Available online at www.most.gov.bd
Volume 06, Issue 02, June 2025, Page: 77-96
DOI: https://doi.org/10.3329/jscitr.v6i2.85458

Journal of Science and Technology Research
Ministry of Science and Technology
Government of the People's Republic of Bangladesh
Bangladesh Secretariat, Dhaka

Spatiotemporal Assessment of Seasonal Water Quality and Quantity of the Peripheral Rivers of Dhaka City Using Multispectral Satellite Images

Masuma Chowdhury[1], Osman Daniel[1], Md. Mahin Uddin[2], Rasel Rana Shykot[1] and Md. Bodruddoza Mia[1]*

[1]*Department of Geology, Faculty of Earth and Environmental Sciences, University of Dhaka, Dhaka-1000, Bangladesh*
[2]*Department of Geography and Environment, Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh*

Received: 15/02/2024
Revised: 04/06/2025
Accepted: 18/06/2025

Abstract

Rivers play a pivotal role in the hydrologic cycle, and in Dhaka, a bustling metropolitan city surrounded by four rivers/khals, rapid population growth has led to adverse effects on these water bodies. The unplanned urbanization for the growing population has caused excessive pollution and contamination, turning the rivers into lifeless swamps. Over time, the land area, water quantity, and quality have steadily decreased. This study aims to address this gap by utilizing multispectral satellite images with field validation to perform spatiotemporal assessments of seasonal water bodies extent and quality in the peripheral rivers of Dhaka city. One of the main objectives of the study is to rank the peripheral rivers with respect to trophic status indexing. The normalized differential water indices were used to retrieve the river water bodies of the study area. The conventional methods of trophic status index with suspended sediment concentration, chlorophyll a concentration and Secchi disk depth of lake water body were applied in this study. The study observed that the extent of water bodies was reduced by about 16% due to urbanization or transformation of the rivers into land between 1977 to 2023. Seasonal water quality parameters showed mostly eutrophic conditions with minor areas of hyper-eutrophic condition in Turag River. Considering the observed water quality parameters, the examined rivers are no longer suitable for any purposes such as drinking, fisheries or even agriculture. The geospatial techniques and field validation both indicated pollution in all the four water bodies.

Keywords: *Spatiotemporal Water Extent, Seasonal Water Quality, Trophic Status of Peripheral Rivers, Dhaka City*

Introduction

As a vital component in the hydrologic cycle, rivers receive, store, and release water in different ways supporting terrestrial and aquatic ecosystems as well as sustaining crop production and farming (Cooper *et al*., 1998). Surface water bodies can serve as crucial habitats for diverse aquatic life and provide aesthetic value to densely populated urban communities. There are four rivers surrounding the capital city, Dhaka namely Buriganga River and Turag River on the west, and Balu Khal and Sitalakhaya River on the east. The Dhaka city has experienced about 4.3% urban growth rates which is fastest among the developing nations which leads to encroachment of urban green spaces and wetlands (Buyantuyev and Wu, 2009; Alam and Rabbani, 2007). This megacity houses 18.89 million people in its about 1500 sq kilometer area (Hossain, 2008; Corner *et al*., 2014). Moreover, the adverse effects of rapid urbanization are manifested in the reduction of water bodies as well as the degraded water environment (Hossain *et al*., 2023; World Bank 2011; Chowdhury *et al.,*

*Corresponding author e-mail: bodruddoza@du.ac.bd

2014; Hoque *et al.,* 2014; Sakamoto *et al.,* 2019; Whitehead *et al.,* 2018). A substantial degree of pollutant mix-up is causing water bodies to become lifeless and stagnant. Recent studies indicate that these water bodies have reached a critical state concerning water quality parameters such as total solids, alkalinity, turbidity, dissolved oxygen levels, and biochemical oxygen demand (Rahman and Hossain, 2019; Sultana and Dewan, 2021). Various studies confirm that seasonal variation of water quality has an added impact of human activities (Hoque *et al.,* 2014; Pramanik and Sarker, 2013), but there is a lack of assessment of long-term variations. Due to overpopulation, unawareness of inhabitants, lack of enforcement of legal instruments; only small areal coverage of the water bodies retains good water quality and biodiversity (Alam, 2014). Several investigations have been carried out in some rivers and lakes situated in the metropolis area to evaluate their water quality (Jan–E–Alam *et al.,* 2017). Although there are few studies on water quantity based on satellite images, there is a lack of research focusing on the spatial assessment of the water quality of the rivers using satellite images to rank the trophic status. This research focuses on the spatiotemporal assessment both on seasonal quantity and quality of surface water bodies in the peripheral rivers of Dhaka city in Bangladesh, in terms of Trophic Status Index (TSI) to depict the degree of pollution.

One of the key objectives of the study is to address the challenges associated with river water quality and quantity degradation as a consequence of changing land use/land cover (LULC) trends and rapid urban growth. Recent advancements in remote sensing and high-resolution satellite data, combined with innovative image processing techniques, have provided valuable tools to efficiently monitor and investigate the dynamic changes in LULC, surface water quantity-quality and urban growth studies (Adjovu *et al.,* 2023. Besides LULC, water quality is another important variable of the river ecosystem

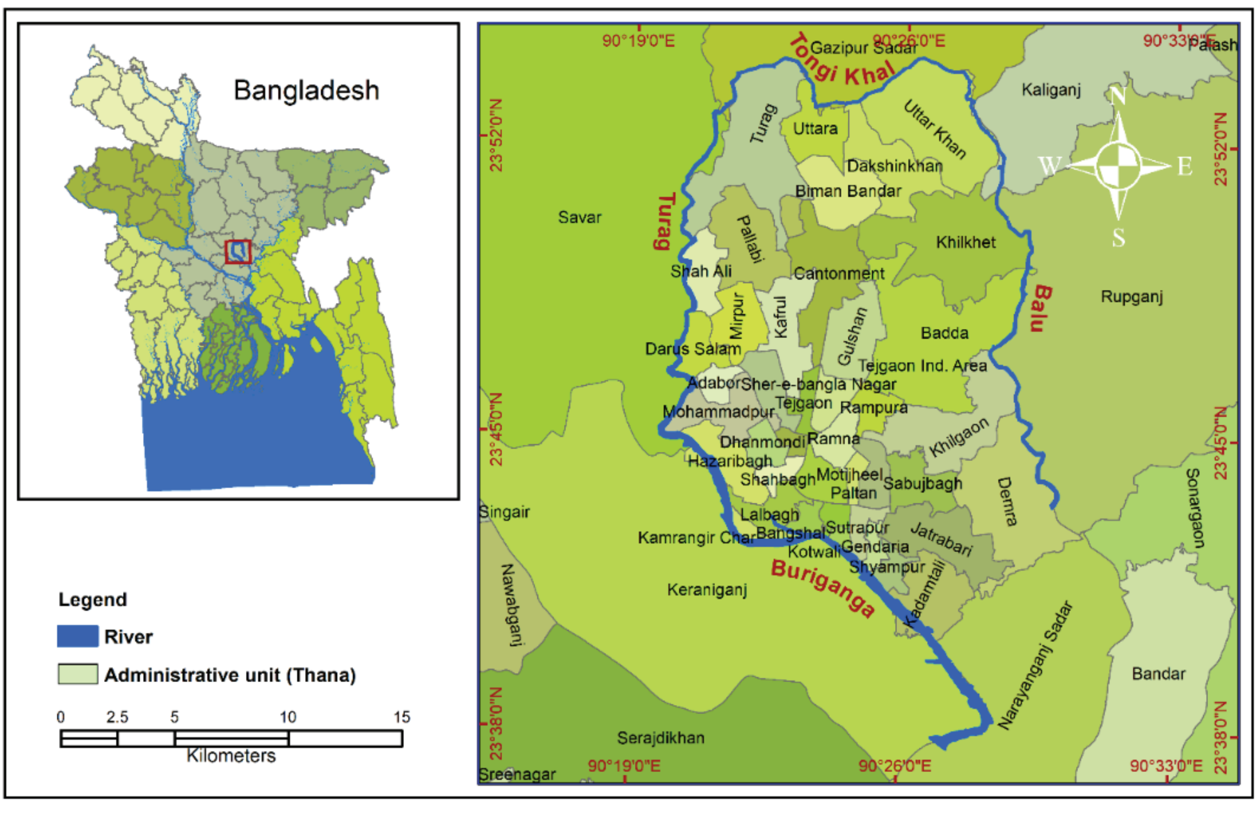

Figure 1. Location of the studied four major rivers/khal such as Buriganga, Turag, Tongi khal and Balu around the Dhaka City, Bangladesh

and can be easily derived from the multispectral remote sensing data through some operations with conventional algorithms. The algorithm can be adapted or improved to suit the context of Bangladesh's river water quality and can be applied to the entire river system of the country. As one of the most densely populated cities in the world, Dhaka city has faced significant water quality degradation in its lakes and rivers in and around the Dhaka city and leading to limited use of these water resources (Sultana and Dewan, 2021). No study has focused on the spatiotemporal water quality variations of the peripheral rivers of Dhaka city using satellite images and establish the relationship of the changes in LULC pattern with the trophic status. Thus, it is imperative to study the relationship between urban growth, LULC change, and their impact on river water quality and aquatic health of the peripheral rivers of Dhaka city.

Materials and Methods

This study evaluated the water quality and quantity, or extent of Dhaka city's surrounding rivers was conducted using geospatial techniques and field validation. Various in-situ water monitoring instruments were employed to collect important water quality parameters from the studied rivers. The data collected with these instruments provides valuable insights into the environmental conditions of the water bodies. The study adopted two main approaches: analyzing the spatial distribution of the water bodies and assessing their water quality. (Figure 2).

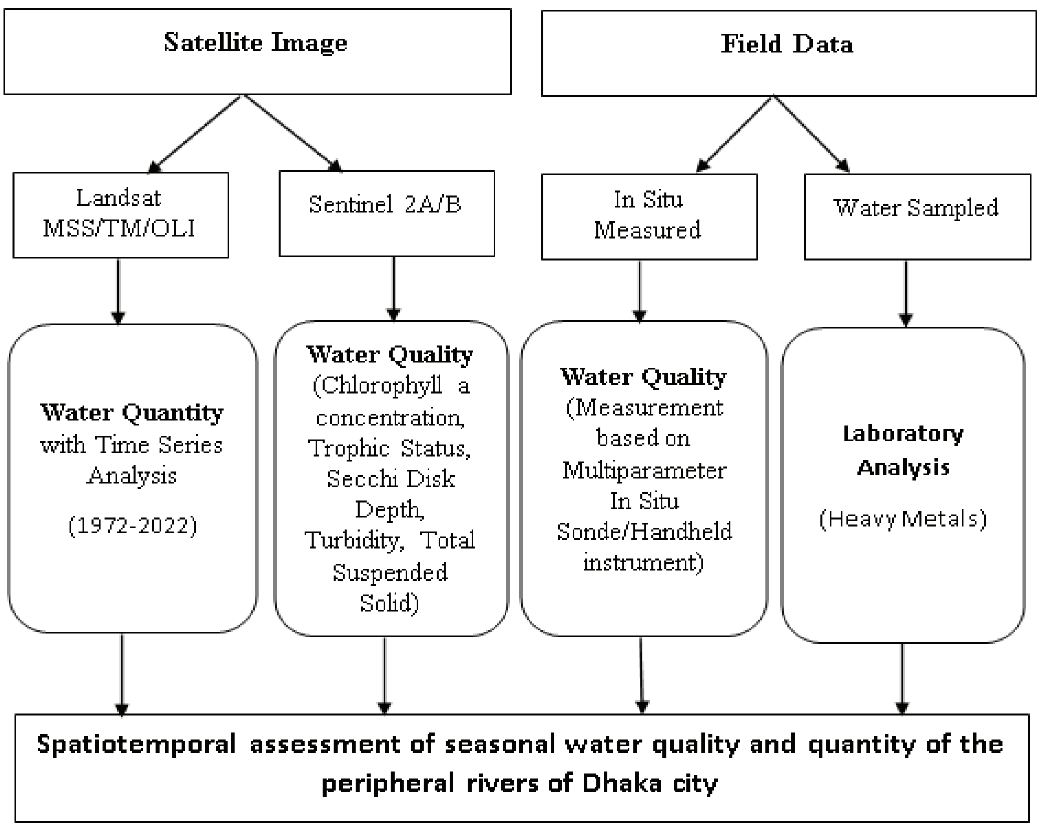

Figure 2. Workflow process involved in this study

Satellite image analyses

The first method involved the quantitative analysis of the coverage of water bodies using nine sets of multispectral satellite images. Time series satellite images, including Landsat MSS, TM, ETM, OLI-TIRS and Sentinel-2A/2B time series satellite images from 1977 to 2023 (Table 1) were analyzed using NDWI (Normalized Difference Water Index) methods, and MNDWI (Modified Normalized Difference Water Index). NDWI was used for Landsat MSS image of 1977 and for the Landsat TM/ OLI images of other years MNDWI was used.

The equations of NDWI and MNDWI are as follows:

$$NDWI = (b1-b4)/(b1+b4) \quad (1)$$

Where, b1 and b4 = the reflectance values for green and near infrared bands and NDWI> 0.5 indicated water bodies.

$$MNDWI = (NIR-R)/(NIR+R) \quad (2)$$

Where, NIR and R = reflectance values for near infrared and red bands and MNDWI> 0.0 indicated water bodies.

These Landsat images of 30m resolution were used for a broad-scale assessment of water bodies and their changes over time whereas Sentinel-2B sensor images of 10-20m resolution were employed to evaluate variation of water quality parameters of the rivers in Dhaka city throughout different seasons (Table 1). The spatiotemporal seasonal water quality parameters of the Dhaka city's periphery rivers were then extracted by the processing and analysis of seasonal satellite images, particularly of Sentinel 2A/2B after atmospheric correction using geospatial software such as ERDAS Imagine 2020

Table 1. Satellite images with their sources, sensor type, acquisition date, and spatial resolution

Data Source	Sensor	Date	Resolution (m)
USGS archive	Landsat MSS	8 February 1977	30
	Landsat TM	5 March 1990	30
	Landsat TM	28 February 2000	30
	Landsat TM	6 March 2011	30
	Landsat OLI	7 March 2023	30
Copernicus Open Access Hub, ESA	Sentinel 2A	12 November 2022	10-20
	Sentinel 2A	11 January 2023	10-20
	Sentinel 2A	11 March 2023	10-20
	Sentinel A	11 May 2023	10-20

Data Source	Sensor	Date	Resolution (m)
USGS archive	Landsat MSS	8 February 1977	30
	Landsat TM	5 March 1990	30
	Landsat TM	28 February 2000	30
	Landsat TM	6 March 2011	30
	Landsat OLI	7 March 2023	30
Copernicus Open Access Hub, ESA	Sentinel 2A	12 November 2022	10-20
	Sentinel 2A	11 January 2023	10-20
	Sentinel 2A	11 March 2023	10-20
	Sentinel A	11 May 2023	10-20

and ArcGIS 10.3. Subsequently, the Chlorophyll-a concentration, trophic status index, Secchi depth, turbidity, and suspended sediment concentration were the variables of interest for the rivers encircling Dhaka.

Concentration of Chlorophyll a (Cchl-a)

The reflectance values of the pertinent bands in the Sentinel 2A images were calculated employing a reference equation and image-specific metadata. The Cchl-a was calculated using Sentinel 2A images using the equation 3 and the chlorophyll-a concentration was using for deducing the trophic status (Table 2):

Cchl a = 113.23 x (R4/R5)2 - 311.67 x (R4/R5) + 216.76 (3)

Where, Cchl a = the returned chlorophyll-a concentration (g/L), and R4 and R5 = the reflectance of the sentinel 2A data's 4th (665 nm) and 5th (705 nm) bands, respectively (Wang *et al.,* 2020).

Table 2. Relationship between Trophic Status & Chlorophyll-a concentration in rivers or Lakes (Boyed, 2015; Patra *et al.,* 2017)

Mean Chlorophyll-a Concentration (µg/L)	Trophic Status with Conditions
<2	Oligotrophic, very little phytoplankton, no aesthetic issues
2-5	Mesotrophic, no oxygen depletion, some algae, and lowered aesthetic values
5-15	Mesotrophic, a high quantity of algae, turbidity, a possible oxygen depletion, and lowered aesthetic values
>15	Eutrophic, increased phytoplankton, severe oxygen depletion, and greatly diminished aesthetic values

Trophic Status Index (TSI)

Based on the chlorophyll-a concentration, the equation 4 was used to compute the Trophic Status Index (TSI) using Carlson's index (Carlson, 1977) to retrieve Trophic status:

TSI (Chl-a) = 10 x (6-(2.04-0.68InChl-a)/In2) (4)

Table 3. Trophic Status classification based on the TSI of the river/ lake water (Carlson, 1977)

TSI	Trophic Status	Water Condition of Waterbody
>70	Hyper-Eutrophic	Lack of transparency, heavy algae growth, green water, and dense macrophytes
50-70	Eutrophic	Low clarity caused by the presence of macrophytes
40-50	Mesotrophic	Poor clarity
>30-40	Oligotrophic	Clean Water

Secchi Disk Depth (SDD)

There are multiple techniques for SD retrieval with different ranges of determination coefficient from 10 to 69% (Rotta et al., 2016; Verdin, 1985; Wu et al., 2008). For SD retrieval utilizing Sentinel 2B data, which has a higher value of the determinant coefficient (R2 = 86%), the most recent algorithm was employed (Rodrigues et al., 2020) as follows:

$$SDD = (0.024\ (R_2/R_3{*}R_4)) + 0.72 \quad (5)$$

Where, R2, R3, and R4 are the sentinel 2B bands' reflectances of 2, 3, and 4, respectively. The recovered SD values of the Dhaka city rivers were categorized into different trophic statuses, including oligotrophic (SDD>4m), mesotrophic (SDD= 2-4m), eutrophic (SDD= 0.5-2m), and hyper-eutrophic (SDD= 0.5) (Carlson and Robert 1977).

Turbidity (FTU)

As an essential indicator of water clarity of aquatic ecosystems, the spatial distribution of turbidity was measured in the rivers surrounding Dhaka city. The linear regression model proposed by Quang *et al.* in 2017 was adopted utilizing data from the Sentinel 2A satellite images to estimate turbidity values of the rivers surrounding Dhaka city for this study (eq. 6). Drinking water or water bodies with acceptable quality typically have turbidity levels less than 1 FTU (Formazin Turbidity Units) or NTU

(Nephelometric Turbidity Units). Higher turbidity values, exceeding 1 FTU, indicate that any water reservoirs contain lower-quality water.

Turbidity (FTU) = 380.32 x R4 – 1.7826 (6)

Where, R4 is the red band of the sentinel 2A satellite image's reflectance.

Suspended Sediment Concentration (SSC):

After retrieving the value of turbidity, the Landsat images were being processed using the equation 7 to retrieve suspended sediment concentration:

SSC = - 0.005 * turbidity^2+4.65 * turbidity+78.002 (Kang et al., 2022) (7)

The reference values of water quality based on the SSC are illustrated in Table 4.

Table 4. Reference water quality based on SSC

Water Quality	SSC Range (mg/L)	Reference
Excellent	Below 10	Ohio Environmental Protection Agency. (2002). Ohio Drinking water standards.
Good	10 - 25	Environmental Protection Agency (EPA). (2017).
Fair	25 - 50	United States Geological Survey (USGS). (2009).
Poor	50 - 100	Alberta Environment and Parks. (2008).
Very Poor	Above 100	Ministry of Environment and Forestry, Republic of Indonesia. (2004).

Field investigation

The second approach involved collecting water quality parameters directly during extensive field investigations (in post-monsoon, winter, spring, and pre-monsoon), encompassing 40 stations in numerous transactions of the rivers using a multiparameter sonde and other digital equipment (Figure 1 and Table 5). Several on-site data measurements, i.e.,Chlorophyll-a concentration (using in-situ multiparameter sonde AQUA TROLL®500 HARDWIRE VERSION 1.51), Secchi Disk Depth(using Secchi disk), turbidity(as Turbidity index), Electrical Conductivity (using HANNA pocket pH meter, HI 98127), pH (pH-EC comb meter, PC tester 35), and Dissolved Oxygen (using OAKTON waterproof pocket DO meter) from the peripheral rivers surrounding Dhaka city was recorded during fieldwork. These measurements are crucial for understanding the acidity or alkalinity of the water (pH), its ability to conduct electricity (EC), and the prevailing temperature conditions aiding the assessment of the environmental conditions and the health of the studied rivers. To ensure the accuracy of the measurements, all instruments were calibrated in the field using standard buffer solutions. GPS was used for acquiring exact position of the ground truth data for validation (Figure 3).

Additionally, signature classes for supervised classification were acquired during the fieldwork. These signature classes are crucial for the retrieval of water bodies' extent within the four rivers and khal around Dhaka city. Furthermore, to validate the water quality metrics obtained from satellite pictures, they were compared against the field in situ measured parameters. Corrections were made to the coefficients of conventional algorithms used for the satellite image-retrieved water quality parameters based on this validation. Subsequently, the spatiotemporal seasonal water quality of the rivers surrounding Dhaka city was then ascertained by processing and analyzing satellite images, particularly of Sentinel 2A/2B.

Table 5. In situ parameters collected by various sensors in the field from 10-16 March 2023

No.	River/Khal Name	Latitude	Longitude	SDD (cm)	Turbidity (NTU)	Chl a (µg/l)	pH	EC (µS/cm)	DO (ppm)
1	Burigonga	23.68500	90.42750	25	24.11	0.87	7.21	809	0.11
2	Burigonga	23.69111	90.42222	22	22.50	2.10	7.18	806	0.09
3	Burigonga	23.69889	90.41500	25	23.60	1.20	6.58	780	0.09
4	Burigonga	23.70583	90.40500	20	24.80	1.10	6.07	780	0.14
5	Burigonga	23.71000	90.39444	22	24.40	2.03	5.85	772	0.25
6	Burigonga	23.70833	90.38222	20	23.00	1.90	7.27	772	0.14
7	Burigonga	23.70806	90.36750	20	26.90	1.65	5.96	753	0.12
8	Burigonga	23.72028	90.35833	22	23.50	1.93	5.82	730	0.16
9	Burigonga	23.73389	90.35250	25	27.30	2.10	5.60	690	0.13
10	Burigonga	23.74667	90.34194	22	30.30	1.74	5.43	730	0.16
11	Burigonga	23.75694	90.33417	20	32.20	1.94	5.29	733	0.22
12	Burigonga	23.77139	90.34139	20	34.50	1.70	5.26	733	0.14
13	Burigonga	23.78194	90.33556	20	44.00	2.10	5.16	725	0.18
14	Burigonga	23.79417	90.33944	15	57.50	1.68	5.08	720	0.16
15	Turag	23.80778	90.33944	18	55.00	1.65	5.17	738	0.29
16	Turag	23.82639	90.34111	15	52.80	1.80	5.17	742	0.20
17	Turag	23.84611	90.33722	15	42.30	1.71	5.18	760	0.32
18	Turag	23.86111	90.34722	18	42.00	1.67	5.12	775	0.27
19	Turag	23.87722	90.35056	15	37.50	1.28	7.33	805	0.44
20	Turag	23.89139	90.35917	15	47.00	1.20	5.90	805	0.39
21	Tongi Khal	23.89611	90.37278	15	41.10	1.10	5.62	820	0.34
22	Tongi Khal	23.89750	90.38556	18	46.20	1.40	5.62	840	0.72
23	Tongi Khal	23.89083	90.39056	12	53.00	2.35	5.62	870	0.46
24	Tongi Khal	23.88111	90.39667	15	54.10	1.20	7.56	860	0.09
25	Tongi Khal	23.88222	90.40806	10	53.00	1.30	7.40	864	0.22
26	Tongi Khal	23.88722	90.42139	10	40.20	1.41	7.50	860	0.16
27	Tongi Khal	23.89639	90.43250	10	40.10	1.25	7.55	978	0.15
28	Tongi Khal	23.89639	90.44889	10	34.70	1.35	7.42	1040	0.09
29	Tongi Khal	23.88472	90.45889	12	30.50	1.45	7.43	1075	0.11
30	Tongi Khal	23.86250	90.47444	15	33.70	1.45	7.43	1025	0.13

31	Tongi Khal	23.84500	90.47222	12	70.10	0.83	7.25	1005	0.11
32	Tongi Khal	23.83139	90.48194	15	62.30	1.37	6.40	992	0.15
33	Balu	23.82139	90.48639	12	76.30	1.40	6.20	970	0.15
34	Balu	23.81000	90.48444	15	67.70	1.75	6.08	905	0.14
35	Balu	23.79361	90.48111	15	68.80	2.45	5.86	910	0.10
36	Balu	23.77861	90.47444	15	67.30	3.10	5.50	855	0.41
37	Balu	23.76667	90.48222	15	67.10	3.10	5.45	846	0.10
38	Balu	23.75500	90.48861	12	75.00	3.30	5.41	842	0.15
39	Balu	23.74389	90.49417	10	93.00	2.95	5.40	830	0.20
40	Balu	23.73056	90.49833	10	65.50	2.75	5.56	925	0.12

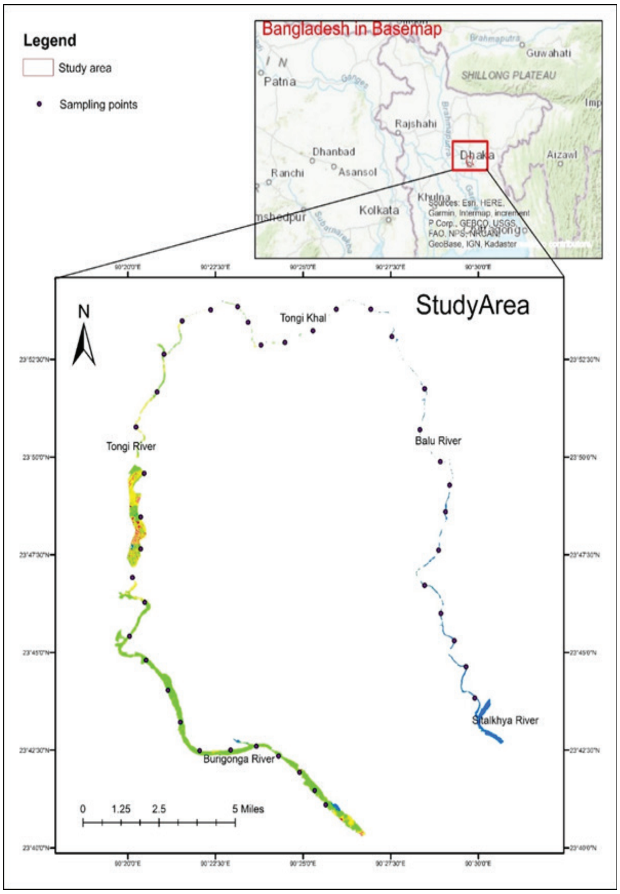

Figure 3. Location of the ground truth data collection points (black dots) in the studied four peripheral rivers around the Dhaka City, Bangladesh

Results and Discussion

Extent of water bodies using satellite images

Spatial distribution of water bodies was retrieved using Landsat MSS/TM/OLI (30 spatial resolution) satellite images to delineate quantitative extent of the four rivers/khal of Dhaka city from 1977 to 2023 (Figure 4) using the NDWI and MNDWI approach. The results showed significant reduction in the extent of the water bodies by 16% from 1977 to 2023. The total coverage of water bodies was about 13.3 sq.km, 11.5 sq.km, 10.4 sq.km, 11.4 sq.km and 11.1 sq.km respectively in 1977, 1990, 2000, 2011 and 2023 (Figure 4). The surrounding floodplain water body might contribute to the overall extent of rivers studies.

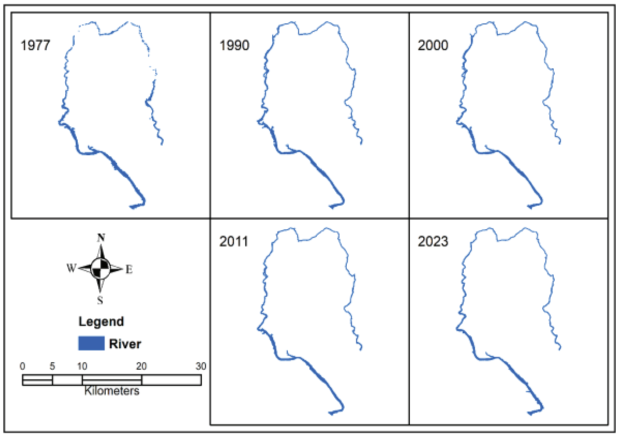

Figure 4. Spatiotemporal extent of water bodies of the surrounding rivers/khal of the Dhaka city from 1977 to 2023

Water quality from satellite images

Water qualities such as such chlorophyll a concentration (Cchl-a), trophic state index based on Cchl-a, turbidity, suspended sediment concentration (SSC) and Secchi disk depth (SDD) were retrieved using the Sentinel 2A sensor images of the surrounding Dhaka city's rivers to assess the spatial and seasonal variation by four seasons (pre-monsoon, winter, spring, and post-monsoon).

Cchl-a concentration

Satellite image analyses infer the trophic status as mesotrophic throughout the year. Areal distribution of Cchl-a reveals lowest Cchl-a concentration in winter followed by post-monsoon and spring, highest in pre-monsoon (Figure 5). Spatial distribution of Cchl-a concentration showed mostly >15 µg/L, indicated the eutrophic or hyper-eutrophic state of the Dhaka city rivers throughout from post to pre-monsoon (Boyed, 2015; Patra *et al.,* 2017). Turag river constantly exhibits an elevated concentration of Cchl-a than other rivers indicating eutrophic conditions year-round. The Burigonga River's Cchl-a levels indicated trophic status in the mesotrophic range during post-monsoon and winter, exhibited a mix of mesotrophic and eutrophic conditions during spring, and displayed eutrophic levels in the pre-monsoon season. Similar patterns were observed in the Tongi khal and Balu River. The maximum Cchl-a values were observed close to the junction of the Turag and Burigonga rivers.

Trophic status index (TSI)

The TSI reduced from post to pre-monsoon in the aspect of minimum values and increased from post to pre-monsoon in the case of maximum values (Figure 5). Satellite images retrieved from TSI values based on the chlorophyll-a concentration of the Dhaka city rivers in post monsoon and spring were mostly in eutrophic condition i.e., TSI=50-70, and some areas show hyper- eutrophic status (TSI >70) in Figure 7 (Carlson 1977). Turag rivers show hyper-eutrophic status in winter season whereas the other three rivers show eutrophic status. The areal coverage of spatial distribution of TSI values shows an increasing trend from post-moon to pre-monsoon (Figure 5b). In Winter the other rivers and khal shows eutrophic nature. In pre-monsoon (May 2023), Some areas of Turag and Burigonga Rivers hyper eutrophic, others mostly eutrophic.

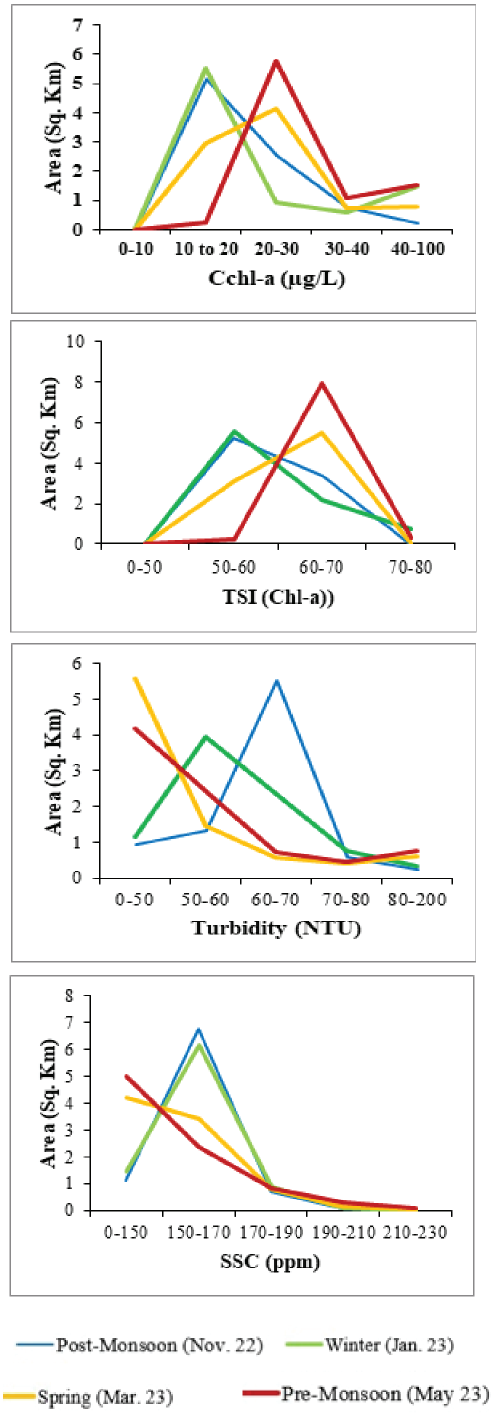

Figure 5. Areal distribution of (a) Cchl-a concentration (b) TSI, (c) Turbidity, (d) SSC within the surrounding rivers of Dhaka city

Turbidity

the values of turbidity increased in the rivers from post to pre-monsoon period considering both minimum and maximum values. Spatial analysis of turbidity of all surrounded rivers of Dhaka city mostly showed values greater than 50 NTU in all seasons, indicating not drinkable as the values are mostly greater than 1NTU (Figure 8). Higher ranges of turbidity coverage found in post-monsoon and then declined with seasons up to pre-monsoon (Figure 5). Among all four water bodies, Balu River has lower turbidity, indicating clearer water, whereas Turag River consistently has the highest, signifying poorer water quality and higher levels of suspended solids.

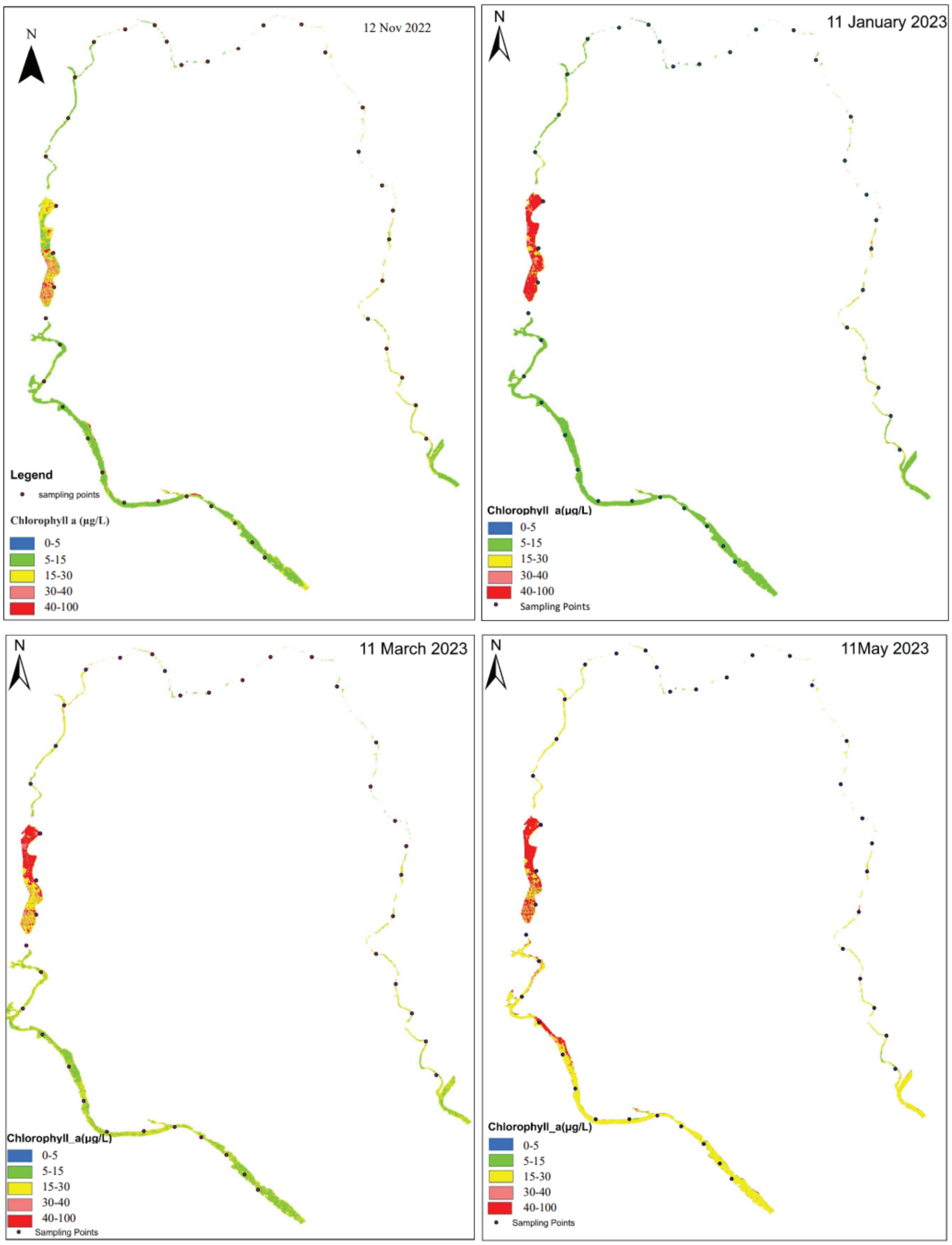

Figure 6. Spatial Distribution of Chlorophyll-a of the four surrounding rivers of Dhaka city

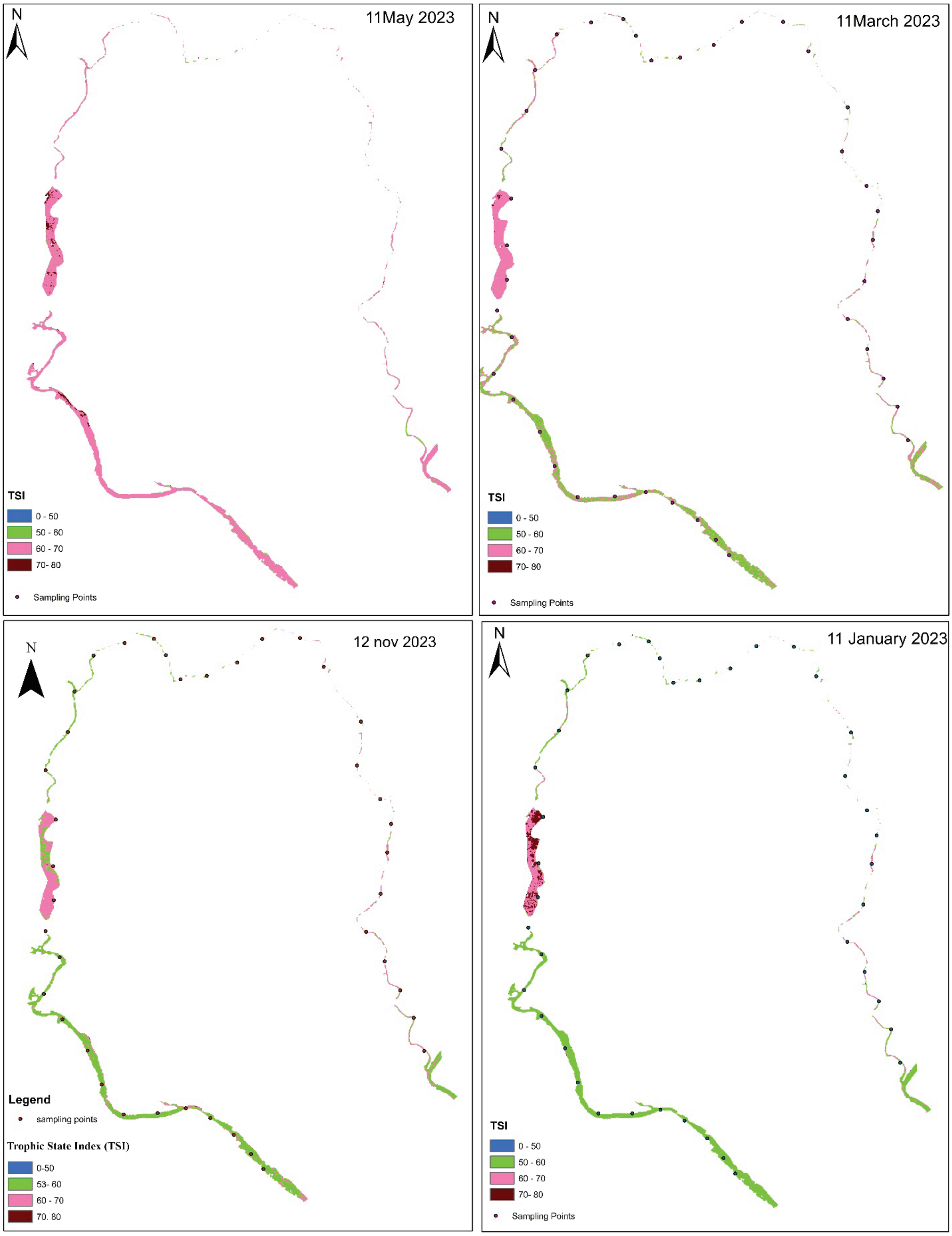

Figure 7. Spatial distribution of tropic state index of the four surrounding rivers of Dhaka city

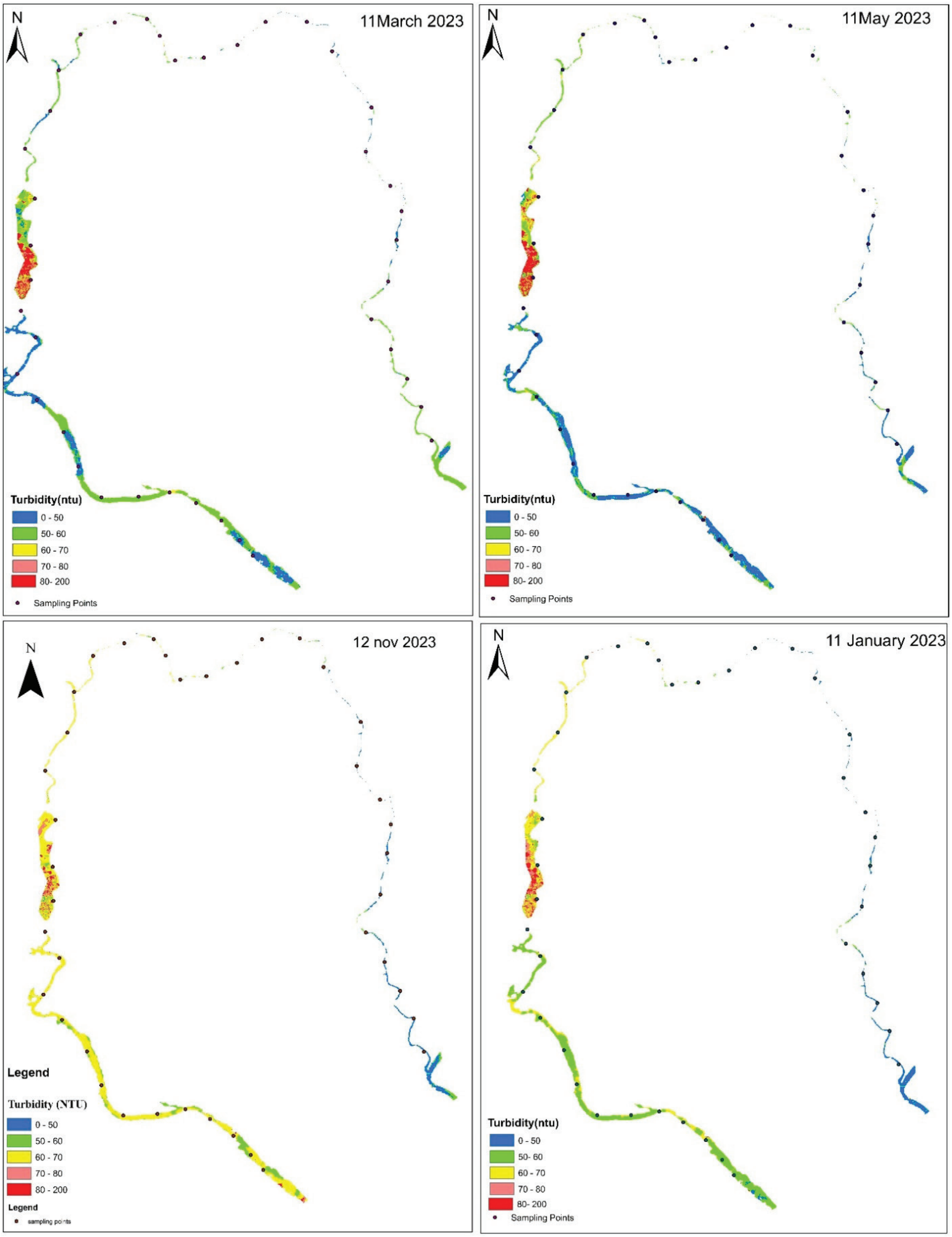

Figure 8. Spatial Distribution of Turbidity of the four surrounding rivers of Dhaka City

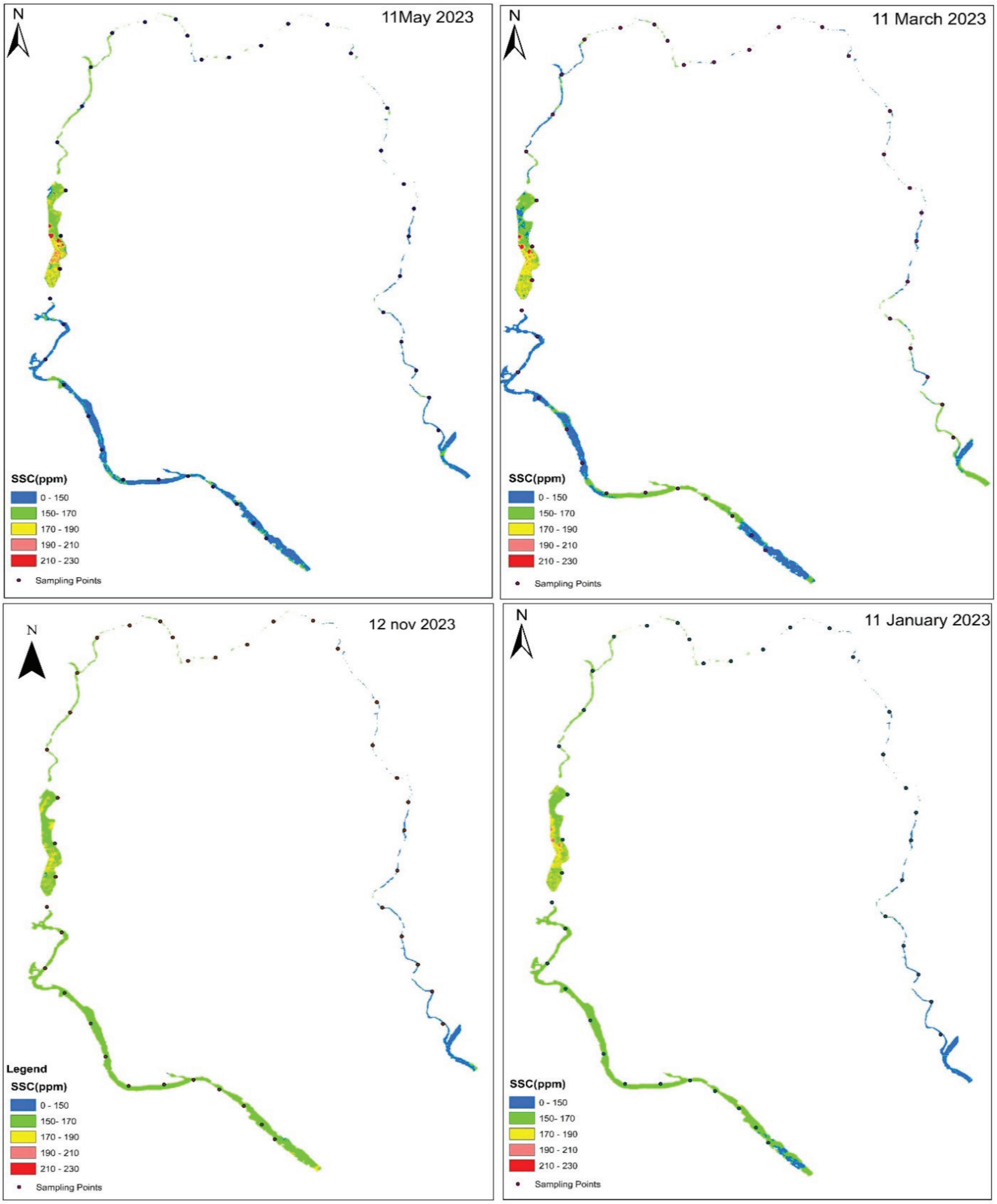

Figure 9. Spatial Distribution of Suspended Sediment Concentration of the Four Surrounding rivers of Dhaka City

Suspended sediment concentration (SSC)

The SSC values increased from post-to pre-monsoon on the aspect of maximum values but higher values in spring in case minimum value. Spatial distribution of suspended sediment concentration showed mostly above 100mg/l, indicating very poor quality of water in the rivers (Figure 8). The range of SSC from 150 to 170 ppm showed most of the rivers in all seasons and higher coverage in post-monsoon to winter and lower coverage in spring and pre-monsoon time (Figure 8). Post-monsoon season generally had highest SSC levels in Balu River (~100-150 ppm) exhibiting poor quality whereas in Tongi River the SSC levels remains consistently >150 ppm exhibiting poorest quality among all four water bodies. In Burigonga river, the SSC levels varied by season, highest in post-monsoon and lowest in pre-monsoon.

Secchi disk depth (SDD)

The Maximum and minimum values of Secchi disk depth were almost similar in Dhaka city's rivers from post-monsoon to pre-monsoon seasons. Retrieved Secchi disk depths from the sentinel 2A satellite images of the surrounding Dhaka city's rivers were observed within the ranges from 0.7 to .8 m, which also indicated eutrophic state (SDD=0.5-2m) in all seasons mostly (Figure 10).

Field observation and data validation

The retrieved satellite images outcomes of water quality were validated with the ground measurement results as follows.

pH: As a markup of acidity or alkalinity of water samples, the Turag River exhibited the lowest average pH of 5.65, followed closely by the Balu River with an average of 5.68, the Burigonga River with an average of 5.98, and the highest of 6.90 at Tongi Khal (Table 6). The average pH for all the samples collected was calculated to be 6.15. This indicates that the water bodies in the studied rivers are mostly acidic in nature. The recommended pH range for irrigation water is 6.5 to 8.5, in accordance with Bangladesh regulations, FAO standards, and Bangladesh Environment Conservation Rule (ADB, 1994; ECR, 1997).

Electrical Conductivity (EC)

During the field measurements, the highest EC value recorded was 1075 µS/cm at Station 29 in Tongi Khal, while the minimum value was 690 µS/cm at Station 09 in the Burigonga River (Table 5). The overall average EC value for all samples collected is calculated to be 837 µS/cm. The Burigonga River had the lowest average EC value of 752 S/cm when the average EC values for each river were considered. The Turag River came in second with an average of 771 S/cm, the Balu River came in third with an average of 885 S/cm, and Tongi Khal had the highest average of 936 S/cm. (Table 6**).** Considering the EC values in the studied rivers, it is evident that the electrical conductivity levels are generally within acceptable ranges for the specified uses according to Bangladesh Environment Conservation Rule (ADB, 1994; ECR, 1997).

Table 6. Summarized In-situ measurements of water quality parameters of the study area

River/ Khal Name	pH			EC (µS/cm)			DO (mg/l)			Turbidity (NTU)		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	**Max**	**Min**	**Avg**
Overall	7.56	5.08	6.15	1075	690	837	0.72	0.09	0.20	93.00	22.50	45.87
Burigonga	7.27	5.08	5.98	809	690	752	0.25	0.09	0.16	57.50	22.50	29.90
Turag	7.33	5.12	5.65	805	738	771	0.44	0.20	0.32	55.00	37.50	46.10
Tongi Khal	7.56	5.62	6.90	1075	820	936	0.72	0.09	0.23	70.10	30.50	46.58
Balu	6.20	5.40	5.68	970	830	885	0.41	0.10	0.17	93.00	65.50	72.59

Dissolved Oxygen (DO)

According to the BDWS (1997) standard, the acceptable DO limit is set at 6 mg/l which is essential for the survival of aquatic life. None of the samples collected in the field met the required DO limit of 6 mg/l. The maximum overall measured DO value was 0.72 mg/l in the Burigonga River, while the minimum was 0.09 mg/l at Station 22 in Tongi Khal. (Table 6). When the average DO values for each river were considered, the Burigonga River had the lowest average DO of 0.16 mg/l, followed by the Balu River with an average of 0.17 mg/l, Tongi Khal with an average of 0.23 mg/l, and Turag River with an average of 0.32 mg/l. (Table 5 & 6). Such low DO levels can lead to poor water quality, harming the biodiversity and ecological balance of the rivers.

Turbidity

The highest turbidity value recorded during the field measurements was 93 NTU in the Balu River, which indicates very poor water clarity in that area. The lowest value of 22.50 NTU was recorded in the Burigonga River, but it still exceeds the acceptable limit for household water. The average turbidity values for each river also show elevated levels, with Balu River having the highest average of 72.59 NTU, followed by Tongi Khal (46.58 NTU), Turag River (46.10 NTU), and Burigonga River (29.90 NTU) (Table 6).

Secchi disk depth

According to Carlson's categorization, the retrieved SDD values of Dhaka city rivers were classified as oligotrophic (SDD>4m), mesotrophic (SDD=2-4m), eutrophic (SDD=0.5-2m), and hyper-eutrophic (SDD0.5) (Carlson and Robert 1977). The study found that the SDD values for all samples in the studied water bodies fell within a narrow range of 0.10 to 0.25 meters (Table 5 & 6). This consistent range of SDD values indicates that the water bodies exhibit hyper-eutrophic conditions. In other words, the water bodies have an extremely high concentration of nutrients, which promotes out of control growth of algae and other aquatic plants, leading to reduced water clarity and degraded water quality. (Table 7). In Tongi Khal and Balu River, higher levels of SDD than other rivers illustrate lower levels of turbidity and chlorophyll-a concentrations. Therefore, SDD was lower than other rivers during the field observations. Cchl-a concentrations were also higher values in samples of the Balu River than other rivers.

Chlorophyll-a

The average Cchl-a values for each river were also examined, providing insights into the overall trophic status of the water bodies in the studied area. The Tongi Khal exhibited the lowest average Cchl-a value of 1.37, indicating a mesotrophic status with some algae and potential turbidity. The Turag River followed closely with an average chl-a value of 1.55, also suggesting a mesotrophic status. The Burigonga River had an average chl-a value of 1.72, indicating a similar mesotrophic status. The highest average chl-a value of 2.60 was observed at Balu River, suggesting a mesotrophic status with high levels of algae, turbidity, and potential oxygen depletion (Table 6). Overall, the Cchl-a concentrations and trophic status of the studied rivers indicate moderate to poor water quality, with varying levels of algae and turbidity. These results highlight the need for effective water quality management strategies and efforts to reduce nutrient pollution and maintain the ecological health of the water bodies in the area.

In-situ measurements trends

The examination of water quality parameters across all the rivers in the Dhaka city area revealed pH, chlorophyll-a (Cchl-a), and turbidity have shown relatively consistent values across all the rivers, indicating similar water quality conditions in terms of acidity, algae concentration, and water clarity. This consistency in these metrics shows that the overall water quality in the rivers analyzed is similar (Figure 10). On the other hand, Secchi Disk Depth (SDD) and Electrical Conductance (EC) showed noticeable variations among the different rivers, indicating differences in water clarity and conductivity. The SDD values for all samples in the studied water bodies fell within a narrow range of 0.10 to 0.25 m. There is a clear downward trend in Secchi Disk Depth from Burigonga River to Balu River (Figure 10). This trend suggests that the water clarity decreases as one moves from the Burigonga River to the Balu River. A lower SDD value means that the water becomes less transparent, which could be due to higher levels of turbidity, suspended particles, or algae in the water. Decrease in SDD may indicate poorer water quality in terms of clarity and light penetration, especially in the Balu River (recorded average value is 0.13 m). The Electrical Conductance (EC) values showed an upward trend from the Burigonga River to the Balu River (Figure 10). Sequentially the lowest average EC value at the Buriganga River, the Turag River, the Balu River, and Tongi Khal were 752 S/cm, 771 S/cm, 885 S/cm, and 936 S/cm. This pattern implies that the conductivity of water from the Burigonga River to the Balu River to Tongi Khal is increasing. Higher EC values may indicate the presence of dissolved salts, minerals, or other ions in the water, all of which can increase conductivity. These trends in SDD and EC values highlight potential variations in water quality and hydrological conditions among the studied rivers (Table 7). The differences in water clarity and conductivity may be caused by the varying sources of pollution, land use patterns, and geographical characteristics of each river's catchment area.

Table 7. In situ measurements with the status of water quality

Parameters	Average	Maximum	Minimum	Comment
SDD (cm)	16	25	10	Hyper-eutrophic
Turbidity (NTU)	45.87	93.00	22.50	Lower quality water
Chl a (µg/l)	1.77	3.30	0.83	Oligotrophic to Mesotrophic
pH	6.15	7.56	5.08	6.5-8 for irrigation use
EC (µS/cm)	837	1075	690	within irrigational uses range
DO (ppm)	0.20	0.72	0.09	< 6ppm of acceptable range

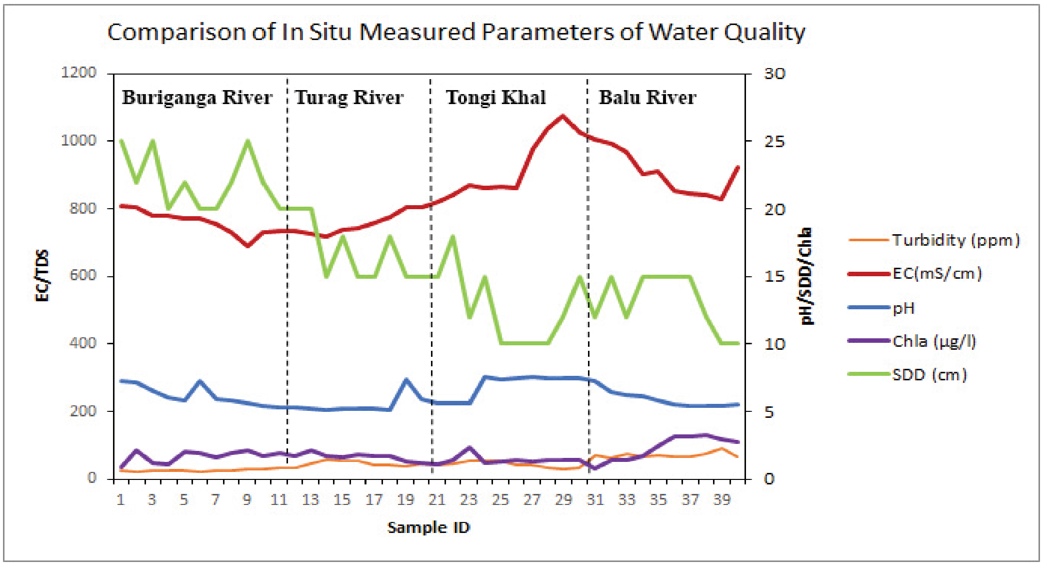

Figure 10. Observed values of water quality in the field

The in-situ sampled values of turbidity and Cchl-a concentration with the images retrieved values, found following similar trend with higher values mostly in the image-retrieved than in-situ observed values (Figure 11). This is mostly due to the pixel average values from the images rather than point samples of in-situ observation. Similar trends also have been observed between the in-situ vs image retrieved Secchi Disk Depth (SDD) of the study area with higher values from the images as these values are pixel average and in situ values are point sampled (Figure 11). In the field, observations supported the image-retrieved values, showing higher levels of turbidity and Cchl-a concentration. Both the satellite image-retrieved and in-situ observed values indicated poor water quality conditions, with a predominance of eutrophic or hyper-eutrophic status in the studied rivers. The pixel averaging in image retrievals accounted for higher values compared to point sampled in-situ observations. Summary statistics analyzed with the minimum and maximum of the water qualities of the four seasons (Table 8).

Table 8. Summary statistics of the image retrieved water quality parameters of the study area

Season	Turbidity (NTU)		Chlorophyll a (μg/L)		Secchi Disk Depth (m)		SSC (ppm)		TSI	
	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
Post-Monsoon	127.60	40.96	67.86	10.72	0.73	0.72	207.13	137.20	71.95	53.85
Winter	138.25	35.41	126.96	7.35	0.72	0.72	210.55	130.16	78.08	50.14
Spring	150.13	45.12	62.28	8.62	0.73	0.72	213.02	142.26	71.11	51.70
Pre-Monsoon	171.75	41.03	82.42	5.20	0.73	0.72	214.13	137.25	73.85	50.10

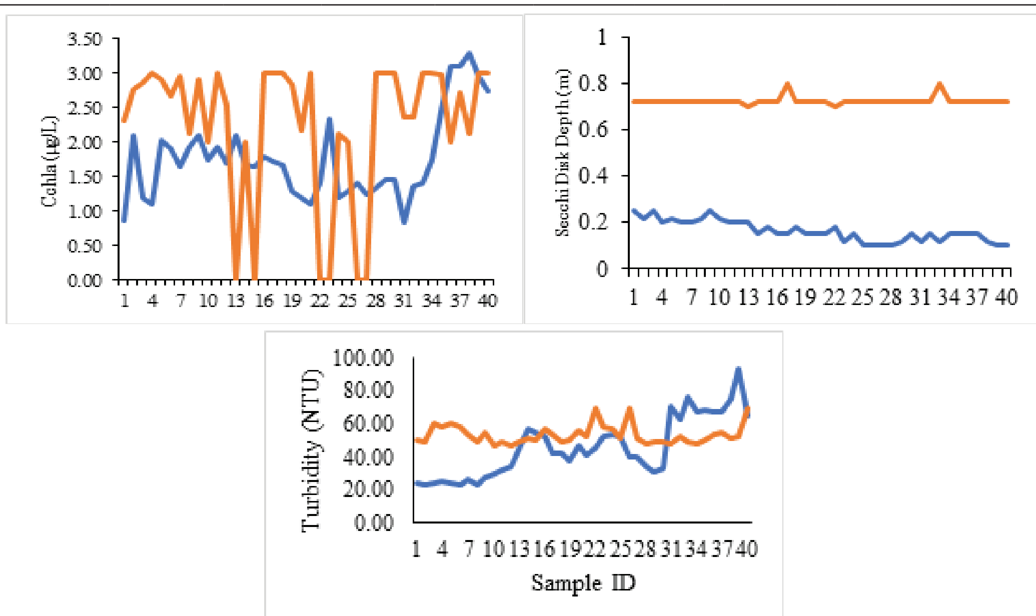

Figure 11. *In-situ* vs Image Retrieved measurements of (a) chlorophyll a concentration, (b) SDD, and (c) turbidity of the study area, where blue line indicates in situ measurements and orange line indicates image retrieved measurement

Conclusions

The studied rivers are one of the biggest sources of water bodies surrounding Dhaka city. Fatal damages are evident as rapid urbanization has caused a lot of pollution to the river water quality and quantity. The water is polluted by household garbages, municipal waste etc. This research focuses on the overall water extent and quality assessments of the four major surrounded rivers/khal of the Dhaka city. Both the extent of the water bodies and water quality of the peripheral rivers of the Dhaka city were studied using multispectral satellite images. Water bodies were reduced by about 16% due to urbanization or transformation of the rivers into land from 1977 to 2023. The in-situ pH values of the rivers show mostly 5 to 7, Tongi Khal shows higher pH values than other rivers. Given the measured pH values in the studied rivers, it is evident that the water quality is raising concerns about its suitability for various uses and highlighting the need for appropriate water management and conservation strategies. Tongi Khal and Balu River show the higher values of EC and TDS in the field than other rivers (Figure 10). During the field measurements, the highest EC value recorded was 1075 µS/cm in Tongi Khal, while the minimum value was 690 µS/cm at Buriganga River. ON the other hand, in the Balu River, the highest EC value was found 970 µS/cm. The average EC value recorded at the Balu River was 885 µS/cm and at the Tongi Khal it was 936 µS/cm which was highest among all. It is evident from the statistics, EC values have exceeded permissible limit for irrigation and are near to the optimum permissible limit for aquaculture (ADB, 1994). Dissolved oxygen level in the field was found mostly below 0.5mg/l, indicating poor quality water for aquatic lives (Table 5 and 6). The low DO levels indicated in the study raise serious concerns about the water quality and its suitability to support aquatic life. None of the samples collected in the field met the required DO limit of 6 mg/l. the Buriganga River had the lowest average DO of 0.16 mg/l, followed by the Balu River with an average of 0.17 mg/l, Tongi Khal with an average of 0.23 mg/l, and Turag River with an average of 0.32 mg/l. Improving the DO levels in the water bodies is essential to ensure the preservation of aquatic ecosystems and to maintain a healthy and sustainable environment. The turbidity values observed in the water bodies are significantly higher than the acceptable standards for drinking water (1 FTU or NTU) and for household water (5 FTU or NTU) indicated that the water quality in the analyzed rivers is unfit for domestic use. The average turbidity values for each river also show elevated levels, with Balu River having the highest average of 72.59 NTU, followed by Tongi Khal (46.58 NTU), Turag River (46.10 NTU), and Buriganga River (29.90 NTU). Even the lowest value of 22.50 NTU was recorded in the Buriganga River exceeds the acceptable limit for household water. This high turbidity indicates a lower water quality in the water reservoirs, which can be attributed to various factors such as sediment runoff, pollutants, and suspended solids in the water. The Cchl-a concentrations highlight the nutrient enrichment and biological productivity in the studied water bodies, with the Turag River standing out as having the highest level of eutrophication. Seasonal water quality parameters showed mostly eutrophic conditions with minor areas of hyper-eutrophic condition in Turag River. Considering all the observed water quality parameters, studied rivers are no longer suitable for any uses such as drinking, fisheries or even agriculture. Proper management strategies and interventions are necessary to control nutrient inputs and restore water quality in these rivers. For future studies, higher temporal and spatial resolutions are recommended. It's high time for the government to take proper measures to stop the degradation of the surrounding rivers of Dhaka city. Public awareness must be ensured to keep the lakes safe from pollution. Thus, we can overcome the crisis and create better living condition for the citizens. The research recommends the urgent need for the government to take appropriate measures like creating public awareness campaigns to halt the degradation of the surrounding rivers of Dhaka city.

Acknowledgements

The research has been funded by the special research allocation of the Ministry of Science and Technology, Government of the People's Republic of Bangladesh. The overall technical and laboratory support was provided by the Department of Geology, University of Dhaka.

References

ADB (Asian Development Bank) 1994. Training manual for environmental monitoring. *Engineering Science Incorporation USA* 2–26.

Adjovu, Godson E, Haroon S, David J and Sajjad Ahmad 2023. Overview of the application of remote sensing in effective monitoring of water quality parameters. *Remote Sensing* **15**(7): 1938.

Afroz, R, Mia M B, Islam M S 2020. Evaluation and monitoring of water quantity and quality of the Buriganga river in Bangladesh using multi-temporal Landsat images. *Dhaka University Journal of Earth and Environmental Sciences* **8**(1): 61–69.

Ahmad, S 2009. The deterioration of water bodies in Dhaka City & their impact upon the environmental situation of Dhaka City. *Bangladesh Journal of Geology* **26**: 28.

Alam, M, Rabbani, M G 2007. Vulnerabilities and responses to climate change for Dhaka. *Environment and Urbanization* **19**(1): 81–97.

Alam, M S 2014. Assessment of water quality of Hatirjheel Lake in Dhaka city. *International Journal of Technology Enhancements and Emerging Engineering Research* **2**(6): 97–100.

Alparslan, E, Aydöner, C, Tufekci, V, Tüfekci, H 2007. Water quality assessment at Ömerli Dam using remote sensing techniques. *Environmental monitoring and assessment* **135**: 391–398.

Boyd, C E 2019. Water quality: an introduction (2nd edition). *Springer Nature*: 357.

Buyantuyev, A, Wu, J 2010. Urban heat islands and landscape heterogeneity: linking spatiotemporal variations in surface temperatures to land-cover and socioeconomic patterns. *Landscape Ecology* **25**: 17–33.

Carlson, R E 1977. A trophic state index for lakes 1. *Limnology and Oceanography* **22**(2): 361–369.

Chowdhury, R A, Rashid, T, Hoque, S 2014. Assessing surface water quality using landsat TM and in situ data: An exploratory analysis. Dhaka Megacity: Geospatial Perspectives on Urbanisation, *Environment and Health*: 301–318.

Chowdhury, M R 2000. An assessment of flood forecasting in Bangladesh: the experience of the 1998 flood. *Natural Hazards* **22**(2): 139–163.

Cooper, J, Rediske, R, Northup, M, Thogerson, M Van Denend, J 1998. Agriculture Water Quality Index, Scientific Technical Reports, *Annis Water Resources Institute*: 1–49.

Corner, R J, Dewan, A M, Chakma, S 2014. Monitoring and prediction of land-use and land-cover (LULC) change. Dhaka megacity: geospatial perspectives on urbanization. *Environment and Health:* 75–97.

ECR (Environmental Conservation Rules) 1997. Government of the People 's Republic of Bangladesh. *Ministry of Environment and Forest*. *Department of Environment, Dhaka, Bangladesh*: 212–214.

EQS (Environmental Quality Standard) 1997. Government of the People 's Republic of Bangladesh. *Ministry of Environment and Forest, Department of Environment, Gazette, registered nr. DA-1, Dhaka, Bangladesh.*

Guan, X, Li, J, Booty, W G, 2011. Monitoring Lake Simcoe water clarity using Landsat-5TM Images. *Water Resources Management* **25**: 2015–2033.

Hossain, S, 2008. Rapid urban growth and poverty in Dhaka City. *Bangladesh e-Journal of Sociology* **5** (1): 1–24.

Hoque, M A, McArthur, J M, Sikdar, P K, Ball, J D, Molla, T N 2014. Tracing recharge to aquifers beneath an Asian megacity with Cl/Br and stable isotopes: the example of Dhaka, Bangladesh. *Hydrogeology Journal* **22**(7): 1549–1560.

Hossain, M J, Mahmud, M M, Islam, S T 2023. Monitoring spatiotemporal changes of urban surface water based on satellite imagery and Google Earth Engine platform in Dhaka City from 1990 to 2021. *Bulletin of the National Research Centre* **47**(1): 150.

Jan-E-Alam, M, Reza, P, Hossain, S, Hossain, M Z 2017. Water quality assessment of Dhanmondi Lake in Dhaka City. *Multidisciplinary Journal of European University of Bangladesh*: 1713(006814).

Kallio, K, Attila, J, Härmä, P 2008. Landsat ETM+ images in the estimation of seasonal Lake water quality in Boreal River Basins. *Environmental Management* **42**: 511–522.

Kang, W, Lee, K, Kim, J 2022. Prediction of suspended sediment concentration based on the turbidity-concentration relationship determined via underwater image analysis. *Applied Sciences* **12**(12): 6125.

Islam, M S, Rehnuma, M, Tithi, S S, Kabir, M H, Sarkar, L 2015. Investigation of water quality parameters from Ramna, Crescent and Hatirjheel Lakes in Dhaka City. *Journal of Environmental Science and*

Natural Resources **8**(1): 1–5.

Patra, P. P., Dubey, S. K., Trivedi, R. K., Sahu, S. K., Rout, S. K 2017. Estimation of chlorophyll-a concentration and trophic states in Nalban Lake of East Kolkata Wetland, India from Landsat 8 OLI data. *Spatial Information Research* **25**(1): 75–87.

Pramanik, B. K., Sarker, D. C 2013. Evaluation of surface water quality of the Buriganga River. *Journal of Water Reuse and Desalination* **3**(2): 160–168.

Quang, N. H., Sasaki, J., Higa, H., Huan, N. H 2017. Spatiotemporal variation of turbidity based on landsat 8 oli in cam ranh bay and thuy trieu lagoon, vietnam. *Water* **9**(8): 570.

Rahman, S. S., & Hossain, M. M 2019. Gulshan Lake, Dhaka City, Bangladesh, an onset of continuous pollution and its environmental impact: a literature review. *Sustainable Water Resources Management* **5**(2): 767–777.

Rahman, S., Hossain, F 2008. Spatial assessment of water quality in peripheral rivers of Dhaka City for optimal relocation of water intake point. *Water Resources Management* **22**: 377–391.

Razzak, N. R. B., Muntasir, S. Y., Chowdhury, S. U. B. R. A. T. A 2012. Pollution scenario of Dhaka city

lakes: a case study of Dhanmondi and Ramna lakes. *Global Engineers and Technologist Review* **2**(7): 1–6.

Rotta, L. H., Alcântara, E. H., Watanabe, F. S., Rodrigues, T. W., & Imai, N. N 2016. Atmospheric correction assessment of SPOT-6 image and its influence on models to estimate water column transparency in tropical reservoir. *Remote Sensing Applications: Society and Environment* **4**:158–166.

Sabit, M.I 2011. Evaluation of water quality and pollution sources of Gulshan Lake, MSc engineering thesis in civil and environmental engineering. *Bangladesh University of Engineering and Technology, Bangladesh.*

Shahid, S 2010. Recent trends in the climate of Bangladesh. *Climate Research* **42**(3): 185–193.

Sakamoto, M., Ahmed, T., Begum, S., Huq, H 2019. Water pollution and the textile industry in Bangladesh: flawed corporate practices or restrictive opportunities. *Sustainability* **11**(7): 1951.

Sultana, M. S., Dewan, A 2021. A reflectance-based water quality index and its application to examine degradation of river water quality in a rapidly urbanising megacity. *Environmental Advances* **5**: 100097.

Taleb, Abu 2012. Comparative study of Urban area extension and flood risk in Dhaka City of Bangladesh.

Verdin, J. P 1985. Monitoring water quality conditions in a large western reservoir with Landsat imagery. *Photogrammetric Engineering and Remote Sensing* **51**(3): 343–353.

Wang, M., Yao, Y., Shen, Q., Gao, H., Li, J., Zhang, F., Wu, Q 2020. Time-Series analysis of surface-water quality in Xiong'an New Area, 2016–2019. *Journal of the Indian Society of Remote Sensing* **49**(4): 857–872.

Wu, G., De Leeuw, J., Skidmore, A. K., Prins, H. H., & Liu, Y 2008. Comparison of MODIS and Landsat TM5 images for mapping tempo–spatial dynamics of Secchi disk depths in Poyang Lake National Nature Reserve, China. *International Journal of Remote Sensing* **29**(8): 2183–2198.

Whitehead, P., Bussi, G., Hossain, M. A., Dolk, M., Das, P., Comber, S., Hossain, M. S 2018. Restoring water quality in the polluted Turag-Tongi-Balu River system, Dhaka: Modelling nutrient and total coliform intervention strategies. *Science of the Total Environment* **631**: 223–232.

WHO 2011. WHO guidelines for drinking-water quality, 4th edn., *World Health Organization, Geneva.*