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Assessment of Water Quality and Quantity in the Lakes of Dhaka Metropolitan City - Remote Sensing, Field and Laboratory Analyses

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ABSTRACT: Lakes in the Dhaka city have been facing extreme deterioration both by quantity and quality due to rapid urban and population growth for several decades. The prime objective is to assess the spatiotemporal changes of water quality and water quantity of the Dhaka city lakes respectively using Sentinel 2B and Landsat satellite images. The study covers the major twelve lakes of the Dhaka city. The four seasonal water qualities such as chlorophyll-a concentration, trophic state index (TSI), Secchi disk depth (SDD) and turbidity were retrieved with the conventional algorithms using Sentinel 2B images. The results showed that the Uttara Park Lake reduced its area dramatically from 1972 to 2020 due to the rapid urbanization in this region. Although the Zoo Lakes areas increased more than three times but the Banani, Hatirjheel and Dhanmondi lakes reduced to about 60-75% from 1972 to 2020 due to the urbanization and filling up the lake's area. On the other hand, Gulshan, Crescent and Ramna Lakes reduced their area slightly about 10-20% during the study period. The chlorophyll-a concentration from post to pre-monsoon, increased in six lakes (Uttara Park, Zoo North, Gulshan, Old Airport, Dhanmondi and Hatirjheel), declined in six lakes (Zoo South, Banani, Ramna, Uttara, Uttara South and Crescent) of Dhaka city. Although the TSI illustrated all lakes in the eutrophic states from post to pre-monsoon but the value of TSI increased in six lakes and declined six lakes of the twelve point samples within the retrieved spatial distribution of TSI using satellite images of Dhaka city. In case of Secchi depth, the SDD values declined from post-monsoon to pre-monsoon in all of the lakes, indicating the deteriorating water quality of the lakes. On the other hand, the turbidity values increased in all lakes of Dhaka city from post-monsoon to pre-monsoon. We observed pH values ranges from 7-9 in the lakes during the field works early March and May of 2021. The observed EC values of the lakes ranges from 148-730µs/cm and 130-690µs/cm respectively in winter and pre-monsoon seasons. None of the samples of the lakes meets the standard of dissolved oxygen (DO) collected in March, 2021, but Dhanmondi and Uttara Lake samples collected in May, 2021 meet the standard. Biological oxygen demand (BOD) value is extremely high and none of the samples meets the acceptable limit of BOD. Among the cations, only Hatirjheel, Gulshan, Uttara, Uttara South/W, Zoo South and North Lake exceeded the acceptable limit for K^+. Among the anions, Hatirjheel, Gulshan, Banani, Uttara, Uttara South/W Lake exceed the standard for $HCO3^-$ and Hatirjheel, Gulshan, Banani, Old Airport, Uttara Park, Uttara South/W Lake exceed the standard limit for $NO3^-$. Uttara Lake shows the maximum concentration of $PO43^-$ and does not meet the standard limit. All the samples meet the standard for Fe and Mn. The outputs of this study could be used to minimize the degradation of Dhaka city lakes both in terms of quantity and quality and will help take necessary measures for healthy and sustainable lake environment.

Keywords: Dhaka City; Lakes; Water Quantity; Water Quality; Multispectral Satellite Image

INTRODUCTION

Wetlands is one of the key parameters in the hydrologic cycle. Generally, wetlands used to receive, store, and release water in different ways i.e., physically through subsurface water, surface water run-off, and biologically through transpiration by vegetation (Razzak et al., 2012). In Dhaka, the lakes are considered as the lungs of this megacity and treated nowadays as recreational areas for the overcrowded people in this city. Lakes can be important habitats for a variety of aquatic life as well as an aesthetic resource to communities. Dhaka city, the capital of Bangladesh, has one of the fastest urban growth rates among the developing nations (UN, 2007; Alam and Rabbani 2007). The side effects of rapid urbanization is also manifested by reduction of water bodies as well as the degraded water environment (World Bank 2000). As almost every natural watershed in Dhaka city, lakes are transforming into a dead swamp by the sufferings from the significant level of pollution. Various causes are responsible for polluting water of the lakes, some

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natural causes are mixture of biodegraded portion of animal and plants to pure water. They also receive untreated sewage and sewage polluted surface run off from adjacent residence, industries, and communities. The recent studies indicate that the lake water has already reached to a dangerous state in terms of parameters like total solid in the water, level of alkalinity, turbidity, dissolved oxygen and biochemical oxygen demand etc. (Rahman and Hossain, 2019). In recent time, due to excessive population pressure, unawareness of users, lack of enforcement of legal matters, very few of the water bodies retain good water quality and biodiversity (Alam et al., 2014). A number of investigations have been carried out in some lakes situated in and around Dhaka metropolis area to evaluate their water quality based on point samples (Jan–E–Alam, et al., 2017). There is no research focuses on the spatial assessment of the water quality of lakes in the megacity Dhaka using satellite images. Now-a-days, lakes in Dhaka city are in critical condition in terms of their water quantity with illegal filling for settlements by influential community. It would be beneficial for employing continuous spatial lake monitoring system in Dhaka city using high resolution satellite images. Spatio-temporal monitoring of water quantity as well as quality using satellite image could assist the policy maker for the betterment of lake management system and to understand the impacts of ongoing degradation of water quality and quantity too. If proper attention has been paid, lakes can be used to enhance the natural beauties of Dhaka city. The prime purposes of this study are (a) quantitative investigation of Dhaka city lakes area using time-series analysis of satellite images from 1980-2020 and (b) assessment of their water quality through seasonal monitoring both in situ and laboratory investigation and satellite image analysis.

STUDY AREA

The study area covers mostly important and accessible twelve lakes of the Dhaka city in Bangladesh (Fig. 1). The name of the studied lakes are (1) Ramna Lake, (2) Dhanmondi Lake, (3) Crescent Lake, (4) Hatirjheel Lake, (5) Old Dhaka Airport Lake, (6) Gulshan Lake, (7) Banani Lake, (8) Zoo South Lake, (9) Zoo North Lake, (10) Uttara South Lake, (11) Uttara Park Lake, and (12) Uttara Lake. They are very important considering all aspects of beauty, ecosystem, surface water conservation, transport systems and recreations.

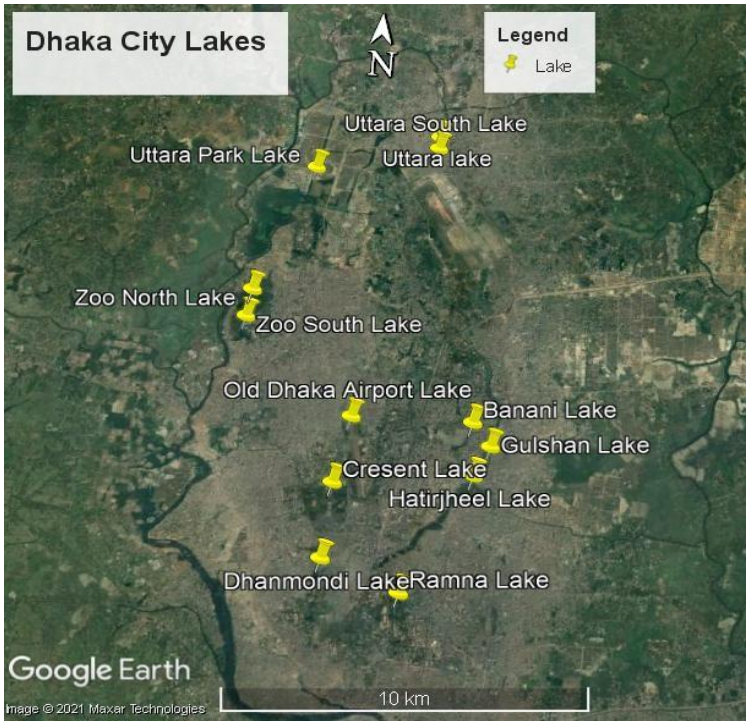

Figure 1: Location of the Studied Lakes of Dhaka City. The Background is the Google Earth Image

MATERIALS AND METHODS

Landsat MSS/TM/OLI sensors images were used for monitoring water bodies quantitatively of the Dhaka city lakes (Table 1). Landsat images were 30m in resolution. Sentinel 2B sensors images were used to evaluate for seasonal water quality parameter of the Dhaka city lakes where the used bands were 10-20m in resolution (Table 1). Other than satellite images, we collected in situ water samples for each lakes to synthesis the chemical quality of those lakes water such as anion- cation, pH, EC, DO, BOD, temperature, iron and manganese etc. A secchi disk was used to measure the depth of the water clarity of the lakes.

Table 1: Used Satellite Images with Date and Their Resolution of the Study

Sensor	Date	Resolution (m)
Landsat MSS	28 December 1972	60
Landsat TM	02 January 1988	30
Landsat TM	29 November 2004	30
Landsat OLI	09 November 2020	30
Sentinel 2B	7 November 2020 (Post-Monsoon)	10-20
Sentinel 2B	27 December 2020 (Winter)	10-20
Sentinel 2B	25 February 2021 (Spring)	10-20
Sentinel 2B	26 April 2021 (Pre-Monsoon)	10-20

The study consists two methods such as (1) satellite images analysis to retrieve both quantity and quality of Dhaka city lakes with validation by the ground truth data and (2) laboratory analysis of water chemistry of two water samples from each lake (Fig. 2).

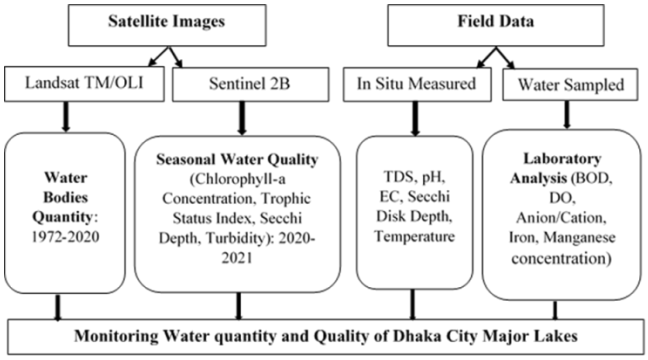

Figure 2: Flow Chart of the Methods used in the Study

Water Quantity: Satellite Image Analysis

Four sets of Landsat MSS/TM/OLI images were analyzed by NDWI/MNDWI method to retrieve the water bodies quantitatively from 1980 to 2020 of the Dhaka city lakes. Before classification, the images were rectified by radiometric and geometric methods.

Water Quality: Satellite Image Analysis, In Situ and Laboratory Chemical Analysis

Four high resolution satellite images of Sentinel 2B (10-20m) were analyzed to retrieve four seasons' (post-monsoon, winter, spring and pre-monsoon) water quality parameters such as chlorophyll-a concentration, trophic state index, secchi disk depth and turbidity of the Dhaka city lakes by the following ways. Hence, after atmospheric correction of those image, the reflectance values of the used bands of the sentinel 2B images were calculated using the reference equation and metadata of those images.

Retrieval of Chlorophyll-a Concentration (Cchl-a)

Chlorophyll-a concentration was retrieved using the Sentinel 2B satellite images in the following equation:

$$C_{chla} = 113.23 \times (R_4/R_5)^2 - 311.67 \times (R_4/R_5) + 216.76 \quad (1)$$

Where, C_{chla} indicates the retrieved chlorophyll-a concentration (µg/L), and R_4 and R_5 indicate the reflectance of the fourth (665 nm) and fifth (705 nm) bands of the sentinel 2A data respectively (Wang et al., 2020).

According to the Boyd (2015), the trophic status was assigned with the mean chlorophyll-a concentration values of the Dhaka city lakes (Table 2) (Patra et al., 2017).

Table 2: Relationship between Trophic Status and Chlorophyll-a Concentration in Lakes (Boyd, 2015; Patra et al., 2017)

Mean Chlorophyll-a concentration (µg/L)	Trophic Status with conditions
<2	*Oligotrophic*, very low phytoplankton, no aesthetic problems
2-5	*Mesotrophic*, some algae with turbidity, no oxygen depletion, reduced aesthetic values
5-15	*Mesotrophic*, high level of algae, turbidity, oxygen depletion likely, reduced aesthetic values
>15	*Eutrophic*, higher level of phytoplankton, serious oxygen depletion, significantly reduced aesthetic values

Trophic State Index (TSI) Based on Cchl-a

The TSI was calculated using the Carlson's index (Carlson, R., 1977) in the following equation based on the chlorophyll-a concentration:

TSI (Chl-a) = 10 x (6-(2.04-0.68InChl-a)/In2) (2)

Trophic status of the Dhaka city lakes was designated based on the retrieved TSI according to the Carlson, R. (1977) system (Table 3).

Table 3: Classification of Trophic Status Based on the TSI of the Lake Water (Carlson, R., 1977)

TSI	Trophic Status	Water condition of the lakes
>30-40	Oligotrophic	Clear Water
40-50	Mesotrophic	Moderate clarity
50-70	Eutrophic	Low clarity due to presence of blue green algae, macrophytes
>70	Hyper-Eutrophic	Greenish water, no clarity, high algal bloom and dense macrophytes

Retrieval of Secchi Disk Depth (SDD) using Sentinel 2B Data

There are a number of algorithms for SD retrieval with various ranges of determination coefficient from 10-69% (Rotta et al., 2016; Verdin, 1985; Wu et al., 2008). We used the latest algorithm of Rodrigues et al., 2020 for SD retrieval using Sentinel 2B data which has a higher value of determinant coefficient (R^2 =86 %). The used algorithm is as follows:

$$SD = (0.024 \times (R_2/R_3 * R_4)) + 0.72 \quad (3)$$

Where, R_2, R_3 and R_4 are the reflectance of the sentinel 2B bands of two, three and four.

The retrieved SD values of the Dhaka city lakes were divided into various types of trophic status according to the Carlson's classification such as oligotrophic (SD>4m), mesotrophic (SD=2-4m), eutrophic (SD=0.5-2m) and hyper-eutrophic (SD<0.5) (Carlson R., 1977).

Retrieval of Turbidity using Sentinel 2B Data

Turbidity is one of the essential quality component of water bodies and acts as a substitute for water clarity. Spatial distribution of water quality of the Dhaka city lakes were retrieved using the following equation of Quang et al., 2017's linear regression model with the sentinel 2B satellite image data. Drinking water or acceptable turbidity values is less than 1 FTU/NTU. Higher the turbidity of more than 1 FTU indicates lower the water quality of any water reservoirs.

$$\text{Turbidity (FTU)} = 380.32 \times R4 - 1.7826 \quad (4)$$

Where, R_4 is the reflectance of red band of the sentinel 2B satellite image.

We conducted two field studies to collect in situ water temperature, Secchi disk depth, pH, EC, TDS and color of the Dhaka city lakes in the months of March and May, 2021. We had also collected water samples from the studied lakes for laboratory analysis to determine cations, anions and trace elements. In situ and laboratory water quality parameters were used to validate the satellite image retrieve results of water quality of the Dhaka city lakes.

RESULTS AND DISCUSSION

Water Quantity

Spatial distribution of water bodies was retrieved using Landsat TM/OLI satellite images to monitor quantitative areas of the twelve lakes of Dhaka city (Fig. 3). The MNDWI method was used to retrieve the water bodies in this study. The results showed that the Uttara Park Lake was reduced its area dramatically from 1972 to 2020 due to the rapid urbanization in this region (Table 4). The Uttara Lake and Uttara south lake changed a little bit during the study period. The Zoo lakes area were increased more than three times from 1972 to 2020. The Banani Lake reduced about half of its area from 1972 to 2020. The Hatirjhil Lake was reduced to about 60% from 1972 to 2020. Area of the Dhanmondi Lake's water body was reduced about 75% from 1972 to 2020 due to the urbanization and filling up the lake's area. Gulshan, Crescent and Ramna Lakes were reduced theirs area slightly about 10-20% during the study period.

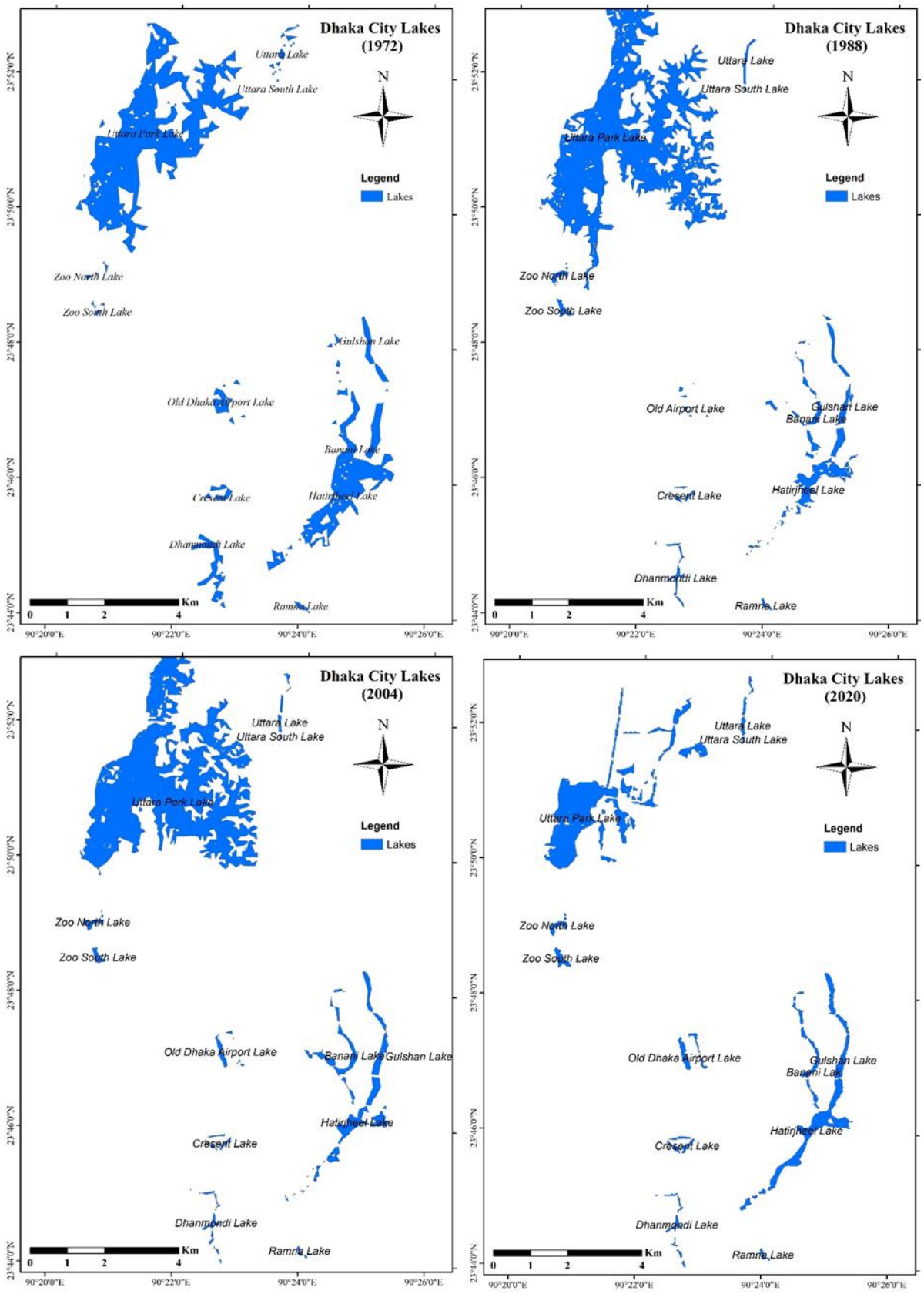

Figure 3: Changes of Areas in the Dhaka City Lakes from 1972 to 2020

Table 4: Areas of Dhaka City Lakes from 1972 to 2020

Dhaka City Lakes Area in Hectares				
Name	**1972**	**1988**	**2004**	**2020**
Uttara Lake	12	8	9	10
Uttara Park Lake	800	1265	1209	338
Uttara South Lake	0	1	1	1
Zoo North Lake	3	8	8	9
Zoo South Lake	2	8	7	10
Banani Lake	47	31	38	26
Gulshan Lake	39	30	34	37
Old Dhaka Airport Lake	24	3	11	17
Hatirjheel Lake	228	85	67	94
Crescent Lake	13	6	6	10
Dhanmondi Lake	45	12	11	11
Ramna Lake	4	3	2	3

Water Quality

Spatial distribution of water qualities such as chlorophyll-a, trophic state index, secchi depth and turbidity were retrieved using the Sentinel 2B sensor images of the Dhaka city lakes for four seasons (pre-monsoon, winter, spring and pre-monsoon) (Fig. 4-8). Summary statistics analysed with the minimum and maximum of the water qualities of the four seasons (Table 5). Minimum concentration of chlorophyll-a was lowest in post monsoon season of 2020 and then increased gradually up to the pre-monsoon season of 2021. Alternatively, maximum concentration of chlorophyll-a decreased from post to pre-monsoon seasons. TSI-Cchl-a increased from post to pre-monsoon in the aspect of minimum values and overall similar values in case of maximum values. Secchi depth declined in the Dhaka city lakes from post-monsoon to pre-monsoon seasons. Turbidity values were increased in the lakes from post to pre-monsoon period.

Spatial distribution of chlorophyll-a concentration showed mostly more than 15 μg/L, that indicated the eutrophic state of the Dhaka city lakes throughout the seasons from post to pre-monsoon (Table 5; Fig. 4). Satellite image retrieved of trophic state index values based on the chlorophyll-a concentration of the Dhaka city lakes were also in the ranges of eutrophic state i.e., TSI=50-70 (Fig. 5-6). Retrieved secchi depth from the sentinel 2B satellite images of the Dhaka city lakes showed within the ranges from 0.5 to 2 m, which also indicated eutrophic state in all seasons mostly (Fig. 7). Spatial analysis of turbidity of all lakes of Dhaka city indicated the mostly greater than 20 FTU from winter to pre-monsoon season, except about half of the lakes area within the ranges of 10 to 20 in post monsoon season (Fig. 8).

Twelve point samples were selected to monitor the seasonal variation of water quality parameters retrieved from satellite sentinel 2B images of the twelve Dhaka city lakes (Fig. 8). The chlorophyll-a concentration from post-monsoon to pre-monsoon, increased in six lakes (Uttara Park, Zoo North, Gulshan, Old Airport, Dhanmondi and Hatirjheel), declined in six lakes (Zoo South, Banani, Ramna, Uttara, Uttara South and Crescent) of Dhaka city (Fig. 8). Although the trophic state index illustrated all lakes in the eutrophic states from post-monsoon to pre-monsoon but the value of TSI increased in six lakes and declined six lakes of the twelve point samples within the retrieved spatial distribution of TSI using satellite images of Dhaka city (Fig. 8). In case of Secchi depth, the SDD values declined from post-monsoon to pre-monsoon in all of the lakes of Dhaka city, indicating the deteriorating the water quality of the lakes (Fig. 8). On the other hand, the turbidity values increased in all lakes of Dhaka city from post-monsoon to pre-monsoon.

Table 5: Summary of the Seasonal Water Quality within the Dhaka City Lakes

Satellite Image Based Water Quality in Dhaka City Lakes	**Post-Monsoon (7 November 2020)**		**Winter (27 December 2020)**		**Spring (25 February 2021)**		**Pre-Monsoon (26 April 2021)**	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Cchl-a (μg/L)	3.38	78.5	8.39	41.97	8.74	57.12	8.88	59.57
TSI-Cchl-a	42.59	73.38	51.41	67.23	52.07	70.25	52.1	70.67
Secchi Disk Depth (m)	0.95	1.53	0.89	1.05	0.87	1.06	0.85	1.03
Turbidity (FTU)	14.88	40.36	33.34	59.45	31.75	61.81	33.29	70.74

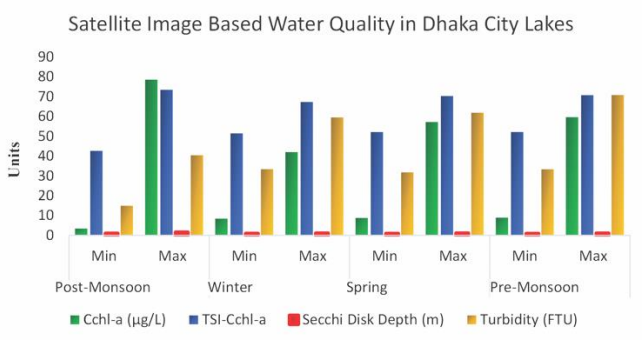

Figure 4: Variation of Seasonal Water Quality Parameters of the Dhaka City Lakes Retrieved using Sentinel 2B Data

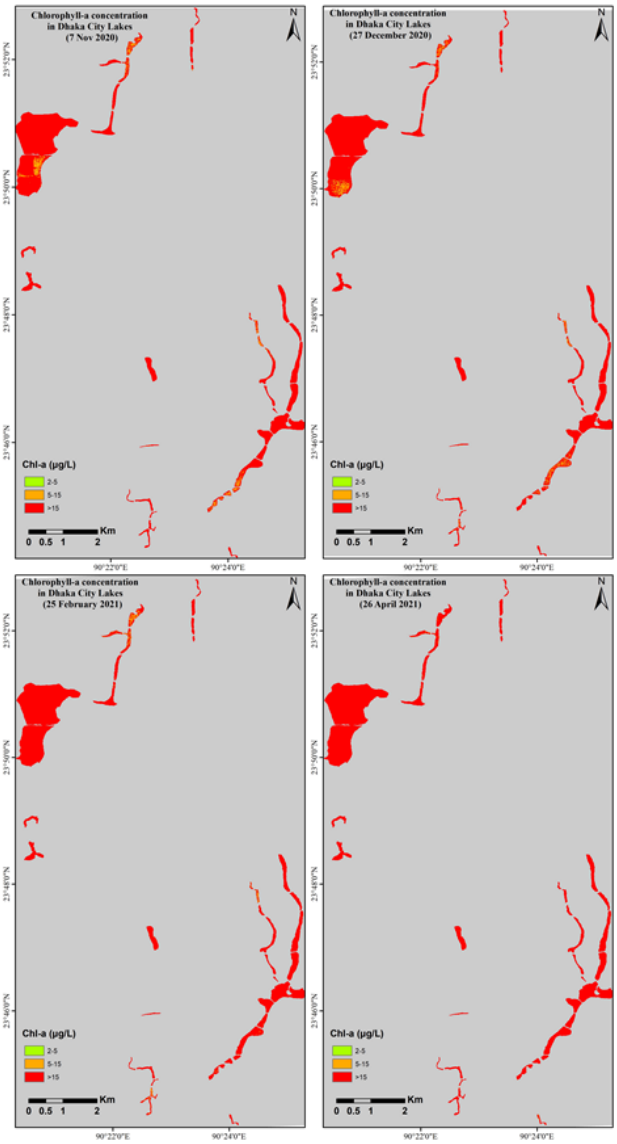

Figure 5: Spatial Distribution of Seasonal Chlorophyll-a Concentration within the Dhaka City Lakes

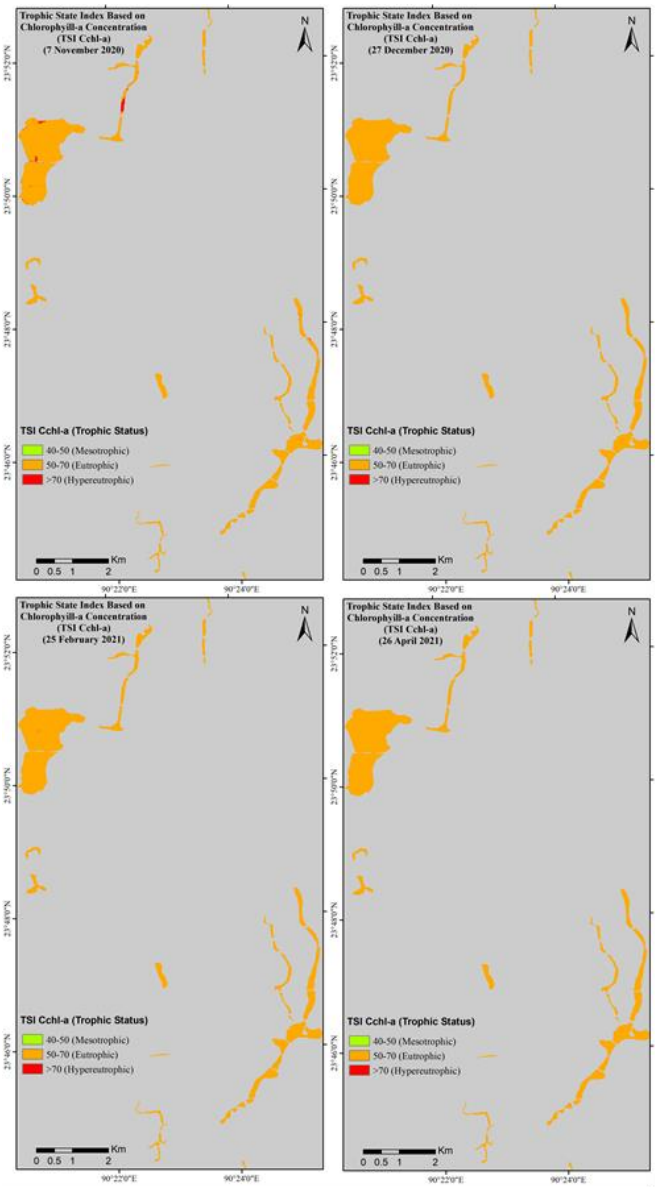

Figure 6: Trophic State Index (TSI) of the Dhaka City Lakes

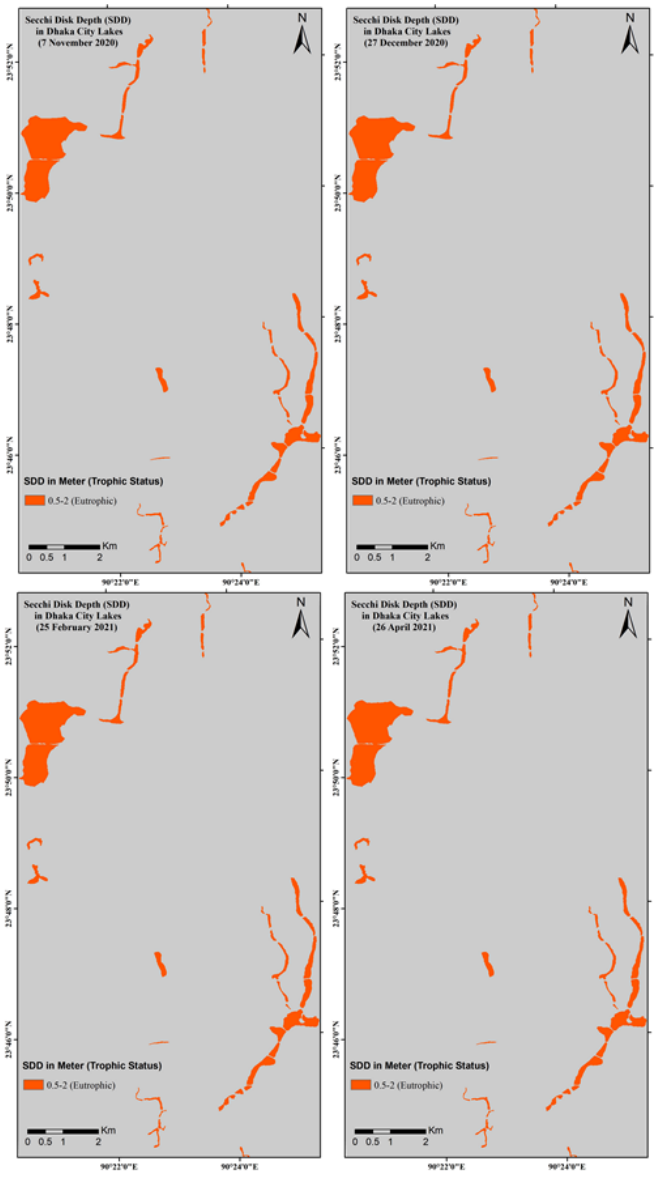

Figure 7: Spatial Distribution of Secchi Disk Depth (SDD) of the Dhaka City Lakes

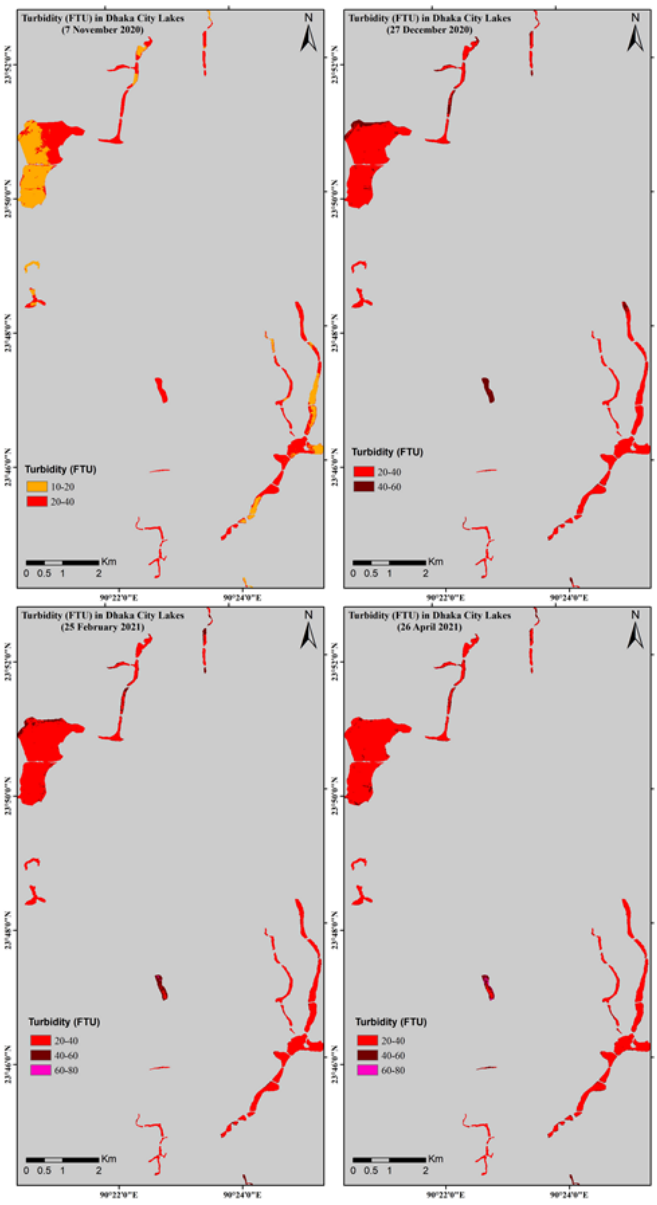

Figure 8: Turbidity (FTU) of the Dhaka City Lakes

PHYSICO-CHEMICAL PROPERTIES OF THE DHAKA CITY LAKES

There was uniform temperature distribution in the studied lakes. Both natural and anthropogenic activity may contribute to the temperature (Table 6 & 7; Fig. 9 & 10). The pH is the index that measures the degree of alkalinity or acidity of any water sample. During the field studies, we obtained pH value in ranges from 7-9.5 i.e., alkaline in nature of the lakes water (Table 6 &7; Fig. 9 & 10). There are several lakes exceeding the Bangladesh standard of drinking (pH: 6.5-8.5) or irrigation (pH: 6.5-8.5) or aquaculture (pH: 6.5-8.0) water such as Crescent, Uttara South, Dhanmondi and Zoo North lakes (ADB, 1994; ECR, 1997). Most of

the lakes are very close to the upper limit of Bangladesh standard value of pH. The EC value ranges from 148 to 730 µs/cm in March 2021 and 170 to 690 µs/cm in May 2021 of the Dhaka city lakes, which indicated the acceptable limit for inland surface water standard according to ECR, 1997 (Table 6 & 7; Fig. 9 & 10). The TDS values were lower in May, 2021 than that of TDS values in March, 2021 for the Dhaka city lakes (Table 6 & 7; Fig. 9 & 10). Uttara lake demonstrates the highest TDS value of 366 ppm and lowest in the Crescent lake 73 ppm in March, 2021. Uttara and Crescent lakes show 356 ppm and 70 ppm TDS value respectively in May 2021. So, all of the lakes water showed somewhat acceptable level according to the standard of TDS for drinking water (1000 ppm), industrial water (1500 ppm), livestock (5000 ppm), and irrigation (2000 ppm) according to ADB 1994 (Table 6 & 7; Fig. 9 & 10).

Table 6: In Situ Measured Water Quality Parameters of Dhaka City Lakes (March 2021)

Sample	Temp (°C)	pH	TDS (ppm)	DO (mg/l)	BOD (mg/l)	EC (µs/cm)	Secchi Depth Measurements (m)
Ramna Lake (RL-01)	25.1	7.35	96	4.85	25.5	187	13
Ramna Lake (RL-02)	25.2	7.38	96			193	13
HatirJheel (HJ-01)	26.3	8	311	3.45	26.5	623	72
HatirJheel (HJ-02)	26.6	7.7	320			640	28
Gulshan Lake (GL-01)	27.6	7.8	290	3.49	25.43	585	22
Gulshan Lake (GL-02)	29.8	7.46	271			546	22
Banani Lake (BL-01)	28	7.44	290	3.76	24.22	580	20
Banani Lake (BL-02)		7.57	300			624	25
Old Airport Lake (OAL-01)	30.2	7.92	107	3.32	22.26	218	32
Cresant Lake (CL-01)	30.1	9.5	73	3.26	22.33	148	60
Dhanmondi Lake (DL-01)	28	8.85	150	5.65	22.45	302	50
Dhanmondi Lake (DL-02)	28.5	8.18	132			264	60?
Uttara Park Lake (UPL-01)	26.9	7.89	189	5.41	18.65	377	26
Uttara Lake (UL-01)	26.3	7.2	366	5.95	19.5	730	20
Uttara South/W Lake (USL-01)	27.4	8.6	294	5.34	18.45	589	26
Zoo South Lake (ZSL-01)	29	7.95	169	3.76	20.04	317	31
Zoo North Lake (ZNL-01)	28	9.45	92	3.23	20.1	183	70

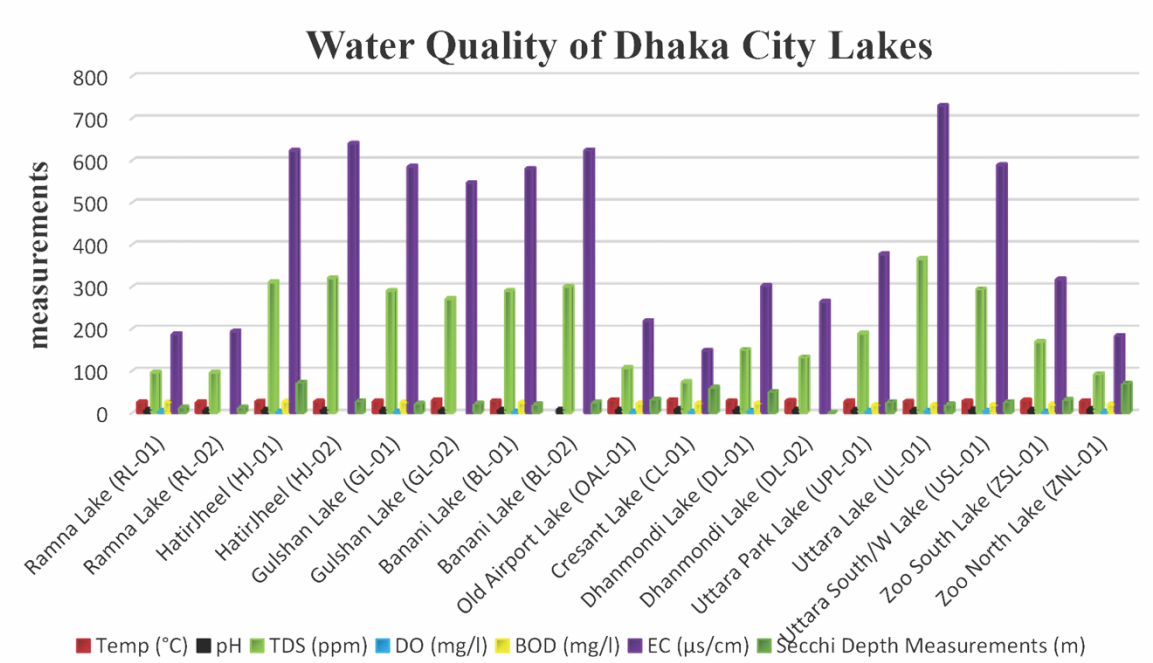

Figure 9: In Situ Water Quality of Dhaka City Lakes (March 2021)

Table 7: In Situ Measured Water Quality Parameters of Dhaka City Lakes (May 2021)

Sample	Temp (°C)	pH	TDS (ppm)	DO (mg/l)	BOD (mg/l)	EC (µs/cm)	Secchi Depth Measurements (m)
Ramna Lake (RL-01)	29.7	7.4	89	4.95	25.6	170	22
Ramna Lake (RL-02)	29.3	7	90			190	22
HatirJheel (HJ-01)	28.8	8	300	3.5	26.1	600	25
HatirJheel (HJ-02)	29.5	7.9	295			667	39
Gulshan Lake (GL-01)	29	7.8	200	3.49	25.7	500	22
Gulshan Lake (GL-02)	29.3	7.8	200			520	24
Banani Lake (BL-01)	28	7.8	210	3.79	23.95	490	25
Banani Lake (BL-02)	28	8	256			610	27
Old Airport Lake (OAL-01)	29	7.9	102	3.4	22.76	215	28
Cresant Lake (CL-01)	30	9	70	3.3	22.45	130	75
Dhanmondi Lake (DL-01)	28.5	9	145	6	22.45	295	67
Dhanmondi Lake (DL-02)	28.5	8.5	128			250	92
Uttara Park Lake (UPL-01)	30	7	187	5.67	18.97	310	37
Uttara Lake (UL-01)	26	7.5	356	6	19.76	690	21
Uttara South/W Lake (USL-01)	27	8.7	289	5.55	18.56	546	28
Zoo South Lake (ZSL-01)	27	8	167	3.45	20.04	310	29
Zoo North Lake (ZNL-01)	29	9	87	3.23	20.1	170	65

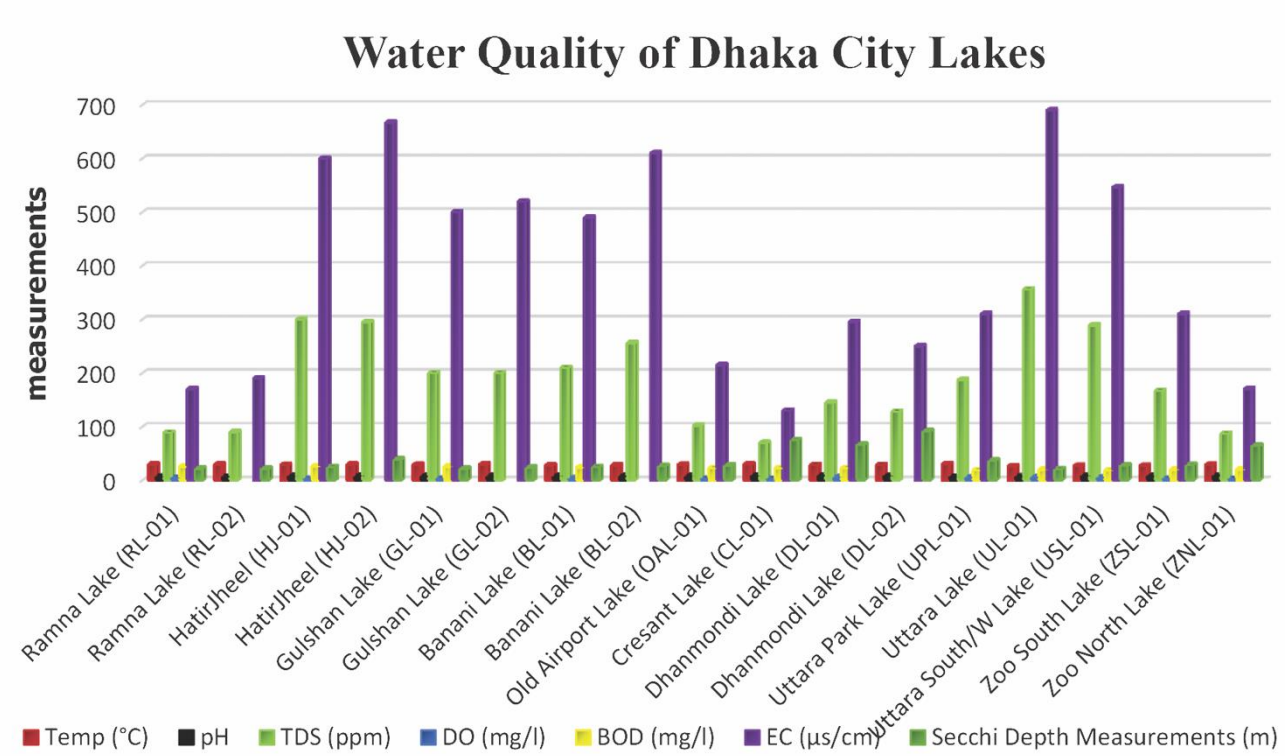

Figure 10: In Situ Water Quality of Dhaka City Lakes (May 2021)

The ionic dominance pattern of the lake water for cation and anion was found $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+} > Fe^{2+} > Mn^{2+}$ and HCO3- > Cl- > NO3- >SO42- respectively which have a contrasting characteristic with the standard ionic dominance pattern for fresh water of cation Ca2+ > Mg2+ > Na+ > K+ and anion HCO3 - > SO4 2-> Cl- (Table 8; Fig. 11 & 12). The dominance of Sodium *over Magnesium and chloride over sulphate* would probably due to the unwise anthropogenic activity like untreated industrial effluents. The pattern of the total cationic and anionic concentration of the studied lakes was Uttara South/W Lake> Uttara Lake> Hatirjheel> Gulshan Lake> Banani Lake> Uttara Park Lake> Dhanmondi Lake> Zoo South Lake> Old airport Lake> Zoo North Lake> Ramna Lake> Cresant Lake and Uttara Lake> Gulshan Lake> Uttara South Lake> Hatirjheel> Banani Lake> Uttara Park Lake> Dhanmonde Lake> Zoo South Lake> Old Airport Lake> Zoo North Lake> Ramna Lake> Cresant Lake consecutively (Table 9; Fig. 11 & 12). This implies that Uttara Park Lake, Uttara Lake, and Gulshan Lake are ionically most imbalanced or polluted.

Table 8: Water Quality of Dhaka City Lakes, Retrieved using Laboratory Analysis (Cation)

	Cation										
Sample ID	Ca^{2+}	*Ca*	Mg^{2+}	*Mg*	Na^{+}	*Na*	K^{+}	*K*	Fe^{2+}	Mn^{2+}	**Total cation**
	(mg/l)	**(meq/l)**	**(mg/l)**	**(meq/l)**	**(mg/l)**	**(meq/l)**	**(mg/l)**	**(meq/l)**	**(mg/l)**	**(mg/l)**	**(meq/l)**
Ramna Lake	16.65	0.83	5.58	0.46	13.49	0.59	4.77	0.12	0.28	0	1.99
Hatirjheel	16.96	0.85	12.4	1.02	61.1	2.66	15.91	0.41	0.07	0.01	4.93
Gulshan Lake	16.57	0.83	14.01	1.15	57.45	2.5	12.69	0.32	0.21	0	4.80

Banani Lake	16.83	0.84	14.69	1.21	54.5	2.37	11.56	0.3	0.13	0.03	4.71
Old Airport Lake	19.84	0.99	9.34	0.77	18.03	0.78	5.52	0.14	0.19	0	2.68
Cresant Lake	10.15	0.51	8.35	0.69	14.7	0.64	0.45	0.01	0.16	0	1.84
Dhanmondi Lake	26.48	1.32	12.16	1.00	29.34	1.28	6.71	0.17	0.23	0	3.77
Uttara Park lake	16.63	0.83	11.71	0.96	46.29	2.01	8.38	0.21	0.1	0	4.02
Uttara Lake	20.71	1.03	15.52	1.28	69.97	3.04	16.61	0.42	0.16	0	5.78
Uttara South Lake	22.48	1.12	16.6	1.37	67.79	2.95	14.35	0.37	0.29	0	5.80
Zoo South Lake	14.31	0.71	10.7	0.88	34.46	1.5	12.83	0.33	0.13	0	3.42
Zoo North Lake	10.69	0.53	6.58	0.54	15.52	0.68	17.35	0.44	0.08	0	2.19

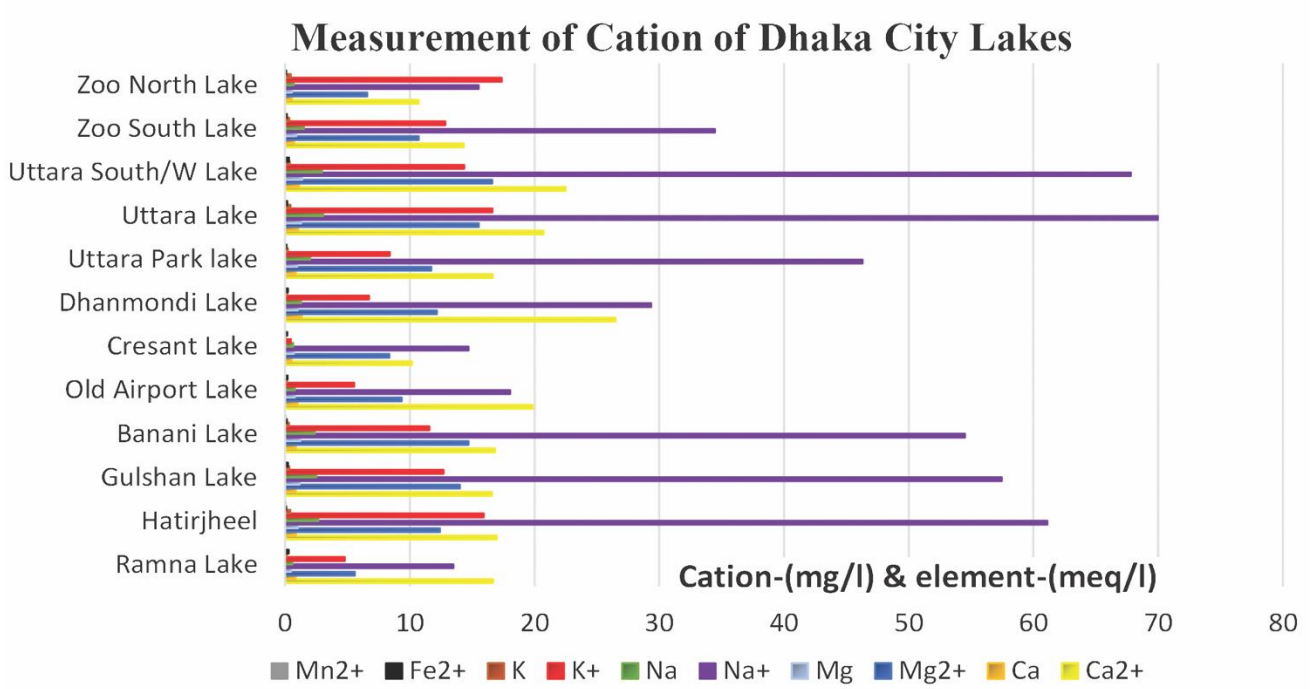

Figure 11: Measurement of Cation of Dhaka City Lakes

Table 9: Water Quality of Dhaka City Lakes, Retrieved using Laboratory Analysis (Anion)

Anion									
Sample ID	HCO_3^- (mg/l)	HCO_3 (meq/l)	Cl^- (mg/l)	Cl (meq/l)	SO_4^{2-} (mg/l)	SO_4 (meq/l)	NO_3^- nitrate (mg/l)	NO_3 (meq/l)	Total anion (meq/l)
Ramna Lake	76.25	1.25	20.03	0.56	20.17	0.42	9.19	0.15	2.38
Hatirjheel	297.38	4.875	63.59	1.79	15.25	0.32	76.36	1.23	8.22
Gulshan Lake	343.13	5.625	50.92	1.43	15	0.31	92.05	1.49	8.86

Banani Lake	366	6	37.61	1.06	13.18	0.27	16.67	0.27	7.60
Old Airport Lake	106.75	1.75	14.93	0.42	9.23	0.19	36.41	0.59	2.95
Cresant Lake	91.5	1.5	4.36	0.12	9.76	0.20	0.25	0.004	1.83
Dhanmondi Lake	175.38	2.88	28.16	0.79	11.46	0.24	4.44	0.07	3.98
Uttara Park lake	198.25	3.25	27.76	0.78	7.93	0.17	37.03	0.6	4.79
Uttara Lake	465.13	7.63	50.63	1.43	17.19	0.36	1.63	0.03	9.44
Uttara South/W Lake	350.75	5.75	52.23	1.47	12.38	0.26	66.6	1.07	8.55
Zoo South Lake	175.38	2.88	26.56	0.75	3.77	0.08	8.06	0.13	3.83
Zoo North Lake	106.75	1.75	14.43	0.41	9.4	0.2	2.89	0.05	2.4

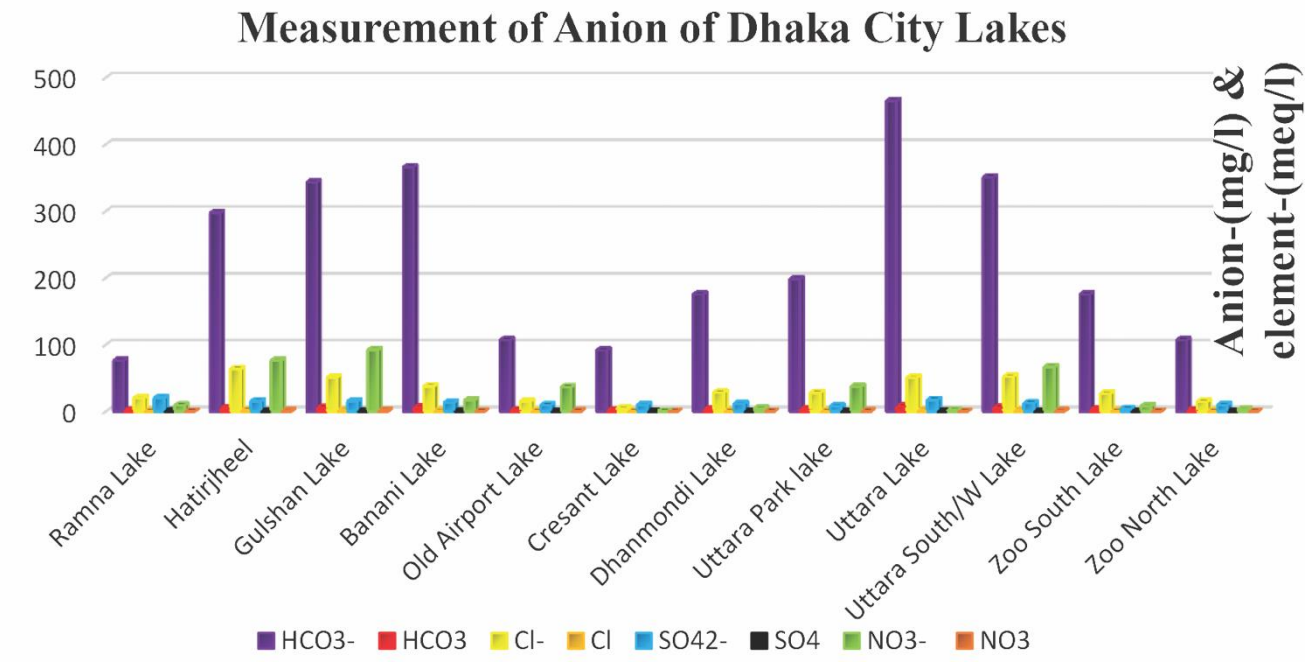

Figure 12: Measurement of Anion of Dhaka City Lakes

CONCLUSIONS

Spatial-temporal distributions of both water quality and quantity were delineated in the lakes of Dhaka Metropolitan City, which were experiencing pay off - deteriorating in quality and quantity due to rapid and unplanned urbanization for decades. The results show that the lakes area decreased drastically from 1972 to 2020 by a percent varying from 25% to 75% except North and south Zoo Lake. Both minimum and maximum concentration of chlorophyll-a and TSI chlorophyll-a were recorded in pre-monsoon season. The Secchi Disk depth showed a decrease, whereas, turbidity of water increased from post monsoon to pre monsoon. Average secchi disk depth found higher in May than March in the field. The pH values recorded in the field describes that the lake water was slightly basic. The TDS, DO, BOD, and EC measurements were almost similar in both March

and May-minor seasonal variation, but varies greatly among lakes. The total Cation concentration of Ca2+, Mg2+, Na+, K+, Fe2+, and Mn2+ and anion concentration of HCO3-, Cl-. SO4 2-, and NO3- were found maximum in Uttara lake and Uttara South/W lake and minimum in Zoo North lake. Moderate Satellite image resolution, conventional algorithms and limited in situ samples were the major limitations of this study. The findings of this study would be a valuable input in planning sustainable city and making the respective authority concerned to protect the lakes from further degradation as well as to improve the existing condition.

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REFERENCES

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

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.

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

Boyd, C. E., 2015. Water quality: An introduction (2nd ed.), Zurich, Springer, pp. 357.

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

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.

Jan–E–Alam, M., Reza, P., Hossain, S., Hossain M. Z., 2017. Water quality assesment of Dhanmondi Lake in Dhaka City, Multidisciplinary Journal of European University of Bangladesh 2, 43-47.

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.

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, 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.

Razzak, N. R. B., Muntasir S. Y., Chowdhury, S., 2012. Pollution scenario of Dhaka city lakes: a case study of Dhanmondi and Ramna lakes, Lobal Engineers & Technologists Review 7(2), 1-6.

Rodrigues, G., Potes, M., Costa, M.J., Novais, M.H., Penha, A.M., Salgado, R., Morais, M.M., 2020. Temporal and spatial variations of Secchi depth and diffuse attenuation coefficient from Sentinel-2 MSI over a Large Reservoir. Remote Sens. 12, 768. https://doi.org/10.3390/rs12050768

Rotta, L. H. S., Alcântara, E. H., Watanabe, F. S. Y., Rodrigues, T. W. P., 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 Sens. Appl. Soc. Environ. 4, 158–166.

UN, 2007. Urban geology of Dhaka, Bangladesh, economic and social commission for Asia and the pacific, Atlas of Urban Geology, United Nation (UN), New York, 1999

Verdin, J. P., 1985. Monitoring water quality conditions in a large western reservoir with Landsat Imagery. Photogramm. Eng. Remote Sens. 51, 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. https://doi.org/10.1007/s12524-020-01264-8

World Bank, 2000. Toward an environment strategy for the World Bank group - a

progress report and discussion Draft. Washington, D.C.

Wu, G., de Leeuw, J., Skidmore, A. K., Prins, H. H. T., Liu, Y., 2008. Comparison of MODIS and 505 Landsat TM5 images for mapping tempo-spatial dynamics of Secchi disk depths in Poyang Lake 506 National Nature Reserve, China. Int. J. Remote Sens. 29, 2183–2198.