversions, development of criteria and indicators (C&Is) and assessment of wetland ecosystem health assisted by Shannon's entropy weighing method and TOPSIS method.

The *fifth chapter* represents the Spatio-temporal change of wetland landscapes in human-dominated floodplains with the help of geospatial analysis.

The *sixth chapter* interprets the amount of WEH with the help of the PSR model using entropy-weighing-assisted TOPSIS. Both qualitative and quantitative data were retrieved using focus group discussions, stakeholders' surveys, and key informants' interactions. It also contains a detailed discussion on the temporal status of pressure system health, state system health, and response system health of wetlands from 2016 to 2020.

The *seventh chapter* contains wetland-specific recommendations that may improve WEH through community interactions, especially stakeholders' awareness, and protect these wetlands so that they become ecologically sustainable. The CWEHI value of each wetland along with FGDs had assisted in formulating wetland-specific management guidelines and restoration policies.

Photograph 1.1 Floral diversity and weed infested Ichhamati river

Chapter 2: Review of Literature

2.1 Understanding the ecological health of freshwater wetlands

Freshwater ecosystems, especially floodplain wetlands, were highly disturbed and modified by human interventions during the Anthropocene around the world (Kopf et al., 2015; Dubois et al., 2018; Reid et al., 2019). Hence, the ecological health of freshwater wetlands was under severe threat due to various socio-economic and developmental activities (Ite et al., 2013; Mishra et al., 2021). The lower Gangetic floodplain of WBabounded with freshwater wetlands of different kinds. Due to its rich common resource pool and dependency on local communities, pollution, degradation, and unabated conversions into croplands, aquafarms, and built-ups increased its ecological vulnerability (Datta and Ghosh, 2015). Therefore, a C&I framework was developed under the PSR model to understand the current situations of WEH of these selected wetlands. Assessment of WEH was found to be important because it facilitated scientists, academicians, and planners for site-specific implementation of management and restoration policies. In this context, several published pieces of research on inland wetlands, oxbow lakes, and anthropogenic impacts on such wetlands were reviewed to understand the current international and national situation. Furthermore, national and international contemporary research works on wetland pressure, state, response, and subsequent WEH were also reviewed. Both offline (journal articles, thesis, books, edited book chapters and reports) and online sources Google Scholar, Web of Science, and Scopus database) were used for this review (Fig. 2.1). These components-wise review of literature was performed for better understanding of various aspects related with this study.

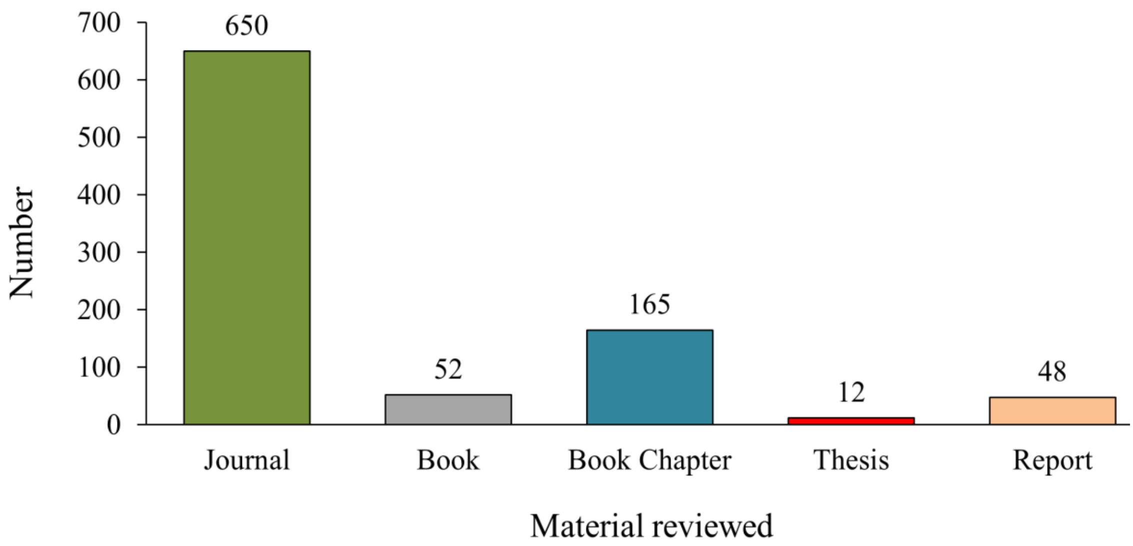

Fig. 2.1 Materials reviewed for content analysis

2.2 Inland wetlands, types, and distribution: Global and Indian perspective

Wetlands serve multiple functions in terms of hydrological processes, biological trait environmental relevance, and economic impact (Panigrahi *et al.,* 2012). On a broader aspect, wetlands were divided primarily into two types: 1. Inland wetlands and 2. coastal wetlands. Thereafter, Inland wetlands were classified into 1. Natural wetlands and 2. Man-made wetlands (Anon, 1994). Natural inland wetlands included lakes/ponds, oxbow lakes/cut-off meanders, seasonally waterlogged, playas, and swamps/marshes (Anon, 1994). Man-made inland wetlands covered reservoirs, tanks, waterlogged, abandoned quarries, and ash ponds/cooling ponds (Anon, 1994). Indeed, there was no specific definition of an inland wetland by the Ramsar Convention Secretariat. However, some organizations and non-governmental organizations have tried to define inland wetlands on their own. For example, the Connecticut Department of Energy and Environmental Protection (2011) attempted to classify inland wetlands as poorly drained, very poorly drained, alluvial, and floodplain based on soil type. Inland wetlands cover floodplains, oxbow lakes, reservoirs, and paddy fields in tropical areas and become natural habitats for water birds, benthos communities, fish stocks, and various types of aquatic weeds. Since inland wetlands were associated with rivers/streams and floodplains, they become soft targets for humans for their wide range of goods and services. 92.8% of the global continental wetland area was inland wetlands (Davidson et al., 2018). Asia had the largest wetland area in the world (31.8%), followed by North America (27.1%), Latin America, and the Caribbean (Neotropics; 15.8%), with smaller areas in Europe (12.5%), Africa (9.9%) and Oceania (2.9%) (Davidson et al., 2018).

The area under wetlands in India varies from 1% to 5% of the country's total geographical area (Space Applications Centre, 2011). According to the Directory of Asian Wetlands (Woistencroft et al., 1989) and the Directory of Indian Wetlands 1993, wetlands in India covered 58.3 m ha, out of which 71% was occupied by paddy fields only. Later, the Ministry of Environment and Forests (1990) stated that wetlands occupied an area of about 4.1 m ha of the total geographical area of India. The latest area of wetlands in India was estimated by the Space Applications Centre (SAC), Ahmedabad to be 7.6 m ha (Garg et al., 1998). However, this estimation did not take into consideration paddy fields, rivers, canals, and irrigation channels.

2.3 Ecological condition of floodplain wetlands and possible threats

Since the Stockholm Conference on Human Environment (1972), ecologists had paid close attention to the study of the response of natural ecosystems which were disturbed by escalating anthropogenic activities. Hence, human activity was considered to be a major factor in global environmental change which largely impacted the earth system (Vitousek et al., 1997). Human activities, well reflected in the land use mosaic and its changes, especially the expansion of croplands and settlement, led to considerable losses of wetlands and biodiversity (Foley et al., 2005). Loss of biodiversity was an inevitable consequence of loss of natural habitat and might reduce ecosystem services by reducing ecosystem vigor through inadequate pollination (Tscharntke et al., 2005). Furthermore, other forms of floodplain wetland degradation included loss of area, siltation and wetland swallowing, serious impediment to function, destruction of the tropic structure, change in water quality, etc. which had serious consequences on the wetland ecology, regional economy, and wetland environment, thereby affecting the wetlands' health and human well-being (Costanza, 2012; Cui et al., 2001; Liu et al., 2004). From several global scientific investigations, it was found that wetland degradation was primarily caused by agricultural activities which resulted in shrinking and fragmentation of faunal habitats (Dong et al., 2015). So, habitat fragmentation and destruction led to a loss of ecosystem services and species extinction (Tillman et al., 2001; Dong et al., 2015). Prasad et al. (2002) opined that man's interaction with wetlands during the last few decades had been of grave concern largely due to the rapid population growth accompanied by intensified industrial, commercial, agricultural, and residential development. These further led to the pollution of wetlands by point sources like domestic and industrial sewage as well as non-point sources agricultural runoffs such as fertilizers and insecticides. Floodplain wetlands are highly susceptible to changes in the quantity and quality of their water supply (Erwin, 2009). It was a fact that climate change had a pronounced impact on wetlands through greater variability in hydrological regimes. Hulme (2005) and Erwin (2009) proposed that climate change was a major threat to species survival and ecosystems' integrity worldwide. Ferrati et al. (2005) stated that pressures on wetlands were likely to be conciliated due to hydrological character change and direct and indirect effects of changes in temperatures and land use change. Das et al. (2000) opined that climate change influenced biological, biogeochemical, and hydrological functions in wetland ecosystems. therefore, climate change, land use change, biodiversity loss, and many other environmental issues had the tremendous effect of human activity which could convert a healthy ecosystem into an unhealthy one (Moss et al., 2010; Foley et al., 2005).

2.4 Evaluation criteria under the PSR system: International and national scenario

Rapport (1989), Rapport et al. (2001), and were Lu et al. (2015) were reviewed for understanding concept of ecosystem health regarding definition, constituents, stressors, contaminants and measures. The development of the C&I framework under the PSR evaluation system required the selection and organization of assessment indicators systematically. Therefore, before the development of the C&I framework, knowledge of various developments in the PSR system was essential for construction of a robust PSR-based evaluation system. For that knowledge, studies of Weiguo et al. (2005), Wang et al. (2011), Jia et al. (2015), Mao et al. (2014), Ren et al. (2014), Sun et al. (2016), Sun et al. (2017), Sun et al. (2019), Sun et al. (2019), Das et al. (2020), and Wang et al. (2021) were thoroughly reviewed for the conception and development of PSR model-based ecosystem health assessment. Only one study was found to be done regarding assessment of WEH using PSR model in Murshidabad District of WB state. Horwitz and Finlayson (2011), Cui et al. (2012), and Lu and Li (2003) were consulted for the development various evaluation criteria and indicators along with Weiguo et al. (2005), Wang et al. (2011), Jia et al. (2015), Mao et al. (2014), Ren et al. (2014), Sun et al. (2016), Sun et al. (2017), Sun et al. (2019), Sun et al. (2019), Das et al. (2020), and Wang et al. (2021). Thereafter, various works indicating degradation of various ecological systems were reviewed mainly under the major nine evaluation criteria as following.

2.4.1 Catchment characteristics of wetlands

Wetlands in the upper course of river Ichhamati was a part of *the Bhagirathi–Hugli – Ichhamati–Jamuna Basin* (Bandyopadhyay et al., 2014). Due to the low regional slope coupled with the degenerated drainage network, several paleochannels and rivulets with vast catchments had been created one of the largest oxbow lake complexes in this region (Gayen et al., 2020). These oxbow lakes were connected with surrounding agricultural land areas and the master stream by narrow waterways, and in some places directly but most of it is surrounded by dykes of dust/mud. Intensive farming activities, habitation, and construction works were observed in the wetland influence zone including the buffer zone. Hence, analysis of LULC changes in wetland influence zone (WIZ) was necessary to understand human-induced stresses on wetland ecosystems. LULC change and the resulting ecological effects were studied by Seto et al. (2002) and Long et al. (2009) respectively. The impact of human-induced activities on land use was studied by Fu et al. (2018) and the effect of surrounding land-use change on the wetland landscape pattern was measured by Xie et al. (2012). The effects of land-use changes on ecosystem services value were also assessed by Camacho et al. (2016). Fragmentation of perennial wetland zone hinders many normal processes of wetlands and thereby put immense pressure on wetland ecological health. These studies had shown how catchment characteristics were influenced by LULC changes. Per capita arable land area indicated a level of fragmentation of WIZ. Ding and Peng (2018) conducted a study on the impact of human activities on ecological footprint taking arable land as one of the main drivers. Various indices of landscape ecology *viz*. patch density (PD), largest patch index (LPI), and Shannon's diversity index (SHDI) were used by Xie et al. (2012), Jia et al. (2014, Liu and Hao (2016), Sun et al. (2016) to understand the ecological effect of LULC and its various metrics on landscape pattern and state system of studied wetlands. Jia et al. (2015) had calculated the patch density (PD) and the largest patch index (LPI) from patch levels and the Shannon diversity index (SHDI) from the landscape levels to assess the health of wetland ecosystems in the Heilongjiang River basin, China. The contagion index of landscape level was studied by Tian et al. (2019) to understand the landscape grain effect in Yancheng coastal wetlands and its response to landscape changes. Xiang (1996) conducted a GIS-based riparian buffer analysis. Various minimum widths of buffer zones for the Minnehaha Creek Watershed District (MCWD) were recommended which was also reviewed for delineation of buffer zone and its ecological impact on wetlands (Emmons and Oliver Resources, 2001). However, they had emphasized the width of the buffer which varies according to ecological function. Schepker et al. (2020) had defined a wetland buffer ≥ 50 m as a vegetative buffer. Haukos et al. (2016) and Johnson (2011) have proposed a minimum 50 m vegetative buffer width maximize contaminant removal from runoff entering playa watersheds. However, Berhane et al. (2020) used a 90 m buffer around wetlands to understand the extent and magnitude of LULC change within the buffer area. The negative impact of water richness and ecosystem services on wetland fragmentation was also studied by Kundu et al. (2021 & 2022). Das et al. (2020) used a few remote sensing-based landscape metrics to understand wetland catchment characteristics in Murshidabad District, West Bengal, India.

2.4.2 Wetland eco-hydrological parameters

Wetlands had complex hydrological and biogeochemical systems that promote biota to perform their physiological activities (Mitsch and Gosselink, 2007). Besides the ecological importance of wetland water, the availability of good quality water directly affects all life forms and various water users (Walmsley, 2002). Hence, wetland hydrology, in terms of hydroperiod, frequencies of inundation, and hydro-regime, plays a crucial role in maintaining its biogeochemical processes and physical entity (Villa and Bernal, 2018). Wetland water is generally pollution-free in its pristine state. However, it contaminated regularly by pollutants from wastewater coming from domestic and industrial sources and through run-off from surrounding agricultural fields. Wetlands are sinks in the landscape and receive almost all forms of waste, debris, and wastewater (Mitsch and Gosselink, 2007). Random use of chemical fertilizers, pesticides, and insecticides in adjacent agricultural fields were crucial in causing substantial damage to water quality as found in studies worldwide (Ongley, 1996). However, wastewater from domestic sources, markets, hospitals, and industries also deteriorated wetland water quality to a large extent (Hasan et al., 2019). As a result, aquatic life faced tremendous pressure from nutrient loads coming into these wetlands from agricultural washouts mixed with pesticides and insecticides.

Cui et al. (2012) studied impact of geochemical indicators of soil in Zoige wetland, south-west China regarding ecosystem health assessment. Li et al. (2022) measured air /underwater light quantum and air/water temperature and five hydro-chemical indices such as total phosphorus (TP), total nitrogen (TN), permanganate index (COD), Chlorophyl a, (Chla), and transparency (SD) were also measured for three Gorges Reservoir, China. Mao et al. (2014) measured COD, BOD, pH, and poisonous chemicals for water quality classification eutrophication level for health assessment of Ulansuhai lake in China. They also calculated trophic level index by Chla, TP, TN, SD, and CODMn for understanding level of eutrophication. Troyer et al. (2016) analyzed pH, temperature, electrical conductivity (EC), TDS, DO, turbidity, chlorophyll a, and total suspended solids (TSS) in streams and wetlands of a fast-growing east African City. U.S. EPA (2002) revealed that the enrichment of nutrients destroys ecological integrity. Cao et al. (2007) reported that increased sediment concentration and severe water pollution put immense pressure on aquatic vascular plants in a constructed wetland in the Yongding River system, China.

In India, Jhingran et al. (1969) established the correlation between water's physicochemical quality and the aquatic body's biological production. Gogoi et al. (2015) measured DO, biological oxygen demand (BOD), FCO_2, alkalinity, total hardness, calcium hardness, chloride, pH, and water temperature to understand the seasonal variation of water quality in three different floodplain wetlands of the Subansiri river basin in Assam. Bhat and Pandit (2014) had determined depth, transparency, temperature, pH, conductivity, orthophosphoric, total phosphorus, ammoniacal nitrogen, nitrite nitrogen, nitrate nitrogen, organic nitrogen, alkalinity, free CO_2, conductivity, chloride, total hardness, calcium hardness, magnesium hardness, Na, K, silicate, sulphate, iron, and total dissolved solids (TDS) for understanding stress caused by these parameters on Wular lake, a Ramsar site in Kashmir. They observed potential impact of anthropogenic activities on spatiotemporal water quality variations. Behera et al. (2012) reported that the agricultural expansion reduced wetland buffer. That resulted in eutrophication and facilitated weed growth due to excessive use of fertilizers in nearby agricultural fields in Samaspur wetlands, Uttar Pradesh. Goswami and Kalita (2012) reported that Deepor *beel*, the Ramsar site in Assam, had been deteriorated by wastewater from nearby towns and cities which caused damage to the aquatic life of this internationally important wetland.

Mondal et al. (2010) analyzed the water quality of two baors *i.e.,* Gopalnagar Baor and Duma Baor. They evaluated the depth of water, dissolved oxygen (DO), free carbon dioxide, pH, total alkalinity, hardness, salinity, conductivity, transparency, and surface water temperature using standard methods and measurements towards fish production. Biswas et al. (2005) measured temperature, DO, and BOD in Ramnagar beel of WB and observed a high BOD value in the water of Ramnagar beel in WB due to agricultural washout mixed with pesticides and insecticides which increased the nutrient load in this wetland and thereby destroyed the trophic structure. Bala and Mukherjee (2010) measured the water quality index of a few wetlands in the Nadia district to assess the water quality of selected wetlands towards its portability of various uses. Bhattacharya et al. (2014) evaluated the effects of idol immersion on the water quality parameters of Indian water bodies. Sugunan et al. (2000) measured 14 physicochemical parameters of water in the selected *Beels* of West Bengal consisting of water temperature, Sechi disk depth, DO, free carbon dioxide (FCO_2), pH, total alkalinity, total hardness, Specific Conductivity, Nitrate-N, Phosphate-P, Silicate, Chloride, Calcium, Magnesium, etc. for understanding water quality.

2.4.3 Physico-chemical properties of wetland soil

Wetland soil is the most important abiotic element that indicates the ecological health of wetlands (Tiwari and Ranga, 2006; Keddy, 2010). Wetlands have typical soils such as hydric soils which develop in a hypoxic and anoxic environment of the wetland (Keddy, 2010). These typical hydric soils are therefore considered as a defining characteristic of wetlands (Ghosh, 2005; Keddy, 2010). The low rate of oxygen diffusion in water mainly gives birth to hydric soils. Reduced soils of wetlands indicated a large amount of organic matter and these reduced elements are chemically transformed instead of leaching (Keddy, 2010). There are three distinct zones in wetland soils: water column with dissolved oxygen, reduced soils layer, and oxidized soils layer (Mitsch and Gosselink, 2007; Keddy, 2010). The following mentioned studies had tried to understand wetland soil condition in terms of physico-chemical properties.

Mao et al. (2014) studied the organic matter component of soil as an indicator for health assessment of Ulansuhai lake in China. Sun et al. (2021) analyzed contents of As, Cd, Cu, Cr, Hg, Pb, and Zn in three land use types in a typical karst plateau lakeshore wetland of south-west China. Johnston (1991), in review article, addressed how the retention of sediment and nutrient affect the surface water quality of wetlands. Bai et al. (2016) had studied heavy metal pollution and source identification in sediment cores from the short-term flooding of riparian wetlands in a Chinese delta on both spatial and temporal scales. Rokosch et al. (2009) stated that the various soil parameters such as microbial biomass, soil C, N, and S, bulk density, and, more importantly, soil moisture could be used as indicators of quality in six forested depressional wetlands in Central Ohio (USA). Gregoire et al. (2009), in a review article, proposed the mitigation of agricultural nonpoint source pesticide pollution in an artificial wetland ecosystem. Lestariningsih and Hairiah (2013) assessed soil compaction with two different soil bulk density measurement methods in oil palm plantation soil in Indonesia. All of the above studies had been highlighted how various physical and chemical parameters of soil put pressure on wetland systems and their subsequent consequences on the physical and ecological state of wetlands.

The state of oxidation level in a wetland directly controls the chemical characteristics of carbon, nitrogen, phosphorus, sulphur and iron, and other elements (Keddy, 2010). Sankaranarayanan and Panampunnayil (1979) had studied organic carbon, nitrogen, and phosphorus in sediments of the Cochin backwater. Mathews and Chandramohankumar (2003) conducted research on the ratios of carbon, nitrogen, and phosphorus in a coastal wetland ecosystem of southern India. Gireeshkumar et al. (2013) have analyzed phosphorus dynamics and its bioavailability along the surface sediments of the Cochin estuary. Rao (2007) indicated the importance of soil health and how soil health is intrinsically related to microbial diversity and ecological sustainability. He also stated that above 90% of the planet's genetic biodiversity rested in soils. Perry et al. (2004) studied competitive control of invasive plants and how a native wetland sedge suppresses *Phalaris arundinacea* in carbon-enriched soil of wetlands. Benny (2009) had stated a benchmark for Sulphur akin to the Cochin Estuarine System. Kumar (2005) and Kumar et al. (2020) had been described limiting factors influencing fish kills at Rewalasar Lake in Western Himalayas. Dash et al. (2020) applied a positive matrix factorization receptor model and elemental analysis to assess sediment contamination and their source apportionment of Deepor Beel, Assam, India. Therefore, various physico-chemical parameters of wetland soils used in the above studies indicated sharply that how wetland soils had been deteriorated by human-induced socioeconomic activities.

2.4.4 Wetland biota: floral characteristics

Wetland biota constitutes a biotic component of the wetland ecosystem. Wetland biota indicates flora and fauna that sustain in a typical wetland environment. Many plants grown in wetland environments are generally invasive or exotic plants, such as alligator species, water hyacinth species, and water Lilly. Few wetland plants are native but most hydrophytes are invasive. These invasive plants expand their colonies rapidly and ensure their stake in the habitat of native plant communities. Zedler and Kercher (2004) conducted an intensive study on the causes and consequences of invasive plants in wetlands. They proposed that wetlands are especially vulnerable to invasive plants. Pejchar and Mooney (2009), Kueffer (2017), Jones and McDermott (2018), and Bartz and Kowarik (2019) also studied the impact of invasive alien plants species (IAPS) on the local biodiversity, ecosystem services, and environmental quality of wetlands. They also observed that IAPS had serious threats to wetland ecosystem services. Pyšek and Richardson (2010), and Stone et al. (2018) identified the impact of IAPS on human health. Wetlands of Ichhamati floodplains are severely threatened by weed infestation, particularly *Eichhornia crassipes* and *Ceratophyllum demersum* and by other various species. The vegetation cover was analyzed surrounding the restored wetland using the normalized difference infrared index (NDII) and normalized difference vegetation index (NDVI) by Wilson and Norman (2018). Floodplain's wetland supports diverse plant communities in its catchment. The diversity and richness of these plant communities reflect the habitat condition of the wetland. Flinn et al. (2008) quantified plant species diversity and composition of wetlands. Pretorius et al. (2016) measured the species richness of the various plant communities within the selected wetlands on the Maputaland Coastal Plain, South Africa. Tree density around wetlands exhibits wetland health and habitat quality. Rayamajhi et al. (2009) established that a decline in exotic tree density facilitates increased plant diversity in south Florida (USA). The health of wetlands ca be assessed using the biological status of trees. Kim et al. (2018) simulated two common wetlands in Texas using the biomass of tree species. Nutrients were accumulated in wetland sink through wastewater and surface run-off from surrounding agricultural fields for a long time. Especially nitrate and phosphorus were massively silted on the wetland bed resulting in the alteration of wetland ecosystem function and eutrophication. Sánchez-Carrillo et al. (2014) inferred that nutrient loading in the wetland is linked with hydrological alterations which affected vegetation patterns and nutrient recycling. They also proposed that the eutrophication processes accelerated primary productivity and increased the net accumulation of organic matter and nutrients in wetland landscapes. They also proposed that eutrophicated wetlands favoured enhanced organic matter decomposition, microbial activity, and soluble nutrients in sediments of wetlands.

Ansari et al. (2010) stated that eutrophication led excessive growth of algae and other submerged and floating aquatic weeds became a global problem associated with fish death, algal bloom, and decreasing ecosystem services in freshwater wetland ecosystems. Jha et al. (2016) studied growth of invasive floristic species in canals and ponds in and around the Kolkata metropolitan city.

Various wetland weeds and other exotic species noticeably consumed the surface of lake waters which had a serious issue for local farmers, fishers as well as environmental planners. Das and Nandi (2004) pointed out the harmful consequences of these weeds in the oxbow lake environment of the Ichhamati river. Majumder and Bhunia (2022) studied vegetation vigour of Ichhamati floodplains. Gayen et al. (2020) reported the presence of widespread availability of *Lemnoideae* varieties of vegetation in the wetlands of Ichhamati floodplains. Saha et al. (2022) estimated vegetation cover in riparian zone of river Ichhamati and in Sashadanga oxbow lake of Ichhamati floodplains.

2.4.5 Wetland biota: faunal characteristics

Invertebrates, both macro and micro types, play a key role in many functions of the freshwater wetlands (Hart et al., 1990). Importantly, macroinvertebrates are greatly affected by a wetland environment's physical, chemical, and biological stressors (Mbaka and Wanjiru, 2015). Hence, macroinvertebrates were considered as indicator variables to characterize wetland habitat quality, water quality, and WEH (Fulazzaky, 2010). Vertebrates of freshwater wetlands comprised heterogenous groups, including mammals, waterbirds, reptiles, amphibians, fishes (Finlayson et al., 2005). Vertebrates are very sensitive to any sort of changes incurred in the physical and chemical properties of the wetland environment (Mbaka and Wanjiru, 2015; Finlayson et al., 2005). Therefore, vertebrates were also considered as indicator variables for understanding the WEH of freshwater wetlands. Interactions and interdependencies of various species of vertebrates and invertebrates created a complex food web and food chain in a wetland environment (McMeans et at., 2015). There is a huge number of insect fauna that lived in wetland environment, few of them were native, and most of them were exotic in origin. All insect fauna were not always harmful such as the diving beetle which acted as a predator and ate mosquitos in wetlands (Russel, 1999). Mosquitoes are harmful from a human perspective; however, it was beneficial from an ecological perspective as it maintained ecological balance by playing the role of prey (Hilgenkamp, 2005; Sharma et al., 2014). Besides ecological and economic roles, insects were treated as good food for carnivorous waterfowl. Batzer and Wissinger (1996) reviewed and synthesized a work on the ecology of insect communities in nontidal wetlands. They proposed to manage wetland insects' stock for waterfowl food and provided remedies to control pest mosquitos. Vinnersten et al. (2009) also studied the predatory insect fauna diving beetle in flooded wetlands. They inferred that this predatory insect was useful in controlling pest mosquitos in a wetland environment. However, few harmful insects had a negative role on WEH.

Nath and Deca (2012) studied fish diversity, conservation status and anthropogenic stress on Chandubi tectonic lake, Assam. Das (2018) studied fish diversity and the conservation status of a wetland of Cooch Behar District, West Bengal, India. Goswami and Goswami (2020) studied Ichthyo faunal diversity and catch statistics of Jamlai wetland in Kamrup District of Assam, India. Aarif et al. (2017) analyzed how traditional fishing activities enhanced the abundance of selected waterbird species in the Kadalundi-Vallikkunnu community reserve forest, Kerala. Tak et al. (2010) observed waterbird diversity and relative abundance at Hathnikund Barrage wetland, Haryana, India. Faunal diversity of *Cladocera* as an indicator species was studied by Sharma and

Sharma (2014) in the largest river island Majuli, Assam, north-east India.

In this study, two vertebrates, i.e., fish and avifauna were considered as these two categories reflect the habitat quality of freshwater wetlands at a point in time. The introduction of exotic fish by fishing communities declined native fish biodiversity in wetland ecosystems. Singh and Lakra (2011) reported that 300 alien species were imported internationally or illegally out of which 291 ornamental species, 31 aquaculture species, and 2 larvicidal fishes which negatively affected native species sustainability. Bhakta and Bandyopadhyay (2007) measured exotic fish diversity in the Churni River of West Bengal, India. Besides, these exotic species efficiently consumed wetland algae and other pollutants thereby stabilized the wetland ecosystem condition. Mondal et al. (2010) studied the relationship between water quality parameters and fish diversity indices as measures of ecological degradation in two wetlands of Gopalnagar and Duma. Mukhopadhyay and Mazumder (2019) comprehended composition, diversity and foraging guild of avifauna in a suburban area of southern west Bengal. Again, Mukhopadhyay and Mazumder (2019) analysed habitat-wise composition and foraging guilds of avian community in a suburban landscape of lower Gangetic plains. Gayen et al. (2020) adopted six widely used ecological indicators of avifauna distribution, species composition, and abundance to understand the avifauna habitability of wetland.

2.4.6 Pressure from human livelihood activities

Interactions between communities and wetlands enhanced many times over the last few decades and became a matter of concern to scientists, academicians, planners, and decision-makers worldwide in global ecosystem assessments (Horwitz et al., 2011). More scientific and meaningful relationships between human activities and wetland settings were of utmost necessity today for the cohesiveness of ecological sustenance of wetlands and human well-being in a row (Ghimire and Pimbert, 2013). Wetlands continued to be declined as people produce more food and energy, and also owing to extract more water from wetlands (Gardner et al., 2015). Hence, human-induced socioeconomic and developmental activities put unbearable pressures on wetland settings that needed to be controlled on immediate basis, otherwise, an incommensurable loss would be destiny (Wickramasinghe, 2021). Because people built their homes and roads inside the catchment of wetlands, human disturbances have grown significantly (Bhattachaiyya and Bora, 1997). People took baths in wetlands, washed their utensils and clothes, and even they did their cattle baths in wetlands also. Inhabitants of WIZ openly defecated in wetlands and even constructed their lavatory within WIZ without having any septic tank which resulted in pathogenic contamination of wetland water by human faces (Sabur and Molla, 2016). Farmers polluted wetland water and added huge toxins each year during monsoon months by jute retting as it was a major source of their income (Ghosh and Biswas, 2015; Ghosh and Biswas, 2018). Also, pesticides, chemical fertilizers, and insecticides used in the agricultural field finally come into wetlands and cause wetland eutrophication and cultural pollution of wetland water (Datta and Ghosh, 2015; Ansari et al., 2010). Therefore, Major threats came from wastewater and agricultural washouts which also threaten these wetlands (Wang et al., 2018).

2.4.7 State of ecosystem products and services derived from the wetlands

On a global scale, area and wetland water quality are declining substantially. Therefore, the number of ecosystem services that wetlands provide was also reduced in numbers and amount significantly (Gardner et al., 2015). Millennium Ecosystem Assessment, a four-year international endeavour (2001-2005), had improved the understanding between ecosystem change and human well-being. MEA had also thrown light on the possible consequences of changes in the ecosystem by human interference. MEA had focused on how such changes in the ecosystem could affect human well-being in the present and near future (MEA, 2005). Bassi et al. (2014) worked on the status of wetlands in India. They had analyzed the extent, ecosystem benefits, threats, and management strategies of wetlands. Datta and Ghosh (2015) had evaluated the sustainability of community endeavours in an Indian floodplain of river Ichhamati using multi-criteria decision analysis. The paper addressed the degrading status of the wetland at present regarding biodiversity conservation and livelihood generation. Fishing activities were also found to be as dominant utilization option, followed by agriculture. All these indicated the present status of ecosystem products and services of wetlands under immense human pressure. Such increased human pressure on wetland ecosystems could also be well understood through ecological and epidemiological responses of wetlands as follows.

2.4.8 Ecological and epidemiological response

Response systems within a wetland ecosystem described as proactive measures, techniques of restoration policy for reducing pressure and improving ecological conditions. When a wetland system came under immense pressure it demands responses.

Few responses were intrinsic and few were extrinsic. Change of vegetation cover was an important indicator of ecological response as it directly affected the faunal community. Hence, measures were found to be taken at the community level and institutional level to replace it with social forestry program and tree plantation. These measures provide habitation and nesting ground to many migratory birds. King et al. (2005) studied how a stream ecosystem was affected by a change in surrounding land cover. Tsegaye et al. (2006) had shown that the chemical influx of streams was an inevitable consequence due to LULC of its kind. Li et al. (2014) inferred that spatial resilience could be achieved with increasing vegetation cover along with other indicators. Zimmerman (1990), Guarino et al. (2002), and Blakey (2017) proposed that vegetation patches in and around wetlands were essential for the food and habitation of native as well as migratory birds. Sarkar and Borah (2018) and Khatun et al. (2021) inferred that the loss of wetland area and decreasing water cover were an important indicators of the eco-hydrological deficit of floodplain wetlands during global warming. Wetland ecological functions and wetland vigor were largely dependent upon water cover and volume. Declining accommodation capacity is caused by increased flood events that finally results in areal loss and wetlands shallowing. Soil erosion is another response indicator. Soil erosion has serious consequences on plant richness, biodiversity, crop productivity, and hydrological functions (Wolka et al., 2015: Ford et al., 2016). Incidences of fish extinction were associated with the effects of pesticides applied in wetland agriculture, reducing the quantity of wetland water and wetland areal loss, and unhealthy competition of native species with exotic ones (Prasad et al., 2002; Baber et al., 2002; Kingsford et al., 2016; Colvin et al., 2019). Deane et al. (2017) pointed out that wetlands shrinking caused a higher rate of extinction. Humans were more susceptible when exposed to various infectious water-borne diseases during their baths in wetlands and resource extraction (Derne et al., 2015). Dale and Knight (2008) stated that wetlands deliver habitat to mosquitos for their eggs and larvae and thereby helping mosquitoes to transmit diseases. Therefore, all these indicators were actually considered as response indicators for understanding WEH in a degraded wetlands.

2.4.9 Economic, socio-cultural, and management response

Economic importance of wetlands could be understood through status of fishers. However, fishers used to take part in out-migration mainly due to the decline of fish production in the wetland (Nayak and Berkes, 2010; Nayak, 2017). The level of satisfaction of the local community regarding the livelihood-generating potential of the wetland depends upon the ability of wetlands to generate income was studied by Lamsal et al., 2015. Furthermore, traditional rituals/activities or traits had decreased substantially due to continued pollution and wetland loss (Bassi et al., 2014; Alam et al., 2017).

Such reduction of ‘non-economic use’ values mainly happened due to a lack of environmental awareness among people resided in the vicinity of these wetlands. Wetland conservation and sustainable initiatives were also important response indicators for understanding existing conservation initiatives of any wetland (Dizdaroglu, 2015). Research activities on any wetland indicated its environmental as well as economic potentials which were ultimately demanded by wetlands under immense stress (Jia et al., 2015). Therefore, many management initiatives could be initiated to restore a stressed wetland through plantation programs, weed removal programs, and organic farming (Zhao et al., 2016; Rohal et al., 2018). In addition to this, wastewater treatment and soil erosion management initiatives could be applied to improve wetland environmental conditions and ecological health while natural capacity to purify water did not work for wetlands.

2.5 Wetland ecological health

An assessment of wetland ecological health was extremely necessary for understanding the present condition of any type of wetland in a human-dominated landscape. Rapport et al. (1985) first measured ecosystem response to stress following stress physiology. Again, Rapport et al. (1989) used ecosystem distress syndrome (EDS) to an ecosystem in an unhealthy condition. "Stress, Exposure and response" was used by Jackson et al. (1990). Thereafter, several sets of indicators were developed by scientists, researchers, and academia to measure the health of wetland ecosystems, most of them being RS and GIS-based indicators (Jia et al., 2014; Das et al., 2020). Furthermore, systematic approaches, mostly from environmental sciences, were also made to develop an indicators system that was also used to measure wetland ecological health (Rapport et al., 1989; Jorgensen et al., 2005). For example, Cairns et al. (1993) proposed a group of five indicators for evaluation processes, whereas, Jorgensen et al. (2010) classified indicators into eight levels, from the most reductionist to the most holistic. Studies of Wang et al. (2011), Jia et al. (2015), Mao et al. (2014), Ren et al. (2014), Sun et al. (2016), Sun et al. (2017), Sun et al. (2019), Sun et al. (2019), Das et al. (2020), and Wang et al. (2021) were also consulted to measure the PSR-based WEH.

Chapter 3: Freshwater Wetlands of Ichhamati Floodplains

3.1 Floodplain wetlands of south-eastern West Bengal

Ganges delta is traversed by many important rivers like the Bhagirathi, Brahmaputra, and the Meghna across India and Bangladesh. However, the Indian part of Ganges delta is crisscrossed by major rivers like the Bhairab, Jalangi, Mathabhanga, Churni, and the Ichhamati. On the western side of this delta, lies the Ichhamati-Hugli River basin, which is an important river basin in the south-eastern part of West Bengal, accounting for 3% of the total geographical area of the state of West Bengal (Bandyopadhyay et al., 2014). Furthermore, Ichhamati, being an important river in the Nadia group of rivers, flows as a transboundary river between India and Bangladesh (Mondal et al., 2020). Thus, the Ichhamati-Hugli basin is naturally endowed with many natural types of wetlands ranging from waterlogged areas, paddy fields, oxbow lakes, paleochannels, reservoirs, and manmade ponds.

As a constituent of the inland wetlands system, floodplain wetlands vary between tectonic depressions, meander scroll depressions, back swamps, sloughs, and lakes. Floodplain wetlands make up a sizeable component of about 58.2 million ha of wetlands in India, mostly in the Ganga-Brahmaputra-Meghna (GBM) basin (Prasad et al., 2002; Koontz et al., 2010; Mukherjee et al., 2009). In WB, floodplain wetlands effectively cover 42,000 acres, or around 22% of the state's total freshwater area (Sugunan et al., 2000).

South-eastern West Bengal consists of six important districts: Nadia, North 24 Parganas, Kolkata, Howrah, Hooghly, and South 24 Parganas. This area is naturally endowed with rich and extensive floodplain wetlands, chiefly due to river shifting and migration processes accelerated by the 1° inclination of the Bengal Basin eastward (Rudra, 2018). Major river systems of this region are the Bhairab, Jalangi, Churni, Ichhamati river, Jamuna, Damodar, Hugli, Saraswati, Kulti, Raymangal, Kalindi, Bidyadhari, Thakuran, Matla, Hariabhanga, Gosaba (Bandyopadhyay et al., 2014). These rivers jointly created these floodplain's wetlands which are vast in extent and prolific in functionality (Mondal et al. 2010; Mondal et al., 2016; Gayen et al., 2020). In India, out of 58.2 million ha of area, floodplain wetlands share a considerable proportion, chiefly within the Ganga-Brahmaputra-Meghna (GBM) basin (Prasad et al., 2002; Koontz et al., 2010; Mukherjee et al., 2009). These low-lying wetlands, act as natural sinks in the landscape and border the river Ichhamati, receive floodwater during monsoon months, and spill over water from the main channel. These wetlands may be from channel cut-offs, oxbow lakes, sloughs, meander scroll depressions, back swamps, residual channels or paleochannels, or tectonic valleys; sometimes often difficult to establish their identity due to natural as well as artificial modifications (Sugunan et al., 2000). These permanent and semi-permanent cut-offs, oxbow lakes, creeks, and other shallow ephemeral wetlands are locally called as *Beel, Baors, Daha, Charhas, and Jheel* (Sugunan et al., 2000; Das & Nandi, 2004; Datta & Gosh, 2015) and become important fishery resources in the state (Mondal et al., 2010). These wetlands are biologically sensitive habitats as they play a crucial role in nursery and culture fisheries. Wetlands are also biologically highly productive as they are enriched with plant nutrients such as total organic carbon (TOC), available nitrogen (N), and available phosphorus (P) (Sugunan et al., 2000).

3.2 Wetlands of Ichhamati floodplains and their recent scenarios

The study area is situated in the *moribund deltaic* part of the Ganga-Brahmaputra River systems of the Bengal Basin (Bhattacharya et al., 1997). River Ichhamati is a mighty river in the "Nadia Group of Rivers" of this locality which is originated from the Mathavanga River near Majhdiya Rail Bridge and follows a meandering course up to Debhata near Hasanabad. Vast floodplains had been created by the GBM river system's cumulative flow in the Bengal delta's lower part (Mukherjee et al., 2009; Mondal et al., 2016). Extreme meandering and channel avulsions in the southern part of this delta had led to the formation of numerous permanent and semi-permanent cut-offs and shallow ephemeral wetlands (Sugunan et al., 2000; Das & Nandi, 2004; Pandey et al., 2005; Datta & Ghosh, 2015). The Ichhamati floodplains, being part of this delta, are also naturally endowed with such wetlands which are biologically highly productive and give ecological dividends to the poor (Mitsch and Gosselink, 1993). Wetlands of this region are of diverse types ranging from swamps to marshy lands, lakes to paleochannels, and natural to artificial (Bassi et al., 2014; Gayen et al., 2020). Administratively, the floodplains fall within the Nadia and North 24 Parganas districts of West Bengal. Eventually, a wetland-complex had been formed with seven oxbow lakes of river Ichhamati (Fig. 3.2), locally called as *Baors* in the Bangaon region of North 24-Parganas (Das & Nandi, 2004), namely Berkrishnapur, Panchpota, Panchita, Aromdanga, Gopalnagar, Manigram, and Madhabpur wetlands. Berkrishnapur, Panchpota, Panchita, Aromdanga, Gopalnagar, Manigram wetlands are connected with the river Ichhamati through narrow waterways except Madhabpur wetland which is connected only during monsoon months.

These wetlands of Ichhamati floodplains also play a key role in providing nutrition and habitat for native and migratory birds (Halls, 1997; Deepa & Ramachandra, 1999; Thompson & Abraham, 2001). These wetland ecosystems once provided food, breeding, and resting grounds to many living organisms even in the water-stressed months (Datta & Ghosh, 2015; Gayen et al., 2020). Moreover, people use these wetlands mainly for paddy cultivation, vegetable production, jute production, and retting and fishing. Nonetheless, the rich legacy of these wetlands as potent avifauna habitats along the river Ichhamati can be traced back to several regional literary texts, historical documents, and artifacts. For instance, the famed Bengali novelist Bibhutibhushan Bandyopadhyay in his famous novel '*Ichhamati*', portrayed a vivid picture of the serene landscape of this area dotted with several notable bird species like *Acridotherestristis*, *Copsychusaularis*, *Turdoidesstriata, and Oriolusxanthornus* and many trees like *Mangifera indica*, *Syzygium cumini*, *Artocarpus heterophyllus*, *Ficus benghalensis, and Bambusa*, etc. (Bandyopadhyay, 1996). Presently, wetlands of this region are covered with various aquatic weeds like water hyacinth (*Eichhornia crassipes* and *Lemna perpusilla*), *Jhanji* (*Ceratophyllum demersum*), duckweeds (*Lemnoideae*), and various other reeds (*Phragmites australis*), and typhus which provide food as well as a habitation to avifauna, fishes and other organisms (Gayen et al., 2020) (Photograph 3.1).

Photograph 3.1 Wetlands are mostly engulfed by water hyacinth; (a) Water hyacinth cover of Gopalnagar, (b) Water hyacinth clearing in Panchita wetland

Despite becoming a member country of the Convention on Biodiversity (CBD) in 1994 (Glowka et al., 1994) and emerging as one of the 'mega biodiversity' countries of the world but India exhibits rampant mass killing and trapping of avifauna in its wetland (Photograph 3.2). Nevertheless, many wetlands had either been degraded severely or converted into other land uses due to decades of unsustainable anthropogenic practices as well as indiscriminate extraction of natural resources (Jogo & Hassan, 2010; Bassi et al., 2014; Datta & Ghosh, 2015).

Photograph 3.2 Trapping and killing of avifauna; (a) *Scolopacidae* trapped by fishing net in Berkrishnapur, (b) *Hydrophasianus chirurgus* caught in Gopalnagar, (c) *Dendrocygna javanica* trapped and killed by fishing net in Panchpota, (d) *Metopidius indicus* trapped and killed by fishing net in Aromdanga

Photograph 3.3 (a)Jute retting in Manigram wetland, (b) jute fiber extraction in Panchpota wetland, (c) jute-stick drying in Gopalnagar wetland

Signs of degradation and deterioration are already discernible in declining fish production and number out-migration of the fishers, algal bloom, and fish death in the wetlands of Ichhamati floodplains. Such deteriorated health was also reflected in the diversity, density, and distribution of the regional avifauna communities (Mondal et al., 2010; Bhattacharyya et al., 2013; Gayen et al., 2020). Therefore, a few of these wetlands have been selected for this study to understand such nature of degradation.

Photograph 3.4 Algal bloom in (a) Berkrishnapur wetland, turtle death in (b) Gopalnagar wetland, an algal bloom in (c) Manigram wetland, and an algal bloom in (d) Aromdanga wetland

3.3 Location of the Ichhamati floodplain wetlands

The Ichhamati-Hugli River basin is situated in the Nadia and the North 24 Parganas districts of the state of West Bengal. However, the studied wetland-complex is located in the Bangaon C. D. Block near Gopalnagar Gram Panchayet of North 24 Parganas district (Fig. 3.1). The selected seven wetlands had been originated as river cut-offs and developed into oxbow lakes. These wetlands are perennial and hydrologically connected to each other through Ichhamati river. These wetlands accommodate wastewater from nearby agricultural lands and other various sources like domestic and market sources such as surface runoff, influx of effluents through irrigation, and sewage canals. Wastewater gets naturally treated with the help of ample sunshine and abundant algae which grows naturally within the wastewater (Ghosh, 2005). The connecting narrow inlets dry up partly from March to May each year, putting immense hydrological pressure on these wetland ecosystems. Despite these stresses, this wetland-complex plays crucial role in biodiversity conservation, flood mitigation, groundwater recharge, irrigational water supply, captive fishing, domestic uses and livestock rearing.

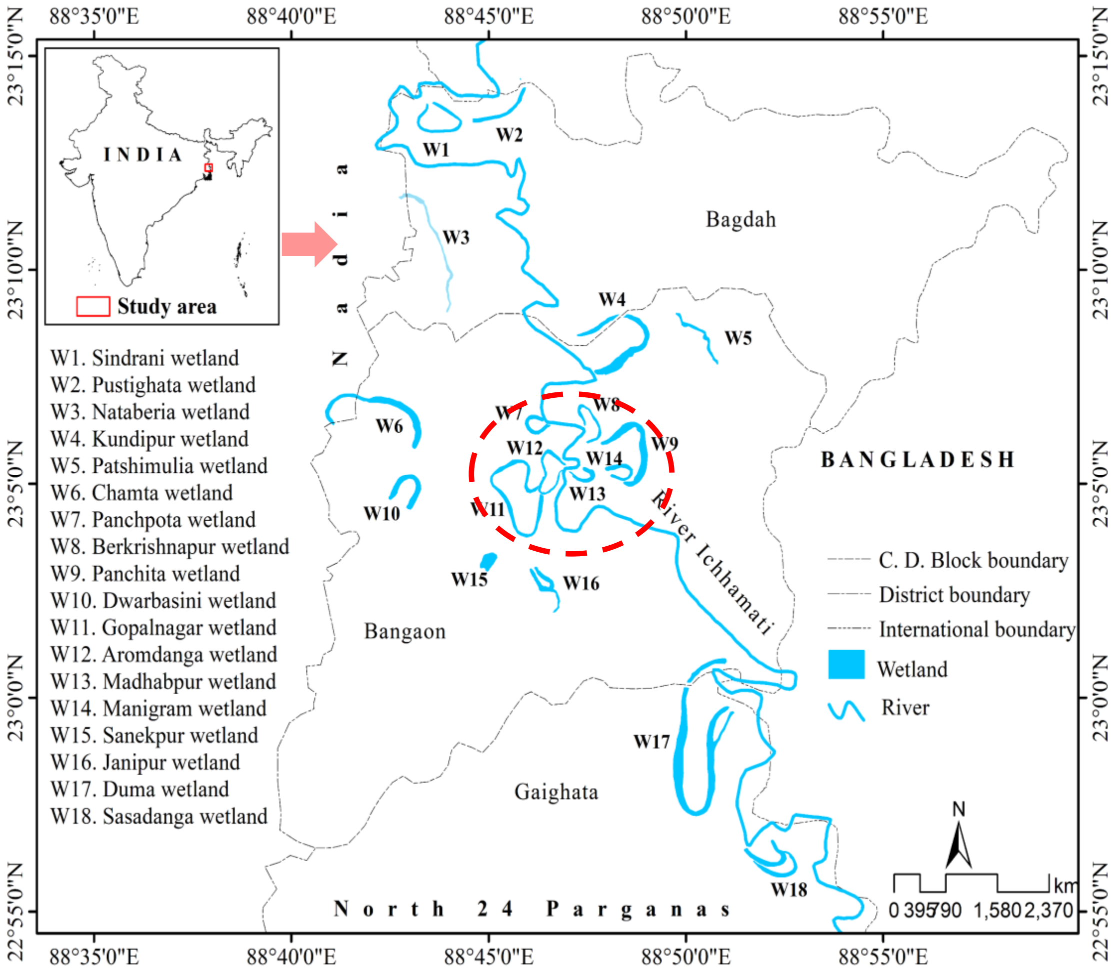

Fig. 3.1 Location map of the study sites

3.3.1 Selection of representative wetlands

Initially, all wetlands with an area ≥ 2.25 ha were shortlisted following the West Bengal 'NWIA' guidelines within the Ichhamati River floodplains (National Wetland Atlas: West Bengal, 2010). However, any wetlands not shortlisted in our scheme may still be important. After that, major eighteen wetlands, located in the Bagdah, Bangaon, and Gaighata Community Development (C.D.) Blocks of North 24 Parganas and an area of at least 10 ha had been shortlisted again in the upper reach of the river Ichhamati for selection of studied wetlands. Out of these eighteen wetlands, only seven wetlands were selected, as they formed a wetland-complex in the Bangaon C.D. Block to understand how wetland ecosystem health varies or remains the same within the almost identical physiographic settings where wetlands are spatially near but characteristically distinct. From north to south, the wetlands of the wetland-complex are Berkrishnapur, Panchpota, Panchita, Aromdanga, Gopalnagar, Manigram, and Madhabpur (Fig. 3.2). Hydro-ecological setup, utilization patterns, and spatial contiguity were also considered during selection of these wetlands (Farooqi et al., 2008; Datta et al., 2012; Gayen et al., 2020). These selected wetlands are hydrologically and ecologically linked to each other by the ecological corridor Ichhamati. This river is tidally active in its lower reach. Although there is a very weak upstream flow during the monsoon season. This periodic tidal flow maintains the hydrological characteristic and revives the biological integrity of such floodplain wetlands. These wetlands are bounded by vast agricultural tracts on one side and settlements on the other. These wetlands act as landscape corridors for animal communities, mainly avifauna and various vertebrates, reptiles, and other invertebrates especially during heavy monsoons (Sui et al., 2015). In spite of the habitat function for local and migrated avifauna, these wetlands are also intensively used by the local populace for farming, fishing, retting of jute, and other domestic purposes (Table 3.1). Almost all of these wetlands are partially or completely engulfed with water hyacinth (*Eichhornia crassipes* and *Lemna perpusilla*), *Jhanji* (*Ceratophyllum demersum*), duckweeds (*Lemnoideae*), and different reeds (*Phragmites australis*) which enhance the habitat quality and ensure food to avifauna. In most sites, thin but extended vegetal cover along the wetland dykes generally attracts most avifauna species as nesting places and foraging platforms (Gayen et al., 2020).

The purpose of this selection was to explain why wetland ecosystem health varies significantly across nearly comparable physiographic environments, particularly within a wetland-complex where wetlands are geographically close but distinctly different and hydrologically and biologically interconnected. Therefore, the first objective was to analyze ecosystem conditions within an intensely humanized landscape. It was believed that this research should address how, why, and under what situations these wetlands are becoming ecologically fragile. Several pilot surveys were conducted before finalizing the number of wetlands that are within or outside of the wetland complex. Thereafter, on the basis of several field visits during the major four seasons, spatial contiguity and distances were keenly observed. Thereafter, on the basis of priori knowledge and several discussions with different stakeholders such as farmers, fishers, livestock rearers, and indirect rearers, seven wetlands namely Berkrishnapur, Panchpota, Panchita, Aromdanga, Gopalnagar, Manigram, and Madhabpur wetlands were selected as they formed a characteristic wetland-complex.

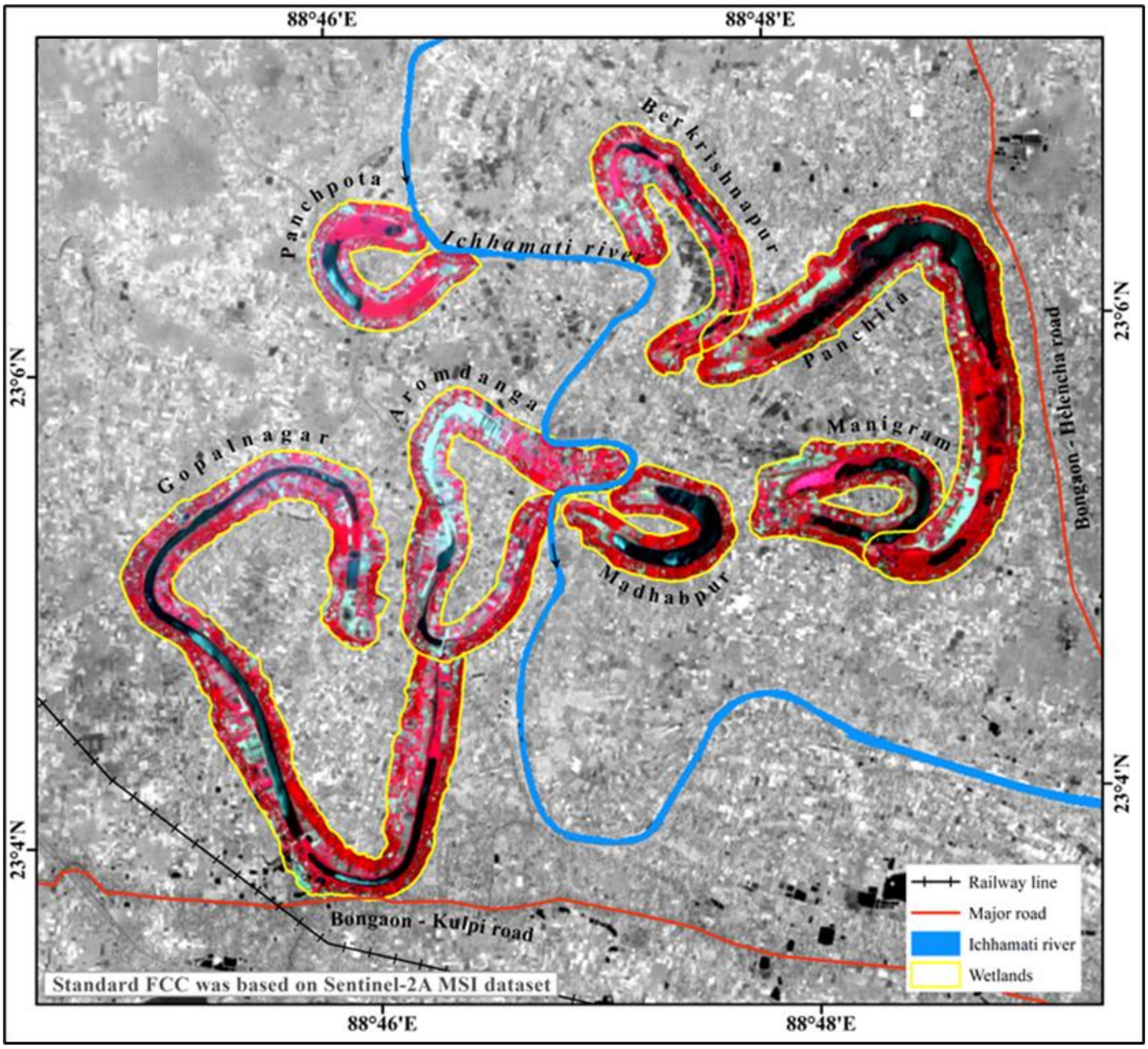

Fig. 3.2 Wetland-complex comprised of Berkrishnapur, Panchpota, Panchita, Aromdanga, Gopalnagar, Manigram, and Madhabpur wetland. This is a standard FCC image based on the Sentinel-2A MSI dataset. Red colour indicates vegetation patches, dark blue color indicates waterbody, and cyan colour represents agricultural land

3.4 Physical environment

The physical environment of the study area will facilitate further understanding of the existing geo-environmental conditions of the studied wetlands. Therefore, the physical environment of the study area was explored through geology, geomorphology, water resource, climate, soil conditions, vegetation cover, and biotic communities.

3.4.1 Climate

Since the study area is located almost within minutes of the Tropic of Cancer in the Torrid Zone (Ghosh, 2005), the summer temperature was observed between 29.0 °C to 41.0 °C in May 2020 and 31.0 °C to 44.0 °C in May 2016. Winter temperatures were observed between 15.0 °C to 20.0 °C in January 2020 and 15.0 °C to 24.0 °C in January 2016 (The Global Historical Weather and Climate Data). The highest monsoonal rainfall in the district was 63.6 mm in August 2020 and 222.9 mm in August 2016. Although, the average precipitation of Bangaon C.D. Block was found 460.35 mm in July (The Global Historical Weather and Climate Data).

Table 3.1 Wetland identity and identified anthropogenic activities

C.D. Block	Wetland complex	Coordinate of mostly accessed points	Area (ha)	Surrounding Census village	Identified major anthropogenic activity
Bangaon	Berkrishnapur wetland	23° 06' 42.48" N 88° 47' 18.39" E	24.99	Nakful Sabhaipur Berkrishnapur	Agriculture, fishing, aquaculture, animal husbandry, construction works, bathing and washing, jute-retting, sanitary activities, etc.
	Panchpota wetland	23° 06' 19.45" N 88° 45' 57.35" E	61.59	Dakhin Panchpota Asurhat Mollahati Sabhaipur Berkrishnapur	Agriculture, fishing, animal husbandry, construction works, bathing and washing, jute-retting, sanitary activities, etc.
	Panchita wetland	23° 05' 37.13" N 88° 49' 01.59" E	115.15	Nakful Panchita Manikgram Chak Dharampukuria Manigram Sabhaipur	Agriculture, fishing, aquaculture, animal husbandry, construction works, bathing and washing, jute-retting, sanitary activities, etc.
	Aromdanga wetland	23° 50' 07.47" N 88° 46' 22.19" E	31.61	Mollahati Sabhaipur Chak Alakulipur Dakhin Baliadanga Barakpur Madhabpur Nakful	Agriculture, fishing, aquaculture, animal husbandry, construction of roads and houses, sanitary activities, bathing and washing, jute-retting, etc.
	Gopalnagar wetland	23° 03' 45.44" N 88° 46' 01.96" E	86.85	Alakulipur Shrirampur Natidanga Dakhin Baliadanga Barakpur Gopalnagar Khamarkulla Saili Matihara	Agriculture, fishing, aquaculture, animal husbandry, construction of houses and roads, sanitary activities, bathing and washing, jute-retting, etc.
	Manigram wetland	23° 05' 21.67" N 88° 48' 16.37" E	23.86	Sabhaipur Manigram	Agriculture, fishing, aquaculture, Animal husbandry, jute-retting
	Madhabpur wetland	23° 05' 08.17" N 88° 47' 40.67" E	52.696	Nakful Sabhaipur Manigram Madhabpur	Agriculture, fishing, aquaculture, animal husbandry, construction works, etc.

Source: Human Development Report, 2010

3.4.2 Geology

The wetland-complex under consideration exists over the Bengal Basin that forms the GBM Delta (Basu, 1981; Basu & Sil, 2003; Bandyopadhyay, 2007; Bandyopadhyay, 2021). This basin is a tectonically active unit in the GBM River basin and is geologically young. The GBM delta is also the largest in the world with an area of 123500 km^2, and it contributes 1.109 t yr^{-1} of sediment discharge annually (Bandyopadhyay, 2007). The GBM delta had been evolved into its present form during the last ~ 150 Ma. The Bengal Basin developed through a series of tectonic movements with sedimentary processes following river shifting, paleo-climatic changes, and the evolution of eustasies (Sarkar, 2004; Bandyopadhyay et al., 2007; Bandyopadhyay et al., 2021). The Indian Shield bounds the Bengal basin to the west, the Shillong Shield to the north, the Naga-Lusai orogenic belt to the east, and the Bay of Bengal to the south (Sengupta, 1956). Extensive lagoons formed the background of the world's largest delta, the GBM Delta, from the Miocene age (Rudra, 2018). They became one of the major sedimentary basins in the Indian subcontinent (Mondal et al., 2018). The Ganga-Brahmaputra-Meghna River system and its tributaries and distributaries transported sediments from the Himalayas and adjacent Indian shield areas and contributed to the formation of this delta system (Roy et al., 2010). The subsurface geology consists of Quaternary fluviatile sediments comprised of silty clay, sand, and sand mixed with occasional gravel (Sikdar & Sahu, 2009).

3.4.3 Geomorphology

Many rivers sub-basins have evolved across the Bengal Basin of which the Ichhamati River and its tributaries constitute an important river basin within the Hooghly-Churni-Ichhamati Interfluves (HCII) (Bandyopadhyay, 2007; Bandyopadhyay et al., 2021). HCII is the land bounded by the Hooghly River to the west, the Ichhamati river to the east, and the Churni to the north and characterized by fluvial origin older floodplains, paleochannels, meander scrolls and oxbow lakes (Mondal et al., 2016). Ichhamati river is a spill channel of the Mathabhanga River and off-take from the River Mathabhanga near Majhdia of Krishnaganj C.D. Block, Nadia district (O'Malley, 1914). In its upper reach, from the off-take point of Mathabhanga River at Majhdiya, Nadia District, up to beri/Swarupnagar, North 24 Parganas District, the river is dying (Mondal & Satpati, 2015; Mondal et al., 2016). It follows a very sinuous and meandering course due to low energy in its upper reach (Mondal et al., 2016). Vast floodplains containing Holocene sediments had been created by the GBM river systems (Mukherjee et al., 2009; Mondal et al., 2016). The river basin is enriched by numerous permanent and semi-permanent oxbow lakes and shallow ephemeral wetland fragments (Pandey et al., 2005; Gallardo et al., 2012; Datta & Ghosh, 2015). Eventually, the extreme meandering flow and low energy budget of the Ichhamati led to the development of abundant scrolls, oxbow lakes, and paleochannels that became influential in the community's livelihood (Datta & Ghosh, 2015; Mondal et al., 2016). The river is underlined by thick recent sediment deposits and is characterized by silt and clay (Mondal et al., 2018) The elevation of the ground in the study area varies from 7.5 to 15 m from the mean sea level (Bandyopadhyay et al., 2014). Geomorphologically the area falls primarily within the non-tidal upper Ganga delta (Bandyopadhyay et al., 2014). Therefore, the upper reach of the river basin is a fluvially originated floodplain.

3.4.4 Water resource

Wetland water is essential for sustaining wetland biota. Water resources of the study region include oxbow lakes, paleochannels, river Ichhamati and man-made ponds. Although, the water level of such water bodies recedes downward maximally in the months of the summer season. The studied wetlands are perennial and fed by rainwater during monsoons and groundwater in dried months. With high evaporation and evapotranspiration rates, the water in the studied wetlands decreases substantially during the summer months. Additionally, irrigation also absorbs a substantial amount of water from wetlands during the lean season. Wastewater and agricultural runoff enter the wetlands through interconnecting drains and sluice gates. Small-scale industries, markets, nursing homes, and dense settlements of wetland catchment contribute wastewater to wetlands and thereby pollute wetland waste unprecedentedly.

Photograph 3.5 Bathing and washing (a) in Panchpota and (b) in Aromdanga wetland.

All aquatic biota such as macrophytes, invertebrates, and vertebrate animals survive in this polluted water and are compelled to run their physiological functions with such water quality. People depend on wetland water in large quantities for washing and bathing, irrigation, jute retting, industrial, and other uses, and deteriorates the water quality of the studied wetlands day by day (Photograph 3.5). Therefore, in summer volume of surface water was reduced significantly mainly due to evaporation, evapotranspiration, and irrigation.

3.4.4.1 Groundwater resource

Mukherjee (2006) and Mukherjee et al. (2007) reported based on hydro stratigraphic characterization of North 24 Parganas and South 24 Parganas that there were two major types of aquifers. According to Mukherjee (2006), the first one was a continuous, semiconfined sand aquifer (hereafter called the main aquifer) underlaid by a thick clay aquitard. This main aquifer, or the Sonar Bangla aquifer, deepened from 50-80 m below ground level (bgl) in the north to 180-200 m bgl in the south (Mukherjee et al., 2007). Discontinuous clay layers locally divided near-surface aquifers to form several deep and confined aquifers in the southern half of the study area. Second, in some areas, many small and isolated aquifers were at greater depths (200-300 m bgl) (Mukherjee et al., 2007). However, all aquifers are interconnected and water may pass through spatially varying grain sizes (Basu & Sil, 2003; Chakraborty et al., 2009). In summer, groundwater is depleted substantially. The groundwater level depth in North 24 Parganas varied from 1.02 m to 6.36 m bgl in January, 2.13 m to 7.85 m bgl in April, and 0.62 m to 4.22 m bgl in November (Smith et al., 2003). Mostly unconfined shallow aquifers (12-15 m bgl) were located in the upper reach, and semi-confined to confined types of aquifers existed in the lower reach of the Ichhamati River. Since the general dip of the Bengal Basin was 1º 30' to the southeast, the surface level of groundwater is also sub-parallel to the land's general slope.

3.4.4.2 Surface water resource

Surface water resources include water from rivers, canals, rivulets, wetlands, swamps, marshes, beels, aquacultural ponds, etc. However, water was sufficient during the monsoon months *i.e.,* June-September. However, water from most canals, rivulets, shallow marshes, and beels evaporated during the lean season. Minimal water remained in perennial wetlands and some parts of the longitudinal course of the Ichhamati River in lean period. As the study area is located in a mature deltaic part, people use river and wetland water for irrigation during dry months, mainly for 'Ravi' crops. As a result, more water was withdrawn for irrigation purposes and wetlands shrunk in terms of water cover

-age during the lean season *i.e.*, March-April-May.

3.4.5 Soil status

Soils of the North 24 Parganas district are composed of recent alluvial deposits and are azonal in nature with little or no profile development (GoWB, 2010). Clay loam is the predominant type of soil; however, sandy clay to clay with muck soils are also found in wetlands. Besides, sandy soils are also found along the littoral zone of wetlands and fine silt consolidates into clays in the flatter parts of the plains, such as the tract known as *Kalantar* (O'Malley, 1914). These soils have been formed from deposits carried down by overland flow and tidal currents. The soil in North 24 Parganas is very deep. A boring at Calcutta at a depth of 481 feet showed no signs of rocky bottom or marine bed; freshwater shells had found at 380 feet below the surface (O'Malley, 1914). This vast tract of alluvium deposited in the floodplains on both sides of the main River Ichhamati attracted many human settlements with lucrative livelihood options resulting in high population density in the region.

3.4.6 Vegetation cover

Wetland vegetation is an important biotic component of wetland ecosystem structure. The studied wetlands are rich in a wide range of floral assemblages. Meanwhile, it was observed that the macrophytes change from one wetland to another around the year. Wetland vegetation of the studied wetlands can be classified into the following major three groups based on place of occurrence, substratum, and exposure to water and air.

3.4.6.1 Emergent vegetation

The tall emergent plants of the studied wetlands included various reeds (*Phragmites australis*), sedges, and typhus like southern cattail (*Typha domingensis*), *Nymphoides hydrophylla*, Indian lotus *(Nelumbo nucifera)*, *Trapa bisponosa*, *Myriophyllum tuberculatum, Potamogeton nodosus, Aponogeton monostachyon, Nymphaea spp, and Marsilea quadrifolia.* Among these, reeds, sedges, and cattail found in abundant along the littoral zones of these wetlands.

3.4.6.2 Floating vegetation

The dominant floating aquatic plants that grow abundantly in the studied wetlands included common water hyacinth (*Eichhornia crassipes*), *Kalmi* (*Ipomoea Aquatica*), and *Helencha (Enhydra fluctuant),* common duckweed *(Lemna minor),* water velvet

(*Azolla pinnata)*, etc.

3.4.6.3 Submerged vegetation

Submerged wetland species prominent in the studied wetlands were *Hygrophila natans*, *Hygrophila difformis*, *Ceratophyllum demersum, Najas indica, Chara zeylanica*, *Ottilia alismoides, Vallisnaria spiralis*, etc.

3.4.7 Wetland fauna

Faunal communities of these wetlands are fish, avifauna, reptiles, amphibians, and other vertebrates and invertebrates. Selected freshwater wetlands have good habitat conditions for fishes (viz. *Labeo rohita, Cirrhinus cirrhosis, Catla catla, Oreochromis mossambicus, Macrobrachium rosenbergii, etc).* Native fish species like *Channa striatus*, *Anabas testudineus*, *Channa marulius*, *Heteropneustes fossilis*, *Clarias batrachus*, *Channa punctatus* were produced in good quantity in these wetlands. However, *Nandus nandus is now* locally threatened species and become mostly rare species in these wetlands. Aquatic weeds, water hyacinth patches, and littoral tract with sedges and typhus were provided favorable habitats for avifauna (viz. *Ardeola grayii, Phalacrocorax fuscicollis, Dendrocygna javanica, Nettapus coromandelianus, Hydrophasianlts chirurgus, Metopidius indicus, Gallinula chloropus, etc.*) and many reptiles (viz. *Varanus salvator, Lissemys punctata, Ophiophagus hannah, Naja kaouthia and Daboia russelii*) few amphibians (viz. *Hoplobatrachus tigerinus* and *Euphlyctis hexadactylus*) (Gayen et al. 2020). Aquatic duckweeds, benthos communities, and fish stock of these wetlands had been used as feeding and breeding grounds by various winters *(viz. Fulica atra, Linnaeus, Gallinula chloropus, Nettapus coromandelianus, Hydrophasianlts chirurgus, and Metopidius indicus)* and summer visitors (viz. *Ixobrychus minutus, Anhinga melanogaster, Vanellus indicus, Hydrophasianlts chirurgus, and Tringa slagnatilis*) (Gayen et al. 2020) (Photograph 3.6). These avifauna play the role of characteristic indicator of these wetlands and indicate habitat suitability as well as WEH of these remaining wetlands under intense human pressures. Water, aquatic vegetation, and rich benthos communities attracted these avifauna. These wetlands also a repository of varieties of indigenous and exotic fishes. However, currently exotic fishes take the stake due to commercial fishing.

Photograph 3.6 Avifauna assemblage; (a) *Botaurus stellaris* in Madhabpur, (b) *Metopidius indicus* in Gopalnagar, (c) *Anastomus oscitans* in Madhabpur, (d) *Hydrophasianus chirurgus* in Manigram, (e) *Vanellus indicus* in Panchita, and (f) *Dendrocygna javanica* in Manigram wetland

3.5 Cultural environment

3.5.1 Demographic characteristics

The District North 24 Parganas covers an area of 4094.00 Km^2 and had 8.93 million population in 2001 and 10 million population in 2011 (GoI, 2001 & 2011). Bongaon C. D. Block covers an area of 336.70 Km^2 and hold 0.38 million people in 2011 and 0.34 population in 2001 (GoI, 2001 & 2011). The Bongaon C.D. Block is subdivided into 150 villages (GoWB, 2010). Out of these 150 villages, people of 21 villages surrounding these seven studied wetlands were directly or indirectly dependent on these wetlands for their livelihood, food, fodder, energy, water, communication, recreation, and more. Alakulipur, Shrirampur, Natidanga, Dakhin Baliadanga, Barakpur, Gopalnagar, Khamarkulla, Saili, and Matihara in the vicinity of Gopalnagar wetland had a total population of 27511 in 2001 and 30613 in 2011 (GoI, 2001 & 2011) (Fig. 3.3). Aromdanga wetland also serves the people of seven villages, namely Mollahati, Sabhaipur Chak, Alakulipur, Dakhin Baliadanga, Barakpur, Madhabpur, and Nakful. Out of these seven villages, three villages, viz. Alakulipur, Dakhin Baliadanga, and Barakpur share the boundaries with the Gopalnagar wetland. The total population of these seven villages was 19.13 thousand in 2001 and 21.23 thousand in 2011 (GoI, 2001 & 2011). Panchpota wetland serves the people of three villages: Dakhin Panchpota, Asurhat, and Mollahati, where Mollahati village also share its boundaries with the Aromdanga wetland.

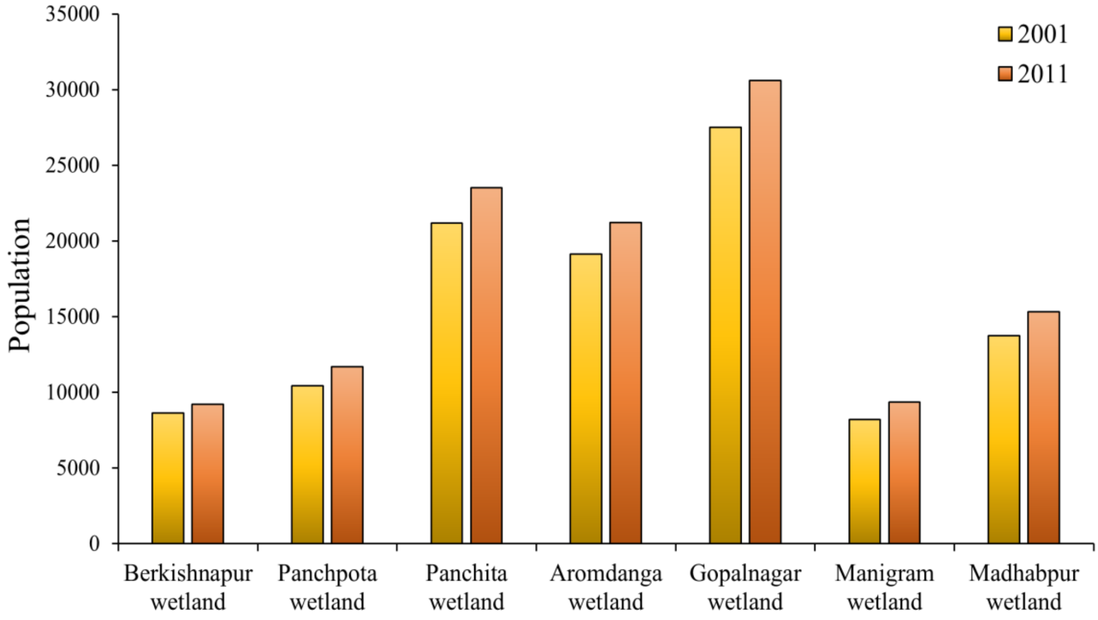

Fig. 3.3 Wetland-wise population trend between 2001 and 2011 (Census of India)

The total population of these three villages was 0.45 thousand in 2001 and 11.67 thousand in 2011 (GoI, 2001 & 2011). Berkrishnapur wetland lies within the administrative boundaries of three villages: Nakful, Sabhaipur, and Berkrishnapur. The total population of these three villages was 8.62 thousand in 2001 and 9.22 thousand in 2011 (GoI, 2001 & 2011). Madhabpur wetland is located within the administrative boundaries of four villages: Nakful, Sabhaipur, Manigram, and Madhabpur. The total population of these villages was 13.74 thousand in 2001 and 15.32 thousand in 2011 (GoI, 2001 & 2011). Manigram wetland is located within the administrative boundaries of two villages, viz. Sabhaipur and Manigram. The population of these two villages was 8.20 and 9.34 thousand in 2001 and 2011 respectively (GoI, 2001 & 2011). Panchita wetland is located within the administrative boundaries of six villages: Nakful, Panchita, Manigram Chak, Dharampukuria, Manigram, and Sabhaipur. Among these six villages, Nakful village shared its boundaries with Berkrishnapur wetland, and Manigram village shared with Manigram wetland. The total population of these six villages was 21.17 thousand in 2001 and 23.52 thousand in 2011 (GoI, 2001 & 2011). According to their geographical position and contiguity, most wetlands shared common villages with other wetlands. The demographic characteristics of these wetlands will help to understand and implement future micro-scale environmental design and planning. All villages had experienced population increase from 2001 to 2011, indicating pressures on wetland.

3.5.2 Livelihood scenario

The four major economic activities were observed in these wetlands are agriculture, jute retting, fishing, and livestock farming. The soils of the study area are highly fertile as they had been originated from the mature deltaic part of the GBM delta. Therefore, both Kharif and Ravi cultivation are practiced in the study area intensively. Various green vegetables such as cucumber (*Cucumis sativus*), bitter gourd (*Momordica charantia),* bottle gourd (*Lagenaria siceraria*), pointed gourd (*Trichosanthes dioica*), ladies' fingers (*Abelmoschus esculentus*), potato (*Solanum tuberosum*), cauliflower (*Brassica oleracea var. botrytis*), cabbage (*Brassica oleracea var. capitata*), brinjal (*Solanum melongena*) are produced in abundance in the agricultural land adjacent to the wetlands. Different fruits like guava (Psidium guajava), papaya (*Carica papaya*), mango (*Magnifera indica*), and banana (*Musa paradisiaca*) were grown in orchards in huge amount. Floriculture was also found to be an economically viable activity in the study area. Fishing activity was the dominant and economically profitable activity of the fishers of the studied wetlands. Both commercial and subsistence fishing was observed in the studied wetlands. Besides, unscientific fishing, lure-based fishing techniques led to the deterioration of water quality and reduced fish production in the studied wetlands. Jute production in and around the wetlands and retting of that jute within the wetlands at zero cost was another major profitable economic activity of the wetland people. Other notable activities were observed in the studied wetlands are fish pond aquaculture, fodder collection, spinach collection, drinking water production in a pouch pack, fords, and ferries, excavation of wetland soils for house construction, landfilling, road construction, and brick making. The collection and use of medicinal plants was another notable economic and folk practice in the study area. These wetlands act as natural pools and habitats for these medicinal plants. Some pottery was found in the vicinity of the studied wetlands. The potters make various deities, clay utensils, and cookwares from the wetland soil and ensured their livelihood. Duck, goat, cow, and sheep rearing was also one of the profitable economic activities that increased women's empowerment in wetland communities.

3.5.3 Sociocultural setup

The study area is inhabited by people of different religions and social groups. Hindus and Muslims are the two major religious groups that reside here. Economically divergent people such as poor marginal farmers; laborers to main workers live in these wetlands. People from various religious groups usually bathe in these wetlands, wash their utensils and use the wetland water for other daily domestic uses. Idol immersion, fishing sports, recreational activities, and ecotourism are some of the non-economic activities observed in the studied wetlands. However, these non-economic activities were also observed declining in almost all studied wetlands.

3.6 Biophysical settings of selected wetlands

Prior knowledge about biophysical settings of wetlands such as catchment characteristics, hydrology, ecology, and anthropogenic use patterns is highly important for proper understanding of each wetland system as well as for identify various actors which affect floodplain wetland ecosystems negatively.

Photograph 3.7 Asian open bill (*Anastomus oscitans*) and great egret (*Ardea alba*) are foraging in Madhabpur wetland

Photograph 3.8 Pointed gourd (*Trichosanthes dioico*) cultivation beside Madhabpur wetland

3.6.1 Berkrishnapur wetland

Berkrishnapur wetland is the northernmost wetland in the wetland complex. It had an elongated oxbow lake shape (Fig. 3.4). Depth at mid of the wetland was 2.55 m during the lean period. In terms of the perimeter, it ranked the fourth position with a perimeter of 6.86 km. Water spread 45 ha area during monsoon months which substantially decreased to 28.5 ha only in the lean period with a 36.67% reduction, thereby putting immense hydrological pressure on this wetland. Berkrishnapur wetland is both an agriculture and fishing-dominated wetland surrounded by vast agricultural land. Major economic activities in and within WIZ were agriculture, fishing, jute retting, and other dry-season crops. Around 160 households from neighboring villages availed their socio-economic benefits from this wetland.

Table 3.2 Characteristics of Berkrishnapur wetland

Wetland	Water spreading area in monsoon (ha)	Water cover area in lean season (ha)	Reduction of water cover (%)	Perimeter (Km)	Depth (m)	Width (m)	Household density (no. of houses/ km^2)
Berkrishnapur	45	28.5	36.67	6.86	2.55	127	241

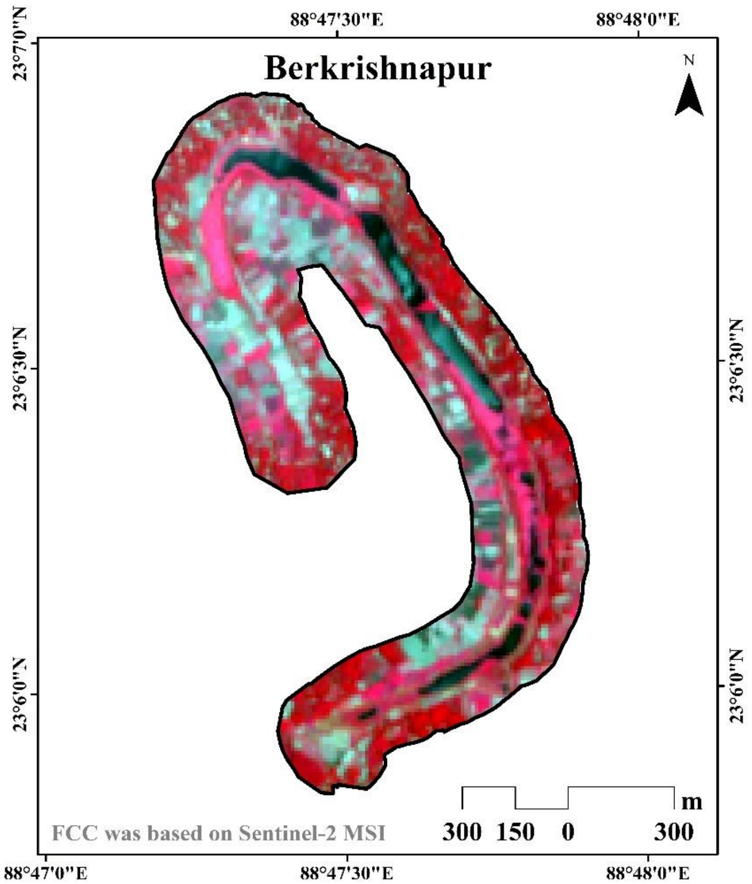

Fig. 3.4 Berkrishnapur wetland

3.6.2 Panchpota wetland

Panchpota wetland can also be found in the complex's northern part. It had the shape of an oxbow lake (Fig. 3.5). This wetland had a high household density of 562 households per km². During the lean season, the depth in the middle of the wetland was 2.5 m. This wetland had a perimeter of 2.3 m and a width of 325 m. Water spread over 32 ha during the monsoon season, but this was reduced to 27.9 ha during the lean season, a 13.62% reduction. Panchpota Wetland was primarily a fishing-dominated wetland. Fishing, jute retting, paddy cultivation, and cultivation of other dry-season crops were found as major economic activities in and within WIZ. This wetland benefitted approximately 210 households in neighboring villages.

Table 3.3 Characteristics of Panchpota wetland

Wetland	Water spreading area in monsoon (ha)	Water cover area in lean season (ha)	Reduction of water cover (%)	Perimeter (Km)	Depth (m)	Width (m)	Household density (no. of houses/km^2)
Panchpota	32.3	27.9	13.62	4.75	2.3	325	562

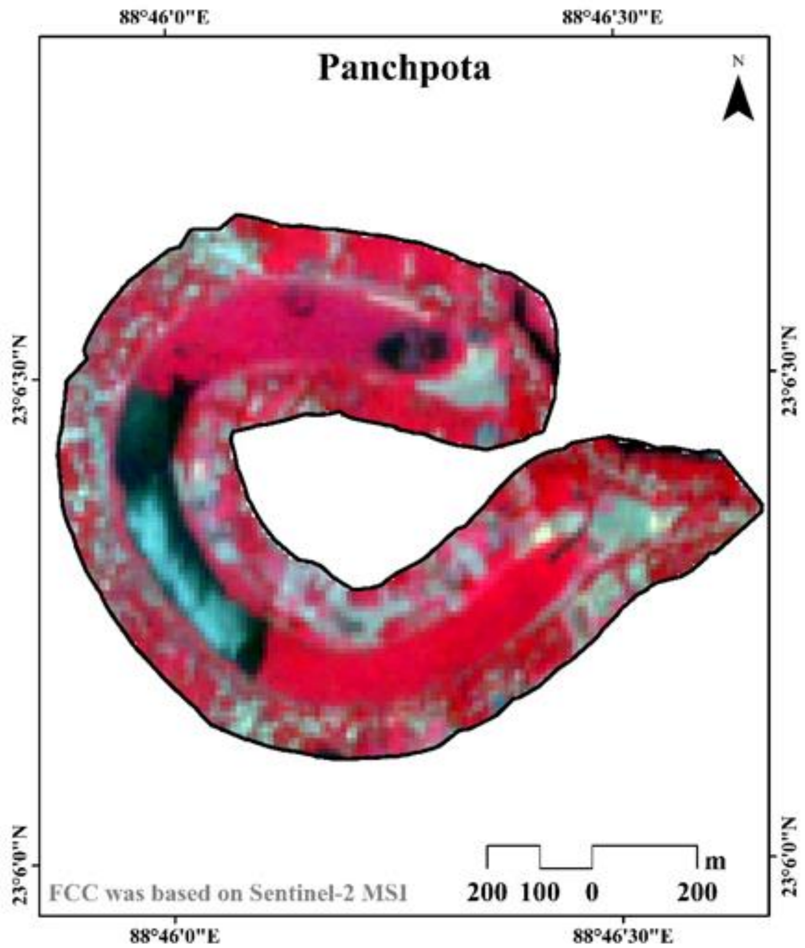

Fig. 3.5 Panchpota wetland

3.6.3 Panchita wetland

Panchita wetland lies in the northern region of the wetland complex. It resembled a long oxbow (Fig. 3.6). With 395 households per km^2, this wetland likewise had a high residential density. With a depth of 7.22 m during the lean period, it came in second place in terms of depth. This wetland had been measured 303 meters wide and 12.5 kilometers around. Water spread across an area of 152 ha during the monsoon season, but this area significantly shrank to 101 ha during the lean season, a drop of 33.55%, placing tremendous strain on aquatic life. The Panchita Wetland was mostly used for agriculture and fishing. Fishing, paddy cultivation, jute retting, and other dry-season crop cultivation were the main economic activities carried out in and within WIZ. A little over 230 households from nearby communities were benefitted from this wetland.

Table 3.4 Characteristics of Panchita wetland

Wetland	Water spreading area in monsoon (ha)	Water cover area in lean season (ha)	Reduction of water cover (%)	Perimeter (Km)	Depth (m)	Width (m)	Household density (no. of houses/km^2)
Panchita	152	101	33.55	12.5	7.22	303	395

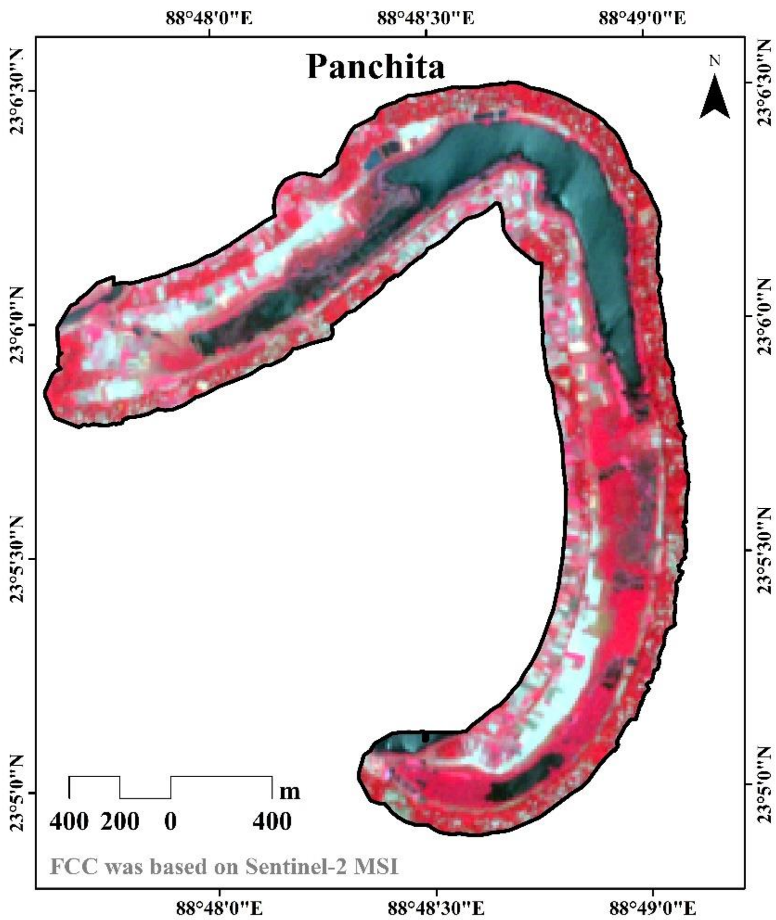

Fig. 3.6 Panchita wetland

3.6.4 Aromdanga wetland

In the southern region of the wetland complex, there is a wetland which was oxbow in shape, named Aromdanga wetland (Fig. 3.7). There were 266 households per km^2 in this wetland. During the lean season, this wetland was 2.78 meters deep. This wetland was measured 231 meters in width and 10 kilometers around. Water spread across an area of 63.7 ha during the monsoon season, but this area significantly reduced to 13.2 ha during the lean season, with a maximum loss of 79.28%, putting great stress on aquatic life. Although there is a fishing community and fishing was performed only in a small portion of the Aromdanga wetland, it was mostly an agriculture-dominated wetland. Paddy farming, fishing, jute retting, and other dry-season crops were found as significant economic activities in and around this wetland. WIZ. A total of 120 families in nearby communities benefitted from this wetland. Major portion of this wetland converted into agricultural land which become seasonally wetland.

Table 3.5 Characteristics of Aromdanga wetland

Wetland	Water spreading area in monsoon (ha)	Water cover area in lean season (ha)	Reduction of water cover (%)	Perimeter (Km)	Depth (m)	Width (m)	Household density (no. of houses/km^2)
Aromdanga	63.7	13.2	79.28	10	2.78	231	266

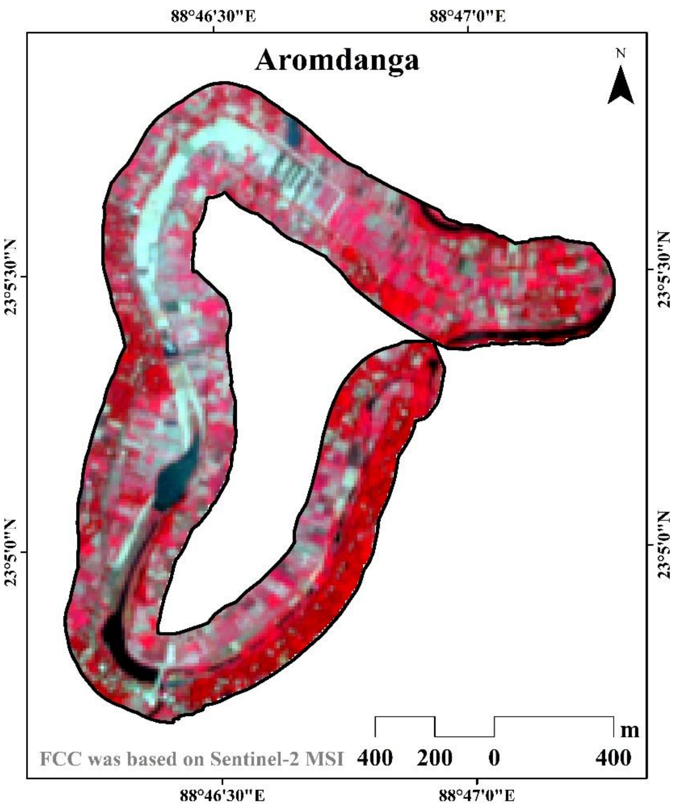

Fig. 3.7 Aromdanga wetland

3.6.5 Gopalnagar wetland

The wetland complex's southernmost wetland is called Gopalnagar. Wetland had an extended oxbow shape (Fig. 3.8). There were 468 households per km^2 in this wetland. During the lean season, this wetland was 2.94 meters deep. This wetland had a circumference of 17 km and an average width of 325 m. Water spread across an area of 152 ha during the monsoon season but significantly decreased to 61.9 ha during the lean season, with the second-highest loss of 59.28%, engaging a great strain on aquatic life. The Gopalnagar Wetland was mostly used for both agriculture and fishing. Fishing, paddy cultivation, jute retting, and other dry-season crops were the main economic activities carried out in and within the WIZ of this wetland. Approximately 240 households from nearby communities extracted their benefits from this wetland.

Table 3.6 Characteristics of Gopalnagar wetland

Wetland	Water spreading area in monsoon (ha)	Water cover area in lean season (ha)	Reduction of water cover (%)	Perimeter (Km)	Depth (m)	Width (m)	Household density (no. of houses/km^2)
Gopalnagar	152	61.9	59.28	17	2.94	325	468

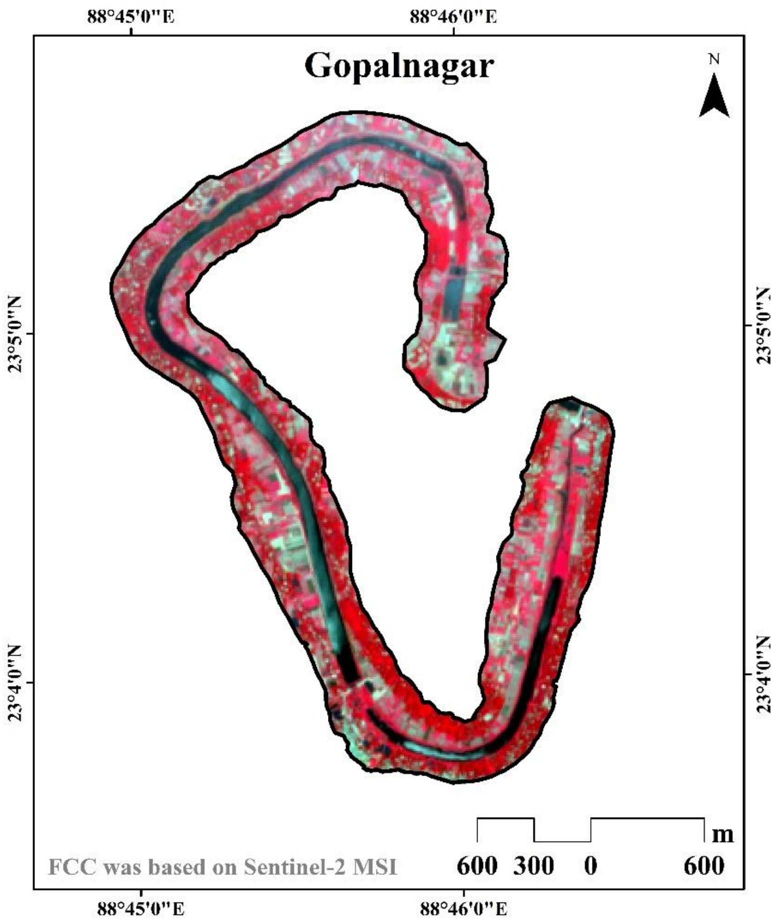

Fig. 3.8 Gopalnagar wetland

3.6.6 Manigram wetland

The Manigram wetland is situated in the center of the wetland complex. It had the exact form of an oxbow (Fig. 3.9). There were 361 households per km^2 in this wetland. During the lean season, this wetland was 5.55 meters deep. This wetland had a circumference of 6.33 km and an average width of 303 m. Water spread across an area of 46.5 ha during the monsoon months, but this area significantly shrunk to 32.9 ha during the lean period, a drop of 29.24%. The Manigram Wetland was mostly used for fishing. Fishing, paddy cultivation, and jute retting were the main economic activities performed in and within the WIZ of this wetland. Approximately 140 families of this wetland got their benefit from this wetland.

Table 3.7 Characteristics of Manigram wetland

Wetland	Water spreading area in monsoon (ha)	Water cover area in lean season (ha)	Reduction of water cover (%)	Perimeter (Km)	Depth (m)	Width (m)	Household density (no. of houses/km^2)
Manigram	46.5	32.9	29.24	6.33	5.55	303	361

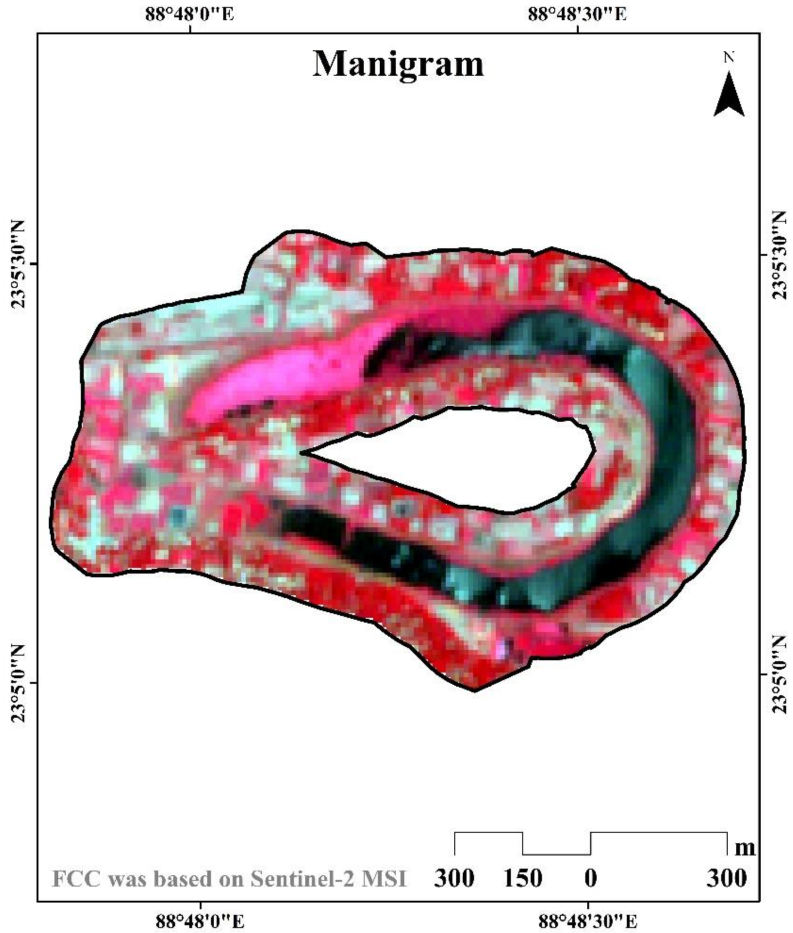

Fig. 3.9 Manigram wetland

3.6.7 Madhabpur wetland

The Madhabpur wetland is also located in the central part of this wetland complex. It was in perfect oxbow form (Fig. 3.10). There were 280 homes per km^2 surrounding this wetland. In this wetland, the lean season had seen the greatest depth of 10.34 m. This wetland had 4.74 km in circumference and 231 m in average width. Water spread across an area of 33.9 ha during the monsoon season, but this area significantly reduced to 21.7 ha during the dry season, a drop of 35.99%. The Madhabpur Wetland was primarily used for agriculture and fishing. However, it was a fishing-dominated wetland. Fishing, paddy cultivation, jute retting, and other dry-season crops were also produced in and surrounding WIZ. Around 80 households from adjacent communities gained their socio-economic benefits from this wetland.

Table 3.8 Characteristics of Madhabpur wetland

Wetland	Water spreading area in monsoon (ha)	Water cover area in lean season (ha)	Reduction of water cover (%)	Perimeter (Km)	Depth (m)	Width (m)	Household density (no. of houses/km^2)
Madhabpur	33.9	21.7	35.99	4.74	10.34	231	280

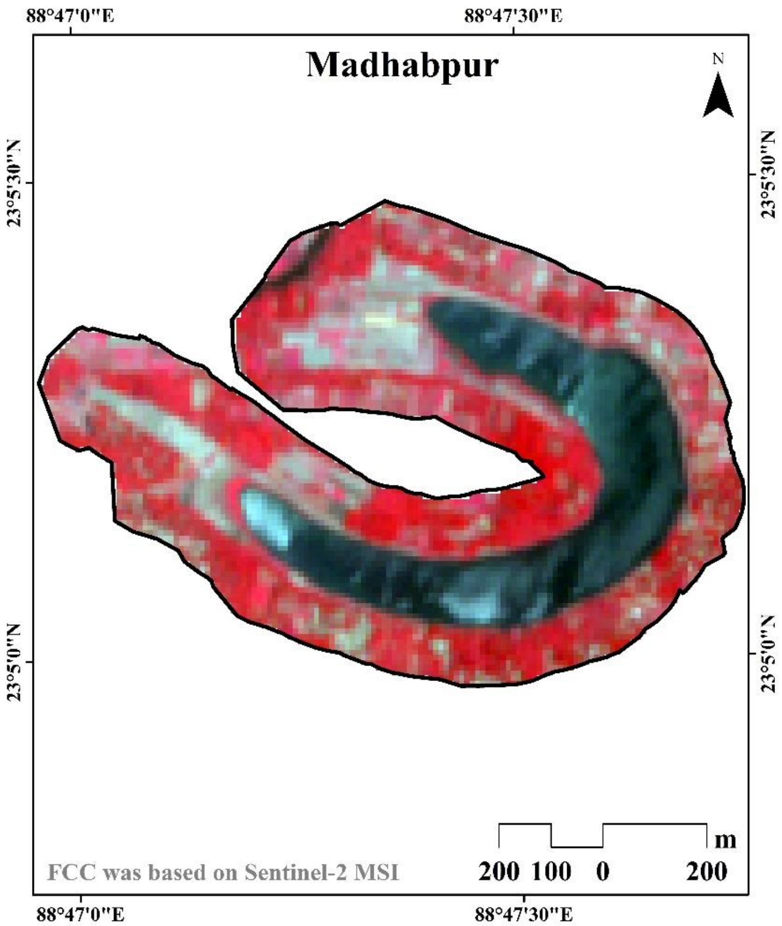

Fig. 3.10 Madhabpur wetland

Chapter 4: Methodology

4.1 Materials and methods applied

A robust research methodology with a realistic design and plan is of vital importance for carrying out a scientifically valid research. Moreover, the methodology for a particular research work is dependent upon the objectives of that research (Datta, 2012). In the present study, collection of water samples, soil samples, avifauna data, and fish data as well as quadrat vegetation surveys were done following simple and appropriate research techniques. Perception studies on the basis of focus group discussions (FGDs) and structured questionnaire-based surveys of stakeholders were also conducted (Fig. 4.1). Since this study required extensive fieldwork, simple and apt research designs and plans were framed to collect field-based data. The major aim of this research was to develop a C&I framework for the assessment of the changing WEH of wetlands of Ichhamati floodplains in North 24 Parganas, West Bengal using traditional, scientifically robust, and easy-to-measure indicators. This chapter includes a detailed description of the nature and sources of the data, the sampling techniques adopted to collect the data, and the various tools and techniques employed in analyzing the data to address the research goals (Fig. 4.1).

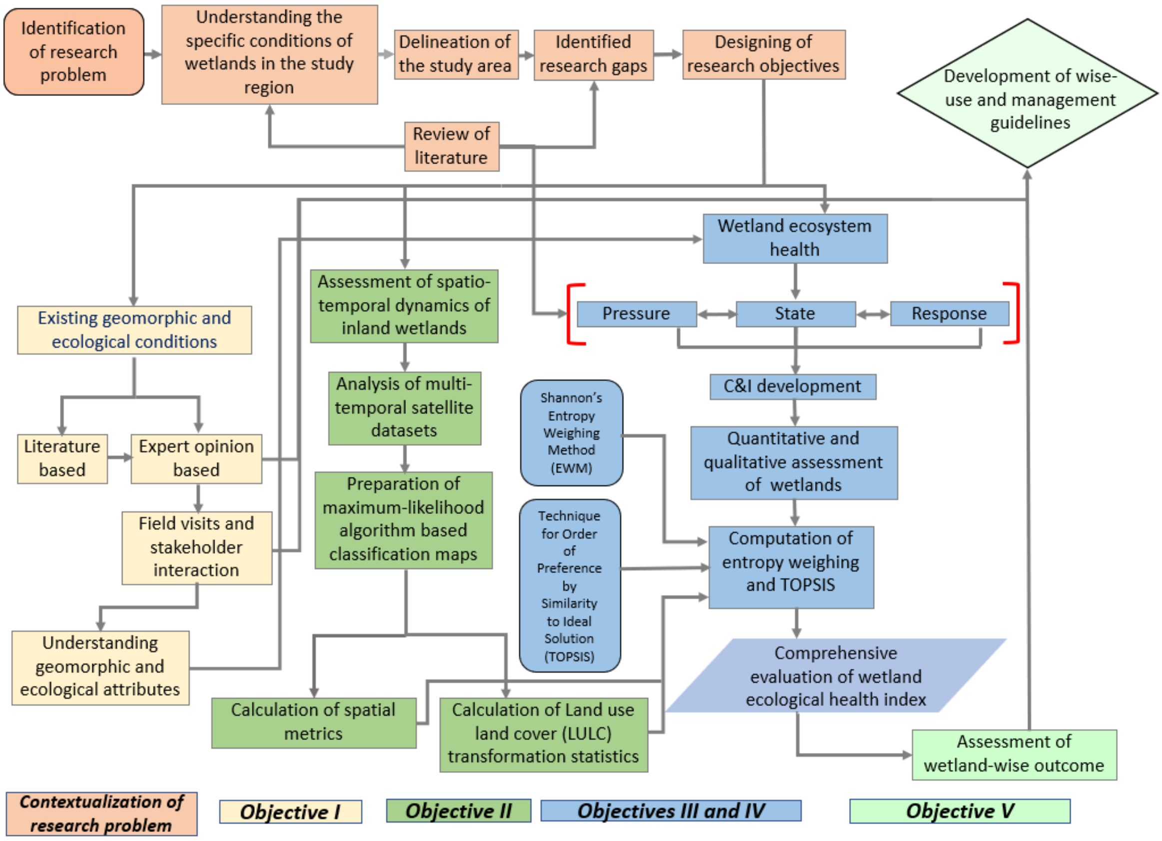

Fig. 4.1 Methodology framework for assessment of changing ecosystem health of wetlands of Ichhamati floodplains in North 24 Parganas, West Bengal

4.1.1 LULC change dynamics

LULC usually denotes the categorization of human-induced land uses and natural land covers within a landscape over a particular period. LULC of floodplain wetlands is a dynamic element and has therefore been changing rapidly due to acute poverty, intensive land use, and rapid growth in scientific and technological advances (Rai et al., 2017). The pattern of LULC, at any place, actually exhibits the intensity of the land use by the community people. Remote sensing (RS) and Geographic information system (GIS) technologies are increasingly used in wetland science to predict and monitor LULC change dynamics of wetland catchments. Therefore, RS and GIS had been applied in this research to capture the changing dynamics of LULC in the WIZ including the buffer zone. For this assessment, LULC maps of two specific years (2016 and 2020) were prepared so that the amount of human-induced stress and its subsequent effects on the environment and ecological state of wetlands can be evaluated. In addition, landscape-level and class-level metrics had also been computed to determine the scientific and exact amount of LULC changes. They are also capable to describe human pressure and subsequent changes in the wetland landscape (Mao et al., 2014; Lu et al., 2015; Liu and Hao, 2017; Das et al., 2020). Along with two LULC maps, normalized difference vegetation index (NDVI) maps for both 2016 and 2020 were also prepared. The LULC maps were then used to derive values for some indicators of catchment characteristics such as human-induced stresses on LULC of wetland influence zone (WIZ), areal fragmentation of perennial wetland zone (PWZ) of pressure criterion, patch density (PD), largest patch index (LPI), the Shannon diversity index (SHDI), the contagion index of WIZ (CONTAG), existing extent of WIZ around the wetland acting as a buffer, ratio of wetland wetted perimeter to WIZ perimeter acting as a buffer to understand the amount of human-induced pressure and subsequent changes in wetland settings using spatial analyst software FRAGSTATS 4.2 (McGarigal and Marks, 1995; Jia et al., 2015; Nandi et al., 2021) (Table 4.1). The PD and SHDI indicated the degree of landscape fragmentation by various types of LULC under human influence. A greater value of SHDI indicated a higher degree of land use *vis-à-vis* whereas, LPI demonstrated the dominant type of land use within WIZ thereby indicating the possible transformation of LULC in near future.

4.1.1.1 Data acquisition

This study was carried out with Sentinel2A MSIL1C and MSIL2A level satellite data

Table 4.1 Calculation methods used of some geospatial indicators for possible adaptation of the developed C&I framework

Evaluation indicator	Method used	Reference
Human-induced stresses on LULC of wetland influence zone	$Pressure\ on\ LULC_{WIZ} = \frac{(A_{BL} + A_{AL} + A_{AF})}{TA_{WIZ}} \times 100$ Where, WIZ = Wetland influence zone; BL = Built up land, AL = Agricultural land, AF = Agricultural fallow, TA = Total area (m^2) of WIZ	Proposed by the authors; Datta et al., 2020
Areal fragmentation of perennial wetland zone	$Areal\ fragmentation_{WPZ} = \frac{TA_{WPZ} - VA_{WPZ}}{TA_{WPZ}}$ Where, TA_{WPZ} = Area (m^2) of perennial wetland zone (WPZ), VA_{WPZ} = Vegetated area (m^2) of WPZ	Proposed by the authors
Patch Density (PD)	$PD = \frac{n_i}{A}$ Where, n_i = number of patches of i^{th} class, A=the total landscape area (m^2)	McGarigal and Marks, 1995; Jia et al., 2015; Sun et al., 2016; Sun et al., 2017
Largest Patch Index (LPI)	$LPI = \frac{max_{j=1}^{n} a_{ij}}{A} \times 100$ Where, a_{ij}= area (m^2) of a patch I and A=the total landscape area (m^2)	McGarigal and Marks, 1995; Jia et al., 2015;
Shannon's Diversity Index (SHDI)	$SHDI = -\sum_{i=1}^{m}(p_i ln p_i)$ Where, p_i= the proportion of the landscape occupied by each patch type i	McGarigal and Marks, 1995; Jia et al., 2015; Liu and Hao, 2016; Sun et al., 2016; Sun et al., 2017
Landscape Contagion Index of WIZ	$CONTAG = [1 + \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}[(P_i)(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}})] \times [ln(P_i)(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}})]}{2\ln(m)}] \times (100)$ Where, P_i = proportion of landscape occupied by i^{th} patch type, g_{ik} = the number of adjacencies between pixels of patch types *i* and *k*, and *m* = the number of patch types present in the landscape	O'Neill et al., 1988; Sun et al., 2017
The existing extent of WIZ around the wetland acts as a buffer	Average width [(Major axis width + minor axis width)/ 2] of WIZ acting as a buffer	Proposed by the authors
The ratio of wetland wetted perimeter to WIZ perimeter acting as a buffer	$Ratio\ of\ WP_{WIZ}\ to\ WP_{WPZ} = \frac{WP_{WIZ}}{WP_{WPZ}} \times 100$ Where WP= wetted perimeter (m)	Proposed by the authors
Normalized difference vegetation index (NDVI)	$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$	Liu and Hao, 2016; Sun et al., 2016; Nandi et al., 2020
Rate of change of vegetated area (VA)	$Reduction\ in\ VA\ (\%) = (\frac{VA_{Y1} - VA_{Y2}}{VA_{Y2}}) \times 100$ Where, VA = Vegetation area (m^2), Y1 = base year, Y2 = final year	Proposed by the authors
Rate of change of open water surface area (OWSA)	$Reduction\ in\ OWSA\ (\%) = (\frac{OWSA_{Y1} - OWSA_{Y2}}{OWSA_{Y2}}) \times 100$ Where, OWSA = open water surface area (m^2), Y1 = base year, Y2 = final year	Proposed by the authors

(Table 4.2). 5-year interval satellite images of the lean period with a moderately fine spatial resolution (10 m) were downloaded from the Copernicus Open Access hub (Nandi et al., 2021).

Table 4.2 Satellite images used for identification of wetland sites and LULC dynamics

Date of acquisition	Satellite	Product Level	Sensor ID	Spatial resolution (m)
30.04.2016	Sentinel-2A	MSIL1C	T45QXF	10
19.04.2020	Sentinel-2A	MSIL2A	T45QXF	10

To obtain cloud-free images and realistic views of wetlands, images of April images both years (2016 and 2020) were chosen. The 2016 image contains Sentinel-2A data with MSI level1C and the 2020 image contains Sentinel-2A MSI level2A satellite data (Tile number: T45QXF).

4.1.1.2 Data processing

The entire pre-processing was conducted using the Sentinel Application Platform (SNAP) software package. The Sen2core toolbox was also used to correct the top-of-atmosphere (TOA) of level-1C data to bottom-of-atmosphere (BOA) reflectance data products. However, no such correction was required for the 2020 image, as the Sentinel-2A MSIL2A data had already been corrected by the European Space Agency (ESA). Then, the corrected data sets were used for further analysis. 180 ground control points (GCPs) were collected during the field phases using the Garmin eTrex 20X handheld device. Afterward, the geometric correction was performed on both satellite images to ensure ground truth with 180 GCPs and reduce the effects of terrain distortion (Hansen and Loveland, 2012; Roy and Datta, 2018). Less than 0.5 pixels, an acceptable error level, was kept as the Root-Mean-Square-Error (RMSE) (Shalaby and Tateishi, 2007; Datta and Deb, 2012).

4.1.1.3 Identification of representative wetlands

Sentinel-2A MSIL1C and MSIL2A satellite images of 2016 and 2020 with 10 m resolution was used for delineating each wetland site with the help of Erdas Imagine 2018 software (Roy and Datta, 2018; Nandi et al., 2020). Satellite images of the lean period were selected for April taking into consideration of low cloud coverage for the selected wetlands.

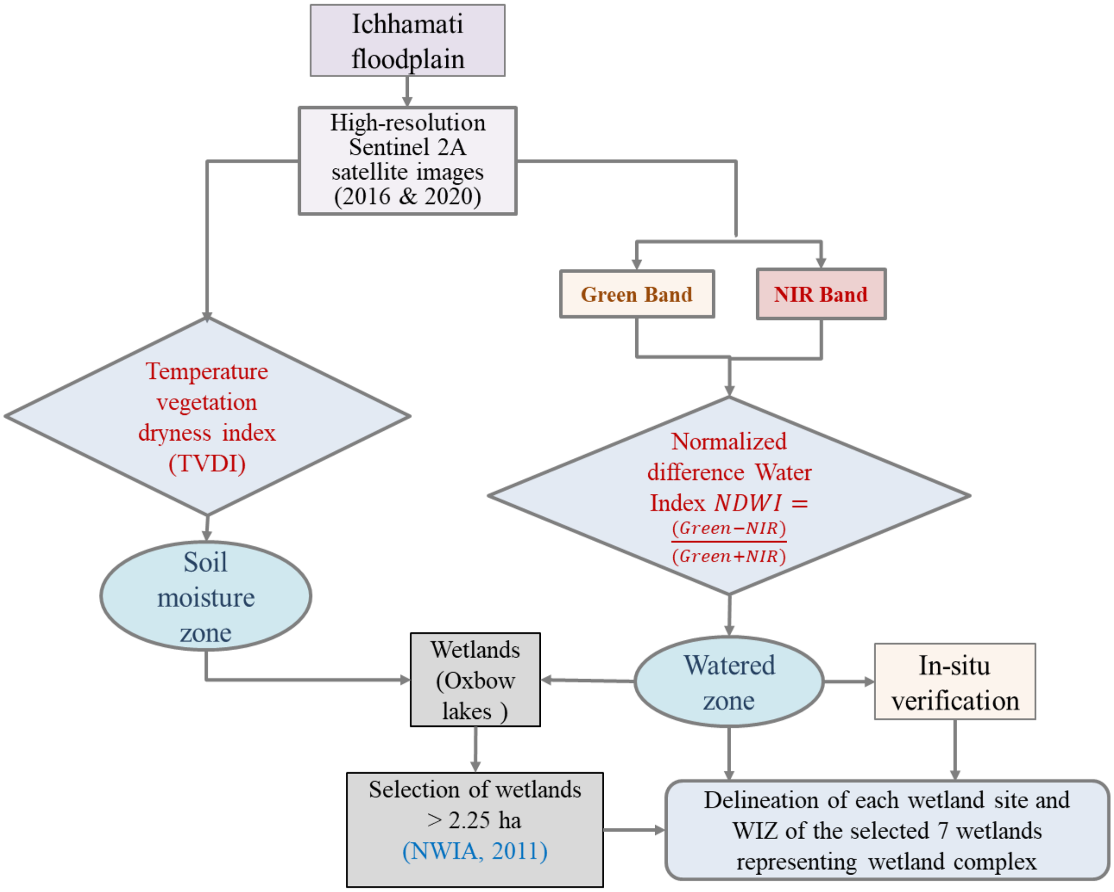

Fig. 4.2 Delineation of each wetland site in the wetland-complex

After that, single class supervised classification technique assisted with a maximum likelihood algorithm was applied to identify moist zone based on spectral reflectance (Li et al., 2018; Roy and Datta, 2018; Datta et al., 2021) (Fig. 4.2). Moreover, McFeeters' Normalized Difference Water Index (NDWI) was used to identify parts of the land covered by permanent water (McFeeters, 1996; Ji et al., 2009; Sing et al., 2015; Wu et al., 2018; Datta et al., 2021). McFeeters described the NDWI as the ratio between the normalized difference of Green and Near Infrared (NIR) bands (Ji et al., 2009; Wang et al., 2018).

The computation equation of NDWI is as follows:

$$NDWI = \frac{(Green-NIR)}{(Green+NIR)} \qquad \text{(Eq. 4.1)}$$

The value of NDWI ranged from +1 to -1, where positive values indicated watered areas and negative values indicated non-watered areas (Ji et al., 2009). Temperature vegetation dryness index (TVDI) was also calculated based on land surface temperature (LST) and normalized difference vegetation index (NDVI) for identifying soil moisture area within WIZ (Patel et al., 2019; Shi et al., 2020; Datta et al., 2021). These two indices i.e., NDWI and TVDI helped in identifying both the watered areas and soil moisture zone of the selected wetlands. The watered area detection and soil moisture zonation were conducted using a threshold-based approach by employing both TVDI and NDWI indices. Furthermore, high-resolution Google earth images were also used to identify wetlands with permanent water cover during the lean time. Wetlands were digitized by putting GCPs on Google Earth and the kml files of these digitized wetlands were converted from kml to layer in the ArcGIS platform. These shape files of wetlands were also used for validation purposes while identifying the watered areas from the NDWI map. Thereafter, the raster dataset with all identified wetlands within the area of interest (AOI) was converted into a vector layer (.Shp) to make it compatible with the ArcGIS platform and for further geospatial analyses (Datta and Deb, 2012; Roy and Datta, 2018). Initially, 2,389 individual wetland polygons were identified. However, major wetlands were identified by removing small wetlands areas of < 2.25 ha and merging isolated polygons into a wetland complex (Panigrahy et al., 2011; Tiner et al., 2015). Thereafter, seven wetlands were identified as the representative wetlands in a wetland-complex from the selected AOI for further detailed study.

4.1.1.4 Establishing a buffer zone around a wetland

Buffer zone always plays a very crucial role in the ecological functioning of the wetland ecosystem. A buffer zone is where most human interaction with wetlands occurs. However, fixing a buffer zone is challenging and requires profuse skill and expertise. In this study, four key biophysical indicators (*viz*., water level during peak monsoon, hydric soils, wetland vegetation, and movement of wetland fauna) were considered to delineate the wetland boundary. A 90 m ring buffer zone was created using ArcGIS 10.5 software based on the researcher's prior field experience, stakeholders' opinions, and the expertise of wetland experts (Chase et al., 1995; McElfish et al., 2008; Ma, 2016).

4.1.1.5 LULC classification and landscape metrics generation

Using the ENVI software package, a supervised classification was performed on both Sentinel-2A data sets. The spectral angle mapper algorithm was used to map the spectral similarity based on the referenced spectra from the sentinel MSI images. The raster data sets were classified into eight major LULC categories such as a) inland wetland, b) river, c) water body, d) terrestrial vegetation, e) cropland, f) agricultural fallow, g) built-up land, h) aquatic vegetal cover (NRSC, 2014). Accuracy assessment was also performed separately for both years. Based on the occupied area (ha) of each LULC class in two different years, several widely used landscape metrics, including the number of patches (NP), PD, LPI, SHDI, and CONTAG had been calculated. In addition, human-induced stresses on LULC of WIZ, areal fragmentation of WPZ, existing extent of WIZ around the wetland acting as a buffer, ratio of wetland wetted perimeter to WIZ perimeter acting as a buffer, NDVI, rate of change of vegetated area (VA) and rate of change of open water surface area (OWSA) were also measured to quantify human stress on wetland systems, prevailing environmental conditions, and ecological responses.

The amount of human-induced pressure on LULC of WIZ was calculated by dividing the summative area of built-up land, cropland, and agricultural fallow by the total LULC area. Through this calculation, the amount of human-induced pressure was obtained in the WIZ, which would otherwise have been in natural form. Areal fragmentation of the perennial wetland zone (WPZ) was calculated by dividing the parcel area of open water surface area by the total area of the WPZ. The amount of open water surface area outside water hyacinth patches was also calculated that is crucial for sunlight penetration and dissolving oxygen into wetland water to sustain aquatic life.

4.1.2 Concept of PSR framework

Ecologists had given close attention to the study of how natural ecosystems responded to various types of stressors resulting from human activities since the inception of the Stockholm Conference on the Human Environment (1972) by the United Nations. At the same time, scientists, researchers, academia, and planners were looking for a tool or framework through which they could deal with environmental responses in a better way. In this context, Rapport (1979) first proposed the concept of the pressure-state-response (PSR) framework in a study entitled *"Towards a Comprehensive Framework for Environmental Statistics: A Stress-Response Approach"*. Subsequently, the Organization for Economic Co-operation and Development (OECD, 1993; Linster and Fletcher, 2001) further developed the concept of the PSR framework. Initially, the PSR framework was created to support environmental policy-making. However, over time it had been used equally in other studies around the world to assess environmental quality, ecosystem sustainability, and ecosystem health. In addition, many well-known organizations had contributed to environmental policy-making by developing several other essential frameworks, including the Driver-Pressure-State-Impact-Response indicators (DPSIR) (OECD, 1997; Jesinghaus, 2000; European Environmental Agency, 2003), the Driving-Force-State-Response (DFSR) (UNCSD, 1996; Commission on Sustainable Development, 2001), the Pressure-State-Use-Response-Capacity (PSURC) (Convention on Biological Diversity, 2003) based on the OECD's original PSR framework. The PSR framework consists of three components: (a) pressure, (b) state, and (c) response (Fig. 4.3).

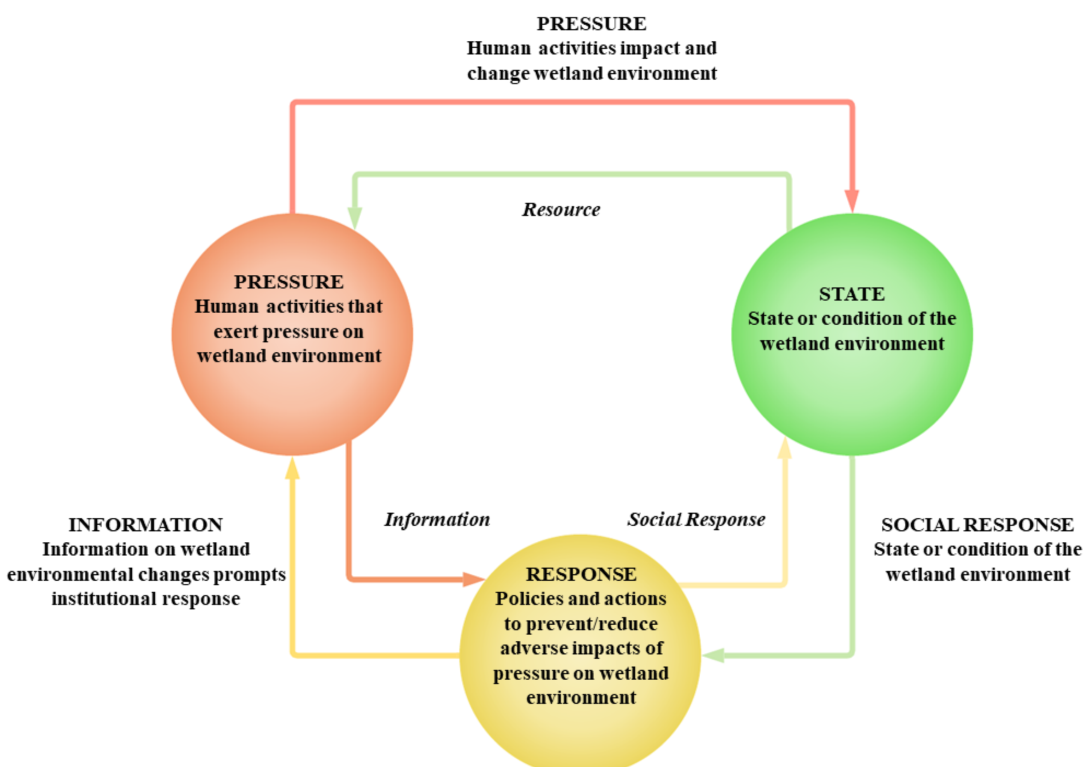

Fig. 4.3 Pressure-state-response (PSR) framework (adapted from OECD 1993)

Pressure describes human activities such as population growth, economic activity, use of environmental resources, and greenhouse gas (GHG) emissions, etc. The state reflects environmental conditions such as algal blooms, fish deaths, declines of migratory birds, global mean temperature rises, etc. It describes changes in the state, including environmental settings or the physical environment triggered by human activities. Response defines the initiative, role, or efforts of society and policy makers to restore the system from further deterioration or degradation towards achieving sustainable environmental conditions (Mao et al., 2014; Jia et al., 2015). Similarly, the response describes the system's response, such as the ecological response when the system is disturbed, including water-borne diseases, wetland soil erosion, or loss, that require immediate management initiatives (Mao et al., 2014). The PSR framework demonstrates the inextricable link between three elements: pressure, state, and response to any environmental system (Jia et al., 2015). These three components are conjointly related to each other: pressure changes the state or setting; changing state or settings requires responses to reduce further pressure on ecosystems. The ultimate aim of the PSR framework is to assess 'pressure' on ecosystem and the physical environment due to the impact of human-induced socioeconomic activities and how much these pressures affect current conditions or the state of the system, and thereafter to what extent social, economic, institutional, and political responses are required for restoration of a disturbed or degraded system into an environmentally friendly state or condition (Mao et al., 2014).

4.1.2.1 Justification for applying PSR framework in WEH assessment

The ecosystem health of wetlands is a newly emerging concept in wetland science and the environment (Jørgensen et al., 2013). A healthy ecosystem is highly essential for human well-being and the environment for its ecological balance (Horwitz et al., 2012). A wetland ecosystem health assessment can only provide information about whether a wetland is in good condition. The PSR model facilitates evaluation and empowers environmental planners to measure the health of wetland ecosystems (Jia et al., 2015). Achieving wetland health optimization is extremely challenging due to the growing and complex human-wetland interactions (Horwitz et al., 2012). As communities extract more food, water, energy, and other services from wetlands, wetland depletion continues (Junk et al., 2013). Furthermore, it is impossible to imagine people in isolation from wetlands in the people-environment nexus (Horwitz et al., 2012). Therefore, periodic health assessments are essential to understand a specific aspect of stressors and how these drivers disrupt the normal state of the wetland and threaten the natural systems. Finally, it is also important to know what kind of social, institutional, and community-level response or initiatives can be taken to restore ecosystem health for the benefit and well-being of human societies and their environment. In this scenario, the PSR framework-based ecosystem health assessment model was one of the best options to address wetland ecosystem health at a time (Mao et al., 2014). Only a meaningful connection between wetland ecosystems and people can improve ecosystem health and society's well-being (Horwitz et al., 2012). The PSR framework gave us that avenue to identify driver variables at three systems levels that significantly impact wetland settings (Jia et al., 2015). Therefore, it will help environmental managers to identify and capture driver variables that negatively impact wetland settings. Indeed, the relative weighing of each indicator under the PSR framework will help in understanding the impact of various important factors that led to wetland degradation and deterioration. The exploitative nature of human economic activities had led to the depletion of most of these precious resources. Therefore, wetland ecosystem health assessment involving pressures on wetlands, wetland states or conditions, and institutional responses of wetlands that similarly go with the objectives of the PSR model. Hence, the PSR model may be justifiable for assessing ecosystem health. Furthermore, under the pressure-state-response framework, one can also perceive and communicate the relationship of each evaluation system to wetland ecosystem health (Hazbavi et al., 2020). Hence, the development of a comprehensive C&I framework is highly essential in this regard.

4.1.3 Developing C&I framework

The first international conference on *"Application of Ecological Indicators for the Assessment of Ecosystem Health*" was held in October 1990 in Fort Lauderdale, Florida (Jørgensen et al., 2013). Since then, many national and international conferences on environmental indicators and ecosystem health assessment (EHA) had been conducted globally. As a result, several indicators had emerged and been applied to assess ecosystem health over the past 32 years. However, the selection of evaluation indicators entirely depends on the type of wetland ecosystem under investigation, its geographical location, and the researcher's specific interests, skills, competencies, and objectives (Cui & Yang, 2002; Jia et al., 2015). General set of environmental indicators with a 'one size fits all' status explicitly do not exist or have not yet been found (Jørgensen et al., 2006; Jørgensen et al., 2013). Moreover, selecting the set of best indicators that accurately portray WEH is always challenging. To bridge this gap, a set of general C&I framework was developed which was scientifically sound, environmentally strong, socio-economically relevant, and able to meet the long-standing demand for WEH assessment in Ichhamati floodplains in specific and similar areas in general. Here, a thorough review of published relevant literature was conducted to identify the best-suited indicators that could accurately reflect WEH in the study sites. The C&I framework was constructed in such a way that it could reflect the health status of the wetlands in terms of ecosystem structure, functionality, and socio-economic relevance (Datta, 2012). In reality, each evaluation criterion of the developed C&I framework under the PSR approach would bear characteristic information only on the part of the overall health of a wetland ecosystem in a specific space-time context (Mao et al., 2014; Jia et al., 2015). Since the wetland ecosystem exhibited a complex structure with many open and closed systems, qualitative and quantitative indicator-based assessments were applied to accrue better results about the overall WEH (Yaxin et al., 2011; Jia et al., 2015). Here, indicators for each evaluation criterion of the PSR approach were identified from aquatic, edaphic, floral, faunal, and human realms of the wetland environment towards a holistic assessment framework.

Assessment of the wetland's changing ecosystem health was initially divided into four levels, including target, evaluation system, evaluation criterion, and evaluation indicators. The *'changing ecosystem health of wetlands of Ichhamati floodplains in North 24 Parganas, West Bengal'* was set as the first level target principle. To address the target principle, the WEH was analyzed by dividing it into three evaluation systems: pressure, state, and response in the second level. Any wetland system's health depends entirely on these three essentials but comprehensibly interconnected systems. Any decline in one system would ultimately affect the health of the wetland ecosystem. The third level refers to the evaluation criterion that described the different biophysical aspects under each evaluation system. The fourth level stated evaluation indicators which indicated scientifically justifiable, environmentally robust, and easy-to-measure indicators by which WEH can be assessed (Jørgensen et al., 2013). These indicators defined evaluation criteria and its meaning with an easy explanation.

4.1.3.1 Identification of target principle

This study addressed changing wetland ecosystem health, a fundamental consideration, as this research aimed to address whether the wetlands under consideration exhibit the expected health (Jia et al., 2015; Mao et al., 2014; Ezquerra, 1987). Therefore, *'changing ecosystem health of wetlands of Ichhamati floodplains in North 24 Parganas, West Bengal'* was fixed as a target principle at the first level. In general, the WEH depends on how healthy the four major components of a wetland ecosystem are, namely the edaphic, aquatic, biotic, and socio-economic components (Fig. 4.4).

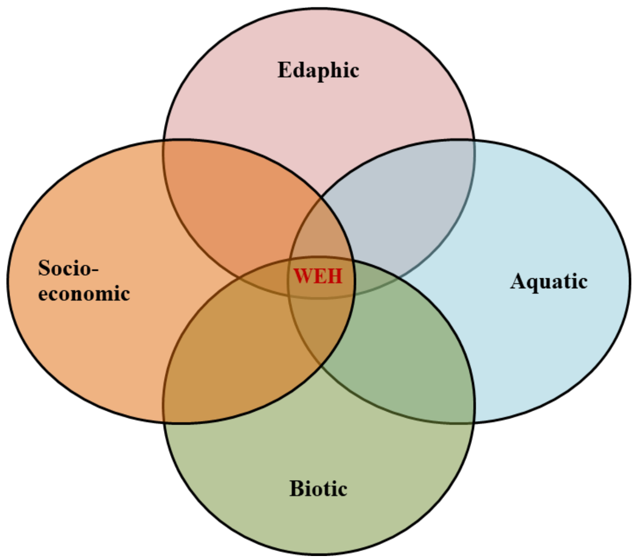

Fig. 4.4 Components of wetland ecosystem health prepared by the researcher

The interactions and interplay of various drivers/actors under these four elements were crucial in defining the health status of selected wetland ecosystems (Jia et al., 2015; Horwitz et al., 2012). In this study, changes in the health of the studied wetland ecosystems were considered as immediate consequences of mutual interactions and connections between aquatic, biotic, edaphic, and socioeconomic components comprehensively. The rationale and findings of Jorgenson et al. (2013), Jia et al. (2015), and Mao et al. (2014) were initially considered as the main reference for the selection of the target principle. Additionally, Sun et al. (2017) and Liu and Hao (2017) were also referred to identify criteria and their related subfields for better understanding.

4.1.3.2 Selection of proper evaluation system under target principle

In this study, the evaluation system occupied the second level immediately after the target level of the PSR framework. An evaluation system for target replication was more consistent and self-explanatory and had a more specific role in wetland ecosystem health assessment under the PSR model. Three evaluation systems (*i.e.*, pressure, state, and response), were used as evaluation systems to understand the health status of the wetland ecosystem. Several pieces of literature were also consulted to develop the C&I framework. Each evaluation criterion under this evaluation system was selected based on factual inferences and case study evidence. In addition, each selected evaluation system somewhat explains the objectives of the ecosystem health assessment. Three evaluation systems included pressure on wetland ecosystems (pressure grew out from expanding population growth, growing demand, unequal resource extraction, use of water resources and greenhouse gas emissions, etc.), state of wetland ecosystems (ecological state, environmental state, and functional state), and response (environmental response, social response, institutional response to restore degraded eco-environmental systems) (Mao et al., 2014).

4.1.3.3 Selection of appropriate evaluation criterion under each system

The evaluation criterion was placed in the third hierarchical level immediately after the evaluation system of the PSR model. Under each evaluation system, a set of relevant and logical evaluation criterion was selected to reflect the characteristics of the four main components of the wetland system (Fig. 4.4) (Mao et al., 2014; Jia et al., 2015). Several indicator frameworks of reputed organizations like OECD, the World Resource Institute (WRI), and the European Union (EU) were considered for the selection of criterion (OECD, 1993; Mao et al., 2014; Jia et al., 2015). Care was taken in selecting each criterion, and several pieces of literature such as journal papers, thesis, and projects were reviewed to capture all the biotic and abiotic components of a wetland ecosystem. The reasoning and findings of Jia et al. (2015) and Mao et al. (2014) were used to understand the constituent elements of the evaluation criterion. Finally, the evaluation criterion consisted of wetlands' biophysical, ecological, environmental, and multi-functional characteristics. Ambastha et al. (2007 and 2008). Mao et al. (2014) and Ren et al. (2014) also helped in defining socio-economic criteria for WEH assessment.

4.1.3.4 Selection of appropriate evaluation indicators under each criterion

Evaluation indicators were placed at the fourth level of hierarchy immediately after the evaluation criterion in the PSR model. Initially, several relevant indicators were compiled based on available literatures under the selected evaluation criterion. Then, the indicators were selected following the PSR framework proposed by the OECD (2001) and the findings

Photograph 4.1 *Vesali net* (local fish catching technique) at Aromdanga wetland

of Jia et al. (2015) and Mao et al. (2014). Finally, major indicators of the pressure system were selected from Piotr (2003), Jia et al. (2015), Mao et al. (2014), and Jorgenson et al. (1989). The initial set of selected indicators for the C&I framework under the PSR model was conveyed to various stakeholders to assess, wetland ecosystem health in a FGD environment. A total of seven FGDs were held in the studied wetlands, one for each wetland, with 10 to 12 persons in each group (Photograph 4.2). FGDs were scheduled on the basis of accessibility, proximity, and preferences of individuals. Resource persons such as secretary or president of fishing cooperatives, fishers, farmers, livestock rearers, school teachers and environmentalists, Panchayat Pradhan and representatives, and representatives of NGO were participated mainly for their rich knowledge about the wetland and its socio-economic activities. This approach was helped researcher to integrate their knowledge into the C&I framework. These resource persons initially evaluated the indicators and then revised another set, incorporating their suggestions into the developed framework. The modified C&I framework was then validated by experts with in-depth knowledge of wetlan

Photograph 4.2 Focus group discussions at Aromdanga wetland

-d ecosystem health. These experts were from geography, ecology, botany, and environmental backgrounds. They were associated with various institutions in the state of West Bengal.

4.1.3.5 Selection of appropriate measures under each indicator

The various relevant easy-to-measures were formed the fifth level of the C&I framework in assessing ecosystem health. It provided highly specific details about an indicator including its meaning as well as precisionness. Measures actually described a method of measuring a particular indicator to infer specific information about the indicator to capture essence of evaluation systems. These simple and self-explanatory measures were sufficient to enable the researcher and even the common person to understand the meaning of it in a very clear, lucid, and meaningful way. These measures were also capable to address the purpose of selecting respective evaluation criteria.

4.1.4 Data collection procedure

4.1.4.1 Sampling techniques used for identification of stakeholders

Wetlands are used by various user groups. However, some user groups were substantially dependent on it and thereby had a copious amount of wetland interaction experiences. These major groups were stakeholders of the wetland namely fishers, farmers, livestock rearers, and indirect users. Hence, a stratified random sampling technique was used to divide the population of wetland user groups into major four strata *i.e.*, namely, fishers, farmers, livestock rearers, and indirect users. 10 to 20% of people from each user group were selected for participatory appraisal and subsequent inference of information on the studied wetland-complex's biological and socio-cultural systems. Hence, a structured questionnaire survey schedule was prepared to comprise forty-nine questions following the assessment criteria and associated indicators (Datta et al., 2010; Datta 2012; Sun et al., 2019) to evaluate stakeholders' perception of the ecological health of selected wetlands (Photograph 4.3).

Photograph 4.3 Questionnaire survey with fishers at Gopalnagar wetland

Since no systematic study had been done on the status of WEH of this wetland complex now, this was selected as the present study area to test the developed C&I framework. To meet this, pertinent attributes of geology, geomorphology, ecology, and anthropogenic uses of these selected wetlands within the wetland-complex had been identified with the help of FGDs (n = 7) involving major stakeholders and on the basis of secondary sources data which subsequently considered during the indicator selection phase. Apart from these, various important issues were discussed in FGDs at each wetland site following water quality deterioration immediately after jute-retting, fish death, algal bloom, weed management, stakeholder’s conflict, waste dumping, bio-surveillance, wastewater accumulation, unscientific fishing techniques, indiscriminate use of pesticides and insecticides.

4.1.4.2 Field and laboratory-based measurement of evaluation indicators

Altogether, twenty-four physico-chemical parameters of surface water health and fourteen physico-chemical parameters of soil health were identified in this study (Cui et al., 2012; Baird and Bridgewater, 2017). Among the surface water health parameters, twelve parameters viz. water depth, surface temperature, turbidity, pH, dissolved oxygen (DO), electrical conductivity (EC), and eutrophication level were measured in-situ using standard instruments and field observations (Photograph 4.6). The remaining twelve parameters of water such as biological oxygen demand (BOD), chemical oxygen demand (COD), fecal coliform bacteria, total coliform (TC), amount of phosphate (P), amount of ammoniacal nitrogen (H6N2), amount of nitrate (NO3), arsenic (As), fluoride (F), the concentration of cadmium (Cd), mercury (Hg), lead (Pb), chromium (Cr) were subsequently tested in the laboratory following the standard procedures of APHA (2017) (Table 4.3). Water samples were collected from wetlands at a depth of 0.5 m under the water and stored in purified glass bottles that were initially washed with nitric acid (HNO3) (Agboola et al., 2016). Sub-surface soil samples were collected from 10-20 cm depths to avoid fresh organic litter (Power et al., 1981; Gallo et al., 2018). Parameters like soil bulk density, soil pH, total organic carbon (TOC), available soil nitrogen (N), available soil phosphorus (P), soil potassium (K), soil EC, the concentration of As, Cd, Hg, Pb, and Cr were also tested in the laboratory (Table 4.3). Among edaphic parameters, only the level of soil moisture was measured in the field (Photograph 4.6).

Photograph 4.4 Jute plants at Gopalnagar wetland

Photograph 4.5 In-situ data collection through (a) DO measurement at Panchpota wetland, (b) soil sample collection at Berkrishnapur wetland, (c) DO and Temperature measurement at Madhabpur wetland, (d) quadrat survey at Panchita wetland, (e) scheduled-based survey with fisher at Aromdanga wetland, (f) quadrat vegetation survey in Manigram wetland, (g) scheduled-based survey with local peasants at Aromdanga wetland

4.1.4.3 Construction of questionnaire surveys for perception based indicators

Several indicators dealt with temporal and societal changes happening in and around the wetland sites, which might not be assessed correctly through direct field measurements or geospatial analyses. Therefore, the only viable option remaining was a participatory appraisal and subsequent inference of information on the studied wetlands' complex biological and socio-cultural systems. Therefore, a structured questionnaire schedule was prepared following the assessment criteria and associated indicators (Datta et al., 2010; Datta, 2012; Sun et al., 2019).

Table 4.3 Field and laboratory based analyses of physico-chemical parameters of water and soil of the studied wetlands. Instruments for in-situ measurement and testing method specifications used in laboratory-based analyses of some indicators are mentioned for possible universal adaptation of the developed C&I framework

Evaluation indicator	Instrument/Method used	Reference
Fecal coliform (mpn 100 mL^{-1})	APHA 23rd Edition-2017	Agboola et al., 2016
Phosphate (P) (mg L^{-1})	APHA 23rd Edition-2017	Agboola et al., 2016
Ammoniacal nitrogen (H_6N_2) (mg L^{-1})	APHA 23rd Edition-2017	Agboola et al., 2016; Henderson et al., 2021
Nitrate (NO_3) (mg L^{-1})	APHA 23rd Edition-2017	Agboola et al., 2016
Arsenic (As) (mg L^{-1})	APHA 23rd Edition-2017	Agboola et al., 2016
Fluoride (F) (mg L^{-1})	APHA 23rd Edition-2017	Agboola et al., 2016
Depth of water (m)	Staff gauge	Magee and Kentula, 2005; Henderson et al., 2021
Turbidity (m)	Sechi disk	Agboola et al., 2016; Henderson et al., 2021
Surface temperature (°C)	A mercury-in-glass thermometer	Agboola et al., 2016; Henderson et al., 2021
Biological oxygen demand (BOD) (mg L^{-1})	APHA 23rd Edition-2017	Agboola et al., 2016
Chemical oxygen demand (COD) (mg L^{-1})	APHA 23rd Edition-2017	Agboola et al., 2016
pH	Hanna Pocket Type pH meter (Model number: HI96107)	Agboola et al., 2016; Henderson et al., 2021
Cadmium (Cd) (mg L^{-1})	APHA 23rd Edition-2017	Agboola et al., 2016
Mercury (Hg) (mg L^{-1})	APHA 23rd Edition-2017	Agboola et al., 2016
Lead (Pb) (mg L^{-1})	APHA 23rd Edition-2017	Agboola et al., 2016
Chromium (Cr) (mg L^{-1})	APHA 23rd Edition-2017	Agboola et al., 2016
Dissolved oxygen (DO) (mg L^{-1})	Lutron DO meter (Model number: Lutron/PDO-520)	Agboola et al., 2016; Henderson et al., 2021
Electrical conductivity (EC) (µS cm^{-1})	HM Digital EC meter (Model number: HM_AP2)	Hardie & Doyle, 2012; Agboola et al., 2016
The salinity of wetland water (ppt)	HM Digital EC meter (Model number: HM_AP2)	Hardie and Doyle, 2012
Rate of siltation (mm h^{-1})	Sediment volume was calculated for 1 hour of residence and settling of colloidal particles of sediment	Wieland et al., 1991
Availability of soil moisture	Luster Leaf 1827 soil moisture meter (Model: Rapitest Digital Plus)	Hájek et al., 2013
Evaluation indicator	Instrument/Method used	Reference
Soil bulk density (g cm^{-3})	Soil bulk density was calculated as the ratio of the mass of dry solids to the bulk volume of soil	Blake and Hartge, 1986; Rokosch et al., 2009
Available soil nitrogen (N) (kg ha^{-1})	The procedure involves distilling the soil with an alkaline potassium permanganate solution and determining the ammonia liberated	Tandon, 1993

Available soil phosphorus (P) (kg ha^{-1})	Olsen's method was used for neutral-alkaline soils while the Bray and Kurtz method was used for acidic soils	Tandon, 1993
Status of potassium (K) (kg ha^{-1})	Potassium with flame photometer model (Systronics flame photometer 128)	Jackson, 1967
Soil organic carbon (SOC) (mg ha^{-1})	Wet oxidation method modified from Walkley and Black	Jackson, 1967
Soil EC (µS cm−1)	Systronic E C meter (Model number: Systronics µ Conductivity meter 306)	Basak, 2000
Soil pH	Systronic pH meter (Systronics µ pH meter 361)	Jackson, 1967
Arsenic (As) (µg kg^{-1})	USEPA Acid Digestion Method 3050	da Silva et al., 2013
Cadmium (Cd) (mg kg^{-1})	USEPA Acid Digestion Method 3050	da Silva et al., 2013
Mercury (Hg) (µg kg^{-1})	USEPA Acid Digestion Method 3050	da Silva et al., 2013
Lead (Pb) (mg kg^{-1})	USEPA Acid Digestion Method 3050	da Silva et al., 2013
Chromium (Cr) (mg kg^{-1})	USEPA Acid Digestion Method 3050	da Silva et al., 2013

This questionnaire was used to evaluate stakeholders' perceptions of the ecological health of selected wetlands. Questions related to wetland ecological conditions were carefully designed to cover four wetland user groups: fishers, farmers, livestock rearers, and indirect users (Datta and Ghosh, 2015). Twenty indicators related to edaphic, aquatic, biotic, and socioeconomic realms of the environment and having qualitative dimensions were selected for this purpose and placed in front of the respondents belonging to different stakeholder groups to understand the amount of 'pressures' on wetland ecosystems exerted by anthropogenic activities. Similarly, thirteen indicators were used to understand the 'state' of the wetland, and sixteen questions were asked to understand the ‘response’ component. At each wetland site, 20 individuals (viz. five from each stakeholder group of farmers, fishers, livestock rearers, and indirect users) were surveyed with a structured questionnaire in a systematic random sampling method. Questions were cautiously organized to maintain a flow of answers, and sentences were simplified to avoid confusion. The number and length of questions were consistently kept as short as practicable. The questionnaire mainly consisted of two types of questions: rating scale or Likert scale questions and binary questions. After the questionnaire was developed, five previously selected wetland experts reviewed it and verified the content and appropriateness of the questionnaire questions following the research rationale. The questions were translated and printed in Bengali script for easy understanding of the stakeholder participants. Then, printouts of the desired number of questionnaires for each stakeholder interview were taken in the field.

4.1.4.4 Preparation of scoring guide

Since the study dealt with a wide variety of quantitative and qualitative evaluation indicators, it was not customary to follow a single scoring method for evaluating all indicators. Therefore, three types of scoring methods were applied as suggested by wetland experts. First, the five-point scoring system was used to standardize the data with different units and different scales of measurement (Datta et al., 2010). Each measure was labelled with one of five possible options, namely 'A', 'B', 'C', 'D' and 'E', indicating 'Very High', 'High', 'Moderate', 'Low' and 'Very Low' respectively. Each option from 'A' to 'E' was represented with a score of 5, 4, 3, 2, and 1, respectively (Datta et al., 2010). Assign direct scores (e.g., 5,4,3,2 and 1) to indicators that have a positive impact on wetland ecosystems, and reverse scores (e.g., 1, 2, 3, 4, and 5) to indicators that have a negative impact on wetland ecosystems were completed (Table 4.4). Second, a few indicators were there having central optimum value. Therefore, highest score i.e., 5 was given to central optimum value and lowest values at two trailing ends. Third, a few indicators could not be assigned with five options because these questions could be answered either 'yes' or 'no'. All these binary questions were assigned a 5 for 'yes' and 1 for 'no' to maintain the five-point scoring system equally (Datta, 2012). The mean and standard deviation of each indicator and the final score was given accordingly (Table 4.4). Then, weight of each indicator was calculated.

Table 4.4 Scoring method of indicator having both positive or negative impact on WEH

Scale	Direct scoring	Reverse scoring	Scale	Central optimum value
> $\bar{x}$+1.5SD	A = 5	E = 1	< $\bar{x}$ - 2 SD	E = 1
($\bar{x}$+0.5 SD) to ($\bar{x}$+1.5SD)	B = 4	D = 2	< $\bar{x}$ -1.5 SD to $\bar{x}$ - 2 SD	D = 2
($\bar{x}$-0.5SD) to ($\bar{x}$+0.5 SD)	C = 3	C = 3	< $\bar{x}$ -1 SD to $\bar{x}$ -1.5 SD	C = 3
($\bar{x}$-1.5SD) to ($\bar{x}$-0.5SD)	D = 2	B = 4	< $\bar{x}$ -0.5 SD to $\bar{x}$ -1 SD	B = 4
< $\bar{x}$-1.5SD	E = 1	A = 5	$\bar{x}$ + 0.5 SD to $\bar{x}$ - 0.5 SD	A = 5
			> $\bar{x}$ + 0.5 SD to $\bar{x}$ + 1 SD	B = 4
			> $\bar{x}$ + 1 SD to $\bar{x}$ + 1.5 SD	C = 3
			> $\bar{x}$ + 1.5 SD to $\bar{x}$ + 2 SD	D = 2
			> $\bar{x}$ + 2 SD	E = 1

4.1.5 Entropy weighing method (EWM)

The concept of the entropy weighing method (EWM), used variably in various scientific fields, was first propounded by C. E. Shannon in 1948 and introduced to the field of ecology through information theory. In physics, entropy indicates the amount of chaos or disorder in a system (Islam and Roy, 2006). For example, in the transportation model, the dispersion of trips between origin and destination was measured by the entropy method (Islam and Roy, 2006). Entropy is also used to measure a dataset's degree of randomness and fuzziness (Güneralp et al., 2007). However, Shannon's entropy, an important measure of the probability of uncertainty in information theory, measures the relative weight of the importance of criteria based on differences in information (Lotfi and Fallahnejad, 2010; Monghasemi et al., 2015). The higher the entropy value for a particular criterion, the lower the weight of that criterion and the relatively less discriminatory power of that criterion in the decision-making process and vice versa (Islam and Roy, 2006; Lotfi and Fallahnejad, 2010). The entropy weighing method incorporates reliable outputs, while the subjective method fails to calculate criteria weights due to decision-makers biases and inadequate decision-making. Apart from data interdependence, this is one of the main advantages of this objective approach (Fig. 4.5).

In the multiple criteria decisions making (MCDM) approach, relative choices are made for evaluating, prioritizing, and selecting alternatives (i) usually attributed to multiple mutually conflicting criteria. Each indicator represents some information that has a significant meaning and must be distinct from the other indicators. Depending on the different roles of the indicators, each indicator will not carry the same weight. Therefore, one of the main objectives of MCDM is to derive appropriate weights for each indicator (j). However, there are several suitable methods for calculating weights that can be broadly classified into two categories: subjective and objective weights (Lotfi and Fallahnejad, 2010). Subjective weights are determined by relative preferences endorsed by the decision makers, whereas objective weights are derived by solving mathematical models without considering decision makers' preferences. Subjective weights can be calculated using the analytical hierarchy process (AHP), Delphi, weighted least square methods, etc. Whereas objective weight calculation can be done using the entropy weighing method (EWM), principal component analysis (PCA), and multiple objective programming (MOP). However, the accuracy of subjective weighing depends entirely on the skill and judgment ability of the decision-makers. In real-life situations, objective weighing is difficult to achieve because it does not involve the expertise and judgment of decision-makers. Besides, objective weights become operative and useful when calculating subjective weights for a dataset becomes difficult. Subjective weighing fails when C&I is linked to quantitative indicators or physical measurements. Therefore, among several measures in practice, researchers and academia have profoundly proposed the Shannon entropy weighing method to derive objective weights for qualitative and quantitative attributes (Lotfi and Fallahnejad, 2010).

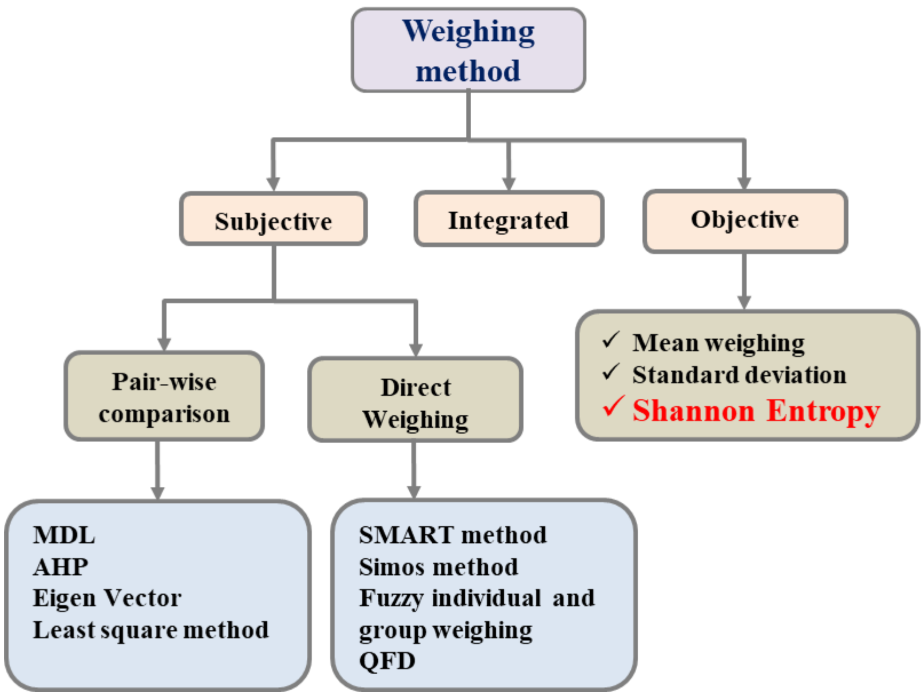

Fig. 4.5 Flowchart for selecting EWM among other weighing methods

Therefore, Shannon's entropy is a highly recommended and practiced method in deriving weights for MCDM problems, especially when the relative preferences and skills of the decision-maker do not work. For that reason, Shannon's EWM was used here to derive weights for both qualitative and quantitative indicators as follows:

In EWM, *m* alternatives (e.g., wetlands) and *n* indicators are considered to evaluate the value of x_{ij}. Here, x_{ij} = the standardized score of the j^{th} indicator for the i^{th} wetland. The obtained decision matrix of these x_{ij} scores are further normalized by Eq. (1) to eliminate anomalies in data dimensions and convert different units and scales into common measurabl

-e units to facilitate comparisons of different indicators.

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \qquad \text{(Eq. 4.2)}$$

where, r_{ij} = the normalized score of jth indicator for ith wetland; *i = 1, 2, 3, ……….m; j = 1, 2, 3, ………. n.* Then, entropy (e_j) for each indicator was computed as follows:

$$e_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} r_{ij} \ln r_{ij} \qquad \text{(Eq. 4.3)}$$

where, $\ln r_{ij}$ is defined as 0, if $r_{ij} = 0$. Thereafter, the calculation of the degree of variation (d_j) for each criterion was done as:

$$d_j = 1 - e_j \qquad \text{(Eq. 4.5)}$$

where d_j measures the degree of variation of vital information for the j^{th} indicator. Lastly, the calculation of the final entropy weight for each indicator (w_j) was as follows:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \qquad \text{(Eq. 4.6)}$$

4.1.6 Construction of CWEHI using the TOPSIS method

A comprehensive ecological health index (CWEHI) to infer the overall condition of the wetlands was developed by merging the weighted scores of indicators (fourth level) under each criterion (second level), i.e., pressure or state, or response. "The Technique for Order of Preference by Similarity to Ideal Solution" is called TOPSIS. TOPSIS was applied as the aggregation method for constructing this composite index (Hwang and Yoon, 1981; Yoon and Hwang, 1985; Aslam et al., 2021). Ching-Lai Hwang and Yoon developed TOPSIS in 1981 to solve multiple decision-making problems. Later, TOPSIS was further improved by Yoon (1987) and Hwang, Lai and Liu (1993) to make the decision-making process more realistic. TOPSIS relies on the principle that the most preferred alternative should be located nearer to the positive ideal solution (PIS) and as far distant as possible from the negative ideal solution (NIS). It allows differentiation among alternatives in terms of the weights of each indicator, its normalized score, and the geometric distance between alternatives in terms of each criterion (Fig. 4.6). In TOPSIS, data normalization is essential to convert criteria from different units and scales into one feasible unit of measurement. Here, the ideal alternative is the one that scores the best in each criterion (Dakos et al., 2015).

For the construction of CWEHI using TOPSIS, an evaluation matrix (X) was conceived first and may be described as:

$$X = (x_{ij})_{m \times n} = \begin{bmatrix} x_{11}, & x_{12}, & x_{1n} \\ x_{21}, & x_{22}, & x_{2n} \\ x_{m1} & x_{m2} & x_{mn} \end{bmatrix} \qquad \text{(Eq. 4.7)}$$

Where, m denotes the total number of wetlands within the complex (P). $P = \{P_i | i = 1, 2, \ldots., m\}$; n denotes a total number of evaluation indicators under a criterion (C). $C = \{C_j | j = 1, 2, \ldots., n\}$. The normalization of the evaluation matrix and computation of the normalized score (r_{ij}) was done using the following equation:

$$\text{Normalized matrix, } R = (r_{ij})_{m \times n} = \begin{bmatrix} r_{11}, & r_{12}, & r_{1n} \\ r_{21}, & r_{22}, & r_{2n} \\ r_{m1} & r_{m2} & r_{mn} \end{bmatrix} \qquad \text{(Eq. 4.8)}$$

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad \text{(Eq. 4.9)}$$

Thereafter, the final normalized weighted score (WS_{ij}) of an indicator was computed as:

$$WS_{ij} = r_{ij} \times w_j \qquad \text{(Eq. 4.10)}$$

where, W_j = final entropy weight for each indicator obtained through Shannon's EWM. $W = \{W_j | j = 1, 2, \ldots., n\}$; $W_j > 0 \text{ and } \sum_{j=1}^{n} W_j = 1$.

The determination of the best alternative (A_b) and the worst alternative (A_w) for each wetland (i^{th}) was then assessed based on the impact of each indicator (positive or negative) interplayed upon the cumulative characteristics of the wetlands. In this case,

$$A_b = \{\langle \min (r_{ij} | \ i = 1, 2, 3, \ldots\ldots, m \mid j \in J_- \rangle, \langle \max(r_{ij} | i = 1, 2, 3, \ldots., m | j \in J_+ \rangle\} \equiv \{r_{bj} | j = 1, 2, 3, \ldots., n\} \qquad \text{(Eq. 4.11)}$$

$$A_w = \{\langle \max (r_{ij} | \ i = 1, 2, 3, \ldots\ldots, m \mid j \in J_- \rangle, \langle \min(r_{ij} | i = 1, 2, 3, \ldots., m | j \in J_+ \rangle\} \equiv \{r_{wj} | j = 1, 2, 3, \ldots, n\} \qquad \text{(Eq. 4.12)}$$

where, $J_+ = \{j = 1, 2, 3, \ldots\ldots, n | j\}$ indicates indicator having a positive impact, and $J_- = \{j = 1, 2, 3, \ldots\ldots, n | j\}$ having a negative impact on overall WEH.

The Euclidean distance **(**$Ed_b^+ \text{ and } Ed_w^-$ respectively) of the i^{th} target alternative from the best and worst alternatives is measured as follows:

$$Ed_b^+ = \left[\sum_{j=1}^{m} (V_{ij} - V_j^+)^2\right]^{0.5} \qquad \text{(Eq. 4.13)}$$

$$Ed_w^- = \left[\sum_{j=1}^{m}\left(V_{ij} - V_j^-\right)^2\right]^{0.5} \qquad \text{(Eq. 4.14)}$$

where, Ed_b^+ and Ed_w^- are two distances from the target alternative i to the PIS and NIS respectively.

The CWEHI of each wetland under each criterion is then computed by Eq. (11):

$$CWEHI_i = \frac{Ed_w^-}{(Ed_w^- + Ed_b^+)} \qquad \text{(Eq. 4.15)}$$

Where, $0 \leq Ed_{iw} \leq 1; i = 1, 2, 3, \ldots\ldots, m$; $CWEHI_i \leq 1$, only if the alternative has the best condition, and $CWEHI_i \geq 0$, only if the alternative solution has the worst condition. Lastly, all wetlands were ranked in ascending order based on these $CWEHI_i$ values for each criterion (Ren et al., 2014; Sun et al., 2019). All the wetlands were also classified using the CWEHI scores as 'morbid' (≤ 0.2), 'weak health' (0.2-0.4), 'moderate health' (0.4-0.6), 'good health' (0.6-0.8) and 'excellent health' (≥ 0.8) as per standard scientific literature on this aspect (Table 4.8) (Sun et al., 2016; Sun et al., 2017; You et al., 2019).

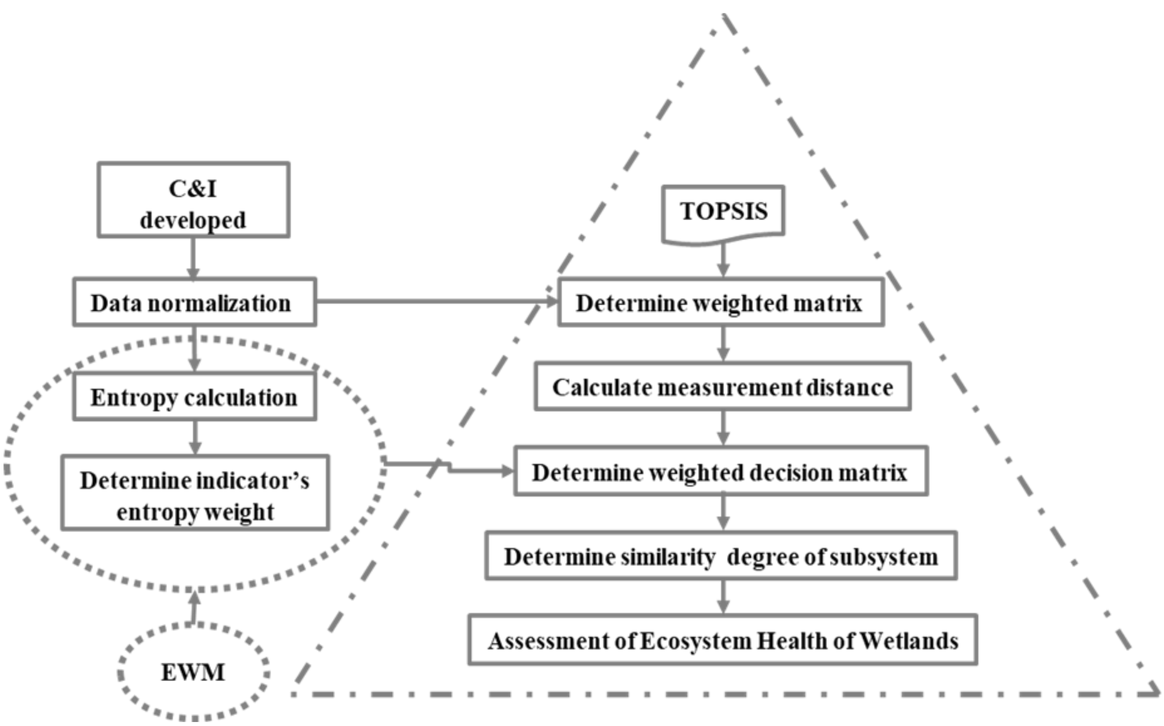

Fig. 4.6 Flowchart of EWM and TOPSIS operation

Table 4.5 Health status, class level, scores of CWEHI and ecological characteristics of studied wetland

Health status (HS)	Class level (CL)	Comprehensive wetland ecological health index (CWEHI)	Wetland ecosystem characteristics
Excellent health	I	0.8-1.0	Wetlands are characterized by relatively low human pressure and strong vigor, exhibiting excellent ecosystem structure and efficiency, the wetland system maintains an ecologically stable state and improved resilience.
Good health	II	0.6-0.8	Wetlands appear to have good structure and functionality, relatively low external pressure, relatively stable, the system maintains a sustainable condition.
Moderate health	III	0.4-0.6	Wetlands have shown relatively low strength, medium structure and functionality, relatively high external pressure, fair elasticity, and stability, and relatively waning vigor, yet the system maintains a fairly durable condition.
Weak health	IV	0.2-0.4	Wetlands exhibited damaged structure and deteriorating functionality, high anthropogenic stress, poor resilience and stability, and low vigor, and the system begins to erode.
Morbid	V	0.0-0.2	With unreasonable structure and severely degraded functionality, very high anthropogenic pressure, very weak elasticity, unstable, and very low vigor, the system is severely degraded.

Photograph 4.6 Alaghar (fish surveillance house) under water in Madhabpur wetland during heavy rainfall in 2016

Chapter 5: Spatio-temporal Transformation of Wetland LULC Dynamics

5.1 Landscape character of wetland catchment area from 2016 to 2020

Wetlands are highly desirable and lucrative in terms of their services, goods, and products for human well-being (MEA, 2005). Hence, wetland catchments, including buffer areas, supported large populations and experienced heavy human-induced socio-economic activities (Gayen et al., 2020). People encroach into the reclaimed parts of the wetlands for their habitation and agriculture during the summer months. Therefore, many human settlements had developed in the WIZ over the years. Furthermore, their influence on the studied wetlands through land use had notably observed (Datta et al., 2021). In the present study, the researcher tried to see through land use intensification, how human-induced pressures increased over the last five years (from 2016 to 2020) within the 90-m buffer zone from the WPZ boundary. Two LULC maps (viz. LULC of 2016 and 2020) were created using Sentinel satellite images to understand the land use intensity of the seven selected wetlands. LULC of 2016 and LULC of 2020 have been discussed in detail in the following sub-sections to understand their dynamic change characteristics.

5.1.1 Accuracy assessment of the 2016 LULC map

An accuracy assessment the of 2016 classified map was done using the same ground control points (GCPs) collected during field visits in 2016. The Kappa coefficient of the classified 2016 LULC map was 0.9064. The overall classification accuracy was obtained at 92.69%. Better overall accuracies were found due to the finer pixel resolution of Sentinel-2A images compared to MSS, TM, ETM+, and OLI sensor-based images.

5.1.2 LULC dynamics in 2016

Supervised classification was performed on both Sentinel data sets using the ENVI software package, and the LULC map of 2016 was prepared. Altogether, eight LULC classes were identified so far including 1) inland wetland, 2) river, 3) waterbody, 4) terrestrial vegetation, 5) cropland, 6) agricultural fallow, 7) built-up and 8) aquatic vegetal cover. The LULC class-wise percentage of the area was given in Table 5.1. The inland wetland class was comprised of wetland water surface areas open or free from hyacinth patches. Maximum inland wetland (24.85%) was found in Madhabpur wetland and minimum in Aromdanga wetland (2.63%) in 2016. The LULC class river indicated that the main river Ichhamati falls within the 90 m buffer area from WPZ. Here, the amount of River area was found to be maximum in the Aromdanga wetland (2.83%) and

Table 5.1 LULC statistics of the selected wetland in 2016

Wetland	LULC class															
	Inland wetland		River		Waterbody		Terrestrial vegetation		Cropland		Agricultural fallow		Builtup		Aquatic vegetal cover	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Berkrishnapur	8.01	7.41	0.12	0.11	0.39	0.36	44.36	41.02	13.64	12.61	29.27	27.07	5.31	4.91	7.03	6.50
Panchpota	8.27	10.55	1.35	1.72	1.61	2.05	30.49	38.88	2.00	2.55	13.90	17.73	8.18	10.43	12.62	16.09
Panchita	47.44	18.27	0.00	0	1.05	0.40	66.48	25.60	32.86	12.65	55.81	21.49	20.97	8.08	35.08	13.51
Aromdanga	4.27	2.63	4.59	2.83	0.65	0.40	37.71	23.25	26.10	16.09	78.34	48.30	9.85	6.07	0.70	0.43
Gopal Nagar	49.4	15.69	0.00	0	2.38	0.76	92.06	29.24	35.59	11.30	97.73	31.04	28.76	9.13	8.96	2.85
Manigram	16.15	16.14	0.00	0	0.45	0.45	15.32	15.31	20.10	20.09	33.25	33.23	5.86	5.86	8.92	8.92
Madhabpur	19.41	24.85	0.76	0.97	0	0	29.55	37.83	9.60	12.29	14.03	17.96	4.65	5.95	0.11	0.14

(2.83%) and Panchpota wetland (1.72%) (Fig. 5.1).

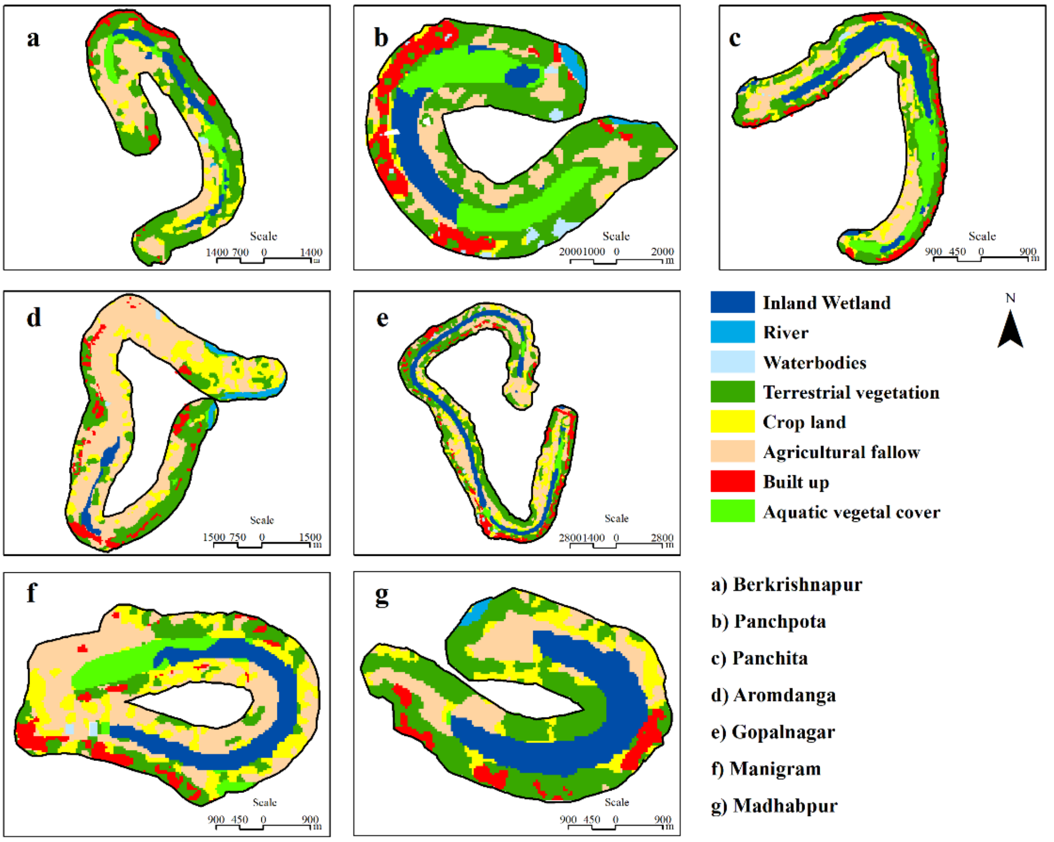

Fig. 5.1 Wetland-wise different LULC types (2016)

The river Ichhamati was very close to these two wetlands. The water body class comprised artificial water features, namely fish ponds excavated for aquaculture farming within the wetlands buffer zone. Here, maximum aquaculture for carp fishes was observed in the Panchpota wetland (2.05%). Madhabpur wetland did not have any waterbody in 2016. The class terrestrial vegetation comprised various kinds of plants, vegetation stands, trees, and shrubs found along the WIZ including wetland buffer zone and along the natural dykes of each wetland. It was one of the essential LULC classes of the studied wetlands as it provides habitats to various avifauna and microorganisms. The highest terrestrial vegetation was found in the Berkrishnapur wetland (41.02%) in 2016 only because of the plantation program of the *Lambu* tree (*Khaya anthotheca*), *Guava* tree (*Psidium guajava*) and *Mango* tree (*Mangifera indica*), and the minimum terrestrial vegetation was found in the Manigram wetland (15.31%) in 2016 due to lack of such plantation program. The class crop land comprised land covered with crops, mainly Ravi crops, as satellite images of April *i.e.*, the lean period for this study had chosen. Maximum cropland was observed in the Manigram wetland (20.09%), followed by the Aromdanga wetland (16.09%), Panchita wetland (12.65%), Berkrishnapur wetland (12.61%) and Madhabpur wetland (12.29%) due to lands reclaimed at two horns and along the littoral tracts of each wetland during the lean season. The class 'agricultural fallow' included land without crops during the lean period or cutting out the crops during the lean period. It was observed that Aromdanga wetland had maximum agricultural fallow land, i.e., 48.30% in 2016 which was attributed to the harvesting of seasonal crops and vegetables, followed by Manigram wetland (33.23%), Gopalnagar wetland (31.04%), and Berkrishnapur wetland (27.07%) just because of harvesting of seasonal vegetables and crops and thereby agricultural plots were left. The class built-up included concrete roofs, tin and asbestos roofs, school buildings, shops, small-scale commercial houses, roads, and state/national highways. Maximum built-up areas were observed in the Panchpota wetland (10.43%) because of settlement expansions and the development of transport networks and a minimum in Berkrishnapur wetland (4.91%) which was relatively at a distant place from the main road and having less population density. The class aquatic vegetation cover comprised with aquatic weeds: water hyacinth, water cabbages, algae, duckweeds, water lily, lotus, various sedges, and reeds. Maximum aquatic vegetation cover was observed in the Panchpota wetland (16.09%), and the minimum was found in the Madhabpur wetland (0.14%) in 2016.

5.1.3 Accuracy assessment of the LULC map of 2020

An accuracy assessment the of 2020 classified map was also performed using 180 ground control points (GCPs) collected during field visits in 2016-2020. The Kappa coefficient of the classified LULC map of 2020 was better *i.e.,* 0.9462 than in 2016. The overall classification accuracies were 95.54% which was also quite good compared to 2016.

5.1.4 LULC dynamics in 2020

The LULC class-wise percentage of the area was given in Table 5.2. The highest amount of inland wetland was found in the Panchpota wetland (30.57%), followed by Madhabpur wetland (27.97%), Berkrishnapur wetland (15.37%), Panchita wetland (13.55%), and Manigram wetland (11.93%) due to weed removal programs of the fishing communities as well as by Gram Panchayat in 2020. However, the low inland wetland was found due to hyacinth patches in Aromdanga (4.18%) and Gopalnagar wetland (9.79%) in 2020.The amount of river class remained same in 2020 as of 2016.

Table 5.2 LULC statistics of the selected wetland in 2020

Wetland	LULC class															
	Inland wetland		River		Waterbody		Terrestrial vegetation		Cropland		Agricultural fallow		Builtup		Aquatic vegetal cover	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Berkrishnapur	16.33	15.37	0.12	0.11	0.10	0.09	34.18	32.18	17.31	16.29	23.64	22.25	6.97	6.56	7.58	7.14
Panchpota	23.26	30.57	1.33	1.75	0.64	0.84	20.06	26.36	6.17	8.11	10.31	13.55	10.11	13.29	4.22	5.55
Panchita	34.86	13.55	0.00	0.00	1.14	0.44	63.91	24.84	36.31	14.11	28.55	11.10	24.31	9.45	68.20	26.51
Aromdanga	6.52	4.18	4.36	2.80	0.54	0.35	30.98	19.88	38.69	24.83	56.06	35.97	12.92	8.29	5.78	3.71
Gopal Nagar	29.37	9.79	0.00	0.00	2.18	0.73	88.34	29.45	40.80	13.60	70.49	23.50	31.53	10.51	37.29	12.43
Manigram	11.82	11.93	0.00	0.00	0.82	0.83	18.38	18.55	14.34	14.47	18.34	18.50	6.91	6.97	28.50	28.76
Madhabpur	21.24	27.97	0.66	0.87	0.07	0.09	29.62	39.01	10.24	13.49	8.23	10.84	5.66	7.45	0.21	0.28

The largest area of waterbody class describing aquaculture farming was observed in the Panchpota wetland (0.84%), followed by the Manigram wetland (0.83%) and Gopalnagar (0.73%), and Panchita wetland (0.44%) in 2020 (Fig. 5.2). The highest amount of terrestrial vegetation cover was found in Madhabpur wetland (39.01%), followed by Berkrishnapur (32.18%) and Gopalnagar (29.45%), Panchpota (26.36%) wetland and Panchita (24.84%) in 2020 because of plantation program of *Lambu* tree (*Khaya anthotheca*), *Guava* tree (*Psidium guajava*) and *Mango* tree (*Mangifera indica*). Only the Manigram wetland (18.55%) and Aromdanga wetland (19.88%) had again shown the lowest vegetation cover in terrestrial vegetation in 2020 due to logging and lack of a significant plantation program. Again, the highest amount of crop cover area was found in Aromdanga (24.83%), followed by Berkrishnapur (16.29%) and Manigram wetland (14.47%), and Panchita (14.11%) wetland which again indicated continued pressure from the local people (Fig. 5.2).

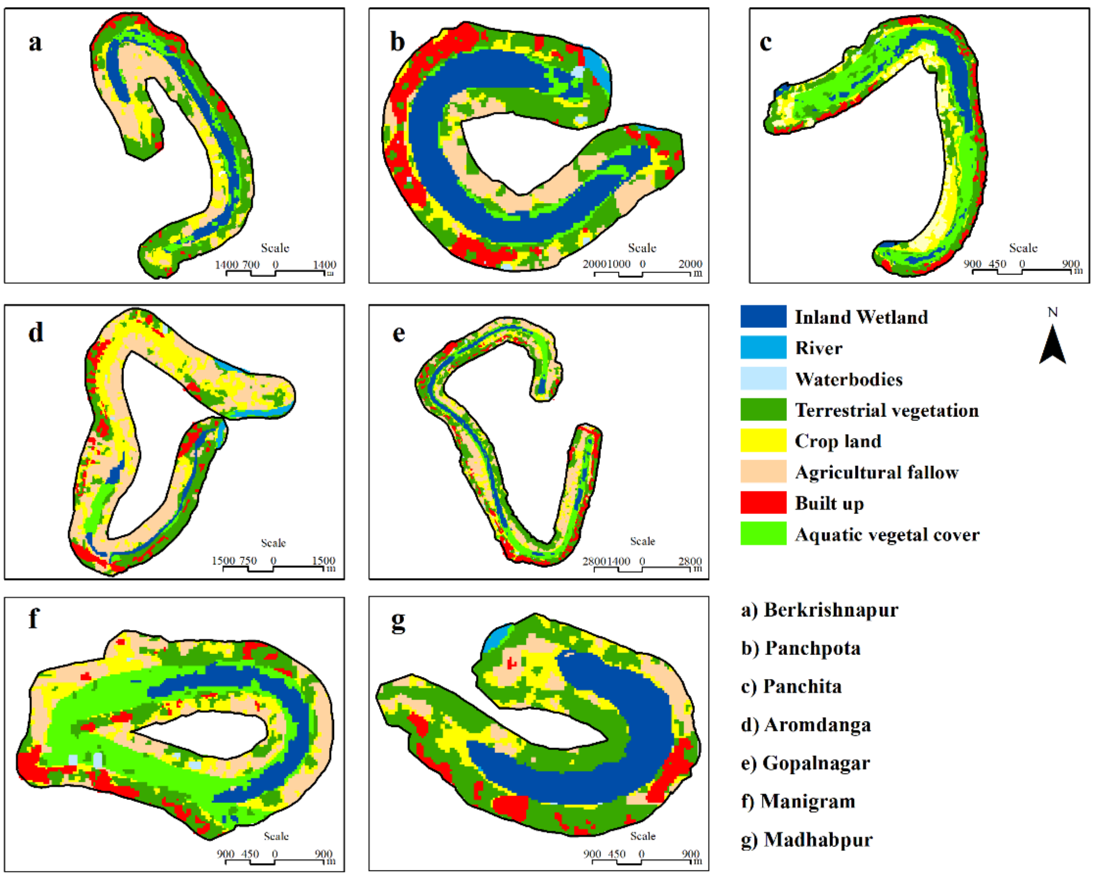

Fig. 5.2 Wetland-wise different LULC types (2020)

However, it was found to be minimum in Panchpota (8.11%) and Madhabpur wetland (13.49%) due to a lack of optimum agricultural plots and inclination of communities to fishing than agriculture and Gopalnagar (13.60%) showed minimum crop area because most of the vegetable crop was harvested during April in 2020. The area under agricultural fallow was found maximum in the Aromdanga wetland (35.97%), followed by Gopalnagar (23.50%), Berkrishnapur (22.25%), Manigram (18.50%), Panchpota (13.55%) wetland in 2020 which was found to be attributed to the harvesting of crops. The built-up area was found maximum in the Panchpota wetland (13.29%), followed by Gopalnagar (10.51%) and Panchita (9.45%) wetland in 2020. However, Panchita (11.10%) and Madhabpur wetland (10.84%) held minimum agricultural fallow land in 2020. Such reduction in the agricultural fallow area was noticed and to be attributed to an increase in crop area and the built-up area in the study sites. The built-up area was found maximum in the Panchpota wetland (13.29%) followed by Gopalnagar (10.51%) and Panchita (9.45%) wetland in 2020 chiefly due to rural settlement expansion. The aquatic vegetal cover area had found again maximum in Manigram (28.76%) followed by Panchita (26.51%), Gopalnagar (12.43%), and Berkrishnapur (7.14%) wetland in 2020 due to plantation of *Lambu* tree by land owners. Madhabpur wetland (0.28%), Aromdanga (3.71%), and Panchpota wetland (5.55%) found to be hold minimum areas respectively in aquatic vegetation cover in 2020 due to periodical weed removal program at both the community and Panchayat level.

5.1.5 LULC change dynamics between 2016 and 2020

The percentage of the area by LULC class was also given in Table 5.3. In 2020, open water coverage in inland wetland class increased in Berkrishnapur wetland (7.96%) and Panchpota wetland (20.02%), Aromdanga wetland (1.55%), and Madhabpur wetland (3.12%) due to weed removal program taken by the fishing communities as well as Gram Panchayat. However, open water coverage had decreased due to increased hyacinth patches in Panchita (4.72%), Gopalnagar (5.9%), and Manigram wetland (4.22%) in 2020. The amount of river class was remained in 2020 as of 2016 in all studied seven wetlands. The area under waterbody indicated aquaculture farming decreased in 2020 in Berkrishnapur (0.27%), Panchpota (1.21%), Aromdanga (0.05%), and Gopalnagar (0.03%) wetland. However, in Manigram (0.38%), Panchita (0.04%), and Madhabpur (0.09%) wetland aquaculture areas had increased in 2020. In 2020, most wetlands showed a decrease in terrestrial vegetation covers, such as Berkrishnapur (8.85%), Panchpota (12.52%), Panchita (0.76%), and Aromdanga (3.37%) wetland. Whereas, Madhabpur, Manigram, and Gopalnagar wetlands showed an increase of 1.18%, 3.23%, and 0.21% respectively in terrestrial vegetation cover in 2020. Apart from the Manigram wetland (5.62% decrease), the remaining six wetlands had shown an increase in crop cover area, namely Berkrishnapur (3.86%), Panchpota (5.56%), Panchita (1.46%), Aromdanga (8.73%), Gopalnagar (2.30%) and Madhabpur (1.20%) wetlands in 2020. The agricultural fallow area was also decreased in selected seven wetlands, namely Berkrishnapur (4.82%), Panchpota (4.18%), Panchita (10.39%), Aromdanga (12.32%), Gopalnagar (7.54%), Manigram (14.73%) and Madhabpur (7.12%) wetlands. Such a decrease in the agricultural fallow area may be attributed to the increase in crop area and

Table 5.3 LULC change dynamics of each LULC class from 2016 to 2020

Wetland	Changes in areal coverage (%)							
	Inland wetland	River	Waterbody	Terrestrial vegetation	Cropland	Agricultural fallow	Builtup	Aquatic vegetal cover
Berkrishnapur	7.96	0.00	-0.27	-8.85	3.68	-4.82	1.65	0.63
Panchpota	20.02	0.03	-1.21	-12.52	5.56	-4.18	2.85	-10.55
Panchita	-4.72	0.00	0.04	-0.76	1.46	-10.39	1.37	13.00
Aromdanga	1.55	-0.03	-0.05	-3.37	8.73	-12.32	2.22	3.28
Gopalnagar	-5.90	0.00	-0.03	0.21	2.30	-7.54	1.38	9.58
Manigram	-4.22	0.00	0.38	3.23	-5.62	-14.73	1.11	19.84
Madhabpur	3.12	-0.10	0.09	1.18	1.20	-7.12	1.50	0.14

the increase in a built-up area in the study sites. The built-up area had increased in six wetlands like Berkrishnapur (1.65%), Panchpota (2.85), Panchita (1.37%), Aromdanga (2.22%), Gopalnagar (1.38%), Manigram (1.11%) and Madhabpur wetland (1.50%) in 2020 as compared to 2016. The aquatic vegetal cover area had increased in six wetlands viz. Berkrishnapur (0.63%), Panchita (13.00%), Aromdanga (3.28%), Gopalnagar (9.58%), Manigram (19.84%) and Madhabpur (0.14%) wetlands in 2020 as compared to 2016. Only the Panchpota wetland showed a 10.55% decrease in aquatic vegetal cover area in 2020 compared to 2016.

5.2 Spatial metrics defining landscape character

LULC of these wetlands had changed rapidly due to acute poverty, intensive land use, and rapid growth in scientific and technological progress. Therefore, remote sensing (RS) and geospatial technologies were used to capture that sort of changes and its LULC dynamics in the WIZ. Mainly, landscape metrics level and class metrics level were calculated to understand this change characteristics of each land use type and overall change characteristics of wetland landscape under intense human-induced socio-economic activities (Mao et al., 2014; Jia et al., 2015; Lu et al., 2015; Liu and Hao, 2017; Zhao et al., 2019; Das et al., 2020). Values of spatial metrics obtained through FRAGSAT analysis are discussed follows wetland-wise to understand wetland-specific human-induced pressure and the existing scenario of each wetland landscape.

5.2.1 Spatial metrics of selected wetlands in 2016

5.2.1.1 Berkrishnapur wetland

Berkrishnapur wetland was a highly fragmented wetland with 118 LULC patches in 2016. A patch density of 109.13 exhibited a high level of fragmentation of this wetland landscape. The value of LPI was 19.40 ha which was occupied by agricultural land and thereby clearly indicating its future transition towards agricultural dominance (Photograph 5.1). A value of 1.53 of SHDI showed a higher level of landscape fragmentation. The low value of CONTAG (50.40) directed the highly fragmented landscape into smaller patches and low connectivity in the Berkrishnapur wetland landscape (Table 5.4).

Photograph 5.1 Paddy cultivation beside eutrophicated Berkrishnapur wetland

Table 5.4 Statistics of landscape metrics in the Berkrishnapur wetland, 2016

WIZ of wetland	NP	PD	LPI	SHDI	CONTAG
Berkrishnapur	118	109.13	19.40	1.53	50.40

5.2.1.2 Panchpota wetland

Panchpota Wetland had 118 LULC patches in 2016, making it an overused wetland. This wetland had a significant degree of fragmentation, as shown by the patch density of 150.47. LPI score of 20.61 hectares indicated terrestrial vegetation (Photograph 5.2). SHDI score of 1.68 showed a significant amount of landscape fragmentation. The Panchpota wetland environment's low CONTAG score (45.46) demonstrated a severely fragmented landscape into smaller parts and limited connectedness (Table 5.5).

Photograph 5.2 House construction and solid waste disposal in Panchpota wetland

Table 5.5 Statistics of landscape metrics in the Panchpota wetland, 2016

WIZ of wetland	NP	PD	LPI	SHDI	CONTAG
Panchpota	118	150.47	20.61	1.68	45.46

5.2.1.3 Panchita wetland

214 LULC patches were present in the Panchita Wetland in 2016, making it an extensively overused wetland. However, this wetland had a moderate amount of patch density (*i.e.*, 82.41). 16.02 ha of the LPI's value were covered by inland wetland, which was a promising indicator for wetland development in the foreseeable future (Photograph 5.3). This wetland had a significant degree of landscape fragmentation, as indicated by the SHDI score of 1.75. CONTAG's low score (*i.e.*, 42.36) suggested that WIZ was severely fragmented and the wetland environment was not well connected (Table 5.6).

Table 5.6 Statistics of landscape metrics in the Panchita wetland, 2016

WIZ of wetland	NP	PD	LPI	SHDI	CONTAG
Panchita	214	82.41	16.02	1.75	42.36

Photograph 5.3 Natural view of fishing-dominated Panchita wetland

5.2.1.4 Aromdanga wetland

With 176 LULC patches in 2016, the Aromdanga wetland was likewise well exploited. In this wetland, a high patch density (*i.e.*, 108.50) was seen. LPI's value of 31.26 hectares, which was shared by agricultural fallow, indicated that agriculture will likely take over in the future in this wetland (Photograph 5.4). This wetland had a significant level of landscape fragmentation, as indicated by an SHDI score of 1.40. Again, the low CONTAG score (i.*e.*, 54.58) demonstrated the WIZ's severe fragmentation and the wetland landscape's poor connectedness (Table 5.7).

Photograph 5.4 Aromdanga wetland: (a) construction of houses within a wetland, and (d) road construction across the wetland

Table 5.7 Statistics of landscape metrics in the Aromdanga wetland, 2016

WIZ of wetland	NP	PD	LPI	SHDI	CONTAG
Aromdanga	176	108.50	31.26	1.40	54.58

5.2.1.5 Gopalnagar wetland

Gopalnagar wetland had 407 LULC patches and was overstressed, according to

2016. This wetland had a high degree of patch density (*i.e*., 123.01). The inland wetland had 10.43 hectares of LPI, which was a promising indicator for a wetland shortly (Photograph 5.5). The Gopalnagar wetland had a high level of landscape fragmentation, as indicated by an SHDI score of 1.62. The low CONTAG score (i.*e*., 42.99) once again demonstrated the landscape's limited connectedness and severely fragmented WIZ (Table 5.8).

Photograph 5.5 Paddy cultivation in Gopalnagar wetland during the lean season

Table 5.8 Statistics of landscape metrics in the Gopalnagar wetland, 2016

WIZ of wetland	NP	PD	LPI	SHDI	CONTAG
Gopalnagar	407	123.01	10.43	1.62	42.99

5.2.1.6 Manigram wetland

In 2016, there were 133 LULC patches in the Manigram wetland. In this wetland, a high patch density (132.93) was attained. 16.14 ha of the LPI's value was covered by inland wetland, which exhibited a potential indicator for wetland improvement in the coming years (Photograph 5.6). The Manigram wetland had a high level of landscape fragmentation, as indicated by an SHDI score of 1.68. The low CONTAG score (42.09) once more demonstrated the WIZ's high fragmentation and poor landscape connectivity (Table 5.9).

Table 5.9 Statistics of landscape metrics in the Manigram wetland, 2016

WIZ of wetland	NP	PD	LPI	SHDI	CONTAG
Manigram	133	132.93	16.14	1.68	42.09


Photograph 5.6 Paddy cultivation in fishing-dominated Manigram wetland

5.2.1.7 Madhabpur wetland

With 71 LULC patches in 2016, Madhabpur wetland was a comparably less fragmented wetland. This wetland seemed to have a high degree of patch density (i.e., 90.90). Inland wetland occupied 24.85 hectares of LPI, which was a favorable indicator for wetland health in the coming years (Photograph 5.7). In this wetland, an SHDI score of 1.50 indicated a substantial level of landscape fragmentation. CONTAG's low score (*i.e.*, 49.60) once again highlighted the WIZ's high fragmentation and low linkage to the wetland ecosystem (Table 5.10).

Table 5.10 Statistics of landscape metrics in the Madhabpur wetland, 2016

WIZ of wetland	NP	PD	LPI	SHDI	CONTAG
Madhabpur	71	90.90	24.85	1.50	49.60


Photograph 5.7 Fishing dominated Madhabpur wetland

5.2.2 Spatial metrics of selected wetlands in 2020

5.2.2.1 Berkrishnapur wetland

In 2020, the Berkrishnapur Wetland had a 183 LULC patches which were substantially increased from 2016. This wetland had again a high patch density (i.e., 172.27) because the community's residents were highly dependent on it. Terrestrial vegetation and inland wetland shared 11.92 ha of LPI, which notably decreased in 2016 (Table 5.11). In the Aromdanga wetland, an SHDI score of 1.66 showed a significant level of landscape fragmentation which was also increased from 2016. The low CONTAG value (i.e., 45.46) again highlighted the WIZ's significant fragmentation and the sparse connectedness of the landscape.

Table 5.11 Statistics of landscape metrics in the Berkrishnapur wetland, 2020

WIZ	NP	PD	LPI	SHDI	CONTAG
Berkrishnapur	183	172.27	11.92	1.66	45.46

5.2.2.2 Panchpota wetland

Panchpota Wetland had 173 LULC patches in 2020 which was quite higher than in 2016 (118), making it an overused wetland. This wetland had a high degree of patch density (*i.e.*, 227.33). Inland wetland made up 29.57 ha of the LPI value, which was a positive indicator for wetland development shortly. In this wetland, an SHDI value of 1.73, which was higher than in 2016 (1.68) interpreted a significant degree of landscape fragmentation. The low CONTAG score (42.64) once more reflected the wetland landscape's poor connectivity and highly fragmented WIZ (Table 5.12).

Table 5.12 Statistics of landscape metrics in the Panchpota wetland, 2020

WIZ	NP	PD	LPI	SHDI	CONTAG
Panchpota	173	227.33	29.57	1.73	42.64

5.2.2.3 Panchita wetland

With 290 LULC patches in 2020, the Panchita Wetland was found the most overused wetland among others. However, the number of patches had increased substantially since 2016 (2014). This wetland had also a greater level of patch density (i.e., 112.72) in 2016 (*i.e.*, 82.41). The LPI value of 14.00 ha, which was covered by the aquatic vegetal cover and substantially reduced from 2016 (16.02 ha). This sort of decrease indicated that wetlands would be depleted gradually (Table 5.13). In this wetland, a score of 1.74 for SHDI indicated a high level of landscape fragmentation. The WIZ was extremely fragmented and the wetland environment had little interconnectedness, as shown by the CONTAG score's low (*i.e.*, 41.16) value.

Table 5.13 Statistics of landscape metrics in the Panchita wetland, 2020

WIZ	NP	PD	LPI	SHDI	CONTAG
Panchita	290	112.72	14.00	1.74	41.16

5.2.2.4 Aromdanga wetland

Aromdanga had 288 LULC patches in 2020 which was only 176 in 2016, rendering it another exploited wetland. In this wetland, a high patch density (i.e., 184.79) was observed which was comparably higher than in 2016 (*i.e.*, 108.50). Cropland represents 11.41 hectares of LPI, which indicated that agriculture will soon take over as the dominant activity. In this wetland, an SHDI score of 1.62 indicated a significant level of landscape fragmentation. The lower value of CONTAG (54.18) once more revealed the WIZ's severe fragmentation and poor interconnectivity of the wetland landscape (Table 5.14).

Table 5.14 Statistics of landscape metrics in the Aromdanga wetland, 2020

WIZ	NP	PD	LPI	SHDI	CONTAG
Aromdanga	288	184.79	11.41	1.62	45.18

5.2.2.5 Gopalnagar wetland

637 LULC patches was found in Gopalnagar wetland in place of 407 LULC patches in 2016 and which indicated a highly stressed wetland in 2020. In this wetland, patch density (i.e., 212.33) also increased significantly from the previous year i.e., 123.01 (Table 5.15). 5.91 hectares of the LPI was shared by inland wetlands, which indicated a healthy sign for wetlands in the years ahead. The Gopalnagar wetland had a high level of landscape fragmentation, as evidenced by the SHDI score of 1.73. The low CONTAG index value (i.e., 37.26) once more emphasized the WIZ's severe fragmentation and limited landscape connectivity.

Table 5.15 Statistics of landscape metrics in the Gopalnagar wetland, 2020

WIZ	NP	PD	LPI	SHDI	CONTAG
Gopalnagar	637	212.33	5.91	1.73	37.26

5.2.2.6 Manigram wetland

In 2020, the Manigram wetland had 188 LULC patches which was quite high than the base year 2016 (*i.e.*, 133). In this wetland, a high patch density (189.69) is found which was also greater than the base year (i.e., 132.93). The aquatic vegetal cover on 26.60 ha of the LPI signified that the wetland would be soon in good health condition. In Manigram wetland, an SHDI score of 1.74 showed a substantial level of landscape fragmentation. The low CONTAG score (38.35) once more demonstrated the WIZ's severe fragmentation and limited landscape connectedness (Table 5.16).

Table 5.16 Statistics of landscape metrics in the Manigram wetland, 2020

WIZ	NP	PD	LPI	SHDI	CONTAG
Manigram	188	189.69	26.60	1.74	38.35

5.2.2.7 Madhabpur wetland

In 2020, there were 117 LULC patches in the Madhabpur wetland which was greater than the base year (i.e., 71 LULC patches only), leaving it an overused wetland. This wetland exhibited a higher level of patch density (i.e., 154.09) which was significantly higher than in 2016 (*i.e.*, 90.90). Inland wetland comprised of 27.97 ha of the value of LPI, which was a promising indicator for wetlands in coming years. This wetland had a significant level of landscape fragmentation, as indicated by the SHDI score of 1.49. Low connectivity in the wetland landscape and a moderately fragmented WIZ were indicated by the moderate CONTAG index score of 51.73 (Table 5.17).

Table 5.17 Statistics of landscape metrics in the Madhabpur wetland, 2020

WIZ	NP	PD	LPI	SHDI	CONTAG
Madhabpur	117	154.09	27.97	1.49	51.73

5.3 LULC transformation from 2016 to 2020

5.3.1 Berkrishnapur wetland

All LULC types experienced a transformation from one type to another. Inland wetlands (8.01 ha) of the 2016 image were converted to cropland (0.35 ha) and agricultural fallow (0.32) in 2020. An area of 0.06 ha was gone under terrestrial vegetation in 2020. Only, a 0.01 ha area was excavated for aquaculture in 2020. The 2016 terrestrial vegetation (42.56 ha) of Berkrishnapur wetland LULC class was also converted to agricultural fallow (4.09 ha), cropland (0.48 ha), and built-up areas (1.46 ha) in 2020. However, the conversion of terrestrial vegetation to aquatic vegetal cover (4.73 ha) was mainly due to the growth of sedges, reeds, and typhus in the littoral zone of wetlands (Table 5.18).

Table 5.18 LULC transformation matrix of Berkrishnapur wetland 2016 to 2020

2016	**2020**							
	Inland wetland	River	Waterbodies	Terrestrial vegetation	Cropland	Agricultural fallow	Builtup	Aquatic vegetal cover
Inland wetland	**5.23**		0.01	0.06	0.35	0.32	0	2.04
River	0	**0.10**	0	0	0.02	0	0	0
Waterbodies	0	0	**0**	0	0.37	0.02	0	0
Terrestrial vegetation	0.40	0.01	0	**31.40**	0.48	4.09	1.46	4.73
Cropland	2.32	0	0.07	0.57	**4.40**	5.67	0	0.17
Agricultural fallow	2.52	0.01	0.02	1.30	11.06	**13.26**	0.34	0.13
Builtup	0	0	0	0.40	0.02	0.02	**4.83**	0
Aquatic vegetal cover	5.86	0	0	0.04	0.50	0.12	0	**0.51**

5.3.2 Panchpota wetland

In the Panchpota wetland, all LULC patches also experienced a transformation from one type to others. Inland wetlands (8.27 ha) in the 2016 image were converted to cropland (0.24 ha), agricultural fallow area (0.04 ha), and built-up area (0.01 ha) in 2020. Waterbody (1.41 ha) were converted to cropland (0.51 ha), agricultural fallow (0.13 ha), and built-up areas (0.16 ha) in 2020. Along with this, 0.13 ha area from the waterbody came under terrestrial vegetation in 2020. 2016 terrestrial vegetation (28.45 ha) of Panchpota wetland LULC class was also converted to agricultural fallow (4.10 ha), cropland (0.47 ha), and built-up area (1.88 ha) in 2020 (Table 5.19) due to increasing demand of unprecedented growth of rural population.

Table 5.19 LULC transformation matrix of Panchpota wetland 2016 to 2020

2016	**2020**							
	Inland wetland	River	Waterbodies	Terrestrial vegetation	Cropland	Agricultural fallow	Builtup	Aquatic vegetal cover
Inland wetland	**7.65**		0	0.04	0.24	0.04	0.01	0.28
River		**1.12**	0	0.08	0	0	0.02	0.02
Waterbodies	0.05	0	**0.40**	0.13	0.51	0.13	0.16	0.03
Terrestrial vegetation	1.03	0.04	0.04	**17.95**	0.47	4.10	1.88	2.96
Cropland	0.06	0	0.02	0.09	**1.38**	0.10	0.23	0
Agricultural fallow	2.47	0.07	0.11	1.10	3.33	**5.66**	0.18	0.47
Builtup	0.01	0	0.04	0.34	0.11	0.05	**7.47**	0.02
Aquatic vegetal cover	11.99	0	0	0.11	0.04	0.04	0	**0.43**

5.3.3 Panchita wetland

In the Panchita wetland, all the LULC patches also experienced a drastic level of conversion. Inland wetlands (47.13 ha) in the 2016 image were converted to cropland (0.49 ha), agricultural fallow areas (0.03 ha), and built-up areas (0.02 ha) in 2020. Waterbody (1.41 ha) were converted to cropland (0.21 ha) and agricultural fallow (0.04 ha) in 2020. The 2016 terrestrial vegetation LULC class (64.54 ha) of the Panchita wetland was converted to agricultural fallow (1.96 ha), cropland (0.68 ha), and built-up area (2.36 ha) in 2020 (Table 5.20).

Table 5.20 LULC transformation matrix of Panchita wetland 2016 to 2020

2016	**2020**							
	Inland wetland	River	Waterbodies	Terrestrial vegetation	Cropland	Agricultural fallow	Builtup	Aquatic vegetal cover
Inland wetland	**29.03**		0.08	0.08	0.49	0.03	0.02	17.40
River	0	**0**	0	0	0	0	0	0
Waterbodies	0.17		**0.23**	0.04	0.21	0.04	0.00	0.36
Terrestrial vegetation	0.41		0.39	**57.40**	0.68	1.96	2.36	1.34
Cropland	0.66		0.15	2.36	**10.40**	9.98	0.13	8.70
Agricultural fallow	0.31		0.23	1.70	21.01	**16.29**	0.20	15.16
Builtup	0		0	0.72	0.02	0	**20.18**	0.00
Aquatic vegetal cover	4.25		0.07	1.20	3.31	0.02	1.00	**25.23**

5.3.4 Aromdanga wetland

In the Aromdanga wetland, all LULC patches also witnessed a severe transformation. Inland wetlands (4.27 ha) in the 2016 image were converted to cropland (0.21 ha) and agricultural fallow (0.70 ha) in 2020. Waterbody (0.62 ha) were converted to cropland (0.22 ha) and agricultural fallow land (0.02 ha) in 2020. Along with this, in 2020, 0.01 ha area from the riverine class was gone under cropland and agricultural fallow separately. As of 2016, Aromdanga terrestrial vegetation patch (35.89 ha) was also converted to agricultural fallow (4.18 ha), cropland (0.23 ha), and built-up areas (1.51 ha) in 2020 (Table 5.21).

5.3.5 Gopalnagar wetland

In the Gopalnagar wetland, all LULC patches were gone through vast conversion. The inland wetland (49.30 ha) in the 2016 image was converted to cropland (1.94 ha), agricultural fallow area (0.30 ha), and built-up area (0.04 ha) in 2020. Water bodies (2.10 ha) were converted to cropland (0.57 ha), agricultural fallow (0.44 ha) and built-up area (0.23 ha) in 2020. The 2016 terrestrial vegetation LULC class (91.04 ha) of Gopalnagar wetland was also converted to agricultural fallow (9.59 ha), cropland (1.48 ha), and built-up areas (3.21 ha) in 2020 (Table 5.22).

Table 5.21 LULC transformation matrix of Aromdanga wetland 2016 to 2020

2016	2020							
	Inland wetland	River	Waterbodies	Terrestrial vegetation	Cropland	Agricultural fallow	Builtup	Aquatic vegetal cover
Inland wetland	**2.34**	0	0	0.03	0.21	0.70	0	0.99
River	0	**4.24**	0	0.01	0.01	0.01	0	0.04
Waterbodies	0	0	**0.37**	0.01	0.22	0.02	0	0
Terrestrial vegetation	2.87	0.06	0.01	**25.42**	0.23	4.18	1.51	1.61
Cropland	0.14	0.01	0	1.39	**8.91**	13.64	0	0.20
Agricultural fallow	0.95	0.01	0.16	3.57	28.67	**37.27**	1.82	2.77
Builtup	0.00	0	0	0.22	0.08	0.05	**9.48**	0
Aquatic vegetal cover	0.22	0.03	0	0.01	0.27	0	0.03	**0.15**

Table 5.22 LULC transformation matrix of Gopalnagar wetland 2016 to 2020

2016	2020							
	Inland wetland	River	Waterbodies	Terrestrial vegetation	Cropland	Agricultural fallow	Builtup	Aquatic vegetal cover
Inland wetland	**25.60**		0.32	1.16	1.94	0.30	0.04	19.95
River	0	**0**	0	0	0	0	0	0
Waterbodies	0.01		**0.63**	0.06	0.57	0.44	0.23	0.18
Terrestrial vegetation	0.62		0.45	**73.45**	1.48	9.59	3.21	2.25
Cropland	0.24		0.04	3.87	**10.83**	18.19	0.52	3.97
Agricultural fallow	1.30		0.62	6.64	24.28	**40.83**	1.68	5.14
Builtup	0		0.05	2.09	0.28	0.37	**25.43**	0.02
Aquatic vegetal cover	1.61		0.06	0.31	1.13	0.02	0.04	**5.78**

5.3.6 Manigram wetland

In Manigram wetland, all LULC patches also experienced notable conversion from one LULC type to another. Inland wetlands (16.15 ha) in the 2016 image were converted to cropland (0.08 ha) and agricultural fallow (0.06 ha) in 2020. Terrestrial vegetation LULC class (14.84 ha) of Manigram wetland of 2016 was also converted to agricultural fallow class (0.92 ha), cropland class (0.33 ha), and built-up areas (0.39 ha) in 2020 (Table 5.23).

5.3.7 Madhabpur wetland

In the Madhabpur wetland, all LULC patches had also experienced a transformation. Inland wetland (19.41 ha) in 2016 image was converted to cropland (0.69 ha), agricultural fallow (0.02 ha) and built-up area (0.12 ha) in 2020. 2016 terrestrial vegetation (27.76 ha) of Manigram wetland LULC class was also converted to agricultural fallow (0.89 ha), cropland (0.52 ha), and built-up area (1.03 ha) in 2020 (Table 5.24).

Table 5.23 LULC transformation matrix of Manigram wetland 2016 to 2020

2016	2020							
	Inland wetland	River	Waterbodies	Terrestrial vegetation	Cropland	Agricultural fallow	Builtup	Aquatic vegetal cover
Inland wetland	**10.21**		0.01	0.06	0.08	0.06	0	5.73
River	0	**0**	0	0	0	0	0	0
Waterbodies	0		**0.41**	0.02	0	0	0	0.02
Terrestrial vegetation	0.03		0.02	**12.96**	0.33	0.92	0.39	0.19
Cropland	0.19		0.01	3.23	**5.25**	5.45	0.32	5.31
Agricultural fallow	0.07		0.37	1.68	8.43	**11.67**	0.64	9.80
Builtup	0		0	0.24	0.08	0.04	**5.48**	0.01
Aquatic vegetal cover	1.33		0	0.07	0.08	0	0	**7.41**

Table 5.24 LULC transformation matrix of Madhabpur wetland 2016 to 2020

2016	2020							
	Inland wetland	River	Waterbodies	Terrestrial vegetation	Cropland	Agricultural fallow	Builtup	Aquatic vegetal cover
Inland wetland	**18.28**	0.03	0.05	0.22	0.69	0.02	0.12	0
River	0	**0.59**	0	0.01	0	0	0	0.07
Waterbodies	0	0	**0**	0	0	0	0	0
Terrestrial vegetation	0.59	0.00	0.01	**24.60**	0.52	0.89	1.03	0.13
Cropland	0.63	0.02	0	2.48	**3.14**	2.61	0.11	0.01
Agricultural fallow	1.70	0	0	1.56	5.69	**4.58**	0.20	0
Builtup	0	0	0	0.34	0.04	0.02	**4.09**	0
Aquatic vegetal cover	0.05	0	0	0	0.06	0.0	0.0	**0.00**

Photograph 5.8 Intensive agriculture in reclaimed part of Aromdanga wetland in lean period (April to May)

Chapter 6: Developed C&I Framework of WEH Assessment and Its Testing on Floodplain Wetlands

6.1 Developed C&I framework under the PSR model

The primary objective of this study was to develop a comprehensive set of C&I framework for the assessment of WEH. Therefore, both bottom-up and top-down approaches had been used for structuring the C&I framework assimilating suggestions and decisions from the stakeholder groups, *i.e.*, fishers, farmers, livestock rearers, indirect users, researchers, wetland experts and academia who had sufficient working experiences in wetland environment. Human-induced pressures, causal-impact relationships between environment and socio-economic aspects and potential change drivers were considered during the development of the C&I framework. Hence, the developed C&I framework for assessing WEH was a unique contribution of this research (Mao et al., 2014; Ren et al., 2014; Jia et al., 2015) (Table 6.1, 6.2, and 6.3). However, initially this developed set of C&I was applied on Ichhamati floodplain wetlands for its testing. Another unique contribution of this study was the development of a set of pertinent environmental attributes of wetlands particularly for wetlands of Ichhamati floodplains (Table 6.4). This set of environmental attributes also helped enormous the development of C&I framework. Thus, the data obtained for each indicator under each criterion was proved to be extremely useful for explaining the ground conditions of recent landscape dynamics between 2016 and 2020. Moreover, this PSR model-based C&I framework of edaphic, aquatic, biotic, and socio-economic aspects of each wetland ecosystem exhibited different health scenarios for pressure, state, and response systems of 2016 and 2020.

Initially, a set of 117 environmental indicators was created based on existing published knowledge, advanced knowledge of researchers, and expert discussions. Then, it was taken to the field for feedback from stakeholders who had sufficient wetland interaction experience. Finally, the arrangement of different sets of indicators under respective criteria were done by five regional wetland experts using the Delphi Consensus method of three rounds (Datta, 2012). Subsequently, few unnecessary and less relevant indicators were omitted and few important but neglected indicators were taken following the advice of stakeholders and wetland experts. However, final set of 105 indicators were finalized based on stakeholders' opinions, expert decisions, and researchers' prior knowledge. Out of these 105 indicators 9 indicators of the state system *i.e.*, S_{13} – S_{16} and S_{27} – S_{31} (Table 6.2) were found to have negligible value, and were not considered in the evaluation process for this study. Therefore, 96 indicators were finally considered and also applied for testing of assessment of WEH on Ichhamati floodplains. However, the developed and proposed C&I framework was consisted with 105 indicators. This developed C&I framework consisted of 1 target, 3 systems, 19 evaluation criteria and 105 indicators which can be applied anywhere with minor site-specific modifications (Table 6.1, 6.2 and 6.3).

This target, "*Changing Ecosystem health of Wetlands of Ichhamati floodplains in North 24 Parganas, West Bengal*" was a deductive statement and sequential processes were needed to evaluate the central truth. Target was divided into three evaluation systems: pressure, state and response which were elaborated below (Mao et al., 2014; Ren et al., 2014; Jia et al., 2015).

6.1.1 Pressure system

The systems were further categorized into the second level of the hierarchy and the systems were evaluated by the evaluation criteria (Mao et al., 2014; Ren et al., 2014). There were eight major evaluation criteria under pressure system such as catchment characteristics of wetlands, pressure on hydrology: physical components, pressure on hydrology: chemical components, pressure on wetland soils: physical components, pressure on wetland soils: chemical components, pressure on biota: floral components, pressure on biota: faunal components, and pressure from livelihood activities. These evaluation was satisfied with the help of robust, scientific and easy-to measure indicators in the fourth hierarchy level (Table 6.1).

6.1.2 State system

Sate system indicates ecological health being pressured by both natural and human induced socio-economic activities. Therefore, eight major pertinent aspects of the evaluation criteria were selected to understand existing health condition of the studied wetlands such as state of wetland catchment, state of wetland hydrology: physical properties, state of wetland hydrology: chemical properties, state of wetland soils: physico-chemical components (WIZ), state of wetland biota: floral characteristics, state of wetland biota: faunal characteristics, and state of ecosystem products and services derived from the wetland (Mao et al., 2014; Ren et al., 2014) (Table 6.2). These evaluation criteria were also satisfied by the relevant and well established and also easy-to-measure indicators to capture amount of degradation of WEH in state system. Cui et al. (2012) was consulted for geo-chemical indicators. Sun et al. (2016), Sun et al. (2017) and Sun et al. (2019) were also reviewed for identifying other indicators of this system.

Table 6.1 Set of criteria and indicators (C&Is), correlation with WEH, measure, scoring methods, and data source for pressure system

Target	Evaluation system	Evaluation criterion	Evaluation indicator	Correlation with WEH	Measure	Scoring	Data source
Assessment of changing ecosystem health of wetlands	Pressure (P)	Catchment characteristics of wetlands	Status of human-induced stresses on LULC of WIZ (P_1)	-	(Built-up area + agricultural land) /Total area	Table 4.4 (Reverse scoring)	RS & GIS interpretation
			Areal fragmentation of perennial wetland zone (P_2)	-	Number of water parcels cover or fragments/Area of WPZ		
			Arable land area per capita (P_3)	+	per capita arable land in WIZ (ha)	Very low (≤0.5 ha) =1; Low (.06-1.0 ha) = 2; Moderate (1.1-1.5 ha) = 3; How (1.6-2.0 ha) = 4; Very how (≥ 2.1 ha) = 5	Questionnaire survey
		Pressure on hydrology: Physical components	The intensity of point sources of pollution (P_4)	-	Number of point sources/ unit area	Very low (≤ 5) = 5; Low (6-7) = 4; Moderate (8-9) = 3; High (10–12) = 2; Very high (≥13) = 1	
			Rate of change of non-point pollution in WIZ (P_5)	-	Rate of change of non-point pollution in WIZ	Very low = 5; Low = 4; Moderate = 3; High = 2; Very high = 1	
			Water resource ownership per capita (P_6)	-	Liter/capita	Very low (≤1000 L) = 5; Low (1001-2000 L) = 4; Moderate (2001-3000 L) =3; High (3001-4000L) = 2; Very high (≥4001 L) = 1	
			Change in the hydraulic perimeter of the channel inlet (P_7)	+	Length of the hydraulic perimeter of channel inlet in unit	Table 4.4 (Direct scoring)	Field measurement
			Rate of change of water flow in channel inlet (P_8)	+	The velocity of water (m^3/s) in the channel inlet		
			Change in the hydraulic perimeter of the channel outlet (P_9)	+	Length of the hydraulic perimeter of channel outlet in unit		
			Rate of change of water flow in channel outlet (P_{10})	+	The velocity of water (m^3/s) in the channel outlet		
		Pressure on hydrology: Chemical components	Status of saline water intrusion through inlets (P_{11})	-	Rate of change in EC (Electrical conductivity) of inlet water	Table 4.4 (Reverse scoring)	
			Status of fecal Coliform bacteria (P_{12})	-	Rate of change in fecal Coliform bacteria		Laboratory analysis
			Amount of phosphate in wetland water (P_{13})	-	Rate of change in the amount of phosphate		
			Amount of ammoniacal nitrogen (P_{14})	-	Rate of change in the amount of ammoniacal nitrogen		
			Amount of nitrate (NO3) in wetland water (P_{15})	-	Rate of change in the amount of nitrate (NO3)		
			Arsenic (P_{16})	-	Rate of change in Arsenic		
			Fluoride (P_{17})	-	Rate of change in Fluoride		

Pressure on wetland soils: physical components	Rate of sedimentation (P_{18})	-	A bowl is to be fixed and over a specific time rate of sedimentation will be calculated and data will be classified		Field measurement
	Availability of soil moisture (P_{19})	+	Rate of change of soil moisture measured by a soil moisture meter	Table 4.4 (Direct scoring)	
Pressure on wetland soils: chemical components	No. of chemical pesticides and insecticides used in WIZ (P_{20})	-	Perception-based indicator	Very low = 5; Low = 4; Moderate = 3; High = 2; Very high = 1	Questionnaire survey
	No. of chemical fertilizers used in WIZ (P_{21})	-			
Pressure on the biota: floral components	Status of invasive species within WPZ (P_{22})	-	Number of invasive species/unit area [20mX20m quadrant]	Table 4.4 (Reverse scoring)	Quadrat survey
	Status of invasive species within WIZ (P_{23})	-	Number of invasive species/unit area [20mX20m quadrant]		
	The magnitude of the harmfulness of invasive plant species (P_{24})	-	$MHI=\sum (S_i X h_i)$	Very low = 5; Low = 4; Moderate = 3; High = 2; Very high = 1	
Pressure on the biota: faunal components	Occurrence of exotic insects (P_{25})	-	Perception-based indicator		Questionnaire survey
	The magnitude of the harmfulness of insects (P_{26})	-			
	Level of the introduction of exotic fishes (P_{27})	-	Amount of exotic fishes/per catch	Very low (≤0.5 Qn) = 5; Low (0.6-1 Qn) = 4; Moderate (1.1-1.5 Qn) = 3; H (1.6-2 Qn) = 2; VH (≥2.1 Qn) =1	
Pressure from livelihood activities	Household density (P_{28})	-	No of houses/ km^2	Very low (<20%) = 5; Low (20%-40%) = 4; Moderate (40%-60%) = 3; High (60%-80%) = 2; Very high (>80%) =1	Census data and RS &GIS, Google Earth
	Road density (P_{29})	-	Road length in km/ km^2	Very low (<20%) = 5; Low (20%-40%) = 4; Moderate (40%-60%) = 3; High (60%-80%) = 2; Very high (>80%) =1	RS & GIS
	Number of dependent populaces per unit of land (P_{30})	-	No. of wetland users/ km^2	Very low (≤10%) = 5; Low (11%-15%) = 4; Moderate (16%-20%) = 3; High (21%-25%) = 2; Very high (≥26%) =1	
	Poaching intensity of birds (P_{31})	-	The average number of reporting of birds killing ($W^{-1} Y^{-1}$)	Very low (≤5%) = 5; Low (6%-8%) = 4; Moderate (9%-11%) = 3; High (12%-14%) = 2; Very high (≥15%) =1	Questionnaire survey
	Status of lift irrigation from wetlands and inlets to total water(P_{32})	-	Perception-based indicator	Very low (≤10%) =5; Low (11%-20%) =4; Moderate (21%-30%) = 3; High (31%-40%) = 2; Very high (≥41%) = 1	

			% of irrigational water for agricultural purposes pumped from groundwater with total requirements (P_{33})	-		Very low (≤10%) =5; Low (11%-20%) =4; Moderate (21%-30%) = 3; High (31%-40%) = 2; Very high (≥41%) = 1	
			Human disturbance intensity (P_{34})	-	Percentage of wetland areas where potentially harmful activities (excavation, land forming, and landfilling) are ongoing	Very low (≤10%) =5, Low (11%-15%) =4; Moderate (16%-20%) = 3; High (21%-25%) = 2; Very high (≥26%) = 1	
			The intensity of using finer nets for catching fish (P_{35})	-	Perception-based indicator	Always = 1; Seldom = 2; Moderate = 3; Very rare = 4; Not at all = 5	
			The intensity of using WIZ for sanitation and domestic purposes (P_{36})	-		Very low = 5; Low = 4; Moderate = 3; High = 2; Very high = 1	
			The intensity of using WIZ for animal husbandry (P_{37})	-			
			The intensity of using WIZ for jute retting (P_{38})	-			

Table 6.2 Set of criteria and indicators (C&Is), correlation with WEH, measure, scoring methods, and data source for the state system

Target	System	Evaluation criterion	Evaluation indicator	Correlation with WEH	Measure	Scoring	Data source
Assessment of changing ecosystem health of wetlands	State (S)	State of wetland catchment	Patch density (S_1)	+	$PD = \frac{n_i}{A}$ Where, n_i = number of patches of i[th] class A=the total landscape area (m^2)	Table 4.4 (Direct scoring)	RS & GIS interpretation
			Largest patch index (S_2)	+	$LPI = \frac{max_{j=1}^{n} a_{ij}}{A} \times 100$ Where, a_{ij}= area (m^2) of the patch I and A = the total landscape area (m^2)		
			Landscape diversity index (SHDI) (S_3)	+	$SHDI = -\sum_{i=1}^{m}(p_i ln p_i)$ Where, p_i= the proportion of the landscape occupied by each patch type *i* [SHDI=0 means one patch; SHDI=>0 means the number of patch types increases]		

	Landscape contagion index of WIZ (S_4)	+	$$CONTAG = \left[1 + \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left[(P_i)\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right] \times \left[ln(P_i)\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]}{2\ln(m)}\right] \times (100)$$ Where, P_i = proportion of landscape occupied by i^{th} patch type, g_{ik} = the number of adjacencies between pixels of patch types *i* and *k*, and *m* = the number of patch types present in the landscape		
	The existing extent of WIZ around the wetland acting as a buffer (S_5)	+	The average width of WIZ around the wetland acting as a buffer		Google earth image and Garmin GPS
	The ratio of wetland wetted perimeter to WIZ perimeter acting as a buffer (S_6)	+	Percentage of wetland perimeter with WIZ perimeter acting as a buffer		RS & GIS interpretation
State of wetland hydrology: Physical properties	Depth of water (S_7)	+	Multiple staff gage (Percentage reduction in wetland depth)		Field measurement
	Average turbidity condition of wetland water (S_8)	-	Sechi Disk measurement	Table 4.4 (Reverse scoring)	
	The temperature of the surface water of the wetland (S_9)	-	A mercury-in-glass thermometer	Table 4.4 (Central optimum value)	
State of wetland hydrology: Chemical properties	Status of biological oxygen demand (S_{10})	-	APHA 23rd Edition-2017		Laboratory analysis
	Status of chemical oxygen demand (S_{11})	-	APHA 23rd Edition-2017		
	Status of pH (S_{12})	-+	Hanna Pocket Type pH meter (Model number: HI96107)		
	The concentration of Cadmium (S_{13})	-	APHA 23rd Edition-2017	Table 4.4 (Reverse scoring)	
	The concentration of Mercury (S_{14})	-	APHA 23rd Edition-2017		
	The concentration of Lead (S_{15})	-	APHA 23rd Edition-2017		
	The concentration of Chromium(S_{16})	-	APHA 23rd Edition-2017		
	Status of dissolved oxygen (S_{17})	-+	Lutron DO meter (Model number: Lutron/PDO-520)	Table 4.4 (Direct scoring)	Field measurement

	Eutrophication level (S_{18})	-	Perception-based indicator	≥5 eutrophic species =VH=1, 4 species = H=2, 3 species = M = 3, 2 species=L=4, ≤1 species=VL=5	
	Status of salinity of wetland water (S_{19})	-	HM Digital EC meter (Model number: HM_AP2)	Table 4.4 (Reverse scoring)	Laboratory analysis
State of wetland soils: Physico-chemical components (WIZ)	Status of soil bulk density (S_{20})	-+	Soil bulk density was calculated as the ratio of the mass of dry solids to the bulk volume of soil		
	Available Nitrogen (S_{21})	+-	The procedure involves distilling the soil with an alkaline potassium permanganate solution and determining the ammonia liberated	Table 4.4 (Central optimum value)	
	Available Phosphorus (S_{22})	+-	Olsen's method was used for neutral-alkaline soils while the Bray and Kurtz method was used for acidic soils		
	Status of potassium (S_{23})	+-	Potassium with flame photometer model (Systronics flame photometer 128)		
	Status of organic carbon (S_{24})	+-	Wet oxidation method modified from Walkley and Black	Table 4.4 (Direct scoring)	
	Soil electrical conductivity (S_{25})	+-	Systronic E C meter (Model number: Systronics µ Conductivity meter 306)	Table 4.4 (Reverse scoring)	
	Soil pH (S_{26})	-	Hanna Pocket Type pH meter (Model number: HI96107)	Table 4.4 (Central optimum value)	
	The concentration of Arsenic (S_{27})	-	APHA 23rd Edition-2017	Table 4.4 (Reverse scoring)	
	The concentration of Cadmium (S_{28})	-	APHA 23rd Edition-2017		
	The concentration of Mercury (S_{29})	-	APHA 23rd Edition-2017		
	The concentration of Lead (S_{30})	-	APHA 23rd Edition-2017		
	The concentration of Chromium (S_{31})	-	APHA 23rd Edition-2017		
State of wetland biota: Floral characteristics	Normalized difference vegetation index (NDVI) (S_{32})	+	NDVI=(NIR-RED)/(NIR+RED)	Table 4.4 (Direct scoring)	RS & GIS interpretation
	Species diversity in WPZ (S_{33})	+	No. of species in 20mx20m quadrant/Area		Field measurement
	Species diversity in WIZ (S_{34})	+	No. of species in 20mx20m quadrant/Area		
	Tree density in WIZ (S_{35})	+	No. of trees in 20mx20m quadrant/Area		

	No. of dominant aquatic species (S_{36})	+	No. of dominant aquatic species in 20mx20m quadrant/Area		
	Level of the presence of eutrophic species (S_{37})	-	No. of eutrophic species in 20mx20m quadrant/Area		
State of wetland biota: Faunal characteristics	Status of fish diversity (S_{38})	+	Shannon-Weiner diversity Index/ Margalef's diversity index		
	Status of avifauna diversity (S_{39})	+	Shannon-Weiner diversity Index / Margalef's diversity index		
State of Ecosystem products and services derived from the wetland	Status of crop productivity (S_{40})	+			
	Availability of sellable wetland flora (S_{41})	+			
	Availability of sellable fish (S_{42})	+			
	Availability of other sellable wetland fauna (S_{43})	+	Perception-based indicator	Very high = 5; High = 4; Moderate = 3; Low = 2; Very low = 1	Questionnaire survey
	Potential to regulate floodwater (S_{44})	+			
	Potential to groundwater recharging (S_{45})	+			
	The capacity of the wetland to facilitate transport (S_{46})	+	Perception-based indicator	Very high = 5; High = 4; Moderate = 3; Low = 2; Very low = 1	Questionnaire survey
	Potential of the wetland as an ecotourism site (S_{47}	+			
	Realization of educational and recreational values (S_{48})	+			
	Presence of traditional, aesthetic, and ritual values (S_{49})	+			

Table 6.3 Set of criteria and indicators (C&Is), correlation with WEH, measure, scoring methods, and data source for the response system

Target	System	Evaluation criterion	Evaluation indicator	Correlation with WEH	Measure	Scoring	Data sources
Assessment of ecosystem health of wetlands	Response (R)	Ecological responses	Rate of change of vegetation area (R_1)	-	% of VCA change = {(VA_{2020} – VA_{2016}) / VA_{2016}} x 100	Very high (≥ - 41%) = 1; High (-31 to -40%) = 2; Moderate (-30% to -21%) = 3; Low (-20% to -11%) = 4; Very low (≤-10%) = 5	RS & GIS
			Rate of change of water cover area (R_2)	-	% of WCA change = {(WCA_{2020} – WCA_{2016}) / WCA_{2016}} x 100		
			Rate of change in the number of sites functioning as the habitat of migratory birds within WIZ (R_3)	-	% of change = (SH_{2020} – SH_{2016}) / SH_{2016} x 100		Questionnaire survey
			The intensity of prominent soil erosion (R_4)	-	Incidences of prominent soil erosion in wiz area.	Very high (No soil erosion) = 5; High (1-2 sites) = 4; Moderate (3-4 sites) = 3; Low (5-6 sites) = 2; Very low (≥7 sites) =1	
			Frequency of floods (R_5)	-	Frequency of events over 10 years	Very low (>6 times) = 1; Low (5-6 times) = 2; Moderate (3-4 times) = 3; High (1-2 times) = 4; Very high (No flood) = 5	
			Incidence of fish species extinction (R_6)	-	Number of extinct fish species reported by the local community during the last 10 years	Very low (≥4 species) = 1; Low (3 species) = 2; Moderate (2 species) = 3; High (1 species) = 4; Very high (No species reported) = 5	
			Incidence of plant species extinction (R_7)	-	Number of extinct plant species reported by the local community during the last 10 years		
		Economic and epidemiological responses	The intensity of out-migration in fishers communities (R_8)	-	Number of out-migration to total fishers populace last 10 years	Very low (≥71%0 = 1; Low (51% - 70%) = 2; Moderate (31% -50%) = 3; High (11% - 30%) = 2; Very high (≤10%) = 5	
			Level of satisfaction of the local community regarding livelihood generating potential of the wetland (R_9)	+	Community satisfaction	Very high = 5; High = 4; Moderate = 3; Low = 2; Very low =1	
			Water borne diseases (R_{10})	-	Number of respondents who are direct users and reported	Very low (≥5 persons) =1; Low (4-3 persons) = 2;	

			suffering from water borne diseases to total respondent	Moderate (2 persons) =3; High (1 person) = 4; Ver high (No one suffered) = 5
Socio-cultural responses	Rate of extinction of wetland related traditional rituals/activities/traits (R_{11})	-	Number of wetlands related traditional rituals/activities/traits reported to be extinct in last 10 years from the surrounding area	Very low (4 nos.) = 1; Low (3 nos.) = 2; Moderate (2 nos.) = 3; High (1 nos.) = 4; Very high (Nil) = 5
	Status of public environmental awareness (R_{12})	+	Number of persons who have answered positively more than 75% respondent of perception based environmental questions with respect to total number of respondents	Very high (≥71%) = 5; High (70% - 51%) = 4; Moderate (50% -31%) = 3; Low (30% - 11%) = 2; Very low (≤10) = 1
	Status of wetland management initiatives (R_{13})	+	Status of wetland management initiatives	Yes = 5, Not sufficient = 1
	Status of Research activities (R_{14})	+	Reporting of any wetland related research activities in the WIZ during last 10 years	Yes = 5; No=1
Management responses	Incidence of plantation and weed removal programme (R_{15})	+	Frequency of plantation and weed removal programme in wetland influence zone during last 10 years	Yes = 5; No=1
	Waste water treatment index (R_{16})	+	Presence of any treatment facility	Yes = 5; No=1
	Intensity of soil erosion management initiatives (R_{17})	+	Number of soil erosion management initiatives/unit area	Yes = 5; No=1
	Incidence of organic farming (R_{18})	+	Number of organic sites/WIZ area	Yes = 5; No=1

Table 6.4 Environmental attributes of studied wetlands of the Ichhamati floodplains. The presence or absence of an environmental characteristic is indicated by yes (+) or no (-) respectively. W1 = Berkrishnapur, W2 = Panchpota, W3 = Panchita, W4 = Aromdanga, W5 = Gopalnagar, W6 = Manigram W7 = Madhabpur

Environmental attribute	Sub-component	Wetland under study						
		W1	W2	W3	W4	W5	W6	W7
Catchment characteristics	River cut-offs	+	+	+	+	+	+	+
	Floodplain sink	-	-	-	-	-	-	-
	Soil with high content of silt	+	+	-	+	-	-	+
	Soil with high content of clay	-	-	+	-	+	+	-
	Land use intensity within the buffer zone	+	+	+	+	+	+	+
	Wetland bed excavation or filled	+	-	+	+	+	+	-
	Reduced wetland area	+	+	+	+	+	+	+
	Reduced wetland depth	+	+	+	+	+	+	+
	Altered wetland form	+	+	+	+	+	+	+
Hydrology	Permanent water	+	+	+	+	+	+	+
	Inflow-outflow with Ichhamati	+	+	-	+	+	-	-
	Secluded	-	-	+	-	-	+	+
	Annual inundation	+	+	+	+	+	-	+
	Siltation	+	+	+	+	+	+	+
	Degraded water quality	+	+	+	+	+	+	+
	Altered hydrology	+	+	+	+	+	+	+
	Wetland's water regime changed by human activities	+	+	+	+	+	+	+
Ecology	Invasion by aquatic plants	+	+	+	+	+	+	+
	Agro-ecosystem	+	+	+	+	+	+	+
	Existence of fish stock	+	+	+	+	+	+	+
	Existence of migratory birds	+	+	+	+	+	+	+
	Existence of tree cover	+	+	+	-	+	-	+
	The reported occurrence of biodiversity loss	+	+	+	+	+	+	+
	Disease control and maintenance of hygiene	-	-	-	-	-	-	-
	Wastewater treatment	-	-	-	-	-	-	-
	Retention of soil and control of soil erosion	+	+	+	+	+	+	+
	Flood control and groundwater recharge	+	+	+	+	+	+	+
	Maintaining local ecology and biodiversity	+	+	+	+	+	+	+
	Other products and services of consumptive values	+	+	+	+	+	+	+
	Community well-being	+	+	+	+	+	+	+
	Native vegetation width surrounding the wetland	+	+	+	+	+	+	+
	Continuous vegetation zone or fragmented	+	+	+	+	+	+	+
	Soil disturbance	+	+	+	+	+	+	+
Anthropogenic use	Invasion by agriculture	+	+	+	+	+	+	+
	Fishing activities	+	+	+	+	+	+	+
	Aquacultural practices	-	-	-	+	-	+	+
	Animal culture	+	+	+	+	+	+	+
	Pump irrigation	+	+	+	+	+	+	+
	Bathing and washing	+	+	+	+	+	+	+
	Sanitary use	+	+	+	+	+	+	+
	Prevalence of jute retting	+	+	+	+	+	+	+
	Ecotourism	-	-	-	-	-	-	-

Anthropogenic use	Encroachment by settlements and roads	+	+	+	+	+	+	+
	Solid waste disposal	+	+	+	+	+	+	+
	Wastewater accumulation	+	+	+	+	+	+	+
	Chemical fertilizers, insecticides, and pesticides	+	+	+	+	+	+	+
	Incidence of waterbirds trapping and killing	+	+	+	+	+	+	-
	Water for drinking and domestic purposes	+	+	+	+	+	+	+
	Used for traditional and ritual values	+	+	+	+	+	+	+
	Used for aesthetic, educational, and recreational purposes	+	+	+	+	+	+	+
	Means of transport for the local community	+	-	+	-	+	-	-

Modified after Gayen et al. (2020)

6.1.3 Response system

The evaluation criteria of response system consisted of four major aspects such as ecological responses, economic and epidemiological responses, socio-cultural responses and management responses. Indicators were chosen in such a way that it could grasp all the responses at institution, community, even individual level and also the ecological response which must be addressed to recover the system from its degraded condition (Ren et al., 2014; Jia et al., 2015; Liu and Hao, 2017).

6.2 Comprehensive wetland ecological health index (CWEHI)

CWEHI was calculated indicating the health condition of wetland ecosystems under human-induced pressures. CWEHI for 2016 and 2020 was derived separately. The WEH of the selected seven wetlands had been changed from 2016 to 2020 considerably. Even the WEH of each system from one year to another had also been changed notably.

6.2.1 Changing ecological health of the pressure system (2016 to 2020)

The amount of human-induced pressure and WEH status of the pressure system among the studied wetlands were tabulated in Table 6.5 and Table 6.6. The Panchpota wetland (81%) had the highest amount of human-induced pressure followed by the Panchita wetland (76%), Aromdanga wetland (75%), Gopalnagar wetland (66%), and Manigram wetlands (51%) in 2016 and showed morbid, weak and moderate ecological health in pressure system respectively (Fig. 6.1). Altogether, five wetlands showed 50% and above human pressure owing to consistent socio-economic and other developmental activities. On the contrary, the Madhabpur wetland indicated a relatively low amount of human pressure (31%) which might be attributed to good management practices exercised by cooperative fishing members. On the other hand, Berkrishnapur wetland (49%) was very close to 50% human pressure due to the ample amount of agricultural land, intensive fishing, and dense human habitation along with its resultant socio-economic activities. Such a high number of human-induced pressures in each system indicated the ecosystem vitality of these wetlands and the livelihood dependencies of the local populace on the studied wetlands which resulted in the overall deterioration of WEH.

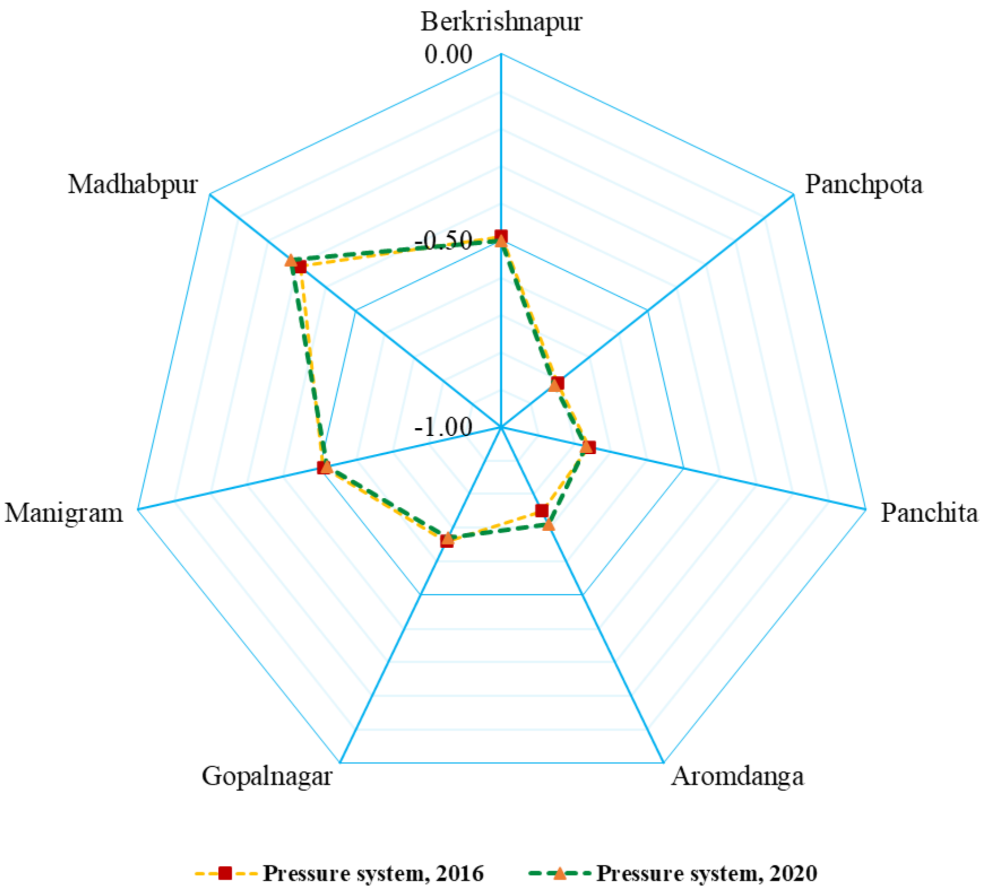

Fig. 6.1 CWEH status of pressure system from 2016 to 2020

Table 6.5 Comprehensive wetland ecological health index (CWEHI) of the studied wetland for 2016 and 2020 obtained from TOPSIS method using 3 systems, 19 evaluation criteria, and 96 indicators

Wetland	2016			2020		
	Pressure system	State system	Response system	Pressure system	State system	Response system
Berkrishnapur	-0.49	0.21	0.06	-0.50	0.19	0.06
Panchpota	-0.81	0.24	0.27	-0.82	0.22	0.28
Panchita	-0.76	0.33	0.37	-0.77	0.32	0.26
Aromdanga	-0.75	0.36	0.05	-0.71	0.30	0.08
Gopalnagar	-0.66	0.50	0.56	-0.67	0.46	0.47
Manigram	-0.51	0.59	0.60	-0.52	0.59	0.63
Madhabpur	-0.31	0.88	0.95	-0.28	0.95	0.97

The amount of health of pressure system in the wetland complex changed noticeably in 2020 (Table 6.5). Among all the wetlands, the amount of human-induced pressure was minimal again in the Madhabpur wetland highlighting its excellent health (28% with a 3% decrease) in the pressure system in 2020. Such reduction in human-induced pressure might be attributed to good practices of fishing cooperatives and positive outcomes of frequently organized meetings and FGDs with stakeholders conducted over the last five years. However, Panchpota wetland (82% with a 1% increase compared to 2016), Aromdanga wetland (71% with a 4% decrease), Gopalnagar wetland (67% with 1% increase compared to 2016), and the Manigram wetland (52% with 1% increase) had achieved morbid, weak and moderate ecological health (Table 6.6). This pattern of human pressure invoked the necessity of these natural systems as a major source of livelihood in community life. A considerable amount of human-induced pressure decreased in the Aromdanga wetland (71% with a 4% decrease compared to 2016) and Madhabpur wetland (28% with a 3% decrease with respect to 2016) probably because of several FGDs, awareness campaign programs and frequent meetings with the major stakeholders.

However, six wetlands in place of five in 2016 depicted 50% and above human pressure in 2020 owing to the region's accelerating socio-economic and other developmental activities. This increasing trend of human pressure on wetland systems in the study region sharply indicated the ecosystem vitality and socio-economic needs of the community populace in the same fashion as in 2016.

6.2.2 Changing ecological health of the state system (2016 to 2020)

Human pressure directly affects the state condition of the wetlands. Subsequent changes of the state system of the WEH were computed and tabulated in Tables 6.5 and 6.6. Although, different natural systems had their unique self-healing mechanisms. These natural systems also can cope with and ameliorate all possible negative impacts induced by human interventions at a certain level (Fig. 6.2). Yet, health of state system had been degraded substantially. Two fishing-dominated wetlands, namely Madhabpur wetland (88%) and Manigram wetland (59%) had scored excellent and moderate health conditions respectively under the state system in 2016. In contrast, both agriculture and fishing dominated wetlands viz. Gopalnagar wetland (50%) achieved moderate health in the state system in 2016. Only these three wetlands were able to attain 50% and above health in the state system in 2016. Despite minimal areal coverage and almost having similar ecological composure, Madhabpur wetland (33.9 ha) and Manigram wetland (46.5 ha) had depicted different health scores in state systems probably due to different conservation practices performed by stakeholders' mainly fishers and farmers. On the contrary, with higher areal coverage, the Gopalnagar wetland exhibited moderate health conditions in the state system probably due to uneven resource extraction and higher human-induced pressure. Besides, Aromdanga wetland (36%), Panchita wetland (33%), Panchpota wetland (24%), and Berkrishnapur wetland (21%) showed weak health conditions (≤ 40%) in the state system in 2016.

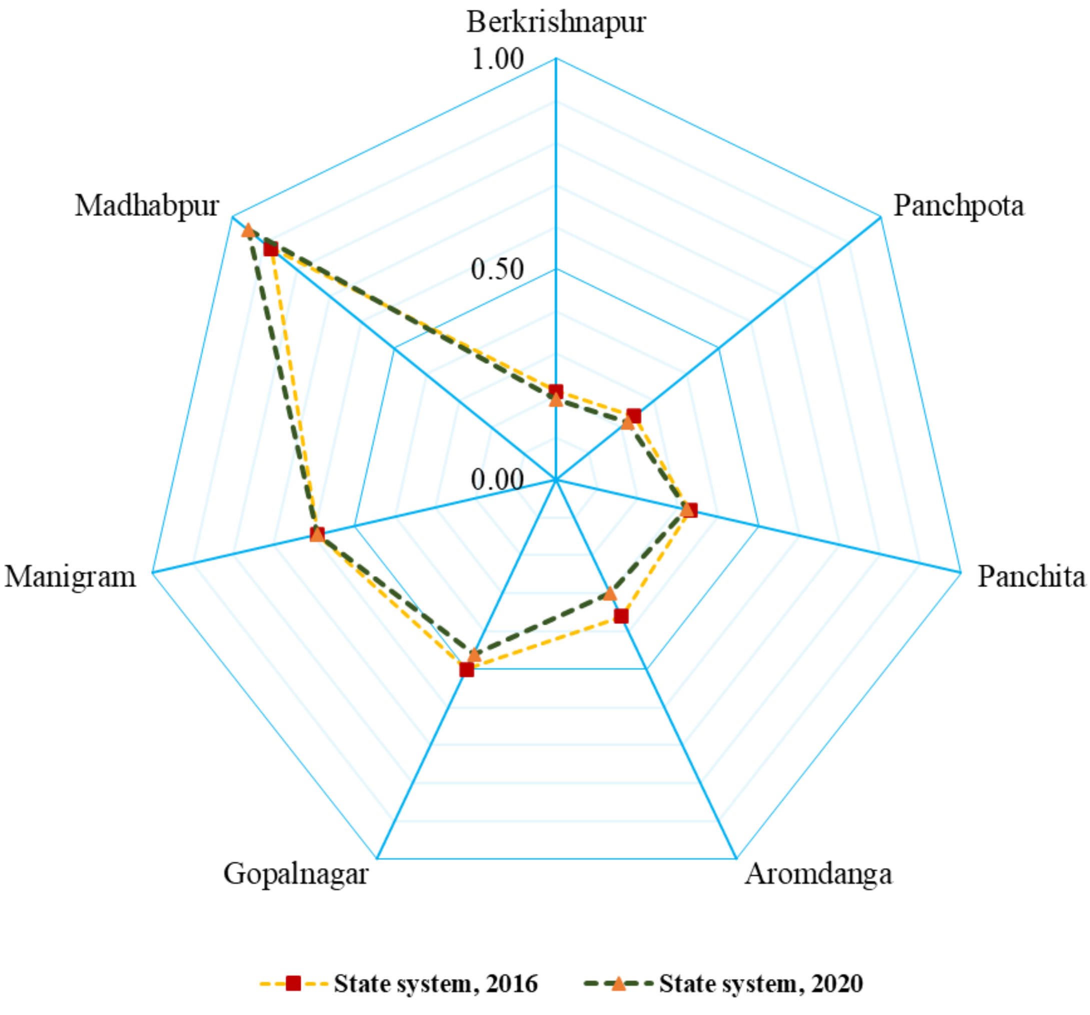

Fig. 6.2 CWEH status of state system from 2016 to 2020

Despite moderate health in the pressure system, Berkrishnapur wetland unexpectedly scored weak health (21%) in the state system, probably due to preceded waning ecological performances and lack of good conservation efforts of the local farmers and fishers. This health status could also be linked to intensive farming and fishing, the unbridled practice of hunting and trapping migratory waterbirds, lack of bio-surveillance, and stakeholder conflicts (Datta and Ghosh, 2015; Gayen et al., 2020). As a result, the amount of health in the state system substantially worsened in 2020. Five wetlands, namely Berkrishnapur wetland (19% with a 2% decrease), Panchpota wetland (22% with a 2% decrease), Panchita wetland (32% with a 1% decrease), Aromdanga wetland (30% with a 6% decrease) and Gopalnagar wetland (46% with a 4% decrease) had shown morbid, weak and moderate ecological health condition in 2020 with respect to 2016 indicating overall declining trends of WEH in the state system (Table 6.5). Aromdanga and Gopalnagar wetlands, two adjoining and closely linked wetlands, had depicted significant deterioration in the health of the state system which indicated a high amount of human pressure and malfunctioning of the system. However, Manigram wetland (59%) had maintained moderate health conditions as of 2016 (Table 6.5). Whereas, Madhabpur wetland (95% with a 7% increase) had achieved exceptional health status in the state system with respect to 2016 which might be again be attributed to positive moments of frequent meetings and FGDs with stakeholders and good practices carried out by cooperative fishing members (Table 6.4). This wetland had minimum areal coverage and the highest depth with a minimum cover of water hyacinth.

6.2.3 Changing ecological health of the response system (2016 to 2020)

WEH score and status of the response system had been calculated and also contained in Tables 6.5 and 6.6. Five wetlands exhibited declining health conditions in the response system except for the Madhabpur wetland and Manigram wetland. Madhabpur wetland (95%) had scored the highest health scores in the response system in 2016 probably due to regulated fishing activities by fishers, very minimum farming activities, and very minimal jute-retting practices (Fig. 6.3).

Manigram wetland (60%) and Gopalnagar wetland (56%) had scored moderate health conditions respectively in the response system in 2016. Weak ecological health conditions were observed in the Panchita wetland (37%) and Panchpota wetland (27%) in 2016. Astonishingly, two wetlands, namely Berkrishnapur (6%) and Aromdanga wetland (5%) represented morbid health conditions in the response system in 2016 which might be attributed to a high number of human-induced pressure, lack of bio-surveillance, unsustainable practices, conflict among stakeholder, the unbridled practice of trapping and killing of avifauna, use of fine net, retting of jute and lack of conservation effort over the long run (Fig. 6.3). This sort of health status in response system undoubtedly indicated indifferent mentality and high reluctancy towards these wetlands.

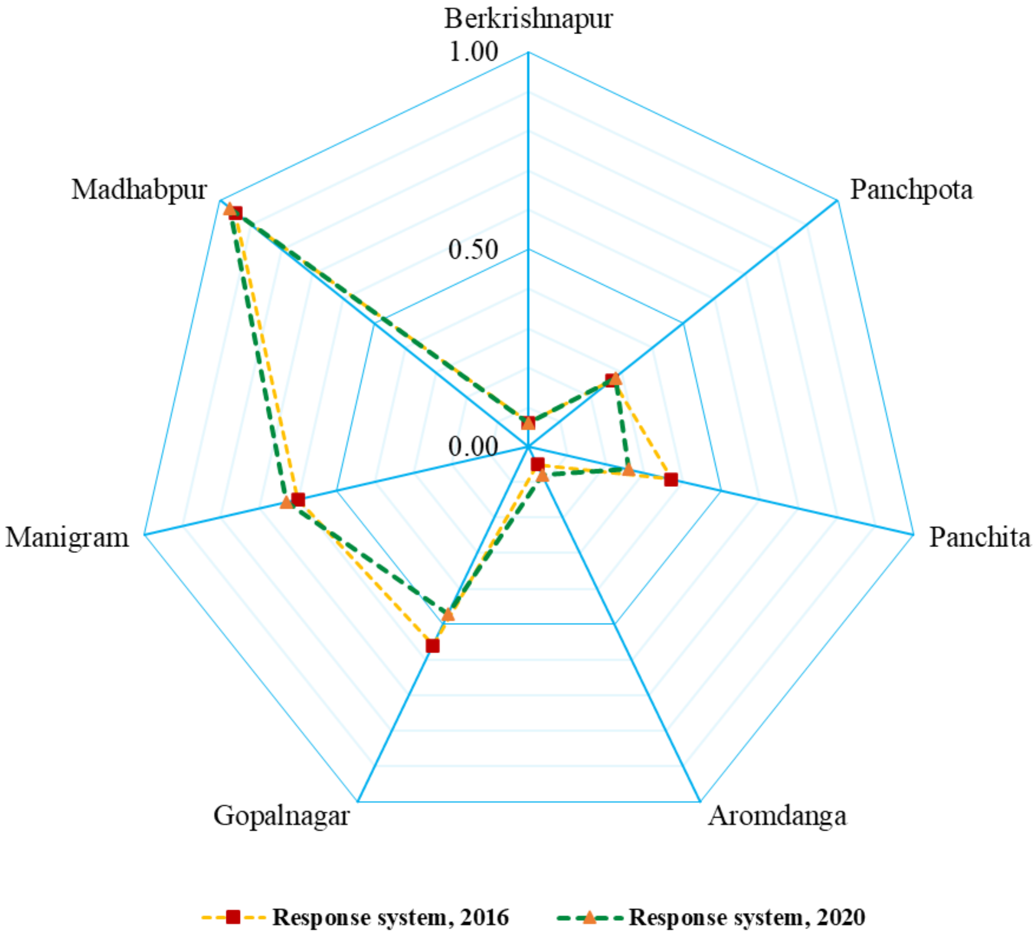

Fig. 6.3 CWEH status of response system from 2016 to 2020

The amount of health in the response system had substantially increased in the year 2020 except Panchita wetland (26% with an 11% decrease) and the Gopalnagar wetland (47% with a 9% decrease). Mainly Berkrishnapur wetland (6% same as of 2016) and Aromdanga wetland (8% with a 3% increase) had depicted morbid condition (Table 6.6). Panchita wetland (26% with an 11% decrease) and Panchpota wetland (28% with an 1% increase) had shown weak ecological health. Gopalnagar wetland (47% with a 9% decrease) had indicated moderate ecological health. Manigram wetland (63% with a 3% increase) exhibited good ecological health and only Madhabpur (97% with a 2% increase) wetland had shown excellent ecological health condition in 2020 with respect to 2016 indicating an overall weak trend of WEH in response system due to poor responses both at community and institutional level (Table 6.5 and 6.6). Panchita wetland and Gopalnagar wetland had depicted significant deterioration in the health of the response system which indicated stakeholders' highly reluctant mentality over decreasing ecosystem goods and services over the past few decades. Madhabpur wetland had achieved exceptional health status in the response system with respect to 2016 which

Table 6.6 Comparative account of the wetland ecological health status of pressure, state, and response system of selected seven wetlands from 2016 to 2020

Year	2016					2020				
HS	Excellent health	Good health	Moderate health	Weak health	Morbid	Excellent health	Good health	Moderate health	Weak health	Morbid
CWEHI	(1.0 – 0.8)	(0.8 – 0.6)	(0.6 – 0.4)	(0.4 – 0.2)	(0.2 – 0.0)	(1.0 – 0.8)	(0.8 – 0.6)	(0.6 – 0.4)	(0.4 – 0.2)	(0.2 – 0.0)
CL	I	II	III	IV	V	I	II	III	IV	V
Berkrishnapur			P-III	S-IV	R-V			P-III		SR-V
Panchpota				SR-IV	P-V				SR-IV	P-V
Panchita				PSR-IV					PSR-IV	
Aromdanga				PS-IV	R-V				PS-IV	R-V
Gopalnagar			SR-III	P-IV				SR-III	P-IV	
Manigram			PSR-III				R-II	PS-III		
Madhabpur	SR-I	P-II				SR-I	P-II			

again, might be attributed to positive instants of frequent meetings and FGDs with various stakeholders regarding awareness enhancing programs. Fishers of Madhabpur wetland received periodic trainings from Fisheries Department, Barrackpore, and *Meen Bhawan* at Barasat on fishing saplings, fish feed, and chemicals applied to various fish diseases. Therefore, fishers had a relatively good knowledge about water quality and its environmental health which was also reflected in the health of the response system.

6.3 Socio-economic and cultural influences on WEH of the studied wetlands

Evaluating WEH is always a challenging task because CWHI depends on the performance score of each indicator of the diverse and dynamic C&I framework (Datta et al., 2010; Datta and Chatterjee, 2012). The developed set of 105 C&I, did not always give positive results on all indicators. The low scores of some indicators having a negative impact on the wetland ecosystem certainly lowered the WEHI. Oppositely, good scores of some indicators having a positive impact on WEH gave enough positive input to generate overall good CWEHI standards. Therefore, the WEH of each indicator was found to be explanatory with this comprehensive C&I framework.

Overall, five wetlands (viz. Panchpota, Panchita, Aromdanga, Gopalnagar, and Manigram wetland) in 2016, and six wetlands (viz. Panchpota, Panchita, Aromdanga, Gopalnagar, Manigram, and Berkrishnapur wetland) in 2020 showed 50% or more human-induced pressure (Fig. 6.4A & 6.4B) which indicated high human-induced stress on LULC, a greater number of wetland-dependent populaces, highly fragmented wetlands, multiple points, and non-point pollution sources, use of chemical fertilizers and pesticides and insecticides, continuous socio-economic and other developmental activities in the wetland influence zone. Of late, incessant construction of houses in the wetland buffer zone and within WIZ, construction of roads across wetlands (Aromdanga and Gopalnagar wetland), and concretization of the major roads and railways (*e.g.*, SH-14, Bangaon-Helencha road and Bangaon-Ranaghat railway line) had further exacerbated pollution and resulted in significant deterioration of WEH in the region (Sun et al., 2019). The development of transport systems with an increasing number of vehicles had put a lot of pressure on the attendance of waterfowl, wetland water quality, aquatic life, and wetland area and consequently reduced the ecosystem products and services (Baral and Inskipp, 2005; Gayen et al., 2020). Due to intensive socio-economic activities such as high per capita arable land, an intensive culture of exotic fishing, use of fine nets for fishing, extraction of water for irrigation, intensive jute-retting, washing and bathing, and dense household density, the Berkrishnapur wetland (49% in 2016) had moved into 50% or more human-induced pressure in 2020 (Fig. 6.4B).

Jute cultivation and retting of jute, one of the main sources of income for the community population, were destroying the wetland ecosystem by increasing the sedimentation process and adding toxic substances, bad odor, and color to the wetland water and thus disrupting ecological functions (Mondal and Kaviraj, 2007; Ghosh and Biswas, 2015; Ghosh and Biswas, 2018). In addition, the use of fine nets for catching juvenile fish, trapping, and selling of endangered species such as migratory waterbirds, freshwater turtles and tortoises, and *cuchia* (*Monopterus cuchia*) led to major threats to wetland biodiversity and thereby degrading wetland ecological health (Mondal and Kaviraj, 2007; Datta and Ghosh, 2015; Gayen et al., 2020).

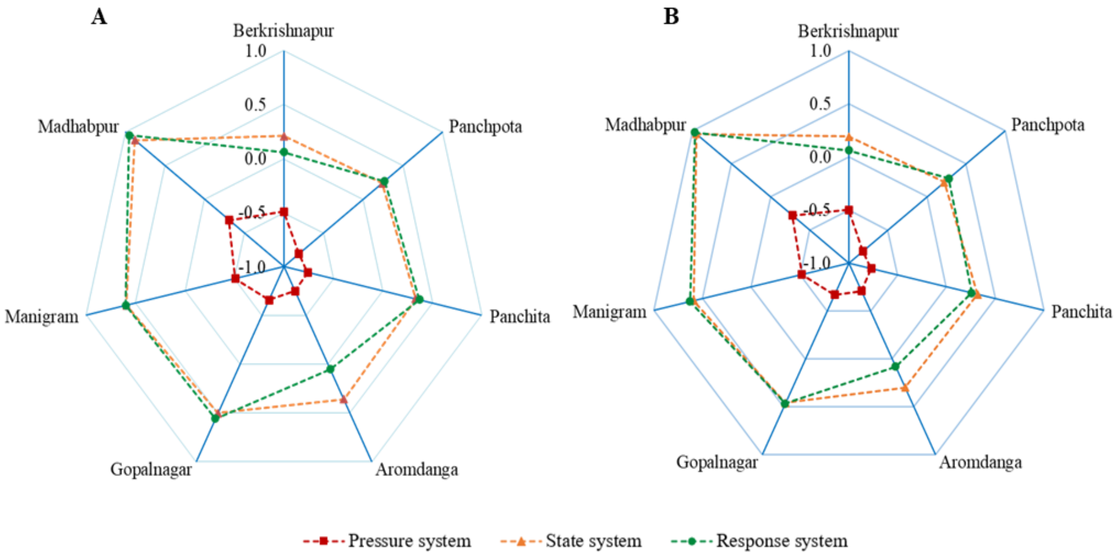

Fig. 6.4 Changing CWEH status from (A) 2016 to (B) 2020

Only, the Madhabpur wetland (31%) faced comparatively less human-induced pressure in 2016 which dropped to 28% in 2020 that could be attributed to very minimum jute-retting, low amount of arable land, existing good management practices exercised by fishing cooperative members and farmers. The high human-induced pressure on each wetland which was understood by this advanced C&I framework also clearly indicated the community dependence and ecosystem vitality of these wetlands in the study area that would otherwise lead to overall deterioration and degradation of WEH (Photograph 6.2). Although the WEH health of the Ichhamati floodplain wetlands was largely controlled by anthropogenic interventions, the role of some physical indicators such as sedimentation, weed infestation, absence of river inflow and outflow during lean times, higher rate of evaporation and evapotranspiration, decomposition and littering of aquatic weeds, has expedited the degradation process alarmingly. Eutrophication took place extensively in five wetlands (*viz*., Aromdanga, Gopalnagar, Panchita, Panchpota, and Berkrishnapur wetland) and partly in two wetlands (Manigram and Madhabpur wetland) due to loading of nutrients (*e.g.*, phosphorus and nitrogen) from wastewater from various sources and nearby agricultural fields (Photograph 6.1) (Cooper, 1993; Ansari et al., 2010; Chen and Wong, 2016; Gayen et al., 2020). Increasing food and energy demand of the growing population, eventually, led to long-term deterioration and degradation of WEH which was seen in the studied wetlands in its state system. Therefore, inevitable consequences of these events was noticeable by fragmentation, habitat encroachment and loss, wetland diminution, reduction of depth, deterioration of water quality, pathogenic contamination, cultural eutrophication, attendance of avifauna and avifauna diversity, fish death and algal bloom and overall declining wetland functions and productivity, etc.

From 2016 to 2020, the WEH of the state system had notably reduced for five wetlands, indicating the unsatisfactory performance of state indicators due to continuous human-induced pressure on these wetlands. Aromdanga (6% decline from 2016), Gopalnagar (4% decline from 2016), Berkrishnapur (2% decline from 2016), Panchita wetland (1% decline from 2016) and Panchpota (2% decline from 2016) had shown notable reductions in WEH of the state system in 2020 (Fig. 6.4B) which might be responsible for high patch density, high turbid condition, decreasing depth of wetlands, low DO and high BOD, high eutrophication level, presence of an excess amount of phosphorus and nitrogen in wetland water, low fish diversity, sellable flora, fishes and other wetland fauna.

Lack of adequate management initiatives and judicious protection hampered the ability of these wetlands to function normally leading to a distressed state of frequent fish deaths, the occurrence of algal bloom and cultural eutrophication (Ansari et al., 2010; Chislock et al., 2013). Again, fishing dominated Madhabpur wetland had achieved exceptional health status and Manigram wetland remained at the same WEH status in the state system in 2020 (Table 6.5) due to good scores of each indicator and positive moments of frequent meetings with stakeholders, FGDs, and good practice performed by fishing cooperative members and fishers. Panchpota (1% increase), Aromdanga (3% increase), Manigram (3% increase), and Madhabpur wetland (2% increase) showed little bit improvement and Berkrishnapur wetland showed no change in WEH of response

Photograph 6.1 Activities indicating waning health: (a) flow abatement by constructing roads across Aromdanga wetland, (b) logging at Manigram wetland, (c) rituals activities at Panchpota wetland, (d) jute retting in a weed-infested Berkrishnapur wetland, (e) paddy cultivation along the reclaimed littoral part of Gopalnagar wetland, (f) Algal blooms at Aromdanga wetland

from 2016 to 2020 due to frequent meetings with various stakeholders, FGDs, and awareness campaigns (Fig 6.4B and Table 6.5). However, the immediate effect of such improvements in the response system was not reflected in the improvement of the WEH of the state system for five wetlands rather their WEH decreased significantly from 2016 to 2020 except Manigram and Madhabpur wetland. These phenomena demonstrated rather clearly that when disturbed, natural systems might not react swiftly. Besides, the WEH of each system of Madhabpur wetland was improved notably in both years probably due to controlled fishing activities by fishers, minimum farming activities, minimal jute-retting, excellent habitat conditions, good management practices by stakeholders along with their high awareness level (Lu et al., 2015). Despite frequent meetings with stakeholders and FGDs, there were a significant decline in WEH in terms of the response system for Panchita (11% reduction with 26% in 2020) and Gopalnagar (9% reduction with 47% in 2020) indicating helplessness of wetland community in drawing their livelihoods from these two wetlands and high reluctance mentality of stakeholders towards the decline of ecosystem goods and services over the past few decades. Such decline in WEH could be attributed to poor performance of indicators in ecological, economic, and epidemiological response, socio-cultural response, and management responses also.

6.4 Existing threats to the studied wetlands

In spite of numerous beneficial effects on the lives and livelihoods of the communities, selected wetlands had been suffered from environmental pollution and degradation such as eutrophication, algal bloom, fish death, and wetland shrinkage. Intensive usage patterns coupled with a lack of proper understanding had degraded the trophic structure of these systems. With all self-regulating factors and processes, leading

Photograph 6.2 Agricultural land reclaimed during the lean period (March-May) beside Madhabpur wetland

human-induced pressures currently threatening the resilience of selected wetlands were largely anthropogenic. These pressures are: firstly, cultivation on small plots within the WIZ led to wetland loss and habitat alteration accompanied by settlement and habitat fragmentation. Second, wetland pollution was associated with agricultural run-off from surrounding agricultural land and wastewater from various point and non-point sources such as houses, markets, hospitals, nursing homes, washing and drying centers, etc. Water pollution, caused by various contaminants, resulted in eutrophication in almost all wetlands and promoted the proliferation of aquatic weeds among which two dominant species were *Eichhornia crassipes* and *Ceratophyllum demersum*. The uncontrolled growth of these two aquatic weeds had threatened both fishing and agriculture in these wetlands. Third, the deliberate and accidental introduction of exotic fish species had increased competition with native species for food and often created opportunities for hybridization. Fourth, reptiles and mammals are accidentally caught in fishing nets. Death of reptiles and fishes were also observed in Gopalnagar, Aromdanga, Panchita, Panchpota, and Berkrishnapur wetlands due to water pollution. Large quantities of *E. Coli* were observed in all wetlands. Attendance of avifauna had declined significantly due to human disturbance, trapping and killing, and lack of bio-surveillance. Fish production was also declining notably due to water pollution, the proliferation of *Ceratophyllum demersum*, and competition with native fish species. Conversion of wetlands to other land uses such as agricultural land, built-up land, and construction of houses and roads were observed as a major threats to these natural systems. Selected wetlands were losing depth due to sedimentation caused by surface run-off and littering and decomposition of aquatic weeds especially *Eichhornia crassipes and Ceratophyllum demersum* after their natural death. Wastewater comes into these wetlands from surrounding agricultural land and domestic sources through drains and sluice gates which also substantially polluted wetland water apart from its autocleaning mechanism. Open feces, animal carcasses, and bird droppings had been increased the microbial contamination of wetland water. Jute retting had increased water pollution by adding toxins to the water and contributed extra silts to wetland which was used for retting jute. Some of the notable unsustainable utilization activities of the selected wetlands observed keenly over the five years of this study were captured through some snaps (Photograph 6.3).

Photograph 6.3 (a) plowing in WIZ of Gopalnagar, (b) boro cultivation of paddy in Gopalnagar, (c) preparing lace for retting in Manigram, (d) jute-stick drying in Gopalnagar, (e) culvert for coming agricultural washouts in Panchita, (f) wastewater outfall canal in Gopalnagar, (g) human and cattle bathing in Panchpota, (h) bathing in Panchpota, (i) solid waste in Gopalnagar, (j) solid waste dumping in Manigram, (k) soil excavation by JCP in Aromdanga, (l) construction of a road across Aromdanga, (m) construction of houses in Aromdanga, (n) trapping and Killing avifauna in Panchpota, (O) algal bloom in Panchpota wetland

Chapter 7: Wetland-Specific Wise Uses and Proposed Management Guidelines

7.1 Wetland-specific identified wise uses

The Ramsar Convention defines wise use as "The wise use of wetlands is their sustainable utilization for the benefit of mankind in a way compatible with the maintenance of the natural properties of the ecosystem" (Ramsar convention, 2010). In general, wise use refers to any use of natural resources that preserves the biological features of any wetland for the benefit of people without impairing the wetland's ecological function. For instance, thousands of people in 21 villages living around the studied wetlands, deteriorate the ecological health of these sites by extracting their natural resources such as fish, water, spinach, fodder, trees, snails, aquatic weeds, and birds, but these wetlands still maintain their natural productivity and ecological character. In the initial phase, a set of 18 wise uses were identified based on community interaction, researcher field experience, existing literature, and expert opinion. Thereafter, for the ground realization of such wise uses of the studied wetlands, the initial set of wise uses was placed before four key stakeholders of these wetlands during focus group discussions with CWEHI-based results (Fig. 7.1). 18 wise usages were discussed in detail in front of various wetland users and their consent was sought. They unanimously agreed and gave their consensus on 12 wise uses. However, 6 uses were rejected as wise uses in the selected wetlands. Stakeholder consensus was reached on 12 wetland uses and those 12 uses were recognized as wise uses of selected seven wetlands (Table 7.1). After that, the final list of 12 wise uses was then crosschecked and validated at three geographical dimensions, namely regional-specific, wetland-complex-specific (WCS), and wetland-specific (WS). Even if all wetlands are located within a wetland complex that is physically adjacent to one another and hydrologically connected, identified wise uses are not practiced in all wetlands equally. Therefore, the overall WEH may deteriorate as a result of this spatial variation in the number of wise uses. It is important to mention that wise usage can play a key role in wetland mitigation and restoration at the community level. Therefore, key stakeholders can employ these wise uses to ensure wetland sustainability. By expanding wise uses, wetland vulnerability can also be lowered to ideal levels. Since ancient times, wetland communities have developed these wise usage through their utilization practices of these natural resources. Moreover, wise uses also helped people to access wetland resources and preserve the biological features of these natural systems simultaneously. These wise use habits enable communities to exist creatively with these wetlands. Therefore, wise uses of wetlands can be instrumental to restore degraded wetland ecosystems and promote community resilience and wetland sustainability.

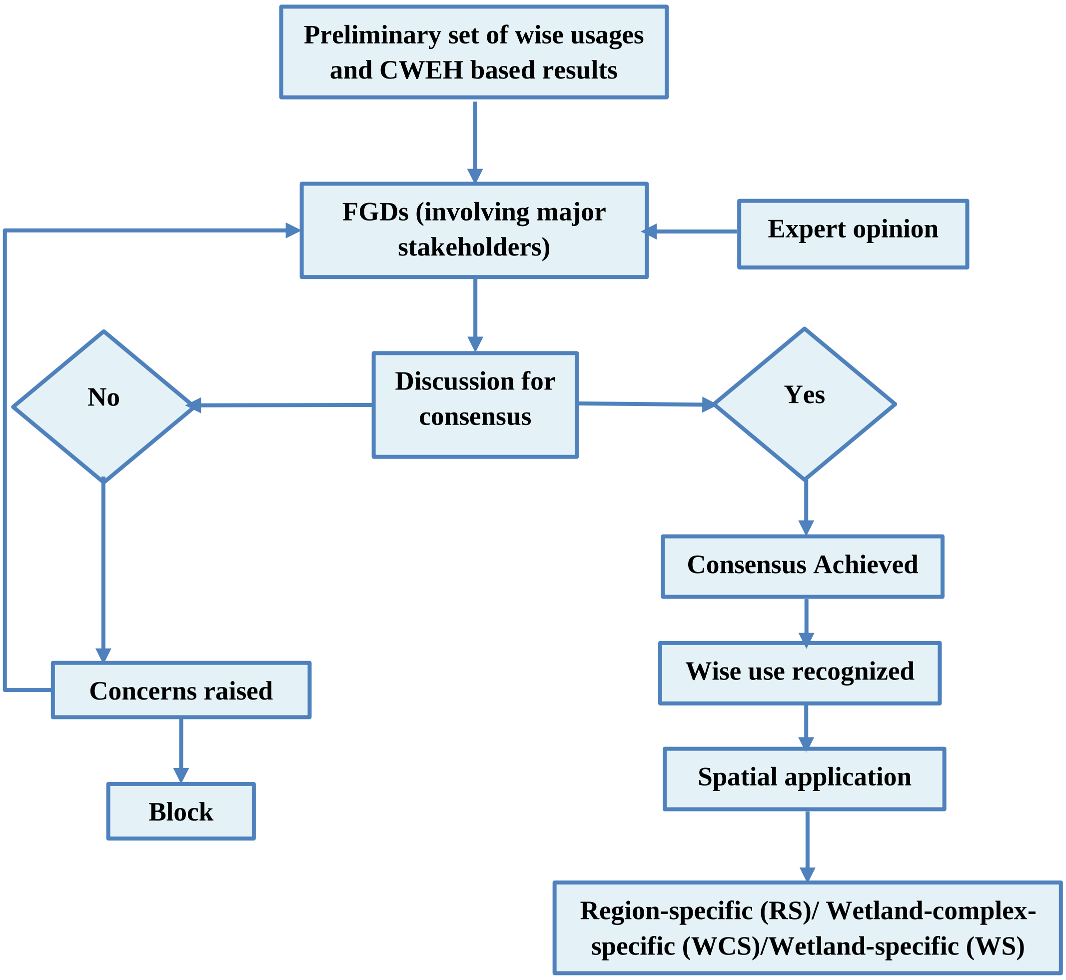

Fig. 7.1 Flowchart for identification of relevant wise uses in the studied wetlands

7.2 Proposed management guidelines

By incorporating the findings and results of WEH, management guidelines and restoration plans were developed. This set of management guidelines will be very effective in rehabilitating these degraded wetlands towards its restoration. Moreover, wetland-specific recommendations will improve WEH by expanding wise uses and raising stakeholder knowledge. This study was able to investigate how the ecological health of the examined wetlands is rapidly declining as a result of many variables that are impairing the ecosystem's structure and function (Gayen et al., 2020). Without implementing specific restoration guidelines and policies, it is challenging to restore these degraded wetlands to their original or natural state under business-as-usual (BaU) circumstances. Therefore, region-specific, wetland-complex-specific, and wetland-specific management guidelines were formulated based on the researcher's experience and issues faced by stakeholders which should be strictly applied to improve resilience, sustainability, and WEH regarding the selected seven wetlands.

7.2.1 Region-specific management guidelines

i. Maintenance of wetland eco-hydrological conditions through channelization of fresh water into wetlands, dredging and deepening of waterbodies, and connecting canals and river itself should be part of action programs. Sediment-trapping grass like vetiver grass (*Chrysopogon zizanioides*) should be planted along the littoral zone to trap silts in order to arrest sedimentation.

ii. Boundaries of the wetland influence zone should be demarcated based on hydrological as well as ecological connectivity. Demarcation of the resource pool and users' rights should be incorporated while designing a regional digital inventory of wetlands.

iii. Within the delineated buffer of the wetland, any construction and road connectivity should be approved based on zonal management plans to reduce wetland fragmentation.

iv. For ease of management and compliance with extant regulatory regimes, wetlands or wetland complexes should be divided into patches or zones such as – fishery, agriculture, horticulture, and nature protection zones.

v. Wetland health cards should be developed annually for every wetland following the PSR evaluation system. Local educational institutions as well as research organizations should be part of these activities.

vi. Multiple use-based land use plans should be promoted to maintain ecological as well as aesthetic balance for tapping newer economic opportunities.

vii. Awareness campaigns should be encouraged to increase public awareness regarding prohibited activities such as hunting, poaching of avifauna, catching of endangered species, and waste disposal. Regular meetings, frequent inspections, and actions of local self-government can help to resolve conflicts arising from such illegal activities.

viii. Greater involvement of community members as well as local CBOs along with local government stakeholders should be assured to take major management initiatives for ecological restoration of degraded wetlands.

ix. Community members should be involved in preparing the micro-plans for wetlands and stakeholders should be encouraged within the existing legal framework for the achievement of good WEH.

x. The rights of water should be ensured as customary and ethical rights of local communities in the context of access to wetlands as common property resources.

7.2.2 Guidelines for management of WEH within the selected wetland complex

i. Local CBOs along with Government executive bodies should take initiatives to enhance wetland connectivity by dredging connecting canals and river Ichhamati for enhancing the ecological and biological value of this wetland complex.

ii. Plantation of *Acacia catechu*, *Leucaena leucocephala*, and *Casuarina equisetifolia* along with *Mangifera indica*, *Psidium guajava*, *Bambusa vulgaris* should be promoted in wetland catchment areas as protective features for nesting and foraging of avifauna.

iii. A seasonal assessment of water quality should be done using the Biological Water Quality Criteria (BWQC) methodology developed by the Central Pollution Control Board (CPCB). It will help to understand the saprobic values and diversity of benthic macro-invertebrate families and their relation with water quality.

iv. Adoption of specified zoning criteria for all wetlands with special reference to conservation areas and environmentally sensitive wetlands should be carried out in collaboration with the different government departments and local Government authorities, NGOs, etc.

v. The survey, collaborative mapping, and demarcation of the extent of wetlands in terms of biodiversity, hydrologic, socio-economic requirements, and cultural values should be prioritized following national guidelines.

vi. A comprehensive baseline assessment of biophysical components through extensive environmental assessment and monitoring should be carried out along with the participatory assessment of socio-economic status to redefine priorities in an existing management plan.

vii. Multiple use-based land management plans for each wetland within the wetland complex should be promoted to maintain ecological as well as aesthetic balance.

viii. Continuous awareness campaigns regarding the vitality of wetland ecology should be carried out among different functional stakeholders for identifying the necessity of conserving this wetland.

ix. Due to large areal coverage and resultant management issues, provisions of the

Bio-rights approach can be promoted here. Thus, incentives for conservation are accompanied by intense capacity building for sustainable development, environmental conservation, and group formation.

7.2.3 Wetland-specific management guidelines

Spatial variation of wise uses perhaps caused variation in WEH. Such diversification of wise uses in intra-wetlands and within wetland complexes leads us to formulate wetland-specific management guidelines to enhance wetland resilience and sustainability.

i. A comprehensive inventory of wetlands based on their socio-ecological importance should be developed and published in the public domain for regular upgradation of information as well as running basic wetland conservational activities.
ii. A wetland influence zone depending on the wetland size and ecological function of wetland fauna (Lane & D'Amico, 2016; Chen & Lin, 2013; Gimmi et al., 2011) should be delineated and fenced to limit rampant human access as well as an encroachment to all wetlands for maintaining habitat conditions.
iii. Farmers of Berkrishnapur, Panchita, Aromdanga, and Gopalnagar should be made aware of the harmful effects of chemical fertilizers, pesticides, and herbicides, especially for wetland sustainability.
iv. It is observed that only Gopalnagar, Manigram, and Madhabpur wetlands are planted with trees. However, this plantation program should be initiated in other wetlands like Berkrishnapur, Panchpota, Panchita, and Aromdanga wetlands for the natural habitat of avifauna and other organisms (Table 7.1).
v. Water hyacinth (*i.e., Eichhornia crassipes*), a major threat to fishers and farmers, can be well managed by keeping small patches with bamboo fences for nesting, resting, and breeding sites of waterfowl and fishes. It can also be well managed by composting it to produce organic manure and this is already practiced on a small scale in Panchita and Manigram wetlands (Islam et al., 2021; Rakotoarisoa et al., 2015). Meanwhile, this good practice can also be extended to other five wetlands such as Berkrishnapur, Panchpota, Aromdanga, Gopalnagar, and Madhabpur wetlands to combat this menace.
vi. Hydroponics farming is not practiced at all in these wetlands but it can be a viable option during flood situations and can become an alternative tool for achieving

food security as sustainable development goals (SDGs).

Table 7.1 Identified wise uses and wetland-specific planning

Identified wise uses	Wetland-specific wise uses identified	Wetland Complex specific	Region-specific	Micro-level planning To be implemented
WU1: Plantation of *Mangifera indica*, *Psidium guajava*, *Acacia auriculiformis*, and Swietenia mahagoni, and *Lambu* tree etc.	Gopalnagar, Manigram and Madhabpur	✓	✓	Berkrishnapur, Panchpota, Panchita, Aromdanga
WU2: Water hyacinth (*Eichhornia crassipes*) mat for fishes and nesting, resting, and breeding place of waterbirds	Madhabpur	✓	-	Berkrishnapur, Panchpota, Panchita, Aromdanga, Gopalnagar, Manigram
WU3: Composting of water hyacinth for preparing organic manures	Panchita and Manigram	✓	-	Berkrishnapur, Panchpota, Aromdanga, Gopalnagar and Madhabpur
WU4: Proper gaps in between two harvesting of fishes	Madhabpur and Panchita wetland	✓	-	Berkrishnapur, Panchpota, Aromdanga, Gopalnagar, and Manigram
WU5: Alaghar (for fish surveillance)	Madhabpur and Aromdanga	✓	-	Berkrishnapur, Panchpota, Panchita, Manigram, and Gopalnagar
WU6: Various herbs, medicinal plants, and spinaches collections bolster the food security of the local community	All wetlands	✓	✓	-
WU7: Snail collection as a protein supplement	Berkrishnapur and Gopalnagar	✓	-	Berkrishnapur, Panchpota, Panchita, Aromdanga, Gopalnagar, Manigram and Madhabpur
WU8: Fodder and fuel collection	All wetlands	✓	✓	-
WU9: Collection of raw materials for making artifacts	All wetlands	✓	✓	-
WU10: Cultivation of fox nut (*Euryale ferox*)	Manigram	✓	-	Berkrishnapur, Panchpota, Panchita, Aromdanga, Gopalnagar, Manigram and Madhabpur
WU11: *Azolla* and *Lemnoideae* cultivation	All wetlands	✓	✓	-
WU12: Excavation and use of nutrient-rich wetland silts for agriculture	Aromdanga and Panchita	✓	-	Berkrishnapur, Panchpota, Manigram, Gopalnagar, and Madhabpur

vii. There should be a proper gap between two consecutive fish harvests to allow fish siblings to grow. Unfortunately, this gap was found to be genuinely maintained only in Panchita and Madhabpur wetlands. Fishery communities in the other five wetlands namely Berkrishnapur, Panchpota, Aromdanga, Gopalnagar, and

Manigram wetlands must maintain this gap towards good fish production as well as fish biodiversity. In addition to these, adaptive fishing approaches such as pre-summer enclosure, torch light fishing deep pool refuge, autumn stocking, and floating aquatic macrophyte refuge should be promoted in all wetland sites for sustainable fish culture and capture. Moreover, utmost importance should be given in maintaining the connectivity of these wetlands for the migration of fish, flora, and fauna.

viii. Alaghar (for fish surveillance) was set up only in two wetlands namely Aromdanga and Madhabpur wetlands for fish surveillance. However, it should be set up in the other five wetlands too for surveillance and fish production augmentation.

ix. Herbs and aquatic plants are collected by community members. However, spinaches like *Kalmi* (*Ipomoea aquatic*), *Chhanchi* (*Alternanthera sessilis*), *Thankuni* (*Centella asiatica*), *Kule Khara* (*Hygrophila auriculata*), *Sushni* (*Marsilea minuta*), *Helencha* (*Enhydra fluctuans*) *and Brahmi* (*Bacopa monnieri*) are mainly harvested by women for small earnings as well as daily food from all wetlands. Therefore, large-scale production of these herbs and aquatic plants can be performed in all wetlands for women's empowerment.

x. Snails are a protein supplement food used only by tribal communities living in Berkrishnapur and Gopalnagar wetlands. However, awareness about the food value of this protein supplement can be raised in the remaining five wetlands.

xi. The community populace should collect fodder from these wetlands. Water hyacinth (*i.e.*, *Eichhornia crassipes*), *Chotokut* (*i.e.*, *Alisma gramineum*) and other grasses can be used as fodder. Dried water hyacinth can be used as fuel by poor communities to save fuel expenses.

xii. Local people collect raw materials from all these wetlands to make various artifacts that are highly demanded in the market. Therefore, stakeholders should be trained to master the craft of making environmentally friendly daily-use products using wetland weeds. Therefore, the current threat to wetlands may be harnessed to create new opportunities for employment and to set the value for the restoration of the WEH standard of the studied wetlands.

xiii. On a smaller scale, Fox nut (*Euryale ferox*) grows naturally only in the Manigram wetland, and can also be cultivated in the remaining six wetlands on a large scale to augment the income of the local communities.

xiv. The water quality of Berkrishnapur, Panchpota, Panchita, Aromdanga, Gopalnagar, and Manigram wetlands should be monitored seasonally. People should be informed about the beneficial use (maintenance of wetland water quality) of mosquito ferns (*Azolla*) and duckweeds (*Lemnoideae*).

xv. Nutrient-rich wetland soils can be used for agricultural lands which were only used in Aromdanga and Panchita. It can also be extended to Berkrishnapur, Panchpota, Gopalnagar, Manigram, and Madhabpur wetlands to regain wetland depth and increase agricultural production.

xvi. Bio-surveillance for the restoration of biodiversity should be introduced in Gopalnagar, Aromdanga, and Berkrishnapur wetlands. Proper surveillance should be present in each wetland to stop the use of trap nets, poisons in fish guilds, and shooting guns. Government and stakeholders should ensure bio-surveillance of these wetlands with the help of wetland Mitra as well as awareness-building campaigns among communities.

xvii. Responsible tourism can be initiated within the purview of an integrated landscape tourism approach that will sustain biodiversity in the studied wetland complex.

xviii. Environmental impact assessment (EIA) and social impact analysis (SIA) along with ecological aspects should be given utmost priority during any sort of construction venture such as the construction of roads, culverts, and bridges otherwise it will lead to serious environmental damage and affect neighboring villages.

xix. Awareness programs should be conducted at least two in a month with major stakeholders for exchanging and sharing knowledge regarding better utilization of wetlands and their conservation. These programs should be initiated by stakeholders including NGOs, wetland experts, resource persons, and environmentalists in all wetlands. FGDs and meetings with key stakeholders should be conducted at regular intervals to raise awareness among wetland users about the need for ecosystem services, their quality and value, and wetland ecosystem restoration. Processions or rallies can be organized with slogans and quotations regarding the values of wetlands and their services.

7.3 Contributions of this study

This study sincerely assessed the ecological health of selected wetlands by combining edaphic, aquatic, biotic, and socio-economic aspects in humanized landscapes that had not been done at all before (Datta et al., 2010). Data obtained by in-situ measurements of physical, physicochemical, and biological parameters were found to be sufficient for explaining the deteriorating condition of wetlands in this region. Scores of landscape metrics and existing mosaic of LULC have also indicated the high dependency of communities on these wetlands which collectively created dismal environmental situations. However, despite frequent meetings and FGDs, a lack of the desired level of knowledge was observed among the local populace during the scheduled-based questionnaire survey with respondents. Yet, their ground-level experience and knowledge helped us in deriving the CWEHI for each wetland. Morbid health of response and the state system in Berkrishnapur wetland, morbid health of pressure system in Panchpota wetland, and morbid health of response system were observed which is indicated by an algal bloom, fish death, and poor water quality and eutrophication in six wetlands except for Madhabpur wetland. Weak health of the PSR systems in the Panchita wetland, weak health of PS systems in the Aromdanga wetland, and weak health of the pressure system of the Gopalnagar wetland were observed indicating deterioration of these three wetlands under intense human pressures. Excellent health of the state and response system and good health of the pressure system in Madhabpur wetland was observed in both years. With this CWEHI standard and FGDs, micro-level plans, as well as some management guidelines, were formulated. These were divided into wetland-specific, wetland-complex-specific, and region-specific categories and may restore these wetlands from further degradation and improve their WEH in near future.

7.4 Future research possibilities

This wetland complex is an ecosystem laboratory and opens many avenues for future research activities. However, the availability of sophisticated logistics, one of the major limitations of this study, may yield better results of the CWEHI of these wetlands. The availability of on-site monitoring instruments is highly essential for real-time monitoring and prediction of environmental resilience and sustainability. Eco-exergy, a thermodynamic concept, can be analyzed in these wetlands to estimate wetland sustainability. The causes and consequences of eutrophication can be studied in these wetlands which is a major issue for stakeholders to draw their livelihoods. Further research is needed for floodplain wetlands in general and the identified seven wetlands in particular on landscape connectivity, hydroponics cultivation for community resilience, biodiversity status, and public health, etc. Economic valuation of these wetlands can be done in the future to understand livelihood sustenance. Finally, keeping in mind the existing conditions and environmental scenarios of these wetlands, the researcher strongly believes that the involvement of key stakeholders and local resource persons can enhance the understanding of this complex system from an ecological or socio-economic perspective.

Photograph 7.1 Lesser whistling ducks (*Dendrocygna javanica*) in a playing mood in the Gopalnagar wetland

Bibliography

Aarif, K. M., Muzaffar, S. B., Babu, S., & Prasadan, P. K. (2014). Shorebird assemblages respond to anthropogenic stress by altering habitat use in a wetland in India. *Biodiversity and Conservation*, *23*(3), 727-740.

Aarif, K. M., Nefla, A., Muzaffar, S. B., Musammilu, K. K., & Prasadan, P. K. (2017). Traditional fishing activities enhance the abundance of selected waterbird species in a wetland in India. *Avian Research*, *8*(1), 1-10.

Agboola, J. I., Ndimele, P. E., Odunuga, S., Akanni, A., Kosemani, B., & Ahove, M. A. (2016). Ecological health status of the Lagos wetland ecosystems: Implications for coastal risk reduction. *Estuarine, Coastal and Shelf Science*, *183*, 73-81.

Akwetaireho, S., & Getzner, M. (2010). Livelihood dependence on ecosystem services of local residents: A case study from Mabamba Bay wetlands (Lake Victoria, Uganda). *International Journal of Biodiversity Science, Ecosystem Services & Management*, *6*(1-2), 75-87.

Alam, M. Z., Carpenter-Boggs, L., Rahman, A., Haque, M. M., Miah, M. R. U., Moniruzzaman, M., Qayum, M. A., & Abdullah, H. M. (2017). Water quality and resident perceptions of declining ecosystem services at Shitalakka wetland in Narayanganj city. *Sustainability of Water Quality and Ecology*, *9*, 53-66.

Anon. (1994). *World development report*. World Bank development report, New York: Oxford University Press.

Ansari, A. A., Singh, G. S., Lanza, G. R., & Rast, W. (2010). *Eutrophication: Causes, consequences and control*. Springer.

APHA (American Public Health Association) (2023). *Standard methods for the examination of water and wastewater*, 23rd Edn. Washington, DC, USA.

Aslam, M., Fahmi, A., Almahdi, F. A. A., & Yaqoob, N. (2021). Extension of TOPSIS method for group decision-making under triangular linguistic neutrosophic cubic sets. *Soft Computing*, *25*(5), 3359-3376.

Assessment, M. E. (2005). *Ecosystems and human well-being: Wetlands and water*. World Resources Institute.

Baber, M. J., Childers, D. L., Babbitt, K. J., & Anderson, D. H. (2002). Controls on fish distribution and abundance in temporary wetlands. *Canadian Journal of Fisheries and Aquatic Sciences*, *59*(9), 1441-1450.

Bai, J., Jia, J., Zhang, G., Zhao, Q., Lu, Q., Cui, B., & Liu, X. (2016). Spatial and temporal dynamics of heavy metal pollution and source identification in sediment cores from the short-term flooding riparian wetlands in a Chinese delta. *Environmental Pollution*, *219*, 379-388.

Bala, G., & Mukherjee, A. (2010). Water quality index of some wetland in Nadia district, West Bengal, India. *International Journal of Lakes and Rivers*, *4*(1), 21-26.

Balasubramanian, V., Sie, M., Hijmans, R. J., & Otsuka, K. (2007). Increasing rice production in sub-Saharan Africa: Challenges and opportunities. *Advances in Agronomy*, *94*, 55-133.

Bandyopadhyay, B. (1996). *Ichhamati*. Kolkata, India: Mitra and Ghosh Publishers.

Bandyopadhyay, S. (2007). Evolution of the Ganga Brahmaputra Delta: A review. *Geographical Review of India*, *69*(3), 235-268.

Bandyopadhyay, S., Das, S., & Kar, N. S. (2021). Avulsion of the Brahmaputra in Bangladesh during the 18th-19th century: A review based on cartographic and literary evidence. *Geomorphology*, *384*, 1-19.

Bandyopadhyay, S., Kar, N. S., Das, S., & Sen, J. (2014). River systems and water resources of West Bengal: A review. *Geological Society of India Special Publication*, *3*, 63-84.

Baoshan, C., & Zhifeng, Y. (2002). Establishing an Indicator System for Ecosystem Health Evaluation on Wetlands I. A Theoretical Framework. *Acta Ecologica Sinica*, *22*(7), 1005-1011.

Baral, H. S. & Inskipp, C. (2005). *Important Bird Areas in Nepal: Key sites for conservation*. Bird Conservation Nepal.

Bartz, R., & Kowarik, I. (2019). Assessing the environmental impacts of invasive alien plants: A review of assessment approaches. *NeoBiota*, *43*, 69-99.

Basak, R. K. (2000). Soil testing and recommendation, Kalyani Publishers, Ludhiana, New Delhi.

Bassi, N., Kumar, M. D., Sharma, A., & Pardha-Saradhi, P. (2014). Status of wetlands in India: A review of extent, ecosystem benefits, threats and management strategies. *Journal of Hydrology: Regional Studies*, *2*, 1-19.

Basu, B., & Sil, S. (2003, January). *Arsenic mapping for North 24-Pargana district of West Bengal-Using GIS and remote sensing technology*. Map India Conference. http://www.gisdevelopment.net/application/ environment/water/pdf/204.pdf

Basu, S. R. (1981). Some considerations on the process of sedimentation in the Hoogly tidal channel. *North Bengal University, Review*, *2*, 61-65.

Batzer, D. P., & Wissinger, S. A. (1996). Ecology of insect communities in nontidal wetlands. *Annual Review of Entomology*, *41*, 75-100.

Behera, M. D., Chitale, V. S., Shaw, A., Roy, P. S., & Murthy, M. S. R. (2012). Wetland monitoring, serving as an index of land use change-A study in Samaspur Wetlands, Uttar Pradesh, India. *Journal of the Indian Society of Remote Sensing*, *40*(2), 287-297.

Benny, N. (2009). *Unravelling a benchmark for Sulphur akin in the Cochin Estuarine System*. Cochin, Kerala.

Berhane, T. M., Lane, C. R., Mengistu, S. G., Christensen, J., Golden, H. E., Qiu, S., Zhu, Z., & Wu, Q. (2020). Land-cover changes to surface-water buffers in the midwestern USA: 25 years of Landsat data analyses (1993-2017). *Remote Sensing*, *12*(5), 1-31.

Bernal, B. (2008) *Carbon pools and profiles in wetland soils: The effect of climate and wetland type*. USA.

Bhakta, J. N., & Bandyopadhyay, P. K. (2007). Exotic fish biodiversity in Churni River of west Bengal, India. *Electronic Journal of Biology*, *3*(1), 13-17.

Bhat, S. A., & Pandit, A. K. (2014). Surface water quality assessment of Wular Lake, a Ramsar site in Kashmir Himalaya, using discriminant analysis and WQI. *Journal of Ecosystems*, *2014*, 1-18.

Bhattachaiyya, N. N., & Bora, A. K. (1997). Floods of the Brahmaputra river in India. *Water International*, *22*(4), 222-229.

Bhattacharya, P., Chatterjee, D., & Jacks, G. (1997). Occurrence of arsenic-contaminated groundwater in alluvial aquifers from delta plains, Eastern India: Options for safe drinking water supply. *International Journal of Water Resources Development*, *13*(1), 79-92.

Bhattacharya, R., Roy, R., & Das, R. (2013). Diversity and distribution of local birds beside the tropic of cancer. *International Journal of Environmental Sciences*, *3*(5), 1322-1329.

Bhattacharya, S., Gupta, K., Debnath, S., & Ghosh, U.C., (2014). Effects of idol emersion on the water quality parameters of Indian water bodies: Environmental health perspectives. *International Letters of Chemistry, Physics and Astronomy, 20*(2), 234-263.

Biswas, M., Roy, P. K., & Mazumdar, A. (2005). A Case Study: An Integrated Approach of Wetland Management in Nadia District, West Bengal. In A. Kumar. (Ed.), *Fundamentals of Limnology*, (1st ed., pp. 143-150). APH Publishing.

Blake, G. R., & Hartge, K. H. (1986). Particle density. In A. Klute (Ed.), *Methods of soil analysis: Part 1 Physical and Mineralogical Methods* (2nd edition., pp. 377-382). American Society of Agronomy.

Blakey, R. (2017). Drivers of bat activity and community structure within floodplains of the Murray-Darling Basin, Australia. (Doctoral thesis, University of New South Wales, Australia).

Braddock, T., & Berntsen, L. (2007). *Wetlands: An Introduction to Ecology, the Law, and Permitting* (2nd Edition). The Scarecrow Press, Plymouth UK.

Brinson, M. M. (1993). A Hydrogeomorphic Classification for Wetlands. Waterways Experiment Station Technical Report WRP-DE-4. Vicksburg, MS: U.S. Army Corps of Engineers. http://libweb.wes.army.mil/uhtbin/ hyperion/TR-WRP-DE-4.pdf (accessed November 2, 2020).

Buwono, N. R., Risjani, Y., & Soegianto, A. (2021). Distribution of microplastic in relation to water quality parameters in the Brantas River, East Java, Indonesia. *Environmental Technology & Innovation*, *24*, 1-10.

C.P.R. Environmental Education Centre. (1989). *Threats to wetlands*. https://vikaspedia.in/energy/environment/know-your-environment/conservation-of-wetlands.

Cairns, J., McCormick, P. V., & Niederlehner, B. R. (1993). A proposed framework for developing indicators of ecosystem health. *Hydrobiologia*, *263*(1), 1-44.

Cao, L., Guisen, D., Bingbin, H., Qingyi, M., Huimin, L., Zijian, W., & Fu, S. (2007). Biodiversity and water quality variations in constructed wetland of Yongding River system. *Acta Ecologica Sinica*, *27*(9), 3670-3677.

Chakraborti, D., Das, B., Rahman, M. M., Chowdhury, U. K., Biswas, B., Goswami, A. B., Nayak, B., Pal, A., Sengupta, M. K., Ahmed, S., Hossain, A., Basu, G., Roychowdhury, T., & Das, D. (2009). Status of groundwater arsenic contamination in the state of West Bengal, India: A 20-year study report. *Molecular Nutrition & Food Research*, *53*(5), 542-551.

Chapman, J. L., & Reiss, M. J. (1999). *Ecology: Principles and applications*. Cambridge University Press.

Chase, V., Deming, L., & Latawiec, F. (1995). *Buffers for wetlands and surface waters: A guidebook for New Hampshire municipalities*. Audubon Society of New Hampshire, USA.

Chen, M. H., Chen, F., Tang, C. J., Lu, Y., & Feng, Y. X. (2022). Integration of DPSIR framework and TOPSIS model reveals insight into the coastal zone ecosystem health. *Ocean & Coastal Management*, *226*, 1-13.

Chen, R. Z., & Wong, M. H. (2016). Integrated wetlands for food production. *Environmental Research*, *148*, 429-442.

Chen, T. S., & Lin, H. J. (2013). Development of a framework for landscape assessment of Taiwanese wetlands. *Ecological Indicators*, *25*, 121-132.

Chislock, M. F., Doster, E., Zitomer, R. A., & Wilson, A. E. (2013). Eutrophication: Causes, consequences, and controls in aquatic ecosystems. *Nature Education Knowledge*, *4*(4), 1-8.

Colvin, S. A. R., Sullivan, S. M. P., Shirey, P. D., Colvin, R. W., Winemiller, K. O., Hughes, R. M., Fausch, K. D., Infante, D. M., Olden, J. D., Bestgen, K. R., Danehy, R. J., & Eby, L. (2019). Headwater streams and wetlands are critical for sustaining fish, fisheries, and ecosystem services. *Fisheries*, *44*(2), 73-91.

Cooper, C. M. (1993). Biological effects of agriculturally derived surface water pollutants on aquatic systems— A review. *Journal of Environmental Quality*, *22*(3), 402-408.

Cooper, H. V., Evers, S., Aplin, P., Crout, N., Dahalan, M. P. B., & Sjogersten, S. (2020). Greenhouse gas emissions resulting from conversion of peat swamp forest to oil palm plantation. *Nature Communications*, *11*(1), 1-8.

Costanza, R. (2012). Ecosystem health and ecological engineering. *Ecological Engineering*, *45*, 24-29.

Cowardin, L. M., & Golet, F. C. (1995). US Fish and Wildlife Service 1979 wetland classification: A review. In C. M. Finlayson & A. G. Valk (Eds.), *Classification and Inventory of the World's Wetlands* (1^{st} ed., pp.139-152). Springer Dordrecht.

Cui, B. S., & Yang, Z. F. (2001). Research review on wetland ecosystem health. *Chinese Journal of Ecology*, *20*(3), 31-36.

Cui, Q., Wang, X., Li, D., & Guo, X. (2012). An ecosystem health assessment method integrating geochemical indicators of soil in Zoige wetland, southwest China. *Procedia Environmental Sciences*, *13*, 1527-1534.

da Silva, Y. J. A. B., do Nascimento, C. W. A., & Biondi, C. M. (2014). Comparison of USEPA digestion methods to heavy metals in soil samples. *Environmental Monitoring and Assessment*, *186*(1), 47-53.

Dakos, V., Carpenter, S. R., van Nes, E. H., & Scheffer, M. (2015). Resilience indicators: Prospects and limitations for early warnings of regime shifts. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1659), 1-10.

Dale, P. E. R., & Knight, J. M. (2008). Wetlands and mosquitoes: A review. *Wetlands Ecology and Management*, *16*(4), 255-276.

Das, R. K. (2018). Fish diversity and the conservation status of a wetland of Cooch Behar District, West Bengal, India. *Journal of Threatened Taxa*, *10*(3), 11423-11431.

Das, S. R., & Nandi, N. C. (2004). Oxbow lake environment and management of Ichhamati river basin, West Bengal. *Journal of Environment and Sociobiology*, *1*, 81-90.

Das, S., Pradhan, B., Shit, P. K., & Alamri, A. M. (2020). Assessment of wetland ecosystem health using the pressure-state-response (PSR) model: A case study of Mursidabad district of West Bengal (India). *Sustainability*, *12*(15), 1-18.

Das, T. K., Moitra, B., Raichaudhuri, A., Jash, T., Ghosh, S., & Mukherjee, A. (2000). Degradation of water bodies and wetlands in West Bengal: Interaction with economic development. *Final Report. Funded by Environmental Economics Research Committee, World Bank Aided India: Environmental Management Capacity Building Programme*.

Dash, S., Borah, S. S., & Kalamdhad, A. S. (2020). Application of positive matrix factorization receptor model and elemental analysis for the assessment of sediment contamination and their source apportionment of Deepor Beel, Assam, India. *Ecological Indicators*, *114*, 1-11.

Datta, D. (2012). Criteria and Indicators for Assessing Sustainable Community Management of Sunderbans Mangroves, India. (Doctoral thesis, Department of Agricultural and Food Engineering Indian Institute of Technology, Kharagpur, India).

Datta, D., & Chatterjee, D. (2012). Assessment of community-based initiatives in sustainable management of Indian dry deciduous forests. *International Journal of Sustainable Development & World Ecology*, *19*(2), 155-171.

Datta, D., & Deb, S. (2012). Analysis of coastal land use/land cover changes in the Indian Sunderbans using remotely sensed data. *Geo-spatial Information Science*, *15*(4), 241-250.

Datta, D., & Ghosh, P. K. (2015). Evaluating sustainability of community endeavours in an Indian floodplain wetland using multi-criteria decision analysis. *Singapore Journal of Tropical Geography*, *36*(1), 38-56.

Datta, D., Chattopadhyay, R. N., & Guha, P. (2012). Community based mangrove management: A review on status and sustainability. *Journal of Environmental Management*, *107,* 84-95.

Datta, D., Guha, P., & Chattopadhyay, R. N. (2010). Application of criteria and indicators in community based sustainable mangrove management in the Sunderbans, India. *Ocean & Coastal Management*, *53*(8), 468-477.

Datta, D., Roy, A. K., Kundu, A., Dutta, D., & Neogy, S. (2021) An alternative approach to delineate wetland influence zone of a tropical intertidal mudflat using geo-information technology. *Estuarine, Coastal and Shelf Science*, *253*, 1-14.

Davidson, N. C. (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research*, *65*(10), 934-941.

Davidson, N. C., Fluet-Chouinard, E., & Finlayson, C. M. (2018). Global extent and distribution of wetlands: Trends and issues. *Marine and Freshwater Research*, *69*(4), 620-627.

De Troyer, N., Mereta, S. T., Goethals, P. L., & Boets, P. (2016). Water quality assessment of streams and wetlands in a fast growing east African city. *Water, 8*(4), 1-21.

Deane, D. C., Fordham, D. A., He, F., & Bradshaw, C. J. (2017). Future extinction risk of wetland plants is higher from individual patch loss than total area reduction. *Biological Conservation*, *209*, 27-33.

Deepa, R. S., & Ramachandra, T. V. (1999, January 19-21). *Impact of Urbanization on the Interconnectivity of Wetlands*. [Paper presentation]. ISRS National Symposium on Remote Sensing Applications for Natural Resources: Retrospective and Perspective, Bangalore, India.

Derne, B. T., Weinstein, P., & Lau, C. L. (2015). Wetlands as sites of exposure to water-borne infectious diseases. In C. Finlayson, P. Horwitz, & P. Weinstein (Eds.), *Wetlands and human health* (1st ed., pp. 45-74). Springer.

Ding, Y., & Peng, J. (2018). Impacts of urbanization of mountainous areas on resources and environment: Based on ecological footprint model. *Sustainability*, *10*(3), 1-15.

Dizdaroglu, D. (2015). Developing micro-level urban ecosystem indicators for sustainability assessment. *Environmental Impact Assessment Review*, *54*, 119-124.

Dong, Z., Wang, Z., & Yang, X. (2015). Changes in suitable waterbirds' habitats from 1990 to 2010 in the Bielahong Watershed of Northeast China. *Journal of the Indian Society of Remote Sensing*, *43*(3), 599-607.

Dubois, N., Saulnier-Talbot, É., Mills, K., Gell, P., Battarbee, R., Bennion, H., Chawchai, S., Dong, X., Francus, P., Flower, R., Gomes, D. F., Gregory-Eaves, I., Humane, S., Kattel, G., Jenny, J. P., Langdon, P., Massaferro, J., McGowan, S., Mikomagi, A, Ngoc, N. T. M., Ratnayake, A. S., Reid, M., Rose, N., Saros, J., Schillereff, D., Tolotti, M., & Valero-Garcés, B. (2018). First human impacts and responses of aquatic systems: A review of paleolimnological records from around the world. *The Anthropocene Review*, *5*(1), 28-68.

Erwin, K. L. (2009). Wetlands and global climate change: The role of wetland restoration in a changing world. *Wetlands Ecology and Management*, *17*(1), 71-84.

Ezquerra, N. F. (1987). Target Recognition Considerations. In J. L. Eaves., & E. K. Reedy (Eds.), *Principles of Modern Radar* (pp. 646-677). Springer.

Farooqi, I. H., Basheer, F., & Chaudhari, R. J. (2008). Constructed wetland system (CWS) for wastewater treatment. In M. Sengupta, & R. Dalwani (Eds.), *Proceedings of Taal 2007: The 12th World Lake Conference* (pp. 1004-1009), Rajasthan, India: Ministry of Environment and Forest & ILEC.

Ferrati, R., Canziani, G. A., & Moreno, D. R. (2005). Esteros del Ibera: Hydrometeorological and hydrological characterization. *Ecological Modelling*, *186*(1), 3-15.

Finlayson, C. M., Lowry, J., Bellio, M. G., Nou, S., Pidgeon, R., Walden, D., Humphrey, C., & Fox, G. (2006). Biodiversity of the wetlands of the Kakadu Region, northern Australia. *Aquatic Sciences*, *68*(3), 374-399.

Finlayson, C., Horwitz, P., Weinstein, P. (2015). A Synthesis: Wetlands as Settings for Human Health. In Finlayson, C., Horwitz, P., Weinstein, P. (Eds.), *Wetlands and Human Health. Wetlands: Ecology, Conservation and Management*, (pp. 251-263). Springer.

Flinn, K. M., Lechowicz, M. J., & Waterway, M. J. (2008). Plant species diversity and composition of wetlands within an upland forest. *American Journal of Botany*, *95*(10), 1216-1224.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., Gibbs, H. K., Helkowski, J. H., Holloway, T., Howard, E. A., Kucharki, C. J., Monfreda, C., Patz, J. A., Prentice, I. C., Ramankutty, N., & Snyder, P. K. (2005). Global consequences of land use. *Science*, *309*(5734), 570-574.

Ford, H., Garbutt, A., Ladd, C., Malarkey, J., & Skov, M. W. (2016). Soil stabilization linked to plant diversity and environmental context in coastal wetlands. *Journal of Vegetation Science*, *27*(2), 259-268.

Fu, D., Wu, X., Duan, C., Guan, Q., & Huang, N. (2018). Changes in functional structure characteristics mediate ecosystem functions during human-induced land-cover alteration: A case study in southwest China. *Journal of Soil and Water Conservation*, *73*(4), 461-468.

Fulazzaky, M. A. (2010). Water quality evaluation system to assess the status and the suitability of the Citarum river water to different uses. *Environmental Monitoring and Assessment*, *168*(1), 669-684.

Gallardo, B., Cabezas, A., Gonzalez, E., & Comín, F. A. (2012). Effectiveness of a newly created oxbow lake to mitigate habitat loss and increase biodiversity in a regulated floodplain. *Restoration Ecology, 20*(3), 387-394.

Gallo, B. C., Demattê, J. A., Rizzo, R., Safanelli, J. L., Mendes, W. D. S., Lepsch, I. F., Sato, M. V., Romero, D. J., & Lacerda, M. P. (2018). Multi-temporal satellite images on topsoil attribute quantification and the relationship with soil classes and geology. *Remote Sensing*, *10*(10), 1-21.

Gardner, R. C., Barchiesi, S., Beltrame, C., Finlayson, C., Galewski, T., Harrison, I., Paganini, M., Perennou, C., Pritchard, D., Rosenqvist, A., & Walpole, M. (2015). State of the world's wetlands and their services to people: A compilation of recent analyses. Ramsar Briefing Note No. 7 Gland, Switzerland: Ramsar Convention Secretariat.

Garg, J. K., Singh, T. S., & Murthy, T. V. R. (1998). Wetlands of India. SAC, Indian Space Research Organisation, Ahmedabad, India.

Gayen, J., Ghosh, P. K., & Datta, D. (2020). Avifauna habitability of wetlands in an intensive cultural landscape: Insights from the Ichhamati floodplains, India. *Environmental Monitoring and Assessment*, *192*(6), 1-16.

Ghimire, K. B., & Pimbert, M. P. (2013). *Social change and conservation*. Routledge.

Ghosh, D. (2005). *Ecology and traditional wetland practice: Lessons from wastewater utilisation in the East Calcutta Wetlands*. Worldview. Kolkata.

Ghosh, D., & Biswas, J. K. (2015). Impact of jute retting on native fish diversity and aquatic health of roadside transitory water bodies: An assessment in Eastern India. *Journal of Ecological Engineering*, *16*(4), 14-21.

Ghosh, D., & Biswas, J. K. (2018). Impact of jute retting on physicochemical profile of Chhariganga oxbow lake in Nadia district, West Bengal, India. *Archives of Agriculture and Environmental Science*, *3*(1), 36-44.

Ghosh, K. S. (2012). Biodiversity and economy of Nature-A case study from West Bengal, India. *Economology Journal*, *3*(2), 3-23.

Gimmi, U., Lachat, T., & Bürgi, M. (2011). Reconstructing the collapse of wetland networks in the Swiss lowlands 1850-2000. *Landscape Ecology*, *26*(8), 1071-1083.

Gireeshkumar, T. R., Deepulal, P. M., & Chandramohankumar, N. (2013). Phosphorous speciation in surface sediments of the Cochin estuary. *Environmental Monitoring and Assessment*, *185*(3), 2535-2552.

Glowka, L., Burhenne-Guilmin, F., & Synge, H. (1994). *A guide to the Convention on Biological Diversity*. IUCN, Gland.

Gogoi, B., Kachari, A., & Das, D. N. (2015). Assessment of water quality in relation to fishery perspective in flood plain wetlands of Subansiri river basin Assam, India. *Journal of Fisheries and Aquatic Science*, *10*(3), 171-180.

GoI. (2001). West Bengal District Census Handbook: North 24 Parganas. Directorate of Census Operations, West Bengal.

GoI. (2011). West Bengal District Census Handbook: North 24 Parganas. Directorate of Census Operations, West Bengal.

Goswami, C., & Kalita, M. P. (2012). Ichthayofaunal Diversity & Anthropogenic Stress on Deepor Beel: The only Ramsar site in Assam. *IOSR Journal of Environmental Science, Toxicology and Food Technology*, *2*(1), 54-59.

Goswami, T. K., & Goswami, M. M. (2020). Ichthyo faunal diversity and catch statistics of Jamlai wetland in Kamrup district of Assam, India. *The Inland Fisheries Society of India*, *38*(2), 38-44.

GoWB. (2010). District Human Development Report: North 24 Parganas. Development and Planning Department, Govt. of West Bengal.

Gregoire, C., Elsaesser, D., Huguenot, D., Lange, J., Lebeau, T., Merli, A., Mose, R., Passeport, E., Payraudeau, S., Schuetz, T., Schulz, R., Tapia-Padilla, G., Tournebize, J., Trevisan, M., & Wanko, A. (2009). Mitigation of agricultural nonpoint-source pesticide pollution in artificial wetland ecosystems-A review. In E. Lichtfouse (Ed.), *Climate Change, Intercropping, Pest Control and Beneficial Microorganisms* (1st ed., pp. 293-338). Springer.

Gross, A., Shmueli, O., Ronen, Z., & Raveh, E. (2007). Recycled vertical flow constructed wetland (RVFCW)—A novel method of recycling greywater for irrigation in small communities and households. *Chemosphere*, *66*(5), 916-923.

Guarino, L., Jarvis, A. R. J. H., Hijmans, R. J., & Maxted, N. (2002). Geographic information systems (GIS) and the conservation and use of plant genetic resources. In J. M. M. Engels, V. R. Rao, A. H. D. Brown, & M. T. Jackson (Eds.), *Managing Plant Genetic Diversity* (pp. 387-404). CABI publishing.

Güneralp, B., Gertner, G., Mendoza, G., & Anderson, A. (2007). Evaluating probabilistic data with a possibilistic criterion in land-restoration decision-making: Effects on the precision of results. *Fuzzy Sets and Systems*, *158*(14), 1546-1560.

Hájek, M., Hájková, P., Kočí, M., Jiroušek, M., Mikulášková, E., & Kintrová, K. (2013). Do we need soil moisture measurements in the vegetation-environment studies in wetlands? *Journal of Vegetation Science*, *24*(1), 127-137.

Halls, A. J. (1997). *Wetlands, Biodiversity and the Ramsar convention: The role of the convention on wetlands in the conservation and wise use of biodiversity*. Gland, Switzerland, Ramsar Convention Bureau.

Hansen, M. C., & Loveland, T. R. (2012). A review of large area monitoring of land cover change using Landsat data. *Remote Sensing of Environment*, *122*, 66-74.

Harbor, J. M. (1994). A practical method for estimating the impact of land-use change on surface runoff, groundwater recharge and wetland hydrology. *Journal of the American Planning Association*, *60*(1), 95-108.

Hardie, M., & Doyle, R. (2012). Measuring soil salinity. In Shabala, S., Cuin, T. (Eds.), *Plant salt tolerance* (pp. 415-425). Humana Press, Totowa, NJ.

Hart, B. T., Bailey, P., Edwards, R., Hortle, K., James, K., McMahon, A., Meredith, C., & Swadling, K. (1990). Effects of salinity on river, stream and wetland ecosystems in Victoria, Australia. *Water Research*, *24*(9), 1103-1117.

Hasan, M. K., Shahriar, A., & Jim, K. U. (2019). Water pollution in Bangladesh and its impact on public health. *Heliyon*, *5*(8), 1-23.

Haukos, D. A., Johnson, L. A., Smith, L. M., & McMurry, S. T. (2016). Effectiveness of vegetation buffers surrounding playa wetlands at contaminant and sediment amelioration. *Journal of Environmental Management*, *181*, 552-562.

Hazbavi, Z., Sadeghi, S. H., Gholamalifard, M., & Davudirad, A. A. (2020). Watershed health assessment using the pressure-state-response (PSR) framework. *Land Degradation & Development*, *31*(1), 3-19.

Henderson, K. A., Murdock, J. N., & Lizotte Jr, R. E. (2021). Water depth influences algal distribution and productivity in shallow agricultural lakes. *Ecohydrology*, *14*(6), 1-16.

Hilgenkamp, K. (2005). *Environmental health: Ecological perspectives*. Jones & Bartlett Learning.

Horwitz, P., & Finlayson, C. M. (2011). Wetlands as settings for human health: Incorporating ecosystem services and health impact assessment into water resource management. *BioScience*, *61*(9), 678-688.

Horwitz, P., Finlayson, C. M., & Weinstein, P. (2012). Healthy wetlands, healthy people: A review of wetlands and human health interactions. Ramsar Technical Report No. 6. Ramsar Convention on Wetlands/ World Health Organisation, Gland, Switzerland.

Hossain, M. A., & Wahab, M. A. (2010). *The diversity of cypriniforms throughout Bangladesh: Present status and conservation challenges*. Nova Science Publishers.

Hossain, M. I., Siwar, C., & Alam, M. M. (2013). Challenges of Community based Fish Culture Program: Case Study on Floodplain Beel Mail in Rajshahi, Bangladesh. *Journal of the Institute of Bangladesh Studies, 36*, 129-136.

Hume, P. E. (2005). Adapting to climate change: Is there scope for ecological management in the face of a global threat? *Journal of Applied Ecology*, 42(5), 784-794.

Hussain, S. A., & De Roy, R. (1993). Directory of Indian wetlands. WWF-India, New Delhi and AWB, Kuala Lumpur.

Hwang, C. L., & Yoon, K. (1981). Methods for multiple attribute decision making. In C. L. Hwang & K. Yoon (Eds.), *Multiple attribute decision making* (pp. 58-191). Springer.

IPCC, (2021). IPCC fifth assessment report. Intergovernmental Panel on Climate Change. Cambridge University Press, New York.

Islam, M. N., Rahman, F., Papri, S. A., Faruk, M. O., Das, A. K., Adhikary, N., Debrot, A. O., & Ahsan, M. N. (2021). Water hyacinth (*Eichhornia crassipes* (Mart.) Solms.) as an alternative raw material for the production of bio-compost and handmade paper. *Journal of Environmental Management*, *294*, 1-9.

Islam, S., & Roy, T. K. (2006). A new fuzzy multi-objective programming: Entropy based geometric programming and its application of transportation problems. *European Journal of Operational Research*, *173*(2), 387-404.

Ite, A. E., Ibok, U. J., Ite, M. U., & Petters, S. W. (2013). Petroleum exploration and production: Past and present environmental issues in the Nigeria's Niger Delta. *American Journal of Environmental Protection*, *1*(4), 78-90.

Jackson, L. E., Kurtz, J. C., & Fisher, W. S. (1990). Environmental monitoring and assessment program: Ecological indicators. USEPA/600/3-90/060. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, North Carolina, USA.

Jackson, M. L. (1967). Soil Chemical analysis, Pentice Hall of India, New Delhi.

Jamwal, P. S., Chandan, P., Rattan, R., Anand, A., Kannan, P. M., & Parsons, M. H. (2017). Survey of avifauna of the Gharana wetland reserve: Implications for conservation in a semi-arid agricultural setting on the Indo-Pakistan border. *BMC Zoology*, *2*(1), 1-9.

Jesinghaus, J. (2000). *The World Economic Forum's Environmental Sustainability Index: Strong and weak points*, European Commission Joint Research Centre, Ispra (Varese), Italy.

Jha, P., Samal, A. C., Santra, S. C., & Dewanji, A. (2016). Heavy metal accumulation potential of some wetland plants growing naturally in the city of Kolkata, India. *American Journal of Plant Sciences*, *7*(15), 2112.

Jhingran, V. G., Natarajan, A. V., Banerjee, S. M., & David, A. (1969). Methodology on reservoir fisheries investigations in India. *Bulletin Central Inland Capture Fisheries Research Institute, Barrackpore*, 12, 1-111.

Ji, L., Zhang, L., & Wylie, B. (2009). Analysis of dynamic thresholds for the normalized difference water index. *Photogrammetric Engineering & Remote Sensing*, *75*(11), 1307-1317.

Jia, H., Pan, D., & Zhang, W. (2015). Health assessment of wetland ecosystems in the Heilongjiang River Basin, China. *Wetlands*, *35*(6), 1185-1200.

Jogo, W., & Hassan, R. (2010). Balancing the use of wetlands for economic well-being and ecological security: The case of the Limpopo wetland in southern Africa. *Ecological Economics*, *69*(7), 1569-1579.

Johnson, L. A. (2011). Occurrence, function, and conservation of playa wetlands: The key to biodiversity of the southern Great Plains, USA. (Doctoral dissertation, Department of Natural Resources Management, Texas Tech University, Lubbock, TX, USA).

Johnston, C. A. (1991). Sediment and nutrient retention by freshwater wetlands: Effects on surface water quality. *Critical Reviews in Environmental Science and Technology*, *21*, 491-565.

Jones, B. A., & McDermott, S. M. (2018). Health impacts of invasive species through an altered natural environment: Assessing air pollution sinks as a causal pathway. *Environmental and Resource Economics*, *71*(1), 23-43.

Jørgensen, S. E. (2006). Application of holistic thermodynamic indicators. *Ecological Indicators*, *6*(1), 24-29.

Jørgensen, S. E., Burkhard, B., & Müller, F. (2013). Twenty volumes of ecological indicators-An accounting short review. *Ecological Indicators*, *28*(5), 4-9.

Jørgensen, S. E., Xu, F. L., Marques, J., & Salas, F. (2010). Application of indicators for the assessment of ecosystem health. In S. E. Jørgensen, F.-L. Xu, & R. Costanza (Eds.), *Handbook of ecological indicators for assessment of ecosystem health* (2nd ed., pp. 9-76). CRC Press.

Jørgensen, S. E., Xu, F., Marques, J., & Salas, F. (2005). Application of indicators for the assessment of ecosystem health. In S. E. Jørgensen, F.-L. Xu, & J. C. Marques (Eds.), *Handbook of ecological indicators for assessment of ecosystem health*. (2nd ed., pp. 5-65). CRC Press.

Junk, W. J. (2002). Long-term environmental trends and the future of tropical wetlands. *Environmental Conservation*, *29*(4), 414-435.

Junk, W. J., An, S., Finlayson, C. M., Gopal, B., Květ, J., Mitchell, S. A., Mitsch, W. J., & Robarts, R. D. (2013). Current state of knowledge regarding the world's wetlands and their future under global climate change: A synthesis. *Aquatic Sciences*, *75*(1), 151-167.

Keddy, P. A. (2010). *Wetland ecology: Principles and conservation*. Cambridge university press.

Kennedy, G., & Mayer, T. (2002). Natural and constructed wetlands in Canada: An overview. *Water Quality Research Journal*, *37*(2), 295-325.

Khan, R., Saxena, A., Shukla, S., Sekar, S., Senapathi, V., & Wu, J. (2021). Environmental contamination by heavy metals and associated human health risk assessment: A case study of surface water in Gomti River Basin, India. *Environmental Science and Pollution Research*, *28*(40), 56105-56116.

Khatun, R., Talukdar, S., Pal, S., & Kundu, S. (2021). Measuring dam induced alteration in water richness and eco-hydrological deficit in flood plain wetland. *Journal of Environmental Management*, *285*, 1-21.

Kim, S. M., Jeong, J., Keesee, D., & Kiniry, J. R. (2018). Development, growth, and biomass simulations of two common wetland tree species in Texas. *Environmental Monitoring and Assessment*, *190*(9), 1-16.

King, R. S., Baker, M. E., Whigham, D. F., Weller, D. E., Jordan, T. E., Kazyak, P. F., & Hurd, M. K. (2005). Spatial considerations for linking watershed land cover to ecological indicators in streams. *Ecological Applications*, *15*(1), 137-153.

Kingsford, R. T., Basset, A., & Jackson, L. (2016). Wetlands: Conservation's poor cousins. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *26*(5), 892-916.

Koontz, J., Huggins, D., Freeman, C., & Kastens, J. (2010). *Assessment of floodplain wetlands of the lower Missouri River Using a Reference-based Study Approach*. Kansas Biological Survey, Lawrence, KS.

Kopf, R. K., Finlayson, C. M., Humphries, P., Sims, N. C., & Hladyz, S. (2015). Anthropocene baselines: Assessing change and managing biodiversity in human-dominated aquatic ecosystems. *BioScience*, *65*(8), 798-811.

Kueffer, C. (2017). Plant invasions in the Anthropocene. *Science*, *358*(6364), 724-725.

Kumar, A. (2005). *Fundamentals of Limnology*. APH Publishing.

Kumar, P., Mahajan, A. K., & Kumar, P. (2020). Determining limiting factors influencing fish kills at Rewalsar Lake: A case study with reference to Dal Lake (Mcleodganj), western Himalaya, India. *Arabian Journal of Geosciences*, *13*(17), 1-21.

Kundu, S., Pal, S., Mandal, I., & Talukdar, S. (2022). How far damming induced wetland fragmentation and water richness change affect wetland ecosystem services? *Remote Sensing Applications: Society and Environment*, *27*, 1-15.

Kundu, S., Pal, S., Talukdar, S., & Mandal, I. (2021). Impact of wetland fragmentation due to damming on the linkages between water richness and ecosystem services. *Environmental Science and Pollution Research*, *28*(36), 50266-50285.

Lamers, L. P., Falla, S. J., Samborska, E. M., Dulken, I. A. V., Hengstum, G. V., & Roelofs, J. G. (2002). Factors controlling the extent of eutrophication and toxicity in sulfate-polluted freshwater wetlands. *Limnology and Oceanography*, *47*(2), 585-593.

Lamsal, P., Pant, K. P., Kumar, L., & Atreya, K. (2015). Sustainable livelihoods through conservation of wetland resources: A case of economic benefits from Ghodaghodi Lake, western Nepal. *Ecology and Society*, *20*(1), 1-11.

Lane, C. R., & D'Amico, E. (2016). Identification of putative geographically isolated wetlands of the conterminous United States. *JAWRA Journal of the American Water Resources Association*, *52*(3), 705-722.

Lestariningsih, I. D., & Hairiah, K. (2013). Assessing soil compaction with two different methods of soil bulk density measurement in oil palm plantation soil. *Procedia Environmental Sciences*, *17*, 172-178.

Li, N., Lu, D., Wu, M., Zhang, Y., & Lu, L. (2018). Coastal wetland classification with multiseasonal high-spatial resolution satellite imagery. *International Journal of Remote Sensing*, *39*(23), 8963-8983.

Li, Y., Shi, Y., Qureshi, S., Bruns, A., & Zhu, X. (2014). Applying the concept of spatial resilience to socio-ecological systems in the urban wetland interface. *Ecological Indicators*, *42*(7), 135-146.

Linster, M., & Fletcher, J. (2001). *Using the Pressure-State-Response model to develop indicators of sustainability: OECD Framework for Environmental Indicators.* Organization for Economic Co-operation and Development, Paris.

Liu, D., & Hao, S. (2017). Ecosystem health assessment at county-scale using the pressure-state-response framework on the Loess Plateau, China. *International Journal of Environmental Research and Public Health*, *14*(1), 1-11.

Liu, H. Y., Zhang, S. K., & Lu, X. G. (2004). Wetland landscape Structure and the spatial-temporal Changes in 50 Years in the Sanjiang Plain. *Acta Geographica Sinica*, *59*(3), 391-400.

Long, H., Liu, Y., Wu, X., & Dong, G. (2009). Spatio-temporal dynamic patterns of farmland and rural settlements in Su-Xi-Chang region: Implications for building a new countryside in coastal China. *Land Use Policy*, *26*(2), 322-333.

Lotfi, F. H., & Fallahnejad, R. (2010). Imprecise Shannon's entropy and multi attribute decision making. *Entropy*, *12*(1), 53-62.

Lu, Y., Wang, R., Zhang, Y., Su, H., Wang, P., Jenkins, A., Ferrier, R. C., Bailey, M., & Squire, G. (2015). Ecosystem health towards sustainability. *Ecosystem Health and Sustainability*, *1*(1), 1-15.

Luo, K., Wu, Z., Bai, H., & Wang, Z. (2019). Bird diversity and waterbird habitat preferences in relation to wetland restoration at Dianchi Lake, south-west China. *Avian Research*, *10*(1), 1-12.

Ma, M. (2016). Riparian buffer zone for wetlands. In C. M. Finlayson, M. Everard, K. Irvine, R. J. McInnes, B. A. Middleton, A. A. van Dam, & N. C. Davidson (Eds.), *The Wetland book: 1. Structure and Function, Management, and Methods* (pp. 148-156). Springer.

Magee, T. K., & Kentula, M. E. (2005). Response of wetland plant species to hydrologic conditions. *Wetlands Ecology and Management*, *13*(2), 163-181.

Majumder, R., & Bhunia, G.S. (2022). Flood Risk Zone Identification Using Multi-criteria Decision Approach. In Pradhan, B., Shit, P. K., Bhunia, G. S., Adhikary, P. P., Pourghasemi, H. R. (Eds.), *Spatial Modelling of Flood Risk and Flood Hazards Societal Implications* (pp. 51-75). Springer.

Mao, X., Wang, X., Chen, Q., & Yin, X. (2014). A PSR-framework-based health assessment of Ulansuhai Lake in China. *Management*, *23*, 2093-2102.

Mathews, L., & Chandramohankumar, N. (2003). The ratios of carbon, nitrogen, and phosphorus in a wetland coastal ecosystem of Southern India. *International Review of Hydrobiology: A Journal Covering all Aspects of Limnology and Marine Biology*, *88*(2), 179-186.

Mazumdar, S. (2017). Composition of avian communities in a human-modified wetland Okhla Bird Sanctuary, India: With notes on conservation initiatives. *Proceedings of the Zoological Society*, *72*(4), 319-333.

Mbaka, J. G., & Wanjiru Mwaniki, M. (2015). A global review of the downstream effects of small impoundments on stream habitat conditions and macroinvertebrates. *Environmental Reviews*, *23*(3), 257-262.

McCartney, M. P., & Acreman, M. C. (2009). Wetlands and Water Resources. In T. Barker & E. Maltby (Eds.), *The wetlands handbook* (1st ed., pp. 357-381). John Wiley & Sons.

McElfish Jr, J. M., Kihslinger, R. L., & Nichols, S. (2008). Setting buffer sizes for wetlands. *National Wetlands Newsletter*, *30*(2), 6-17.

McFeeters, S. K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing*, *17*(7), 1425-1432.

McGarigal, K., & Marks, B. J. (1995). FRAGSTATS. *Spatial pattern analysis program for quantifying landscape structure*. USDA Forest Service General Technical Report PNW-GTR-351. Pacific Northwest Research Station, Portland, Oregon, USA.

McMeans, B. C., McCann, K. S., Humphries, M., Rooney, N., & Fisk, A. T. (2015). Food web structure in temporally-forced ecosystems. *Trends in Ecology & Evolution*, *30*(11), 662-672.

Millennium Ecosystem Assessment (MEA) (2005). Ecosystems and Human Well-being: Wetlands and Water Synthesis. World Resources Institute, Washington DC.

Minasny, B., Malone, B. P., McBratney, A. B., Angers, D. A., Arrouays, D., Chambers, A., Chaplot, V., Chen, Z. S., Cheng, K., Das, B. S., Field, D. J., Gimona, A., Hedley, C. B., Hong, S. Y., Mandal, B., Marchant, B. P., Martin, M., McConkey, B. G., Mulder, V. L., O'Rourke, S., Richer-de-Forges, A. C., Odeh, I., Padarian, J., Paustian, K., Pan, G., Poggio, L., Savin, I., Stolbovoy, V., Stockmann, U., Sulaeman, Y., Tsui, C., Vagen, T., Wesemael, B. V., & Winowiecki, L. (2017). Soil carbon 4 per mille. *Geoderma*, *292*, 59-86.

Mishra, B. K., Kumar, P., Saraswat, C., Chakraborty, S., & Gautam, A. (2021). Water security in a changing environment: Concept, challenges and solutions. *Water*, *13*(4), 1-21.

Mitsch. W. J., & Gosselink, J. G. (1993). *Wetlands*. 2nd ed. Van Nostrand Reinhold and John Wiley & Sons, New York.

MoEF, (1990). Directory of Wetlands in India, Ministry of Environment and Forests, Govt. of India.

MoEF, (1998). Ministry of Environment of Forests Annual Report 1998-99. New Delhi, India.

Mohd-Taib, F. S., & Kamaruddin, H. A. (2018). The rice-growing cycle influences diversity and species assemblages of birds in the paddy field ecosystem in east peninsular Malaysia. *Pertanika Journal of Tropical Agricultural Science*, *41*(4), 1669-1683.

Mondal, D. K., & Kaviraj, A. (2008). Ecotoxicological effects of jute retting on the survival of two freshwater fish and two invertebrates. *Ecotoxicology*, *17*(3), 207-211.

Mondal, D. K., & Kaviraj, A. (2013). Feeding and reproductive biology of Amblypharyngodon mola (*Cyrpiniformes: Cyprinidae*) from two floodplain lakes of India. *International Journal of Aquatic Biology*, *1*(3), 125-131.

Mondal, D. K., Kaviraj, A., & Saha, S. (2010). Water quality parameters and fish biodiversity indices as measures of ecological degradation: A case study in two floodplain lakes of India. *Journal of Water Resource and Protection*, *2*(1), 85-92.

Mondal, I., Bandyopadhyay, J., & Paul, A. K. (2016). Estimation of hydrodynamic pattern change of Ichamati River using HEC RAS model, West Bengal, India. *Modeling Earth Systems and Environment*, *2*(3), 1-13.

Mondal, I., Thakur, S., & Bandyopadhyay, J. (2020). Delineating lateral channel migration and risk zones of Ichamati River, West Bengal, India. *Journal of Cleaner Production*, *244*, 1-16.

Mondal, K., Kaviraj, A., Mukhopadhyay, P. K., Datta, M., & Sengupta, C. (2007). Evaluation of fermented fish offal in formulated diet of the Indian major carp, rohu, Labeo rohita (Hamilton). *Acta Ichthyologica et Piscatoria*, *37*(2), 99-105.

Mondal, M., & Satpati, L. N. (2016). Changing character of pool-riffle sequence: A quantitative representation of long profile of Ichamati, India. *Indian Journal of Power and River Valley Development*, *66*(1), 14-21.

Mondal, M., Ghosh, S., & Satpati, L. N. (2018). Optimum cross section index (OCI): A new approach for identification of an optimum channel—A case study of the Ichamati River, India. *Arabian Journal of Geosciences*, *11*(12), 1-19.

Monghasemi, S., Nikoo, M. R., Fasaee, M. A. K., & Adamowski, J. (2015). A novel multi criteria decision making model for optimizing time-cost-quality trade-off problems in construction projects. *Expert Systems with Applications*, *42*(6), 3089-3104.

Moss, R. H., Edmonds, J. A., Hibbard, K. A., Manning, M. R., Rose, S. K., Van Vuuren, D. P., Carter, T. R., Emori, S., Kainuma, M., Kram, T., Meehl, G. A., Mitchell, J. F. B., Nakicenovic, N., Riahi, K., Smith, S. J., Stouffer, R. J., Thomson, A. M., Weyant, J. P., & Wilbanks, T. J. (2010). The next generation of scenarios for climate change research and assessment. *Nature*, *463*(7282), 747-756.

Mukherjee, A. (2006). Deeper groundwater flow and chemistry in the arsenic affected western Bengal basin, West Bengal, India. (Doctoral thesis, in the College of Arts and Sciences, University of Kentucky, USA).

Mukherjee, A., Fryar, A. E., & Howell, P. D. (2007). Regional hydrostratigraphy and groundwater flow modeling in the arsenic-affected areas of the western Bengal basin, West Bengal, India. *Hydrogeology Journal*, *15*(7), 1397-1418.

Mukherjee, A., Fryar, A. E., & Thomas, W. A. (2009). Geologic, geomorphic and hydrologic framework and evolution of the Bengal basin, India and Bangladesh. *Journal of Asian Earth Sciences*, *34*(3), 227-224.

Mukherjee, K., & Pal, S. (2021). Hydrological and landscape dynamics of floodplain wetlands of the Diara region, Eastern India. *Ecological Indicators*, *121*, 1-17.

Mukherjee, S., & Kumar, M. D. (2012). Economic valuation of a multiple use wetland water system: A case study from India. *Water Policy*, *14*(1), 80-98.

Mukhopadhyay, S., & Mazumdar, S. (2017). Composition, diversity and foraging guilds of avifauna in a suburban area of southern West Bengal, India. *The Ring*, *39*(1), 103-120.

Mukhopadhyay, S., & Mazumdar, S. (2019). Habitat-wise composition and foraging guilds of avian community in a suburban landscape of lower Gangetic plains, West Bengal, India. *Biologia*, *74*(8), 1001-1010.

Nandi, G., Neogy, S., Roy, A. K., & Datta, D. (2020). Immediate disturbances induced by tropical cyclone Fani on the coastal forest landscape of eastern India: A geospatial analysis. *Remote Sensing Applications. Society and Environment*, *20*, 1-13.

Nath, B., & Deka, C. (2012). A study on fish diversity, conservation status and anthropogenic stress of Chandubi tectonic lake, Assam, India. *Journal Bio Innovation*, *1*(6), 148-155.

National Wetland Atlas: West Bengal, SAC/RESA/AFEG/NWIA/ATLAS/09/2010, Ahmedabad: Space Applications Centre, ISRO, Ahmedabad, India.

Nayak, P. K. (2017). Fisher communities in transition: Understanding change from a livelihood perspective in Chilika Lagoon, India. *Maritime Studies*, *16*(1), 1-33.

Nayak, P. K., & Berkes, F. (2010). Whose marginalisation? Politics around environmental injustices in India's Chilika lagoon. *Local Environment*, *15*(6), 553-567.

NRSC, (2014). *Land Use / Land Cover database on 1:50,000 scale, Natural Resources Census Project, LUCMD, LRUMG, RSAA*. National Remote Sensing Centre, ISRO, Hyderabad.

O'Malley, L. S. S. (1914). Bengal District Gazetteers: 24 Parganas. West Bengal Government Publication.

O'Neill, R. V., Krummel, J. R., Gardner, R. E. A., Sugihara, G., Jackson, B., DeAngelis, D. L., Milne, B. T., Turner, M. G., Zygmunt, B., Christensen, S. W., Dale, V. H., & Graham, R. L. (1988). Indices of landscape pattern. *Landscape Ecology*, *1*(3), 153-162.

Ongley, E. D. (1996). *Control of water pollution from agriculture*. Food & Agriculture Organization.

Organisation for Economic Co-Operation and Development (1993). OECD core set of indicators for environmental performance reviews. Environment monographs 83. OECD, Paris.

Organisation for Economic Co-Operation and Development (OECD), (2001). *Environmental Indicators for Agriculture*, vol. 3. Publications Service, OECD, Paris.

Organisation for Economic Co-Operation and Development OECD, (1997). *Environmental Indicators for Agriculture*, vol. 1. Publications Service, OECD, Paris.

Pandey, P. N., Gorai, B. K., & Jha, B. C. (2005). *Economics of Fisheries: Ecology and Fisheries of Oxbow Lakes.* New Delhi: APH Publishing Corporation.

Panigrahy, S., Patel, J. G., & Parihar, J. S. (2012). National Wetland Atlas: High Altitude Lakes on India, Space Applications Centre, ISRO, Ahmedabad, India.

Panigrahy, S., Patel, J. G., Murthy, T. V. R., & Singh, T. S. (2011). *Information brochure-National Wetland Inventory and Assessment.* Ahmedabad: Space Applications Centre, ISRO, Ahmedabad, India.

Patel, N. R., Mukund, A., & Parida, B. R. (2019). Satellite-derived vegetation temperature condition index to infer root zone soil moisture in semi-arid province of Rajasthan, India. *Geocarto International*, *37*(1), 179-195.

Pejchar, L., & Mooney, H. A. (2009). Invasive species, ecosystem services and human well-being. *Trends in Ecology & Evolution*, *24*(9), 497-504.

Perry, L. G., Galatowitsch, S. M., & Rosen, C. J. (2004). Competitive control of invasive vegetation: A native wetland sedge suppresses Phalaris arundinacea in carbon-enriched soil. *Journal of Applied Ecology*, *41*(1), 151-162.

Piorr, H. P. (2003). Environmental policy, agri-environmental indicators and landscape indicators. *Agriculture, Ecosystems & Environment*, *98*(1-3), 17-33.

Power, J. F., Sandoval, F. M., Ries, R. E., & Merrill, S. D. (1981). Effects of topsoil and subsoil thickness on soil water content and crop production on a disturbed soil. *Soil Science Society of America Journal*, *45*(1), 124-129.

Prasad, S. N., Ramachandra, T. V., Ahalya, N., Sengupta, T., Kumar, A., Tiwari, A. K., Vijayan, V. S., & Vijayan, L. (2002). Conservation of wetlands of India -A review. *Tropical Ecology*, *43*(1), 173-186.

Pretorius, M. L. (2016). Selected soil properties and vegetation composition of five wetland systems on the Maputaland Coastal Plain, Kwazulu-Natal. South Africa. (Doctoral thesis, University of South Africa, South Africa).

Pretorius, M. L., Brown, L. R., Bredenkamp, G. J., & Van Huyssteen, C. W. (2014). The ecology and species richness of the different plant communities within selected wetlands on the Maputaland Coastal Plain, South Africa. In O. Grillo (Ed.), *Biodiversity: The dynamic balance of the planet* (1st ed., pp. 275-296). InTech.

Pyšek, P., & Richardson, D. M. (2010). Invasive species, environmental change and management, and health. *Annual Review of Environment and Resources*, *35*, 25-55.

Rai, R., Zhang, Y., Paudel, B., Li, S., & Khanal, N. R. (2017). A synthesis of studies on land use and land cover dynamics during 1930-2015 in Bangladesh. *Sustainability*, *9*(10), 1-20.

Rakib, M. R. J., Jolly, Y. N., Begum, B. A., Choudhury, T. R., Fatema, K. J., Islam, M. S., Ali, M. M., & Idris, A. M. (2022). Assessment of trace element toxicity in surface water of a fish breeding river in Bangladesh: A novel approach for ecological and health risk evaluation. *Toxin Reviews*, *41*(2), 420-436.

Rakotoarisoa, T. F., Waeber, P. O., Richter, T., & Mantilla-Contreras, J. (2015). Water hyacinth (*Eichhornia crassipes*), any opportunities for the Alaotra wetlands and livelihoods? *Madagascar Conservation & Development*, *10*(3), 128-136.

Ramachandra, T. V. (2001). Restoration and management strategies of wetlands in developing countries. *Electronic Green Journal*, *1*(15), 1-18.

Ramsar Convention on Wetland. (2015a). *The Ramsar Convention: What's It All About*? The Ramsar Convention Secretariat. Fact Sheet 6.2.

Ramsar Convention Secretariat. (2013). The Ramsar Convention Manual: A guide to the Convention on Wetlands (Ramsar, Iran, 1971). Available online: https://aquadocs.org/handle/1834/330 (accessed on 10 December 2021).

Rao, D. L. N. (2007). Microbial diversity, soil health and sustainability. *Journal of the Indian Society of Soil Science, 55*(4), 392-403.

Rapport, D. J. (1989). What constitutes ecosystem health? *Perspectives in Biology and Medicine*, *33*(1), 120-132.

Rapport, D. J., & Friend, A. (1979). Towards a comprehensive framework for environmental statistics: A stress-response approach. *Statistics Canada Catalogue*, 11-510. Minister of Supply and Services Canada, Ottawa.

Rapport, D. J., Costanza, R., & McMichael, A. J. (1998). Assessing ecosystem health. *Trends in Ecology & Evolution*, *13*(10), 397-402.

Rapport, D. J., Fyfe, W. S., Costanza, R., Spiegel, J., Yassie, A., Bohm, G. M., Patil, G. P., Lannigan, R., Anjema, C. M., Whitford, W. G., & Horwitz, P. (2001). Ecosystem health: Definitions, assessment and case studies. In M. K. Tolba (Ed.), *Our Fragile World: Challenges and Opportunities for Sustainable Development* (1st ed., pp. 21-42). Eolss Publishers Co. Ltd.

Rapport, D. J., Regier, H. A., & Hutchinson, T. C. (1985). Ecosystem behavior under stress. *The American Naturalist*, *125*(5), 617-640.

Rayamajhi, M. B., Pratt, P. D., Center, T. D., Tipping, P. W., & Van, T. K. (2009). Decline in exotic tree density facilitates increased plant diversity: The experience from Melaleuca quinquenervia invaded wetlands. *Wetlands Ecology and Management*, *17*(5), 455-467.

Reid, A. J., Carlson, A. K., Creed, I. F., Eliason, E. J., Gell, P. A., Johnson, P. T. J., Kidd, K. A., MacCormak, T. J., Olden, J. D., Ormerod, S. J., Smol, J. P., Taylor, W. W., Tockner, K., Vermaire, J. C., Dudgeon, D., & Cooke, S. J. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews*, *94*(3), 849-873.

Reis, V., Hermoso, V., Hamilton, S. K., Ward, D., Fluet-Chouinard, E., Lehner, B., & Linke, S. (2017). A global assessment of inland wetland conservation status. *Bioscience*, *67*(6), 523-533.

Reiss, K. C. (2006). Florida wetland condition index for depressional forested wetlands. *Ecological Indicators*, *6*(2), 337-352.

Ren, L., Liu, J. T., Ni, J. J., & Xiang, X. Y. (2014). Health evaluation of a lake wetland ecosystem based on the TOPSIS method. *Polish Journal of Environmental Studies*, *23*(6), 2183-2190.

Rodger, B., & Bridgewater, L. (2017). Standard methods for the examination of water and wastewater. *American Journal of Public Health and the Nation's Health*, *56*, 387-388.

Rohal, C. B., Kettenring, K. M., Sims, K., Hazelton, E. L. G., & Ma, Z. (2018). Surveying managers to inform a regionally relevant invasive Phragmites australis control research program. *Journal of Environmental Management*, *206*, 807-816.

Rokosch, A. E., Bouchard, V., Fennessy, S., & Dick, R. (2009). The use of soil parameters as indicators of quality in forested depressional wetlands. *Wetlands*, *29*(2), 666-677.

Roy, A. K., & Datta, D. (2018). Analyzing the effects of afforestation on estuarine environment of river Subarnarekha, India using geospatial technologies and participatory appraisals. *Environmental Monitoring and Assessment*, *190*(11), 1-16.

Roy, D. K., Ray, G. K., & Biswas, A. K. (2010). Overview of overpressure in Bengal basin, India. *Journal of the Geological Society of India*, *75*(4), 644-660.

Rudra, K. (2018). Evolution of the Bengal Basin. In *Rivers of the Ganga-Brahmaputra-Meghna Delta* (pp. 15-25). Springer.

Russell, R. C. (1999). Constructed wetlands and mosquitoes: health hazards and management options—An Australian perspective. *Ecological Engineering*, *12,* 107-124.

Russi, D., ten Brink, P., Farmer, A., Badura, T., Coates, D., Förster, J., Kumar, R., & Davidson, N. (2013). *The economics of ecosystems and biodiversity (TEEB) for water and wetlands*. Institute for European Environmental Policy, London, UK.

Sabur, M. A., & Molla, M. H. (2016). Environmental Analysis and Household Health Risk in Existing Solid Waste Management Practices on Different Residential Areas of Chittagong City. *A Journal for Social Development*, *6*, 127-138.

Saha, S., Chukwuka, A. V., Mukherjee, D., Saha, N. C., & Adeogun, A. O. (2022). Hydrological connectivity, surface water quality and distribution of fish species within sub-locations of an urban oxbow lake, East India. *Watershed Ecology and the Environment*, *4*(1), 44-58.

Sánchez-Carrillo, S., Reddy, K. R., Inglett, K. S., Álvarez-Cobelas, M., & Sánchez-Andrés, R. (2014). Biogeochemical indicators of nutrient enrichments in wetlands: the microbial response as a sensitive indicator of wetland eutrophication. In A. Ansari & S. S. Gill (Eds.), *Eutrophication: Causes, consequences and control* (2^{nd} ed., pp 203-222). Springer.

Sankaranarayanan, V. N., & Panampunnayil, S. U. (1979). Studies on organic carbon, nitrogen and phosphorus in sediments of the Cochin Backwater. *Indian Journal of Marine Sciences*, *8*, 27-30.

Saran, L. M., Pissarra, T. C. T., Silveira, G. A., Constancio, M. T. L., de Melo, W. J., & Alves, L. M. C. (2018). Land use impact on potentially toxic metals concentration on surface water and resistant microorganisms in watersheds. *Ecotoxicology and Environmental Safety*, *166*, 366-374.

Sarkar, A. (2004). River Bank Erosion: Geomorphology and Environment, ACB Publications, Kol, India, 86-106.

Sarkar, U. K., & Borah, B. C. (2017). Flood plain wetland fisheries of India: With special reference to impact of climate change. *Wetlands Ecology and Management*, *26*(1), 1-15.

Saturday, A., Lyimo, T. J., Machiwa, J., & Pamba, S. (2021). Spatio-temporal variations in physicochemical water quality parameters of Lake Bunyonyi, Southwestern Uganda. *SN Applied Sciences*, *3*(7), 1-14.

Schepker, T. J., Webb, E. B., Tillitt, D., & LaGrange, T. (2020). Neonicotinoid insecticide concentrations in agricultural wetlands and associations with aquatic invertebrate communities. *Agriculture, Ecosystems & Environment*, *287*, 1-11.

Schinasi, L. H., Benmarhnia, T., & De Roos, A. J. (2018). Modification of the association between high ambient temperature and health by urban microclimate indicators: A systematic review and meta-analysis. *Environmental Research*, *161*, 168-180.

Seto, K. C., Woodcock, C. E., Song, C., Huang, X., Lu, J., & Kaufmann, R. K. (2002). Monitoring land-use change in the Pearl River Delta using Landsat TM. *International Journal of Remote Sensing*, *23*(10), 1985-2004.

Shalaby, A., & Tateishi, R. (2007). Remote sensing and GIS for mapping and monitoring land cover and land-use changes in the Northwestern coastal zone of Egypt. *Applied Geography*, *27*(1), 28-41.

Shannon, C. E. (1948). A mathematical theory of communication. *The Bell System Technical Journal*, *27*(3), 379-423.

Sharma, B. K., & Sharma, S. (2014). Faunal diversity of Cladocera (*Crustacea: Branchiopoda)* in wetlands of Majuli (the largest river island), Assam, northeast India. *Opuscula Zoologica*, *45*(1), 83-94.

Sharma, R., Aggarwal, N., & Kumar, S. (2014). Ecological sustainability in India through the ages. *International Research Journal of Environment Sciences*, *3*(1), 70-73.

Shi, S., Yao, F., Zhang, J., & Yang, S. (2020). Evaluation of temperature vegetation dryness index on drought monitoring over Eurasia. *Institute of Electrical and Electronics Engineers Access*, *8*, 30050-30059.

Shine, C., & De Klemm, C. (1999). *Wetlands, Water, and the Law: Using law to advance wetland conservation and wise use*, IUCN.

Sikdar, P. K., & Sahu, P. (2009). Understanding wetland sub-surface hydrology using geologic and isotopic signatures. *Hydrology and Earth System Sciences*, *13*(7), 1313-1323.

Singh, A. K., & Lakra, W. S. (2011). Risk and benefit assessment of alien fish species of the aquaculture and aquarium trade into India. *Reviews in Aquaculture*, *3*(1), 3-18.

Singh, K. V., Setia, R., Sahoo, S., Prasad, A., & Pateriya, B. (2015). Evaluation of NDWI and MNDWI for assessment of waterlogging by integrating digital elevation model and groundwater level. *Geocarto International*, *30*(6), 650-661.

Smith, M. M. H., Hore, T., Chakraborty, P., Chakraborty, D. K., Savarimuthu, X., & Smith, A. H. (2003). A Dugwell program to provide arsenic-safe water in West Bengal, India: Preliminary results. *Journal of Environmental Science and Health, Part A*, *38*(1), 289-299.

Space Applications Centre (SAC) (2011). National Wetland Atlas. SAC, Indian Space Research Organisation, Ahmedabad.

Stone, C. M., Witt, A. B., Walsh, G. C., Foster, W. A., & Murphy, S. T. (2018). Would the control of invasive alien plants reduce malaria transmission? A review. *Parasites & Vectors*, *11*(1), 1-18.

Sugunan, V. V., Vinci, G. K., Bhattacharjya, B. K., & Hassan, M. A. (2000). *Ecology and fisheries of beels in West Bengal* (Bulletin No. 103). Barrackpore: Central Inland Capture Fisheries Research Institute.

Sui, X., Chen, L., Chen, A., Wang, D., Wang, W., Ge, H., & Ji, G. (2015). Assessment of temporal and spatial landscape and avifauna changes in the Yellow River wetland natural reserves in 1990-2013, China. *Ecological Engineering*, *84*, 520-531.

Sun, B., Tang, J., Yu, D., Song, Z., & Wang, P. (2019). Ecosystem health assessment: A PSR analysis combining AHP and FCE methods for Jiaozhou Bay, China1. *Ocean & Coastal Management*, *168*, 41-50.

Sun, C., Zhu, S., Zhao, B., Li, W., Gao, X., & Wang, X. (2020). Effect of land use conversion on surface soil heavy metal contamination in a typical Karst Plateau Lakeshore Wetland of Southwest China. *International Journal of Environmental Research and Public Health*, *17*(1), 84.

Sun, R., Yao, P., Wang, W., Yue, B., & Liu, G. (2017). Assessment of wetland ecosystem health in the Yangtze and Amazon River Basins. *ISPRS International Journal of Geo-Information*, *6*(3), 1-14.

Sun, T., Lin, W., Chen, G., Guo, P., & Zeng, Y. (2016). Wetland ecosystem health assessment through integrating remote sensing and inventory data with an assessment model for the Hangzhou Bay, China. *Science of the Total Environment*, *566*, 627-640.

Supriya, S. (1966). Geological and geophysical studies in western part of Bengal basin, India. *American Association of Petroleum Geologists Bulletin*, *50*(5), 1001-1017.

Tak, P. C., Sati, J. P., & Rizvi, A. N. (2010). Status of waterbirds at Hathnikund Barrage wetland, Yamunanagar District, Haryana, India. *Journal of Threatened Taxa*, *2*(4), 841-844.

Tandon, H. L. S. (1993). *Method of analysis of soils, plants, water and fertilizers*. Fertilizer Development and Consultation Organization 204-204A. Bhanot Corner, 1-2 Pamposh Enclave, New Delhi-110048, India.

Thompson, K. T., & Abraham, S. (2001). Socio-economic issues of biodiversity loss in Cochin backwaters', Paper Presented at the Workshop on Environment and Biodiversity, organized by KRPLLD held in Kannur, during 9-11 February. Centre for Development Studies, Thiruvananthapuram.

Tian, P., Cao, L., Li, J., Pu, R., Shi, X., Wang, L., Liu, R., Xu, H., Tong, C., Zhou, Z., & Shao, S. (2019). Landscape grain effect in Yancheng coastal wetland and its response to landscape changes. *International Journal of Environmental Research and Public Health*, *16*(12), 1-20.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W. H., Simberloff, D., & Swackhamer, D. (2001). Forecasting agriculturally driven global environmental change. *Science*, *292*(5515), 281-284.

Tiner, R. W., Lang, M. W., & Klemas, V. V. (2015). *Remote sensing of wetlands: Applications and advances*. CRC Press, USA.

Tockner, K., & Stanford, J. A. (2002). Riverine flood plains: Present state and future trends. *Environmental Conservation*, *29*(3), 308-330.

Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I., & Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity—Ecosystem service management. *Ecology Letters, 8*(8), 857-874.

Tsegaye, T., Sheppard, D., Islam, K. R., Tadesse, W., Atalay, A., & Marzen, L. (2006). Development of chemical index as a measure of in-stream water quality in response to land-use and land cover changes. *Water, Air, and Soil Pollution*, *174*(1), 161-179.

U.S. Environment Protection Agency (U.S.EPA), 2002. *Methods for evaluating wetland condition: Using vegetation to assess environmental conditions in wetlands*. Washington D.C.

Valdez, V. C., Ruiz-Luna, A., & Berlanga-Robles, C. A. (2016). Effects of land use changes on ecosystem services value provided by coastal wetlands: Recent and future landscape scenarios. *Journal of Coastal Zone Management*, *19*(1), 1-7.

Villa, J. A., & Bernal, B. (2018). Carbon sequestration in wetlands, from science to practice: An overview of the biogeochemical process, measurement methods, and policy framework. *Ecological Engineering*, *114*, 115-128.

Vinnersten, T. Z. P., Lundström, J. O., Petersson, E., & Landin, J. (2009). Diving beetle assemblages of flooded wetlands in relation to time, wetland type and Bti-based mosquito control. *Hydrobiologia*, *635*(1), 189-203.

Vitousek, P. M., Mooney, H. A., Lubchenco, J., & Melillo, J. M. (1997). Human domination of Earth's ecosystems. *Science, 277*, 494-499.

Walmsley, J. J. (2002). Framework for measuring sustainable development in catchment systems. *Environmental Management, 29*(2), 195-206.

Wang, L., Dai, L., Li, L., & Liang, T. (2018). Multivariable cokriging prediction and source analysis of potentially toxic elements (Cr, Cu, Cd, Pb, and Zn) in surface sediments from Dongting Lake, China. *Ecological Indicators, 94*, 312-319.

Wang, Z., Liu, J., Li, J., & Zhang, D. D. (2018). Multi-spectral water index (MuWI): A native 10-m multi-spectral water index for accurate water mapping on Sentinel-2. *Remote Sensing*, *10*(10), 1-21.

Weather and Climate (2022). The Global Historical Weather and Climate Data of Bangaon, accessed August 2022, https://tcktcktck.org/india/west-bengal/bangaon.

Weiland, M. A., & Hayward, R. S. (1997). Cause for the decline of large rainbow trout in a tailwater fishery: Too much putting or too much taking? *Transactions of the American Fisheries Society*, *126*(5), 758-773.

Wickramasinghe, D. (2021). Ecosystem-based disaster risk reduction. In D. Benouar (Ed.), *Oxford research encyclopedia of natural hazard science* (pp. 1-27). Oxford Research Encyclopedias, Natural Hazard Science.

Wilson, N. R., & Norman, L. M. (2018). Analysis of vegetation recovery surrounding a restored wetland using the normalized difference infrared index (NDII) and normalized difference vegetation index (NDVI). *International Journal of Remote Sensing*, *39*(10), 3243-3274.

Woistencroft, J. A., Hussain, S. A., & Varshney, C. K. (1989). India: Introduction. In D. A. Scott (Ed.), *A Directory of Asian Wetlands*. International Union for Conservation of Nature, Switzerland.

Wolka, K., Tadesse, H., Garedew, E., & Yimer, F. (2015). Soil erosion risk assessment in the Chaleleka wetland watershed, Central Rift Valley of Ethiopia. *Environmental Systems Research*, *4*(1), 1-12.

Wong, C. P., Jiang, B., Bohn, T. J., Lee, K. N., Lettenmaier, D. P., Ma, D., & Ouyang, Z. (2017). Lake and wetland ecosystem services measuring water storage and local climate regulation. *Water Resources Research*, *53*(4), 3197-3223.

Wu, M., Yang, C., Song, X., Hoffmann, W. C., Huang, W., Niu, Z., Wang, C., Li, W., & Yu, B. (2018). Monitoring cotton root rot by synthetic Sentinel-2 NDVI time series using improved spatial and temporal data fusion. *Scientific Reports*, *8*(1), 1-12.

Xiang, W. N. (1996). GIS-based riparian buffer analysis: Injecting geographic information into landscape planning. *Landscape and Urban Planning*, *34*(1), 1-10.

Xie, Z., Liu, J., Ma, Z., Duan, X., & Cui, Y. (2012). Effect of surrounding land-use change on the wetland landscape pattern of a natural protected area in Tianjin, China. *International Journal of Sustainable Development & World Ecology*, *19*(1), 16-24.

Yaxin, W., Shi, C., Hongbo, J., Huaiqing, Z., Dong, J., & Dafang, Z. (2011). Evaluating sustainability of wetland system: A case study in East Dongting Lake Area, China. *African Journal of Agricultural Research*, *6*(28), 6167-6176.

Yoon, K., & Hwang, C. L. (1985). Manufacturing plant location analysis by multiple attribute decision making: Part I—Single-plant strategy. *International Journal of Production Research*, *23*(2), 345-359.

You, H., Fan, H., Xu, L., Wu, Y., Liu, L., & Yao, Z. (2019). Poyang lake wetland ecosystem health assessment of using the wetland landscape classification characteristics. *Water*, *11*(4), 1-14.

Yu, X., Ding, S., Zou, Y., Xue, Z., Lyu, X., & Wang, G. (2018). Review of rapid transformation of floodplain wetlands in northeast China: Roles of human development and global environmental change. *Chinese Geographical Science*, *28*(4), 654-664.

Zedler, J. B., & Kercher, S. (2004). Causes and consequences of invasive plants in wetlands: Opportunities, opportunists, and outcomes. *Critical Reviews in Plant Sciences*, *23*(5), 431-452.

Zedler, J. B., & Kercher, S. (2005). Wetland resources: Status, trends, ecosystem services, and restorability. *Annual Review of Environment and Resources*, *30*, 39-74.

Zhang, X., He, Y., Zhang, B., Qin, L., Yang, Q., & Huang, H. (2019). Factors affecting microbiological quality of household drinking water supplied by small-scale ultrafiltration systems: A field study. *Science of The Total Environment*, *689*, 725-733.

Zhao, F., Li, H., Li, C., Cai, Y., Wang, X., & Liu, Q. (2019). Analyzing the influence of landscape pattern change on ecological water requirements in an arid/semiarid region of China. *Journal of Hydrology*, *578*, 1-13.

Zhao, Q., Bai, J., Huang, L., Gu, B., Lu, Q., & Gao, Z. (2016). A review of methodologies and success indicators for coastal wetland restoration. *Ecological Indicators*, *60*, 442-452.

Zhu, Y., Tian, D., & Yan, F. (2020). Effectiveness of entropy weight method in decision-making. *Mathematical Problems in Engineering*, *2020*, 1-5.

Zimmerman, J. L. (1990). *Cheyenne Bottoms: Wetland in jeopardy*. University Press of Kansas.

Annexure

Annexure 6.1 Observed value of each indicator of pressure system, 2016

Wetland	Indicator																																				
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
Berkrishnapur	40.54	49.049	2.00	2.00	2.50	3.00	4.70	9.40	4.70	9.40	241.00	208.00	0.20	0.59	0.49	0.01	0.64	3.10	9.80	1.45	1.45	12.00	22.00	2.95	3.00	2.95	1.95	203.28	1.96	1.25	3.55	2.90	3.00	3.00	2.95	2.95	2.95	1.00
Panchpota	32.21	63.194	1.95	1.90	2.05	2.90	8.10	0.00	8.10	0.00	214.00	137.00	0.10	1.01	0.40	0.01	0.59	1.47	10.00	2.00	2.85	8.00	14.00	3.40	3.35	3.50	1.30	502.29	4.99	2.00	4.50	3.05	4.00	4.65	1.80	2.60	4.35	1.00
Panchita	37.21	50.476	2.95	1.20	1.85	1.30	5.20	0.00	5.20	0.00	184.00	421.00	0.12	0.79	0.30	0.01	0.39	2.10	9.90	1.90	1.95	9.00	19.00	2.10	2.30	2.15	1.50	357.36	2.70	1.10	4.05	2.80	2.75	4.05	2.05	2.90	3.55	1.00
Aromdanga	64.31	40.012	2.05	2.15	1.95	1.95	32.80	0.00	32.80	0.00	217.00	1650.00	0.19	0.35	0.20	0.01	0.61	2.20	9.50	1.95	2.10	11.00	21.00	2.95	2.55	2.60	1.95	197.84	4.29	2.95	4.05	2.05	2.95	2.05	3.00	3.00	2.75	1.00
Gopalnagar	45.96	45.034	3.40	2.50	2.40	2.00	18.00	0.00	18.00	0.00	187.00	302.00	0.20	1.61	0.40	0.01	0.49	1.80	10.00	1.90	1.90	13.00	25.00	2.05	2.60	2.45	1.95	390.64	4.41	2.00	4.00	1.90	3.25	2.85	1.95	3.00	2.85	1.00
Manigram	57.02	42.642	3.40	3.15	3.60	3.20	1.92	0.00	1.92	0.00	218.00	105.00	0.10	0.25	0.40	0.01	0.30	2.60	10.00	2.45	2.30	8.00	17.00	3.40	3.85	3.80	1.90	285.98	4.25	1.45	4.10	2.45	3.95	3.45	2.65	3.85	3.85	1.35
Madhabpur	34.21	15.087	3.90	2.05	2.95	1.95	3.90	0.00	3.90	0.00	149.00	210.00	0.10	0.10	0.40	0.01	0.59	1.10	10.00	3.50	3.60	5.00	12.00	3.50	2.95	3.50	2.00	209.50	1.44	1.90	4.85	3.70	2.45	4.30	2.70	3.70	3.95	1.55

Annexure 6.2 Observed value of each indicator of state system, 2016

Wetland	Indicator																																						
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40
Berkrishnapur	99.88	22.69	1.42	53.84	50.94	94.60	3.70	0.28	30.70	24.00	83.00	6.90	2.10	1.00	159.36	0.01	169.80	12.40	125.30	0.66	167.59	0.63	300.00	550.00	2.00	1.00	1.00	1.24	1.10	3.55	3.50	3.45	3.60	3.05	3.50	4.50	4.50	2.20	2.35	2.70
Panchpota	95.71	20.19	1.65	48.29	11.69	94.91	2.50	0.24	32.40	5.20	20.00	7.70	4.50	1.00	144.00	0.08	377.40	105.10	205.00	1.03	319.52	0.59	200.00	350.00	4.00	1.00	2.00	1.32	1.10	4.15	4.30	3.35	3.50	2.80	3.70	4.55	4.80	2.75	2.85	2.85
Panchita	76.84	18.11	1.65	45.73	52.22	98.93	7.60	0.44	32.70	6.00	22.00	7.30	3.90	1.00	122.88	0.03	642.70	25.30	84.00	0.77	89.31	0.66	225.00	475.00	4.00	1.00	1.00	1.33	1.22	4.15	4.60	4.25	4.80	2.30	4.20	4.00	4.15	3.95	4.25	4.80
Aromdanga	92.53	29.78	1.32	57.46	35.92	52.02	3.70	0.36	32.90	8.00	32.00	8.60	3.80	1.00	145.28	0.01	166.50	11.10	127.10	0.48	91.30	0.62	275.00	525.00	2.00	1.00	1.00	1.25	1.05	3.95	3.90	2.90	3.00	2.90	2.55	3.90	3.50	2.80	2.40	3.40
Gopalnagar	109.72	10.50	1.56	45.54	74.38	94.76	3.80	0.68	31.10	6.50	24.00	7.40	4.20	1.00	126.72	0.04	317.30	14.20	76.50	0.52	140.96	0.65	325.00	625.00	3.00	1.00	1.00	1.35	1.35	4.25	4.40	4.40	4.45	2.35	2.80	4.75	4.85	4.20	4.50	4.50
Manigram	99.95	16.14	1.56	42.24	25.93	84.14	6.40	0.90	33.10	5.50	20.00	7.20	4.10	3.00	146.56	0.05	169.10	7.30	49.50	0.54	97.52	0.63	200.00	425.00	4.00	1.00	1.00	1.26	1.23	4.50	3.80	3.35	4.00	2.80	4.70	4.75	4.40	3.40	3.60	3.45
Madhabpur	81.95	24.78	1.44	51.99	30.66	76.74	10.40	0.35	34.10	7.00	28.00	8.00	4.20	4.00	159.16	0.06	109.10	9.03	33.50	0.28	144.36	0.06	125.00	300.00	4.00	5.00	3.00	1.27	1.09	4.40	3.75	3.00	5.00	2.65	4.10	4.80	4.60	3.00	2.95	3.80

Annexure 6.3 Observed value of each indicator of response system, 2016

Wetland	Indicator																	
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
Berkrishnapur	3.00	1.00	1.00	1.55	3.00	2.45	4.00	4.00	2.05	1.35	2.95	3.40	1.00	1.00	1.00	1.00	1.00	1.00
Panchpota	4.00	3.00	3.00	4.00	4.00	2.95	3.05	3.05	3.05	2.00	2.05	3.00	2.05	1.00	1.00	1.00	1.00	1.00
Panchita	5.00	4.00	3.00	3.00	3.05	2.10	3.50	3.00	3.30	2.05	2.05	4.00	2.10	2.05	2.40	1.00	1.00	1.00
Aromdanga	2.00	2.00	1.00	2.00	2.05	2.00	2.40	2.20	1.95	2.00	2.05	4.05	1.00	1.00	1.00	1.00	1.00	1.00
Gopalnagar	4.00	2.00	3.00	3.25	2.35	3.25	3.55	3.20	3.75	3.05	1.90	4.05	1.80	1.15	2.05	1.00	1.00	1.00
Manigram	5.00	3.00	4.00	4.00	4.00	2.95	3.85	3.00	4.00	2.10	3.95	4.05	1.00	1.00	1.40	1.00	1.00	1.00
Madhabpur	5.00	5.00	4.00	4.00	3.80	3.15	3.95	3.80	3.50	3.60	3.90	3.80	1.00	1.00	1.00	1.00	1.00	1.00

Annexure 6.1.1 Decision matrix (Valid score of each indicator for pressure system, 2016)

Wetland	Indicator																																					
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
Berkrishnapur	3.00	3.00	2.00	2.00	2.50	3.00	2.00	5.00	2.00	5.00	1.00	3.00	2.00	3.00	2.00	3.00	2.00	2.00	3.00	1.45	1.45	2.00	2.00	2.95	3.00	2.95	1.95	4.00	4.00	1.25	3.55	2.90	3.00	3.00	2.95	2.95	2.95	1.00
Panchpota	2.00	3.00	3.00	3.15	3.25	2.00	3.00	1.00	3.00	1.00	3.00	4.00	4.00	2.00	3.00	3.00	2.00	4.00	4.00	3.00	3.15	3.00	4.00	3.10	3.00	2.80	1.95	3.00	3.00	1.95	4.10	2.00	3.10	4.10	2.75	2.60	3.25	1.00
Panchita	2.00	3.00	2.95	1.20	1.85	4.00	3.00	1.00	3.00	1.00	4.00	3.00	3.00	3.00	4.00	3.00	4.00	3.00	4.00	1.90	1.95	3.00	3.00	2.10	2.30	2.15	1.50	2.00	4.00	1.10	4.05	2.80	2.75	4.05	2.05	2.90	3.55	1.00
Aromdanga	4.00	3.00	2.05	2.15	1.95	4.00	5.00	1.00	5.00	1.00	2.00	1.00	2.00	4.00	5.00	3.00	2.00	3.00	3.00	1.95	2.10	2.00	2.00	2.95	2.55	2.60	1.95	4.00	2.00	2.95	4.05	2.05	2.95	2.05	3.00	3.00	2.75	1.00
Gopalnagar	3.00	3.00	4.00	4.00	4.20	3.00	4.00	1.00	4.00	1.00	3.00	3.00	2.00	1.00	3.00	3.00	3.00	3.00	4.00	3.90	3.80	2.00	2.00	3.20	3.50	3.45	2.80	2.70	2.80	2.00	4.00	2.80	3.25	2.85	2.40	3.00	2.85	1.00
Manigram	4.00	3.00	4.00	4.00	4.00	2.00	2.00	1.00	2.00	1.00	2.00	4.00	4.00	4.00	3.00	3.00	5.00	2.00	4.00	4.00	4.00	4.00	3.00	3.40	3.85	3.80	3.00	3.90	3.25	3.00	4.50	3.10	3.95	3.45	2.65	3.85	3.85	1.35
Madhabpur	2.00	1.00	3.90	3.00	3.00	3.00	2.00	1.00	2.00	1.00	5.00	3.00	4.00	4.00	3.00	3.00	2.00	4.00	4.00	3.50	3.60	5.00	4.00	3.50	2.95	3.50	2.00	4.00	4.00	1.90	4.85	3.70	2.45	4.30	2.70	3.70	3.95	1.35

Annexure 6.1.2 Normalization of the decision matrix

Wetland	Indicator																																					
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
Berkrishnapur	0.15	0.16	0.09	0.10	0.12	0.14	0.10	0.45	0.10	0.45	0.05	0.14	0.10	0.14	0.09	0.14	0.10	0.10	0.12	0.07	0.07	0.10	0.10	0.14	0.14	0.14	0.13	0.17	0.17	0.09	0.12	0.15	0.14	0.13	0.16	0.13	0.13	0.13
Panchpota	0.10	0.16	0.14	0.16	0.16	0.10	0.14	0.09	0.14	0.09	0.15	0.19	0.19	0.10	0.13	0.14	0.10	0.19	0.15	0.15	0.16	0.14	0.20	0.15	0.14	0.13	0.13	0.13	0.13	0.14	0.14	0.10	0.14	0.17	0.15	0.12	0.14	0.13
Panchita	0.10	0.16	0.13	0.06	0.09	0.19	0.14	0.09	0.14	0.09	0.20	0.14	0.14	0.14	0.17	0.14	0.20	0.14	0.15	0.10	0.10	0.14	0.15	0.10	0.11	0.10	0.10	0.08	0.17	0.08	0.14	0.14	0.13	0.17	0.11	0.13	0.15	0.13
Aromdanga	0.20	0.16	0.09	0.11	0.09	0.19	0.24	0.09	0.24	0.09	0.10	0.05	0.10	0.19	0.22	0.14	0.10	0.14	0.12	0.10	0.10	0.10	0.10	0.14	0.12	0.12	0.13	0.17	0.09	0.21	0.14	0.11	0.14	0.09	0.16	0.14	0.12	0.13
Gopalnagar	0.15	0.16	0.18	0.21	0.20	0.14	0.19	0.09	0.19	0.09	0.15	0.14	0.10	0.05	0.13	0.14	0.15	0.14	0.15	0.20	0.19	0.10	0.10	0.15	0.17	0.16	0.18	0.11	0.12	0.14	0.14	0.14	0.15	0.12	0.13	0.14	0.12	0.13
Manigram	0.20	0.16	0.18	0.21	0.19	0.10	0.10	0.09	0.10	0.09	0.10	0.19	0.19	0.19	0.13	0.14	0.25	0.10	0.15	0.20	0.20	0.19	0.15	0.16	0.18	0.18	0.20	0.17	0.14	0.21	0.15	0.16	0.18	0.14	0.14	0.18	0.17	0.18
Madhabpur	0.10	0.05	0.18	0.15	0.14	0.14	0.10	0.09	0.10	0.09	0.25	0.14	0.19	0.19	0.13	0.14	0.10	0.19	0.15	0.18	0.18	0.24	0.20	0.17	0.14	0.16	0.13	0.17	0.17	0.13	0.17	0.19	0.11	0.18	0.15	0.17	0.17	0.18
Sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Annexure 6.1.3 Computation of entropy, degree of diversification and indicator weight

Wetland	Indicator																																						
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	**Sum**
Berkrishnapur	-0.28	-0.29	-0.22	-0.23	-0.25	-0.28	-0.22	-0.36	-0.22	-0.36	-0.15	-0.28	-0.22	-0.28	-0.21	-0.28	-0.23	-0.22	-0.25	-0.19	-0.19	-0.22	-0.23	-0.27	-0.28	-0.27	-0.26	-0.30	-0.30	-0.21	-0.26	-0.28	-0.28	-0.26	-0.29	-0.27	-0.26	-0.27	
Panchpota	-0.23	-0.29	-0.27	-0.29	-0.29	-0.22	-0.28	-0.22	-0.28	-0.22	-0.28	-0.32	-0.32	-0.22	-0.27	-0.28	-0.23	-0.32	-0.29	-0.29	-0.29	-0.28	-0.32	-0.28	-0.28	-0.27	-0.26	-0.26	-0.27	-0.27	-0.28	-0.23	-0.28	-0.30	-0.28	-0.25	-0.28	-0.27	
Panchita	-0.23	-0.29	-0.27	-0.17	-0.22	-0.32	-0.28	-0.22	-0.28	-0.22	-0.32	-0.28	-0.28	-0.28	-0.30	-0.28	-0.32	-0.28	-0.29	-0.23	-0.23	-0.28	-0.28	-0.23	-0.24	-0.23	-0.23	-0.21	-0.30	-0.20	-0.27	-0.28	-0.26	-0.30	-0.24	-0.27	-0.29	-0.27	
Aromdanga	-0.32	-0.29	-0.22	-0.24	-0.22	-0.32	-0.34	-0.22	-0.34	-0.22	-0.23	-0.14	-0.22	-0.32	-0.33	-0.28	-0.23	-0.28	-0.25	-0.23	-0.24	-0.22	-0.23	-0.27	-0.26	-0.26	-0.26	-0.30	-0.21	-0.33	-0.27	-0.24	-0.27	-0.21	-0.29	-0.27	-0.25	-0.27	
Gopalnagar	-0.28	-0.29	-0.31	-0.32	-0.32	-0.28	-0.32	-0.22	-0.32	-0.22	-0.28	-0.28	-0.22	-0.14	-0.27	-0.28	-0.28	-0.28	-0.29	-0.32	-0.32	-0.22	-0.23	-0.29	-0.30	-0.30	-0.31	-0.25	-0.26	-0.28	-0.27	-0.28	-0.29	-0.25	-0.26	-0.27	-0.26	-0.27	
Manigram	-0.32	-0.29	-0.31	-0.32	-0.32	-0.22	-0.22	-0.22	-0.22	-0.22	-0.23	-0.32	-0.32	-0.32	-0.27	-0.28	-0.35	-0.22	-0.29	-0.32	-0.32	-0.32	-0.28	-0.29	-0.31	-0.31	-0.32	-0.30	-0.28	-0.33	-0.29	-0.29	-0.31	-0.28	-0.28	-0.31	-0.30	-0.31	
Madhabpur	-0.23	-0.15	-0.31	-0.29	-0.28	-0.28	-0.22	-0.22	-0.22	-0.22	-0.35	-0.28	-0.32	-0.32	-0.27	-0.28	-0.23	-0.32	-0.29	-0.31	-0.31	-0.34	-0.32	-0.30	-0.27	-0.30	-0.27	-0.30	-0.30	-0.27	-0.30	-0.32	-0.25	-0.31	-0.28	-0.30	-0.30	-0.31	
Entropy	-1.90	-1.90	-1.91	-1.88	-1.90	-1.91	-1.89	-1.67	-1.89	-1.67	-1.85	-1.89	-1.90	-1.87	-1.91	-1.95	-1.87	-1.91	-1.94	-1.88	-1.89	-1.89	-1.90	-1.94	-1.93	-1.93	-1.92	-1.92	-1.92	-1.89	-1.94	-1.93	-1.94	-1.92	-1.94	-1.94	-1.94	-1.94	
Entropy value	0.98	0.98	0.98	0.97	0.98	0.98	0.97	0.86	0.97	0.86	0.95	0.97	0.98	0.96	0.98	1.00	0.96	0.98	1.00	0.97	0.97	0.97	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.97	1.00	0.99	1.00	0.99	1.00	1.00	1.00	0.99	
Degree of diversification	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.14	0.03	0.14	0.05	0.03	0.02	0.04	0.02	0.00	0.04	0.02	0.00	0.03	0.03	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	**0.95**
Weight	**0.02**	**0.02**	**0.02**	**0.04**	**0.02**	**0.02**	**0.03**	**0.15**	**0.03**	**0.15**	**0.05**	**0.03**	**0.03**	**0.04**	**0.02**	**0.00**	**0.04**	**0.02**	**0.00**	**0.03**	**0.03**	**0.03**	**0.02**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.03**	**0.00**	**0.01**	**0.01**	**0.01**	**0.00**	**0.00**	**0.00**	**0.01**	**1.00**

Annexure 6.1.4 Evaluation matrix with indicator weight

Wetland	Indicator																																					
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
Berkrishnapur	3.00	3.00	2.00	2.00	2.50	3.00	2.00	5.00	2.00	5.00	1.00	3.00	2.00	3.00	2.00	3.00	2.00	2.00	3.00	1.45	1.45	2.00	2.00	2.95	3.00	2.95	1.95	4.00	4.00	1.25	3.55	2.90	3.00	3.00	2.95	2.95	2.95	1.00
Panchpota	2.00	3.00	3.00	3.15	3.25	2.00	3.00	1.00	3.00	1.00	3.00	4.00	4.00	2.00	3.00	3.00	2.00	4.00	4.00	3.00	3.15	3.00	4.00	3.10	3.00	2.80	1.95	3.00	3.00	1.95	4.10	2.00	3.10	4.10	2.75	2.60	3.25	1.00
Panchita	2.00	3.00	2.95	1.20	1.85	4.00	3.00	1.00	3.00	1.00	4.00	3.00	3.00	3.00	4.00	3.00	4.00	3.00	4.00	1.90	1.95	3.00	3.00	2.10	2.30	2.15	1.50	2.00	4.00	1.10	4.05	2.80	2.75	4.05	2.05	2.90	3.55	1.00
Aromdanga	4.00	3.00	2.05	2.15	1.95	4.00	5.00	1.00	5.00	1.00	2.00	1.00	2.00	4.00	5.00	3.00	2.00	3.00	3.00	1.95	2.10	2.00	2.00	2.95	2.55	2.60	1.95	4.00	2.00	2.95	4.05	2.05	2.95	2.05	3.00	3.00	2.75	1.00
Gopalnagar	3.00	3.00	4.00	4.00	4.20	3.00	4.00	1.00	4.00	1.00	3.00	3.00	2.00	1.00	3.00	3.00	3.00	3.00	4.00	3.90	3.80	2.00	2.00	3.20	3.50	3.45	2.80	2.70	2.80	2.00	4.00	2.80	3.25	2.85	2.40	3.00	2.85	1.00
Manigram	4.00	3.00	4.00	4.00	4.00	2.00	2.00	1.00	2.00	1.00	2.00	4.00	4.00	4.00	3.00	3.00	5.00	2.00	4.00	4.00	4.00	4.00	3.00	3.40	3.85	3.80	3.00	3.90	3.25	3.00	4.50	3.10	3.95	3.45	2.65	3.85	3.85	1.35
Madhabpur	2.00	1.00	3.90	3.00	3.00	3.00	2.00	1.00	2.00	1.00	5.00	3.00	4.00	4.00	3.00	3.00	2.00	4.00	4.00	3.50	3.60	5.00	4.00	3.50	2.95	3.50	2.00	4.00	4.00	1.90	4.85	3.70	2.45	4.30	2.70	3.70	3.95	1.35
Weight	**0.023**	**0.023**	**0.019**	**0.035**	**0.023**	**0.017**	**0.033**	**0.151**	**0.033**	**0.151**	**0.053**	**0.031**	**0.026**	**0.040**	**0.019**	**0.000**	**0.039**	**0.017**	**0.004**	**0.033**	**0.031**	**0.033**	**0.023**	**0.006**	**0.007**	**0.009**	**0.014**	**0.014**	**0.013**	**0.031**	**0.002**	**0.011**	**0.005**	**0.014**	**0.004**	**0.005**	**0.005**	**0.005**

Annexure 6.1.5 Vector normalization

Wetland	Indicator																																					
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
Berkrishnapur	0.38	0.40	0.23	0.26	0.31	0.37	0.24	0.90	0.24	0.90	0.12	0.36	0.24	0.36	0.22	0.38	0.25	0.24	0.30	0.18	0.18	0.24	0.25	0.36	0.37	0.36	0.33	0.44	0.45	0.22	0.32	0.39	0.37	0.33	0.42	0.35	0.33	0.34
Panchpota	0.27	0.44	0.36	0.42	0.42	0.26	0.37	0.41	0.37	0.41	0.37	0.52	0.50	0.25	0.34	0.41	0.25	0.50	0.42	0.39	0.40	0.37	0.53	0.41	0.40	0.37	0.35	0.37	0.38	0.35	0.39	0.29	0.41	0.47	0.43	0.33	0.39	0.36
Panchita	0.29	0.49	0.38	0.17	0.26	0.54	0.39	0.45	0.39	0.45	0.53	0.45	0.43	0.39	0.49	0.45	0.53	0.44	0.47	0.27	0.27	0.39	0.46	0.31	0.33	0.30	0.29	0.26	0.54	0.21	0.42	0.43	0.40	0.53	0.36	0.39	0.46	0.39
Aromdanga	0.60	0.57	0.29	0.32	0.29	0.65	0.71	0.46	0.71	0.46	0.31	0.17	0.32	0.57	0.69	0.50	0.31	0.49	0.40	0.28	0.30	0.29	0.35	0.45	0.39	0.39	0.39	0.54	0.32	0.59	0.46	0.34	0.46	0.31	0.55	0.44	0.40	0.42
Gopalnagar	0.55	0.68	0.58	0.62	0.64	0.64	0.81	0.50	0.81	0.50	0.49	0.51	0.33	0.17	0.58	0.57	0.49	0.55	0.58	0.59	0.58	0.30	0.37	0.55	0.58	0.55	0.61	0.43	0.48	0.49	0.52	0.50	0.57	0.46	0.53	0.49	0.46	0.45
Manigram	0.89	0.92	0.71	0.80	0.79	0.54	0.69	0.56	0.69	0.56	0.37	0.79	0.70	0.70	0.70	0.70	0.92	0.44	0.70	0.75	0.74	0.62	0.59	0.69	0.79	0.73	0.82	0.69	0.62	0.84	0.68	0.64	0.84	0.62	0.69	0.72	0.69	0.67
Madhabpur	0.93	0.72	0.99	0.98	0.98	0.95	0.91	0.65	0.91	0.65	0.99	0.97	0.98	0.98	0.95	0.96	0.94	0.98	0.98	0.99	0.99	0.99	0.98	0.98	0.97	0.98	0.95	0.98	0.98	0.93	0.99	0.98	0.95	0.98	0.95	0.98	0.98	0.87

Annexure 6.1.6 Weighted normalized matrix

Wetland	Indicator																																					
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
Berkrishnapur	0.009	0.009	0.004	0.009	0.007	0.006	0.008	0.135	0.008	0.135	0.006	0.011	0.006	0.014	0.004	0.000	0.010	0.004	0.001	0.006	0.006	0.008	0.006	0.002	0.003	0.003	0.005	0.006	0.006	0.007	0.001	0.004	0.002	0.005	0.002	0.002	0.002	0.002
Panchpota	0.006	0.010	0.007	0.015	0.010	0.005	0.012	0.062	0.012	0.062	0.019	0.016	0.013	0.010	0.006	0.000	0.010	0.009	0.002	0.013	0.012	0.012	0.012	0.002	0.003	0.003	0.005	0.005	0.005	0.011	0.001	0.003	0.002	0.007	0.002	0.002	0.002	0.002
Panchita	0.007	0.011	0.007	0.006	0.006	0.010	0.013	0.067	0.013	0.067	0.028	0.014	0.011	0.016	0.009	0.000	0.020	0.008	0.002	0.009	0.008	0.013	0.011	0.002	0.002	0.003	0.004	0.004	0.007	0.007	0.001	0.005	0.002	0.007	0.001	0.002	0.002	0.002
Aromdanga	0.014	0.013	0.005	0.011	0.007	0.011	0.023	0.069	0.023	0.069	0.016	0.005	0.008	0.023	0.013	0.000	0.012	0.008	0.002	0.009	0.009	0.009	0.008	0.003	0.003	0.003	0.005	0.008	0.004	0.018	0.001	0.004	0.002	0.004	0.002	0.002	0.002	0.002
Gopalnagar	0.013	0.016	0.011	0.022	0.015	0.011	0.027	0.076	0.027	0.076	0.026	0.016	0.009	0.007	0.011	0.000	0.019	0.010	0.002	0.020	0.018	0.010	0.008	0.003	0.004	0.005	0.008	0.006	0.006	0.015	0.001	0.005	0.003	0.006	0.002	0.002	0.002	0.002
Manigram	0.020	0.021	0.013	0.028	0.018	0.010	0.023	0.085	0.023	0.085	0.019	0.024	0.018	0.028	0.013	0.000	0.036	0.008	0.003	0.025	0.023	0.020	0.014	0.004	0.006	0.006	0.011	0.010	0.008	0.026	0.002	0.007	0.004	0.009	0.003	0.003	0.003	0.004
Madhabpur	0.021	0.016	0.019	0.035	0.022	0.017	0.030	0.098	0.030	0.098	0.052	0.030	0.026	0.039	0.018	0.000	0.037	0.017	0.004	0.033	0.030	0.032	0.022	0.006	0.007	0.008	0.013	0.014	0.013	0.029	0.002	0.011	0.005	0.014	0.004	0.005	0.005	0.005

Annexure 6.1.7 Computation of ideal best and ideal worst value

	P1	P2	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
Ideal best (V+)	0.021	0.021	0.035	0.022	0.017	0.030	0.135	0.030	0.135	0.052	0.030	0.026	0.039	0.018	0.000	0.037	0.017	0.004	0.033	0.030	0.032	0.022	0.006	0.007	0.008	0.013	0.014	0.013	0.029	0.002	0.011	0.005	0.014	0.004	0.005	0.005	0.005
Ideal worst (V-)	0.006	0.009	0.006	0.006	0.005	0.008	0.062	0.008	0.062	0.006	0.005	0.006	0.007	0.004	0.000	0.010	0.004	0.001	0.006	0.006	0.008	0.006	0.002	0.002	0.003	0.004	0.004	0.004	0.007	0.001	0.003	0.002	0.004	0.001	0.002	0.002	0.002

Annexure 6.1.8 Calculation of Euclidean distance from ideal best and worst, performance score and ranking of wetland, 2016

Wetland	Si+	Si-	Pi	Rank
Berkrishnapur	0.100	0.105	0.51	2
Panchpota	0.134	0.031	0.19	7
Panchita	0.126	0.039	0.24	6
Aromdanga	0.124	0.042	0.25	5
Gopalnagar	0.108	0.055	0.34	4
Manigram	0.085	0.080	0.49	3
Madhabpur	0.054	0.122	0.69	1

Annexure 6.2.1 Decision matrix (Valid score of each indicator for state system, 2016)

Wetland	Indicator																																						
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40
Berkrishnapur	4.00	3.00	2.00	4.00	3.00	4.00	2.00	4.00	3.00	1.00	1.00	3.00	3.00	4.00	3.00	3.00	1.00	5.00	2.00	4.00	2.00	5.00	5.00	3.00	3.00	5.00	2.00	2.00	3.00	4.25	3.00	4.00	4.00	3.05	3.50	4.50	2.00	2.00	2.35	3.00
Panchpota	3.00	3.00	4.00	3.00	2.00	4.00	2.00	4.00	5.00	4.00	4.00	5.00	4.00	3.00	5.00	3.00	4.00	2.00	3.00	2.00	4.00	1.00	2.00	5.00	1.00	5.00	3.00	3.00	2.00	4.15	3.00	2.00	2.00	2.80	3.70	4.55	3.00	2.00	2.85	2.85
Panchita	1.00	3.00	4.00	2.00	4.00	4.00	4.00	3.00	5.00	5.00	5.00	4.00	5.00	1.00	3.00	5.00	2.00	5.00	4.00	3.00	5.00	5.00	5.00	4.00	4.00	5.00	2.00	4.00	3.00	4.15	4.00	3.00	3.00	2.30	4.20	4.00	4.00	3.00	4.25	4.80
Aromdanga	3.00	5.00	1.00	5.00	3.00	3.00	2.00	3.00	5.00	5.00	5.00	2.00	3.00	2.00	3.00	3.00	2.00	3.00	3.00	4.00	2.00	5.00	5.00	2.00	4.00	5.00	2.00	2.00	2.00	3.95	3.00	4.00	4.00	2.60	1.90	2.20	2.00	2.00	2.10	2.60
Gopalnagar	4.00	1.00	3.00	2.00	5.00	4.00	2.00	2.00	3.00	5.00	5.00	5.00	5.00	3.00	3.00	5.00	3.00	5.00	4.00	3.00	3.00	5.00	5.00	3.00	3.00	5.00	3.00	4.00	5.00	4.25	3.00	4.00	4.00	2.35	2.80	4.75	4.00	5.00	4.50	4.50
Manigram	4.00	2.00	3.00	2.00	2.00	3.00	3.00	1.00	4.00	4.00	4.00	4.00	5.00	3.00	5.00	5.00	3.00	4.00	3.00	3.00	2.00	4.00	4.00	3.00	4.00	5.00	3.00	2.00	4.00	4.50	3.00	2.00	3.00	2.80	4.70	4.75	2.00	4.00	3.60	3.45
Madhabpur	2.00	4.00	2.00	4.00	3.00	2.00	5.00	3.00	3.00	5.00	5.00	4.00	5.00	5.00	5.00	4.00	3.00	5.00	2.00	2.00	2.00	5.00	3.00	2.00	3.00	1.00	5.00	3.00	2.00	4.40	1.00	1.00	2.00	4.00	3.80	3.80	3.00	2.00	4.00	4.20

Annexure 6.2.2 Normalization of the decision matrix

Wetland	Indicator																																						
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40
Berkrishnapur	0.19	0.14	0.11	0.18	0.14	0.17	0.10	0.20	0.11	0.03	0.03	0.11	0.10	0.19	0.11	0.11	0.06	0.17	0.10	0.19	0.10	0.17	0.17	0.14	0.14	0.16	0.10	0.10	0.14	0.14	0.15	0.20	0.18	0.15	0.14	0.16	0.10	0.10	0.10	0.12
Panchpota	0.14	0.14	0.21	0.14	0.09	0.17	0.10	0.20	0.18	0.14	0.14	0.19	0.13	0.14	0.19	0.11	0.22	0.07	0.14	0.10	0.20	0.03	0.07	0.23	0.05	0.16	0.15	0.15	0.10	0.14	0.15	0.10	0.09	0.14	0.15	0.16	0.15	0.10	0.12	0.11
Panchita	0.05	0.14	0.21	0.09	0.18	0.17	0.20	0.15	0.18	0.17	0.17	0.15	0.17	0.05	0.11	0.18	0.11	0.17	0.19	0.14	0.25	0.17	0.17	0.18	0.18	0.16	0.10	0.20	0.14	0.14	0.20	0.15	0.14	0.12	0.17	0.14	0.20	0.15	0.18	0.19
Aromdanga	0.14	0.24	0.05	0.23	0.14	0.13	0.10	0.15	0.18	0.17	0.17	0.07	0.10	0.10	0.11	0.11	0.11	0.10	0.14	0.19	0.10	0.17	0.17	0.09	0.18	0.16	0.10	0.10	0.10	0.13	0.15	0.20	0.18	0.13	0.08	0.08	0.10	0.10	0.09	0.10
Gopalnagar	0.19	0.05	0.16	0.09	0.23	0.17	0.10	0.10	0.11	0.17	0.17	0.19	0.17	0.14	0.11	0.18	0.17	0.17	0.19	0.14	0.15	0.17	0.17	0.14	0.14	0.16	0.15	0.20	0.24	0.14	0.15	0.20	0.18	0.12	0.11	0.17	0.20	0.25	0.19	0.18
Manigram	0.19	0.10	0.16	0.09	0.09	0.13	0.15	0.05	0.14	0.14	0.14	0.15	0.17	0.14	0.19	0.18	0.17	0.14	0.14	0.14	0.10	0.13	0.14	0.14	0.18	0.16	0.15	0.10	0.19	0.15	0.15	0.10	0.14	0.14	0.19	0.17	0.10	0.20	0.15	0.14
Madhabpur	0.10	0.19	0.11	0.18	0.14	0.08	0.25	0.15	0.11	0.17	0.17	0.15	0.17	0.24	0.19	0.14	0.17	0.17	0.10	0.10	0.10	0.17	0.10	0.09	0.14	0.03	0.25	0.15	0.10	0.15	0.05	0.05	0.09	0.20	0.15	0.13	0.15	0.10	0.17	0.17
Sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1.**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Annexure 6.2.3 Computation of entropy, degree of diversification and indicator weight

Wetland	Indicator																			
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
Berkrishnapur	-0.32	-0.28	-0.24	-0.31	-0.27	-0.30	-0.23	-0.32	-0.24	-0.12	-0.12	-0.24	-0.23	-0.32	-0.24	-0.24	-0.16	-0.30	-0.22	-0.32
Panchpota	-0.28	-0.28	-0.33	-0.27	-0.22	-0.30	-0.23	-0.32	-0.31	-0.27	-0.27	-0.31	-0.27	-0.28	-0.31	-0.24	-0.33	-0.18	-0.28	-0.22
Panchita	-0.14	-0.28	-0.33	-0.22	-0.31	-0.30	-0.32	-0.28	-0.31	-0.30	-0.30	-0.28	-0.30	-0.14	-0.24	-0.31	-0.24	-0.30	-0.32	-0.28
Aromdanga	-0.28	-0.34	-0.15	-0.34	-0.27	-0.26	-0.23	-0.28	-0.31	-0.30	-0.30	-0.19	-0.23	-0.22	-0.24	-0.24	-0.24	-0.23	-0.28	-0.32
Gopalnagar	-0.32	-0.14	-0.29	-0.22	-0.34	-0.30	-0.23	-0.23	-0.24	-0.30	-0.30	-0.31	-0.30	-0.28	-0.24	-0.31	-0.30	-0.30	-0.32	-0.28
Manigram	-0.32	-0.22	-0.29	-0.22	-0.22	-0.26	-0.28	-0.15	-0.28	-0.27	-0.27	-0.28	-0.30	-0.28	-0.31	-0.31	-0.30	-0.27	-0.28	-0.28
Madhabpur	-0.22	-0.32	-0.24	-0.31	-0.27	-0.21	-0.35	-0.28	-0.24	-0.30	-0.30	-0.28	-0.30	-0.34	-0.31	-0.28	-0.30	-0.30	-0.22	-0.22
Entropy	-1.87	-1.86	-1.87	-1.88	-1.90	-1.92	-1.87	-1.88	-1.92	-1.87	-1.87	-1.91	-1.92	-1.86	-1.91	-1.92	-1.88	-1.90	-1.91	-1.91
Entropy value	0.96	0.96	0.96	0.97	0.98	0.99	0.96	0.96	0.99	0.96	0.96	0.98	0.99	0.96	0.98	0.99	0.97	0.98	0.98	0.98
Degree of diversification	0.04	0.04	0.04	0.03	0.02	0.01	0.04	0.04	0.01	0.04	0.04	0.02	0.01	0.04	0.02	0.01	0.03	0.02	0.02	0.02
Weight	**0.04**	**0.04**	**0.04**	**0.03**	**0.02**	**0.01**	**0.04**	**0.03**	**0.01**	**0.04**	**0.04**	**0.02**	**0.01**	**0.04**	**0.02**	**0.01**	**0.03**	**0.02**	**0.02**	**0.02**

Wetland	Indicator																				
	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40	**Sum**
Berkrishnapur	-0.23	-0.30	-0.30	-0.27	-0.27	-0.29	-0.23	-0.23	-0.28	-0.28	-0.28	-0.32	-0.31	-0.29	-0.28	-0.29	-0.23	-0.23	-0.23	-0.25	
Panchpota	-0.32	-0.11	-0.18	-0.34	-0.14	-0.29	-0.28	-0.28	-0.22	-0.28	-0.28	-0.23	-0.22	-0.28	-0.28	-0.29	-0.28	-0.23	-0.25	-0.25	
Panchita	-0.35	-0.30	-0.30	-0.31	-0.31	-0.29	-0.23	-0.32	-0.28	-0.28	-0.32	-0.28	-0.27	-0.25	-0.30	-0.28	-0.32	-0.28	-0.31	-0.31	
Aromdanga	-0.23	-0.30	-0.30	-0.22	-0.31	-0.29	-0.23	-0.23	-0.22	-0.27	-0.28	-0.32	-0.31	-0.27	-0.20	-0.20	-0.23	-0.23	-0.22	-0.23	
Gopalnagar	-0.28	-0.30	-0.30	-0.27	-0.27	-0.29	-0.28	-0.32	-0.34	-0.28	-0.28	-0.32	-0.31	-0.25	-0.25	-0.30	-0.32	-0.35	-0.32	-0.31	
Manigram	-0.23	-0.27	-0.27	-0.27	-0.31	-0.29	-0.28	-0.23	-0.32	-0.29	-0.28	-0.23	-0.27	-0.28	-0.32	-0.30	-0.23	-0.32	-0.29	-0.27	
Madhabpur	-0.23	-0.30	-0.23	-0.22	-0.27	-0.11	-0.35	-0.28	-0.22	-0.28	-0.15	-0.15	-0.22	-0.32	-0.29	-0.27	-0.28	-0.23	-0.30	-0.30	
Entropy	-1.87	-1.88	-1.90	-1.90	-1.89	-1.88	-1.89	-1.90	-1.89	-1.95	-1.89	-1.86	-1.91	-1.93	-1.91	-1.92	-1.90	-1.87	-1.91	-1.92	
Entropy value	0.96	0.96	0.98	0.98	0.97	0.96	0.97	0.98	0.97	1.00	0.97	0.96	0.98	0.99	0.98	0.99	0.98	0.96	0.98	0.99	
Degree of diversification	0.04	0.04	0.02	0.02	0.03	0.04	0.03	0.02	0.03	0.00	0.03	0.04	0.02	0.01	0.02	0.01	0.02	0.04	0.02	0.01	**1.03**
Weight	**0.04**	**0.04**	**0.02**	**0.02**	**0.03**	**0.03**	**0.03**	**0.02**	**0.03**	**0.00**	**0.03**	**0.04**	**0.02**	**0.01**	**0.02**	**0.01**	**0.02**	**0.04**	**0.02**	**0.01**	**1.00**

Annexure 6.2.4 Evaluation matrix with indicator weight

Wetland	Indicator																			
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
Berkrishnapur	4.00	3.00	2.00	4.00	3.00	4.00	2.00	4.00	3.00	1.00	1.00	3.00	3.00	4.00	3.00	3.00	1.00	5.00	2.00	4.00
Panchpota	3.00	3.00	4.00	3.00	2.00	4.00	2.00	4.00	5.00	4.00	4.00	5.00	4.00	3.00	5.00	3.00	4.00	2.00	3.00	2.00
Panchita	1.00	3.00	4.00	2.00	4.00	4.00	4.00	3.00	5.00	5.00	5.00	4.00	5.00	1.00	3.00	5.00	2.00	5.00	4.00	3.00
Aromdanga	3.00	5.00	1.00	5.00	3.00	3.00	2.00	3.00	5.00	5.00	5.00	2.00	3.00	2.00	3.00	3.00	2.00	3.00	3.00	4.00
Gopalnagar	4.00	1.00	3.00	2.00	5.00	4.00	2.00	2.00	3.00	5.00	5.00	5.00	5.00	3.00	3.00	5.00	3.00	5.00	4.00	3.00
Manigram	4.00	2.00	3.00	2.00	2.00	3.00	3.00	1.00	4.00	4.00	4.00	4.00	5.00	3.00	5.00	5.00	3.00	4.00	3.00	3.00
Madhabpur	2.00	4.00	2.00	4.00	3.00	2.00	5.00	3.00	3.00	5.00	5.00	4.00	5.00	5.00	5.00	4.00	3.00	5.00	2.00	2.00
Weight	**0.037**	**0.043**	**0.039**	**0.032**	**0.024**	**0.012**	**0.036**	**0.034**	**0.014**	**0.036**	**0.036**	**0.018**	**0.011**	**0.043**	**0.016**	**0.014**	**0.033**	**0.021**	**0.016**	**0.016**

Wetland	Indicator																			
	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40
Berkrishnapur	2.00	5.00	5.00	3.00	3.00	5.00	2.00	2.00	3.00	4.25	3.00	4.00	4.00	3.05	3.50	4.50	2.00	2.00	2.35	3.00
Panchpota	4.00	1.00	2.00	5.00	1.00	5.00	3.00	3.00	2.00	4.15	3.00	2.00	2.00	2.80	3.70	4.55	3.00	2.00	2.85	2.85
Panchita	5.00	5.00	5.00	4.00	4.00	5.00	2.00	4.00	3.00	4.15	4.00	3.00	3.00	2.30	4.20	4.00	4.00	3.00	4.25	4.80
Aromdanga	2.00	5.00	5.00	2.00	4.00	5.00	2.00	2.00	2.00	3.95	3.00	4.00	4.00	2.60	1.90	2.20	2.00	2.00	2.10	2.60
Gopalnagar	3.00	5.00	5.00	3.00	3.00	5.00	3.00	4.00	5.00	4.25	3.00	4.00	4.00	2.35	2.80	4.75	4.00	5.00	4.50	4.50
Manigram	2.00	4.00	4.00	3.00	4.00	5.00	3.00	2.00	4.00	4.50	3.00	2.00	3.00	2.80	4.70	4.75	2.00	4.00	3.60	3.45
Madhabpur	2.00	5.00	3.00	2.00	3.00	1.00	5.00	3.00	2.00	4.40	1.00	1.00	2.00	4.00	3.80	3.80	3.00	2.00	4.00	4.20
Weight	**0.036**	**0.035**	**0.021**	**0.024**	**0.030**	**0.035**	**0.027**	**0.021**	**0.030**	**0.000**	**0.026**	**0.043**	**0.018**	**0.008**	**0.016**	**0.012**	**0.021**	**0.036**	**0.018**	**0.012**

Annexure 6.2.5 Vector normalization

Wetland	Indicator																			
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
Berkrishnapur	0.47	0.35	0.26	0.45	0.34	0.43	0.25	0.50	0.28	0.09	0.09	0.28	0.26	0.47	0.28	0.28	0.14	0.44	0.24	0.49
Panchpota	0.40	0.38	0.54	0.38	0.24	0.48	0.25	0.58	0.48	0.35	0.35	0.50	0.36	0.40	0.50	0.29	0.56	0.20	0.38	0.28
Panchita	0.15	0.40	0.64	0.27	0.50	0.54	0.53	0.53	0.55	0.46	0.46	0.46	0.48	0.14	0.34	0.50	0.34	0.50	0.54	0.44
Aromdanga	0.45	0.74	0.21	0.71	0.44	0.49	0.31	0.62	0.65	0.52	0.52	0.26	0.33	0.29	0.36	0.35	0.36	0.35	0.49	0.65
Gopalnagar	0.66	0.22	0.63	0.41	0.81	0.74	0.32	0.52	0.51	0.61	0.61	0.66	0.58	0.46	0.39	0.61	0.57	0.61	0.74	0.64
Manigram	0.89	0.44	0.81	0.44	0.55	0.81	0.51	0.30	0.79	0.62	0.62	0.70	0.70	0.51	0.70	0.78	0.70	0.62	0.82	0.82
Madhabpur	0.93	0.97	0.91	0.97	0.97	0.90	0.99	0.94	0.95	0.99	0.99	0.98	0.99	0.99	0.99	0.98	0.97	0.99	0.92	0.90

Wetland	Indicator																			
	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40
Berkrishnapur	0.25	0.42	0.44	0.34	0.34	0.41	0.25	0.25	0.36	0.38	0.38	0.49	0.46	0.40	0.37	0.41	0.25	0.25	0.25	0.31
Panchpota	0.51	0.09	0.20	0.61	0.12	0.45	0.39	0.39	0.25	0.40	0.41	0.28	0.26	0.40	0.42	0.45	0.39	0.25	0.32	0.30
Panchita	0.74	0.46	0.50	0.62	0.49	0.50	0.28	0.57	0.39	0.44	0.60	0.44	0.41	0.36	0.52	0.45	0.57	0.39	0.50	0.54
Aromdanga	0.44	0.52	0.58	0.39	0.57	0.57	0.29	0.35	0.29	0.46	0.57	0.66	0.59	0.43	0.27	0.27	0.35	0.29	0.29	0.35
Gopalnagar	0.72	0.61	0.71	0.63	0.51	0.70	0.46	0.74	0.74	0.56	0.68	0.87	0.74	0.43	0.42	0.61	0.74	0.74	0.64	0.64
Manigram	0.67	0.62	0.79	0.81	0.79	0.97	0.51	0.54	0.89	0.71	0.92	0.85	0.82	0.57	0.77	0.77	0.54	0.89	0.66	0.63
Madhabpur	0.89	0.99	0.96	0.89	0.96	0.72	0.99	0.96	0.95	0.98	0.71	0.72	0.91	0.98	0.98	0.98	0.96	0.96	0.98	0.98

Annexure 6.2.6 Weighted normalized matrix

Wetland	Indicator																																						
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40
Berkrishnapur	0.017	0.015	0.010	0.014	0.008	0.005	0.009	0.017	0.004	0.003	0.003	0.005	0.003	0.020	0.005	0.004	0.005	0.009	0.004	0.008	0.009	0.015	0.009	0.008	0.010	0.014	0.007	0.005	0.011	0.000	0.010	0.021	0.009	0.003	0.006	0.005	0.005	0.009	0.004	0.004
Panchpota	0.015	0.016	0.021	0.012	0.006	0.006	0.009	0.020	0.006	0.012	0.012	0.009	0.004	0.017	0.008	0.004	0.019	0.004	0.006	0.005	0.018	0.003	0.004	0.015	0.004	0.015	0.011	0.008	0.008	0.000	0.011	0.012	0.005	0.003	0.007	0.005	0.008	0.009	0.006	0.004
Panchita	0.005	0.017	0.025	0.009	0.012	0.007	0.019	0.018	0.007	0.016	0.016	0.008	0.005	0.006	0.006	0.007	0.011	0.010	0.009	0.007	0.027	0.016	0.010	0.015	0.015	0.017	0.008	0.012	0.012	0.000	0.016	0.019	0.007	0.003	0.008	0.005	0.012	0.014	0.009	0.007
Aromdanga	0.016	0.031	0.008	0.023	0.011	0.006	0.011	0.021	0.009	0.019	0.019	0.005	0.004	0.012	0.006	0.005	0.012	0.007	0.008	0.010	0.016	0.019	0.012	0.009	0.017	0.020	0.008	0.007	0.009	0.000	0.015	0.028	0.011	0.004	0.004	0.003	0.007	0.010	0.005	0.004
Gopalnagar	0.024	0.009	0.025	0.013	0.020	0.009	0.012	0.018	0.007	0.022	0.022	0.012	0.006	0.019	0.006	0.008	0.019	0.013	0.012	0.010	0.026	0.022	0.015	0.015	0.016	0.024	0.013	0.016	0.023	0.000	0.018	0.037	0.014	0.004	0.007	0.007	0.016	0.027	0.011	0.008
Manigram	0.033	0.019	0.032	0.014	0.013	0.010	0.018	0.010	0.011	0.022	0.022	0.013	0.008	0.022	0.011	0.011	0.023	0.013	0.013	0.013	0.024	0.022	0.016	0.019	0.024	0.034	0.014	0.011	0.027	0.000	0.024	0.036	0.015	0.005	0.012	0.009	0.011	0.032	0.012	0.008
Madhabpur	0.034	0.042	0.036	0.031	0.023	0.011	0.036	0.032	0.013	0.035	0.035	0.018	0.011	0.042	0.016	0.013	0.032	0.020	0.015	0.015	0.032	0.035	0.020	0.022	0.029	0.025	0.027	0.020	0.029	0.000	0.018	0.031	0.017	0.008	0.016	0.012	0.020	0.034	0.017	0.012

Annexure 6.2.7 Computation of ideal best and ideal worst value

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39
Ideal best (V+)	0.034	0.042	0.036	0.031	0.023	0.011	0.036	0.032	0.013	0.035	0.035	0.018	0.011	0.042	0.016	0.013	0.032	0.020	0.015	0.015	0.032	0.035	0.020	0.022	0.029	0.034	0.027	0.020	0.029	0.000	0.024	0.037	0.017	0.008	0.016	0.012	0.020	0.034	0.017
Ideal worst (V-)	0.005	0.009	0.008	0.009	0.006	0.005	0.009	0.010	0.004	0.003	0.003	0.005	0.003	0.006	0.005	0.004	0.005	0.004	0.004	0.005	0.009	0.003	0.004	0.008	0.004	0.014	0.007	0.005	0.008	0.000	0.010	0.012	0.005	0.003	0.004	0.003	0.005	0.009	0.004

Annexure 6.2.8 Calculation of Euclidean distance from ideal best and worst, performance score and ranking of wetland, 2016

Wetland	**Si+**	**Si-**	**Pi**	**Rank**
Berkrishnapur	0.10938	0.02841	0.21	7
Panchpota	0.10376	0.03331	0.24	6
Panchita	0.09204	0.04517	0.33	5
Aromdanga	0.08949	0.05002	0.36	4
Gopalnagar	0.06990	0.07031	0.50	3
Manigram	0.05858	0.08425	0.59	2
Madhabpur	0.01685	0.12453	0.88	1

Annexure 6.3.1 Decision matrix (Valid score of each indicator for response system, 2016)

Wetland	Indicator																	
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
Berkrishnapur	2.00	2.00	1.25	2.00	2.30	2.30	2.80	2.40	2.05	1.35	1.35	2.50	1.00	2.00	1.00	1.00	1.00	1.00
Panchpota	2.00	2.00	1.30	2.00	2.30	2.30	2.50	2.40	2.10	1.75	2.20	2.40	2.00	2.00	3.00	1.00	1.00	1.00
Panchita	2.00	2.00	1.20	1.90	2.20	2.30	2.50	2.60	2.25	2.00	2.45	3.65	3.00	3.00	2.00	1.00	1.00	1.00
Aromdanga	2.00	2.00	1.00	2.00	2.05	2.00	2.40	2.20	1.95	1.40	1.45	2.00	1.00	1.00	1.00	1.00	1.00	1.00
Gopalnagar	2.00	2.00	1.30	2.10	2.20	2.40	2.90	2.80	2.50	2.95	2.00	2.20	3.00	3.00	3.00	1.00	1.00	1.00
Manigram	2.00	2.00	1.40	2.10	2.20	2.30	2.40	2.70	2.70	2.20	2.00	2.80	2.00	2.00	3.00	1.00	1.00	1.00
Madhabpur	3.00	3.00	2.30	2.20	2.30	2.30	2.90	2.90	2.70	2.90	2.60	3.30	3.00	1.00	3.00	1.00	1.00	1.00

Annexure 6.3.2 Normalization of the decision matrix

Wetland	Indicator																	
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
Berkrishnapur	0.13	0.13	0.13	0.14	0.15	0.14	0.15	0.13	0.13	0.09	0.10	0.13	0.07	0.14	0.06	0.14	0.14	0.14
Panchpota	0.13	0.13	0.13	0.14	0.15	0.14	0.14	0.13	0.13	0.12	0.16	0.13	0.13	0.14	0.19	0.14	0.14	0.14
Panchita	0.13	0.13	0.12	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.17	0.19	0.20	0.21	0.13	0.14	0.14	0.14
Aromdanga	0.13	0.13	0.10	0.14	0.13	0.13	0.13	0.12	0.12	0.10	0.10	0.11	0.07	0.07	0.06	0.14	0.14	0.14
Gopalnagar	0.13	0.13	0.13	0.15	0.14	0.15	0.16	0.16	0.15	0.20	0.14	0.12	0.20	0.21	0.19	0.14	0.14	0.14
Manigram	0.13	0.13	0.14	0.15	0.14	0.14	0.13	0.15	0.17	0.15	0.14	0.15	0.13	0.14	0.19	0.14	0.14	0.14
Madhabpur	0.20	0.20	0.24	0.15	0.15	0.14	0.16	0.16	0.17	0.20	0.19	0.18	0.20	0.07	0.19	0.14	0.14	0.14
Sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Annexure 6.3.3 Computation of entropy, degree of diversification and indicator weight

Wetland	Indicator																		
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	**Sum**
Berkrishnapur	-0.269	-0.269	-0.263	-0.275	-0.283	-0.280	-0.287	-0.269	-0.261	-0.221	-0.225	-0.268	-0.181	-0.278	-0.173	-0.278	-0.278	-0.278	
Panchpota	-0.269	-0.269	-0.269	-0.275	-0.283	-0.280	-0.271	-0.269	-0.264	-0.255	-0.290	-0.262	-0.269	-0.278	-0.314	-0.278	-0.278	-0.278	
Panchita	-0.269	-0.269	-0.258	-0.268	-0.277	-0.280	-0.271	-0.279	-0.274	-0.273	-0.305	-0.318	-0.322	-0.330	-0.260	-0.278	-0.278	-0.278	
Aromdanga	-0.269	-0.269	-0.234	-0.275	-0.267	-0.261	-0.266	-0.257	-0.254	-0.225	-0.234	-0.238	-0.181	-0.189	-0.173	-0.278	-0.278	-0.278	
Gopalnagar	-0.269	-0.269	-0.269	-0.282	-0.277	-0.285	-0.291	-0.289	-0.288	-0.324	-0.278	-0.251	-0.322	-0.330	-0.314	-0.278	-0.278	-0.278	
Manigram	-0.269	-0.269	-0.279	-0.282	-0.277	-0.280	-0.266	-0.285	-0.298	-0.286	-0.278	-0.283	-0.269	-0.278	-0.314	-0.278	-0.278	-0.278	
Madhabpur	-0.322	-0.322	-0.341	-0.288	-0.283	-0.280	-0.291	-0.294	-0.298	-0.321	-0.312	-0.305	-0.322	-0.189	-0.314	-0.278	-0.278	-0.278	
Entropy	-1.934	-1.934	-1.911	-1.945	-1.945	-1.945	-1.943	-1.942	-1.938	-1.904	-1.922	-1.925	-1.864	-1.871	-1.862	-1.946	-1.946	-1.946	
Entropy value	0.994	0.994	0.982	0.999	1.000	0.999	0.998	0.998	0.996	0.978	0.987	0.989	0.958	0.962	0.957	1.000	1.000	1.000	
Degree of diversification	0.006	0.006	0.018	0.001	0.000	0.001	0.002	0.002	0.004	0.022	0.013	0.011	0.042	0.038	0.043	0.000	0.000	0.000	**0.208**
Weight	**0.030**	**0.030**	**0.085**	**0.002**	**0.002**	**0.003**	**0.008**	**0.010**	**0.019**	**0.104**	**0.060**	**0.051**	**0.203**	**0.185**	**0.208**	**0.000**	**0.000**	**0.000**	**1.000**

Annexure 6.3.4 Evaluation matrix with indicator weight

Wetland	Indicator																	
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
Berkrishnapur	2.00	2.00	1.25	2.00	2.30	2.30	2.80	2.40	2.05	1.35	1.35	2.50	1.00	2.00	1.00	1.00	1.00	1.00
Panchpota	2.00	2.00	1.30	2.00	2.30	2.30	2.50	2.40	2.10	1.75	2.20	2.40	2.00	2.00	3.00	1.00	1.00	1.00
Panchita	2.00	2.00	1.20	1.90	2.20	2.30	2.50	2.60	2.25	2.00	2.45	3.65	3.00	3.00	2.00	1.00	1.00	1.00
Aromdanga	2.00	2.00	1.00	2.00	2.05	2.00	2.40	2.20	1.95	1.40	1.45	2.00	1.00	1.00	1.00	1.00	1.00	1.00
Gopalnagar	2.00	2.00	1.30	2.10	2.20	2.40	2.90	2.80	2.50	2.95	2.00	2.20	3.00	3.00	3.00	1.00	1.00	1.00
Manigram	2.00	2.00	1.40	2.10	2.20	2.30	2.40	2.70	2.70	2.20	2.00	2.80	2.00	2.00	3.00	1.00	1.00	1.00
Madhabpur	3.00	3.00	2.30	2.20	2.30	2.30	2.90	2.90	2.70	2.90	2.60	3.30	3.00	1.00	3.00	1.00	1.00	1.00
Weight	**0.030**	**0.030**	**0.085**	**0.002**	**0.002**	**0.003**	**0.008**	**0.010**	**0.019**	**0.104**	**0.060**	**0.051**	**0.203**	**0.185**	**0.208**	**0.000**	**0.000**	**0.000**

Annexure 6.3.5 Vector normalization

Wetland	Indicator																	
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
Berkrishnapur	0.13	0.13	0.13	0.14	0.15	0.14	0.15	0.13	0.13	0.09	0.10	0.13	0.07	0.14	0.06	0.14	0.14	0.14
Panchpota	0.13	0.13	0.13	0.14	0.15	0.14	0.14	0.13	0.13	0.12	0.16	0.13	0.13	0.14	0.19	0.14	0.14	0.14
Panchita	0.13	0.13	0.12	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.17	0.19	0.20	0.21	0.13	0.14	0.14	0.14
Aromdanga	0.13	0.13	0.10	0.14	0.13	0.13	0.13	0.12	0.12	0.10	0.10	0.11	0.07	0.07	0.06	0.14	0.14	0.14
Gopalnagar	0.13	0.13	0.13	0.15	0.14	0.15	0.16	0.16	0.15	0.20	0.14	0.12	0.20	0.21	0.19	0.14	0.14	0.14
Manigram	0.13	0.13	0.14	0.15	0.14	0.14	0.13	0.15	0.17	0.15	0.14	0.15	0.13	0.14	0.19	0.14	0.14	0.14
Madhabpur	0.20	0.20	0.24	0.15	0.15	0.14	0.16	0.16	0.17	0.20	0.19	0.18	0.20	0.07	0.19	0.14	0.14	0.14

Annexure 6.3.6 Weighted normalized matrix

Wetland	Indicator																	
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
Berkrishnapur	0.010	0.010	0.028	0.001	0.001	0.001	0.003	0.004	0.006	0.024	0.015	0.018	0.033	0.065	0.032	0.000	0.000	0.000
Panchpota	0.011	0.011	0.031	0.001	0.001	0.001	0.003	0.004	0.007	0.033	0.025	0.018	0.068	0.070	0.097	0.000	0.000	0.000
Panchita	0.012	0.012	0.030	0.001	0.001	0.002	0.003	0.004	0.008	0.039	0.031	0.029	0.107	0.113	0.073	0.000	0.000	0.000
Aromdanga	0.013	0.013	0.027	0.001	0.001	0.001	0.004	0.004	0.007	0.030	0.021	0.019	0.042	0.048	0.039	0.000	0.000	0.000
Gopalnagar	0.014	0.014	0.037	0.001	0.001	0.002	0.005	0.006	0.010	0.065	0.031	0.023	0.129	0.147	0.119	0.000	0.000	0.000
Manigram	0.016	0.016	0.043	0.002	0.001	0.002	0.005	0.007	0.013	0.062	0.036	0.033	0.111	0.156	0.145	0.000	0.000	0.000
Madhabpur	0.029	0.029	0.082	0.002	0.002	0.003	0.008	0.010	0.018	0.101	0.058	0.049	0.198	0.142	0.203	0.000	0.000	0.000

Annexure 6.3.7 Computation of ideal best and ideal worst value

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
Ideal best (V+)	0.0290	0.0290	0.0818	0.0023	0.0017	0.0031	0.0077	0.0097	0.0184	0.1014	0.0576	0.0494	0.1976	0.1557	0.2032	0.0000	0.0000	0.0000
Ideal worst (V-)	0.0104	0.0104	0.0269	0.0009	0.0007	0.0013	0.0031	0.0035	0.0063	0.0244	0.0150	0.0175	0.0333	0.0476	0.0320	0.0000	0.0000	0.0000

Annexure 6.3.8 Calculation of Euclidean distance from ideal best and worst, performance score and ranking of wetland, 2016

Wetland	**Si+**	**Si-**	**Pi**	**Rank**
Berkrishnapur	0.27749	0.01786	0.06	7
Panchpota	0.21380	0.07821	0.27	5
Panchita	0.18746	0.11024	0.37	4
Aromdanga	0.27163	0.01472	0.05	6
Gopalnagar	0.13061	0.16964	0.56	3
Manigram	0.12273	0.18165	0.60	2
Madhabpur	0.01424	0.27887	0.95	1

Annexure 6.4 Observed value of each indicator of pressure system, 2020

Wetland	Indicator																																					
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
Berkrishnapur	42.91	62.11	2.60	1.40	1.45	1.45	3.80	7.84	3.80	7.84	249.00	220.00	0.22	0.66	0.51	0.01	0.68	3.50	9.70	1.00	1.00	14.00	19.00	2.65	3.00	3.05	1.65	240.52	2.16	1.65	2.60	2.50	1.50	3.80	2.90	3.70	3.40	1.20
Panchpota	30.04	48.75	1.40	1.95	2.90	2.90	7.40	0.00	7.40	0.00	225.00	140.00	<0.15	1.06	<0.5	<0.01	0.62	1.50	9.80	1.90	1.95	10.00	12.00	3.10	3.05	3.35	1.75	561.51	5.40	2.65	3.90	4.50	1.95	4.10	2.15	4.05	4.20	1.05
Panchita	30.04	59.38	2.29	2.29	2.29	2.29	4.60	0.00	4.60	0.00	192.00	450.00	<0.15	0.82	<0.5	<0.01	0.48	2.40	9.90	1.40	1.60	10.00	21.00	1.80	2.00	2.05	1.80	394.60	2.72	1.15	4.50	4.65	1.85	3.75	1.80	3.95	3.40	1.10
Aromdanga	69.86	46.74	3.00	3.35	3.25	3.10	32.00	0.00	32.00	0.00	226.66	1700.00	0.21	0.38	<0.5	0.02	0.67	2.50	9.20	1.95	1.95	11.00	21.00	2.65	2.55	2.85	3.30	266.47	4.24	3.35	4.65	1.85	2.10	2.75	2.55	3.55	3.40	1.35
Gopalnagar	44.05	33.65	3.50	2.21	2.14	2.00	17.00	0.00	17.00	0.00	197.97	310.00	0.23	1.69	<0.5	0.01	0.51	2.00	10.00	1.17	1.75	12.00	24.00	1.46	2.15	2.25	2.00	468.13	4.65	2.08	4.29	3.79	1.50	2.45	1.74	3.70	2.85	1.00
Manigram	37.67	57.14	3.10	3.47	3.50	4.00	1.86	0.00	1.86	0.00	229.00	110.00	<0.15	0.29	<0.5	<0.01	0.33	3.00	10.00	2.17	2.22	7.00	15.00	3.53	4.00	3.55	1.55	360.92	4.37	1.80	4.55	3.17	3.25	3.15	2.40	3.60	3.30	1.25
Madhabpur	29.28	6.45	3.40	1.55	2.60	1.70	3.50	0.00	3.50	0.00	159.00	220.00	<0.15	0.12	<0.5	<0.01	0.63	1.20	9.90	3.30	3.35	4.00	11.00	3.05	2.65	3.30	1.50	279.79	1.57	1.50	5.00	4.25	1.60	4.15	2.35	4.10	3.95	1.00

Annexure 6.5 Observed value of each indicator of state system, 2020

Wetland	Indicator																																							
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40
Berkrishnapur	166.67	13.61	1.60	44.00	35.38	104.34	2.55	45.00	27.02	24.00	83.00	7.43	2.10	1.00	248.88	0.01	642.70	25.30	84.00	0.77	171.35	0.93	350.00	475.00	2.00	2.00	1.00	1.23	0.95	2.90	3.35	3.20	3.40	2.65	3.65	4.25	4.30	1.60	2.05	2.45
Panchpota	192.08	29.60	1.74	43.55	7.67	98.59	2.30	48.00	27.49	5.20	20.00	7.57	4.50	1.00	224.94	0.05	377.40	105.10	205.00	1.03	327.05	0.93	250.00	300.00	5.00	5.00	2.00	1.21	1.10	3.70	4.10	3.00	3.25	1.90	3.50	4.30	4.60	2.25	2.50	2.45
Panchita	112.14	14.12	1.67	43.28	49.06	102.57	7.22	56.00	26.99	6.00	22.00	7.44	3.90	1.00	192.46	0.03	169.10	7.30	49.50	0.54	90.90	0.94	250.00	525.00	4.00	4.00	1.00	1.21	1.12	3.35	4.40	4.05	4.65	1.70	3.95	3.70	4.05	3.55	4.10	4.65
Aromdanga	166.00	11.63	1.56	47.27	30.74	68.57	2.78	35.00	27.68	8.00	32.00	7.89	3.80	1.00	226.66	0.00	166.50	11.10	127.10	0.48	148.21	0.94	275.00	525.00	1.00	1.00	1.00	1.22	0.98	4.05	3.40	2.50	2.15	2.40	1.40	3.68	3.40	2.40	2.10	3.20
Gopalnagar	193.67	5.93	1.67	39.96	66.36	96.75	2.94	52.00	27.01	6.50	24.00	7.47	4.20	1.50	197.90	0.03	317.30	14.20	76.50	0.52	144.10	0.95	300.00	600.00	4.00	3.00	2.00	1.22	1.15	4.05	4.35	3.90	4.26	1.75	1.60	4.55	4.75	4.00	4.35	4.20
Manigram	173.77	26.75	1.69	40.54	29.12	92.96	5.65	65.00	27.64	5.50	20.00	7.52	4.10	2.60	229.15	0.02	169.10	7.30	49.50	0.54	101.28	0.93	175.00	375.00	3.00	3.00	2.00	1.17	1.12	4.00	3.50	2.55	3.45	1.20	4.60	4.60	4.15	2.55	2.80	3.10
Madhabpur	146.07	28.02	1.43	53.53	24.86	71.36	10.34	68.00	27.94	7.00	28.00	8.31	4.20	3.60	159.16	0.04	109.10	9.03	33.50	0.28	148.85	0.97	100.00	275.00	4.00	4.00	3.00	1.19	1.11	3.90	3.45	2.60	5.00	1.75	3.85	4.65	4.15	2.50	2.30	3.25

Annexure 6.6 Observed value of each indicator of response system, 2020

Wetland	Indicator																	
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
Berkrishnapur	2.00	1.00	1.00	1.50	2.75	2.35	3.65	3.90	2.00	1.00	2.65	2.75	1.00	1.00	1.00	1.00	1.00	1.00
Panchpota	4.00	3.00	3.00	3.50	3.65	2.45	2.90	2.80	1.95	1.15	1.90	2.75	1.30	1.05	1.00	1.00	1.00	1.00
Panchita	1.00	4.00	1.00	2.85	2.45	1.40	2.70	2.00	2.60	1.30	2.40	4.15	1.20	1.55	1.35	1.00	1.00	1.00
Aromdanga	1.00	1.00	1.00	2.10	1.35	1.90	2.25	1.95	2.60	1.75	1.95	4.53	1.15	1.00	1.00	1.00	1.00	1.00
Gopalnagar	4.00	4.00	3.00	2.85	2.55	2.90	3.60	2.85	3.50	2.95	2.15	4.45	1.55	1.55	1.55	1.00	1.00	1.00
Manigram	5.00	4.00	4.00	3.40	3.95	2.45	3.20	2.25	3.16	1.60	3.70	3.63	1.00	1.00	1.00	1.00	1.00	1.00
Madhabpur	5.00	5.00	4.00	4.30	3.15	2.85	3.90	3.20	3.20	2.45	3.45	3.15	1.00	1.00	1.00	0.95	0.95	1.00

Annexure 6.4.1 Decision matrix (Valid score of each indicator for pressure system, 2020)

Wetland	Indicator																																				
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
Berkrishnapur	3.00	2.00	3.00	1.40	1.45	4.00	2.00	5.00	2.00	5.00	2.00	3.00	2.00	3.00	2.00	3.00	2.00	2.00	3.00	1.00	1.00	2.00	3.00	2.65	3.00	3.05	1.65	4.00	4.00	1.65	2.60	2.50	1.50	3.80	2.90	3.70	3.40	1.20
Panchpota	4.00	3.00	1.00	1.95	2.90	2.00	3.00	1.00	3.00	1.00	3.00	4.00	4.00	2.00	3.00	3.00	3.00	4.00	3.00	1.90	1.95	3.00	4.00	3.10	3.05	3.35	1.75	1.00	2.00	2.65	3.90	4.50	1.95	4.10	2.15	4.05	4.20	1.05
Panchita	4.00	2.00	2.00	1.07	1.13	4.00	2.00	1.00	3.00	1.00	4.00	3.00	4.00	3.00	5.00	3.00	4.00	3.00	3.00	1.40	1.60	3.00	2.00	1.80	2.00	2.05	1.80	3.00	3.00	1.15	4.50	4.65	1.85	3.75	1.80	3.95	3.40	1.10
Aromdanga	1.00	3.00	3.00	3.35	3.25	2.00	5.00	1.00	5.00	1.00	2.00	1.00	2.00	4.00	3.00	1.00	2.00	3.00	3.00	1.95	1.95	3.00	2.00	2.65	2.55	2.85	3.30	4.00	2.00	3.35	4.65	1.85	2.10	2.75	2.55	3.55	3.40	1.35
Gopalnagar	3.00	4.00	4.00	2.21	2.14	3.00	4.00	1.00	4.00	1.00	3.00	3.00	2.00	1.00	3.00	3.00	3.00	3.00	4.00	1.17	1.75	2.00	2.00	1.46	2.15	2.25	2.00	2.00	2.00	2.08	4.29	3.79	1.50	2.45	1.74	3.70	2.85	1.00
Manigram	3.00	2.00	3.00	3.47	3.50	1.00	2.00	1.00	2.00	1.00	2.00	4.00	4.00	4.00	3.00	3.00	5.00	2.00	4.00	2.17	2.22	4.00	4.00	3.53	4.00	3.55	1.55	3.00	3.00	1.80	4.55	3.17	3.25	3.15	2.40	3.60	3.30	1.25
Madhabpur	4.00	5.00	4.00	1.55	2.60	3.00	2.00	1.00	2.00	1.00	5.00	3.00	4.00	4.00	3.00	3.00	2.00	4.00	3.00	3.30	3.35	5.00	4.00	3.05	2.65	3.30	1.50	4.00	4.00	1.50	5.00	4.25	1.60	4.15	2.35	4.10	3.95	1.00

Annexure 6.4.2 Normalization of the decision matrix

Wetland	Indicator																																				
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
Berkrishnapur	0.14	0.10	0.15	0.09	0.09	0.21	0.10	0.45	0.10	0.45	0.10	0.14	0.09	0.14	0.09	0.16	0.10	0.10	0.13	0.08	0.07	0.09	0.14	0.15	0.15	0.15	0.12	0.19	0.20	0.12	0.09	0.10	0.11	0.16	0.18	0.14	0.14	0.15
Panchpota	0.18	0.14	0.05	0.13	0.17	0.11	0.15	0.09	0.14	0.09	0.14	0.19	0.18	0.10	0.14	0.16	0.14	0.19	0.13	0.15	0.14	0.14	0.19	0.17	0.16	0.16	0.13	0.05	0.10	0.19	0.13	0.18	0.14	0.17	0.14	0.15	0.17	0.13
Panchita	0.18	0.10	0.10	0.07	0.07	0.21	0.10	0.09	0.14	0.09	0.19	0.14	0.18	0.14	0.23	0.16	0.19	0.14	0.13	0.11	0.12	0.14	0.10	0.10	0.10	0.10	0.13	0.14	0.15	0.08	0.15	0.19	0.13	0.16	0.11	0.15	0.14	0.14
Aromdanga	0.05	0.14	0.15	0.22	0.19	0.11	0.25	0.09	0.24	0.09	0.10	0.05	0.09	0.19	0.14	0.05	0.10	0.14	0.13	0.15	0.14	0.14	0.10	0.15	0.13	0.14	0.24	0.19	0.10	0.24	0.16	0.07	0.15	0.11	0.16	0.13	0.14	0.17
Gopalnagar	0.14	0.19	0.20	0.15	0.13	0.16	0.20	0.09	0.19	0.09	0.14	0.14	0.09	0.05	0.14	0.16	0.14	0.14	0.17	0.09	0.13	0.09	0.10	0.08	0.11	0.11	0.15	0.10	0.10	0.15	0.15	0.15	0.11	0.10	0.11	0.14	0.12	0.13
Manigram	0.14	0.10	0.15	0.23	0.21	0.05	0.10	0.09	0.10	0.09	0.10	0.19	0.18	0.19	0.14	0.16	0.24	0.10	0.17	0.17	0.16	0.18	0.19	0.19	0.21	0.17	0.11	0.14	0.15	0.13	0.15	0.13	0.24	0.13	0.15	0.14	0.13	0.16
Madhabpur	0.18	0.24	0.20	0.10	0.15	0.16	0.10	0.09	0.10	0.09	0.24	0.14	0.18	0.19	0.14	0.16	0.10	0.19	0.13	0.26	0.24	0.23	0.19	0.17	0.14	0.16	0.11	0.19	0.20	0.11	0.17	0.17	0.12	0.17	0.15	0.15	0.16	0.13
Sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Annexure 6.4.3 Computation of entropy, degree of diversification and indicator weight

Wetland	Indicator																																					
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	**Sum**
Berkrishnapur	-0.27	-0.22	-0.28	-0.22	-0.21	-0.33	-0.23	-0.36	-0.22	-0.36	-0.22	-0.28	-0.22	-0.28	-0.22	-0.29	-0.22	-0.22	-0.27	-0.20	-0.19	-0.22	-0.28	-0.28	-0.29	-0.28	-0.26	-0.32	-0.32	-0.25	-0.21	-0.23	-0.24	-0.29	-0.31	-0.27	-0.27	-0.29	
Panchpota	-0.31	-0.28	-0.15	-0.27	-0.30	-0.24	-0.28	-0.22	-0.28	-0.22	-0.28	-0.32	-0.31	-0.22	-0.27	-0.29	-0.28	-0.32	-0.27	-0.28	-0.28	-0.27	-0.32	-0.30	-0.29	-0.30	-0.26	-0.14	-0.23	-0.31	-0.27	-0.31	-0.28	-0.30	-0.27	-0.29	-0.30	-0.27	
Panchita	-0.31	-0.22	-0.23	-0.19	-0.18	-0.33	-0.23	-0.22	-0.28	-0.22	-0.32	-0.28	-0.31	-0.28	-0.34	-0.29	-0.32	-0.28	-0.27	-0.24	-0.25	-0.27	-0.22	-0.23	-0.23	-0.23	-0.27	-0.28	-0.28	-0.20	-0.29	-0.31	-0.27	-0.29	-0.25	-0.28	-0.27	-0.27	
Aromdanga	-0.14	-0.28	-0.28	-0.33	-0.32	-0.24	-0.35	-0.22	-0.34	-0.22	-0.22	-0.14	-0.22	-0.32	-0.27	-0.15	-0.22	-0.28	-0.27	-0.29	-0.28	-0.27	-0.22	-0.28	-0.27	-0.27	-0.34	-0.32	-0.23	-0.34	-0.29	-0.19	-0.29	-0.25	-0.29	-0.27	-0.27	-0.30	
Gopalnagar	-0.27	-0.32	-0.32	-0.28	-0.26	-0.29	-0.32	-0.22	-0.32	-0.22	-0.28	-0.28	-0.22	-0.14	-0.27	-0.29	-0.28	-0.28	-0.30	-0.22	-0.26	-0.22	-0.22	-0.20	-0.24	-0.24	-0.28	-0.22	-0.23	-0.28	-0.28	-0.29	-0.24	-0.23	-0.24	-0.27	-0.25	-0.26	
Manigram	-0.27	-0.22	-0.28	-0.34	-0.33	-0.15	-0.23	-0.22	-0.22	-0.22	-0.22	-0.32	-0.31	-0.32	-0.27	-0.29	-0.34	-0.22	-0.30	-0.30	-0.29	-0.31	-0.32	-0.32	-0.33	-0.30	-0.25	-0.28	-0.28	-0.26	-0.29	-0.26	-0.34	-0.27	-0.29	-0.27	-0.27	-0.29	
Madhabpur	-0.31	-0.34	-0.32	-0.23	-0.29	-0.29	-0.23	-0.22	-0.22	-0.22	-0.34	-0.28	-0.31	-0.32	-0.27	-0.29	-0.22	-0.32	-0.27	-0.35	-0.34	-0.34	-0.32	-0.30	-0.27	-0.29	-0.24	-0.32	-0.32	-0.24	-0.30	-0.30	-0.25	-0.30	-0.28	-0.29	-0.29	-0.26	
Entropy	-1.89	-1.89	-1.88	-1.86	-1.88	-1.87	-1.87	-1.67	-1.89	-1.67	-1.89	-1.89	-1.89	-1.87	-1.91	-1.90	-1.89	-1.91	-1.94	-1.87	-1.89	-1.90	-1.90	-1.91	-1.92	-1.93	-1.91	-1.87	-1.90	-1.89	-1.93	-1.90	-1.91	-1.93	-1.93	-1.94	-1.94	-1.94	
Entropy value	0.97	0.97	0.96	0.96	0.97	0.96	0.96	0.86	0.97	0.86	0.97	0.97	0.97	0.96	0.98	0.98	0.97	0.98	1.00	0.96	0.97	0.98	0.98	0.98	0.99	0.99	0.98	0.96	0.98	0.97	0.99	0.98	0.98	0.99	0.99	1.00	1.00	1.00	
Degree of diversification	0.03	0.03	0.04	0.04	0.03	0.04	0.04	0.14	0.03	0.14	0.03	0.03	0.03	0.04	0.02	0.02	0.03	0.02	0.00	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.02	0.04	0.02	0.03	0.01	0.02	0.02	0.01	0.01	0.00	0.00	0.00	**1.12**
Weight	**0.028**	**0.028**	**0.031**	**0.037**	**0.029**	**0.036**	**0.033**	**0.128**	**0.028**	**0.128**	**0.028**	**0.026**	**0.024**	**0.034**	**0.015**	**0.019**	**0.028**	**0.015**	**0.004**	**0.033**	**0.025**	**0.022**	**0.022**	**0.017**	**0.011**	**0.008**	**0.018**	**0.034**	**0.019**	**0.026**	**0.008**	**0.019**	**0.017**	**0.008**	**0.007**	**0.001**	**0.003**	**0.003**	**1.000**

Annexure 6.4.4 Evaluation matrix with indicator weight

Wetland	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
	Indicator																																					
Berkrishnapur		3.00	2.00	3.00	1.40	1.45	4.00	2.00	5.00	2.00	5.00	2.00	3.00	2.00	3.00	2.00	3.00	2.00	2.00	3.00	1.00	1.00	2.00	3.00	2.65	3.00	3.05	1.65	4.00	4.00	1.65	2.60	2.50	1.50	3.80	2.90	3.70	3.40
Panchpota		4.00	3.00	1.00	1.95	2.90	2.00	3.00	1.00	3.00	1.00	3.00	4.00	4.00	2.00	3.00	3.00	3.00	4.00	3.00	1.90	1.95	3.00	4.00	3.10	3.05	3.35	1.75	1.00	2.00	2.65	3.90	4.50	1.95	4.10	2.15	4.05	4.20
Panchita		4.00	2.00	2.00	1.07	1.13	4.00	2.00	1.00	3.00	1.00	4.00	3.00	4.00	3.00	5.00	3.00	4.00	3.00	3.00	1.40	1.60	3.00	2.00	1.80	2.00	2.05	1.80	3.00	3.00	1.15	4.50	4.65	1.85	3.75	1.80	3.95	3.40
Aromdanga		1.00	3.00	3.00	3.35	3.25	2.00	5.00	1.00	5.00	1.00	2.00	1.00	2.00	4.00	3.00	1.00	2.00	3.00	3.00	1.95	1.95	3.00	2.00	2.65	2.55	2.85	3.30	4.00	2.00	3.35	4.65	1.85	2.10	2.75	2.55	3.55	3.40
Gopalnagar		3.00	4.00	4.00	2.21	2.14	3.00	4.00	1.00	4.00	1.00	3.00	3.00	2.00	1.00	3.00	3.00	3.00	3.00	4.00	1.17	1.75	2.00	2.00	1.46	2.15	2.25	2.00	2.00	2.00	2.08	4.29	3.79	1.50	2.45	1.74	3.70	2.85
Manigram		3.00	2.00	3.00	3.47	3.50	1.00	2.00	1.00	2.00	1.00	2.00	4.00	4.00	4.00	3.00	3.00	5.00	2.00	4.00	2.17	2.22	4.00	4.00	3.53	4.00	3.55	1.55	3.00	3.00	1.80	4.55	3.17	3.25	3.15	2.40	3.60	3.30
Madhabpur		4.00	5.00	4.00	1.55	2.60	3.00	2.00	1.00	2.00	1.00	5.00	3.00	4.00	4.00	3.00	3.00	2.00	4.00	3.00	3.30	3.35	5.00	4.00	3.05	2.65	3.30	1.50	4.00	4.00	1.50	5.00	4.25	1.60	4.15	2.35	4.10	3.95
Weight		**0.028**	**0.028**	**0.031**	**0.037**	**0.029**	**0.036**	**0.033**	**0.128**	**0.028**	**0.128**	**0.028**	**0.026**	**0.024**	**0.034**	**0.015**	**0.019**	**0.028**	**0.015**	**0.004**	**0.033**	**0.025**	**0.022**	**0.022**	**0.017**	**0.011**	**0.008**	**0.018**	**0.034**	**0.019**	**0.026**	**0.008**	**0.019**	**0.017**	**0.008**	**0.007**	**0.001**	**0.003**

Annexure 6.4.5 Vector normalization

Wetland	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
	Indicator																																					
Berkrishnapur	0.344	0.237	0.375	0.229	0.214	0.521	0.246	0.898	0.237	0.898	0.237	0.361	0.229	0.356	0.232	0.405	0.237	0.244	0.342	0.191	0.181	0.229	0.361	0.372	0.399	0.389	0.309	0.475	0.508	0.291	0.230	0.258	0.277	0.410	0.476	0.367	0.365	0.397
Panchpota	0.489	0.367	0.135	0.327	0.438	0.305	0.381	0.408	0.367	0.408	0.367	0.516	0.471	0.254	0.359	0.442	0.367	0.504	0.364	0.370	0.360	0.354	0.516	0.469	0.443	0.464	0.344	0.135	0.295	0.489	0.354	0.480	0.375	0.485	0.402	0.432	0.484	0.378
Panchita	0.560	0.263	0.272	0.189	0.190	0.641	0.275	0.447	0.394	0.447	0.525	0.452	0.535	0.394	0.640	0.493	0.525	0.438	0.391	0.294	0.316	0.378	0.302	0.308	0.324	0.321	0.377	0.408	0.463	0.243	0.437	0.566	0.384	0.507	0.367	0.467	0.447	0.428
Aromdanga	0.169	0.408	0.424	0.605	0.556	0.415	0.714	0.456	0.714	0.456	0.308	0.169	0.316	0.571	0.500	0.188	0.308	0.486	0.424	0.428	0.406	0.408	0.316	0.476	0.435	0.470	0.745	0.595	0.347	0.729	0.502	0.273	0.471	0.430	0.556	0.474	0.500	0.573
Gopalnagar	0.512	0.595	0.623	0.501	0.439	0.682	0.813	0.502	0.813	0.502	0.485	0.512	0.332	0.174	0.575	0.574	0.485	0.554	0.623	0.282	0.397	0.298	0.332	0.297	0.406	0.418	0.672	0.370	0.369	0.653	0.535	0.579	0.380	0.423	0.453	0.559	0.482	0.509
Manigram	0.592	0.370	0.597	0.907	0.797	0.305	0.695	0.561	0.692	0.561	0.368	0.791	0.701	0.703	0.696	0.696	0.921	0.442	0.794	0.544	0.548	0.622	0.702	0.749	0.825	0.725	0.693	0.595	0.593	0.743	0.670	0.591	0.885	0.597	0.699	0.654	0.634	0.716
Madhabpur	0.979	0.992	0.987	0.900	0.960	0.951	0.914	0.648	0.908	0.648	0.989	0.967	0.980	0.980	0.956	0.966	0.936	0.978	0.969	0.980	0.981	0.990	0.982	0.965	0.957	0.970	0.844	0.977	0.979	0.843	0.988	0.981	0.902	0.976	0.932	0.978	0.975	0.743

Annexure 6.4.6 Weighted normalized matrix

Wetland	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
	Indicator																																					
Berkrishnapur	0.010	0.007	0.012	0.009	0.006	0.019	0.008	0.115	0.007	0.115	0.007	0.010	0.005	0.012	0.003	0.008	0.007	0.004	0.001	0.006	0.005	0.005	0.008	0.006	0.004	0.003	0.006	0.016	0.010	0.008	0.002	0.005	0.005	0.003	0.003	0.000	0.001	0.001
Panchpota	0.014	0.010	0.004	0.012	0.013	0.011	0.013	0.052	0.010	0.052	0.010	0.014	0.011	0.009	0.005	0.009	0.010	0.007	0.002	0.012	0.009	0.008	0.012	0.008	0.005	0.004	0.006	0.005	0.006	0.013	0.003	0.009	0.006	0.004	0.003	0.000	0.002	0.001
Panchita	0.016	0.007	0.009	0.007	0.005	0.023	0.009	0.057	0.011	0.057	0.015	0.012	0.013	0.013	0.010	0.010	0.015	0.007	0.002	0.010	0.008	0.008	0.007	0.005	0.004	0.003	0.007	0.014	0.009	0.006	0.003	0.011	0.007	0.004	0.002	0.000	0.001	0.001
Aromdanga	0.005	0.011	0.013	0.023	0.016	0.015	0.024	0.059	0.020	0.059	0.009	0.004	0.008	0.019	0.008	0.004	0.009	0.007	0.002	0.014	0.010	0.009	0.007	0.008	0.005	0.004	0.013	0.020	0.007	0.019	0.004	0.005	0.008	0.003	0.004	0.000	0.002	0.002
Gopalnagar	0.014	0.017	0.020	0.019	0.013	0.024	0.027	0.064	0.023	0.064	0.014	0.013	0.008	0.006	0.009	0.011	0.014	0.008	0.003	0.009	0.010	0.007	0.007	0.005	0.005	0.003	0.012	0.012	0.007	0.017	0.004	0.011	0.007	0.003	0.003	0.000	0.002	0.001
Manigram	0.016	0.010	0.019	0.034	0.023	0.011	0.023	0.072	0.019	0.072	0.010	0.021	0.017	0.024	0.010	0.014	0.026	0.007	0.003	0.018	0.014	0.014	0.016	0.013	0.009	0.006	0.012	0.020	0.012	0.019	0.005	0.011	0.015	0.005	0.005	0.000	0.002	0.002
Madhabpur	0.027	0.028	0.031	0.034	0.028	0.034	0.030	0.083	0.025	0.083	0.028	0.025	0.023	0.033	0.014	0.019	0.026	0.015	0.004	0.032	0.025	0.022	0.022	0.016	0.011	0.008	0.015	0.033	0.019	0.022	0.007	0.019	0.016	0.008	0.006	0.001	0.003	0.002

Annexure 6.4.7 Computation of ideal best and ideal worst value

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
Ideal value (V+)	0.027	0.028	0.031	0.034	0.028	0.034	0.030	0.115	0.025	0.115	0.028	0.025	0.023	0.033	0.014	0.019	0.026	0.015	0.004	0.032	0.025	0.022	0.022	0.016	0.011	0.008	0.015	0.033	0.019	0.022	0.007	0.019	0.016	0.008	0.006	0.001	0.003	0.002
Worst value (V-)	0.005	0.007	0.004	0.007	0.005	0.011	0.008	0.052	0.007	0.052	0.007	0.004	0.005	0.006	0.003	0.004	0.007	0.004	0.001	0.006	0.005	0.005	0.007	0.005	0.004	0.003	0.006	0.005	0.006	0.006	0.002	0.005	0.005	0.003	0.002	0.000	0.001	0.001

Annexure 6.4.8 Calculation of Euclidean distance from ideal best and worst, performance score and ranking of wetland, 2020

Wetland	Si+	Si-	Pi	Rank
Berkrishnapur	0.09	0.09	0.50	2
Panchpota	0.12	0.03	0.18	7
Panchita	0.12	0.03	0.23	6
Aromdanga	0.11	0.05	0.29	5
Gopalnagar	0.10	0.05	0.33	4
Manigram	0.08	0.07	0.48	3
Madhabpur	0.05	0.11	0.72	1

Annexure 6.5.1 Decision matrix (Valid score of each indicator for state system, 2020)

Wetland	Indicator																																							
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40
Berkrishnapur	3.00	2.00	3.00	3.00	3.00	4.00	2.00	4.00	4.00	1.00	1.00	4.00	1.00	1.00	3.00	3.00	1.00	5.00	2.00	4.00	5.00	5.00	5.00	4.00	3.00	5.00	2.00	4.00	1.00	2.90	3.35	3.20	3.40	2.65	3.65	4.25	4.30	1.60	2.05	2.45
Panchpota	4.00	4.00	4.00	3.00	1.00	4.00	2.00	3.00	5.00	4.00	4.00	5.00	4.00	1.00	5.00	3.00	4.00	1.00	3.00	4.00	4.00	1.00	2.00	5.00	1.00	1.00	3.00	3.00	3.00	3.70	4.10	3.00	3.25	1.90	3.50	4.30	4.60	2.25	2.50	2.45
Panchita	1.00	3.00	3.00	3.00	4.00	4.00	4.00	3.00	3.00	5.00	5.00	4.00	5.00	1.00	4.00	5.00	2.00	4.00	4.00	3.00	2.00	4.00	4.00	3.00	4.00	5.00	2.00	3.00	4.00	3.35	4.40	4.05	4.65	1.70	3.95	3.70	4.05	3.55	4.10	4.65
Aromdanga	3.00	2.00	2.00	4.00	3.00	1.00	2.00	5.00	4.00	5.00	5.00	4.00	5.00	1.00	4.00	3.00	2.00	5.00	2.00	4.00	2.00	5.00	4.00	3.00	3.00	4.00	2.00	4.00	2.00	4.05	3.40	2.50	2.15	2.40	1.40	3.68	3.40	2.40	2.10	3.20
Gopalnagar	4.00	1.00	3.00	2.00	5.00	3.00	2.00	3.00	4.00	5.00	5.00	4.00	5.00	1.50	5.00	5.00	3.00	5.00	3.00	3.00	3.00	5.00	5.00	3.00	3.00	5.00	3.00	4.00	4.00	4.05	4.35	3.90	4.26	1.75	1.60	4.55	4.75	4.00	4.35	4.20
Manigram	3.00	4.00	4.00	2.00	2.00	3.00	3.00	2.00	4.00	4.00	4.00	5.00	5.00	2.60	4.00	4.00	3.00	4.00	2.00	3.00	2.00	4.00	4.00	3.00	4.00	4.00	3.00	1.00	4.00	4.00	3.50	2.55	3.45	1.20	4.60	4.60	4.15	2.55	2.80	3.10
Madhabpur	2.00	4.00	1.00	5.00	2.00	2.00	5.00	2.00	3.00	5.00	5.00	2.00	5.00	3.60	2.00	4.00	3.00	5.00	5.00	2.00	2.00	5.00	4.00	2.00	3.00	5.00	5.00	2.00	3.00	3.90	3.45	2.60	5.00	1.75	3.85	4.65	4.15	2.50	2.30	3.25

Annexure 6.5.2 Normalization of the decision matrix

Wetland	Indicator																																							
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40
Berkrishnapur	0.15	0.10	0.15	0.14	0.15	0.19	0.10	0.18	0.15	0.03	0.03	0.14	0.03	0.09	0.11	0.11	0.06	0.17	0.10	0.17	0.25	0.17	0.18	0.17	0.14	0.17	0.10	0.19	0.05	0.11	0.13	0.15	0.13	0.20	0.16	0.14	0.15	0.08	0.10	0.11
Panchpota	0.20	0.20	0.20	0.14	0.05	0.19	0.10	0.14	0.19	0.14	0.14	0.18	0.13	0.09	0.19	0.11	0.22	0.03	0.14	0.17	0.20	0.03	0.07	0.22	0.05	0.03	0.15	0.14	0.14	0.14	0.15	0.14	0.12	0.14	0.16	0.14	0.16	0.12	0.12	0.11
Panchita	0.05	0.15	0.15	0.14	0.20	0.19	0.20	0.14	0.11	0.17	0.17	0.14	0.17	0.09	0.15	0.19	0.11	0.14	0.19	0.13	0.10	0.14	0.14	0.13	0.19	0.17	0.10	0.14	0.19	0.13	0.17	0.19	0.18	0.13	0.18	0.12	0.14	0.19	0.20	0.20
Aromdanga	0.15	0.10	0.10	0.18	0.15	0.05	0.10	0.23	0.15	0.17	0.17	0.14	0.17	0.09	0.15	0.11	0.11	0.17	0.10	0.17	0.10	0.17	0.14	0.13	0.14	0.14	0.10	0.19	0.10	0.16	0.13	0.11	0.08	0.18	0.06	0.12	0.12	0.13	0.10	0.14
Gopalnagar	0.20	0.05	0.15	0.09	0.25	0.14	0.10	0.14	0.15	0.17	0.17	0.14	0.17	0.13	0.19	0.19	0.17	0.17	0.14	0.13	0.15	0.17	0.18	0.13	0.14	0.17	0.15	0.19	0.19	0.16	0.16	0.18	0.16	0.13	0.07	0.15	0.16	0.21	0.22	0.18
Manigram	0.15	0.20	0.20	0.09	0.10	0.14	0.15	0.09	0.15	0.14	0.14	0.18	0.17	0.22	0.15	0.15	0.17	0.14	0.10	0.13	0.10	0.14	0.14	0.13	0.19	0.14	0.15	0.05	0.19	0.15	0.13	0.12	0.13	0.09	0.20	0.15	0.14	0.14	0.14	0.13
Madhabpur	0.10	0.20	0.05	0.23	0.10	0.10	0.25	0.09	0.11	0.17	0.17	0.07	0.17	0.31	0.07	0.15	0.17	0.17	0.24	0.09	0.10	0.17	0.14	0.09	0.14	0.17	0.25	0.10	0.14	0.15	0.13	0.12	0.19	0.13	0.17	0.16	0.14	0.13	0.11	0.14
Sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Annexure 6.5.3 Computation of entropy, degree of diversification and indicator weight

Wetland	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
Berkrishnapur	-0.28	-0.23	-0.28	-0.27	-0.28	-0.32	-0.23	-0.31	-0.28	-0.12	-0.12	-0.28	-0.11	-0.21	-0.24	-0.24	-0.16	-0.30	-0.22	-0.30
Panchpota	-0.32	-0.32	-0.32	-0.27	-0.15	-0.32	-0.23	-0.27	-0.31	-0.27	-0.27	-0.31	-0.27	-0.21	-0.31	-0.24	-0.33	-0.12	-0.28	-0.30
Panchita	-0.15	-0.28	-0.28	-0.27	-0.32	-0.32	-0.32	-0.27	-0.24	-0.30	-0.30	-0.28	-0.30	-0.21	-0.28	-0.31	-0.24	-0.27	-0.32	-0.27
Aromdanga	-0.28	-0.23	-0.23	-0.31	-0.28	-0.14	-0.23	-0.34	-0.28	-0.30	-0.30	-0.28	-0.30	-0.21	-0.28	-0.24	-0.24	-0.30	-0.22	-0.30
Gopalnagar	-0.32	-0.15	-0.28	-0.22	-0.35	-0.28	-0.23	-0.27	-0.28	-0.30	-0.30	-0.28	-0.30	-0.26	-0.31	-0.31	-0.30	-0.30	-0.28	-0.27
Manigram	-0.28	-0.32	-0.32	-0.22	-0.23	-0.28	-0.28	-0.22	-0.28	-0.27	-0.27	-0.31	-0.30	-0.33	-0.28	-0.28	-0.30	-0.27	-0.22	-0.27
Madhabpur	-0.23	-0.32	-0.15	-0.34	-0.23	-0.22	-0.35	-0.22	-0.24	-0.30	-0.30	-0.19	-0.30	-0.36	-0.19	-0.28	-0.30	-0.30	-0.34	-0.21
Entropy	-1.88	-1.86	-1.88	-1.90	-1.85	-1.87	-1.87	-1.90	-1.93	-1.87	-1.87	-1.92	-1.88	-1.80	-1.91	-1.92	-1.88	-1.87	-1.89	-1.92
Entropy value	0.96	0.96	0.96	0.98	0.95	0.96	0.96	0.98	0.99	0.96	0.96	0.98	0.96	0.93	0.98	0.99	0.97	0.96	0.97	0.99
Degree of diversification	0.04	0.04	0.04	0.02	0.05	0.04	0.04	0.02	0.01	0.04	0.04	0.02	0.04	0.07	0.02	0.01	0.03	0.04	0.03	0.01
Weight	**0.033**	**0.041**	**0.033**	**0.023**	**0.048**	**0.036**	**0.035**	**0.023**	**0.007**	**0.034**	**0.034**	**0.015**	**0.034**	**0.070**	**0.017**	**0.011**	**0.033**	**0.034**	**0.029**	**0.012**

Wetland	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40	Sum
Berkrishnapur	-0.35	-0.30	-0.31	-0.30	-0.28	-0.30	-0.23	-0.32	-0.14	-0.24	-0.26	-0.28	-0.27	-0.32	-0.29	-0.28	-0.28	-0.21	-0.23	-0.24	
Panchpota	-0.32	-0.12	-0.19	-0.33	-0.14	-0.12	-0.28	-0.28	-0.28	-0.28	-0.29	-0.27	-0.26	-0.28	-0.29	-0.28	-0.29	-0.25	-0.26	-0.24	
Panchita	-0.23	-0.27	-0.28	-0.27	-0.32	-0.30	-0.23	-0.28	-0.32	-0.26	-0.30	-0.31	-0.31	-0.26	-0.31	-0.26	-0.27	-0.31	-0.32	-0.32	
Aromdanga	-0.23	-0.30	-0.28	-0.27	-0.28	-0.27	-0.23	-0.32	-0.22	-0.29	-0.26	-0.25	-0.21	-0.31	-0.17	-0.26	-0.25	-0.26	-0.24	-0.27	
Gopalnagar	-0.28	-0.30	-0.31	-0.27	-0.28	-0.30	-0.28	-0.32	-0.32	-0.29	-0.30	-0.31	-0.30	-0.27	-0.19	-0.29	-0.29	-0.33	-0.33	-0.31	
Manigram	-0.23	-0.27	-0.28	-0.27	-0.32	-0.27	-0.28	-0.14	-0.32	-0.29	-0.27	-0.25	-0.27	-0.22	-0.32	-0.29	-0.28	-0.27	-0.27	-0.27	
Madhabpur	-0.23	-0.30	-0.28	-0.21	-0.28	-0.30	-0.35	-0.22	-0.28	-0.28	-0.27	-0.25	-0.32	-0.27	-0.30	-0.29	-0.28	-0.27	-0.25	-0.27	
Entropy	-1.87	-1.87	-1.92	-1.91	-1.89	-1.87	-1.89	-1.87	-1.87	-1.94	-1.94	-1.93	-1.92	-1.92	-1.88	-1.94	-1.94	-1.91	-1.90	-1.92	
Entropy value	0.96	0.96	0.98	0.98	0.97	0.96	0.97	0.96	0.96	1.00	1.00	0.99	0.98	0.99	0.96	1.00	1.00	0.98	0.98	0.99	
Degree of diversification	0.04	0.04	0.02	0.02	0.03	0.04	0.03	0.04	0.04	0.00	0.00	0.01	0.02	0.01	0.04	0.00	0.00	0.02	0.02	0.01	**1.06**
Weight	**0.035**	**0.034**	**0.015**	**0.017**	**0.028**	**0.034**	**0.027**	**0.036**	**0.036**	**0.003**	**0.003**	**0.009**	**0.015**	**0.013**	**0.034**	**0.002**	**0.002**	**0.019**	**0.021**	**0.013**	**1.00**

Annexure 6.5.4 Evaluation matrix with indicator weight

Wetland	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
Berkrishnapur	3.00	2.00	3.00	3.00	3.00	4.00	2.00	4.00	4.00	1.00	1.00	4.00	1.00	1.00	3.00	3.00	1.00	5.00	2.00	4.00
Panchpota	4.00	4.00	4.00	3.00	1.00	4.00	2.00	3.00	5.00	4.00	4.00	5.00	4.00	1.00	5.00	3.00	4.00	1.00	3.00	4.00
Panchita	1.00	3.00	3.00	3.00	4.00	4.00	4.00	3.00	3.00	5.00	5.00	4.00	5.00	1.00	4.00	5.00	2.00	4.00	4.00	3.00
Aromdanga	3.00	2.00	2.00	4.00	3.00	1.00	2.00	5.00	4.00	5.00	5.00	4.00	5.00	1.00	4.00	3.00	2.00	5.00	2.00	4.00
Gopalnagar	4.00	1.00	3.00	2.00	5.00	3.00	2.00	3.00	4.00	5.00	5.00	4.00	5.00	1.50	5.00	5.00	3.00	5.00	3.00	3.00
Manigram	3.00	4.00	4.00	2.00	2.00	3.00	3.00	2.00	4.00	4.00	4.00	5.00	5.00	2.60	4.00	4.00	3.00	4.00	2.00	3.00
Madhabpur	2.00	4.00	1.00	5.00	2.00	2.00	5.00	2.00	3.00	5.00	5.00	2.00	5.00	3.60	2.00	4.00	3.00	5.00	5.00	2.00
Weight	**0.033**	**0.041**	**0.033**	**0.023**	**0.048**	**0.036**	**0.035**	**0.023**	**0.007**	**0.034**	**0.034**	**0.015**	**0.034**	**0.070**	**0.017**	**0.011**	**0.033**	**0.034**	**0.029**	**0.012**

Wetland	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40
Berkrishnapur	5.00	5.00	5.00	4.00	3.00	5.00	2.00	4.00	1.00	2.90	3.35	3.20	3.40	2.65	3.65	4.25	4.30	1.60	2.05	2.45
Panchpota	4.00	1.00	2.00	5.00	1.00	1.00	3.00	3.00	3.00	3.70	4.10	3.00	3.25	1.90	3.50	4.30	4.60	2.25	2.50	2.45
Panchita	2.00	4.00	4.00	3.00	4.00	5.00	2.00	3.00	4.00	3.35	4.40	4.05	4.65	1.70	3.95	3.70	4.05	3.55	4.10	4.65
Aromdanga	2.00	5.00	4.00	3.00	3.00	4.00	2.00	4.00	2.00	4.05	3.40	2.50	2.15	2.40	1.40	3.68	3.40	2.40	2.10	3.20
Gopalnagar	3.00	5.00	5.00	3.00	3.00	5.00	3.00	4.00	4.00	4.05	4.35	3.90	4.26	1.75	1.60	4.55	4.75	4.00	4.35	4.20
Manigram	2.00	4.00	4.00	3.00	4.00	4.00	3.00	1.00	4.00	4.00	3.50	2.55	3.45	1.20	4.60	4.60	4.15	2.55	2.80	3.10
Madhabpur	2.00	5.00	4.00	2.00	3.00	5.00	5.00	2.00	3.00	3.90	3.45	2.60	5.00	1.75	3.85	4.65	4.15	2.50	2.30	3.25
Weight	**0.035**	**0.034**	**0.015**	**0.017**	**0.028**	**0.034**	**0.027**	**0.036**	**0.036**	**0.003**	**0.003**	**0.009**	**0.015**	**0.013**	**0.034**	**0.002**	**0.002**	**0.019**	**0.021**	**0.013**

Annexure 6.5.5 Vector normalization

Wetland	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
Berkrishnapur	0.375	0.246	0.375	0.344	0.364	0.475	0.246	0.459	0.387	0.087	0.087	0.368	0.084	0.196	0.285	0.287	0.139	0.434	0.237	0.450
Panchpota	0.539	0.508	0.539	0.367	0.130	0.539	0.254	0.387	0.524	0.348	0.348	0.495	0.337	0.200	0.495	0.300	0.560	0.096	0.367	0.504
Panchita	0.160	0.442	0.480	0.394	0.525	0.641	0.525	0.420	0.369	0.464	0.464	0.456	0.447	0.204	0.456	0.524	0.338	0.387	0.525	0.438
Aromdanga	0.486	0.329	0.364	0.571	0.462	0.208	0.308	0.770	0.529	0.524	0.524	0.512	0.500	0.208	0.512	0.369	0.359	0.524	0.308	0.647
Gopalnagar	0.737	0.173	0.584	0.347	0.868	0.632	0.324	0.720	0.621	0.615	0.615	0.594	0.577	0.319	0.743	0.661	0.574	0.615	0.485	0.633
Manigram	0.818	0.701	0.952	0.369	0.689	0.804	0.511	0.685	0.791	0.622	0.622	0.919	0.705	0.584	0.883	0.702	0.698	0.622	0.368	0.812
Madhabpur	0.923	0.981	0.746	0.986	0.929	0.897	0.990	0.883	0.956	0.988	0.988	0.908	0.989	0.994	0.913	0.982	0.969	0.988	0.989	0.889

Wetland	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40
Berkrishnapur	0.615	0.434	0.460	0.444	0.361	0.434	0.250	0.475	0.119	0.294	0.332	0.381	0.334	0.511	0.404	0.377	0.385	0.216	0.257	0.271
Panchpota	0.625	0.096	0.207	0.620	0.129	0.096	0.387	0.405	0.359	0.392	0.430	0.387	0.339	0.427	0.423	0.411	0.447	0.311	0.324	0.282
Panchita	0.400	0.387	0.424	0.474	0.521	0.483	0.280	0.442	0.512	0.386	0.512	0.566	0.516	0.422	0.527	0.388	0.439	0.517	0.562	0.557
Aromdanga	0.433	0.524	0.467	0.537	0.457	0.441	0.292	0.656	0.298	0.506	0.460	0.423	0.278	0.651	0.220	0.419	0.410	0.408	0.347	0.461
Gopalnagar	0.712	0.615	0.661	0.631	0.513	0.615	0.456	0.865	0.624	0.585	0.661	0.727	0.573	0.618	0.257	0.570	0.627	0.744	0.766	0.682
Manigram	0.669	0.622	0.702	0.807	0.793	0.621	0.512	0.423	0.794	0.712	0.704	0.684	0.564	0.530	0.760	0.700	0.702	0.703	0.759	0.682
Madhabpur	0.884	0.988	0.980	0.886	0.967	0.988	0.993	0.893	0.974	0.979	0.969	0.946	0.989	0.863	0.978	0.986	0.980	0.957	0.947	0.969

Annexure 6.5.6 Weighted normalized matrix

Wetland	Indicator																			
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
Berkrishnapur	0.012	0.010	0.012	0.008	0.017	0.017	0.009	0.011	0.003	0.003	0.003	0.005	0.003	0.014	0.005	0.003	0.005	0.015	0.007	0.005
Panchpota	0.018	0.021	0.018	0.009	0.006	0.019	0.009	0.009	0.004	0.012	0.012	0.007	0.012	0.014	0.009	0.003	0.018	0.003	0.011	0.006
Panchita	0.005	0.018	0.016	0.009	0.025	0.023	0.018	0.010	0.002	0.016	0.016	0.007	0.015	0.014	0.008	0.006	0.011	0.013	0.015	0.005
Aromdanga	0.016	0.014	0.012	0.013	0.022	0.007	0.011	0.018	0.004	0.018	0.018	0.008	0.017	0.015	0.009	0.004	0.012	0.018	0.009	0.008
Gopalnagar	0.024	0.007	0.019	0.008	0.041	0.023	0.011	0.017	0.004	0.021	0.021	0.009	0.020	0.022	0.013	0.007	0.019	0.021	0.014	0.007
Manigram	0.027	0.029	0.032	0.009	0.033	0.029	0.018	0.016	0.005	0.021	0.021	0.013	0.024	0.041	0.015	0.008	0.023	0.021	0.011	0.009
Madhabpur	0.031	0.041	0.025	0.023	0.044	0.032	0.035	0.021	0.006	0.034	0.034	0.013	0.034	0.070	0.016	0.011	0.032	0.034	0.029	0.010

Wetland	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40
Berkrishnapur	0.021	0.015	0.007	0.008	0.010	0.015	0.007	0.017	0.004	0.001	0.001	0.003	0.005	0.007	0.014	0.001	0.001	0.004	0.006	0.003
Panchpota	0.022	0.003	0.003	0.011	0.004	0.003	0.010	0.014	0.013	0.001	0.001	0.003	0.005	0.006	0.015	0.001	0.001	0.006	0.007	0.004
Panchita	0.014	0.013	0.006	0.008	0.014	0.017	0.007	0.016	0.018	0.001	0.002	0.005	0.008	0.006	0.018	0.001	0.001	0.010	0.012	0.007
Aromdanga	0.015	0.018	0.007	0.009	0.013	0.015	0.008	0.023	0.011	0.002	0.001	0.004	0.004	0.009	0.008	0.001	0.001	0.008	0.007	0.006
Gopalnagar	0.025	0.021	0.010	0.011	0.014	0.021	0.012	0.031	0.022	0.002	0.002	0.006	0.008	0.008	0.009	0.001	0.001	0.014	0.016	0.009
Manigram	0.023	0.021	0.010	0.014	0.022	0.021	0.014	0.015	0.028	0.002	0.002	0.006	0.008	0.007	0.026	0.001	0.002	0.013	0.016	0.009
Madhabpur	0.031	0.034	0.014	0.015	0.027	0.034	0.026	0.032	0.035	0.003	0.003	0.008	0.015	0.011	0.034	0.002	0.002	0.018	0.020	0.012

Annexure 6.5.7 Computation of ideal best and ideal worst value

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
Ideal best value (V+)	0.031	0.041	0.032	0.023	0.044	0.032	0.035	0.021	0.006	0.034	0.034	0.013	0.034	0.070	0.016	0.011	0.032	0.034	0.029	0.010
Ideal worst value (V-)	0.005	0.007	0.012	0.008	0.006	0.007	0.009	0.009	0.002	0.003	0.003	0.005	0.003	0.014	0.005	0.003	0.005	0.003	0.007	0.005

	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40
Ideal best value (V+)	0.031	0.034	0.014	0.015	0.027	0.034	0.026	0.032	0.035	0.003	0.003	0.008	0.015	0.011	0.034	0.002	0.002	0.018	0.020	0.012
Ideal worst value (V-)	0.014	0.003	0.003	0.008	0.004	0.003	0.007	0.014	0.004	0.001	0.001	0.003	0.004	0.006	0.008	0.001	0.001	0.004	0.006	0.003

Annexure 6.5.8 Calculation of Euclidean distance from ideal best and worst, performance score and ranking of wetland, 2020

Wetland	Si+	Si-	Pi	Rank
Berkrishnapur	0.12	0.03	0.19	7
Panchpota	0.12	0.03	0.22	6
Panchita	0.10	0.05	0.32	4
Aromdanga	0.11	0.05	0.30	5
Gopalnagar	0.08	0.07	0.46	3
Manigram	0.06	0.09	0.59	2
Madhabpur	0.01	0.14	0.95	1

Annexure 6.6.1 Decision matrix (Valid score of each indicator for response system, 2020)

Wetland	Indicator																	
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
Berkrishnapur	2.00	1.00	1.00	1.50	2.75	2.35	3.65	3.90	2.00	1.00	2.65	2.75	1.00	1.00	1.00	1.00	1.00	1.00
Panchpota	4.00	3.00	3.00	3.50	3.65	2.45	2.90	2.80	1.95	1.15	1.90	2.75	1.00	1.00	2.00	1.00	1.00	1.00
Panchita	1.00	4.00	1.00	2.85	2.45	1.40	2.70	2.00	2.60	1.30	2.40	4.15	2.00	3.00	2.00	1.00	1.00	1.00
Aromdanga	1.00	1.00	1.00	2.10	1.35	1.90	2.25	1.95	2.60	1.75	1.95	2.75	1.00	1.00	1.00	1.00	1.00	1.00
Gopalnagar	4.00	4.00	3.00	2.85	2.55	2.90	3.60	2.85	3.50	2.95	2.15	4.45	2.00	2.00	3.00	1.00	1.00	1.00
Manigram	5.00	4.00	4.00	3.40	3.95	2.45	3.20	2.25	3.16	1.60	3.70	3.63	2.00	1.00	3.00	1.00	1.00	1.00
Madhabpur	5.00	5.00	4.00	4.30	3.15	2.85	3.90	3.20	3.20	2.45	3.45	3.15	3.00	1.00	2.00	1.00	1.00	1.00

Annexure 6.6.2 Normalization of the decision matrix

Wetland	Indicator																	
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
Berkrishnapur	0.09	0.05	0.06	0.07	0.14	0.14	0.16	0.21	0.11	0.08	0.15	0.12	0.08	0.10	0.07	0.14	0.14	0.14
Panchpota	0.18	0.14	0.18	0.17	0.18	0.15	0.13	0.15	0.10	0.09	0.10	0.12	0.08	0.10	0.14	0.14	0.14	0.14
Panchita	0.05	0.18	0.06	0.14	0.12	0.09	0.12	0.11	0.14	0.11	0.13	0.18	0.17	0.30	0.14	0.14	0.14	0.14
Aromdanga	0.05	0.05	0.06	0.10	0.07	0.12	0.10	0.10	0.14	0.14	0.11	0.12	0.08	0.10	0.07	0.14	0.14	0.14
Gopalnagar	0.18	0.18	0.18	0.14	0.13	0.18	0.16	0.15	0.18	0.24	0.12	0.19	0.17	0.20	0.21	0.14	0.14	0.14
Manigram	0.23	0.18	0.24	0.17	0.20	0.15	0.14	0.12	0.17	0.13	0.20	0.15	0.17	0.10	0.21	0.14	0.14	0.14
Madhabpur	0.23	0.23	0.24	0.21	0.16	0.17	0.18	0.17	0.17	0.20	0.19	0.13	0.25	0.10	0.14	0.14	0.14	0.14
Sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Annexure 6.6.3 Computation of entropy, degree of diversification and indicator weight

Wetland	Indicator																		
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	**Sum**
Berkrishnapur	-0.22	-0.14	-0.17	-0.19	-0.27	-0.28	-0.30	-0.33	-0.24	-0.21	-0.28	-0.25	-0.21	-0.23	-0.19	-0.28	-0.28	-0.28	
Panchpota	-0.31	-0.27	-0.31	-0.30	-0.31	-0.28	-0.27	-0.28	-0.23	-0.22	-0.24	-0.25	-0.21	-0.23	-0.28	-0.28	-0.28	-0.28	
Panchita	-0.14	-0.31	-0.17	-0.27	-0.26	-0.21	-0.26	-0.24	-0.27	-0.24	-0.27	-0.31	-0.30	-0.36	-0.28	-0.28	-0.28	-0.28	
Aromdanga	-0.14	-0.14	-0.17	-0.23	-0.18	-0.25	-0.23	-0.23	-0.27	-0.28	-0.24	-0.25	-0.21	-0.23	-0.19	-0.28	-0.28	-0.28	
Gopalnagar	-0.31	-0.31	-0.31	-0.27	-0.26	-0.31	-0.29	-0.28	-0.31	-0.34	-0.25	-0.31	-0.30	-0.32	-0.33	-0.28	-0.28	-0.28	
Manigram	-0.34	-0.31	-0.34	-0.30	-0.32	-0.28	-0.28	-0.25	-0.30	-0.27	-0.32	-0.29	-0.30	-0.23	-0.33	-0.28	-0.28	-0.28	
Madhabpur	-0.34	-0.34	-0.34	-0.33	-0.29	-0.30	-0.31	-0.30	-0.30	-0.32	-0.32	-0.27	-0.35	-0.23	-0.28	-0.28	-0.28	-0.28	
Entropy	-1.79	-1.82	-1.79	-1.90	-1.90	-1.92	-1.93	-1.92	-1.92	-1.88	-1.91	-1.93	-1.86	-1.83	-1.87	-1.95	-1.95	-1.95	
Entropy value	0.921	0.935	0.921	0.977	0.978	0.988	0.992	0.985	0.989	0.965	0.984	0.990	0.958	0.943	0.962	1.000	1.000	1.000	
Degree of diversification	0.079	0.065	0.079	0.023	0.022	0.012	0.008	0.015	0.011	0.035	0.016	0.010	0.042	0.057	0.038	0.000	0.000	0.000	**0.51**
Weight	**0.154**	**0.127**	**0.153**	**0.045**	**0.043**	**0.024**	**0.015**	**0.029**	**0.021**	**0.069**	**0.032**	**0.019**	**0.082**	**0.112**	**0.075**	**0.000**	**0.000**	**0.000**	**1.00**

Annexure 6.6.4 Evaluation matrix with indicator weight

Wetland	Indicator																	
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
Berkrishnapur	2.00	1.00	1.00	1.50	2.75	2.35	3.65	3.90	2.00	1.00	2.65	2.75	1.00	1.00	1.00	1.00	1.00	1.00
Panchpota	4.00	3.00	3.00	3.50	3.65	2.45	2.90	2.80	1.95	1.15	1.90	2.75	1.00	1.00	2.00	1.00	1.00	1.00
Panchita	1.00	4.00	1.00	2.85	2.45	1.40	2.70	2.00	2.60	1.30	2.40	4.15	2.00	3.00	2.00	1.00	1.00	1.00
Aromdanga	1.00	1.00	1.00	2.10	1.35	1.90	2.25	1.95	2.60	1.75	1.95	2.75	1.00	1.00	1.00	1.00	1.00	1.00
Gopalnagar	4.00	4.00	3.00	2.85	2.55	2.90	3.60	2.85	3.50	2.95	2.15	4.45	2.00	2.00	3.00	1.00	1.00	1.00
Manigram	5.00	4.00	4.00	3.40	3.95	2.45	3.20	2.25	3.16	1.60	3.70	3.63	2.00	1.00	3.00	1.00	1.00	1.00
Madhabpur	5.00	5.00	4.00	4.30	3.15	2.85	3.90	3.20	3.20	2.45	3.45	3.15	3.00	1.00	2.00	1.00	1.00	1.00
Weight	**0.15**	**0.13**	**0.15**	**0.05**	**0.04**	**0.02**	**0.02**	**0.03**	**0.02**	**0.07**	**0.03**	**0.02**	**0.08**	**0.11**	**0.07**	**0.00**	**0.00**	**0.00**

Annexure 6.6.5 Vector normalization

Wetland	Indicator																	
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
Berkrishnapur	0.21	0.11	0.14	0.19	0.35	0.37	0.43	0.53	0.27	0.20	0.37	0.30	0.20	0.24	0.18	0.38	0.38	0.38
Panchpota	0.44	0.33	0.42	0.44	0.50	0.42	0.38	0.45	0.28	0.24	0.29	0.32	0.21	0.24	0.36	0.41	0.41	0.41
Panchita	0.12	0.46	0.15	0.40	0.39	0.26	0.38	0.36	0.38	0.28	0.38	0.50	0.43	0.75	0.38	0.45	0.45	0.45
Aromdanga	0.12	0.13	0.15	0.32	0.23	0.37	0.34	0.37	0.41	0.39	0.33	0.39	0.24	0.38	0.21	0.49	0.49	0.49
Gopalnagar	0.49	0.53	0.47	0.46	0.45	0.61	0.58	0.58	0.61	0.71	0.39	0.68	0.48	0.81	0.64	0.55	0.55	0.55
Manigram	0.71	0.62	0.70	0.62	0.77	0.64	0.63	0.56	0.70	0.54	0.73	0.75	0.55	0.61	0.82	0.63	0.63	0.63
Madhabpur	0.99	0.99	0.99	0.99	0.97	0.97	0.98	0.97	0.98	0.97	0.98	0.97	0.98	0.74	0.96	0.76	0.76	0.76

Annexure 6.6.6 Weighted normalized matrix

Wetland	Indicator																	
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
Berkrishnapur	0.03	0.01	0.02	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.03	0.01	0.00	0.00	0.00
Panchpota	0.07	0.04	0.06	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.03	0.03	0.00	0.00	0.00
Panchita	0.02	0.06	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.04	0.08	0.03	0.00	0.00	0.00
Aromdanga	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.01	0.02	0.04	0.02	0.00	0.00	0.00
Gopalnagar	0.08	0.07	0.07	0.02	0.02	0.01	0.01	0.02	0.01	0.05	0.01	0.01	0.04	0.09	0.05	0.00	0.00	0.00
Manigram	0.11	0.08	0.11	0.03	0.03	0.02	0.01	0.02	0.01	0.04	0.02	0.01	0.05	0.07	0.06	0.00	0.00	0.00
Madhabpur	0.15	0.13	0.15	0.04	0.04	0.02	0.01	0.03	0.02	0.07	0.03	0.02	0.08	0.08	0.07	0.00	0.00	0.00

Annexure 6.6.7 Computation of ideal best and ideal worst value

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
Ideal best (V+)	0.15	0.13	0.15	0.04	0.04	0.02	0.01	0.03	0.02	0.07	0.03	0.02	0.08	0.09	0.07	0.00	0.00	0.00
Ideal worst (V-)	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.01	0.00	0.00	0.00

Annexure 6.6.8 Calculation of Euclidean distance from ideal best and worst, performance score and ranking of wetland, 2020

Wetland	**Si+**	**Si-**	**Pi**	**Rank**
Berkrishnapur	0.25	0.02	0.06	7
Panchpota	0.19	0.07	0.28	4
Panchita	0.22	0.08	0.26	5
Aromdanga	0.25	0.02	0.08	6
Gopalnagar	0.14	0.13	0.47	3
Manigram	0.10	0.16	0.63	2
Madhabpur	0.01	0.26	0.97	1

Changing Ecosystem Health of Wetlands of Ichham...

By: Jibananda Gayen

As of: Oct 28, 2022 6:12:19 PM
41,290 words - 230 matches - 147 sources

Similarity Index

7%

Mode: Summary Report

sources:

424 words / 1% - Internet from 08-Sep-2022 12:00AM
link.springer.com

22 words / < 1% match - Internet from 23-Mar-2020 12:00AM
link.springer.com

15 words / < 1% match - Internet from 18-Jul-202012:00AM
link.springer.com

15 words / < 1% match - Internet from 17-May-2019 12:00AM
link.springer.com

15 words / < 1% match - Internet from 04-Feb-2020 12:00AM
link.springer.com

13 words / < 1% match - Internet from 28-Oct-2021 12:00AM
link.springer.com

11 words / < 1% match - Internet from 18-Mar-2020 12:00AM
link.springer.com

9 words / < 1% match - Internet from 23-Sep-2022 12:00AM
link.springer.com

105 words / < 1% match - Internet from 07-Dec-2020 12:00AM
www.tandfonline.com

37 words / < 1% match - Internet from 28-May-2020 12:00AM
www.tandfonline.com

13 words / < 1% match - Internet from 03-Jun-2020 12:00AM
www.tandfonline.com

60 words / < 1% match - Internet from 10-Aug-2022 12:00AM

mdpi-res.com

13 words / < 1% match - Internet from 29-Sep-2022 12:00AM
mdpi-res.com

11 words / < 1% match - Internet from 09-Aug-2022 12:00AM
mdpi-res.com

76 words / < 1% match - ProQuest
Szponar, Natalie. "Tracing Atmospheric Sources of Mercury Through Passive Air Sampling and Isotope Characterization", University of Toronto (Canada), 2022

67 words / < 1% match - Crossref
Tengteng Sun, Wenpeng Lin, Guangsheng Chen, Pupu Guo, Ying Zeng. "Wetland ecosystem health assessment through integrating remote sensing and inventory data with an assessment model for the Hangzhou Bay, China", Science of The Total Environment, 2016

37 words / < 1% match - Internet from 11-Oct-2022 12:00AM
dokumen.pub

18 words / < 1% match - Internet from 02-Oct-2022 12:00AM
dokumen.pub

50 words / < 1% match - Internet from 13-Sep-2022 12:00AM
tel.archives-ouvertes.fr

30 words / < 1% match - Internet from 31-Jul-2022 12:00AM
www.researchgate.net

20 words / < 1% match - Internet from 15-Oct-2022 12:00AM
www.researchgate.net

47 words / < 1% match - Crossref
Cavallaro, F.. "Fuzzy TOPSIS approach for assessing thermal-energy storage in concentrated solar power (CSP) systems", Applied Energy, 201002

37 words / < 1% match - Internet from 19-Jan-2022 12:00AM
sahris.sahra.org.za

10 words / < 1% match - Internet from 18-Jan-2022 12:00AM
sahris.sahra.org.za

45 words / < 1% match - Crossref
Madhab Mondal, Sandip Ghosh, L. N. Satpati. "Optimum cross section index (OCI): a new approach for identification of an optimum channel—a case study of the Ichamati River, India", Arabian Journal of Geosciences, 2018

42 words / < 1% match - Crossref
Abhijit Mukherjee, Alan E. Fryar. "Deeper groundwater chemistry and geochemical modeling of the arsenic affected western Bengal basin, West Bengal, India", Applied Geochemistry, 2008

39 words / < 1% match - Crossref
O. Ajayi Clement, A. Elujoba Anthony, M. Kasali Félicien, G. Tenywa Mercy et al. "A review for selecting medicinal plants commonly used for malaria in Uganda", African Journal of Pharmacy and Pharmacology, 2020

39 words / < 1% match - Internet from 19-Apr-2022 12:00AM
orbi.uliege.be

37 words / < 1% match - Internet from 31-Oct-2021 12:00AM
buuconference.buu.ac.th

34 words / < 1% match - Internet
Stanojević, Dragan. "Procena genetskih parametara osobina dugovečnosti goveda crno bele rase", Univerzitet u Beogradu, Poljoprivredni fakultet, 2017

34 words / < 1% match - Internet from 19-Aug-2022 12:00AM
wgbis.ces.iisc.ernet.in

33 words / < 1% match - Internet from 24-Jan-2013 12:00AM
archimer.ifremer.fr

32 words / < 1% match - Crossref
Florencia Heredia, Agostina L Martinez, Valentina Surraco Urtubey. "The importance of lithium for achieving a low-carbon future: overview of the lithium extraction in the 'Lithium Triangle'", Journal of Energy & Natural Resources Law, 2020

31 words / < 1% match - Crossref
"Spatial Modeling in Forest Resources Management", Springer Science and Business Media LLC, 2021

31 words / < 1% match - Crossref
Huicong Jia, Donghua Pan, Wanchang Zhang. "Health Assessment of Wetland Ecosystems in the Heilongjiang River Basin, China", Wetlands, 2015

28 words / < 1% match - Crossref
Meera M. Hira Smith. "A Dugwell Program to Provide Arsenic-Safe Water in West Bengal, India: Preliminary Results", Journal of Environmental Science and Health Part A, 3/1/2003

28 words / < 1% match - Internet from 17-Oct-2022 12:00AM
a-a-r-s.org

19 words / < 1% match - Internet from 27-Oct-2021 12:00AM
www.hindawi.com

9 words / < 1% match - Internet from 11-Nov-2021 12:00AM
www.hindawi.com

27 words / < 1% match - Crossref
Yuan Li, Lingchao Fang, Wang Yuanzhu, Wujuan Mi, Li Ji, Zhang Guixiang, Pingheng Yang, Zhongbing Chen, Yonghong Bi. "Anthropogenic activities accelerated the evolution of river trophic status", Ecological Indicators, 2022

26 words / < 1% match - Internet
Kolli, Meena Kumari. "Lake Catchment Interaction Analysis by Using Remote Sensing and GIS Techniques – the case study of Kolleru Lake, South India", Philipps-Universität Marburg, 2020

24 words / < 1% match - ProQuest
Bhadrecha, M. H.. "Ecosystem Assessment of Thol Bird Sanctuary with Special Reference to Benthic Macro Invertebrate Community.", Maharaja Sayajirao University of Baroda (India), 2020

24 words / < 1% match - Internet from 20-Jul-2014 12:00AM
as1.ori.nic.in

24 words / < 1% match - Internet
Prabhat Kumar Rai, J.S. Singh. "Invasive alien plant species: Their impact on environment, ecosystem services and human health", Ecological Indicators

23 words / < 1% match - ProQuest
Onwuchekwa, Chioma O.. "Adsorption of Methamphetamine on Select Microplastics and the Evaluation of Microplastic Content in Surface Water and a Wastewater Treatment Plant", Tennessee Technological University, 2022

23 words / < 1% match - Internet from 23-Sep-2022 12:00AM
www.europeangrassland.org

22 words / < 1% match - Internet from 12-Jan-2007 12:00AM
soil.scijournals.org

21 words / < 1% match - Crossref
Debajit Datta, Asit Kumar Roy, Arnab Kundu, Dipanwita Dutta, Sohini Neogy. "An alternative approach to delineate wetland influence zone of a tropical intertidal mudflat using geo-information technology", Estuarine, Coastal and Shelf Science, 2021

21 words / < 1% match - Crossref
Debajit Datta, Proshanta Kumar Ghosh. "Evaluating sustainability of community endeavours in an Indian floodplain wetland using multi-criteria decision analysis", Singapore Journal of Tropical Geography, 2015

21 words / < 1% match - Crossref
Dilip K Datta, Lallan P Gupta, V Subramanian. "Distribution of C, N and P in the sediments of the Ganges–Brahmaputra–Meghna river system in the Bengal basin", Organic Geochemistry, 1999

21 words / < 1% match - Crossref
Wanxu Chen. "A multi-scale assessment of ecosystem health based on the Pressure-State-Response framework: a case in the Middle Reaches of the Yangtze River Urban Agglomerations, China", Environmental Science and Pollution Research, 2022

21 words / < 1% match - Crossref
Wenlong Li, Chenli Liu, Wenliang Su, Xuanlong Ma, Huakun Zhou, Wenying Wang, Gaofeng Zhu. "Spatiotemporal evaluation of alpine pastoral ecosystem health by using the Basic-Pressure-State-Response Framework: A case study of the Gannan region, northwest China", Ecological Indicators, 2021

21 words / < 1% match - Internet from 23-Aug-2018 12:00AM
www.ijenas.com

20 words / < 1% match - Crossref
Md Nasiruddin, Abu Reza Md Towfiqul Islam, Md Abu Bakar Siddique, Md Hasanuzaman et al. "Distribution, sources, and pollution levels of toxic metal(loid)s in an urban river (Ichamati), Bangladesh using SOM and PMF modeling with GIS tool", Environmental Science and Pollution Research, 2022

20 words / < 1% match - Internet from 22-Aug-2021 12:00AM
core.ac.uk

20 words / < 1% match - Internet from 06-Aug-2019 12:00AM
digital.csic.es

20 words / < 1% match - Internet from 16-Jan-2017 12:00AM
documents.mx

20 words / < 1% match - Internet from 30-Jan-2016 12:00AM
file.scirp.org

20 words / < 1% match - Internet from 17-Feb-2021 12:00AM
iwaponline.com

20 words / < 1% match - Internet from 15-Oct-2015 12:00AM
onlinelibrary.wiley.com

20 words / < 1% match - Internet from 02-Feb-2013 12:00AM
water.epa.gov

11 words / < 1% match - Internet from 01-Oct-2022 12:00AM
www.mdpi.com

9 words / < 1% match - Internet from 25-May-2018 12:00AM
www.mdpi.com

20 words / < 1% match - Internet from 25-Sep-2022 12:00AM
www.sciencepubco.com

19 words / < 1% match - Internet from 08-Feb-2014 12:00AM
dive-deck.ru

19 words / < 1% match - Internet from 16-Sep-2022 12:00AM
eprints.ukmc.ac.id

18 words / < 1% match - Crossref
K. Alivelu, S. Srivastava, A. Subba Rao, K. N. Singh, G. Selvakumari, N. S. Raju. "Comparison of Modified Mitscherlich and Response Plateau Models for Calibrating Soil Test Based Nitrogen Recommendations for Rice on Typic Ustropept", Communications in Soil Science and Plant Analysis, 2007

18 words / < 1% match - ProQuest
Sevinc, Nuray. "Wetland Conservation within the Framework of City Planning.", Izmir Institute of Technology (Turkey), 2021

18 words / < 1% match - Internet from 03-Oct-2022 12:00AM
www.tcsae.org

17 words / < 1% match - Crossref
Nitin Bassi. "Implications of Institutional Vacuum in Wetland Conservation for Water Management", IIM Kozhikode Society & Management Review, 2016

17 words / < 1% match - Internet from 29-May-2020 12:00AM
cyberleninka.org

17 words / < 1% match - Internet from 29-Sep-2022 12:00AM
epubs.icar.org.in

17 words / < 1% match - Internet from 24-Mar-2016 12:00AM
tdx.cat

17 words / < 1% match - Internet from 08-Mar-2019 12:00AM
www.hydrol-earth-syst-sci.net

17 words / < 1% match - Internet from 22-Sep-2022 12:00AM
www.wetlands.org

16 words / < 1% match - Crossref
Anouk G.W. Norden, Gert W. Dijk, Marc D. Huizen, Ale Algra, Gabriël J.E. Rinkel. "Interobserver agreement and predictive value for outcome of two rating scales for the amount of extravasated blood after aneurysmal subarachnoid haemorrhage", Journal of Neurology, 2006

16 words / < 1% match - Crossref

T V Ramachandra, V Sincy, K S Asulabha. "Accounting of Ecosystem Services of Wetlands in Karnataka State, India", Journal of Resources, Energy and Development, 2022

16 words / < 1% match - Internet from 28-Dec-2021 12:00AM
escholarship.org

16 words / < 1% match - Internet from 17-Sep-2021 12:00AM
opus.sanbi.org

16 words / < 1% match - Internet from 22-Sep-2022 12:00AM
www.isoe-publikationen.de

16 words / < 1% match - Internet from 16-Oct-2022 12:00AM
www.zsl.org

15 words / < 1% match - Internet from 28-Jan-2022 12:00AM
f1000researchdata.s3.amazonaws.com

14 words / < 1% match - Crossref
Lizen Mathews, N. Chandramohanakumar. "The Ratios of Carbon, Nitrogen, and Phosphorus in a Wetland Coastal Ecosystem of Southern India", International Review of Hydrobiology, 2003

14 words / < 1% match - Internet from 23-Oct-2022 12:00AM
ecologicalprocesses.springeropen.com

14 words / < 1% match - Internet from 09-Apr-2019 12:00AM
jalgalbiomass.com

14 words / < 1% match - Internet from 28-Sep-2022 12:00AM
journals.plos.org

14 words / < 1% match - Internet from 20-Oct-2022 12:00AM
maxwellsci.com

14 words / < 1% match - Internet from 03-Jan-2022 12:00AM
www.csir.co.za

13 words / < 1% match - Internet
CEA. "National wetland policy and strategy", CEA:Battaramulla, 40p., 2006

13 words / < 1% match - Internet from 18-Oct-2019 12:00AM
cgspace.cgiar.org

13 words / < 1% match - Internet from 14-Apr-2009 12:00AM

quake.abag.ca.gov

12 words / < 1% match - Crossref
"Ecosystem Services of Headwater Catchments", Springer Science and Business Media LLC, 2017

12 words / < 1% match - Crossref
Budhin Gogoi, Akash Kachari, Debangshu Narayan Da. "Assessment of Water Quality in Relation to Fishery Perspective in Flood Plain Wetlands of Subansiri River Basin Assam, India", Journal of Fisheries and Aquatic Science, 2015

12 words / < 1% match - ProQuest
Moreira, Ines Neto. "Caracterizacao Da acumulacao De Elementos Potencialmente toxicos Em Alface (Lactuca SativaL.).", Universidade de Lisboa (Portugal), 2021

12 words / < 1% match - Internet from 10-Feb-2018 12:00AM
aquafind.com

12 words / < 1% match - Internet from 11-Oct-2021 12:00AM
etd.aau.edu.et

12 words / < 1% match - Internet from 21-Jan-2020 12:00AM
repository.tudelft.nl

12 words / < 1% match - Internet from 18-Oct-2022 12:00AM
www.prnewswire.com

12 words / < 1% match - Internet from 20-Jul-2022 12:00AM
www.science.gov

11 words / < 1% match - Crossref
Debbage, Neil, and Marshall Shepherd. "The urban heat island effect and city contiguity", Computers Environment and Urban Systems, 2015.

11 words / < 1% match - Crossref
J√∏rgensen, S. "Introduction", Applied Ecology and Environmental Management, 2005.

11 words / < 1% match - Crossref
M. H. Bhadrecha, Nitasha Khatri, Sanjiv Tyagi. "Rapid integrated water quality evaluation of Mahisagar river using benthic macroinvertebrates", Environmental Monitoring and Assessment, 2016

11 words / < 1% match - Crossref
Md Hafijur Rahaman Khan, Jianguo Liu, Shengfa Liu, Ashraf Ali Seddique, Li Cao, Ananna Rahman. "Clay mineral compositions in surface sediments of the Ganges-Brahmaputra-Meghna river system of Bengal Basin, Bangladesh", Marine Geology, 2019

11 words / < 1% match - Crossref

Tasso Tayung, Lianthuamluaia Lianthuamluaia, Pritijyoti Majhi, Uttam Kumar Sarkar et al. "Assessing spatio-temporal pattern of macrozoobenthic community in relation to water quality in a tropical Indian reservoir", Arabian Journal of Geosciences, 2022

11 words / < 1% match - Crossref
Ubaid Illahi, Mohammad Shafi Mir. "Assessment of transport sustainability using a hybrid approach: A comparison of four metropolitan cities of India", Case Studies on Transport Policy, 2021

11 words / < 1% match - Internet from 10-Apr-2013 12:00AM
extension.ucdavis.edu

11 words / < 1% match - Internet from 25-Sep-2022 12:00AM
rsis.ramsar.org

11 words / < 1% match - Internet from 18-Nov-2019 12:00AM
www.prismcalibration.com

11 words / < 1% match - Internet from 02-Sep-2021 12:00AM
www.repository.cam.ac.uk

11 words / < 1% match - Internet from 07-Sep-2017 12:00AM
www1.udel.edu

10 words / < 1% match - Crossref
C. F. Zhao, Y. Fei, C. Zhao, S. H. Jia. "Analysis of Expanded Radius and Internal Expanding Pressure for Undrained Cylindrical Cavity Expansion", International Journal of Geomechanics, 2018

10 words / < 1% match - Crossref
Chalachew A. Mulatu, Alessandra Crosato, Eddy J. Langendoen, Michael M. Moges, Michael E. McClain. "Alteration of the Fogera Plain flood regime due to Ribb Dam construction, Upper Blue Nile Basin, Ethiopia", Journal of Applied Water Engineering and Research, 2021

10 words / < 1% match - Crossref
Julissa Rojas-Sandoval, James D. Ackerman. "Ornamentals lead the way: global influences on plant invasions in the Caribbean", NeoBiota, 2021

10 words / < 1% match - Crossref
P SAHU, P K SIKDAR. "Threat of land subsidence in and around Kolkata City and East Kolkata Wetlands, West Bengal, India", Journal of Earth System Science, 2011

10 words / < 1% match - Crossref
T. R. Athira, Aymen Nefla, C. T. Shifa, H. Shamna et al. "The impact of long-term environmental change on zooplankton along the southwestern coast of India", Environmental Monitoring and Assessment, 2022

10 words / < 1% match - Crossref
Ya Wu, Ting Zong, Chenyang Shuai, Shiju Liao, Liudan Jiao, Liyin Shen. "Does resource environment carrying capacity have a coercive effect on urbanization quality? Evidence from the Yangtze River Economic Belt, China",

Journal of Cleaner Production, 2022

10 words / < 1% match - Internet from 21-Oct-2022 12:00AM
cedarhimalaya.org

10 words / < 1% match - Internet from 03-Oct-2022 12:00AM
dir.indiamart.com

10 words / < 1% match - Internet from 17-Oct-2022 12:00AM
ore.exeter.ac.uk

10 words / < 1% match - Internet from 09-Apr-2015 12:00AM
planningcommission.gov.in

10 words / < 1% match - Internet from 07-Sep-2022 12:00AM
ripublication.com

10 words / < 1% match - Internet from 29-May-2016 12:00AM
www.academicjournals.org

9 words / < 1% match - Crossref
"Geo-Informatics in Resource Management and Sustainable Ecosystem", Springer Nature, 2015

9 words / < 1% match - Publications
Asian Journal on Quality, Volume 8, Issue 2

9 words / < 1% match - Crossref
Chengcheng Shen, Wei Zheng, Honghua Shi, Dewen Ding, Zongling Wang. "Assessment and regulation of ocean health based on ecosystem services: Case study in the Laizhou Bay, China", Acta Oceanologica Sinica, 2015

9 words / < 1% match - Crossref
Junhong Bai, Jia Jia, Guangliang Zhang, Qingqing Zhao, Qiongqiong Lu, Baoshan Cui, Xinhui Liu. "Spatial and temporal dynamics of heavy metal pollution and source identification in sediment cores from the short-term flooding riparian wetlands in a Chinese delta", Environmental Pollution, 2016

9 words / < 1% match - Crossref
Kashif Imdad, Mohd Rihan, Mehebub Sahana, Samsad Parween, Rayees Ahmed, Romulus Costache, Archana Chaudhary, Richa Tripathi. "Wetland health, water quality, and resident perceptions of declining ecosystem services: a case study of Mount Abu, Rajasthan, India", Environmental Science and Pollution Research, 2022

9 words / < 1% match - Crossref
M.H. Siti Khairiyah, S. Usman, Y. Suzita, L. Florinsiah, N. Nur Shahirah. "The effect of elevations on diversity and abundance of class insecta at Taman Negara Gunung Ledang, Johor", 2013 IEEE Business Engineering and Industrial Applications Colloquium (BEIAC), 2013

9 words / < 1% match - Crossref

Mehebub Sahana, Monika Saini, Gopala Areendran, Kashif Imdad, Kiranmay Sarma, Haroon Sajjad. "Assessing Wetland ecosystem health in Sundarban Biosphere Reserve using pressure-state-response model and geospatial techniques", Remote Sensing Applications: Society and Environment, 2022

9 words / < 1% match - Crossref
Plant Invasions in Protected Areas, 2013.

9 words / < 1% match - Crossref
Sharad K. Jain. "Physical Environment of India", Water Science and Technology Library, 2007

9 words / < 1% match - Crossref Posted Content
Shristi Neupane, Ramesh Raj Pant, Lal B Thapa, Deep Narayan Shah et al. "Hydrochemical characteristics of the Ramsar-listed Koshi Tappu Wetland, Nepal", Research Square Platform LLC, 2022

9 words / < 1% match - Crossref
Weiwei Liu, Ziliang Guo, Bo Jiang, Fei Lu, Henian Wang, Daan Wang, Manyin Zhang, Lijuan Cui. "Improving wetland ecosystem health in China", Ecological Indicators, 2020

9 words / < 1% match - Crossref
Xia Jing, Yufang Huang, Guangyan Lou, Yiwei Bao. "Analysis of wetland dynamic change and ecological health in Wuliangsuhai based on multi-temporal remote sensing image", 2018 Fifth International Workshop on Earth Observation and Remote Sensing Applications (EORSA), 2018

9 words / < 1% match - Internet from 26-Sep-2022 12:00AM
apps.sfwmd.gov

9 words / < 1% match - Internet from 22-Sep-2022 12:00AM
cosia.ca

9 words / < 1% match - Internet from 31-Jan-2022 12:00AM
daneshyari.com

9 words / < 1% match - Internet from 23-Jul-2022 12:00AM
gpcb.gujarat.gov.in

9 words / < 1% match - Internet from 19-Oct-2022 12:00AM
ipbes.net

9 words / < 1% match - Internet from 10-Sep-2022 12:00AM
macau.uni-kiel.de

9 words / < 1% match - Internet from 08-Aug-2020 12:00AM
mafiadoc.com

9 words / < 1% match - Internet from 22-Jun-2022 12:00AM
pubmed.ncbi.nlm.nih.gov

9 words / < 1% match - Internet from 21-Sep-2021 12:00AM
pure.rug.nl

9 words / < 1% match - Internet from 18-Sep-2022 12:00AM
www.apec.org

9 words / < 1% match - Internet from 10-Oct-2022 12:00AM
www.ecozone.ro

9 words / < 1% match - Internet from 20-Sep-2022 12:00AM
www.epa.gov

9 words / < 1% match - Internet from 16-Mar-2016 12:00AM
www.ierigz.waw.pl

My Folders

My Folders (https://app.ithenticate.com/en_us/group/folders/2279100)

My Documents (https://app.ithenticate.cc

Trash (https://app.ithenticate.com/en_us/folder/2921480)

My Documents

Documents (https://app.ithenticate.com/en_us/folder/2921481)
Sharing (https://app.ithenticate.com/en_us/folder/sharing/2921481)
Settings (https://app.ithenticate.com/en_us/folder/settings/2921481)

Folder Options (https://app.ithenticate.com/en_us/folder/settings/2921481)

Report Filters (https://app.ithenticate.com/en_us/folder/url_filter/2921481)

Phrase Exclusions (https://app.ithenticate.com/en_us/folder/excludephrase/2921481)

Report Filters

Use this page to manage the list of URLs that are filtered out of the matching content search when a report is being generated. These filters only apply to documents submitted within this folder.

Existing URL Filters:

https://doi.org/10.1007/s10661-020-08306-1 (https://app.ithenticate.com/en_us/folder/url_edit/2921481

Add URL Filter. The URL may be as specific or general as you wish.
For example:

http://example.com/ - exclude entire site (note trailing "/")
http://example.com/docs/ - exclude all sources from a specific directory
http://example.com/docs/paper.pdf - exclude specific document

Add URL

Cancel (https://app.ithenticate.com/en_us/folder)

Submit a document

1,697 Documents remaining

Upload a File (https://app.ithenticate.com/en_

Zip File Upload (https://app.ithenticate.com/en_

Cut & Paste (https://app.ithenticate.com/en_

Doc-to-Doc Comparison (https://app.ithenticate.com/en_

View: Recent Uploads (https://app.ithenticate.com/en_

New folder

New Folder (https://app.ithenticate.com/en_

New Folder Group (https://app.ithenticate.com/en_

Folder Info

Name: My Documents

Shared with: nobody (https://app.ithenticate.com/en_

My Documents

Folder Name *

My Documents

Check to exclude quoted text from comparison of documents submitted in this folder

☑ **Exclude quotes**

Check to exclude bibliography from comparison of documents submitted in this folder

☑ **Exclude bibliography**

Check to exclude phrases associated with this folder (or with your account) from comparison of documents submitted in this folder

☐ **Exclude Phrases**

Check to exclude match instances from reports that are below the set word count.

☑ **Exclude Small Matches**

Set match exclusion threshold:

Exclude all match instances below the set threshold from reports.

Word Count

9

words

Check to exclude sources below the set thresholds from reports.

☐ **Exclude Small Sources**

Exclude Sections:

Check to exclude the Abstract from comparison of documents submitted to this folder.

☐ **Abstract**

Check to exclude the Methods and Materials section from comparison of documents submitted to this folder. Includes variations: Method, Methods, Materials and Methods

☐ **Methods and Materials**

Limit searches to these repositories *

Documents submitted in this folder will search checked repositories.

Submit a document

1,697 Documents remaining

Upload a File (https://app.ithenticate.com/en_

Zip File Upload (https://app.ithenticate.com/en_

Cut & Paste (https://app.ithenticate.com/en_

Doc-to-Doc Comparison (https://app.ithenticate.com/en_

View: Recent Uploads (https://app.ithenticate.com/en_

New folder

New Folder (https://app.ithenticate.com/en_

New Folder Group (https://app.ithenticate.com/en_

Folder Info

Name: My Documents

Shared with: nobody (https://app.ithenticate.com/en_

- [x] Crossref
- [x] Crossref Posted Content
- [x] Internet
- [x] ProQuest
- [x] Publications

Update Settings   Cancel (https://app.ithenticate.com/en_us/folder)
