Government of the People's Republic of Bangladesh Ministry of Housing and Public Works Urban Development Directorate

Final Report

on

Environmental Survey and Studies

under "Preparation of Development Plan for Meherpur Zilla" Project of Urban Development Directorate (UDD)

Date: June 2025

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Chapter-1: Introduction

1.1. Background

Urban Development Directorate under the Ministry of Housing and Public Works, has launched a project titled "Preparation of Development Plan for Meherpur Zilla Project". This initiative aims to formulate a development plan for the next 20 years, divided into essential sectors to create a risk-sensitive and sustainable strategy. To understand the socio-economic and demographic profile of the study area is pivotal step for understanding the immediate needs and forecast the future needs for the next 20 years. Existing data and features are instrumental in providing a clear spatial understanding of the project area, accurately reflecting the potentials and problems of the existing scoria economic related conditions, and facilitating the representation within the development plan. Overall, the scope of socio-economic project signifies a comprehensive and forward-looking approach to urban development, emphasizing sustainability and thoughtful planning over the next two decades.

Environment is one of the important development modules of this project. In this development plan, 'environmental survey and studies' consider is an important tool for a durable and sustainable urbanization. Land use planning is an important component for a modern urban development. But practicing urban development using a proper land use plan is not developed in Bangladesh. Prior to land use planning it is very essential to access environmetal conditions (air, water, soil and noise) and the relevant information in and around the site of future urban development. Therefore, a rigorous environmental survey and study is needed to carry out for a resilient urban development.

1.2. Description of the Study Area

Meherpur Zilla, located in the southwestern part of Bangladesh, holds a significant place in the country's history and culture. Known for its rich heritage and pivotal role in the liberation war, Meherpur continues to thrive with its diverse economy, agricultural abundance, and growing infrastructure. This proposal aims to highlight the key aspects of Meherpur Zilla, focusing on its socio-economic landscape, cultural heritage, and potential for future development. The district comprises three Upazilas: Meherpur Sadar, Mujibnagar, and Gangni. Meherpur Sadar serves as the administrative and economic hub, with a diverse economy primarily based on agriculture and trade. Mujibnagar, formerly Bhoborpara, is renowned for its historical importance in the Liberation War, attracting many tourists to its memorial complex. Gangni Upazila is notable for its vibrant agricultural activities and emerging industrial potential. Collectively, these Upazilas contribute to the district's cultural richness, economic diversity, and historical legacy, positioning Meherpur Zilla as a region of significant importance and development potential in Bangladesh.

Meherpur Zilla is bordered by Kushtia to the east, Chuadanga to the south, and the Indian state of West Bengal to the west and north, situated in the Khulna Division. The district's strategic location offers significant advantages for cross-border trade and cultural exchange. The district is predominantly rural, with a diverse population comprising various ethnic and religious communities. The literacy rate is gradually improving, with ongoing efforts to enhance educational facilities and opportunities.

a. Gangni Upazila

Gangni Upazila (Meherpur district) area 363.95 sq km, located in between 23°44' and 23°52' North latitudes and in between 88°34' and 88°47' East longitudes. It is bounded by Daulatpur (Kushtia) upazila on the North, Alamdanga and Meherpur Sadar upazilas on the South, Daulatpur (Kushtia), Mirpur (Kushtia) and' Alamdanga upazilas on the East, Meherpur Sadar upazila and West Bengal state of India on the West.

Population Total 299607; male 148250, female 151357; Muslim 295458, Hindu 2726, Christian 1313 and others 110. Water bodies Main rivers: Bhairab, Ichamati, Mathabhanga and Kazla; Elangi Beel, Nuner Beel and Elalgari Damash Beel are notable. Administration Gangni Thana was formed in 1923 and it was turned into an upazila on 24 February 1984.' Gangni Upazila consist of one Municipality, 9 Unions, 90 Mouzas and 137 Villages.

b. Meherpur Sadar Upazila

Meherpur Sadar Upazila (Meherpur district) area 276.15 sq km, located in between 23°40' and 23°52' North latitudes and in between 88°34' and 88°47' East longitudes. It is bounded by Gangni upazila and West Bengal state of India on the North, Damurhuda and Mujibnagar upazilas on the South, Gangni and Alamdanga upazilas on the East, West Bengal state of India on the West.

Population Total 256642; male 127300, female 129342; Muslim 252323, Hindu 4199, Buddhist 1, Christian 114 and others 5. Water bodies Main rivers: Bhairab, Kazla; Bhatgari and Chand Beels are notable. Administration Meherpur Thana was turned into an upazila in 1984. Meherpur Municipality was formed in 1960. Meherpur Sadar consist of one Municipality, 5 Unions, 61 Mouzas and 104 Villages.

c. Mujibnagar Upazila

Mujibnagar Upazila (Meherpur district) area 111.51 sq km, located in between 23°36' and 23°45' North latitudes and in between 88°34' and 88°43' East longitudes. It is bounded by Meherpur Sadar upazila on the North, Damurhuda and Meherpur Sadar upazilas on the East, West Bengal of India on the South and on the West. Population Total 99143; male 49084, female 50059; Muslim 92970, Hindu 945, Buddhist 13, Christian 5200 and others 15. Water bodies Bhairab River, Sarashati Canal and Datpur Beel are notable. Administration Mujibnagar upazila was formed on 24 February 2000. Mujibnagar Upazila consist of 4 Unions, 29 Mouza and 33 Villages.

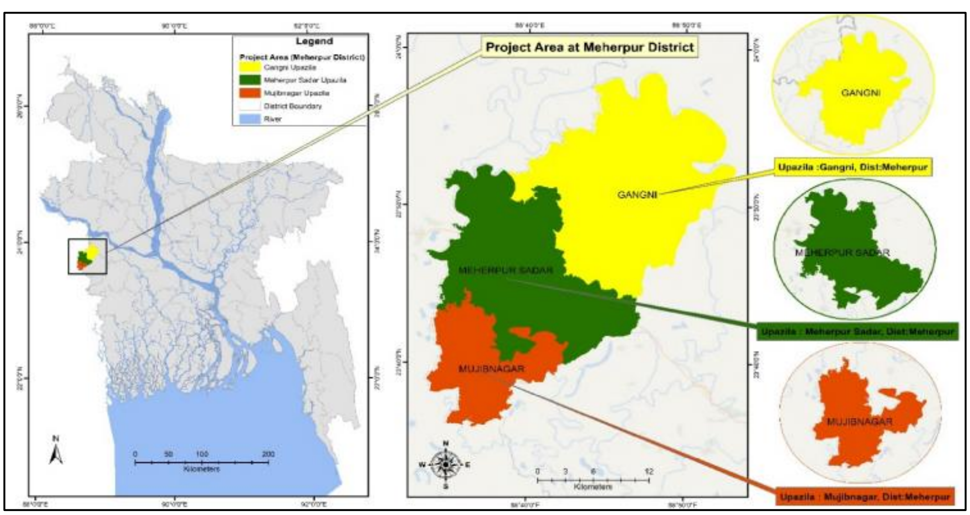

Figure -1.1: Study Area Map

1.3. Objectives

Main objectives of the project

The aim of Environmental study for urban areas of Meherpur Zilla is to identify the noise, water and air pollution condition of the project area including variation at day and nighttime. The study is also intended to examine the water quality, identify the noise level of the project area and the air pollution like particle matter ranges from 0.5 to 10.0, suspended particle matter and finally the air pollution index (API) determination which will be correlated to the development plan for the implementation of the project. The Environmental study data and information shall have to integrate with both spatial and attribute data of output of other components of planning package of "Preparation of Development Plan for Meherpur Zilla'Mn order to keep the environment sustainable.

Specific objectives of present study as per scope of work:
With a view to attain the aim of Environmental study of the project areas, the objectives of the work comprise the following:

- To collect the noise level at major growth centers and road intersections
- To collect the air quality like PM 0.5, PM 2.5, PM 5, PM 10 and Suspended Particle Matter (SPM) at major growth centers and road intersections and spatial distribution maps, graphs and dataset.
- To determind the water quality
- Finally, determine the Air Pollution Index (API) of the project area to specify the tolerable limit of noise and air pollution with the international and national standard to predict the percussions needed for future development planning.

1.4. Scope of work

As per TOR, description of the field investigation is given in the Table-1.1 below.

Table-1.1: Description of Field Investigations

SI. No.	Description of Items	Unit	Total Number
1	Preparation of Intial land use and land cover map based on secondary source data.		**1**
2	Noise level	No	65 (-30 rural -35 urban)
3	Water sample coletion point for examining the surface Water Quality from Major River, Haor & Baor, Canal water and pond water.	No	22
4	Location points of air sample for Air pollution Index determination and reporting	No	20
5	Climate and climate change impact assessment though FGD and KII	No	6
6	Desktop study of existing literature	No	1

Beside the above scope of work, agricultural soil quality data has to be colectd from SRDI (Soil resourcese development Institute). Climatic data also collected from weather station in and around the project area or nearby area to prepare climate change model.

Chapter-2: Methodology For the Assignment

2.1. Land Use and Land Cover Map Preparation

The methodology involved data preprocessing, training data preparation, classification, visualization, and export, implemented using the GEE JavaScript API.

Data Preprocessing

The Sentinel-2 image collection was filtered to include images within Meherpur, acquired between April 1, 2024, and September 30, 2024. A cloud cover threshold of less than 20% ("CLOUDY_PIXEL_PERCENTAGE < 20") was applied to ensure high-quality images. Then a cloud-masking function used the Scene Classification Layer (SCL) band to mask pixels classified as clouds (SCL = 9) or cloud shadows (SCL = 8), retaining only clear pixels. After that the image collection was subset to include bands B2, B3, B4, B8, and B11, critical for land cover differentiation.

A median composite was generated from the filtered image collection to create a single, cloud-free image representing typical conditions. The composite was clipped to the Meherpur geometry.

Pre LULC analysis

To get the training data for LULC analysis, some other analyses were done. Gathered satellite bands were used to do the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Built-up Index (BUI), Indexed Built-up Index (IBI), and Enhanced Built-up and Bareness Index (EBBI) to identify the temporal signature of different types of land use and collect them as training data.

Training Data Preparation

Each training sample was assigned a numeric land cover code given in Table 2.1.

Table 2.1. Each LULC Class and Its Class Code

Class name	Class code
Water body	1
Sparse vegetation or Agri land	2
Dense vegetation	3
Built-up area	4
Barren land	5

Then the training datasets were merged into a single Feature Collection containing 2500 samples (500 per class). The median composite was sampled at the training point locations using a 10-meter scale (native resolution of Sentinel-2 bands B2, B3, B4, and B8). The sampled data included the land cover class and band values.

Classification

The CART algorithm, implemented as "ee.Classifier.smileCart", was used for classification due to its simplicity and effectiveness. The classifier was trained with:

- Features: The sampled training data.

- Class Property: The "landcover" property (values 1 to 5).

- Input Properties: Bands B2, B3, B4, B8, and B11.

The trained classifier was applied to the median composite to generate a classified image, assigning each pixel to one of the five land cover classes.

Accuracy Assessment and Visualization

The classified map was visualized in the GEE map viewer with the designated color code and then exported into the Google Drive to the local folder as a .tiff file. Then the exported raster file was imported into QGIS 3.40 to check the accuracy and visualization.

The accuracy assessment was done with the help of the semi-classification plugin in QGIS 3.40. The RGB composite of the real satellite images that were classified was used as reference data. The result showed an overall accuracy of 92.01% and kappa hat classification value was 0.8830.

Then the classified image was exported as png format for the visualization by using QGIS 3.40.

2.2. Noise Level Measurement

Sampling Method:

- Monitoring of ambient noise level will be carried out for a period of 1-24 hours (15 hours day-time (0600 – 2100) and 9 hours night-time (2100 – 0900) using a Class 1 Sound Level Meter (Model: SL – 4022 or upper version). The duration of noise level monitoring will be decided based on the consultation with the client.
- A tripod/stand should be used for monitoring.
- To obtain the most accurate data, hold out the SLM at arm's length and hold it out to inspector's side with the microphone pointed towards the source of the noise, to minimize sound reflecting off his body.
- Noise reading should always be taken at the height of the receptor. If the receptor is at the ground level, take a measurement at the ground level (1.2–1.5m off the ground).
- To prevent disturbance from reflecting surfaces, the noise meter microphone facing towards the noise source with clearance of around 3 meters from any structures will be ensured.
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Figure-2.1: Noise Level Meter (Class 1)

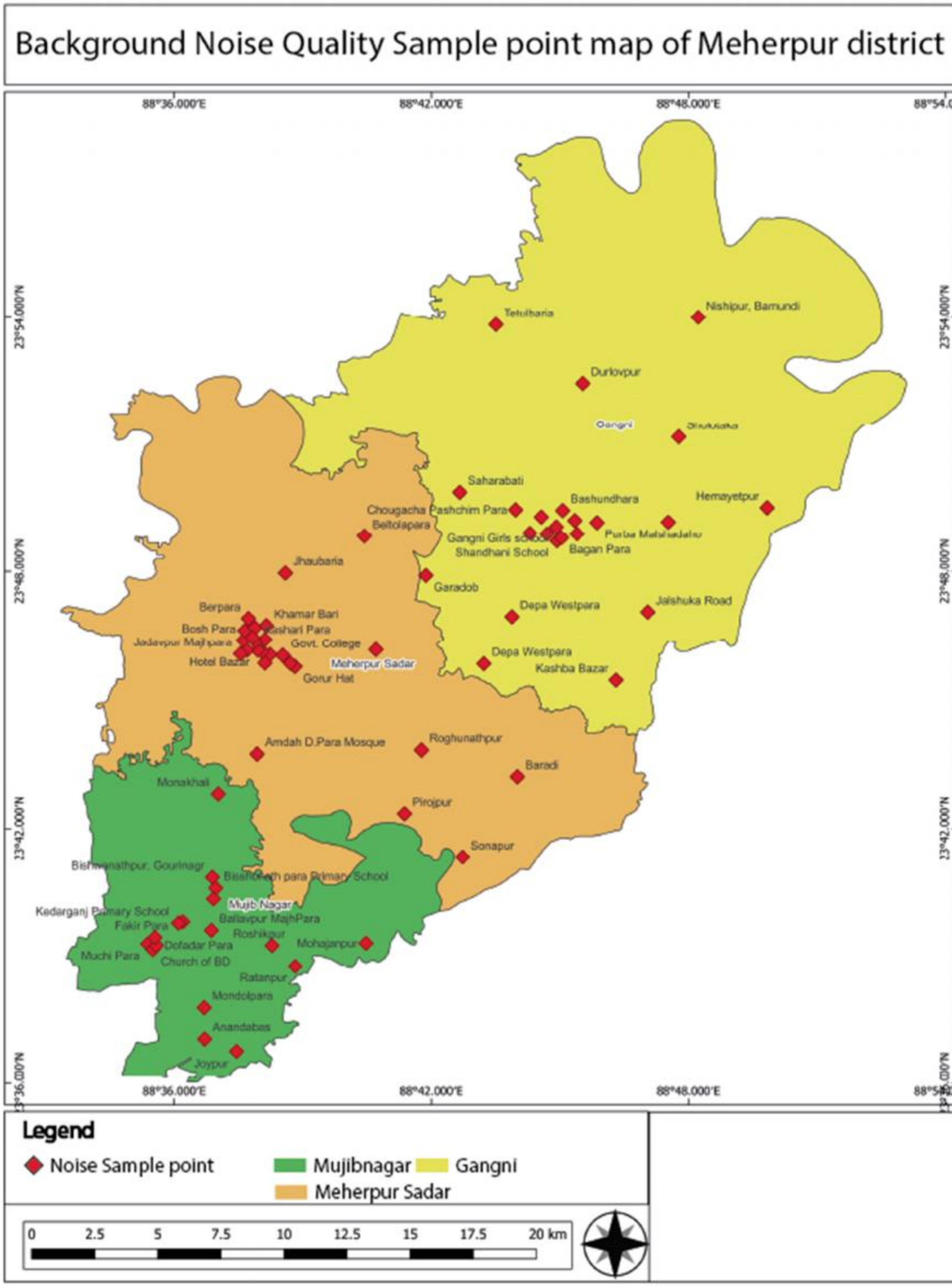

Figure-2.2: Background Noise quality sample point map of Meherpur District

2.3. Air Quality Measurement

Parameters of Ambient air quality, sampling method and laboratory analysis methods are given below:

Table-2.2: Air Quality Measurement

Parameters	Sampling Method	Laboratory Analysis Method
SPM	• Sample of ambient air is to be carried out by Respirable Dust Sampler [Model 36C12] or portable air quality device (no lab analysis needed). • Sampling will be conducted for 1-24 hours (duration to be decided based on the discussion with the client). • Sampler placed at an open area (minimum 20 m clearance from any tall structures or vegetations/trees/shrubs) to prevent disturbance. • After completion of sampling, each filter paper with trapped PM shall be preserved in an airtight Polly packet and is again packed in an envelope. All samples are to be accompanied by Chain of Custody (CoC) forms for QA/QC purpose.	IS 11255 (Part 1):1985
PM10		IS 5182 (Part 23):2006 - Methods for Measurement of Air Pollution, Part 23: Respirable Suspended Particulate Matter (PM10), Cyclonic Flow Technique
PM2.5	• Sample of ambient air is to be carried out by fine particulate monitor [Model APS-302] or portable air quality device (no lab analysis needed). • Sampling to be conducted for 1-24 hours (duration to be decided based on the consultation with the client). • Sampler placed at an open area (minimum 20 m clearance from any tall structures or vegetations / trees / shrubs) to prevent disturbance. • After completion of sampling, each filter paper with trapped PM shall be preserved in airtight Polly packet and is again packed in an envelope. All samples to be accompanied by Chain of Custody (CoC) forms for QA/QC purpose.	In House Gravimetric Method

Location of Air sample: Ambient air quality sampling points of Meherpur District

Table-2.3: Ambient air quality sampling points map of Meherpur District

Sl No	ID	Location	Latitude	Longitude
1	AQ-1	Mollickpara Road Meherpur Sadar	23°46'10.12"	88°38'3.82"
2	AQ-2	BAT DPO-1 Meherpur Sadar	23°45'48.58"	88°38'50.20"
3	AQ-03	Mondol Bari Mor Meherpur Sadar	23°47'57.79"	88°38'36.84"
4	AQ-04	Roghunathpur Jame Mosque Meherpur Sadar	23°43'49.87"	88°41'46.0775"
5	AQ-05	Sonapur malithapara bajar Meherpur	23°41'20.426"	88°42'43.965"
6	AQ-06	Amdah D: Para Jame Mosjid Meherpur	23°43'44.434"	88°37'54.5893"
7	AQ-07	Baradi Bazar Meherpur	23°43'12.56"	88°44'0.209"
8	AQ-08	Beltolapara Government Primary School Meherpur	23°48'50.33"	88°40'27.02"
9	AQ-09	Kasba Bazar	23°45'27.100"	88°46'18.536"
10	AQ-10	Agrani Bank PLC Bamundi Bazar Branch Gangni	23°53'59.958"	88°48'73.74"
11	AQ-11	Tetulbaria westpara jame mosque Gangni	23°53'49.512"	88°43'30.512"
12	AQ-12	Bagan Para 08 No. Ward Gangni	23°48'47.845"	88°45'1.687"
13	AQ-13	Garadob High School Gangni	23°47'54.382"	88°47'52.551"
14	AQ-14	Depa Westpara Jame Mosque Gangni	23°45'49.929"	88°43'13.463"
15	AQ-15	Jalshuka-Arpara-Jalshuka road Gangni	23°54'43.752"	88°47'5.136"

16	AQ-16	Church Of Christ Road Gangni	23°38'45.835"	88°38'49.045"
17	AQ-17	Mohajanpur bazar Mujib Nagar	23°39'49.17"	88°36'17.01"
18	AQ-18	Monakhali Moddo Para Jame Mosjid Mujib Nagar	23°42'18.944"	88°40'28.519"
19	AQ-19	Bishwanathpur Monakhali Mujib Nagar	23°40'45.85"	88°37'2.05"
20	AQ-20	Anandabas Bazar Mujib Nagar	23°37'4.395"	88°36'40.859"

Location Map: Ambient air quality sampling points map of Meherpur District

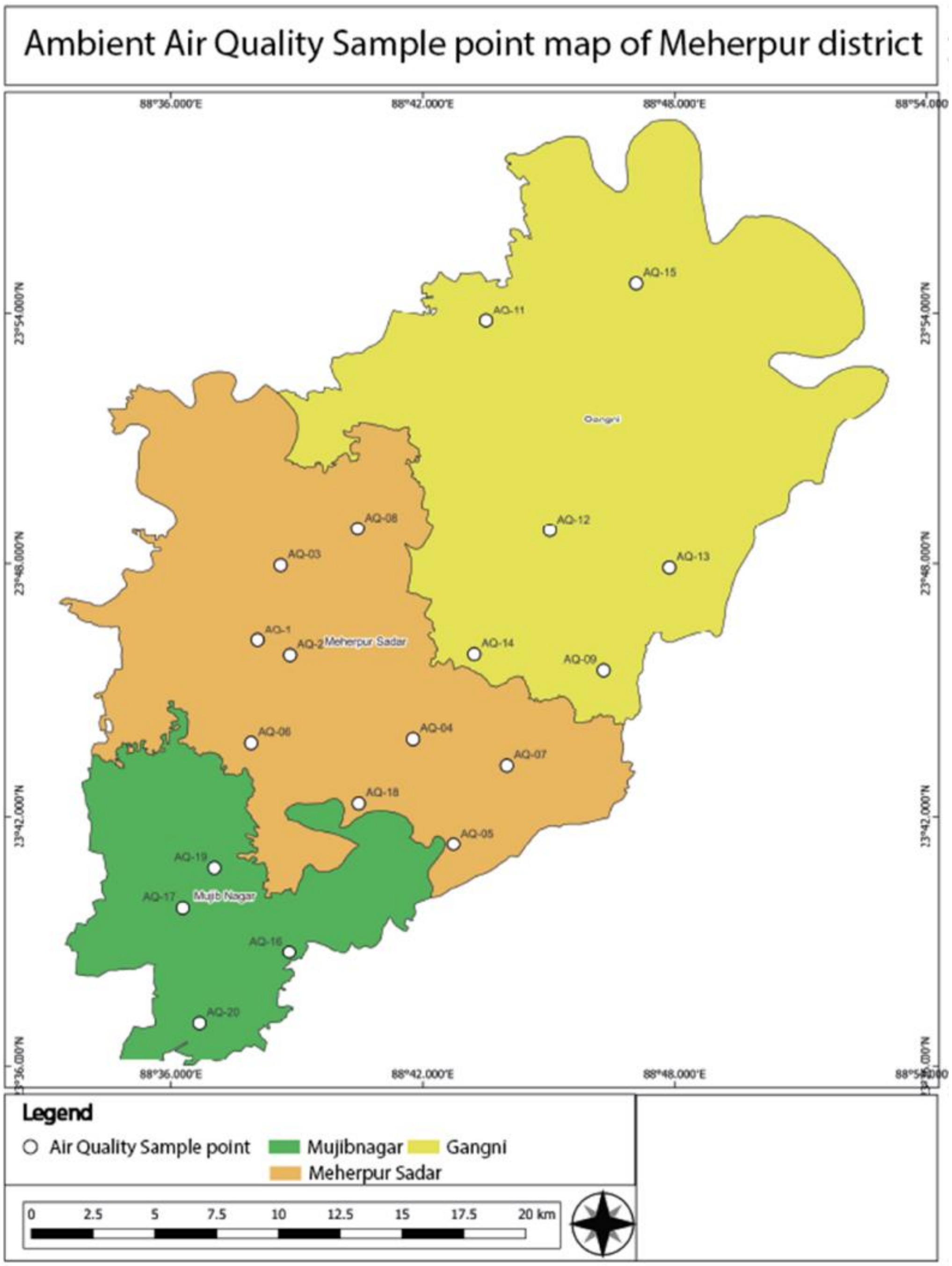

Figure-2.3: Ambient Air Quality Sample Point Map of Meherpur District

2.4. Water Quality Measurement

Water sample has to be tested and the testing parameters of surface water are the Lab test for examining the ground water quality including (i) Hydro-Geological field parameter test (Arsenic, Ph, EC, TDS, etc) (ii) Major Cataion and Anaion (wet and dry seasons) of groundwater and surface water, (iii) Trace Element Analysis (wet and dry seasons) of groundwater and surface water. All parameters will be tested in APHA/USEPA/ISO/IS method except some in-situ parameters (Temperature, Salinity, and Turbidity) to be tested by the electromagnetic method.

Sampling Method:

- Sampling program will be undertaken according to the procedures outlined in ISO 5667-9:1992 -Water Quality Sampling Guidance.
- Sampling will be conducted using a vertical Van Dorn Water Sampler (Beta Plus) to collect the surface water samples.
- New sampling bottles will be rinsed with distilled water for three times and then two times with sample water.
- 2.5 liters of sample per location will be collected.
- All sampling bottles will be properly labeled and transported in ice box (4°C) from site to SGS laboratory at Dhaka.
- All samples will be accompanied by Chain of Custody (CoC) forms for QA/QC purpose.

Water Sample Location:

Total number of water sample was 22, which has been collected from different surface water bodies (river, cannel, pond and bill area) of the study area. Location points are showing table-2.4 and given bellow respect to the sample ID.

Table-2.4: Surface Water Sampling Collection point

Sl No	ID	Location	Latitude	Longitude
1	SW-01	Dariapur	23°42'25.078"	88°36'27.69"
2	SW-02	Bondor Muzibnagar Road	23°45'0.407"	88°37'35.307"
3	SW-03	GOR Pond	23°46'33.51"	88°37'57.522"
4	SW-04	Near BAT Meherpur	23°45'38.148"	88°39'10.518"
5	SW-05	Chandbil Meherpur	23°44'59.706"	88°40'29.4"
6	SW-06	Amjhupi Meherpur	23°44'59.076"	88°40'31.428"
7	SW-07	Dighipara Meherpur	23°46'42"	88°39'1.686"
8	SW-08	Gopalpur Meherpur	23°46'57.468"	88°39'44.602"
9	SW-09	Malshadaha	23°50'8.72005"	88°46'1.57303"
10	SW-10	Baot	23°53'9.174"	88°49'35.694"
11	SW-11	Malshadaha	23°50'56.37678"	88°43'54.2226"
12	SW-12	Arpara-Chandmari Road	23°46'52.726"	88°48'14.944"
13	SW-13	Gangni Biswaspara Jame Mosque	23°50'8.75371"	88°46'1.54513"
14	SW-14	Terail	23°52'18.03"	88°47'13.05"
15	SW-15	Harbhanga	23°54'43.752"	88°47'5.136"
16	SW-16	Jalshuka-Arpara Road	23°47'22.16476"	88°46'19.9759"
17	SW-17	Kedarganj	23°39'49.17"	88°36'17.01"
18	SW-18	Biswanathpur	23°40'45.144"	88°36'53.236"
19	SW-19	Mohajonpur	23°39'15.174"	88°40'18.848"
20	SW-20	Taranagar	23°38'8.64"	88°38'23.484"
21	SW-21	Ballovpur	23°39'8.514"	88°36'48.078"
22	SW-22	Taranagar	23°37'48.639"	88°37'15.487"

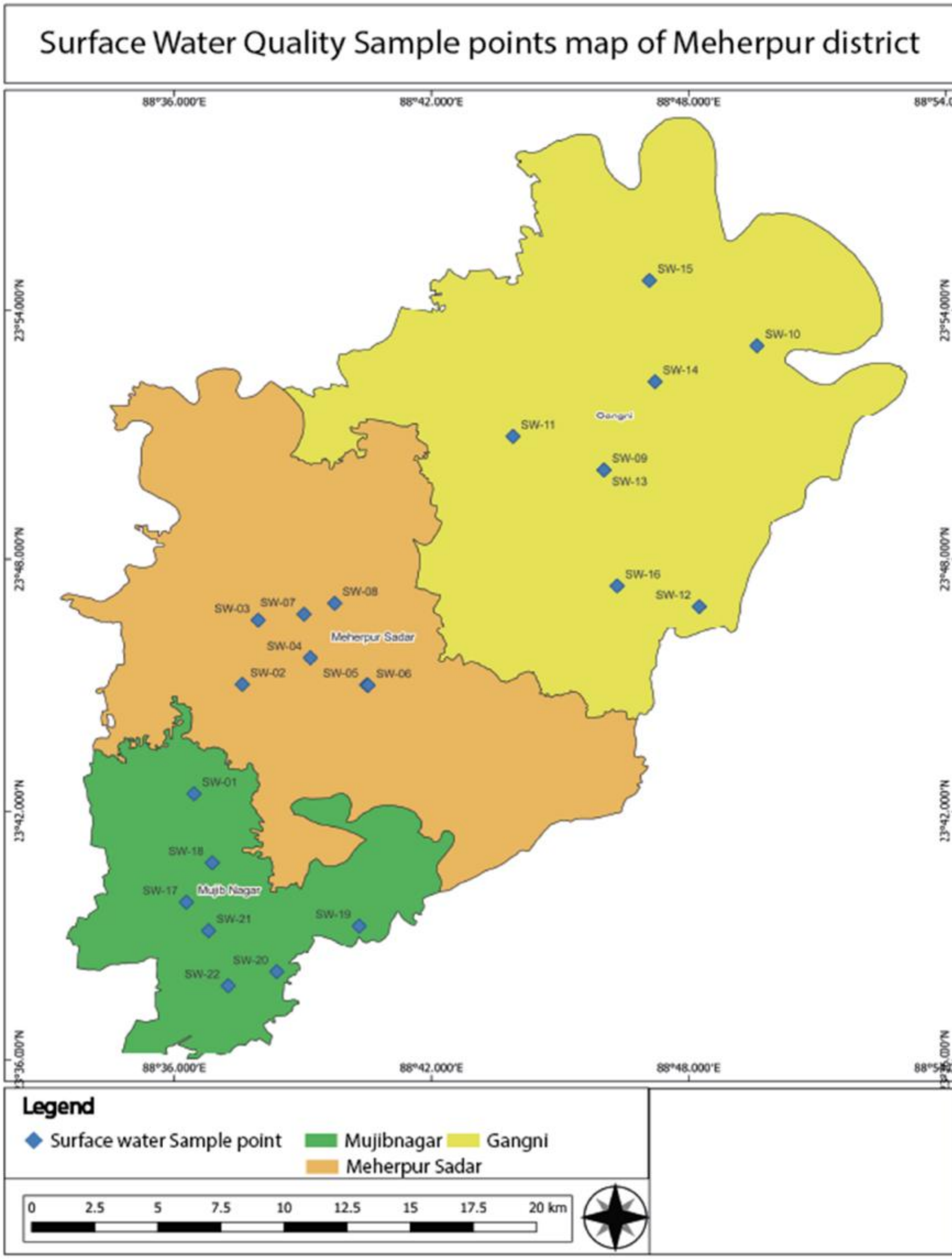

Figure-2.4: Surface Water Quality Sampling Points Map of Meherpur District

2.5. Air Pollution Index

1. Data Collection and Preparation

Data Collection:

- Ensure that the air pollution data for PM10, PM2.5, and SPM is collected using standardized equipment and methodologies as prescribed by national and international guidelines (e.g., WHO, EPA, NAAQS).

Data Preparation:

- Validate the collected data for any anomalies or missing values.
- Aggregate the data to a consistent time scale, such as daily averages, if not already done.

Sample location point of Air and Noise:

2. Selection of Standards and Index Calculation

Reference Standards:

- Choose appropriate reference standards for PM10, PM2.5, and SPM from both international (e.g., WHO Air Quality Guidelines, US EPA National Ambient Air Quality Standards) and national standards (e.g., NAAQS in India).

3. Calculation of Sub-indices

- Each pollutant's concentration is converted into a sub-index using a predefined scale. This can be done using linear interpolation between breakpoints.

Steps:

- Determine the Breakpoints: Identify the concentration breakpoints for each pollutant according to the selected standards.
- Linear Interpolation: For each pollutant, convert the observed concentration to a sub-index using the formula:

  $$Ip = \frac{(I_H - I_L)}{(B_H - B_L)} \times (Cp - BPLO) + ILO$$

Where:

- Ip is the sub-index for pollutant p
- Cp is the concentration of pollutant p
- BPHI and BPLO are the upper and lower concentration breakpoints for the category in which Cp falls.
- IHI and ILO are the upper and lower index breakpoints corresponding to BPHI and BPLO

4. Calculation of Overall API

- The overall API is determined by taking the highest sub-index value among the pollutants.
- API = max (IPM10, IPM2.5, ISPM)

5. Reporting

Categorization:

- Classify the API into categories (e.g., Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Very Unhealthy, Hazardous) based on the sub-index values.
- Groundwater status mapping using geo-spatial analysis: Groundwater table data will be collected from the water development board. They have an archive of monthly water table data. We will map and identify the region vulnerable to ground water depletion using geospatial and geostatistical data processing. Any Other Activities in Consultation with PD

2.6. Climate Change Assessment

This part of the study analyzes the climatological trends in Meherpur District, Bangladesh, based on monthly average data spanning from 2000 to 2024. The dataset includes six key variables: minimum temperature (°C), maximum temperature (°C), precipitation (mm), wind speed (m/s), relative humidity, and vapor pressure (kPa). All the data were collected from the terraclimate and MODIS sources by masking out the shape file of Meherpur by using Google Earth Engine.

Then different kinds of analysis were done, as seasonal patterns and trends, monthly trends, and decadal differences. To calculate and illustrate the result, Python 3 was used through Jupyter notebook under an Anaconda environment.

Besides that, three tea stall meetings (one tea stall meeting for each Upazila) and two KII were held to accommodate the local people's observation and perspective about climate change.

Chapter-3: Literature review and environmental laws and policies

Environmental quality assessments, including water, air, noise, and climate change analyses, are critical for any environmental survey and study report, as well as for understanding the sustainability and livability of regions like Meherpur district, Bangladesh. Meherpur, a predominantly agricultural district in the Khulna Division, faces unique environmental challenges due to its geographical location, socio-economic activities, and vulnerability to climate change. This literature review synthesizes existing studies on water quality, air quality, noise pollution, and climate change impacts in Bangladesh, with a focus on regional studies where applicable, to contextualize the environmental assessment of Meherpur district and identify research gaps. And for the latter part of this chapter, existing legislations and policies are going to be reviewed for a better understanding.

3.1. Water quality assessment

Water quality is a significant concern in Bangladesh due to its dependence on groundwater and surface water for domestic, agricultural, and industrial purposes. Studies have highlighted widespread contamination of water sources in rural and urban areas. For instance, Hossain (2006) found that groundwater in many parts of Bangladesh, including the southwestern region, is affected by arsenic contamination, with concentrations exceeding WHO guidelines in several districts. Meherpur, located in this region, may face similar risks due to its reliance on groundwater for irrigation and drinking (Rahman et al., 2022). Arsenic as a contaminant can create a cycle of contamination around soil, water, and food, which ultimately toxifies the whole community (Rahaman et al., 2022). Thanks to intensive mitigation initiatives like tubewell testing and replacement, usage of deeper wells, surface water preservation and treatment, use of sanitary dug wells, river sand and pond sand filters, rainwater collection and storage, household-scale and large-scale arsenic filtrations, and rural pipeline water supply installation from different government and non-governmental organizations, helped the country to recover from the arsenic disaster (Milton et al., 2012).

Surface water quality is also a concern. Inclusion of excessive heavy metals or the presence of pesticide residues can cause serious health concerns. Various rivers and inland water bodies in Bangladesh, especially located in the urban areas, contain such amounts of pollutants, including heavy metals, pesticide and insecticide residues, radionuclides, and pathogens, that pose a potential threat to humans and the environment (Bhuiyan et al., 2015; Chowdhury et al., 2013; Dewan et al., 2013; Hasan et al., 2014; Hasanuzzaman et al., 2017; Hossain et al., 2015; Md. S. Islam et al., 2015; S. Islam et al., 2015; O'Neal et al., 2015; Seddique et al., 2016; M Amin Uddin et al., 2013; Mohammad Afsar Uddin et al., 2013).

Mallick et al. (2021) investigated water quality in the rivers of southwestern Bangladesh and reported high levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD), indicating organic pollution from agricultural runoff and untreated domestic waste. While Meherpur-specific studies are scarce, the district's agricultural intensity suggests potential water quality degradation from pesticide and fertilizer runoff (Kabir and Naser, 2011; M Amin Uddin et al., 2013; Zafor, 1997).

Despite this, there is limited literature on water quality specific to Meherpur, particularly regarding seasonal variations and the impact of local agricultural practices on both surface and groundwater quality.

3.2. Air quality assessment

Air pollution remains one of the most critical environmental threats of our time, particularly in low- and middle-income countries experiencing rapid industrialization and urbanization. It is widely acknowledged that pollutants such as particulate matter (PM2.5 and PM10), sulfur oxides (SOx), nitrogen oxides (NOx), ozone (O_3), carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), and volatile organic compounds (VOCs) contribute significantly to environmental degradation and pose substantial risks to public health (Aneja et al., 2008). The composition and concentration of these pollutants vary depending on local sources, climatic conditions, and geographical settings.

Air quality in rural Bangladesh has received less attention compared to urban centers like Dhaka. However, studies indicate that rural areas are not immune to air pollution. Studies found that biomass burning, vehicular emissions, and dust from agricultural activities contribute to particulate matter (PM2.5 and PM10) in rural districts (Begum et al., 2013, 2009; Islam et al., 2022; Khalequzzaman et al., 2011). In Meherpur, where agriculture and small-scale industries dominate, similar sources of air pollution are likely relevant. According to Mitra and Czajkowski (2025) seasonal variations revealed notably high PM2.5 concentrations during the winter season.

Additionally, transboundary air pollution from industrial activities in neighboring regions may affect Meherpur. However, district-specific air quality data for Meherpur is limited, and most studies focus on urban or industrial hubs. There is a lack of localized air quality monitoring data for Meherpur, particularly regarding the contribution of agricultural practices and seasonal variations to PM levels.

3.3. Noise quality assessment

Noise pollution, often overlooked in environmental assessments, is an emerging public health concern in both urban and rural areas of Bangladesh. In Meherpur, a predominantly agricultural district in the Khulna Division, noise from agricultural machinery, transportation, and local markets may impact community well-being. This literature review examines existing studies on noise pollution in Bangladesh, focusing on rural and semi-urban contexts, to provide a foundation for assessing noise quality in Meherpur and to identify gaps in the literature.

Noise pollution in rural areas of Bangladesh has received less attention compared to urban centers like Dhaka, where traffic and industrial activities dominate. However, studies indicate that rural districts are increasingly affected by noise due to modernization and infrastructure development. AAmin et al. (2014) conducted a study on noise pollution in rural and semi-urban areas of Bangladesh and found that noise levels often exceed the World Health Organization's (WHO) recommended limit of 55 dB(A) for residential areas during the daytime. Sources included vehicular traffic, small-scale industries, and community activities such as markets and religious gatherings.

In agricultural regions similar to Meherpur, the operation of machinery such as tractors, irrigation pumps, and rice mills contributes significantly to noise pollution. Sultana et al. (2020) investigated noise levels in rural districts of southwestern Bangladesh and reported that market areas and roads near agricultural fields frequently experience noise levels between 60-75 dB(A), posing risks to auditory health and community well-being. The study emphasized that prolonged exposure to such levels can lead to stress, sleep disturbances, and reduced productivity among rural populations.

Despite the growing body of literature on noise pollution in Bangladesh, there is a notable lack of district-specific studies, particularly for Meherpur. Most research focuses on urban or peri-urban areas, leaving rural agricultural districts underexplored.

3.4. Climate change assessment

Climate change poses significant challenges to Bangladesh, one of the most vulnerable countries to its impacts, particularly in its southwestern districts like Meherpur. As an agrarian region in the Khulna Division, Meherpur faces risks from rising temperatures, erratic rainfall, and increasing salinity, which threaten agricultural productivity and livelihoods. This literature review examines existing studies on climate change impacts in Bangladesh, focusing on rural and southwestern contexts, to provide a foundation for analyzing climate change in Meherpur and to identify gaps in the literature. Bangladesh's vulnerability to climate change is well-documented, with southwestern districts experiencing a range of impacts. Hossain et al. (2019) analyzed climate trends in the Khulna Division and reported a temperature increase of approximately 0.8°C over the past three decades, coupled with erratic monsoon patterns. These changes disrupt agricultural cycles, particularly for rice and other staple crops prevalent in the regions (Mannan and Rahman, 2017). The studies highlighted that prolonged dry spells and delayed monsoons reduce crop yields, affecting smallholder farmers who dominate the region's economy.

Salinity intrusion is another critical issue in southwestern Bangladesh. Studies found that reduced upstream freshwater flow, combined with sea-level rise, increases soil and water salinity in districts like Meherpur, though less severely than in coastal areas (Mannan and Rahman, 2017). This impacts soil fertility and limits crop choices, forcing farmers to adopt salinity-tolerant varieties. Salinity, combined with drought, exacerbates water scarcity for irrigation in agrarian districts, a concern relevant to Meherpur's agriculture-dependent landscape (Shaibur et al., 2022).

Adaptation to climate change is a growing focus in the literature. Kabir et al. (2017) explored adaptive strategies in western Bangladesh, including the adoption of climate-resilient crop varieties and improved irrigation techniques. However, the study emphasized that resource constraints limit the adoption of such measures among smallholder farmers. In Meherpur, where farming is the primary livelihood, similar challenges likely exist. A study by Kamruzzaman et al. (2021) highlighted community-based adaptation, such as rainwater harvesting and crop diversification, as viable strategies, but their implementation in Meherpur remains understudied. Climate change also affects socio-economic systems. According to Hossain (2023), rural communities in southwestern Bangladesh face increased migration due to reduced agricultural productivity and climate-induced stressors. Meherpur's proximity to urban centers like Khulna may amplify such trends, though district-specific data is scarce.

The literature underscores that climate change significantly impacts southwestern Bangladesh, with rising temperatures, erratic rainfall, and salinity threatening agricultural systems in districts like Meherpur. However, district-specific studies are sparse, leaving a gap in understanding Meherpur's unique vulnerabilities and adaptation needs. This review highlights the importance of localized climate change analysis to inform sustainable development and resilience strategies in Meherpur, contributing to the broader discourse on climate impacts in rural Bangladesh.

3.5. Laws and policies

The framework of proper or ideal environmental conditions stands on some laws and policies in Bangladesh. In this section, we will have a brief look at the most relevant environmental laws and policies those had been taken by the Bangladesh Government over the years, which form the structure of the environmental framework of the country.

3.5.1. Bangladesh Environment Conservation Act

The Bangladesh Environment Conservation Act, 1995 (Act No. 1 of 1995) is the principal legislative framework for environmental protection and conservation in Bangladesh. Enacted on February 16, 1995, and administered by the Ministry of Environment, Forest and Climate Change (MoEFCC) through the Department of Environment (DoE), the Act was introduced to address growing concerns over environmental degradation and pollution. It got three new amendments in the year 2000, 2002, and 2010.

Its primary objectives include the conservation and improvement of the environment, prevention of environmental pollution, and sustainable use of natural resources. A significant feature of the Act is the provision to declare Ecologically Critical Areas (ECAs) in regions that are deemed environmentally vulnerable—such as the Sundarbans, Saint Martin's Island, and parts of Cox's Bazar—to restrict activities that could further harm these ecosystems.

Another core element of the Act is the requirement for all development or industrial projects to obtain an Environmental Clearance Certificate (ECC) from the DoE prior to commencement. These projects are categorized based on their potential environmental impact (Green, Orange-A, Orange-B, and Red), and the level of scrutiny increases accordingly. The Act also grants the government authority to set and enforce standards for air, water, and soil quality, control the disposal of waste, and monitor hazardous substances. Furthermore, it stipulates legal penalties, including fines and imprisonment, for any violations. The establishment of Environmental Courts, made possible through later legislation (Environment Court Act, 2000), also stems from the powers provided in this Act, enabling more focused legal action on environmental offenses.

The Act was amended in 2010 to incorporate stricter enforcement mechanisms and reflect emerging environmental concerns. Various rules and guidelines, such as the Environment Conservation Rules, 1997, and EIA guidelines, have since been developed under its provisions. Overall, this Act serves as the foundational legal tool for implementing both national and international environmental obligations, and plays a crucial role in promoting environmentally responsible development in Bangladesh.

3.5.2. Environmental Conservation Rules, 2023

The Environment Conservation Rules, 2023 (SRO No. 53/Law/2023) were officially enacted on March 5, 2023, superseding the earlier 1997 rules. Framed under Section 20 of the Bangladesh Environment Conservation Act, 1995, these updated regulations aim to balance rapid economic development with sustainable environmental management, offering a robust structure to control pollution, conserve ecologically sensitive areas, and ensure public participation.

Under the new regime, industrial projects are classified into four distinct categories, 'Green', 'Yellow', 'Orange', and 'Red', based on their potential environmental impact. Green-category projects require only an Environmental Clearance Certificate (ECC), while Yellow, Orange, and Red category projects must secure both 'Location Clearance' and 'Environmental Clearance Certificates' from the Department of Environment (DoE) before beginning construction or operation. Exceptions apply to facilities in approved economic zones and export-processing zones, which need only the ECC.

The Rules also streamline environmental governance through clear processes for environmental sampling, public complaints, and environmental impact assessments (EIA). They establish strict thresholds for emissions and effluents, mandate the development and implementation of waste and wastewater treatment systems, and require ongoing monitoring and compliance reports. Provisions for public participation (Rule 3) allow citizens affected by pollution to seek redress within 30 working days, and ensure that communities can submit feedback on project EIAs . Additional regulations address noise pollution and specify environmental standards for water, air, and soil quality, complemented by mandatory establishment of sewage treatment plants for industrial establishments.
In summary, the 2023 Rules introduce stronger clarity and enforcement mechanisms, especially through dual clearance certificates, stricter environmental standards, public grievance channels, and updated sectoral classifications, to reinforce environmental safeguards and operational accountability across Bangladesh's industrial and infrastructural growth landscape.

3.5.3. Air Pollution (Control) Rules, 2022

The Air Pollution (Control) Rules, 2022 (formalized as SRO No. 255-Law/2022 on July 26, 2022, under Section 20 of the Bangladesh Environment Conservation Act, 1995) were issued to address the dire public health and environmental threats posed by worsening air quality. These comprehensive rules empower the Director General of the Department of Environment (DoE) to design and execute a National Air Quality Management Plan, declare areas with persistently poor air quality as "Degraded Air Sheds", and create detailed catalogues of pollution-causing activities spanning industries, vehicles, construction projects, waste sites, brick kilns, and more. To ensure collaborative governance, the Rules establish a 27-member high-level National Executive Council chaired by the Cabinet Secretary and backed by an expert secretariat. The Council is tasked with overseeing the effectiveness of air quality measures and issuing policy guidance. Rule 15 specifically mandates the formation of a multi-agency implementation committee that includes ministries, government bodies, universities, and local government representatives. Legally, the Rules impose penalties of up to 2 years' imprisonment and a fine of up to Tk 200,000 for any non-compliance tied to releasing harmful air pollutants. They also introduce innovative incentives, Rule 16 sets aside award for individuals or institutions contributing to air quality improvement.

Additionally, the DoE is directed to use mobile courts and collaborate with agencies like the BRTA, BRTC, and local governments to enforce emissions standards, monitor construction dust, shutter illegal kilns, and control vehicular black smoke. A key element in prevention is the Vehicle Emission Inspection Program (VEIP) under the CASE project, which tracks and curtails emissions from diesel vehicles, two-wheelers, and CNG units—with findings showing diesel vehicles are the worst offenders. Despite these new rules, environmental advocates have noted concerns, such as elevated permissible particulate levels compared to WHO recommendations (increased to 35 µg/m³ from 15 µg/m³) and the absence of a standalone Clean Air Act. Since implementation, DoE's mobile court operations under the 2022 Rules have led to widespread enforcement actions, shutting illegal brick kilns, fining construction sites, penalizing smoky vehicles, and collecting millions of taka in fines across Bangladesh.

In summary, the Air Pollution (Control) Rules, 2022 provide a legally binding, multi-faceted framework with enforcement powers, institutional collaboration, public incentives, and periodic review mechanisms aimed at reversing the country's toxic air crisis, though experts are still calling for stricter standards and deeper implementation.

3.5.4. Noise Pollution (Control) Rules, 2006

The Noise Pollution (Control) Rules, 2006 were introduced under Section 20 of the Bangladesh Environment Conservation Act, 1995, to regulate sound levels across different zones—silent, residential, mixed, commercial, and industrial—and to mitigate the growing issue of noise pollution, particularly in urban centers like Dhaka. These Rules define daytime (6 AM–9 PM) and nighttime (9 PM–6 AM) periods and set permissible noise limits: 50 dB day / 40 dB night in silent areas, 55/45 dB in residential zones, 60/50 dB in mixed areas, 70/60 dB in commercial zones, and 75/70 dB in industrial areas. Silent zones, which include hospitals, schools, offices, and a 100-meter buffer, strictly prohibit vehicle horn use. The Rules also regulate machinery usage, such as construction equipment, restricting their operation within 500 m of residential areas and during nighttime hours without permission. For social, cultural, political, or religious events in open spaces, permission must be obtained three days in advance (or one day in urgent cases), with operations limited to five hours per day and no later than 10 PM. Notably, religious gatherings and national celebrations are exempt from these regulations. Enforcement is supported through mobile courts and empowered DoE officials who can issue warnings, seize offending equipment, and levy penalties: up to 1 month jail or a BDT 5,000 fine for first offenses, escalating to six months imprisonment or BDT 10,000 for repeat infractions. However, widespread implementation challenges persist due to poor monitoring and lack of clarity about enforcement roles, especially concerning horn use and loudspeaker noise, which results in habitual violations across the country.

3.5.5. The Bangladesh Water Act, 2013

The Bangladesh Water Act, 2013 is a comprehensive legal framework for integrated water resources management, enacted in August 2013 under the guidance of the Ministry of Water Resources and operationalized through the National Water Resources Council (chaired by the Prime Minister) and its Executive Committee. The Act asserts government ownership of all forms of water, surface, groundwater, rainwater, seawater, and atmospheric water, on behalf of the people, yet allows private landowners limited use of surface water on their property. One of its key reforms is the requirement of permits for large-scale water withdrawals and the prohibition of any activity, such as constructing structures or dredging, that obstructs natural water flows, without prior authorization. The Act establishes a clear hierarchy for water use in areas with scarce resources, prioritizing drinking water, domestic use, irrigation, fish culture, biodiversity, wildlife, ecological flow, industry, salinity control, power generation, recreation, and miscellaneous purposes. It mandates public hearings for national water management plans and empowers the Executive Committee to issue protection and compliance orders, along with penalties of up to five years' imprisonment or a fine of BDT 10,000 for non-compliance. In addition, Section 28 defines water pollution, such as discharges from textile factories, as a punishable offence, allowing for compensation recovery and even freezing of bank accounts under Section 43 by invoking the "polluter pays" principle.

3.5.6. The Bangladesh Water Rules, 2018

The Bangladesh Water Rules, 2018, officially gazetted on August 16, 2018, under the auspices of the Water Act, 2013, provide detailed guidance to operationalize the Act's broad legal framework for water management. Crafted by the Water Resources Planning Organization (WARPO) and overseen by the Executive Committee of the National Water Resources Council, these Rules set in motion practical mechanisms to prevent unsustainable water use, unauthorized construction on water bodies, and pollution. Under the Rules, the minimum safe yield of groundwater aquifers in various regions must be scientifically determined through surveys and officially declared in the Gazette, with WARPO responsible for ensuring that withdrawals, especially in water-stressed zones, do not exceed these limits. A permit (No Objection Certificate) is required for most commercial or large-scale water-related activities, though small domestic tube-well use is exempt unless in declared stress areas. Applications must be submitted to the Executive Committee, which issues Clearance Certificates after reviewing compliance with the National Water Resources Plan. To enforce compliance, the Rules empower authorities to issue compliance or protection orders, demand removal of unauthorized structures, impose fines, and even issue imprisonment for violations. They also introduce a clear priority hierarchy of water usage in stressed regions, echoing the Act's ranking: drinking, domestic, irrigation, fishery, ecology, industry, power, and recreation.

3.5.7. The National 3R Strategy for Waste Management, 2010

The National 3R Strategy for Waste Management, 2010 was officially endorsed by the Government of Bangladesh in November 2010 and launched in December 2010 by the Ministry of Environment, Forest, and Climate Change (then MoEF) and the Department of Environment (DoE) in collaboration with the UN Centre for Regional Development (UNCRD). As a comprehensive, multi-sectoral policy, the Strategy promotes the principles of Reduce, Reuse, and Recycle (3R) to tackle waste issues across urban and rural sectors, integrating municipal, industrial, biomedical, institutional, commercial, agricultural, and agricultural-waste streams. It sets ambitious targets such as eliminating open dumping in rivers, wetlands, floodplains by 2015, while encouraging mandatory source segregation and developing markets and incentives for recycled products. The Strategy defines key guiding principles: waste should be treated as a resource, source-separated, and processed using affordable, appropriate, and environmentally sound technologies. It emphasizes cleaner production, life-extension of products, industrial symbiosis, the "polluter pays" principle, and formalized public-private partnerships. To ensure institutional backing, the DoE was instructed to set up a 3R secretariat, with stakeholders, including local governments, NGOs, private sector, academia, and informal recyclers, involved via public consultations. An action plan framework directs local authorities to set quantified targets, secure funding (including via Clean Development Mechanism), periodically review progress, and execute waste reduction and resource recovery activities.

3.5.8. Solid Waste Management Rules, 2021

The Solid Waste Management Rules, 2021 were formally gazetted in late 2021 under Section 20 of the Bangladesh Environment Conservation Act, 1995, marking the first comprehensive national legal framework for municipal and commercial waste. These Rules impose obligations on a broad range of actors, residents, households, businesses, manufacturers, importers, retailers, and waste collectors, to segregate waste at source into at least three categories (organic, inorganic, hazardous) using color-coded bins, and ensure proper packaging and disposal. Landfilling or open dumping of unsegregated waste is strictly forbidden, and plastic bags are banned as waste containers. The Rules introduce Extended Producer Responsibility (EPR), requiring manufacturers and importers of items such as tin, glass, plastic, single-use plastics, multilayer packaging, bottles, cans, etc., to collect post-consumer waste. They also establish a national coordination committee comprising officials from the Environment Ministry, Finance Division, city corporations, and experts to oversee implementation, issue directives, and enforce compliance. Penalties for breaches include up to two years' imprisonment, fines up to BDT 200,000, or both.

3.5.9. The National Water Policy, 1999

The National Water Policy (NWP), 1999 is Bangladesh's first formalized water governance policy, approved by the government in January 1999 and developed under the leadership of the Ministry of Water Resources. It was designed to ensure the sustainable development, management, and equitable distribution of the country's vast and vital water resources. The policy was shaped in response to mounting water challenges in the country, including seasonal variability, pollution, poor irrigation efficiency, flood management issues, and transboundary river concerns. A central objective of the National Water Policy is to ensure equitable and sustainable access to water for all sectors, especially for drinking, sanitation, agriculture, fisheries, industry, and environmental conservation. It emphasizes integrated water resources management (IWRM) and explicitly acknowledges the importance of participation by local communities, NGOs, and the private sector. It mandates that all water sector projects must conduct environmental impact assessments (EIA) to prevent adverse ecological outcomes. The policy recognizes the special needs of women and marginalized groups in water use and decision-making, and stresses decentralization and community-based management—especially for minor irrigation and rural water supply.

The policy promotes efficient use of surface and groundwater, and encourages conjunctive use to reduce over-extraction from aquifers. It also introduces guidelines for floodplain zoning, embankment management, water pricing, and private sector participation in infrastructure development. Importantly, the National Water Policy provides the foundation for the National Water Management Plan (NWMP) and guides other legal instruments like the Bangladesh Water Act, 2013, and Bangladesh Water Rules, 2018.

Despite its forward-looking vision, the implementation of the National Water Policy has faced institutional and financial challenges. Overlapping responsibilities among water-related agencies, inadequate coordination, and the lack of a unified regulatory authority have hampered policy effectiveness. Nevertheless, the 1999 Policy remains a cornerstone in Bangladesh's journey toward integrated, inclusive, and sustainable water governance, particularly in light of climate vulnerability, population growth, and transboundary water conflicts.

3.5.10. The National Land Use Policy, 2001

The National Land Use Policy, 2001 was introduced by the Ministry of Land of Bangladesh with the aim of ensuring planned, equitable, and sustainable use of land—a critical and increasingly scarce resource in the country. Officially adopted in August 2001, the policy seeks to prevent the uncoordinated and excessive conversion of agricultural land for non-agricultural uses, protect the environment, promote food security, and mitigate the negative impacts of urbanization, industrialization, and population growth on land resources. One of the primary objectives of the policy is to protect and preserve arable land, especially in the face of rapid urban sprawl and infrastructure expansion. It explicitly prohibits the conversion of fertile agricultural land into housing, industry, or other non-agricultural purposes without government approval. The policy promotes zoning regulations, categorizing land into uses such as agricultural, residential, commercial, industrial, forest, wetland, and ecologically sensitive areas, to ensure land resources are utilized in a rational and scientific manner.

The policy also emphasizes the preparation of land use maps and land zoning based on local ecological and geographical characteristics. It calls for the integration of GIS and remote sensing in land monitoring and management. Additionally, it encourages the formation of land use planning committees at national, district, and upazila levels to oversee policy enforcement and promote inter-agency coordination. The policy recognizes the need for public awareness and participation in land management decisions, and underlines the importance of gender equity, especially in terms of women's land rights and access. Environmental conservation is a major concern reflected in the policy, which discourages activities such as the filling of water bodies, destruction of hills, and deforestation. It aligns with broader national strategies including the National Environment Policy, 1992 and the Bangladesh Climate Change Strategy and Action Plan (BCCSAP), 2009 by addressing the role of land use in ecological sustainability.

Chapter-4: Land Use and Land Cover condition of the study area.

Land use and land cover (LULC) analysis is a critical process in understanding how land surfaces are utilized and characterized, providing insights into the interaction between human activities and the natural environment. Land use refers to the human activities or purposes assigned to land, such as agriculture, urban development, or forestry, while land cover describes the physical material on the Earth's surface, such as vegetation, water bodies, or built structures. LULC analysis involves mapping, monitoring, and assessing these patterns over time, often using remote sensing, geographic information systems (GIS), and field surveys.

This analysis is essential for applications like urban planning, environmental management, disaster risk assessment, and climate change studies. By examining changes in land use and cover, researchers can evaluate impacts on ecosystems, biodiversity, carbon cycles, and resource availability. For example, LULC data helps identify deforestation trends, urban sprawl, or wetland degradation, informing sustainable development policies. Advanced technologies, such as satellite imagery and machine learning, enhance the accuracy and efficiency of LULC mapping, enabling dynamic monitoring of global and regional landscapes.

In this study, LULC analysis of Meherpur district has been done in several dimensions. An overall LUCL analysis has been done withstanding three different Upazilas and two Paurashavas. The LULC was performed using Sentinel images from 2024. Google Earth Engine was used to run the operations. In each classification "GME classifier" was used to classify the images (Leurcharusmee et al., 2014). Each classification was categorized into five different classes. These were 'water bodies', 'sparse vegetation or agricultural land', 'dense vegetation', 'built-up areas', and 'barren land'.

4.1. LULC of the Meherpur district (Including three Upazila)

The trained classifier was applied to the median composite to generate a classified image, assigning each pixel to one of the five land cover classes. According to this study following classes of land use and land cover types are identified, which are shown in Table 4.1. Based on image interpretation, major classes of land use and land cover are agricultural or sparse vegetation (87.53%), but on the other hand, water bodies classes are showing less amount of area (2.57%). In reality, water bodies can be higher percentages because most of the water bodies are covered with aquatic vegetation. Even built-up area is also underestimated because most of the village settlements are covered with trees, which are classified as dense vegetation.

Table 4.1: Land Use and Land Cover Type of Meherpur District

Class name	Percentage %	Area [metre^2]	Area (Sq km)
Water bodies	2.57	18685420.39	18.68542039
Agricultural or sparse vegetation	87.53	637562190.7	637.5621907
Dense vegetation	8.51	61959309.15	61.95930915
Builtup area	1.07	7767298.68	7.76729868
Barren land	0.34	2452657.42	2.45265742

4.2. LULC of the individual Upazilas:

4.2.1. Meherpur Upazila

Meherpur Upazila's LULC data underscores its rural and agricultural focus. Sparse vegetation or agricultural land covers 89.81% (236.63 square kilometers), reinforcing the region's agrarian economy.

Dense vegetation occupies 6.54% (17.22 square kilometers), while waterbodies account for 2.32% (6.10 square kilometers), indicating a balanced presence of natural features. Built-up areas are minimal at 0.94% (2.47 square kilometers), and barren land is scarce at 0.4% (1.05 square kilometers). Compared to Meherpur Paurashava, the Upazila has less urban development and more extensive agricultural land, typical of a broader rural administrative unit. Details have been given in Table 4.2 and Figure 4.2.

Table 4.2: Land Use and Land Cover Type of Meherpur upazila

Classes	Percentage %	Area [SQ km]
Waterbodies	2.32	6.099503
Sparse vegetation or agricultural land	89.81	236.6251
Dense vegetation	6.54	17.2229
Built-up areas	0.94	2.468198
Barren land	0.4	1.04754

4.2.2. Gangni Upazila

The land use and land cover (LULC) data for Gangni Upazila reveals a predominantly agricultural landscape. Sparse vegetation or agricultural land dominates, covering 90.1% of the total area, equivalent to 311.07 square kilometers (311,073,138.2 square meters). Dense vegetation, likely representing forested or thickly vegetated areas, accounts for 6.46% (22.29 square kilometers). Waterbodies, such as rivers or ponds, constitute 2.67% (9.22 square kilometers), indicating a moderate presence of aquatic features. Built-up areas, representing urban or residential zones, are minimal at 0.47% (1.63 square kilometers), and barren land is even less significant at 0.3% (1.05 square kilometers). This distribution highlights the rural and agrarian character of Gangni Upazila, with limited urban development. Details have been given in Table 4.3 and Figure 4.3.

Table 4.3: Land Use and Land Cover Type of Gangni Upazila

Classes	Percentage %	Area [metre^2]	Area (Sq Km)
Waterbodies	2.67	9224062	9.224062
Sparse vegetation or agricultural land	90.1	3.11E+08	311.0731
Dense vegetation	6.46	22289490	22.28949
Built-up areas	0.47	1627096	1.627096
Barren land	0.3	1045696	1.045696

4.2.3. Mujibnagar Upazila

The LULC data for Mujibnagar closely mirrors the rural patterns seen in the other Upazilas. Sparse vegetation or agricultural land is the most extensive class, covering 90.87% (105.98 square kilometers or 105,981,967.2 square meters). Dense vegetation accounts for 5.93% (6.91 square kilometers), and waterbodies cover 2.26% (2.64 square kilometers), both contributing to the natural landscape. Built-up areas are limited at 0.68% (0.79 square kilometers), reflecting minimal urban development. Barren land is the least significant at 0.27% (0.32 square kilometers). This distribution emphasizes Mujibnagar's predominantly agricultural character with sparse urban or barren features.

Table 4.4: Land Use and Land Cover Type of Mujibnagar Upazila

Classes	Percentage %	Area [metre^2]	Area (Sq Km)
Waterbodies	2.26	2635039	2.635039
Sparse vegetation or agricultural land	90.87	1.06E+08	105.982
Dense vegetation	5.93	6912119	6.912119
Built-up areas	0.68	788775.3	0.788775
Barren land	0.27	315840.9	0.315841

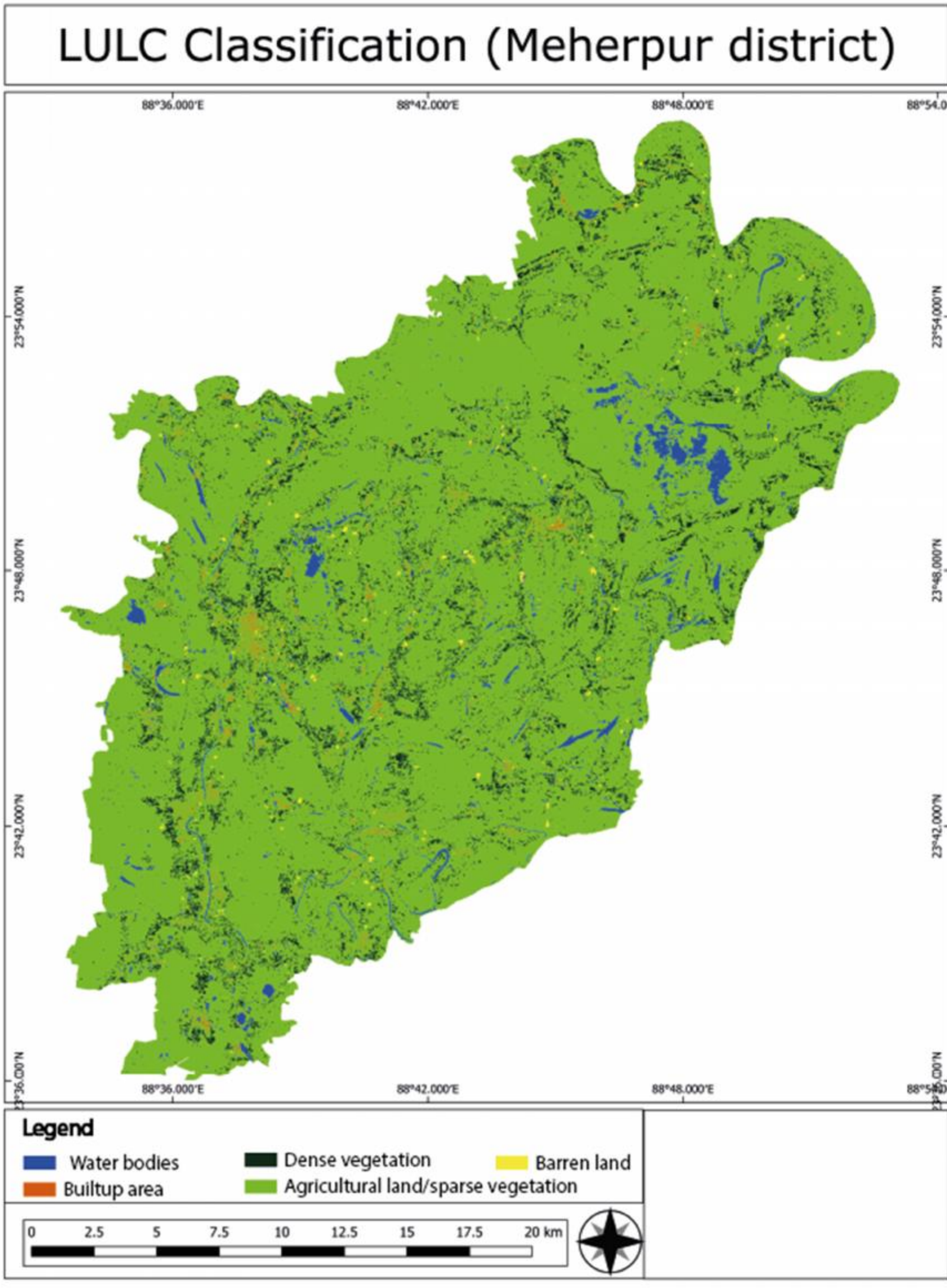

Figure 4.1: Land Use and Land Cover Map of The Meherpur District.

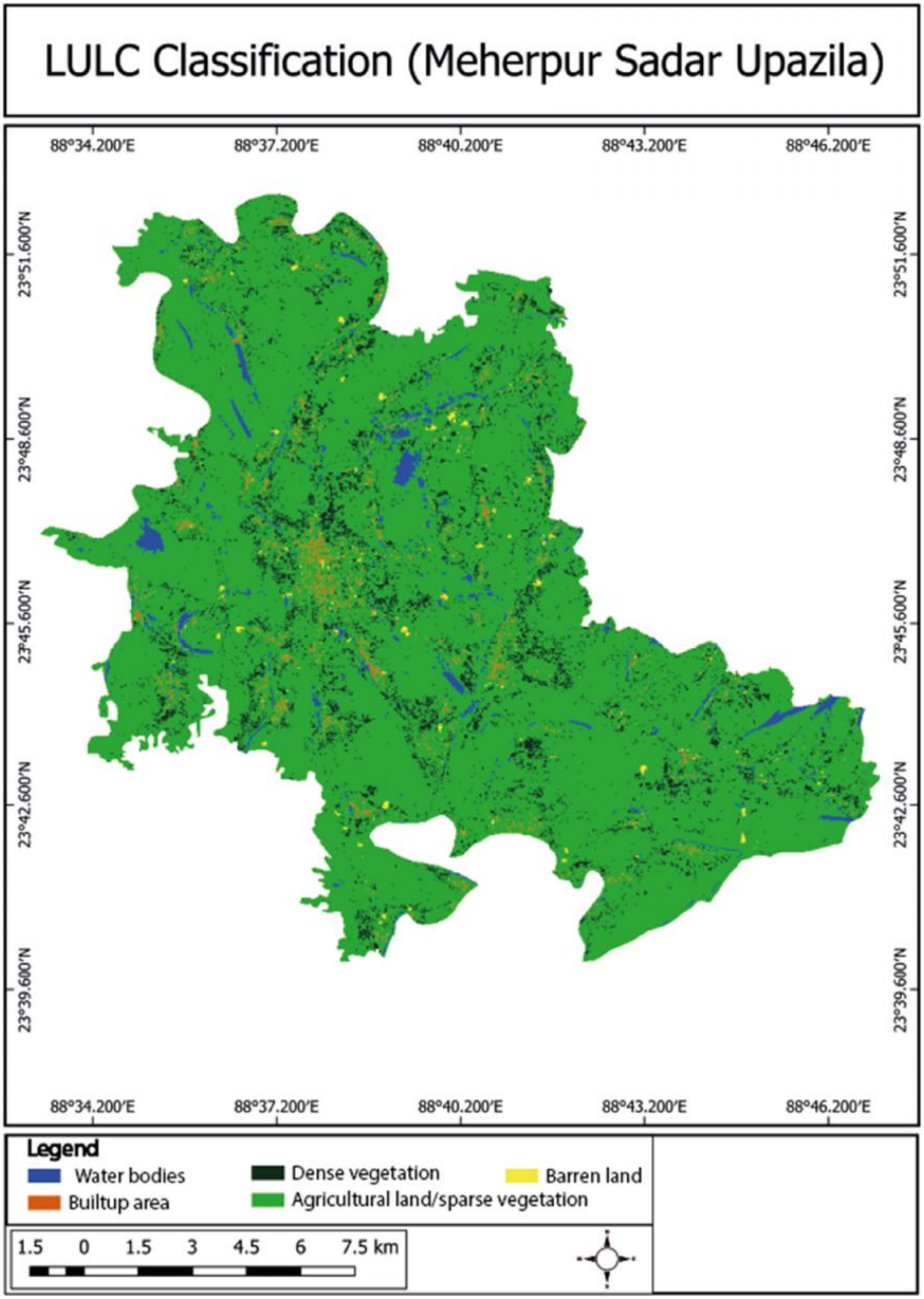

Figure 4.2: Land Use and Land Cover Map of The Meherpur Upazila

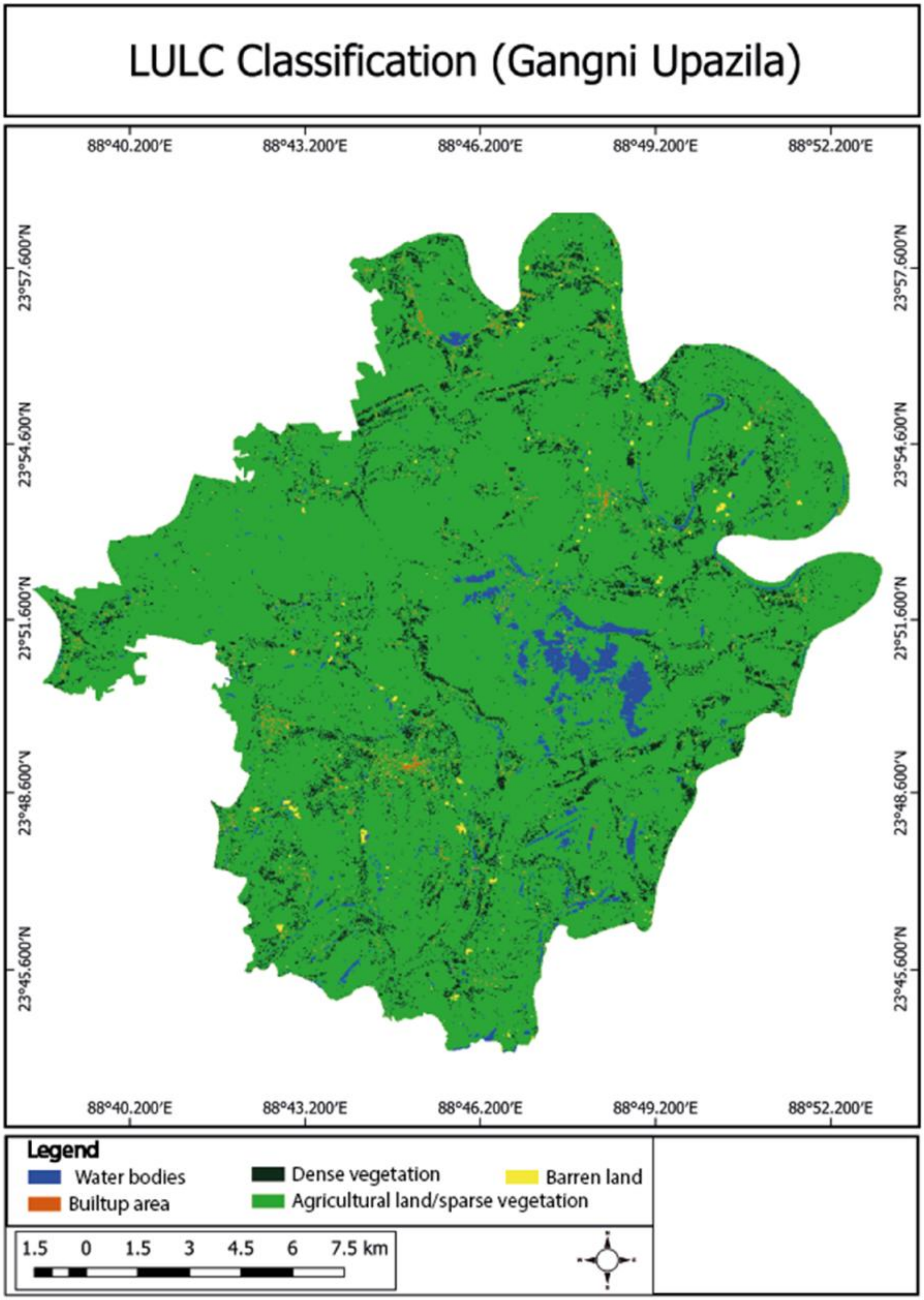

Figure 4.3: Land Use and Land Cover Map of the Gangni Upazila

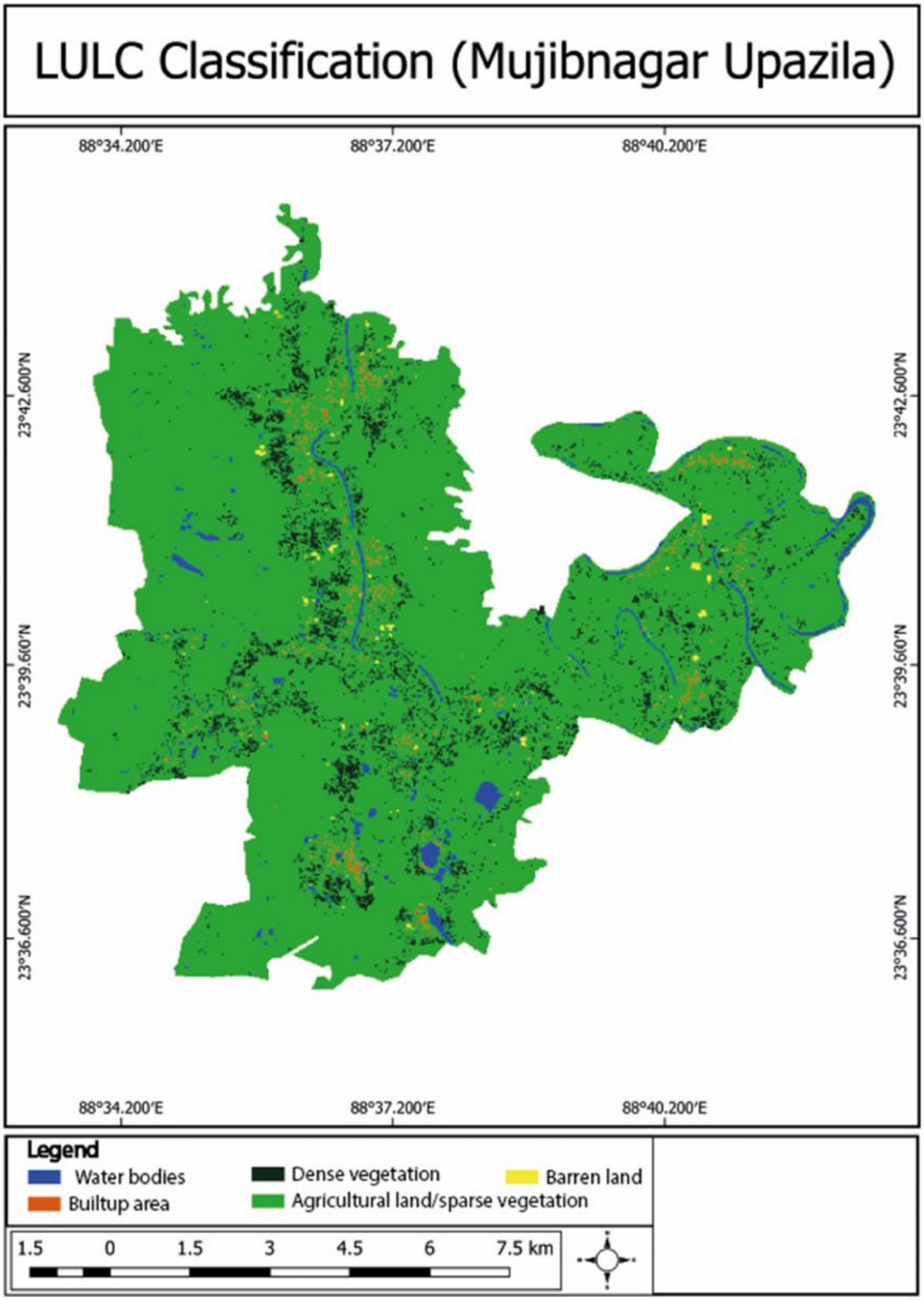

Figure 4.4: Land Use and Land Cover Map of the Mujibnagar Upazila

4.3. LULC of the Paurashavas

4.3.1. Meherpur Paurashava

The LULC data for Meherpur Paurashava shows a landscape heavily oriented toward agriculture, with sparse vegetation or agricultural land covering 81.85% (11.26 square kilometers or 11,262,784.48 square meters). Dense vegetation is notably higher than in other regions, at 12.92% (1.78 square kilometers), suggesting significant green cover or forested areas. Built-up areas account for 3.7% (0.51 square kilometers), the highest among the datasets, indicating a relatively urbanized setting compared to the Upazilas. Waterbodies are limited at 0.91% (0.13 square kilometers), and barren land is negligible at 0.61% (0.08 square kilometers). This distribution reflects a semi-urban area with substantial agricultural activity and green spaces. Details have been given in Table 4.5 and Figure 4.5.

Table 4.5: Land Use and Land Cover Type of Meherpur Paurashava

Classes	Percentage %	Area [metre^2]	Area (Sq km)
Waterbodies	0.91	125674.9	0.125675
Sparse vegetation or agricultural land	81.85	11262784	11.26278
Dense vegetation	12.92	1778465	1.778465
Built-up areas	3.7	509314	0.509314
Barren land	0.61	84334.46	0.084334

4.3.2. Gangni Paurashava

In Gangni Paurashava, a smaller administrative unit, the LULC pattern is similar to Gangni Upazila but with slight variations due to its more urbanized context. Sparse vegetation or agricultural land remains the dominant class, covering 87.78% (14.87 square kilometers or 14,873,549.8 square meters). Dense vegetation is slightly more prominent here at 8.34% (1.41 square kilometers), suggesting patches of greenery within the area. Built-up areas, at 1.86% (0.32 square kilometers), are more significant than in Gangni Upazila, reflecting the urban nature of the Paurashava. Waterbodies occupy 1.14% (0.19 square kilometers), and barren land is minimal at 0.87% (0.15 square kilometers). This indicates a blend of agricultural dominance with emerging urban features. Details have been given in Table 4.6 and Figure 4.6.

Table 4.6: Land Use and Land Cover Type of Gangni Paurashava

Classes	**Percentage %**	**Area [metre^2]**	**Area (Sq Km)**
Waterbodies	1.14	193741.2	0.193741
Sparse vegetation or agricultural land	87.78	14873550	14.87355
Dense vegetation	8.34	1413074	1.413074
Built-up areas	1.86	315756.9	0.315757
Barren land	0.87	147573.1	0.147573

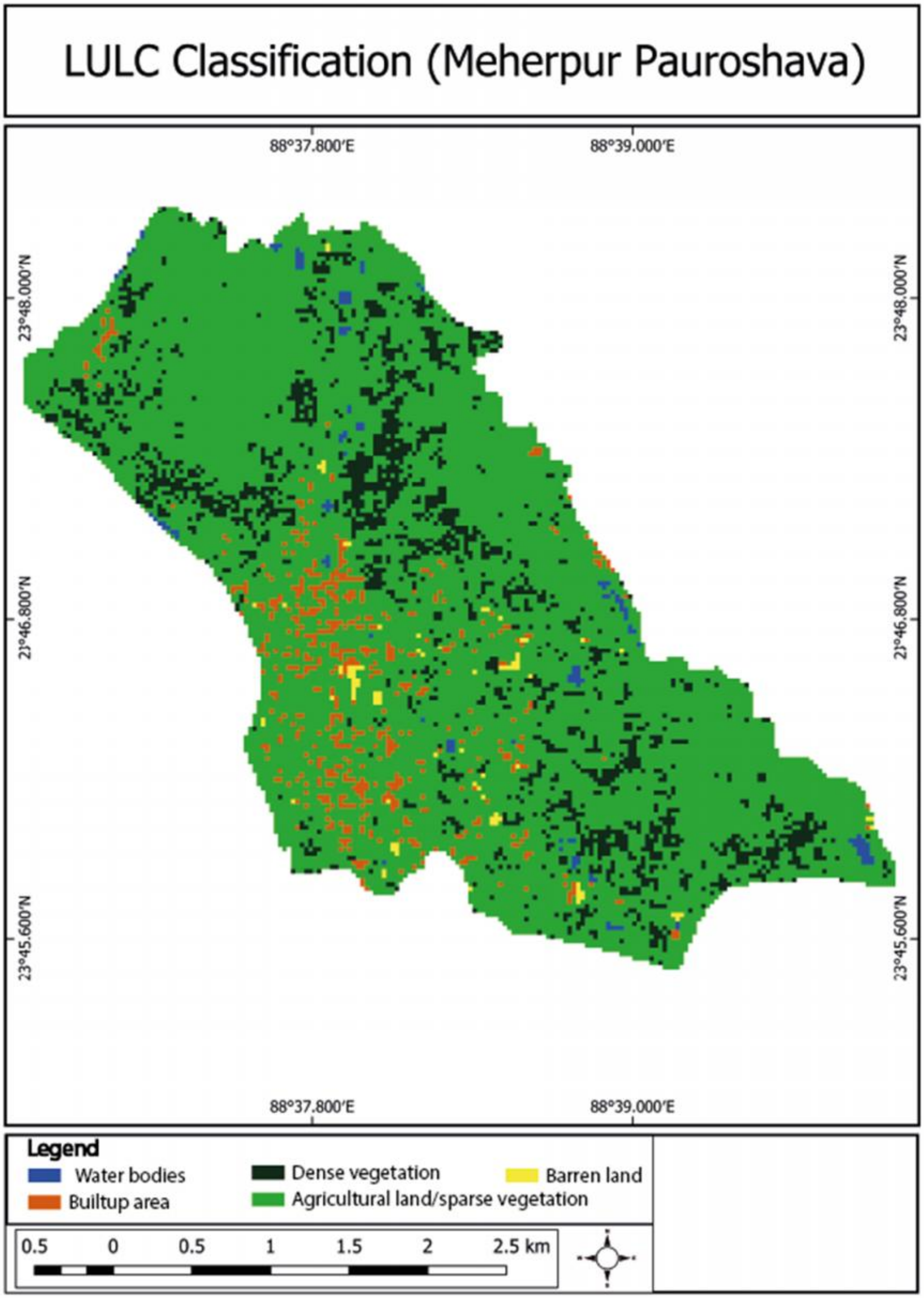

Figure 4.5: Land Use and Land Cover Map of the Meherpur Paurashava

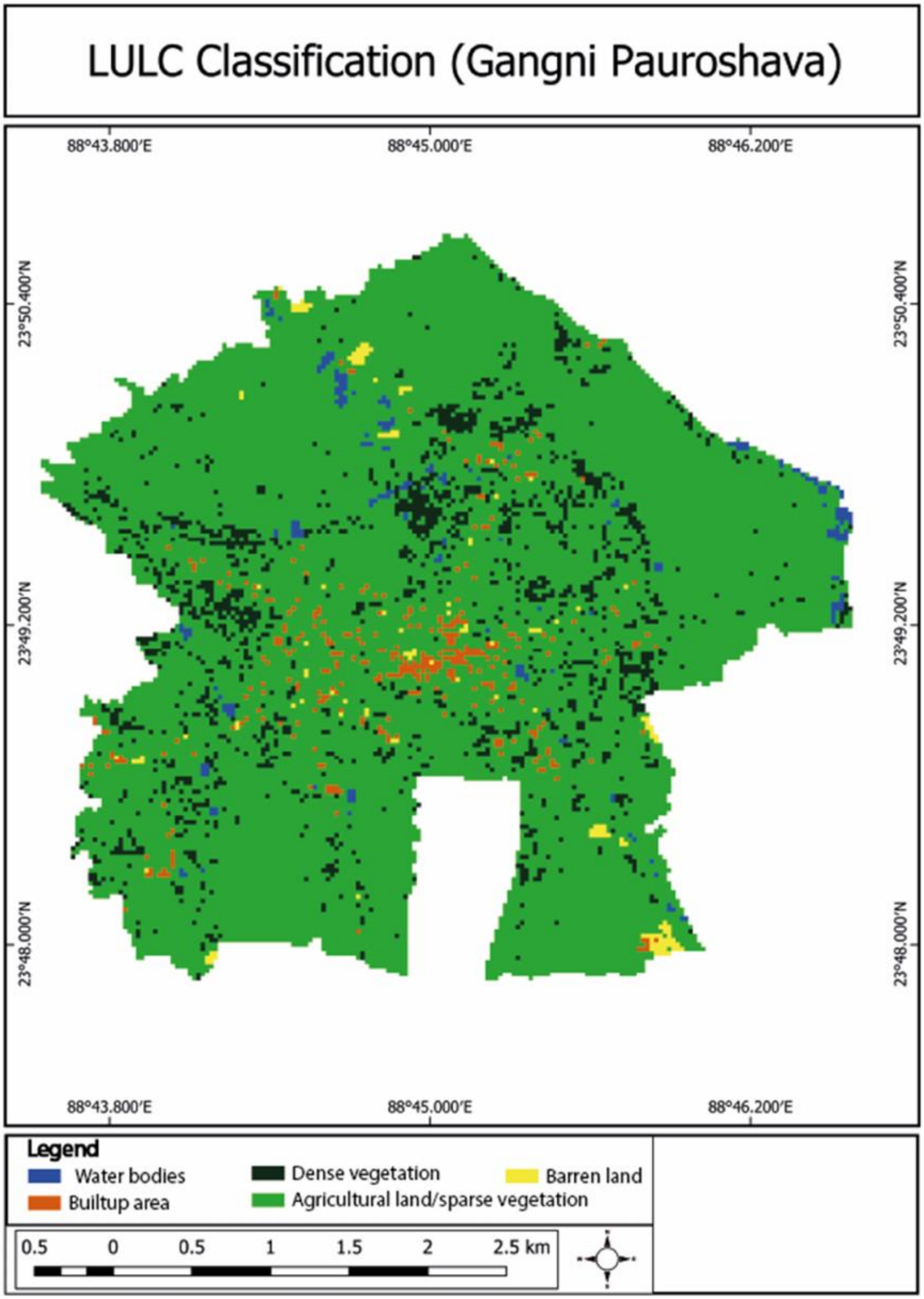

Figure 4.6: Land Use and Land Cover Map of the Gangni Paurashava

Chapter-5: Water Quality Assessment

Water quality assessment is a critical scientific process that evaluates the physical, chemical, and biological characteristics of water bodies to determine their suitability for various uses, such as drinking, agriculture, industrial activities, and sustaining aquatic ecosystems (Whitehead et al., 2009). This systematic analysis is essential for understanding the health of water resources, identifying pollution sources, and ensuring compliance with environmental standards and regulations. By examining parameters such as temperature, pH, dissolved oxygen (DO), turbidity, total dissolved solids (TDS), electrical conductivity (EC), total suspended solids (TSS), chloride, biological oxygen demand (BOD), and chemical oxygen demand (COD), water quality assessments provide a comprehensive picture of water conditions and their implications for human health, biodiversity, and environmental sustainability (Hounslow, 2018).

The importance of water quality assessment stems from the increasing pressures on water resources due to urbanization, industrialization, agricultural runoff, and climate change. Contaminants such as organic matter, heavy metals, nutrients, and pathogens can degrade water quality, posing risks to human health, including waterborne diseases, and threatening aquatic ecosystems by disrupting food chains and reducing biodiversity (Chapman et al., 2019). For instance, low DO levels can lead to hypoxic conditions, suffocating fish and other organisms, while high BOD and COD indicate organic pollution that may render water unsafe for consumption or irrigation. Similarly, elevated turbidity and TSS can reduce water clarity, affecting photosynthesis in aquatic plants and clogging water treatment systems (Askenaizer, 2003; Bozorg-Haddad et al., 2021; Prasanna Medha and Kumar, 2021). These assessments are vital for detecting such issues early, enabling timely interventions to protect water resources.

Water quality assessments typically employ a combination of field measurements, laboratory analyses, and advanced technologies like remote sensing and geographic information systems (GIS). Field data collection involves using instruments such as pH meters, turbidimeters, and DO probes to measure parameters in real-time, while laboratory tests provide detailed insights into chemical and biological contaminants. These methods allow researchers to monitor spatial and temporal variations in water quality, particularly in regions like Meherpur district, where seasonal changes (wet vs. dry seasons) influence water characteristics due to rainfall, runoff, and evaporation. For example, wet seasons often dilute pollutants, improving water quality, while dry seasons concentrate contaminants, exacerbating pollution levels.

Globally, water quality assessments inform policy decisions, guide water management strategies, and support sustainable development goals, particularly those related to clean water and sanitation. In regions like Meherpur, where agriculture dominates and urban centers are emerging, assessing water quality is crucial for ensuring safe irrigation, protecting public health, and maintaining ecological balance. High levels of pollutants, such as those indicated by elevated BOD or COD, can stem from agricultural runoff or untreated wastewater, necessitating targeted interventions like improved waste management or land-use regulations. Additionally, climate change exacerbates water quality challenges by altering precipitation patterns and increasing temperatures, which can intensify pollutant concentration and affect aquatic ecosystems.

In conclusion, water quality assessment is a cornerstone of environmental management, providing data-driven insights to safeguard water resources. By identifying pollution sources, assessing seasonal variations, and guiding mitigation efforts, it plays a pivotal role in promoting sustainable water use and protecting ecosystems and communities from the adverse effects of water degradation. In areas like Meherpur, such assessments are essential for balancing agricultural needs with environmental conservation, ensuring water remains a viable resource for future generations.

5.1. Surface water quality of Meherpur

In this connection water sample has to be collected from different surface water body for two seasons (Dry season and Wet season) and tested in the laboratory. The testing parameters of surface water are the Lab test for examining the ground water quality including (i) Hydro-Geological field parameter test (ii) Major Cation and Anion (dry seasons) of and surface water, (iii) Trace Element Analysis (dry seasons) of groundwater and surface water. All parameters will be tested in APHA/USEPA/ISO/IS method except some in-situ parameters (Temperature, Salinity, and Turbidity) to be tested by the electromagnetic method. In this study, 22 sample has been tested for this study among them 6, 7 and 7 sample has been collected from Meherpur Sadar Upazila, Ganni Upazila and Mujibnagar Upazila respectively. Water quality test result for dry season and wet season is showing in table-5.1 (in annex) and table-5.2 (in annex) respectively.

Surface water quality of Meherpur was tested over various parameters. Altogether, 12 parameters were tested to get a holistic idea about the water quality. The parameters were temperature, alkalinity, turbidity, BOD, COD, pH, DO, electrical conductivity, TDS, TSS, chloride, and salinity. To get the seasonal variation, we took data during the dry season and the wet season. In the dry season, water was collected from 22 points, and in the wet season, 12 points were selected as water collection points.

5.2. Dry Season Water Quality

The dry season table covers 22 locations, reflecting conditions when water bodies experience reduced flow and higher pollutant concentration due to less dilution. Key observations:
Temperature: Higher than the wet season, ranging from 23.8°C (Terail) to 32.4°C (Taranagar), reflecting warmer, drier conditions.

pH: Ranges from 6.51 (Kedarganj) to 9.7 (Biswanathpur), with some locations (e.g., Malshadaha, Biswanathpur) showing alkaline conditions (>9), potentially harmful to aquatic life.

Salinity: Remains low (0.01–0.04 ppt), similar to the wet season, indicating consistent freshwater characteristics.

Turbidity: Highly variable, from 12.1 NTU (Kedarganj) to 177 NTU (Taranagar). Taranagar's extremely high turbidity suggests significant sediment or pollution, reducing water clarity.

Dissolved Oxygen (DO): Ranges from 3.4 mg/L (Biswanathpur) to 9 mg/L (Malshadaha). Low DO at Biswanathpur could threaten aquatic life, while most sites are adequate (>5 mg/L).
Total Dissolved Solids (TDS): Varies from 117 mg/L (Ballovpur) to 522 mg/L (Terail), with higher values indicating concentrated dissolved substances due to lower water volumes.

Electrical Conductivity (EC): Ranges from 202 µS/cm (Taranagar) to 780 µS/cm (Terail), correlating with TDS and reflecting higher ionic content in the dry season.

Total Alkalinity: Ranges from 110 mg/L (Taranagar) to 420 mg/L (Bondor Muzibnagar Road), showing strong buffering capacity, especially at Bondor.

Total Suspended Solids (TSS): Varies from 4 mg/L (Kedarganj) to 420 mg/L (Taranagar), with Taranagar's high TSS indicating severe sediment or pollution issues.

Chloride: Ranges from <0.5 mg/L (Gopalpur, Kedarganj) to 51.98 mg/L (Harbhanga), generally low but slightly higher than the wet season.

Biological Oxygen Demand (BOD): Ranges from <0.5 mg/L (Gopalpur, Kedarganj) to 20 mg/L (Taranagar), with Taranagar showing significant organic pollution.

Chemical Oxygen Demand (COD): Ranges from 12 mg/L (Mohajonpur) to 200 mg/L (Taranagar), with Taranagar's high COD indicating substantial chemical or organic pollution.

The dry season data shows more variability and higher pollutant levels, particularly at Taranagar, which has extreme turbidity, TSS, BOD, and COD, indicating severe pollution. Alkaline pH in some areas and low DO at Biswanathpur is additional concerns.

5.3. Wet Season Water Quality

The wet season table includes data from 12 locations in Meherpur district, collected during the monsoon period when water bodies are typically replenished by rainfall. Key observations: Temperature: Ranges from 25.9°C (Amjhupi Meherpur) to 28.2°C (Taranagar), typical for tropical wet seasons, indicating stable thermal conditions.

pH: Varies from 5.9 (Terail) to 7.9 (Harbhanga), with most values near neutral (6.5–7.5), suitable for aquatic life. Terail's slightly acidic pH may indicate organic matter or pollution.

Salinity: Low across all sites (0.01–0.04 ppt), reflecting freshwater dominance typical of the wet season due to dilution from rainfall.

Turbidity: Ranges widely from 7.3 NTU (Harbhanga) to 67.3 NTU (GOR Pond), indicating variable water clarity. High turbidity at GOR Pond suggests sediment or organic matter, potentially impacting aquatic ecosystems.

Dissolved Oxygen (DO): Varies from 4.9 mg/L (GOR Pond) to 7.3 mg/L (Terail), generally within acceptable ranges (>5 mg/L) for aquatic life, though GOR Pond's lower DO could stress organisms.

Total Dissolved Solids (TDS): Ranges from 104 mg/L (Harbhanga) to 398 mg/L (Amjhupi Meherpur). Higher TDS may indicate dissolved minerals or pollutants but is within safe limits for most uses.

Electrical Conductivity (EC): Varies from 137 µS/cm (Gopalpur Meherpur) to 408 µS/cm (Dariapur), correlating with TDS and reflecting ionic content.

Total Alkalinity: Ranges from 110.2 mg/L (Terail) to 255.4 mg/L (Amjhupi Meherpur), indicating good buffering capacity against pH changes.

Total Suspended Solids (TSS): Varies from 5 mg/L (Harbhanga) to 67 mg/L (GOR Pond), with higher values suggesting sediment runoff, especially at GOR Pond.

Chloride: Ranges from 5.7 mg/L (Harbhanga) to 42.4 mg/L (Amjhupi Meherpur), generally low and safe for aquatic life.

Biological Oxygen Demand (BOD): Ranges from 4 mg/L (Harbhanga) to 25 mg/L (GOR Pond), with higher values indicating organic pollution. GOR Pond's high BOD suggests contamination.

Chemical Oxygen Demand (COD): Ranges from 25 mg/L (Harbhanga) to 88 mg/L (GOR Pond), with elevated levels at GOR Pond indicating significant organic or chemical pollutants.

The wet season data shows generally acceptable water quality, with GOR Pond standing out due to high turbidity, TSS, BOD, and COD, suggesting pollution from runoff or human activity. Most other locations have moderate parameters, suitable for aquatic ecosystems.

5.4. Comparison of Wet and Dry Seasons

Comparing water quality between the wet and dry seasons reveals distinct differences driven by seasonal hydrology and human impacts:

Temperature: Dry season temperatures (23.8–32.4°C) are higher than wet season (25.9–28.2°C) due to reduced water flow and warmer ambient conditions, potentially stressing aquatic ecosystems.

pH: Wet season pH (5.9–7.9) is generally closer to neutral, while dry season pH (6.51–9.7) shows alkaline extremes in some locations (e.g., Malshadaha, Biswanathpur), likely due to concentrated pollutants or algal blooms, which can harm aquatic life.

Salinity: Both seasons show low salinity (0.01–0.04 ppt), indicating consistent freshwater systems unaffected by seasonal changes.

Turbidity: Dry season turbidity is significantly higher at some sites (e.g., Taranagar at 177 NTU vs. 13.7 NTU in wet season), reflecting reduced water volume and concentrated sediments or pollutants. Wet season turbidity is also high at GOR Pond (67.3 NTU).

Dissolved Oxygen (grazingDO): Wet season DO (4.9–7.3 mg/L) is generally healthier than dry season (3.4–9 mg/L), with Biswanathpur's low DO (3.4 mg/L) in the dry season indicating potential hypoxia risks.

TDS and EC: Dry season shows higher TDS (up to 522 mg/L) and EC (up to 780 µS/cm) compared to wet season (TDS up to 398 mg/L, EC up to 408 µS/cm), due to less dilution and higher pollutant concentration.

Total Alkalinity: Dry season alkalinity is higher (up to 420 mg/L) than wet season (up to 255.4 mg/L), reflecting concentrated minerals in reduced water volumes.

TSS: Dry season TSS is notably higher at Taranagar (420 mg/L vs. 34 mg/L in wet season), indicating sediment accumulation, while GOR Pond has high TSS in the wet season (67 mg/L).

Chloride: Dry season chloride levels are slightly higher (up to 51.98 mg/L) than wet season (up to 42.4 mg/L), but both remain low and safe.

BOD and COD: Dry season shows higher extremes, with Taranagar at 20 mg/L BOD and 200 mg/L COD compared to wet season's 25 mg/L BOD and 88 mg/L COD at GOR Pond. This suggests greater organic and chemical pollution in the dry season due to reduced dilution.

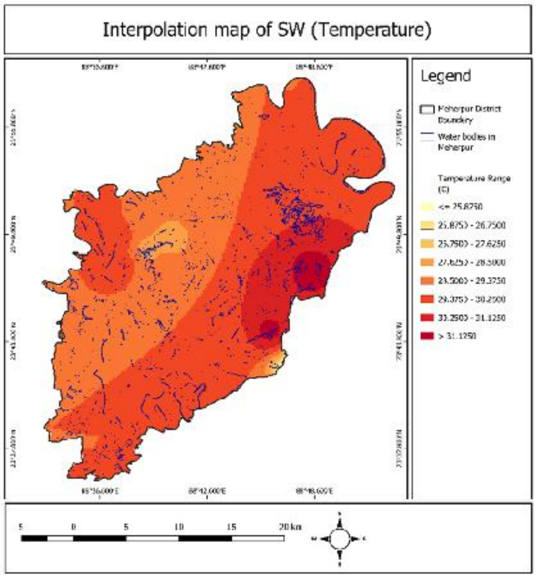

Figure 5.1: Temperature in dry season

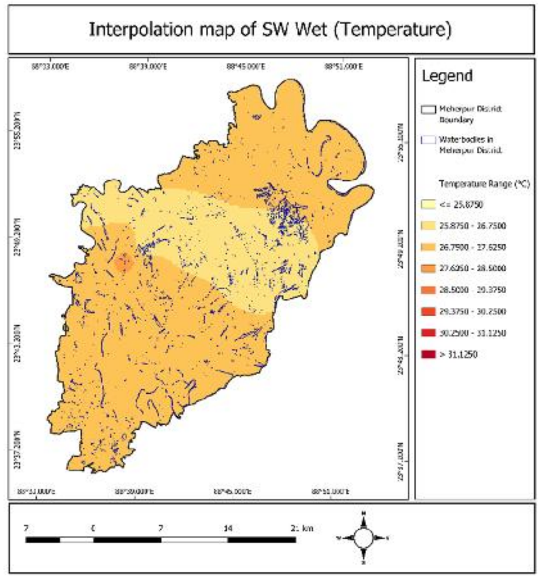

Figure 5.2: Temperature in the wet season

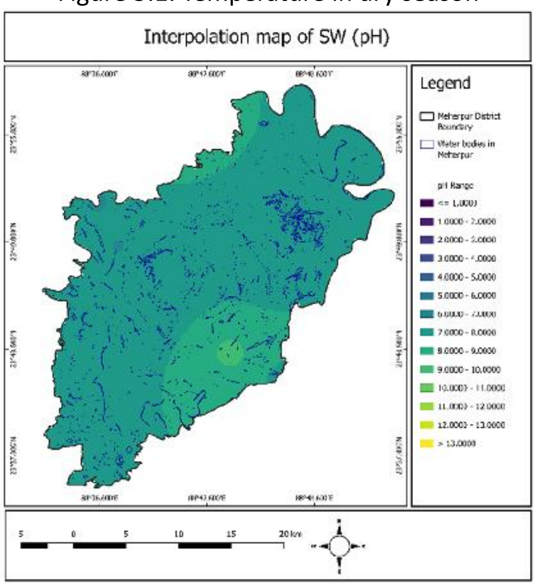

Figure 5.3: pH in the dry season

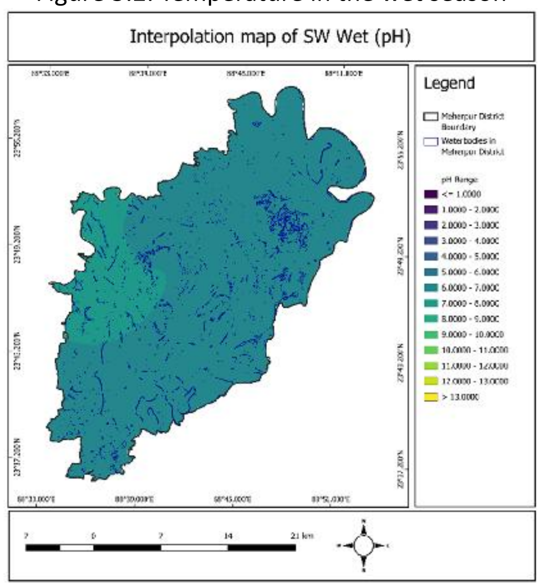

Figure 5.4: pH in the wet season

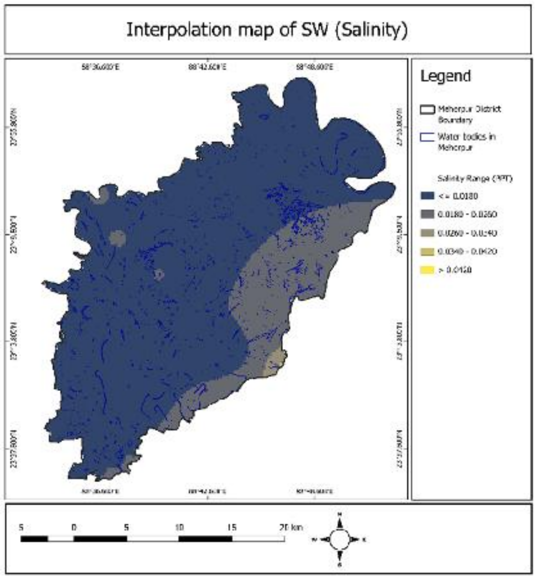

Figure 5.5: Salinity in the dry season

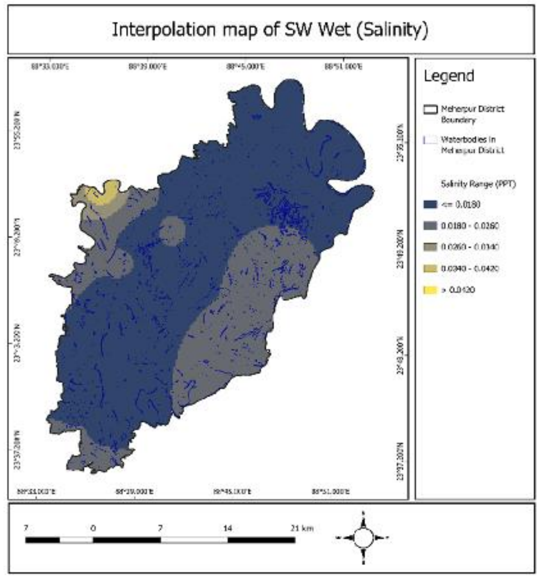

Figure 5.6: Salinity in the wet season

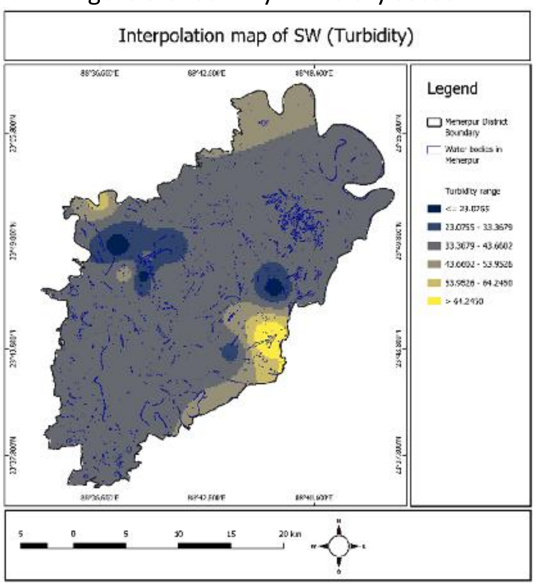

Figure 5.7: Turbidity in the dry season

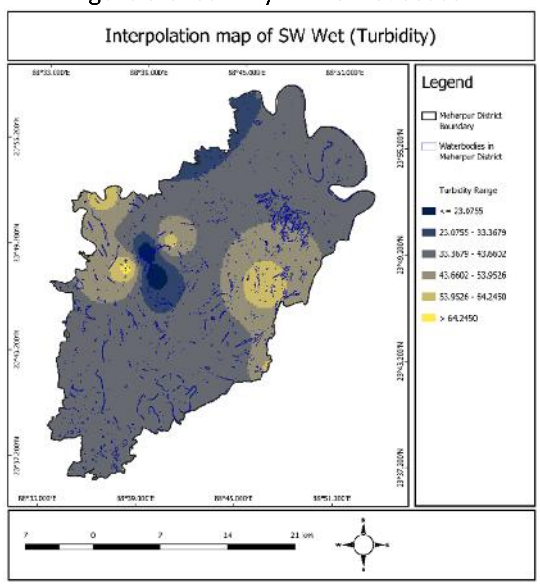

Figure 5.8: Turbidity in the wet season

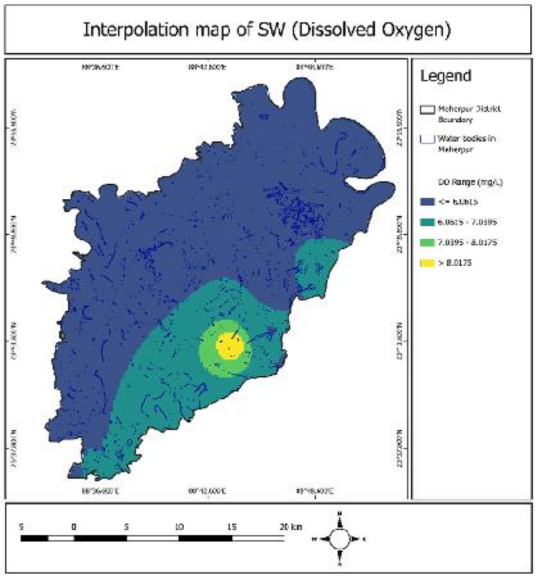

Figure 5.9: DO in the dry season

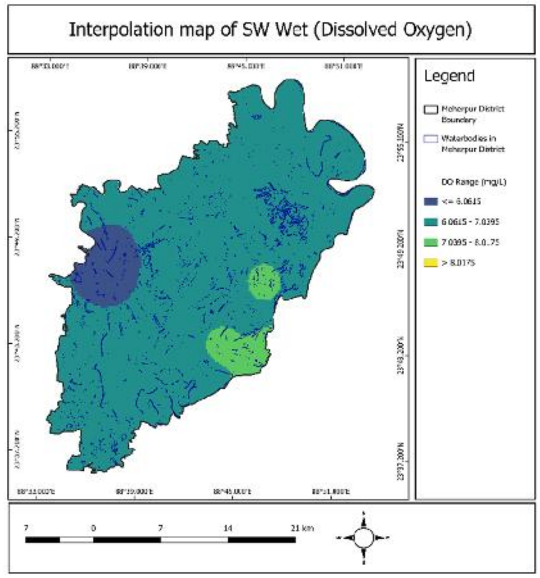

Figure 5.10: DO in the wet season

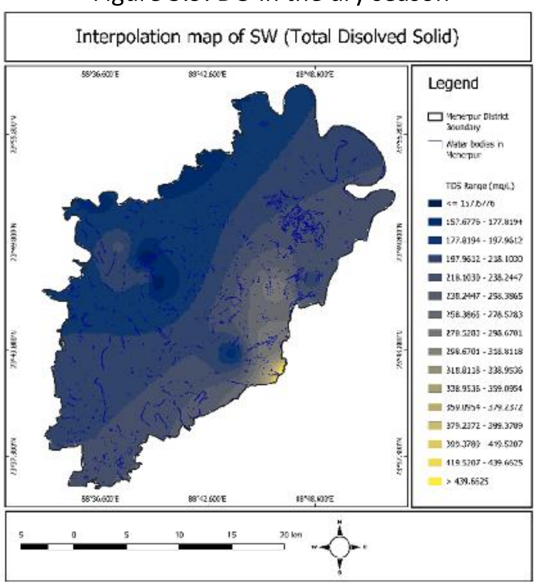

Figure 5.11: Total dissolved solids in the dry season

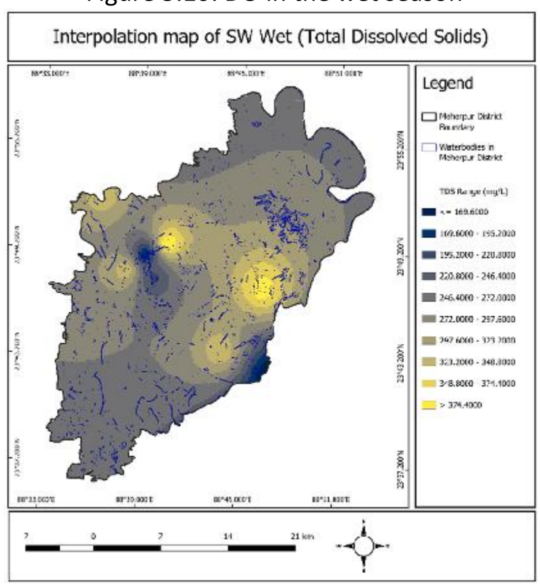

Figure 5.12: Total dissolved solids in the wet season

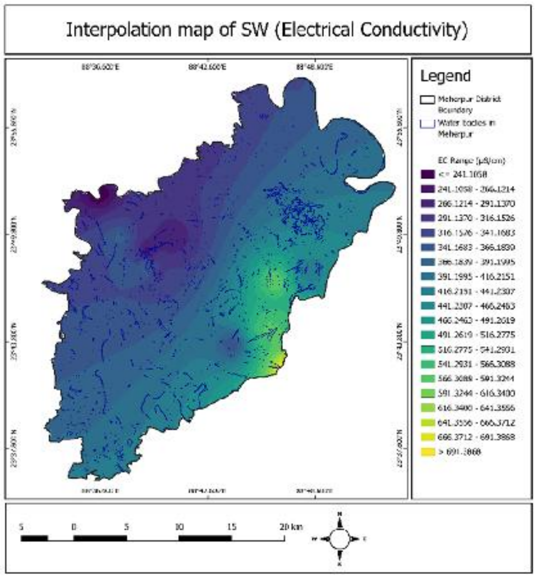

Figure 5.13: Electrical conductivity in the dry season

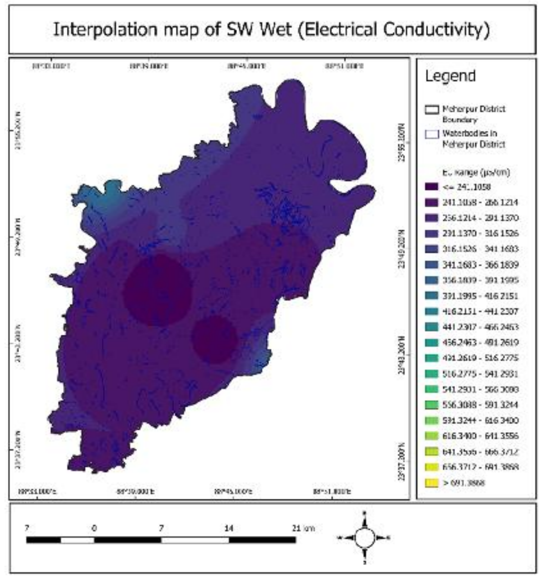

Figure 5.14: Electrical conductivity in the wet season

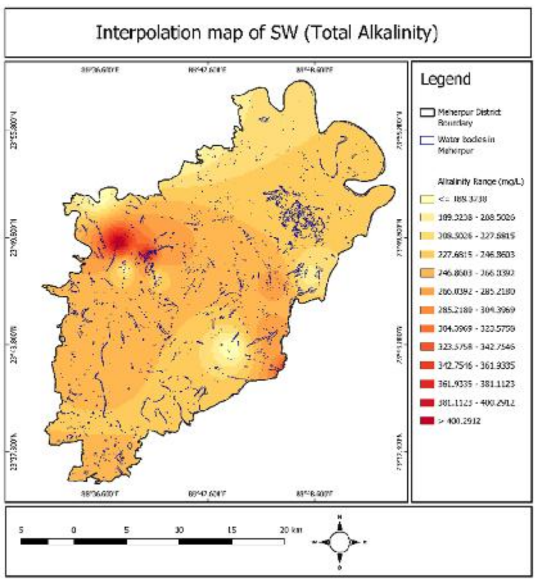

Figure 5.15: Total alkalinity in the dry season

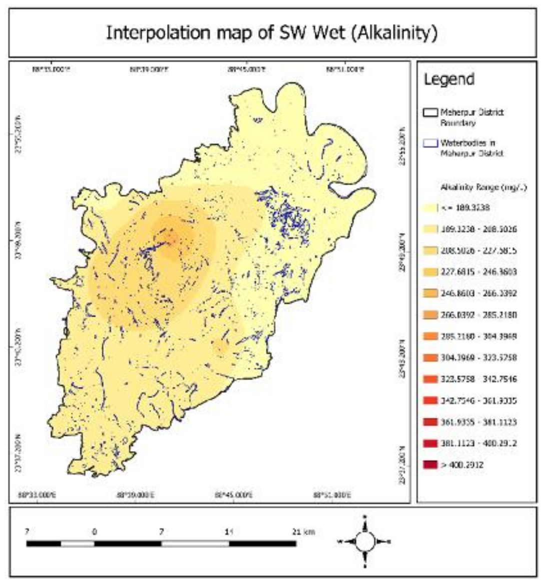

Figure 5.16: Total Alkanity in the wet season

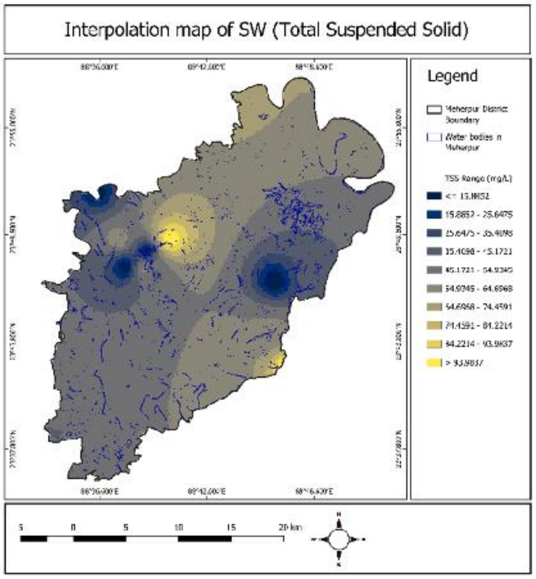

Figure 5.17: Total suspended solids in dry season

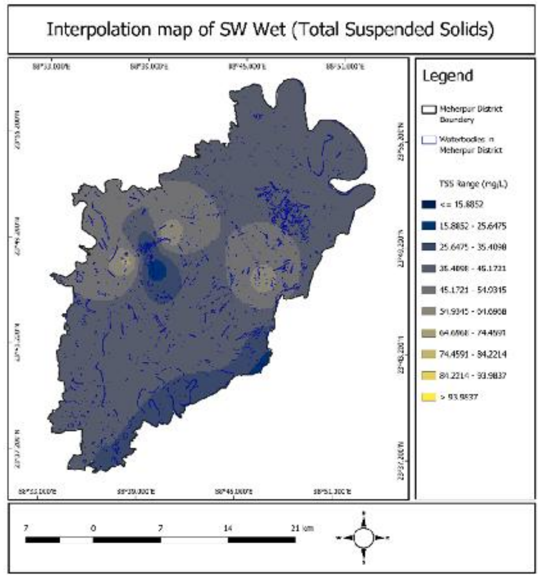

Figure 5.18: Total suspended solids in the wet season

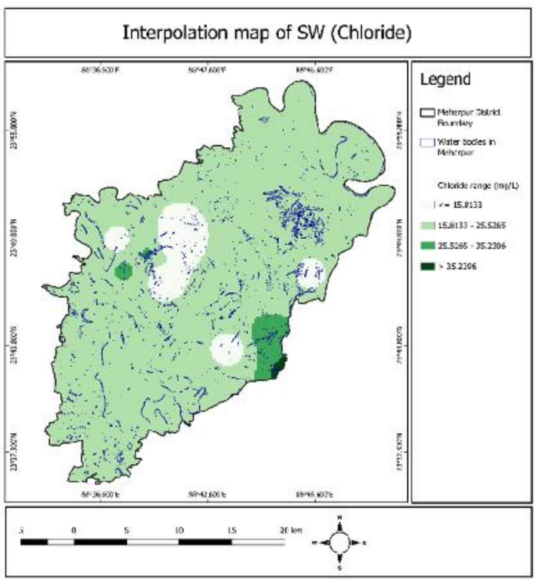

Figure 5.19: Chloride in the dry season

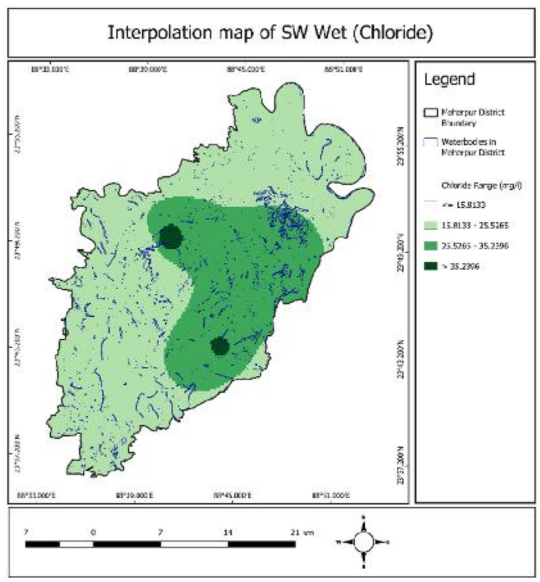

Figure 5.20: Chloride in the wet season

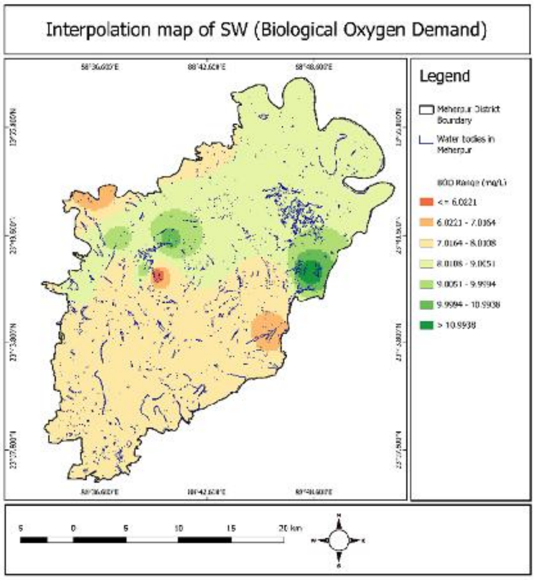

Figure 5.21: BOD in the dry season

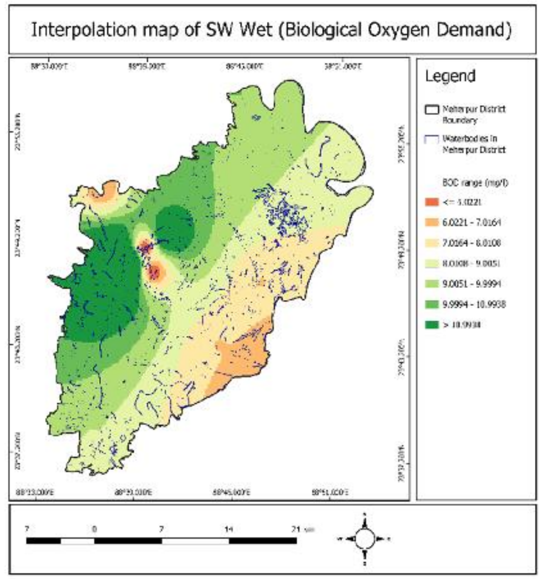

Figure 5.22: BOD in the wet season

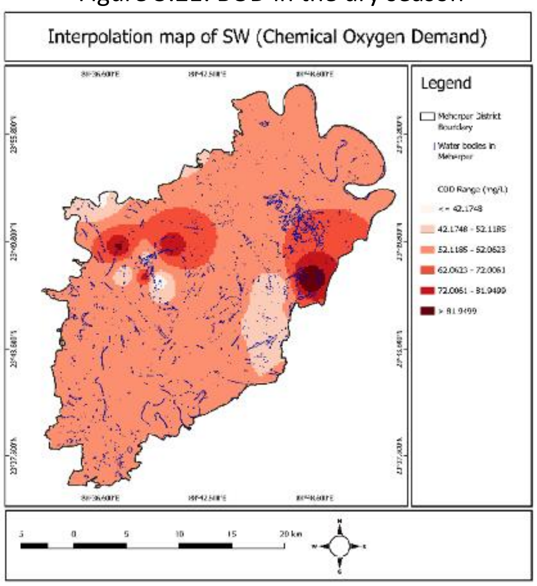

Figure 5.23: COD in the dry season

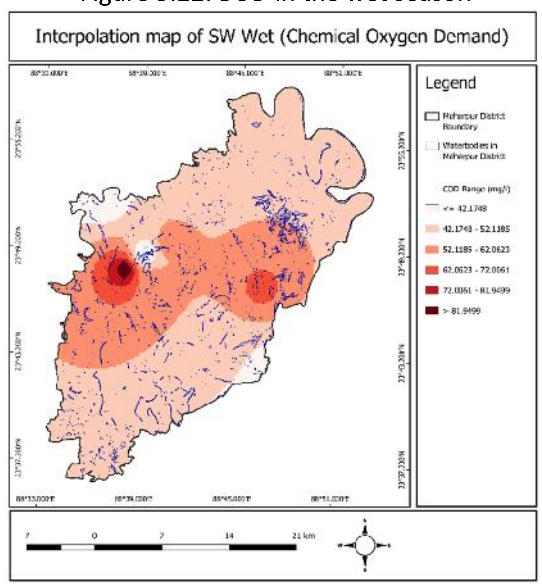

Figure 5.4: COD in the wet season

5.5. Key Observations

- The wet season benefits from rainfall dilution, resulting in lower pollutant concentrations (TDS, EC, TSS, BOD, COD) and more stable pH and DO levels.
- The dry season shows increased pollution, particularly at Taranagar, with extreme turbidity, TSS, BOD, and COD, and alkaline pH in some areas, indicating reduced water quality.
- GOR Pond (wet season) and Taranagar (dry season) are pollution hotspots, likely due to urban runoff or human activities.
- Low DO in the dry season (e.g., Biswanathpur) and high BOD/COD in both seasons at certain sites suggest organic pollution, potentially from agricultural runoff or untreated waste.

5.6. Cautions and Potential Threats

High Pollution Sites: Taranagar (dry season) and GOR Pond (wet season) show elevated BOD, COD, and TSS, indicating organic and chemical pollution that could harm aquatic life and human health if used for drinking or irrigation.
Low DO: Biswanathpur's low DO (3.4 mg/L) in the dry season could lead to hypoxic conditions, threatening fish and other aquatic organisms.
Alkaline pH: Dry season pH values above 9 (e.g., Malshadaha, Biswanathpur) may disrupt aquatic ecosystems and affect water usability.
Mitigation Needs: Pollution hotspots require monitoring and interventions like wastewater treatment, runoff control, or land-use regulations to reduce sediment and organic inputs, especially in the dry season when water quality deteriorates.
Heavy Metal Measurement: from 15 location point surface water samples were tested for identification of heavy metals concentration and test results are given bellow table-5.1.

Table 5.1: Concentration of Heavy Metals

SN	Concentration (ppm)					
	Cd	Cr	Cu	Ni	Pb	Zn
W-01	1.25	9.28	29.23	10.7	56.15	243.2
W-02	0.32	1.65	10.18	6.43	16.06	40.17
W-03	0.76	8.75	25.16	6.85	38.3	241.05
W-04	0.68	11.28	25.81	10.37	45.93	91.59
W-05	0.6	9.23	25.92	11.1	52.1	121.96
W-06	0.97	15.53	27.33	7.98	43.38	97.79
W-07	0.68	8.25	33.6	14.55	55.35	127.02
W-08	0.41	4.09	18.49	6.5	31.1	51.89
W-09	0.35	8.13	20.93	7.76	42.12	61.81
W-10	1.39	10.11	32.16	13	46.9	86.43
W-11	0.67	5.81	19.66	6.25	49.66	54.7
W-12	0.59	6.7	20.53	10.12	38.08	73.53
W-13	0.95	4.24	19.36	8.06	44.21	48.73
W-14	2.39	5.66	29.09	6.08	48.34	106.31
W-15	0.36	11.06	16.09	6.12	33.03	47.86

The table presents the concentrations (in parts per million, ppm) of six heavy metals parameter—Cadmium (Cd), Chromium (Cr), Copper (Cu), Nickel (Ni), Lead (Pb), and Zinc (Zn)—

across 15 water samples labeled W-01 to W-15. Among these, Zn exhibits the highest concentration overall, peaking at 243.2 ppm in sample W-01, followed by Cu, which also shows relatively elevated levels, particularly in W-07 (33.6 ppm) and W-10 (32.16 ppm). Cd concentrations are generally low, ranging from 0.32 to 2.39 ppm, with the highest in W-14. Cr varies considerably, with a maximum of 15.53 ppm in W-06. Ni values fluctuate between 6.08 and 14.55 ppm, the latter recorded in W-07. Pb concentrations are moderate to high, reaching up to 56.15 ppm in W-01, indicating potential contamination. Overall, W-01 stands out with the highest combined metal concentrations, suggesting it may be the most impacted by heavy metal pollution.

5.7. Water Quality Index from water test result

The table provides a detailed assessment of surface water quality from 22 different sites in Meherpur district, Bangladesh, encompassing rivers, ponds, and lakes. Water quality index (WAI) has been calculated based on the water quality parameters which are physicochemical parameters essential for evaluating water quality. These parameters include temperature (°C), pH, turbidity (NTU), dissolved oxygen (DO, mg/L), total dissolved solids (TDS, mg/L), electrical conductivity (EC, µS/cm), and biochemical oxygen demand (BOD, mg/L). These values are crucial in determining the suitability of water for various uses, including drinking, irrigation, and industrial applications. The dataset also includes the calculated Water Quality Index (WQI), a composite indicator derived from the physicochemical data, used to categorize water quality into qualitative classes such as "Good," "Poor," "Very Poor," or "Unsuitable." For example, the Bhairab River sample (SW-01) was rated "Poor," while the Bamonpara Pond (SW-02) had "Good" quality, and others like GOR Lake (SW-03) were deemed "Unsuitable" for direct use. Additionally, recommendations for usage—such as "irrigation only" or "requires treatment"—are included based on the WQI outcome. This comprehensive evaluation highlights spatial variability in water quality and underscores the importance of monitoring and managing local water resources to ensure their safe and sustainable use.

Table 5.2: Water Quality Index of surface water

Parameter	**WQI**	**Status**	**Possible usage**
Unit			
SW-01	71.02	Poor	Irrigation & industrial
SW-02	48.57	Good	Drinking, irrigation & industrial
SW-03	123.5	Unsuitable	Proper treatment required
SW-04	82.26	Very poor	Irrigation
SW-05	108.04	Unsuitable	Proper treatment required
SW-06	95.74	Very poor	Irrigation
SW-07	295.84	Unsuitable	Proper treatment required
SW-08	133.97	Unsuitable	Proper treatment required
SW-09	111.38	Unsuitable	Proper treatment required
SW-10	122.92	Unsuitable	Proper treatment required
SW-11	265.49	Unsuitable	Proper treatment required
SW-12	248.02	Unsuitable	Proper treatment required
SW-13	316.9	Unsuitable	Proper treatment required
SW-14	69.51	Poor	Irrigation & industrial
SW-15	77.07	Very poor	Irrigation

Chapter-6: Noise Quality Assessment of Meherpur District

Noise quality assessment is the systematic evaluation of sound levels in a given environment to understand their sources, intensity, and impact on human health, ecosystems, and quality of life. It involves measuring noise levels, identifying sources such as traffic, industrial activities, or urban development, and analyzing their spatial and temporal patterns. Typically conducted using sound level meters, noise mapping, and modeling techniques, this assessment helps quantify noise pollution in decibels (dB) and compare it against regulatory standards or guidelines. Noise quality assessment is crucial for urban planning, public health, and environmental management, as excessive noise can lead to stress, hearing loss, sleep disturbances, and reduced biodiversity. By providing data-driven insights, it supports the development of mitigation strategies, such as sound barriers or zoning policies, to create healthier and more sustainable living environments.

6.1. Noise quality of Meherpur district

The study allowed us to measure the noise level at various locations across Meherpur district, including Meherpur, Gangni, and Mujibnagar. Noise levels range from 38.87 dB to 63.95 dB, reflecting diverse acoustic environments influenced by location type (urban, rural, or commercial).

In Meherpur, noise levels vary significantly. Hotel Bazar records the highest at 63.95 dB, likely due to commercial activity and traffic, followed by Bara Bazar at 55.75 dB. These exceed the World Health Organization's (WHO) 55 dB threshold for residential areas, indicating potential health risks like stress or sleep disturbances. Quieter areas include Khoksha (38.87 dB) and Mallik Para (42.52 dB), suggesting rural or less busy settings. Locations like Stadium Para (52.86 dB) and Kazi Para (54.49 dB) show moderate noise, typical of semi-urban zones.

Gangni generally has lower noise levels, with Bashundhara at 40.23 dB and Chougacha Pashchim Para at 41.10 dB, indicating quiet, likely rural areas. However, Saharabati (55.84 dB) and Durlovpur (52.72 dB) are noisier, possibly due to market or road activity. Educational sites like Gangni Girls School (50.89 dB) show moderate noise, potentially from student activity or nearby traffic.

Mujibnagar has relatively low noise levels, with Muchi Para at 40.68 dB and Church of BD at 41.39 dB, reflecting rural tranquility. Kedarganj Primary School (50.46 dB) and Mohajanpur (52.65 dB) are slightly noisier, possibly due to community or school activities. No location in Mujibnagar exceeds the 55 dB threshold.

Overall, Meherpur's urban centers, particularly commercial hubs, exhibit elevated noise levels, posing potential health concerns. Gangni and Mujibnagar are quieter, with occasional spikes in busier areas. Mitigation, such as traffic control or sound barriers, may be needed in high-noise zones like Hotel Bazar to protect residents.

Detailed data with location of the sample points has been given in Table 6.1. An interpolate noise map of Meherpur district has been given in Figure 6.1.

Table 6.1: Average Noise Data with Location

Sl. No	Location	City	Lat	Long	Total avg (dB)
1	Gorur Hat	Meherpur	23.76277778	88.64694444	45.88
2	Govt. College	Meherpur	23.76722222	88.64222222	46.495
3	Stadium Para	Meherpur	23.7675	88.63722222	52.85625
4	Stadium Para 2	Meherpur	23.76416667	88.63527778	47.7025
5	Kazi Para	Meherpur	23.76861111	88.63416667	54.48625
6	Hotel Bazar	Meherpur	23.76916667	88.6325	63.95375
7	Jadavpur Ghat	Meherpur	23.76916667	88.62833333	46.90625
8	Jadavpur Majhpara	Meherpur	23.76777778	88.62583333	45.6075
9	Bosh Para	Meherpur	23.77305556	88.62694444	45.505
10	Haldar Para	Meherpur	23.77694444	88.6275	48.2575
11	Bara Bazar	Meherpur	23.77805556	88.63138889	55.7475
12	Khamar Bari	Meherpur	23.77888889	88.63583333	48.0475
13	Berpara	Meherpur	23.78166667	88.62888889	45.22
14	Mallik Para	Meherpur	23.77333333	88.63527778	42.5175
15	Kashari Para	Meherpur	23.77277778	88.63166667	46.49375
16	Bose Para	Meherpur	23.77416667	88.63055556	51.02
17	Gangni Girls school	Gangni	23.8175	88.74861111	50.8875
18	Chougacha Pashchim Para	Gangni	23.82416667	88.73277778	41.10375
19	Masjid Para	Gangni	23.82138889	88.74277778	44.84125
20	Notun Para Moor	Gangni	23.815	88.73833333	45.29
21	Bashundhara	Gangni	23.82388889	88.75111111	40.22875
22	Eid ga Para	Gangni	23.82	88.75583333	42.2725
23	Purba Malshadaho	Gangni	23.81916667	88.76444444	42.7425
24	Oli Para	Gangni	23.81472222	88.75666667	42.67
25	Shandhani School	Gangni	23.81194444	88.74888889	41.63625
26	Krishi unnoyon Corporation	Gangni	23.81472222	88.745	45.4
27	Bisshonath para–Primary School	Mujibnagar	23.67666667	88.61611111	43.16375
28	Shibpur Ideal School	Mujibnagar	23.6725	88.61527778	43.83875
29	Ballavpur MajhPara	Mujibnagar	23.66027778	88.61444444	43.55375
30	Muchi Para	Mujibnagar	23.655	88.58972222	40.68375
31	Church of BD	Mujibnagar	23.65277778	88.59166667	41.3875
32	Dofadar Para	Mujibnagar	23.65444444	88.59305556	42.25875
33	Fakir Para	Mujibnagar	23.6575	88.5925	41.9025
34	Kedarganj Primary School	Mujibnagar	23.66361111	88.60333333	50.46
35	Kedarganj Primary School	Mujibnagar	23.66305556	88.60166667	43.4975
36	Mollickpara Road	Meherpur	23.769425	88.67846222	38.87083
37	BAT-01	Meherpur Sadar	23.76403667	88.64515333	51.4
38	Jhaubaria	Meherpur	23.79939167	88.6432475	48.14861
39	Roghunathpur	Meherpur	23.73044789	88.69617667	50.87639
40	Sonapur	Malithapara Bazar	23.68889639	88.71219139	49.30694
41	Amdah D.Para Mosque	Meherpur	23.72892333	88.63223333	47.62083
42	Baradi	Meherpur	23.72016028	88.73346694	46.6
43	Beltolapara	Meherpur	23.81391	88.6739775	42.03056
44	Kashba Bazar	Gangni	23.75747417	88.77183194	49.6875
45	Nishipur, Bamundi	Gangni	23.89997806	88.80382167	42.23194
46	Tetulbaria	Gangni	23.89708667	88.72514222	46.45236
47	Bagan Para	Gangni	23.813185	88.75067694	42.65694
48	Garadob	Gangni	23.79845056	88.69788667	43.4
49	Depa Westpara	Gangni	23.76389278	88.72041833	43.48889
50	Jalshuka Road	Gangni	23.78416361	88.78418917	41.41944
51	Ratanpur	Gangni	23.64615583	88.64705944	43.57361

52	Mohajanpur	Muzibnagar	23.65526167	88.67459111	52.65
53	Monakhali	Muzibnagar	23.71350167	88.61714	50.7
54	Bishwanathpur, Gourinagr	Muzibnagar	23.68091333	88.61486167	51.38194
55	Anandabas	Muzibnagar	23.61781556	88.61183806	49.24722
56	Roshikpur	Muzibnagar	23.65436417	88.63805917	49.8
57	Hemayetpur	Muzibnagar	23.82497306	88.83061417	48.66944
58	Mondolpara	Muzibnagar	23.62995333	88.61165694	51.08611
59	Joypur	Muzibnagar	23.61300417	88.62423111	48.525
60	Shimultala Gangni	Gangni	23.81936778	88.792145	49.71528
61	Durlovpur	Gangni	23.87408694	88.7589175	52.71528
62	Pirojpur	Muzibnagar	23.70586722	88.689565	51.55417
63	Saharabati	Gangni	23.83098167	88.71108861	55.84028
64	Sholotaka	Gangni	23.85259083	88.79623194	44.84028
65	Depa Westpara	Gangni	23.78236139	88.73136528	45.38472

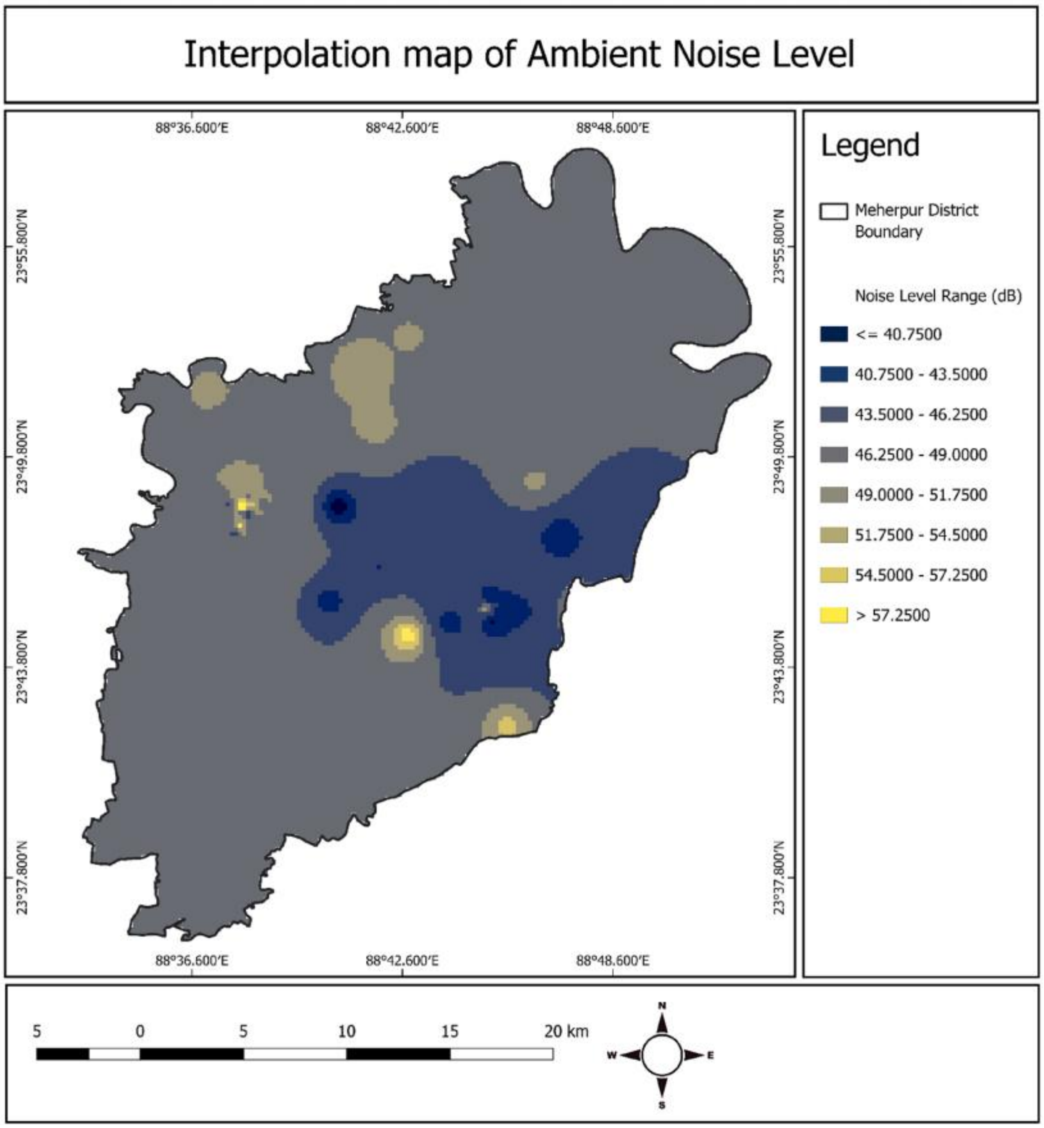

Figure 6.1: Noise Level Map of Meherpur District

Chapter-7: Air Quality Assessment and Air quality Index

7.1. Introduction

Air pollution is increasingly recognized as a significant environmental and public health concern across the globe, particularly in developing countries like Bangladesh. With growing urbanization, industrialization, and agricultural intensification, the concentration of harmful pollutants in the atmosphere is rising at an alarming rate. Air pollution not only degrades environmental quality but also poses substantial risks to human health, especially for vulnerable populations such as children, the elderly, and individuals with pre-existing medical conditions (Chen and Lippmann, 2009; Kelly and Fussell, 2015; Stanek et al., 2011; Zhang and Batterman, 2013). Despite growing awareness, there remains a significant knowledge gap in localized air quality monitoring, particularly in smaller districts like Meherpur. Understanding pollution dynamics in both urban and rural environments within such regions is essential for devising effective and context-specific mitigation strategies.

This study aims to conduct a detailed and comparative evaluation of air quality in the urban and rural areas of Meherpur District, with a particular focus on key atmospheric pollutants. The pollutants selected for analysis include Particulate Matter (PM2.5 and PM10), Sulfur Oxides (SOx), Nitrogen Oxides (NOx), Carbon Dioxide (CO2), Volatile Organic Compounds (VOCs), Sulfur Dioxide (SO2), Carbon Monoxide (CO), and Ozone (O3). Each of these pollutants is known to have distinct sources and health implications. For instance, PM2.5 and PM10 are fine particulates that can penetrate deep into the respiratory system, while gases like SO2, NO2, and O3 are associated with respiratory inflammation, cardiovascular stress, and oxidative damage. VOCs and CO, commonly released from combustion processes and industrial solvents, also pose severe health threats, including neurological effects and impaired oxygen delivery to vital organs.

7.2. Air Quality of Meherpur

Urban zones in Meherpur are increasingly experiencing emissions from motor vehicles, construction activities, and small manufacturing units. These contribute significantly to NOx, CO, PM2.5, and VOC concentrations. In contrast, rural regions, though often perceived as less polluted, are influenced by localized sources such as brick kilns, crop residue burning, and traditional cooking methods, which elevate levels of SO2, CO2, and PM10. Additionally, seasonal agricultural practices and wind patterns may facilitate the transport of pollutants across zones, further complicating the pollution landscape.

Ambient air quality data have been collected from different locations of the study area. The total number of samples was 20, among them 9 from Meherpure Sadar, 7 from Gangni, and 4 from Mujib Nagar. The following air quality data have been tested which are CO, O3, PM2.5, PM10, SOx, NOx, and Pb. Table 7.1 (in the annex) shows test results for each location point.

The table 7.1 provides data on ambient air quality across 20 locations in Meherpur district, covering Meherpur Sadar, Gangni, and Mujibnagar. It measures concentrations of key air pollutants: carbon monoxide (CO, mg/m³), ozone (O3, µg/m³), particulate matter (PM2.5 and PM10, µg/m³), sulfur oxides (SOx, µg/m³), nitrogen oxides (NOx, µg/m³), and lead (Pb, µg/m³). The measurements were conducted using methods such as real-time electrochemical sensors and gravimetric techniques, with a test duration of 12 hours.

7.2.1. Air Quality of Meherpur Sadar

CO: Ranges from 0.421 mg/m³ (Roghunathpur Jame Mosque) to 0.843 mg/m³ (BAT DPO-1 and Beltolapara). All values are well below the standard of 20 mg/m³, indicating low CO pollution, likely due to limited industrial activity.

O_3: Consistently below 0.1 µg/m³, far below the 180 µg/m³ standard, suggesting negligible ozone pollution.

PM2.5: Varies from 6.3 µg/m³ (Sonapur Malithapara Bazar) to 14.68 µg/m³ (Amdah D. Para Jame Mosque). All values are below the 65 µg/m³ standard, indicating safe levels of fine particulate matter.

PM10: Ranges from 28.25 µg/m³ (BAT DPO-1) to 147.79 µg/m³ (Amdah D. Para Jame Mosque). All values are below the 150 µg/m³ standard, though Amdah is close, suggesting localized dust or particulate sources.

SOx and NOx: Both are below 2.5 µg/m³ and 5 µg/m³, respectively, except for BAT DPO-1 (NOx: 5.76 µg/m³). These are well below the 80 µg/m³ standards, indicating minimal sulfur and nitrogen oxide pollution.

Pb: Below 0.3 µg/m³ across all sites, well below the 0.5 µg/m³ standard, except for an erroneous entry at AQ-19 (discussed below).

7.2.2. Air Quality of Gangni

CO: Ranges from 0.000 mg/m³ (Agrani Bank, Bamundi Bazar) to 1.226 mg/m³ (Depa Westpara Jame Mosque), all significantly below the 20 mg/m³ standard.

O_3: Below 0.1 µg/m³, indicating no ozone concerns.

PM2.5: Varies from 10 µg/m³ (Agrani Bank, Bamundi Bazar) to 25.79 µg/m³ (Kasba Bazar), all below the 65 µg/m³ standard. Kasba Bazar's higher PM2.5 suggests market-related dust or vehicle emissions.

PM10: Ranges from 24.73 µg/m³ (Jalshuka-Arpara Road) to 69.68 µg/m³ (Beltolapara). All are below the 150 µg/m³ standard, indicating moderate particulate levels.

SOx and NOx: Below 2.5 µg/m³ and 5 µg/m³, respectively, showing low gaseous pollutant levels.

Pb: Below 0.3 µg/m³, well within the 0.5 µg/m³ standard.

7.2.3. Air Quality of Mujibnagar

CO: Ranges from 0.000 mg/m³ (Monakhali Moddo Para and Bishwanathpur) to 0.651 mg/m³ (Mohajanpur Bazar), all far below 20 mg/m³.

O_3: Below 0.1 µg/m³, indicating no ozone pollution.

PM2.5: Varies from 10.69 µg/m³ (Anandabas Bazar) to 28.66 µg/m³ (Monakhali Moddo Para), the highest in the dataset but still below 65 µg/m³. This suggests localized particulate sources, possibly from traffic or markets.

PM10: Ranges from 18.13 µg/m³ (Anandabas Bazar) to 75.01 µg/m³ (Monakhali Moddo Para), all below 150 µg/m³.

SOx and NOx: Below 2.5 µg/m³ and 5 µg/m³, respectively, except Mohajanpur Bazar (NOx: 5.42 µg/m³), all well below standards.

Pb: An anomalous value of 18.52 µg/m³ at Bishwanathpur (AQ-19) exceeds the 0.5 µg/m³ standard, likely a data error as other sites report <0.3 µg/m³. This should be verified, as high lead levels could indicate contamination from industrial or vehicular sources.

7.3. Overall Air Quality Insights

CO and O_3: Extremely low across all locations, indicating minimal vehicle or industrial emissions and no significant photochemical smog.

PM2.5 and PM10: Generally low, with Monakhali Moddo Para (PM2.5: 28.66 µg/m³) and Amdah D. Para (PM10: 147.79 µg/m³) showing the highest values, likely due to dust from markets, roads, or construction. All are within standards, but high PM10 at Amdah approaches the limit, warranting monitoring.

SOx and NOx: Consistently low, reflecting limited industrial activity or fossil fuel combustion in Meherpur's predominantly agricultural setting.

Pb: The Bishwanathpur value (18.52 µg/m³) is a potential concern, as it far exceeds the 0.5 µg/m³ standard. This outlier is likely erroneous, given other sites' low values, but if accurate, it suggests localized lead contamination requiring investigation.

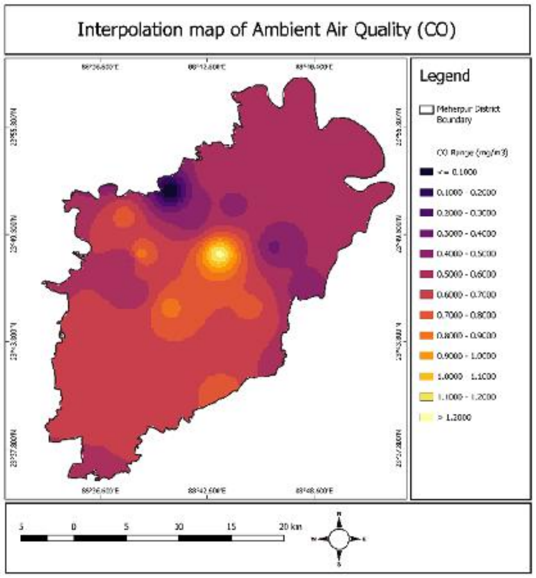

Figure 7.1: Interpolation map of CO in Meherpur district.

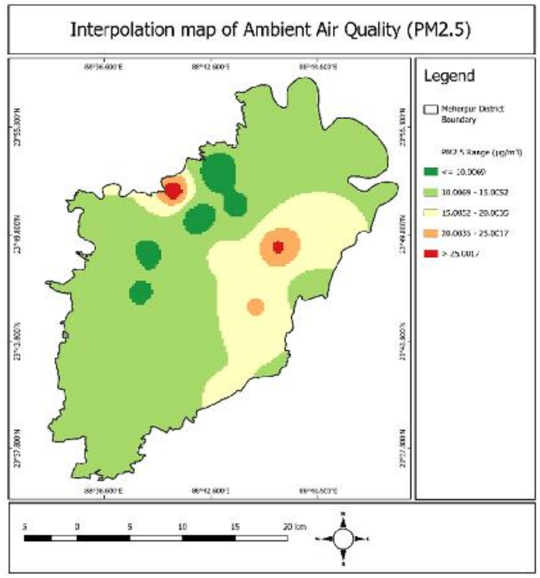

Figure 7.2: Interpolation map of PM2.5 in Meherpur district.

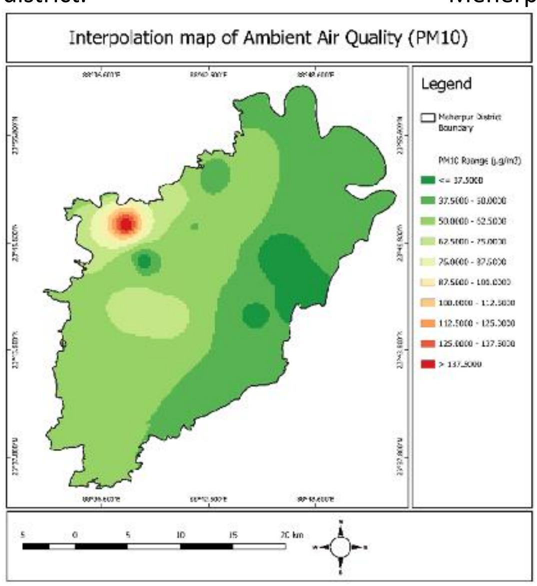

Figure 7.3: Interpolation map of PM10 in Meherpur district.

7.4. Cautions and Potential Threats

PM10 at Amdah D. Para: The value (147.79 µg/m³) is close to the 150 µg/m³ standard, indicating a potential risk of respiratory issues if levels rise further, especially in dry seasons with more dust (Davidson et al., 2005; Kim et al., 2015; Thompson, 2018).

PM2.5 at Monakhali Moddo Para: At 28.66 µg/m³, it's the highest recorded, and while below the standard, prolonged exposure to elevated PM2.5 can cause health issues like asthma or cardiovascular problems (Davidson et al., 2005; Kim et al., 2015; Thompson, 2018).

Pb Anomaly at Bishwanathpur: If the 18.52 µg/m³ value is accurate, it poses a significant health risk (e.g., neurological damage), necessitating immediate investigation into potential sources like old paint, batteries, or industrial waste (Chen and Lippmann, 2009; Mielke et al., 2022).

Localized Pollution: Higher PM levels in market areas (e.g., Kasba Bazar, Monakhali) suggest vehicle emissions or dust from human activity. Urban planning and dust control measures (e.g., road paving, green barriers) could mitigate this.

7.5. Air quality Index

The Air Quality Index (AQI) is a standardized tool developed to report daily air quality levels to the public. It translates complex air pollutant concentration data into a single, easily understandable number or category, ranging from "Good" to "Hazardous." AQI values are calculated based on the concentration of key pollutants such as PM2.5, PM10, CO, SO_2, and others.

For this study, the AQI was calculated using the United States Environmental Protection Agency (US EPA) methodology (Yousefi et al., 2019). The following pollutants were considered: PM2.5, PM10, Carbon Monoxide (CO), and Sulfur Dioxide (SO_2).

Table 7.2: Air Quality Index (AQI) results of 20 sample locations

SL NO	ID of Sample Location	AQI (PM2.5)	AQI (PM10)	API (Overall)	API category
1	AQ-1,Mollickpara Road Meherpur Sadar, GPS Coordinates: 23°46'10.12"N 88°38'3.82"E	51.06	52.55	**52.55**	Moderate
2	AQ-2, BAT DPO-1 Meherpur Sadar, GPS Coordinates: 23°45'48.58"N 88°38'50.20"E	28.54	26.16	**28.54**	Good
3	AQ-03, Mondol Bari Mor, Meherpur Sadar GPS Coordinates: 23°47'57.79"N 88°38'36.84"E	38.38	60.17	**60.17**	Moderate
4	AQ-04 Roghunathpur Jame Mosque, Meherpur Sadar GPS Coordinates: 23°43'49.87"N 88°41'46.0775"E	20.83	45.92	**45.92**	Good

SL NO	ID of Sample Location	AQI (PM2.5)	AQI (PM10)	API (Overall)	API category
5	AQ-05 Sonapur malithapara bajar, Meherpur GPS Coordinates: 23°41'20.426"N 88°42'43.965"E	26.25	42.27	**42.27**	Good
6	AQ-06 Amdah D: Para Jame Mosjid, Meherpur GPS Coordinates: 23°43'44.434"N 88°37'54.5893"E	56.43	96.93	**96.93**	Moderate
7	AQ-07 Baradi Bazar, Meherpur GPS Coordinates: 23°43'12.56"N 88°44'0.209"E	36.25	54.59	**54.59**	Moderate
8	AQ-08 Beltolapara Government Primary School, Meherpur GPS Coordinates: 23°48'50.33"N 88°40'27.02"E	44.96	58.27	**58.27**	Moderate
9	AQ-09 Kasba Bazar GPS Coordinates: 23°45'27.100"N 88°46'18.536"E	79.79	23.98	**79.79**	Moderate
10	AQ-10 Agrani Bank PLC, Bamundi Bazar Branch,Gangni GPS Coordinates: 23°53'59.958"N 88°48'73.74"E	41.67	42.22	**42.22**	Good
11	AQ-11 Tetulbaria westpara jame mosque, Gangni GPS Coordinates: 23°53'49.512"N 88°43'30.512"E	56.39	36.91	**56.39**	Moderate
12	AQ-12 Bagan Para 08 No. Ward, Gangni GPS Coordinates: 23°48'47.845"N 88°45'1.687"E	70.55	34.16	**70.55**	Moderate
13	AQ-13 Garadob High School, Gangni GPS Coordinates: 23°47'54.382"N 88°47'52.551"E	41.44	29.86	**41.44**	Good
14	AQ-14 Depa Westpara Jame Mosque, Gangni GPS Coordinates: 23°45'49.929"N 88°43'13.463"E	71.88	50.98	**71.88**	Moderate
15	AQ-15 Jalshuka-Arpara-Jalshuka road, Gangni GPS Coordinates: 23°54'43.752"N 88°47'5.136"E	56.27	24.03	**56.27**	Moderate
16	AQ-16 Church Of Christ Road, Gangni GPS Coordinates: 23°38'45.835"N 88°38'49.045"E	30.58	26.97	**30.58**	Good
17	AQ-17 Mohajanpur bazar, Mujib Nagar GPS Coordinates: 23°39'49.17"N 88°36'17.01"E	66.55	38.97	**66.55**	Moderate

SL NO	ID of Sample Location	AQI (PM2.5)	AQI (PM10)	API (Overall)	API category
18	AQ-18 Monakhali Moddo Para Jame Mosjid , Mujib Nagar GPS Coordinates: 23°42'18.944"N 88°40'28.519"E	98.14	74.61	**98.14**	Moderate
19	AQ-19 Bishwanathpur, Monakhali, Mujib Nagar GPS Coordinates: 23°40'45.85"N 88°37'2.05"E	62.08	33.39	**62.08**	Moderate
20	AQ-20 Anandabas Bazar, Mujib Nagar GPS Coordinates: 23°37'4.395"N 88°36'40.859"E	36.64	18.13	**36.64**	Good

Meherpur's air quality is generally good, with most pollutants well below Bangladesh's standards, reflecting its rural and agricultural character. However, localized spikes in PM2.5 and PM10 in busy areas and the potential lead issue at Bishwanathpur highlight the need for targeted monitoring and verification to ensure public health and environmental safety.

Chapter-8: Climate Change Analysis of Meherpur District

Climate change analysis is the systematic study of long-term shifts in global and regional climate patterns, driven primarily by human activities such as greenhouse gas emissions, deforestation, and industrialization. It involves assessing changes in temperature, precipitation, sea levels, and extreme weather events using observational data, climate models, and statistical methods. This analysis is critical for understanding the impacts of climate change on ecosystems, agriculture, water resources, human health, and economies. By integrating data from sources like satellite observations, weather stations, and paleoclimatic records, researchers can project future climate scenarios and inform mitigation and adaptation strategies. Climate change analysis underpins global efforts to reduce carbon emissions, enhance resilience, and promote sustainable development, addressing one of the most pressing challenges of the 21st century.

Meherpur District, located in southwestern Bangladesh, lies within the Khulna Division. It experiences a tropical monsoon climate, characterized by distinct wet and dry seasons, influenced by the South Asian monsoon system. The district's climate plays a critical role in its agricultural productivity, as it is part of the fertile Ganges Delta.

Six vital climatic factors were considered to analyze the climatic conditions of Meherpur district. These are minimum temperatures, maximum temperatures, windspeed, relative humidity, precipitation, and vapor pressure. All this data was collected monthly from 2000 to 2024. By analyzing the climatic data, the study found that the mean minimum and maximum temperatures of Meherpur over 25 years were 20.82 °C and 31.86 °C, respectively. For the minimum temperature, the lowest reading was 8.82 °C, while the highest reading was 28.09 °C. Seasonal Fluctuations are clear, showing cyclical ups and downs across the year. Maximum Temperature appears to show higher variability and a possible gradual increase over the long term. Minimum temperatures also exhibit increases, hinting at possible warming, particularly in winter lows.

On the other hand, for the maximum temperature lowest reading was 22.36 °C, and the highest reading was 39.38 °C. For the vapor pressure, the highest pressure was 3.61 kPa, and the lowest was 1.29 kPa, while the mean was 2.53 kPa. Alongside, the average windspeed was 1.28 m/s. Appears to fluctuate mildly without a clear increasing or decreasing trend.

An average of 52.85% relative humidity is observed in the area, while the lowest was 31.56% and the highest was 74.81%. A slight decline after the mid-2010s is noticeable. Humidity mirrors vapor pressure and could affect perceived temperatures (heat index).

For the precipitation, the average rainfall was 120.54 mm/month, which is lower than the country's average (Bangladesh Meteorological Department, 2024). High Variability with some months receiving over 600 mm while others have zero, suggesting intense wet and dry seasons. May indicate monsoonal or highly seasonal precipitation regime. Details about the overview of the climatic scenario have been given in Table 8.1.

Table 8.1: Overview of the climatic variables of Meherpur district from 2000 to 2024

Variable	***Mean***	***Std Dev***	***Min***	***Max***
Min Temp (°C)	20.82	5.86	8.82	28.09
Max Temp (°C)	31.86	3.61	22.36	39.38
Vapor Pressure (kPa)	2.53	0.77	1.29	3.61
Wind Speed (m/s)	1.28	0.57	0.31	2.64
Precipitation (mm)	120.54	125.48	0.00	639.21
Relative Humidity (%)	52.85	11.99	31.56	74.81

8.1. Climatological Study for Meherpur District: Seasonal trends

8.1.1. Minimum Temperature (°C)

Range: temperature ranges from 10.4°C to 26.5°C across the year.

Trend: The minimum temperature follows a clear seasonal cycle. The coldest month is January (10.4°C), with temperatures gradually rising to a peak in July (26.5°C) during the monsoon season. By December, the temperature drops to 13.8°C.

Insight: This pattern reflects the typical tropical monsoon climate, with cooler winters (Dec–Feb) and warmer summers (Jun–Aug). The relatively small annual range (16.1°C) indicates a stable thermal regime.

8.1.2. Maximum Temperature (°C)

Range: temperature ranges from 24.8°C to 36.8°C across the year.

Trend: The maximum temperature follows a seasonal cycle like as the minimum temperature but with a slight difference. The temperature remains lowest in December to February (from 24°C to 28°C), while it reaches its peak in April to May (around 36°C to 37°C), signifying as the hottest months of the year.

Insight: The synchronized rise and fall of minimum and maximum temperatures indicate consistent diurnal temperature variations throughout the year, typical of a tropical climate.

8.1.3. Precipitation (mm)

Range: 7.9 mm to 296.7 mm

Trend: Precipitation shows a stark seasonal contrast. Low values (5 to 60 mm) dominate from January to April and September to December, indicating dry periods. A significant increase occurs from May to August, peaking in July (150 to 300 mm), marking the monsoon season.

Insight: The monsoon season (May–Aug) brings the bulk of annual rainfall, with July being the wettest month. This aligns with the South Asian monsoon pattern, where heavy rainfall supports rice cultivation, a staple crop in Meherpur.

8.1.4. Wind Speed (m/s)

Range: 0.6 m/s to 2 m/s

Trend: Wind speed remains relatively stable throughout the year, with minor variations (reaches it's peak in June to July). There are no extreme peaks or troughs.

Insight: The lack of significant seasonal variation suggests that Meherpur does not experience strong monsoon winds or cyclonic activity compared to coastal areas of Bangladesh. Stable wind speeds are beneficial for agriculture, minimizing crop damage.

8.1.5. Relative Humidity

Range: 36% to 69.1%.

Trend: Represented by the red line, relative humidity starts at around 45% in January, dips to a low of about 35% in March, rises sharply to a peak of nearly 70% in June and July, and then gradually declines to around 50% by December.

Insight: Relative humidity peaks during the monsoon season (Jun–Jul), coinciding with high rainfall, and is lowest during the dry season (Feb–Mar). This pattern reflects the influence of monsoon moisture on atmospheric humidity.

8.1.6. Vapor Pressure (kPa)

Range: 1.4 kPa to 3.4 kPa

Trend: Vapor pressure follows a pattern similar to temperature, with higher values in the warmer months (May–Sept) and lower values in the cooler months (Dec–Feb).

Insight: Vapor pressure, a measure of atmospheric moisture, correlates with temperature, as warmer air can hold more water vapor. The increase during the monsoon months reflects higher moisture content due to rainfall and elevated temperatures. The small range indicates a relatively stable moisture regime.

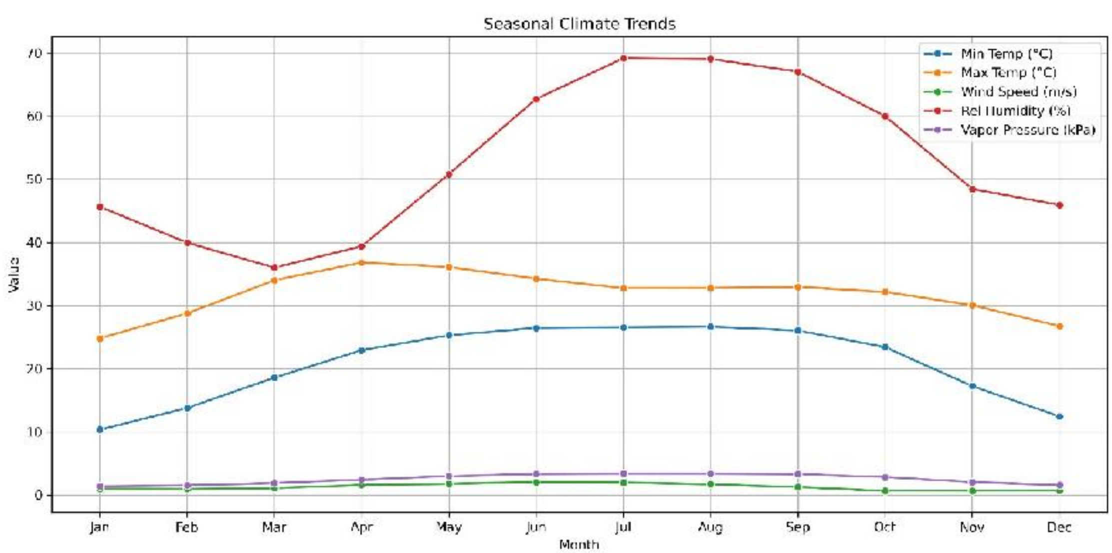

Figure 8.1: Seasonal Trends of Climatic Variables in Meherpur District

8.2. Monthly trend analysis

8.2.1. Precipitation

Figure 8.2 provides a polynomial trendline of the monthly mean precipitation of Meherpur district, with data points ranging from 0 to 300 mm across 12 months. The green dots represent individual mean precipitation data points for each month, while the solid green line shows the polynomial trend. The trend starts low in January (around 8.7 mm), rises steadily to a peak in July (around 296.7 mm), and then declines sharply towards December (around 8 mm), reflecting a seasonal pattern.

Precipitation values increased from 8.68 mm in January to a high of 296.67 mm in July, then decreased to 7.95 mm by December. This suggests a strong seasonal influence, likely tied to a wet season peaking in mid-year and a dry season toward the year's end.
An interesting highlight is the rapid drop from September (246.63 mm) to October (129.32 mm), indicating a sudden shift that might warrant further investigation into local weather events.

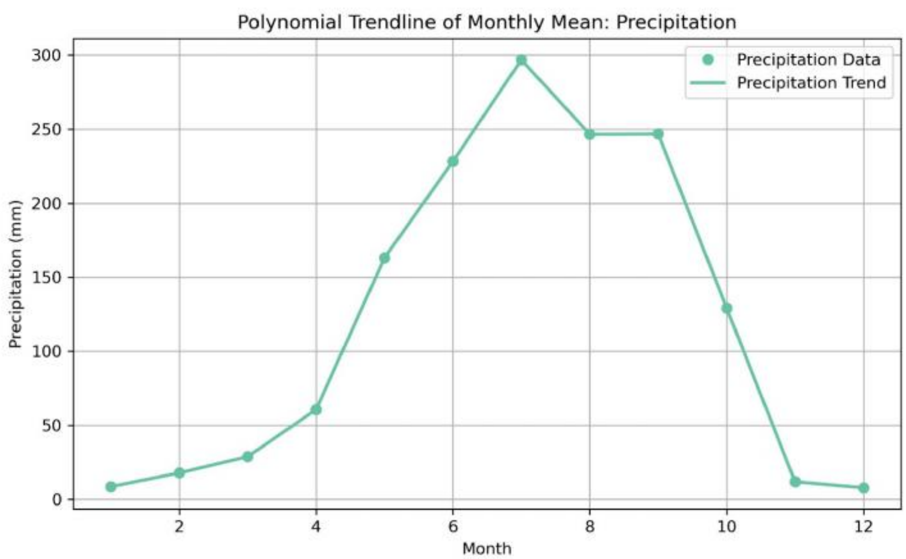

Figure 8.2: Monthly average trendline of precipitation of Meherpur district

8.2.2. Temperature and humidity

Figure 8.3 illustrates polynomial trendlines for the monthly means of temperature and humidity of Meherpur district over 12 months. The minimum temperature (pink) rises from around 10°C in January to a peak near 26°C in mid-year (July-August), then declines to about 12°C by December. The maximum temperature (green) follows a similar pattern, increasing from 25°C in January to around 37°C in April-May, peaking, and dropping to 27°C by December. Relative humidity (yellow) starts at 46%, peaks at approximately 69% in July-August, and falls to 46% by December, showing a seasonal alignment with temperature trends.
The minimum temperature rises from 10.36°C in January to 26.54°C in July, the maximum temperature peaks at 36.82°C in April, and relative humidity reaches 69.16% in July. An interesting observation is the humidity's sharp rise from 50.82% in May to 62.71% in June, indicating the onset of a wetter season.

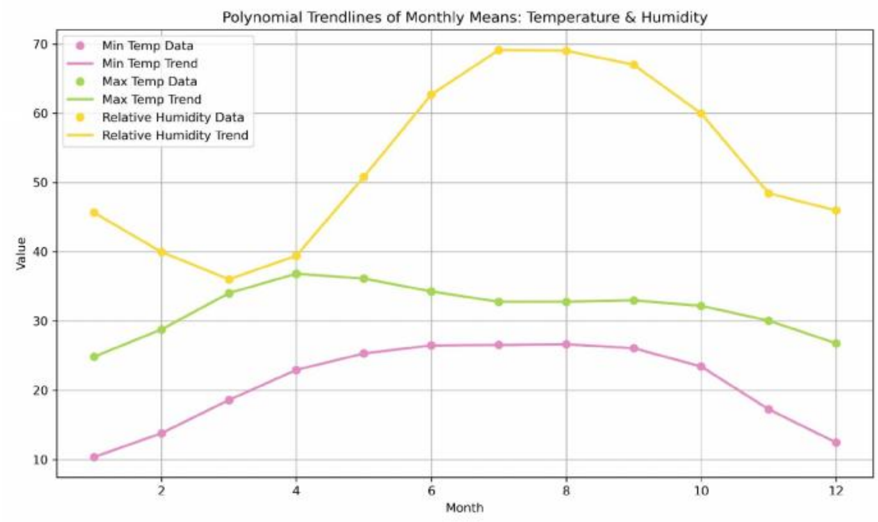

Figure 8.3: Monthly average trendline of Temperature and humidity of Meherpur district

8.2.3. Wind and vapor pressure

Figure 8.4 shows polynomial trendlines for the monthly means of wind speed and vapor pressure over 12 months of the Meherpur district. Wind speed (orange) starts at 0.96 m/s in January, dips slightly, rises to a peak of 2.05 m/s in June, and then drops to 0.69 m/s by December. Vapor pressure (blue) increases from 1.42 kPa in January to a peak of 3.40 kPa in July, then decreases to 1.60 kPa by December, following a seasonal pattern.

The wind speed peaks at 2.05 m/s in June, and the vapor pressure reaches 3.40 kPa in July. An interesting highlight is the sharp drop in wind speed from 1.28 m/s in September to 0.66 m/s in October, suggesting a sudden change in wind patterns, possibly linked to seasonal shifts.

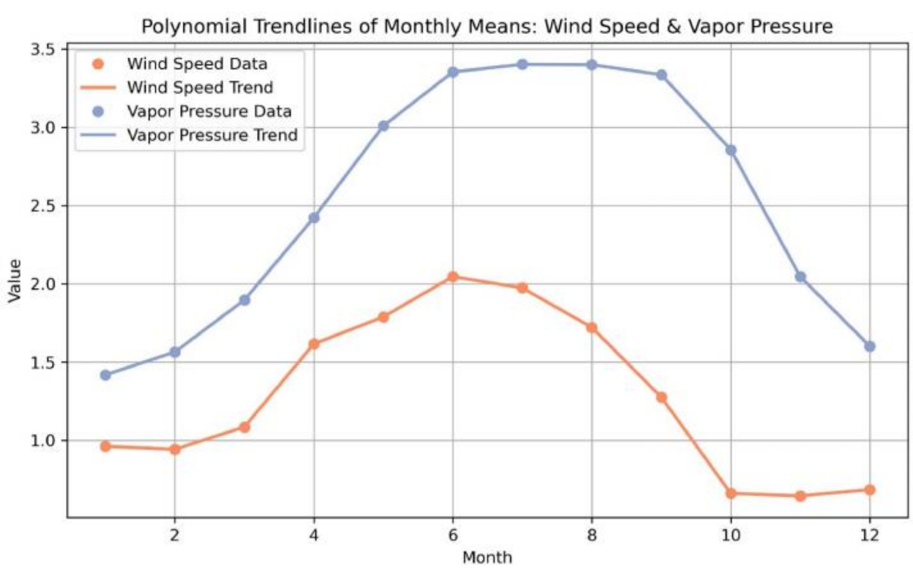

Figure 8.4: Monthly average trendline of Wind speed and Vapor pressure of Meherpur district

8.3. Analysis of Decadal Climate Trends

8.3.1. Decadal Average: Minimum Temperature (°C)

Description: The histogram (Figure 8.5) shows the average minimum temperature (°C) for each decade. The y-axis represents temperature (°C), ranging from 0°C to 20°C.

Key Observations:

Trend: Slight decrease from 20.95°C (2000s) to 20.56°C (2010s), then an increase to 21.08°C (2020s).

Insight: The overall warming trend (+0.13°C from 2000s to 2020s) suggests fewer cold spells, aligning with regional warming patterns.

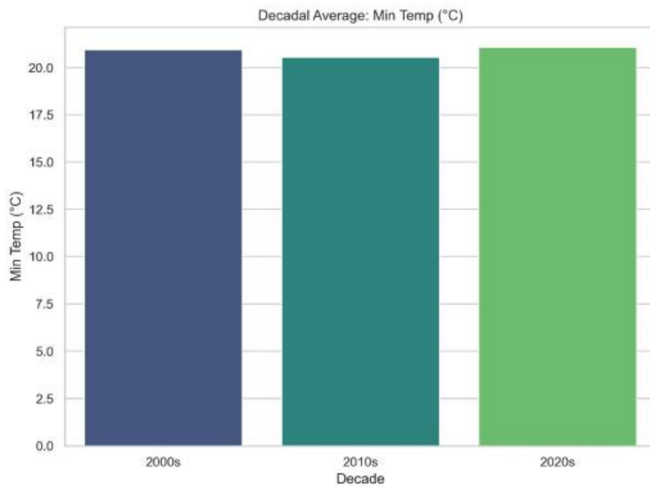

Figure 8.5: Decadal Average: Minimum Temperature (°C)

8.3.2. Decadal Average: Maximum Temperature (°C)

Description: The histogram (Figure 8.6) shows the average maximum temperature (°C) for each decade. The y-axis represents temperature (°C), ranging from 0°C to 30°C.

Key Observations:

Trend: Decrease from 31.99°C (2000s) to 31.60°C (2010s), then a slight increase to 32.10°C (2020s).

Insight: The slight rise in the 2020s (+0.11°C from 2000s) indicates potential for more frequent heatwaves, consistent with climate variability.

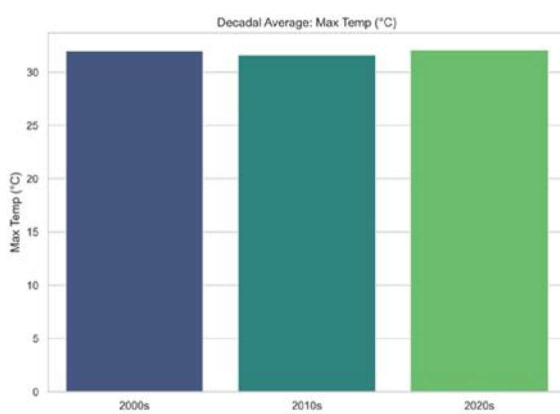

Figure 8.6: Decadal Average: Maximum Temperature (°C) in Meherpur

8.3.3. Decadal Average: Precipitation (mm)

Description: The histogram (Figure 8.7) shows the average annual precipitation (mm) for each decade. The y-axis represents precipitation (mm), ranging from 0 mm to 140 mm.

Key Observations:

Trend: Significant decline from 135.48 mm (2000s) to 110.82 mm (2010s), and further to 110.11 mm (2020s).

Insight: A 25.37 mm decrease over 24 years reflects a drying trend, likely impacting monsoon-dependent agriculture.

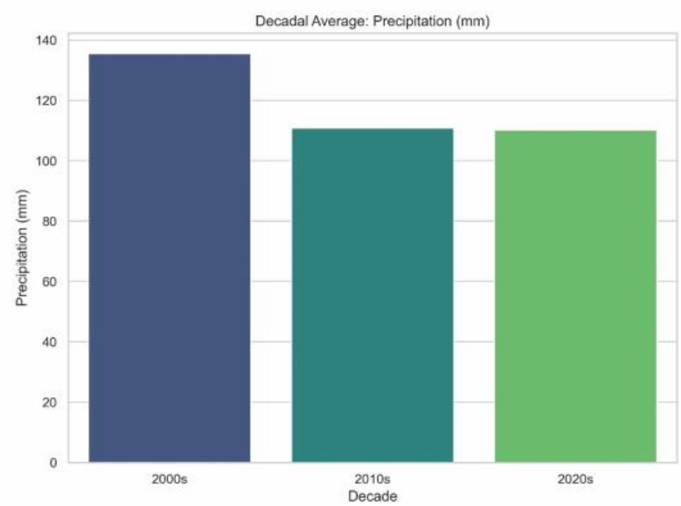

Figure 8.7: Decadal Average: Precipitation (mm) in Meherpur

8.3.4. Decadal Average: Relative Humidity (%)

Description: The histogram (Figure 8.8) shows the average relative humidity (%) for each decade. The y-axis represents humidity (%), ranging from 0% to 50%.

Key Observations:

Trend: Stable at 52.59% (2000s) and 52.62% (2010s), then an increase to 53.81% (2020s).

Insight: The 1.22% rise in the 2020s may exacerbate heat stress, as higher humidity reduces evaporative cooling.

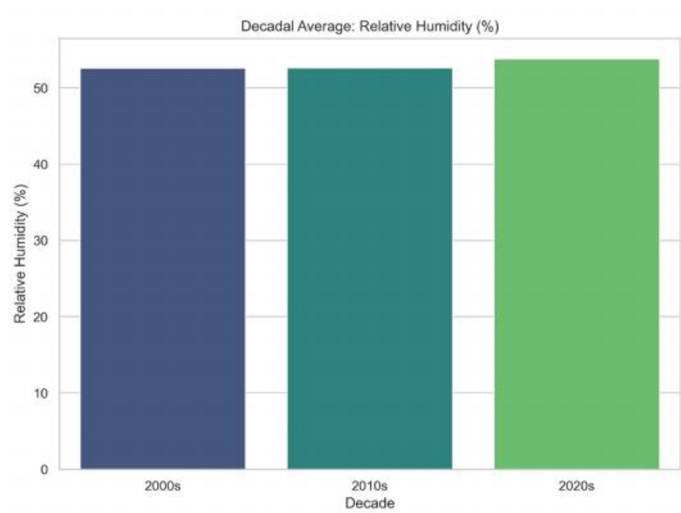

Figure 8.8: Decadal Average: Relative Humidity (%)

8.3.5. Decadal Average: Vapor Pressure (kPa)

Description: The histogram (Figure 8.9) shows the average vapor pressure (kPa) for each decade. The y-axis represents vapor pressure (kPa), ranging from 0 kPa to 2.5 kPa.

Key Observations:

Trend: Slight decrease from 2.52 kPa (2000s) to 2.49 kPa (2010s), then an increase to 2.61 kPa (2020s).

Insight: The 0.09 kPa rise in the 2020s correlates with higher humidity, reflecting increased atmospheric moisture.

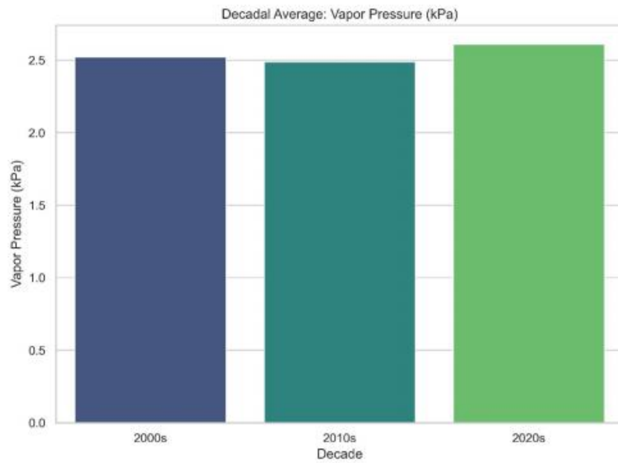

Figure 8.9: Decadal Average: Vapor Pressure (kPa)

8.3.6. Decadal Average: Wind Speed (m/s)

Description: The histogram (Figure 8.10) shows the average wind speed (m/s) for each decade. The y-axis represents wind speed (m/s), ranging from 0 m/s to 1.2 m/s.

Key Observations:

Trend: Slight decrease from 1.31 m/s (2000s) to 1.26 m/s (2010s), then a minor increase to 1.28 m/s (2020s).

Insight: The stability in wind speed aligns with previous analyses showing wind speeds consistently between 1–2 m/s, with no significant seasonal variation. The slight decrease may reflect minor changes in regional atmospheric circulation, but the values remain low, indicating minimal wind-related impacts.

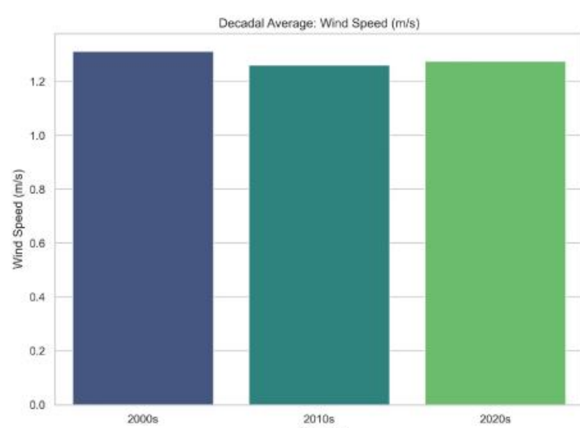

Figure 8.10: Decadal Average: Wind Speed (m/s)

8.4. Key Findings

8.4.1. Warming Trend:

Minimum temperatures show a clear warming trend, increasing by 1.0°C over the period, while maximum temperatures remain stable, though extreme heatwaves (e.g., 2024) indicate potential for more intense events.

8.4.2. Declining Precipitation:

Average annual precipitation has decreased by 30 mm from the 2000s to the 2020s, suggesting a drying trend, particularly in the 2020s, which may impact monsoon rainfall.

8.4.3. Rising Humidity:

Relative humidity and vapor pressure have increased in the 2020s, indicating higher atmospheric moisture, possibly due to rising temperatures and evaporation.

8.4.4. Stable Wind Speed:

Wind speed remains stable at around 1.1–1.2 m/s, with a slight decrease, confirming that Meherpur is not prone to significant wind events.

8.4.5. Climate Shifts:

The combination of warming minimum temperatures, declining precipitation, and rising humidity suggests a shifting climate, potentially influenced by global warming, with implications for agriculture and water management.

Despite a decline in precipitation, vapor pressure and humidity have increased in the 2020s, suggesting that the region retains more atmospheric moisture, potentially leading to more intense, albeit less frequent, rainfall events.

8.5. Climate change impacts

In our study, to understand the climate change impact in real-life scenarios, tea-stall meetings and KIIs were performed. From the observation and analysis of these data, the output is described as below.

- Water scarcity: Many people indicate the water scarcity problem in the agricultural sector and orchard farms. Lesser precipitation every year is making this problem more and more dominant.
- Pest and insect attack: Due to changes in the environment and climate, some selected species of insects and pests boost their reproduction and which causes damage to the crop yield. Farmers are forced to use more and more pesticides and insecticides to control these, but due to a lack of proper knowledge and monitoring, residues of these chemicals are mixing with soil and water, and ultimately, polluting the environment.
- Short and intense winter: The winter season is getting shorter day by day, and inversely, the intensity is increasing. That puts the marginal people in a vulnerable state.
- Long and hot summer: Due to climate change, the summer is getting hotter, less wet, and difficult for humans and other animals. Each year, the number of heat-related victims is increasing.

Chapter-9: Major Findings and Discussion

Meherpur district, located in southwestern Bangladesh within the Khulna Division, is a predominantly agricultural region characterized by its tropical monsoon climate and fertile Ganges Delta landscape. As a vital hub for rice cultivation and rural livelihoods, the district's environmental health and climatic stability are critical to its socioeconomic fabric. The comprehensive assessments detailed in Chapters 5 through 8 of the provided documents offer an in-depth analysis of Meherpur's water quality, noise levels, air quality, and climate change dynamics, spanning data from 2000 to 2024. These studies evaluate key environmental parameters—physicochemical water properties, noise pollution, atmospheric pollutants, and climatic variables—alongside qualitative insights from community engagements, such as tea-stall meetings and Key Informant Interviews (KIIs). The findings reveal a district grappling with localized environmental challenges, including water pollution hotspots, elevated noise in commercial areas, emerging air quality concerns, and shifting climate patterns marked by warming temperatures, declining precipitation, and rising humidity. These issues threaten agricultural productivity, public health, and ecological balance in a region where 87.53% of land is agricultural and only 1.07% is urbanized. The following sections synthesize the major findings and propose targeted recommendations to address these challenges, integrating cross-sectoral strategies for water, air, noise, and climate management. By aligning with Sustainable Development Goals (SDGs) and leveraging Meherpur's predominantly rural character, these recommendations aim to enhance environmental resilience, safeguard community well-being, and promote sustainable development in the face of growing environmental and climatic pressures.

9.1. Land Use and Land Cover (LULC) Analysis of Meherpur District

The LULC analysis of Meherpur district, as detailed in Chapter 4 provides a comprehensive overview of the land use and land cover patterns across the entire district, three Upazilas (Meherpur, Gangni, Mujibnagar), and two Paurashavas (Meherpur, Gangni). Conducted using 2024 Sentinel images processed through Google Earth Engine with the GME classifier, the study categorizes land into five classes: water bodies, sparse vegetation or agricultural land, dense vegetation, built-up areas, and barren land.

9.1.1. District-Wide LULC Patterns

Agricultural Dominance: Sparse vegetation or agricultural land covers 87.53% of Meherpur district (637.56 sq km), underscoring its agrarian economy.
Limited Water Bodies: Water bodies constitute only 2.57% (18.69 sq km), potentially underestimated due to aquatic vegetation cover misclassified as dense vegetation.
Dense Vegetation: Accounts for 8.51% (61.96 sq km), indicating significant green cover, though some may mask village settlements.
Minimal Urbanization: Built-up areas cover 1.07% (7.77 sq km), likely underestimated due to tree cover over settlements.
Barren Land: Minimal at 0.34% (2.45 sq km), reflecting intensive land use.

9.1.2. Meherpur Upazila

Agricultural Focus: Sparse vegetation or agricultural land dominates at 89.81% (236.63 sq km), reinforcing the rural character.
Natural Features: Dense vegetation (6.54%, 17.22 sq km) and water bodies (2.32%, 6.10 sq km) are moderately present.
Low Urbanization: Built-up areas (0.94%, 2.47 sq km) and barren land (0.4%, 1.05 sq km) are minimal, indicating limited urban development compared to the Paurashava.

9.1.3. Gangni Upazila

Highly Agricultural: Sparse vegetation or agricultural land covers 90.1% (311.07 sq km), the highest among Upazilas, highlighting its agrarian landscape.
Moderate Natural Cover: Dense vegetation (6.46%, 22.29 sq km) and water bodies (2.67%, 9.22 sq km) are present but limited.
Minimal Urbanization: Built-up areas (0.47%, 1.63 sq km) and barren land (0.3%, 1.05 sq km) are scarce, reflecting a rural setting.

9.1.4. Mujibnagar Upazila

Agricultural Prevalence: Sparse vegetation or agricultural land is extensive at 90.87% (105.98 sq km), similar to Gangni.
Lower Natural Cover: Dense vegetation (5.93%, 6.91 sq km) and water bodies (2.26%, 2.64 sq km) are slightly less prominent.
Limited Development: Built-up areas (0.68%, 0.79 sq km) and barren land (0.27%, 0.32 sq km) are minimal, indicating a rural landscape.

9.1.5. Meherpur Paurashava

Semi-Urban Character: Sparse vegetation or agricultural land covers 81.85% (11.26 sq km), but built-up areas are higher at 3.7% (0.51 sq km), reflecting urbanization.
Significant Green Cover: Dense vegetation is notable at 12.92% (1.78 sq km), suggesting urban greenery.
Limited Water and Barren Land: Water bodies (0.91%, 0.13 sq km) and barren land (0.61%, 0.08 sq km) are minimal.

9.1.6. Gangni Paurashava

Agricultural with Urban Elements: Sparse vegetation or agricultural land dominates at 87.78% (14.87 sq km), but built-up areas (1.86%, 0.32 sq km) are more prominent than in Gangni Upazila.
Moderate Greenery: Dense vegetation covers 8.34% (1.41 sq km), indicating green patches.
Low Water and Barren Land: Water bodies (1.14%, 0.19 sq km) and barren land (0.87%, 0.15 sq km) are limited.

9.1.7. Methodological Considerations

Underestimation Issues: Water bodies and built-up areas may be underestimated due to aquatic vegetation and tree cover over settlements being classified as dense vegetation.
Technological Application: The use of Sentinel imagery, Google Earth Engine, and the GME classifier ensures high-resolution analysis but highlights challenges in distinguishing certain land cover types (Isbaex and Coelho, 2021).

9.1.8. Recommendations

Based on the findings, the following recommendations are proposed to enhance land use planning, environmental management, and sustainable development in Meherpur district:

Promote Sustainable Agriculture

- Optimize Land Use: Given the dominance of agricultural land (87–91%), promote sustainable farming practices like crop rotation, organic farming, and precision agriculture to maintain soil fertility and reduce environmental degradation (Loewen, 2023; Monteiro et al., 2021; Ransinghe et al., 2023).
- Protect Water Bodies: The low percentage of water bodies (1–3%) suggests a need for conservation efforts, such as restoring ponds and rivers, to support irrigation and biodiversity. Clear aquatic vegetation to improve water storage capacity.

Manage Urbanization

- Plan Urban Expansion: The higher built-up areas in Paurashavas (1.86–3.7%) indicate emerging urbanization. Develop urban plans to control sprawl, preserve agricultural land, and integrate green spaces, as seen in Meherpur Paurashava's dense vegetation (12.92%).
- Infrastructure Development: In Upazilas with minimal built-up areas (0.47–0.94%), prioritize eco-friendly infrastructure to support rural development without compromising agricultural land (Rawat et al., 2010).

Enhance Environmental Conservation

- Protect Dense Vegetation: Dense vegetation (5–13%) is a critical ecological asset. Implement reforestation and afforestation programs to maintain or expand green cover (Green and Unruh, 2010), especially in Mujibnagar, where it is lowest (5.93%).
- Reduce Barren Land: The small percentage of barren land (0.27–0.87%) should be targeted for reclamation through afforestation or agricultural restoration to maximize land productivity.

Support Climate Resilience

- Climate Change Adaptation: Use LULC data to inform climate adaptation strategies, such as identifying areas prone to flooding (water bodies) or drought (barren land). Protect water bodies to enhance water security during dry seasons.
- Carbon Sequestration: Leverage dense vegetation areas for carbon sequestration initiatives to mitigate climate change impacts.

Community Engagement and Policy Integration

- Raise Awareness: Educate local communities about the importance of preserving agricultural land, water bodies, and vegetation to ensure sustainable land use.
- Policy Alignment: Integrate LULC findings into district-level planning and national policies, aligning with Bangladesh's sustainable development goals to balance agriculture, urbanization, and environmental conservation.

Continuous Monitoring

- Regular LULC Updates: Establish a monitoring system using Google Earth Engine to track LULC changes annually, enabling timely interventions to address urban sprawl, deforestation, or water body degradation.
- Collaborative Research: Partner with academic institutions and environmental organizations to refine LULC methodologies and address classification challenges.

9.1.9. Remarks

The LULC analysis reveals Meherpur district's predominantly agricultural landscape with limited urbanization and critical natural features like water bodies and dense vegetation. While the district's air and water quality (from related datasets) are generally acceptable, the LULC data highlights the need for sustainable land management to preserve its agrarian base and ecological assets. Implementing refined classification, sustainable agriculture, controlled urbanization, and conservation measures will ensure Meherpur's long-term environmental and economic resilience.

9.2. Water Quality Assessment of Meherpur District

Chapter 5 provides a detailed water quality assessment of Meherpur district, focusing on surface water quality across Meherpur Sadar, Gangni, and Mujibnagar Upazilas. The study evaluates 12 physicochemical parameters (temperature, pH, salinity, turbidity, dissolved oxygen (DO), total dissolved solids (TDS), electrical conductivity (EC), total alkalinity, total suspended solids (TSS), chloride, biological oxygen demand (BOD), and chemical oxygen demand (COD)) during wet and dry seasons, alongside heavy metal concentrations and a Water Quality Index (WQI). Below are the major findings:

9.2.1. Seasonal Variations in Water Quality

Dry Season (22 Locations)

Temperature: Higher (23.8–32.4°C) than the wet season, with Taranagar at 32.4°C, indicating warmer conditions that may stress aquatic life.

pH: Ranges from 6.51 (Kedarganj) to 9.7 (Biswanathpur), with alkaline values (>9) at Malshadaha and Biswanathpur, potentially harmful to aquatic ecosystems.

Turbidity: Extremely high at Taranagar (177 NTU), reflecting sediment or pollution concentration due to low water volume.

DO: Varies from 3.4 mg/L (Biswanathpur, indicating hypoxia risk) to 9 mg/L (Malshadaha), with most sites above 5 mg/L.

TDS and EC: Higher (up to 522 mg/L and 780 µS/cm at Terail) due to reduced dilution, indicating concentrated pollutants.

TSS: Peaks at Taranagar (420 mg/L), suggesting severe sediment issues.

BOD and COD: Taranagar shows extreme values (20 mg/L BOD, 200 mg/L COD), indicating significant organic and chemical pollution.

Wet Season (12 Locations)

Temperature: More stable (25.9–28.2°C), typical for monsoon conditions.

pH: Near neutral (5.9–7.9), with Terail slightly acidic (5.9), suitable for aquatic life.

Turbidity: High at GOR Pond (67.3 NTU), indicating runoff-related sediment.

DO: Ranges from 4.9 mg/L (GOR Pond, potential stress) to 7.3 mg/L (Terail), generally healthier than dry season.

TDS and EC: Lower (up to 398 mg/L and 408 µS/cm), reflecting rainfall dilution.

TSS: High at GOR Pond (67 mg/L), but lower than dry season extremes.

BOD and COD: GOR Pond shows high values (25 mg/L BOD, 88 mg/L COD), suggesting urban runoff pollution.

Comparison: Wet season benefits from dilution, resulting in lower pollutant levels and healthier DO and pH. Dry season shows higher pollution, particularly at Taranagar, due to concentrated contaminants.

9.2.2. Pollution Hotspots

Taranagar (Dry Season): Extreme turbidity (177 NTU), TSS (420 mg/L), BOD (20 mg/L), and COD (200 mg/L) indicate severe organic and chemical pollution, likely from agricultural runoff or untreated waste.
GOR Pond (Wet Season): High turbidity (67.3 NTU), TSS (67 mg/L), BOD (25 mg/L), and COD (88 mg/L) suggest urban runoff or human activity impacts.
Biswanathpur (Dry Season): Low DO (3.4 mg/L) indicates hypoxia risk, threatening aquatic life.

9.2.3. Heavy Metal Contamination

Across 15 locations, heavy metal concentrations (Cd, Cr, Cu, Ni, Pb, Zn) were tested, with Zn showing the highest levels (up to 243.2 ppm at W-01) and Pb reaching 56.15 ppm (W-01). Cd is low (0.32–2.39 ppm), but Pb and Zn levels suggest potential contamination, possibly from agricultural or industrial sources. W-01 is the most impacted site, indicating a need for targeted investigation.

9.2.4. Water Quality Index (WQI)

WQI values range from 48.57 (SW-02, Bamonpara Pond, "Good" for drinking, irrigation, industrial use) to 316.9 (SW-13, Gangni Biswaspara, "Unsuitable" requiring treatment).
Only SW-02 is rated "Good"; SW-01 and SW-14 are "Poor" (suitable for irrigation/industrial use); SW-04, SW-06, and SW-15 are "Very Poor" (irrigation only); and nine sites (SW-03, SW-05, SW-07–13) are "Unsuitable," requiring treatment due to high pollution levels.
Spatial variability highlights better quality at rural sites (e.g., SW-02) and poor quality near urban or agricultural areas (e.g., SW-03, GOR Lake).

9.2.5. Compliance with Standards

Per Bangladesh's ECR'23 Inland Surface Water Standards, most parameters meet limits (pH: 6.5–8.5, TDS: 1000 mg/L, EC: 2250 µS/cm, BOD: ≤12 mg/L, COD: 100 mg/L), but exceptions include:
Dry season pH >8.5 at Malshadaha and Biswanathpur.
BOD >12 mg/L at Taranagar (dry) and GOR Pond (wet).
COD >100 mg/L at Taranagar (dry, 200 mg/L).

9.2.6. Recommendations

Based on the findings, the following recommendations are proposed to improve water quality management in Meherpur district:

Target Pollution Hotspots

Taranagar and GOR Pond: Implement wastewater treatment facilities and runoff control measures (e.g., sediment traps, vegetative buffers) to reduce organic and chemical pollution (Barling and Moore, 1994; Yuan et al., 2009). Regular monitoring is needed to track BOD, COD, TSS, and turbidity levels.

Biswanathpur: Address low DO through aeration techniques or pollution source control to prevent hypoxic conditions (Åmand et al., 2013; Baldwin et al., 2021; Gu et al., 2023).

Mitigate Heavy Metal Contamination

- Investigate W-01: Conduct detailed source tracking for high Pb (56.15 ppm) and Zn (243.2 ppm) levels, potentially from agricultural fertilizers, pesticides, or industrial effluents. Install filtration systems or phytoremediation (e.g., using aquatic plants) to reduce metal concentrations (Ali et al., 2013; Ghosh and Singh, 2005; Muthusaravanan et al., 2018).
- Set Thresholds: Establish local heavy metal standards, as current ECR'23 lacks specific limits for Cd, Cr, Cu, Ni, Pb, and Zn in surface water. Compare with WHO or USEPA guidelines to assess health risks.

Enhance Seasonal Management

- Dry Season: Increase water flow through reservoir releases or canal maintenance to dilute pollutants. Promote low-water-use irrigation to reduce stress on water bodies.
- Wet Season: Strengthen runoff management in urban areas (e.g., GOR Pond) through stormwater drainage systems to minimize sediment and pollutant influx.

Improve Water Quality for Use

- Treatment for Unsuitable Sites: For nine "Unsuitable" sites (SW-03, SW-05, SW-07–13), install treatment plants (e.g., coagulation, filtration, disinfection) to make water safe for irrigation or industrial use.
- Protect Good Quality Sites: Safeguard SW-02 (Bamonpara Pond) through zoning restrictions to prevent agricultural or urban pollution, ensuring its suitability for drinking.

Integrate with Land Use Planning

Link water quality findings with LULC data (from Chapter 4), noting that 87.53% agricultural land contributes to runoff pollution. Promote sustainable farming practices (e.g., reduced pesticide use, organic fertilizers) to minimize BOD, COD, and heavy metal inputs.

Protect the 2.57% water bodies by restoring aquatic ecosystems and clearing vegetation to enhance water storage.

Strengthen Monitoring and Policy

- Continuous Monitoring: Establish a real-time monitoring network using sensors for key parameters (pH, DO, turbidity) at critical sites like Taranagar and GOR Pond.
- Policy Enforcement: Enforce ECR'23 standards strictly, particularly for BOD and COD, and update regulations to include heavy metal limits. Align with SDG 6 (Clean Water and Sanitation).
- Community Awareness: Educate farmers and residents about pollution impacts and best practices for water use, especially in agricultural areas.

Address Climate Change Impacts

Develop climate-resilient water management plans to counter temperature increases and altered rainfall patterns, which exacerbate dry season pollution. Use WQI data to prioritize vulnerable sites for adaptation measures.

9.2.7. Remarks

Meherpur's surface water quality varies significantly by season and location, with wet season dilution improving conditions and dry season concentration worsening pollution, particularly at Taranagar. GOR Pond and Biswanathpur are critical hotspots, and heavy metal levels (especially Pb and Zn) pose potential risks. The WQI indicates most sites are unsuitable or poor for direct use, necessitating treatment and management interventions. By targeting pollution sources, enhancing monitoring, and integrating sustainable practices, Meherpur can safeguard its water resources for agriculture, ecosystems, and public health.

9.3. Noise Quality Assessment of Meherpur District

Chapter 6 presents a comprehensive noise quality assessment of Meherpur district, covering Meherpur Sadar, Gangni, and Mujibnagar Upazilas. The study measures average noise levels (in decibels, dB) at 65 locations, ranging from 38.87 dB to 63.95 dB, using sound level meters. The findings highlight spatial variations in noise pollution influenced by urban, rural, and commercial activities, with comparisons to the World Health Organization (WHO) guideline of 55 dB for residential areas to prevent health risks like stress or sleep disturbances (Schwela, 2001). Below are the major findings:

9.3.1. Noise Level Variations Across the District

Range: Noise levels range from 38.87 dB (Mollickpara Road, Meherpur) to 63.95 dB (Hotel Bazar, Meherpur), reflecting diverse acoustic environments.
Urban vs. Rural: Urban and commercial areas (e.g., Hotel Bazar, Bara Bazar) show higher noise levels, while rural areas (e.g., Mollickpara Road, Bashundhara) are quieter.
Exceedance of WHO Guideline: Locations like Hotel Bazar (63.95 dB), Bara Bazar (55.75 dB), Saharabati (55.84 dB), and Kazi Para (54.49 dB) exceed the WHO's 55 dB threshold for residential areas, posing potential health risks.

9.3.2. Meherpur Sadar

Highest Noise: Hotel Bazar records the highest noise level at 63.95 dB, driven by commercial activity and traffic, followed by Bara Bazar (55.75 dB) and Kazi Para (54.49 dB).
Moderate Noise: Areas like Stadium Para (52.86 dB), BAT-01 (51.4 dB), and Roghunathpur (50.88 dB) show semi-urban characteristics with moderate noise from human activity or traffic.

Quiet Areas: Mollickpara Road (38.87 dB), Mallik Para (42.52 dB), and Beltolapara (42.03 dB) are the quietest, likely rural or residential with minimal traffic.
Key Observation: Commercial hubs in Meherpur Sadar are significant noise pollution sources, requiring mitigation.

9.3.3. Gangni Upazila

Generally Quieter: Most locations are below 55 dB, with Bashundhara (40.23 dB), Chougacha Pashchim Para (41.10 dB), and Jalshuka Road (41.42 dB) among the quietest, reflecting rural settings.

Noisy Exceptions: Saharabati (55.84 dB) and Durlovpur (52.72 dB) exceed or approach the WHO threshold, likely due to market activity or roads.

Educational Sites: Gangni Girls School (50.89 dB) and Shandhani School (41.64 dB) show moderate noise, possibly from student activities or nearby traffic.

Key Observation: Gangni is predominantly quiet, but market areas like Saharabati require noise control measures.

9.3.4. Mujibnagar Upazila

Low Noise Levels: All locations are below 55 dB, with Muchi Para (40.68 dB) and Church of BD (41.39 dB) being the quietest, indicating rural tranquility.

Moderate Noise: Kedarganj Primary School (50.46 dB), Mohajanpur (52.65 dB), and Pirojpur (51.55 dB) are noisier, likely due to school or community activities.

Key Observation: Mujibnagar maintains a quiet acoustic environment, with no significant noise pollution concerns.

9.3.5. Sources of Noise Pollution

Commercial Activity: High noise in Hotel Bazar, Bara Bazar, and Saharabati is linked to markets, shops, and pedestrian activity.

Traffic: Roads and bazaars (e.g., Kazi Para, Durlovpur) contribute to elevated noise due to vehicles and honking.

Human Activity: Schools (e.g., Gangni Girls School, Kedarganj Primary School) and community areas (e.g., Mohajanpur) show moderate noise from gatherings or daily activities.

9.3.6. Health and Environmental Implications

Locations exceeding 55 dB (e.g., Hotel Bazar, Saharabati) pose risks of stress, sleep disturbances, and reduced quality of life, particularly in residential areas.

Rural areas with low noise levels (e.g., Mollickpara Road, Bashundhara) support healthier acoustic environments but may still be vulnerable to future urbanization.

9.3.7. Recommendations

Based on the noise quality assessment, the following recommendations are proposed to mitigate noise pollution and enhance the acoustic environment in Meherpur district:

Target High-Noise Areas

Hotel Bazar and Bara Bazar (Meherpur): Implement traffic management measures, such as speed limits, no-honking zones, and pedestrian-only hours, to reduce noise from vehicles and commercial activity. Install sound barriers or green belts (trees) along roads to absorb noise (Khan et al., 2023; Rathoure and Modi, 2019; Van Renterghem et al., 2015).

Saharabati (Gangni): Regulate market hours and enforce noise limits for shops and vendors. Promote quiet zones near residential areas adjacent to markets.

Urban Planning and Zoning

- Separate Commercial and Residential Zones: In Meherpur Sadar, enforce zoning regulations to distance noisy commercial areas (e.g., Hotel Bazar) from residential zones like Mallik Para to protect residents from noise exposure.

- Limit Urban Sprawl: As Meherpur's built-up areas are minimal (1.07% per LULC data), plan urban expansion to avoid encroaching on quiet rural areas like Bashundhara or Muchi Para, preserving their low noise levels.

Traffic Noise Reduction

- Road Improvements: Pave roads in noisy areas like Kazi Para and Durlovpur to reduce vehicle-related noise. Use noise-reducing asphalt where feasible.
- Public Transport: Encourage public transport use in commercial hubs to decrease private vehicle traffic, a major noise source in Hotel Bazar and Saharabati.

Protect Quiet Areas

- Rural Preservation: Safeguard low-noise areas like Mollickpara Road (38.87 dB), Bashundhara (40.23 dB), and Muchi Para (40.68 dB) by restricting industrial or commercial development. Promote eco-tourism or green spaces to maintain tranquility.
- School Noise Control: In educational sites like Gangni Girls School (50.89 dB) and Kedarganj Primary School (50.46 dB), install soundproofing in classrooms or limit external activities during study hours to minimize disruptions.

Public Awareness and Community Engagement

- Educate Residents: Raise awareness about noise pollution's health impacts (e.g., stress, hearing loss) through campaigns in high-noise areas like Hotel Bazar and Bara Bazar. Encourage quieter practices, such as reduced honking or lower speaker volumes.
- Community Monitoring: Involve local communities in noise monitoring using low-cost sound meters to track levels in areas like Saharabati or Mohajanpur, fostering accountability.

Policy and Regulation Enforcement

- Adopt Noise Standards: Align with WHO's 55 dB guideline for residential areas and Bangladesh's noise pollution control rules (e.g., 50 dB for residential, 70 dB for commercial). Enforce stricter limits in Meherpur Sadar's commercial zones.
- Regular Inspections: Conduct periodic noise assessments in high-risk areas (e.g., Hotel Bazar, Saharabati) to ensure compliance with standards and evaluate mitigation effectiveness.

Integrate with Environmental Management

Link with LULC Data: Use LULC findings (87.53% agricultural land, 1.07% built-up) to prioritize noise control in urbanizing Paurashavas (Meherpur, Gangni) where built-up areas are higher (3.7% and 1.86%). Protect agricultural and dense vegetation areas (8.51%) as natural noise buffers.

Coordinate with Water and Air Quality Efforts: Combine noise mitigation with water quality (e.g., reducing runoff near noisy roads) and air quality (e.g., controlling vehicle emissions in Hotel Bazar) strategies for holistic environmental management.

Continuous Monitoring and Mapping

Expand Noise Mapping: Enhance Figure 6.1's interpolated noise map with real-time data collection using automated sound level meters in critical areas like Hotel Bazar and Saharabati.

Seasonal Assessments: Conduct noise assessments during wet and dry seasons to capture variations, as traffic or market activity may differ with agricultural cycles.

9.3.8. Remarks

Meherpur district's noise levels reflect its mixed urban-rural character, with commercial hubs like Hotel Bazar (63.95 dB) and Saharabati (55.84 dB) exceeding WHO's 55 dB threshold, posing health risks. Rural areas like Mollickpara Road (38.87 dB) and Muchi Para (40.68 dB) maintain quiet environments, supporting quality of life. Targeted mitigation in high-noise areas, urban planning, traffic control, and policy enforcement can reduce noise pollution, while preserving quiet zones ensures Meherpur's acoustic health. Integrating noise management with land use, water, and air quality efforts will promote a sustainable and livable environment.

9.4. Air Quality Assessment of Meherpur District

Chapter 7 provides a detailed air quality assessment of Meherpur district, covering Meherpur Sadar, Gangni, and Mujibnagar Upazilas. The study analyzes ambient air quality at 20 locations (9 in Meherpur Sadar, 7 in Gangni, 4 in Mujibnagar) for key pollutants: carbon monoxide (CO), ozone (O3), particulate matter (PM2.5 and PM10), sulfur oxides (SOx), nitrogen oxides (NOx), and lead (Pb). Measurements were conducted using real-time electrochemical sensors and gravimetric techniques over 12 hours, with results compared to Bangladesh's Air Pollution Control Rules 2022 standards. The Air Quality Index (AQI) was calculated using US EPA methodology for PM2.5, PM10, CO, and SO2. Below are the major findings:

9.4.1. Overall Air Quality

Generally Good: Most pollutant concentrations are well below Bangladesh standards (CO: 20 mg/m³, O3: 180 µg/m³, PM2.5: 65 µg/m³, PM10: 150 µg/m³, SOx: 80 µg/m³, NOx: 80 µg/m³, Pb: 0.5 µg/m³), reflecting Meherpur's predominantly agricultural setting (87.53% agricultural land per LULC data).

Localized Concerns: Elevated PM2.5 and PM10 in specific areas and a potential Pb anomaly at Bishwanathpur highlight localized pollution risks.

9.4.2. *Meherpur Sadar*

CO: Ranges from 0.421 mg/m³ (Roghunathpur Jame Mosque) to 0.843 mg/m³ (BAT DPO-1, Beltolapara), all far below 20 mg/m³, indicating low vehicle or industrial emissions.

O3: Consistently <0.1 µg/m³, well below 180 µg/m³, suggesting negligible photochemical smog.

PM2.5: Varies from 6.3 µg/m³ (Sonapur Malithapara Bazar) to 14.68 µg/m³ (Amdah D. Para Jame Mosque), all below 65 µg/m³, but Amdah's higher value suggests dust or market activity.

PM10: Ranges from 28.25 µg/m³ (BAT DPO-1) to 147.79 µg/m³ (Amdah D. Para Jame Mosque), approaching the 150 µg/m³ limit at Amdah, indicating potential dust or construction sources.

SOx and NOx: Below 2.5 µg/m³ and 5 µg/m³, respectively, except BAT DPO-1 (NOx: 5.76 µg/m³), all well below 80 µg/m³, reflecting minimal industrial activity.

Pb: Below 0.3 µg/m³, compliant with 0.5 µg/m³ standard.

Key Observation: Amdah D. Para's high PM10 (147.79 µg/m³) is a concern, warranting monitoring due to proximity to the standard limit.

9.4.3. Gangni Upazila

CO: Ranges from 0.000 mg/m³ (Agrani Bank, Bamundi Bazar) to 1.226 mg/m³ (Depa Westpara Jame Mosque), all below 20 mg/m³.

O3: Below 0.1 µg/m³, no concerns.
PM2.5: Varies from 10 µg/m³ (Agrani Bank) to 25.79 µg/m³ (Kasba Bazar), below 65 µg/m³, with Kasba Bazar's higher value linked to market or vehicle emissions.
PM10: Ranges from 24.73 µg/m³ (Jalshuka-Arpara Road) to 69.68 µg/m³ (Beltolapara), all below 150 µg/m³, indicating moderate particulate levels.
SOx and NOx: Below 2.5 µg/m³ and 5 µg/m³, respectively, showing low gaseous pollution.
Pb: Below 0.3 µg/m³, compliant with standard.
Key Observation: Kasba Bazar's elevated PM2.5 (25.79 µg/m³) suggests localized pollution from market activities.

9.4.4. Mujibnagar Upazila

CO: Ranges from 0.000 mg/m³ (Monakhali Moddo Para, Bishwanathpur) to 0.651 mg/m³ (Mohajanpur Bazar), all below 20 mg/m³.
O3: Below 0.1 µg/m³, no concerns.
PM2.5: Varies from 10.69 µg/m³ (Anandabas Bazar) to 28.66 µg/m³ (Monakhali Moddo Para), the highest in the dataset but below 65 µg/m³, suggesting traffic or market-related sources.
PM10: Ranges from 18.13 µg/m³ (Anandabas Bazar) to 75.01 µg/m³ (Monakhali Moddo Para), all below 150 µg/m³.
SOx and NOx: Below 2.5 µg/m³ and 5 µg/m³, except Mohajanpur Bazar (NOx: 5.42 µg/m³), all below 80 µg/m³.
Pb: An anomalous 18.52 µg/m³ at Bishwanathpur (AQ-19) exceeds the 0.5 µg/m³ standard, likely a data error given other sites' <0.3 µg/m³ values, but if accurate, it indicates potential contamination.
Key Observation: Monakhali Moddo Para's high PM2.5 (28.66 µg/m³) and Bishwanathpur's Pb anomaly require further investigation.

9.4.5. Air Quality Index (AQI)

Range: AQI values range from 28.54 (BAT DPO-1, "Good") to 98.14 (Monakhali Moddo Para, "Moderate").
Categories: Seven locations (AQ-2, AQ-4, AQ-5, AQ-10, AQ-13, AQ-16, AQ-20) are "Good" (AQI 0–50), suitable for all activities. Thirteen locations are "Moderate" (AQI 51–100), indicating acceptable air quality but potential concern for sensitive groups (e.g., asthmatics) with prolonged exposure.
Dominant Pollutant: PM2.5 drives higher AQI values in most cases (e.g., Monakhali: 98.14, Kasba Bazar: 79.79), reflecting particulate matter as the primary concern.
Key Observation: No locations reach "Unhealthy" (AQI >100), but Monakhali's AQI (98.14) approaches this threshold, warranting attention.

9.4.6. Pollution Sources

Urban Areas: In Meherpur Sadar (1.07% built-up per LULC), vehicle emissions, construction, and market activities (e.g., Amdah, Kasba Bazar) contribute to PM2.5 and PM10.
Rural Areas: In Gangni and Mujibnagar, agricultural practices (e.g., crop residue burning), brick kilns, and traditional cooking may elevate PM10 and PM2.5, particularly in Monakhali.
Pb Anomaly: If valid, Bishwanathpur's Pb (18.52 µg/m³) could stem from industrial waste, old paint, or battery recycling, though this requires verification.
Health and Environmental Implications:

PM10 at Amdah: Near-standard levels (147.79 µg/m³) pose respiratory risks, especially in dry seasons with increased dust.
PM2.5 at Monakhali and Kasba Bazar: Elevated levels (28.66 µg/m³, 25.79 µg/m³) may cause asthma or cardiovascular issues with long-term exposure, particularly for sensitive groups.
Pb at Bishwanathpur: If accurate, high Pb levels could lead to neurological damage, especially in children, necessitating urgent investigation.

9.4.7. Recommendations

Based on the air quality assessment, the following recommendations are proposed to maintain and improve air quality in Meherpur district:

Target Localized Pollution Hotspots

Amdah D. Para (PM10: 147.79 µg/m³): Implement dust control measures, such as road paving, water sprinkling, and vegetative barriers, to reduce PM10 from construction or market activities. Monitor seasonally to prevent exceedance of the 150 µg/m³ standard.
Monakhali Moddo Para (PM2.5: 28.66 µg/m³, AQI: 98.14): Reduce vehicle emissions through traffic management (e.g., speed limits, no-idling zones) and promote cleaner fuels. Install air quality sensors for real-time monitoring.
Kasba Bazar (PM2.5: 25.79 µg/m³): Enforce dust suppression in markets (e.g., covering loose soil, regular cleaning) and limit heavy vehicle access during peak hours.

Strengthen Air Quality Monitoring

Expand Network: Install additional low-cost air quality sensors in high-risk areas (Amdah, Monakhali, Kasba Bazar) to track PM2.5 and PM10 in real-time, especially during dry seasons when dust increases.
Seasonal Assessments: Conduct air quality tests in wet and dry seasons to capture variations, as agricultural burning and dust may elevate PM levels in rural areas.

Mitigate Pollution Sources

Urban Areas (Meherpur Sadar): In areas with higher built-up land (3.7% in Meherpur Paurashava per LULC), promote public transport and electric vehicles to reduce CO and NOx from traffic. Regulate construction sites to minimize dust emissions.
Rural Areas (Gangni, Mujibnagar): Discourage crop residue burning through awareness campaigns and provide subsidies for cleaner cooking fuels to reduce PM10 and SOx from traditional stoves. Regulate brick kilns to use cleaner technologies.
Link with LULC: Protect dense vegetation (8.51% per LULC) as natural air filters and expand green belts in urbanizing areas to absorb PM and CO2.

Policy and Regulation Enforcement

- Enforce Standards: Strictly monitor compliance with Bangladesh's Air Pollution Control Rules 2022, particularly for PM10 in Amdah and Pb in Bishwanathpur. Update standards to include VOCs, not currently regulated.
- AQI Communication: Regularly publish AQI results through local media or mobile apps to inform residents, especially in "Moderate" areas like Monakhali, about precautions for sensitive groups.
- Align with SDGs: Integrate air quality management into SDG 3 (Good Health) and SDG 11 (Sustainable Cities) by prioritizing pollution control in urbanizing Paurashavas.

Public Awareness and Community Engagement

- Educate Communities: Conduct campaigns in markets (Kasba Bazar, Mohajanpur) and schools (Beltolapara) about PM2.5 health risks and mitigation (e.g., masks, reduced outdoor activity during dusty periods).
- Community Monitoring: Train locals to use portable air quality monitors in rural areas like Monakhali to track PM levels and report pollution sources, fostering grassroots action.

Integrate with Other Environmental Assessments

Water Quality: Address runoff from dusty roads (linked to PM10) to prevent water pollution (e.g., high TSS in Taranagar per Chapter 5). Coordinate wastewater treatment to reduce VOC emissions.

Noise Quality: Combine traffic management for air quality (e.g., in Kasba Bazar) with noise reduction (e.g., in Saharabati per Chapter 6) to create quieter, cleaner urban hubs.

LULC Synergy: Use LULC data to guide air quality planning, prioritizing agricultural areas (87.53%) for reduced burning and urban areas (1.07%) for emission controls.

Climate Resilience

Develop climate-adaptive air quality plans to address seasonal dust (dry season) and biomass burning (post-harvest), which may worsen with climate change. Use AQI data to prioritize vulnerable sites like Monakhali for early interventions.

9.4.8. Remarks

Meherpur district's air quality is generally good, with most pollutants well below Bangladesh standards, reflecting its rural, agricultural character. However, localized spikes in PM2.5 (Monakhali: 28.66 µg/m³) and PM10 (Amdah: 147.79 µg/m³) in market and urbanizing areas, alongside a potential Pb anomaly at Bishwanathpur (18.52 µg/m³), highlight risks requiring targeted action. The AQI indicates "Good" to "Moderate" conditions, with PM2.5 as the primary concern. By enhancing monitoring, mitigating dust and emissions, enforcing regulations, and integrating with LULC, water, and noise management, Meherpur can sustain its clean air while addressing emerging pollution challenges.

9.5. Climate Change Analysis of Meherpur District

Chapter 8 presents a comprehensive climate change analysis of Meherpur district, located in southwestern Bangladesh, from 2000 to 2024. The study examines six climatic variables—minimum temperature, maximum temperature, precipitation, relative humidity, vapor pressure, and wind speed—using monthly data to identify seasonal and decadal trends. It also incorporates qualitative insights from tea-stall meetings and Key Informant Interviews (KIIs) to assess real-world climate change impacts. Below are the major findings:

9.5.1. Climatic Overview (2000–2024)

Minimum Temperature: Mean of 20.82°C, ranging from 8.82°C to 28.09°C. Seasonal cycle peaks in July (26.5°C) and dips in January (10.4°C), with a 1.0°C warming trend over 24 years.

Maximum Temperature: Mean of 31.86°C, ranging from 22.36°C to 39.38°C. Peaks in April–May (36–37°C), lowest in December–February (24–28°C). Slight increase of 0.11°C from 2000s to 2020s, with potential for more heatwaves (e.g., 2024).

Precipitation: Mean monthly rainfall of 120.54 mm, ranging from 0 to 639.21 mm. High variability, with monsoon peaks in July (296.7 mm) and dry periods in January–April and

September–December. Declined by 25.37 mm from 2000s (135.48 mm) to 2020s (110.11 mm).

Relative Humidity: Mean of 52.85%, ranging from 31.56% to 74.81%. Peaks in June–July (69.1%), lowest in March (36%). Increased by 1.22% in 2020s, indicating higher moisture.
Vapor Pressure: Mean of 2.53 kPa, ranging from 1.29 to 3.61 kPa. Peaks in July (3.4 kPa), lowest in January (1.4 kPa). Increased by 0.09 kPa in 2020s, correlating with humidity rise.
Wind Speed: Mean of 1.28 m/s, ranging from 0.31 to 2.64 m/s. Peaks in June (2.05 m/s), stable with minor decrease (1.31 m/s in 2000s to 1.28 m/s in 2020s).

9.5.2. Seasonal Trends

Temperature: Both minimum and maximum temperatures follow a tropical monsoon cycle, with warmer months (May–August) and cooler months (December–February). Maximum temperatures peak earlier (April–May) than minimums (July), reflecting diurnal variations.
Precipitation: Monsoon season (May–August) dominates rainfall, with July as the wettest month. Sharp drop from September (246.63 mm) to October (129.32 mm) indicates abrupt seasonal shifts.
Humidity and Vapor Pressure: Peak during monsoon (June–July), lowest in dry season (February–March). Sharp humidity rise from May (50.82%) to June (62.71%) marks monsoon onset.
Wind Speed: Stable with slight peak in June–July, no extreme variations, indicating minimal cyclonic influence compared to coastal Bangladesh.

9.5.3. Decadal Trends

Warming Trend: Minimum temperature increased by 0.13°C from 2000s (20.95°C) to 2020s (21.08°C), suggesting fewer cold spells. Maximum temperature rose by 0.11°C from 2000s (31.99°C) to 2020s (32.10°C), indicating potential for more heatwaves.
Drying Trend: Precipitation decreased by 25.37 mm from 2000s (135.48 mm) to 2020s (110.11 mm), impacting monsoon-dependent agriculture.
Rising Moisture: Relative humidity rose by 1.22% and vapor pressure by 0.09 kPa in 2020s, suggesting increased atmospheric moisture despite reduced rainfall, potentially leading to intense but less frequent rain events.
Stable Winds: Wind speed remained stable (1.31 m/s in 2000s to 1.28 m/s in 2020s), with minimal impact on agriculture or infrastructure.

9.5.4. Climate Change Impacts (Qualitative Insights)

Water Scarcity: Declining precipitation exacerbates water shortages in agriculture and orchards, threatening crop yields in a district with 87.53% agricultural land (per LULC data).
Pest and Insect Attacks: Warmer temperatures and changing climates boost pest reproduction, damaging crops. Increased pesticide use pollutes soil and water (e.g., high TSS and heavy metals in Chapter 5).
Short, Intense Winters: Shorter winters with higher intensity impact marginal communities, increasing vulnerability to cold spells.
Long, Hot Summers: Hotter, drier summers increase heat-related health issues, straining human and animal well-being.

9.5.5. Implications for Meherpur

Agriculture: Reduced rainfall and water scarcity threaten rice and other monsoon-dependent crops, critical in a district with 2.57% water bodies and high agricultural reliance.

Health: Rising humidity and temperatures exacerbate heat stress, while pest-related pesticide use may pose health risks via water and soil contamination.

Ecosystems: Warmer winters and changing precipitation patterns disrupt local biodiversity, affecting pollinators and pest-predator balances.

Socioeconomic: Marginal farmers face increased costs for irrigation and pesticides, while heatwaves and water shortages reduce labor productivity.

Chart: Decadal Trends of Key Climatic Variables

To visualize the decadal trends, the following chart displays the average values of minimum temperature, maximum temperature, precipitation, and relative humidity across the 2000s, 2010s, and 2020s.

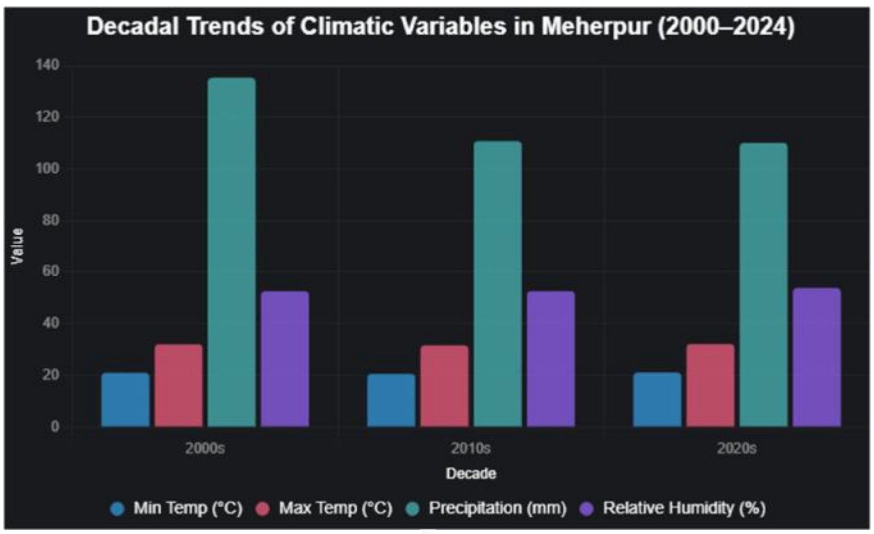

Figure 9.1: Decadal Trends of Climatic Variables in Meherpur (2000-2024)

Figure 9.1 shows a clear warming trend in minimum temperature, a slight increase in maximum temperature, a significant decline in precipitation, and a rise in relative humidity in the 2020s, highlighting Meherpur's shifting climate.

9.5.6. Recommendations

Based on the climate change analysis, the following recommendations are proposed to enhance resilience and sustainability in Meherpur district:

Address Water Scarcity

- Improve Irrigation: Promote efficient irrigation systems (e.g., drip irrigation) to counter declining precipitation (110.11 mm in 2020s). Expand water storage in 2.57% water bodies (per LULC) through reservoir maintenance.
- Rainwater Harvesting: Install community rainwater harvesting systems in agricultural areas to supplement water during dry seasons (January–April, September–December) (Al-Batsh et al., 2019; Ghimire and Johnston, 2019; Motsi et al., 2004; Oweis et al., 2012).

- Link with Water Quality: Use Chapter 5 findings to ensure harvested water is treated to avoid contamination (e.g., high TSS at Taranagar).

Mitigate Pest and Insect Attacks

- Integrated Pest Management (IPM): Train farmers on IPM to reduce pesticide use, minimizing soil and water pollution (e.g., Pb and Zn in Chapter 5). Promote natural predators and resistant crop varieties.
- Monitor Pesticide Residues: Establish soil and water testing programs to track pesticide contamination, ensuring compliance with environmental standards.
- Awareness Campaigns: Educate farmers on safe pesticide application, leveraging tea-stall meetings to disseminate knowledge.

Adapt to Shorter, Intense Winters

- Support Marginal Communities: Provide subsidized heating and shelters for vulnerable groups during intense winter spells (January, 10.4°C). Use KII insights to identify at-risk areas.
- Crop Diversification: Promote cold-tolerant crops (e.g., winter vegetables) to leverage shorter winters, reducing reliance on monsoon crops.

Manage Long, Hot Summers

- Heatwave Preparedness: Develop early warning systems for heatwaves (e.g., April–May, 36–37°C) and provide cooling centers in urban areas like Meherpur Sadar (1.07% built-up). Educate on heat stress prevention.
- Shade and Green Spaces: Expand tree cover in urbanizing Paurashavas (3.7% built-up) to reduce heat island effects, using dense vegetation (8.51% per LULC) as a model.
- Link with Air Quality: Combine heatwave measures with PM2.5 reduction (e.g., Monakhali, Chapter 7) through dust control to improve summer air quality.

Strengthen Agricultural Resilience

- Climate-Smart Agriculture: Introduce drought-resistant crops and adjust planting schedules to align with shifting monsoon patterns (May–August peak). Use seasonal precipitation data (Figure 8.2) for planning.
- Soil Conservation: Promote organic farming to enhance soil moisture retention, reducing water demand and pesticide runoff (linked to Chapter 5's heavy metal concerns).
- Insurance Schemes: Expand crop insurance to protect farmers from yield losses due to reduced rainfall or pest attacks.

Enhance Climate Monitoring

- Expand Weather Stations: Install additional stations in Gangni and Mujibnagar to improve spatial data coverage, complementing existing monthly data (2000–2024).
- Real-Time Data: Use satellite and IoT sensors for real-time temperature, humidity, and precipitation monitoring to support early warnings for heatwaves or dry spells.
- Update Models: Refine climate models with 2020s data (e.g., 110.11 mm precipitation) to project future scenarios, focusing on drying trends and humidity rise.

Policy and Community Engagement

- Climate Action Plan: Develop a district-level climate adaptation plan, aligning with SDG 13 (Climate Action) and Bangladesh's National Adaptation Plan. Prioritize water and agriculture based on KII findings.

- Community Involvement: Scale up tea-stall meetings to co-design adaptation strategies, ensuring farmer input on water and pest issues. Engage women and youth for inclusive resilience.
- Link with Noise and Air Quality: Integrate climate measures with noise reduction (e.g., green barriers in Hotel Bazar, Chapter 6) and air quality improvement (e.g., PM10 control in Amdah, Chapter 7) for holistic environmental management.

Address Rising Humidity and Moisture

- Ventilation in Buildings: Promote climate-resilient housing with improved ventilation to counter high humidity (53.81% in 2020s), reducing heat stress in urban areas.
- Flood Preparedness: Prepare for intense rainfall events (despite lower annual precipitation) by improving drainage in low-lying areas, leveraging Chapter 5's water management insights.

9.5.7. Remarks

Meherpur district exhibits clear climate change signals: a 1.0°C rise in minimum temperatures, a 0.11°C increase in maximum temperatures, a 25.37 mm decline in precipitation, and rising humidity (1.22%) and vapor pressure (0.09 kPa) from 2000 to 2024. These trends, coupled with stable wind speeds, indicate a warming, drying climate with increased atmospheric moisture, impacting agriculture, water availability, and human health. Qualitative insights highlight water scarcity, pest proliferation, intense winters, and hotter summers as key challenges. By implementing water-efficient irrigation, IPM, heatwave preparedness, and climate-smart agriculture, while integrating with water, air, and noise management (Chapters 5–7), Meherpur can build resilience against climate change, safeguarding its agricultural economy and community well-being.

Chapter-10: Conclusion

The integrated environmental and climate assessments of Meherpur district, as detailed in Chapters 5 through 8, reveal a region with a predominantly agricultural landscape (87.53% per LULC data) facing multifaceted challenges that threaten its ecological balance, public health, and socioeconomic stability. The water quality assessment (Chapter 5) highlights significant pollution in hotspots like Taranagar and GOR Pond, with high BOD, COD, and heavy metal levels (e.g., Pb and Zn at W-01), particularly during the dry season, rendering most water bodies unsuitable for direct use without treatment. Noise quality analysis (Chapter 6) identifies commercial hubs like Hotel Bazar (63.95 dB) and Saharabati (55.84 dB) as exceeding WHO's 55 dB residential threshold, posing health risks, while rural areas like Mollickpara Road (38.87 dB) remain tranquil. Air quality findings (Chapter 7) indicate generally good conditions, with pollutants like CO, O3, SOx, and NOx well below Bangladesh's 2022 standards, but localized PM2.5 (Monakhali: 28.66 $\mu g/m^3$) and PM10 (Amdah: 147.79 $\mu g/m^3$) spikes, alongside a potential Pb anomaly (Bishwanathpur: 18.52 $\mu g/m^3$), signal emerging concerns. The climate change analysis (Chapter 8) confirms a warming trend (minimum temperature +1.0°C, maximum +0.11°C from 2000 to 2024), declining precipitation (-25.37 mm), and rising humidity (+1.22%), exacerbating water scarcity, pest proliferation, intense winters, and hotter summers, with significant implications for Meherpur's agriculture-dependent economy.

These findings underscore the need for holistic, cross-sectoral interventions. Recommendations include targeted pollution control for water (e.g., wastewater treatment in Taranagar), noise (e.g., traffic management in Hotel Bazar), and air (e.g., dust suppression in Amdah), alongside climate-adaptive measures like efficient irrigation, integrated pest management, and heatwave preparedness. Integrating these strategies with land use planning (leveraging 8.51% dense vegetation and 2.57% water bodies) and community engagement through tea-stall meetings ensures locally relevant solutions. Continuous monitoring, policy enforcement aligned with SDGs (3, 6, 11, 13), and real-time data collection will strengthen resilience. By addressing these interconnected challenges, Meherpur can safeguard its environmental health, protect public well-being, and sustain its agricultural productivity, fostering a resilient and sustainable future in the face of growing environmental and climatic pressures.

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Appendix – 1: Photos of Different activities of surveys

1. Land use and Land cover field picture

Deep vegetation (Orchad) cover

Agricultural or sparse vegetation cover

Water body (river)

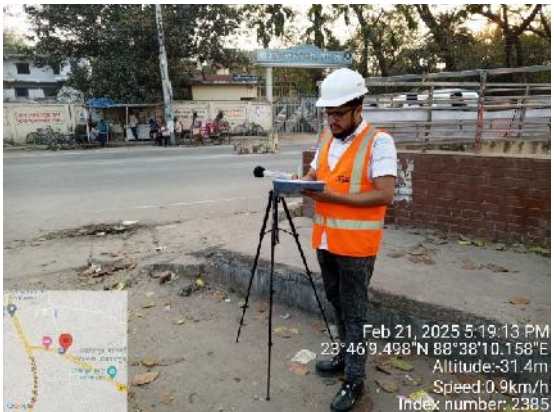
Water body (standing water body)

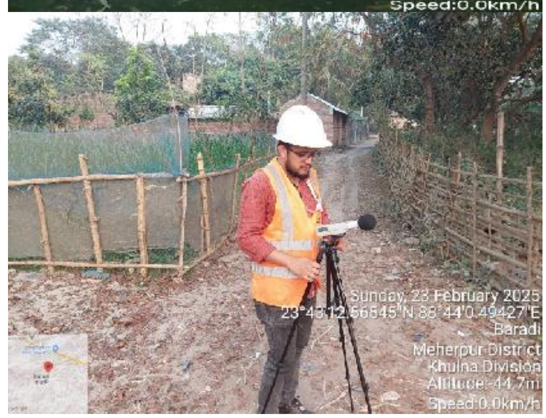
Urban area

Road type

2. Picture of Water Sampling process in the Project Area

3. Picture of Noise Sampling in The Project Area





4. Picture of Air quality Sampling in The Project Area

Appendix – 2: Different data information

Table : Surface Water Quality Test Reports- Dry Season

Parameter	Location	GPS Coordinates	Temp	pH	Salinity	Turbidity	Dissolved Oxygen (DO)	Total Dissolved Solids (TDS)	Electrical Conductivity (EC)	Total alkalinity	Total Suspended Solid (TSS)	Chloride	Biological Oxygen Demand (BOD)	Chemical Oxygen Demand (COD)
Unit			**°C**	**-**	**ppt**	**NTU**	**mg/L**	**mg/L**	**µS/cm**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
SW-01	Dariapur	23°42'25.078"N 88°36'27.69"E	30.27	6.7	0.02	64.1	5.3	170	214	170	10	19.99	6	40
SW-02	Bondor Muzibnagar Road	23°45'0.407"N 88°37'35.307"E	30.2	6.9	0.02	12.7	5.8	224	372	420	64	12	10	84
SW-03	GOR Pond	23°46'33.51"N 88°37'57.522"E	30.3	7.6	0.01	51	5.9	210	351	200	6	29.99	7	44
SW-04	Near BAT, Meherpur	23°45'38.148"N 88°39'10.518"E	27.8	7.71	0.01	34.12	5.4	137	259	370	12	27.99	8	48
SW-05	Chandbil Meherpur	23°44'59.706"N 88°40'29.4"E	28	6.9	0.01	29.2	5.7	184	291	260	104	17.99	12	88
SW-06	Amjhupi Meherpur	23°44'59.076"N 88°40'31.428"E	28.4	7.2	0.01	34.5	6.2	178	252	280	98	6	9	68
SW-07	Dighipara, Meherpur	23°46'42"N 88°39'1.686"E	28.5	7.7	0.01	16.8	5.9	212	371	270	58	21.99	10	76
SW-08	Gopalpur, Meherpur	23°46'57.468"N 88°39'44.602"E	29.4	7.8	0.02	40.17	6.0	143	310	220	44	< 0.50	5	32
SW-09	Malshadaha	23°50'8.72005"N 88°46'1.57303"E	30.9	9.38	0.02	112	5.2	201	406	210	78	6	7	56
SW-10	Baot	23°53'9.174"N 88°49'35.694"E	30.1	8.4	0.01	41.47	5.9	134	269	110	50	14	6	56
SW-11	Malshadaha	23°50'56.37678"N 88°43'54.2226"E	29.7	9.4	0.01	29.32	9.0	172	345	170	60	14	8	56
SW-12	Arpara-Chandmari Road	23°46'52.726"N 88°48'14.944"E	31.9	7.87	0.02	40.27	6.3	212	426	200	38	10	12	92
SW-13	Gangni, Biswaspara Jame Mosque	23°50'8.75371"N 88°46'1.54513"E	31.9	7.64	0.03	36.79	6.9	370	743	340	36	14	6	36
SW-14	Terail	23°52'18.03"N 88°47'13.05"E	23.8	7.4	0.04	70	5.8	522	780	370	120	45.99	8	56

SW-15	Harbhanga	23°54'43.752"N 88°47'5.136"E	32.0	7.84	0.03	42.68	6.2	357	723	240	26	51.98	6	40
SW-16	Jalshuka-Arpara Road	23°47'22.16476"N 88°46'19.9759"E	30.9	7.32	0.02	17.31	5.5	293	588	280	6	12	7	44
SW-17	Kedarganj	23°39'49.17"N 88°36'17.01"E	26.8	6.51	0.01	12.1	6.2	150	299	170	4	< 0.50	5	24
SW-18	Biswanathpur	23°40'45.144"N 88°36'53.236"E	28.6	9.7	0.01	17.84	3.4	228	343	150	16	16	6	28
SW-19	Mohajonpur	23°39'15.174"N 88°40'18.848"E	28.9	9.44	0.01	33.32	5.0	125	254	120	6	10	4	12
SW-20	Taranagar	23°38'8.64"N 88°38'23.484"E	32.4	9.07	0.01	177	5.5	131	259	110	420	12	20	200
SW-21	Ballovpur	23°39'8.514"N 88°36'48.078"E	27.2	7.1	0.01	23.2	5.8	117	228	300	14	19.99	7	44
SW-22	Taranagar	23°37'48.639"N 88°37'15.487"E	28.9	7.3	0.02	14.3	5.9	154	202	150	16	4	5	32
Requirements have been followed as per E.C.R'23(BD), Inland Surface Water Standard, Schedule-2(Ka-6).				6.5-8.5				1000	2250			0.1	≤12	100

Table : Surface Water Quality Test Reports-Wet Season

Parameter	Location	GPS Coordinates	Temp	pH	Salinity	Turbidity	Dissolved Oxygen (DO)	Total Dissolved Solids (TDS)	Electrical Conductivity (EC)	Total alkalinity	Total Suspended Solid (TSS)	Chloride	Biological Oxygen Demand (BOD)	Chemical Oxygen Demand (COD)
Unit			°C	-	ppt	NTU	mg/L	mg/L	µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L
SW-22	Roshikpur, Mujibnagar, Meherpur	23°38'53.66"N 88°38'00.14"E	28.2	6.9	0.01	13.7	5.9	214	324	160.0	34.0	8.0	12	46
SW-19	Islampur, Meherpur Sadar, Meherpur	23°41'19.40"N 88°40'29.63"E	27.3	6.8	0.01	21.7	6.7	233	308	123.4	45.0	16.3	10	41
SW-01	Dariapur, Mujibnagar, Meherpur	23°42'30.08"N 88°36'39.47"E	26	7.3	0.04	58.9	6.2	337	408	181.5	55.0	21.4	6	28
SW-03	Boshpara, Meherpur Sadar, Meherpur	23°46'21.91"N 88°37'34.89"E	27.9	7.7	0.02	67.3	4.9	341	248	210.9	67.0	23.3	25	88
SW-04	New Bus Stand , Meherpur Sadar, Meherpur	23°45'39.33"N 88°38'55.86"E	26.5	6.7	0.01	13.9	6.2	178	287	223.2	24.0	15.7	5	28
SW-06	Chandbill, Meherpur Sadar, Meherpur	23°44'45.64"N 88°40'7.34"E	25.9	6.1	0.02	57.9	6.8	398	314	255.4	64.0	42.4	14	58
SW-16	Hijuli, Meherpur Sadar, Meherpur	23°44'15.53"N 88°42'32.08"E	26.3	6.2	0.02	61.3	7.1	387	244	175.5	58.0	34.1	7	66
SW-08	Gopalpur, Meherpur Sadar, Meherpur	23°46'59.05"N 88°39'49.44"E	27.1	7.1	0.01	14.9	6.8	216	137	220.1	18.0	17.4	5	56
SW-09	Garadob, Meherpur Sadar, Meherpur	23°48'3.80"N 88°41'37.91"E	26.9	6.8	0.02	38.9	7.1	342	219	210.9	41.0	36.5	7	48
SW-14	Jorpukur, Gangni, Meherpur	23°52'16.46"N 88°47'10.09"E	27.8	5.9	0.02	62.7	7.3	134	389	110.2	24.0	25.1	6	32
SW-10	Baot, Gangni, Meherpur	23°53'9.35"N 88°49'35.30"E	26.7	6.8	0.01	11.8	6.9	169	207	154.7	11.0	10.4	5	41
SW-15	Near Khalishakundi, Gangni, Meherpur	23°53'32.58"N 88°52'18.31"E	26.8	7.9	0.02	7.3	7.1	104	278	225.4	5.0	5.7	4	25

Table: Concentration of Pollutants in Ambient Air Quality

SL NO	ID of Sample Location	Concentration of Pollutants in Ambient Air						
		CO	O_3	PM2.5	PM10	SOx	NOx	Pb
1	AQ-1,Mollickpara Road Meherpur Sadar, GPS Coordinates: 23°46'10.12"N 88°38'3.82"E	**0.498**	**<0.1**	**12.13**	**58.14**	**< 2.50**	**< 5.00**	**< 0.30**
2	AQ-2, BAT DPO-1 Meherpur Sadar, GPS Coordinates: 23°45'48.58"N 88°38'50.20"E	**0.843**	**<0.1**	**6.85**	**28.25**	**< 2.50**	**5.76**	**< 0.30**
3	AQ-03, Mondol Bari Mor, Meherpur Sadar GPS Coordinates: 23°47'57.79"N 88°38'36.84"E	**0.536**	**<0.1**	**9.21**	**73.52**	**< 2.50**	**< 5.00**	**< 0.30**
4	AQ-04 Roghunathpur Jame Mosque, Meherpur Sadar GPS Coordinates: 23°43'49.87"N 88°41'46.0775"E	**0.421**	**<0.1**	**< 5.00**	**49.59**	**< 2.50**	**< 5.00**	**< 0.30**
5	AQ-05 Sonapur malithapara bajar, Meherpur GPS Coordinates: 23°41'20.426"N 88°42'43.965"E	**0.575**	**<0.1**	**6.3**	**45.65**	**< 2.50**	**< 5.00**	**< 0.30**
6	AQ-06 Amdah D: Para Jame Mosjid, Meherpur GPS Coordinates: 23°43'44.434"N 88°37'54.5893"E	**0.766**	**<0.1**	**14.68**	**147.79**	**< 2.50**	**< 5.00**	**< 0.30**
7	AQ-07 Baradi Bazar, Meherpur GPS Coordinates: 23°43'12.56"N 88°44'0.209"E	**0.460**	**<0.1**	**8.7**	**62.25**	**< 2.50**	**< 5.00**	**< 0.30**
8	AQ-08 Beltolapara Government Primary School, Meherpur GPS Coordinates: 23°48'50.33"N 88°40'27.02"E	**0.843**	**<0.1**	**10.79**	**69.68**	**< 2.50**	**< 5.00**	**< 0.30**
9	AQ-09 Kasba Bazar GPS Coordinates: 23°45'27.100"N 88°46'18.536"E	**0.383**	**<0.1**	**25.79**	**25.9**	**< 2.50**	**< 5.00**	**< 0.30**
10	AQ-10 Agrani Bank PLC, Bamundi Bazar Branch,Gangni GPS Coordinates: 23°53'59.958"N 88°48'73.74"E	**0.000**	**<0.1**	**10**	**45.6**	**< 2.50**	**< 5.00**	**< 0.30**
11	AQ-11 Tetulbaria westpara jame mosque, Gangni GPS Coordinates: 23°53'49.512"N 88°43'30.512"E	**0.766**	**<0.1**	**15.79**	**37.75**	**< 2.50**	**< 5.00**	**< 0.30**
12	AQ-12 Bagan Para 08 No. Ward, Gangni GPS Coordinates: 23°48'47.845"N 88°45'1.687"E	**0.728**	**<0.1**	**20.79**	**35**	**< 2.50**	**< 5.00**	**< 0.30**
13	AQ-13 Garadob High School, Gangni GPS Coordinates: 23°47'54.382"N 88°47'52.551"E	**0.460**	**<0.1**	**12.22**	**30.56**	**< 2.50**	**< 5.00**	**< 0.30**

14	AQ-14 Depa Westpara Jame Mosque, Gangni GPS Coordinates: 23°45'49.929"N 88°43'13.463"E	**1.226**	**<0.1**	**17.27**	**52.53**	**< 2.50**	**< 5.00**	**< 0.30**
15	AQ-15 Jalshuka-Arpara-Jalshuka road, Gangni GPS Coordinates: 23°54'43.752"N 88°47'5.136"E	**0.536**	**<0.1**	**14.86**	**24.73**	**< 2.50**	**< 5.00**	**< 0.30**
16	AQ-16 Church Of Christ Road, Gangni GPS Coordinates: 23°38'45.835"N 88°38'49.045"E	**1.073**	**<0.1**	**8.06**	**27.74**	**< 2.50**	**< 5.00**	**< 0.30**
17	AQ-17 Mohajanpur bazar, Mujib Nagar GPS Coordinates: 23°39'49.17"N 88°36'17.01"E	**0.651**	**<0.1**	**17.45**	**42.77**	**< 2.50**	**5.42**	**< 0.30**
18	AQ-18 Monakhali Moddo Para Jame Mosjid , Mujib Nagar GPS Coordinates: 23°42'18.944"N 88°40'28.519"E	**0.000**	**<0.1**	**28.66**	**75.01**	**< 2.50**	**< 5.00**	**< 0.30**
19	AQ-19 Bishwanathpur, Monakhali, Mujib Nagar GPS Coordinates: 23°40'45.85"N 88°37'2.05"E	**0.000**	**<0.1**	**18.13**	**33.73**	**< 2.50**	**< 5.00**	**18.52**
20	AQ-20 Anandabas Bazar, Mujib Nagar GPS Coordinates: 23°37'4.395"N 88°36'40.859"E	**0.460**	**<0.1**	**10.69**	**18.13**	**< 2.50**	**< 5.00**	**< 0.30**
Units		**mg/m³**	**µg/m³**					
Method of Analysis		Real-Time Electrochemical Sensor (In- House, in-situ)		In-House method based on Gravimetric Method	In-House method based on IS 5182-6:2006			
Test Duration (Hours)		12 Hr						
Bangladesh Standard (According to Air Pollution Control Rules 2022, Schedule 1, Published Date 26 July 2022)		**20**	**180**	**65**	**150**	**80**	**80**	**0.5**