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GIS-based Spatial Assessment of Post COVID Water Quality Status of Turag River for Water Resource Conservation in Bangladesh

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Abstract

The COVID-19 pandemic has had enormous effects on human life and the environment, particularly freshwater ecosystems, on a global scale. Despite its numerous effects, the pandemic has improved the quality of the environment, allowing devastated ecosystems to recover. During the COVID lockdown period, many researchers observed positive amendments in environmental quality in various parts of the world. Due to increased industrialization and urbanization over the past several decades, Dhaka's peripheral rivers have grown highly polluted. In this study, an attempt was made to illustrate the post-covid surface water quality scenario of Bangladesh's hihgly contaminated Turag River. Therefore, for the first time, a GIS-based spatial analysis of water quality index was used to endeavor to quantify 16 water quality parameters (pH, EC, temperature, turbidity, salinity, TDS, DO, Na+, K+ Ca2+, Mg2+ Cl-, Cu, Pb, Fe, and Cd) in the river Turag. Thus, it could serve as a reference work for future researches in Bangladesh. After calculating the WQI for the collected samples, it was determined that the water quality status at all sampling stations was extremely poor because each WQI was greater than 100. Using the Kriging method of interpolation, the encroaching WQS were predicted and visually represented using GIS maps. The findings of this study are particularly concerning, as all recorded WQS samples surpassed the standard limits. Based on these findings, we urged for the rapid deployment of proper water management practices and policies in order to safeguard and manage the water resources.

1. Introduction

Rivers are the most important sources of water resources, which are utilized for a wide variety of reasons, including but not limited to domestic, irrigational, and industrial uses. These uses are carried out with the assistance of rivers. The quality of the water that supports human life is unfortunately becoming harder to preserve in today's world, despite the fact that humans' very survival is dependent on the availability of water. The fact that the world's water supplies are undergoing significant degradation is now something that practically every nation on the planet can see for itself. The deterioration of water quality has developed into a highly pressing problem on a global scale as a result of the massive amounts of natural and anthropogenic pressures that are being introduced into rivers (Wang et al., 2018; Todd et al., 2016; Wu et al., 2021). It is possible that in the not-too-distant future, the quality of water all around the world will be put in jeopardy. The very recent deadly COVID-19 pandemic, which was recorded for the first time in December 2019 in Wuhan, China, had left a variety of severely damaging impressions in all sectors of the economy and environment around the world (Franch et al, 2020;Denninson et al., 2020; Pant et al., 2020). As a result of the detrimental effects that this COVID-19 pandemic has had, the socio-economic prosperity of the entire world has suffered an irreparable setback. On the other hand, it was discovered that the deteriorated imprints in ecosystems recovered throughout the period of lockdown as a result of a considerable decrease in environmental contamination (Chaurasia et al., 2020; Denninson et al., 2020). Recent research shows that there has been a dramatic improvement in the freshwater habitats that were extremely contaminated before to the lockout (Yunus et al., 2020;Corlett et al., 2020; Denninson et al., 2020). After the imprints that the global pandemic COVID-19 has left, it is vital to check the quality of both the surface water and the ground water.After the pandemic, there has been a significant decline in the chemical, physical, and biological characteristics of the quality of surface water in recent years (Kareem et al.,2021). As a result of the lifting of the lockdown period, anthropogenic activities, which are the principal sources of a large number of contaminants, have increased. These toxins are also finding their way into the water supply, which contributes to the contamination and degradation of the ecosystem. The world's ecosystem is undergoing dynamic regulated and uncontrolled modifications, and a huge number of pollutants are being dumped into the rivers, which puts the safety of the world's water supply in jeopardy (Kabir et al.,2022). Rivers are becoming increasingly important to people's lives as the world's population continues to expand at an alarming rate (Wang et al., 2020). As a result, these natural resources are being subjected to a significant amount of strain (Berotti and Rosa, 2019). There are around 238 main rivers in Bangladesh, the majority of which are tributaries of larger rivers that flow beyond international boundaries, such as the Meghna, Brahmaputra, and Ganges (Uddin and jeong, 2021). There is a close relationship between anthropogenic activities such as industrialization and the deterioration of water quality in Bangladesh. The most significant contributors to a decline in the quality of surface water are effluents from industrial processes, trash from households, and runoff from irrigational activities (Uddin and jeong, 2021). The effluents that are contained in large quantities in industrial discharge contribute to the degradation of the water quality in rivers (Bansal et al.,2018). In developing nations, more than eighty percent of sewage is dumped straight into rivers and other bodies of water (Kabir et al., 2022). The bulk of Bangladesh's factories are located in close proximity to the country's rivers, and now that COVID-19 has passed, the country's industrialists are concentrating their efforts on rehabilitating their businesses, the water quality of the rivers is in jeopardy. The Turag River in Bangladesh is a perfect example of a river that is currently struggling with severe pollution. It may be found in Dhaka, which is the name of the capital city of Bangladesh. This river has been turned into a dumping ground for all kinds of waste, including chemical, liquid, and solid waste, and it is currently at a standstill (Rahman et al., 2021).WQM (Water Quality Modelling) is the most popular technique for optimizing water quality, and it is also extensively used for showing the strength of pollution control programs (Nadiri et al., 2018; Fan et al., 2021). When it comes to determining the quality of water, one of the most useful and popular tools available is the Water Quality Index (WQI) (Mohebbi et al., 2013;Wu et al.,2013). It is therefore possible to easily display vast amounts of data by utilizing a single value, which eliminates the complexity of data analysis (Vinod et al.,2013; Kareem et al.,2013). It is possible to reduce the various water quality metrics, such as pH and dissolved oxygen (DO), as well as metals, down to a single value that describes the current state of the water's quality (Sutadian et al.,2016). There are a total of three aspects that determine the standard for calculating WQI. These are the selection of parameters, the definition of the sub-index (the parameter quality function), and the aggregation of the sub-indices through the use of mathematical tools (Al-sujairi and S.O.H, 2013; Kachroud et al., 2019; Kareem et al.,2021). Monitoring the spatial and temporal variations of a cluster of predefined water quality parameters is currently the most popular method for determining the quality of surface water (Yotova et al.,2021). Although there are a large number of methods available today for determining the quality of surface water, monitoring these variations is the most common method used by environmental experts. The Geographical Information System, also known as GIS, is an extremely important component in the process of creating a visual representation of WQI through the utilization of a wide variety of map formats. It is possible to utilize GIS in a straightforward manner to represent the current state of water quality based on fluctuations in space and time.

In this study, we evaluated a total of 30 distinct sampling stations along the Turag River in Bangladesh's capital city of Dhaka to determine the levels of 16 different water quality indices. In order to undertake analysis on the mandated monitoring data, we coupled the statistical tools available with the GIS tools. The objective was to detect, on a station-by-station basis, the spatial variations in water quality and then, for the purpose of visual representation, to portray such variations using GIS maps. ArcGIS 10.8 was used to demonstrate the post COVID-19 water quality standards that were found in the Turag River Basin (TRB) of Bangladesh. The findings that were collected can be put to use in the development of pollution prevention plans and policies in the future, with the goal of improving the current water quality situation of TRB in Bangladesh.

2. Materials and Methods

2.1 Study Area

The study was conducted in the Turag River Basin (TRB), which is located near Dhaka, Bangladesh's capital. Dhaka is one of the world's fastest-growing megacities (Hossain and Farson,2017). This river's source is the Bangshi river, an upper tributary of the renowned and very polluted Buriganga river, which flows through the northern district of Dhaka (Whitehead et al,2018). The Turag is one of the most major rivers in Bangladesh, being commercially significant and navigable year-round. This investigation was conducted in a region also known as "Tongi Heavy Industrial Area." Due to the enormous discharge of industrial effluents, the water quality of this river has been substantially deteriorated (Tania et al,2018) over the past few decades, as a result of the massive industrial expansion and influx near the Turag River's margins. The Department of Environment Bangladesh has designated the Turag River as one of its "Ecologically Critical Areas" (ECA). As the global lockdown during the COVID-19 pandemic rehabilitated many ecosystems and environmental conditions, this river has been chosen as the study region to determine whether the WQS (Water Quality Status) is close to standard standards or has been deteriorated. Table 1 & Figure 1 depicts the geography of the study region and the details of 30 sampling points.

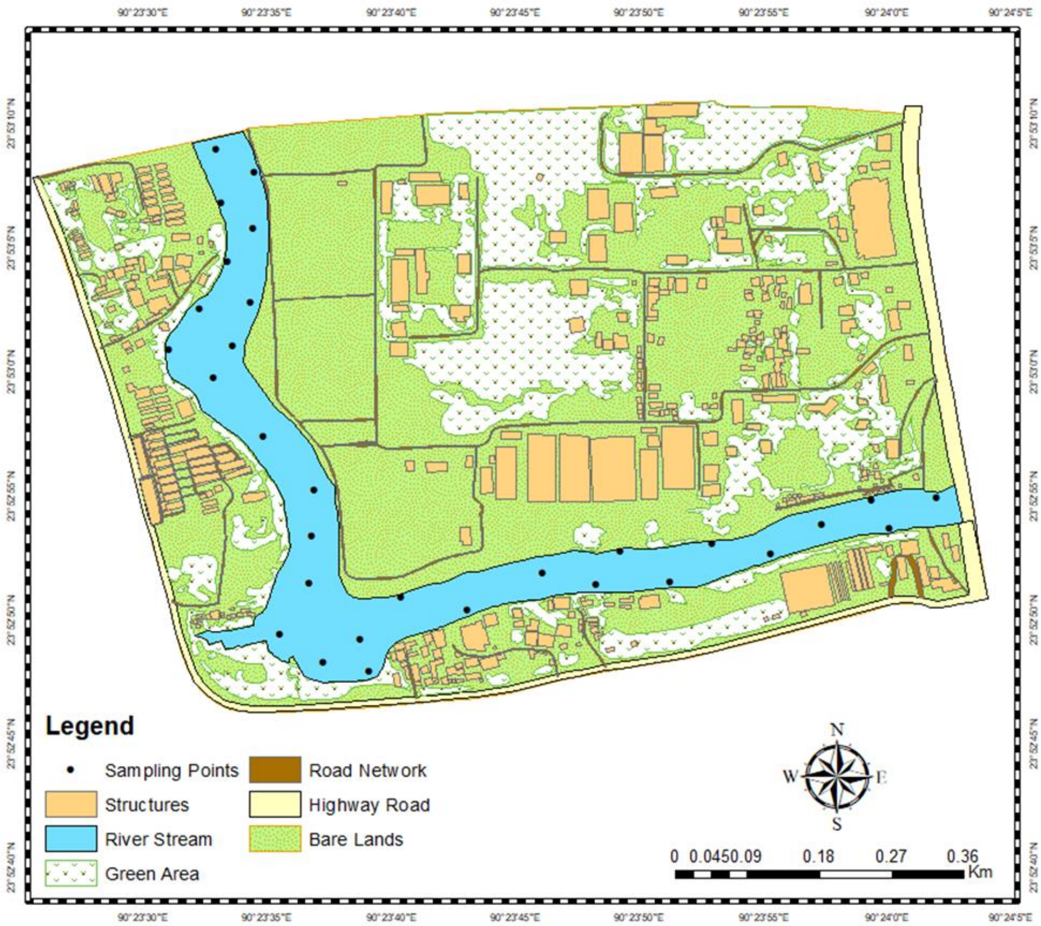


Figure 1: Map of the study area and sampling stations in the Turag River

Table 1: Locations of sampling stations.

Sampling ID	Latitude	Longitude	Sampling ID	Latitude	Longitude	Sampling ID	Latitude	Longitude
S1	23.88192	90.40055	S11	23.88039	90.39318	S21	23.88556	90.3929
S2	23.88157	90.40002	S12	23.88096	90.39352	S22	23.88523	90.39253
S3	23.88162	90.39925	S13	23.882	90.39357	S23	23.88456	90.3926
S4	23.8813	90.39869	S14	23.88261	90.393	S24	23.88362	90.39265
S5	23.88141	90.39804	S15	23.88327	90.39245	S25	23.88358	90.39195
S6	23.88098	90.39755	S16	23.88403	90.39228	S26	23.88131	90.39701
S7	23.88107	90.39613	S17	23.88149	90.39354	S27	23.87998	90.39419
S8	23.88066	90.39528	S18	23.88493	90.39288	S28	23.88081	90.39455
S9	23.88033	90.39409	S19	23.88582	90.39247	S29	23.8819	90.39982
S10	23.88008	90.39367	S20	23.8841	90.39286	S30	23.88095	90.39673

2.2 Water Sampling

As depicted in Figure 1, random river water samples were obtained from 30 different locations along the Turag River in June 2022. Using one-liter High Density Polyethylene (HDPE) bottles with tamper-evident covers, a total of 90 samples were taken from the middle and subsurface water of the river (three from each sampling point). Prior to sampling, the bottles were autoclaved, rinsed with warm water, thoroughly washed with 10 ml of the inorganic chemical compound NaClO (sodium hypochlorite), 400 ml warm water, and then rinsed with acetone. The bottles were then washed with river water prior to sampling. Each bottle was then branded with a permanent marker and wrapped in parafilm to prevent contact with air. The water samples were transported in a cooler to the laboratory, where they were stored at 4°C until examination. All sample collecting, transportation, and laboratory testing methods were carried out in accordance with The American Public Health Association (Buetler er al,2014) and Computing Centre for Water Research, 2000 guidelines.

2.3. Analytical Methods

Total 16 parameters were estimated in order to determine the experimental outcomes. Initially, pH, TDS, EC, temperature, salinity, and DO values were obtained in the field using an instrumental manual (Multiparameter Meter, Hanna- H19829), and then Na+, K+ Ca2+, Mg2+ Cl-, Cu, Pb, Fe, and Cd concentrations were determined in the laboratory using an AAS (Atomic absorption spectrometer, Shimadzu –AA 6200) according to the standard procedure (American Public Health Association et al., 1998). The accompanying Table 2, provides all pertinent information regarding the parameters and instruments employed. After conducting statistical data analysis to determine the numerical or quantitative status of water quality, ArcGIS version 10.8 was utilized to conduct spatial analysis and map the WQS of the Turag river basin (TRB).

Table 2: Methods/Instruments of laboratory analysis of physicochemical parameters of water samples.

Physicochemical Parameters	Units	Abbreviation	Methods/Instruments
pH	pH unit	pH	Multimeter (Hanna, H19829)
Electrical Conductivity	$\mu S\ cm^{-1}$	EC	Multimeter (Hanna, H19829)
Dissolved Oxygen	$mg\ L^{-1}$	DO	Multimeter (Hanna, H19829)
Turbidity	NTU		Multimeter (Hanna, H19829)
Salinity	PSU		Multimeter (Hanna, H19829)
Total Dissolved Solids	$mg\ L^{-1}$	TDS	Multimeter (Hanna, H19829)
Temperature	°C	T	Multimeter (Hanna, H19829)
Sodium	$mg\ L^{-1}$	Na^+	Atomic Absorption Spectrometer (Shimadzu -AA 6300)
Potassium	$mg\ L^{-1}$	K^+	Atomic Absorption Spectrometer (Shimadzu -AA 6300)
Calcium	$mg\ L^{-1}$	Ca^{2+}	Atomic Absorption Spectrometer (Shimadzu -AA 6300)

Magnesium	mg L^{-1}	Mg^{2+}	Atomic Absorption Spectrometer (Shimadzu -AA 6300)
Chlorine	mg L^{-1}	Cl^{-}	Trimetric
Lead	mg L^{-1}	Pb	Atomic Absorption Spectrometer (Shimadzu -AA 6300)
Iron	mg L^{-1}	Fe	Atomic Absorption Spectrometer (Shimadzu -AA 6300)
Copper	mg L^{-1}	Cu	Atomic Absorption Spectrometer (Shimadzu -AA 6300)
Cadmium	mg L^{-1}	Cd	Atomic Absorption Spectrometer (Shimadzu -AA 6300)

2.4 Water Pearson's Coefficient of Correlation (r)

Coefficient of correlation is used to illustrate the strength of the correlation between two or more correlated variables. It is the measure of the strength or goodness of fit if linear relationship that exists between the variables. It is denoted by r.

Let x and y be two correlated variables where i=1,2, 3, … …, n (n represents that there are n pair of values). Then the coefficient of correlation can be illustrated as:

$$r = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2 \sum_{i=1}^{n}(y_i-\bar{y})^2}} \quad [1]$$

Here in equation 1, the value of r lies in between -1 and +1. Normally we can get 3 extreme cases from the value of r which are mentioned din the Table 3 below:

Table 3: Three general cases of correlation between variables.

Values of "r"	Relationship between variables
-1	Perfect negative correlation
0	No correlation
+1	Perfect positive correlation

2.5 Coefficient of Determination (R^2)

It is the square of r i.e., coefficient of correlation (r) which is used to test the goodness of fit of a linear relationship. The higher is the value the better is the goodness of fit for the observations. It is denoted by R^2. If R^2=1 then it means that all the observed data points fall perfectly on the regression line.

2.6 Water Quality Index (WQI)

The WQI is an extremely powerful and popular tool that can depict water quality status (WQS) using a single value only. The generated values are easily understandable to the public and thus helps policy makers to take decision smoothly (Nasirjan et al., 2007; Dos et al.,2008) This tool very much efficient and can be used for developing any type of water management related strategies**.** For the calculation of WQI, a set of 16 physicochemical parameters (pH, EC, TDS, Salinity, Turbidity, Temperature, DO, lead, cadmium, iron, copper, sodium, magnesium, chlorine, potassium, calcium) were chosen in this study to represent the water quality status (WQS) of Turag river basin (TRB). In this research study, we have used (WHO, 2014) standard values for water as the permissible limit for WQI and Bangladesh drinking water standard (GoB, 1997) were only used during the cases in which WHO values were not available to us (UNICEF, 2015)To calculate the WQI, the weighted arithmetic index method (Brown et al.,1970)has been used following the equation(Oni and Fasakin, 2016)

$$WQI = \frac{\sum Q_n W_n}{\sum W_n} \quad [2]$$

Where, Q_n = Quality rating for n^{th} water quality parameters and W_n = Unit Weight for the n^{th} parameters.

Then the quality rating or sub-index (Q_n) was calculated using following equation or expression:

$Q_n = \frac{V_n - V_i}{S_n - V_i} * 100$ [3]

Where, V_n= estimated value of the n^{th} parameter at a given sampling station, V_i= ideal value of n^{th} parameter in pure water. (i.e., 0 for all parameters except pH and Dissolved Oxygen which is 7.0 and 14.6 mg/L respectively) S_n = standard permissible value of nth parameter.

Unit Weight (W_n) was calculated using the following equation:

$W_n = \frac{K}{S_n}$ [4]

where, S_n = Standard permissible value of n^{th} parameter and K = Proportionality constant. This proportionality constant can be obtained from the following expression:

$K = \frac{1}{\Sigma(\frac{1}{Sn})}$ [5]

The calculation sample for one sampling station along with classification of water quality using WQI are shown in Table 4 and Table 5 respectively.

Table 4: WQI calculation of collected sample for a single sampling station.

Parameter	**WHO standard (S_n)**	**$1/S_n$**	**$\sum 1/S_n$**	**$K=1/(\sum 1/S_n)$**	**$W_i = K/S_n$**	**Ideal Value (V_o)**	**Mean Value (V_n)**	**Vn/Sn**	**Qn = (Vn/Sn)*100**	**W_iQ_n**
Temp.	30	0.033	124.43	0.00804	0.000268	0	32.41	1.08033	108.033	0.0289
pH	6.5	0.154	124.43	0.00804	0.001236	7	5.64	0.86769	86.769	0.1073
DO	6	0.167	124.43	0.00804	0.001339	0	5.23	0.87167	87.167	0.1168
EC	300	0.003	124.43	0.00804	0.000027	0	2003.62	6.67873	667.873	0.0179
TDS	500	0.002	124.43	0.00804	0.000016	0	3561.76	7.12352	712.352	0.0115
Salinity	250	0.004	124.43	0.00804	0.000032	0	0.16	0.00064	0.064	0.0000
Lead	0.05	20	124.43	0.00804	0.160737	0	0.45	9.00000	900.000	144.6629
Cadmium	0.01	100	124.43	0.00804	0.803683	0	0.03	3.00000	300.000	241.1049
Copper	2	0.500	124.43	0.00804	0.004018	0	1.27	0.63500	63.500	0.2552
Iron	0.3	3.333	124.43	0.00804	0.026789	0	3.7	12.3333	1233.333	33.0403
Turbidity	5	0.200	124.43	0.00804	0.001607	0	20.7	4.14000	414.000	0.6654
Na+	200	0.005	124.43	0.00804	0.000040	0	2.9	0.01450	1.450	0.0001
K+	200	0.005	124.43	0.00804	0.000040	0	1.9	0.00950	0.950	0.0000
Ca2+	100	0.010	124.43	0.00804	0.000080	0	5.7	0.05700	5.700	0.0005
Mg2+	150	0.007	124.43	0.00804	0.000054	0	1.7	0.01133	1.133	0.0001
Cl-	250	0.004	124.43	0.00804	0.000032	0	8.9	0.03560	3.560	0.0001
	$\sum \frac{1}{S_n} =$	124.43		$\sum \frac{K}{S_n} =$	1.000000				$\sum W_iQ_n =$	420.0118

Table 5: The classification of water quality status (WQS) based on water quality index (WQI) value [39, 41]

WQI Level	**Water quality status**
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
>100	Not suitable for drinking or requires proper treatment prior to use

2.7 Spatial analysis of WQS

All the collected water samples after being tested in the laboratory were assigned with WQI values after calculation. After completing statistical analysis, the obtained values were plotted into ArcGIS 10.8 version using the geographical coordinates and then we used kriging method of interpolation under spatial analyst tool from toolbox. In this method weights are assigned to each interpolated point based on the spatial structure of the interpolated location with respect to all sampled points. Weights are calculated from the variogram based on the spatial structure of the data and applied to the sampled points using the following mathematical expression:

$$\hat{z}(x_0) = \sum_{i=1}^{N} \lambda_i z(x_i) \quad [6]$$

Where, n= number of observations, $z(x_1)$, $z(x_2)$, … …, $z(x_n)$ are the values at point of observations (x_1, x_2, x_3 ,… …, x_n) which are distributed engulfing the surrounding of x_0.

In order to minimize the error in variance and to check unbiasedness constraint the following expression is used:

$$\sigma_k^2 = \text{var}\ [\hat{z}(x_0) - z(x_0)] = 0\ \text{(mean error = 0)} \quad [7]$$

The structural functions or variogram must be estimated accurately for interpolation in kriging method which is can be expressed mathematically in the following way:

$$\lambda(h) = \frac{1}{2}\ [z(x) - z(x+h)^2] \quad [8]$$

Where, z(x) and z(x+h) are two known variables with separation distance = h. N(h) represents number of pairs of data set points with separation distance h.

3. Results

3.1 Physicochemical parameters

The Table 6 below shows all the values of 16 parameters which were evaluated for calculating the WQI values of Turag river. It has been observed that the highest temperature in Turag was 33.13 °C which exceeded the WHO standard but unfortunately it has been seen that all the stations depicted temperature values above the WHO standard and top 10% values are above 33°C. In case of pH only one sampling stations mean value of pH exceeded the standard limit but the other stations mean value were within the WHO limit. Unfortunately, in majority of the stations the value of dissolved oxygen exceeded 6 ppm which is also an alarming indicator. It shows that 80% of the data set values are not within the desired standard limit and the highest value was 8.45 ppm. The electrical conductivity values in each of the sampling stations are far above the danger limit. Since all the values that were generated by multimeter were deviating highly from the standard values so the machine was again dipped into the samples later on just to identify if any errors were present in the device or not. But the values were almost close to the main values obtained earlier. Similar upshots were also obtained in case of TDS as well. In both the cases of EC and TDS, 100% data depicted values far beyond standard limits. The salinity of the Turag river is extremely low and is almost near to zero. The top 10% values were in between 0.17-0.18 PSU. Another alarming situation raised in case of lead concentration as well. After the laboratory analysis of the samples, it was found that the concentration of lead present in the river basin was very much alarming and exceeded the standard permissible limit in all the sampling stations. In case of all the heavy metals lead, cadmium and iron it was very much evident that all are above the permissible standard limit by WHO but an exception was seen in case of copper the top 10% values were < 2 mg/l, actually all the stations contained permissible amount of Cu. The turbidity of TRB is extremely high and all the stations depicted turbidity above 20 NTU which is also alarming for researchers and practitioners. In case of cations Na^+, K^+, Mg^{2+}, Ca^{2+} and Cl^- all the sampling station values were within the standard limits as per WHO standard**.**

Table 6: Physicochemical parameters of water samples collected after COVID-19 impact from different locations of Turag river basin (TRB)

Parameters	WHO standard	1	2	3	4	5	6	7	8	9	10
Temp.(°C)	25-30	32.41	30.46	32.71	33.03	30.42	30.41	32.12	31.12	31.15	32.92
pH	6.5-8.5	5.64	5.32	4.98	5.78	6	6.2	5.4	5.89	4.85	4.93
DO (ppm)	4.0-6.0	5.23	5.2	5.34	5.55	4.98	5.1	6.3	6.6	6.1	7.54
EC (µs/cm)	300	2003.62	2630.57	2031.26	2903.36	2675.8	2817.32	2269.64	2412.24	2830.7	2115.85
TDS (ppm)	500	3561.76	3471.7	3474.96	3415.2	3500.68	3350.79	3458.25	3538.74	3593.83	3404.53
Salinity (PSU)	250	0.16	0.14	0.13	0.13	0.17	0.16	0.15	0.15	0.17	0.14
Lead (mg/l)	0.05	0.45	0.42	0.33	0.39	0.41	0.49	0.48	0.56	0.56	0.59
Cadmium(mg/l)	0.01	0.03	0.03	0.03	0.03	0.03	0.03	0.01	0.02	0.02	0.02
Copper(mg/l)	2	1.27	1.22	1.2	1.11	1.56	0.89	0.88	1.12	1.62	1.23
Iron (mg/l)	0.3	3.7	3.5	2.9	2.5	2.9	2.9	2.8	3.1	2.9	3.2
Turbidity (NTU)	5	20.7	21.8	20.9	21.6	20.9	21.6	22.3	21.6	22.1	21.4
Na+ (mg/l)	200	2.9	2.7	2.4	1.9	3.8	3.7	3.8	3.9	2.6	2.5
K+(mg/l)	200	1.9	1.9	1.7	1.7	1.8	1.9	1.8	1.9	1.7	1.8
Ca2+(mg/l)	100	5.7	6.1	6.5	7.8	7.7	6.9	6.9	6.8	8.5	8.6
Mg2+(mg/l)	150	1.7	1.6	1.7	2.1	2.2	2.7	2.6	2.7	1.9	1.6
Cl-(mg/l)	250	8.9	9.1	9.4	9.5	8.8	8.6	8.8	8.8	8.8	8.8
Parameters	**WHO standard**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Temp.(°C)	25-30	31.54	32.39	30.35	31.74	32.86	33.04	31.77	32.71	32.39	32.55
pH	6.5-8.5	4.84	5.1	5.32	5.22	4.98	5.48	6.3	6.54	7.23	7.16
DO (ppm)	4.0-6.0	7.33	7.68	7.82	8.23	8.17	8.2	7.42	8.36	8.45	8.18
EC (µs/cm)	300	2760.76	2066.02	2602.66	2348.32	2160.73	2467.43	2044.99	2593.89	2057.56	2580.95
TDS (ppm)	500	3510.39	3342.57	3441.66	3456.84	3411.16	3584.1	3404.16	3446.37	3448.64	3497.87
Salinity (PSU)	250	0.16	0.18	0.16	0.16	0.14	0.15	0.14	0.16	0.13	0.14
Lead (mg/l)	0.05	0.42	0.45	0.44	0.45	0.56	0.59	0.62	0.49	0.38	0.39
Cadmium(mg/l)	0.01	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03	0.03
Copper(mg/l)	2	1.28	1.27	1.33	1.56	0.98	0.99	1.12	1.13	1.11	1.12
Iron (mg/l)	0.3	3.1	2.8	2.9	2.7	2.9	3.1	3.2	3.1	3.6	3.6
Turbidity (NTU)	5	20.9	21.6	22.5	22.7	21.7	22.1	20.6	21.9	22.9	22.5
Na+(mg/l)	200	2.8	2.9	2.9	2.8	3.5	3.7	3.7	3.2	3.4	2.7
K+(mg/l)	200	1.9	1.8	2.1	1.9	1.8	2.1	2.2	2.1	2.1	1.8
Ca2+(mg/l)	100	8.5	6.1	5.9	5.9	5.8	6.1	7.5	7.8	7.9	8.2
Mg2+(mg/l)	150	1.7	1.8	2.1	2.1	2.2	2.1	1.9	1.6	1.5	1.9
Cl-(mg/l)	250	8.9	9.2	10.6	10.5	9.8	9.9	9.9	10.1	10.5	10.4
Parameters	**WHO standard**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Temp.(°C)	25-30	30.19	31.06	33.13	33.01	30.64	32.77	30.52	31.2	31.54	33.04
pH	6.5-8.5	6.9	8.54	8.34	7.2	6.1	5.9	5.32	5.34	6.21	6.11
DO (ppm)	4.0-6.0	7.99	8.1	7.92	7.35	7.41	7.81	7.22	7.1	8.22	8.19
EC (µs/cm)	300	2782.06	2673.38	2414.89	2490.71	2594.53	2796.38	2689.38	2634.43	2323.94	2279.93
TDS (ppm)	500	3443.1	3421.02	3563.19	3459.7	3581.15	3393.89	3451.77	3469.24	3479.08	3459.28
Salinity (PSU)	250	0.15	0.15	0.16	0.17	0.15	0.18	0.14	0.16	0.16	0.13
Lead (mg/l)	0.05	0.26	0.28	0.29	0.68	0.69	0.68	0.61	0.58	0.55	0.58
Cadmium(mg/l)	0.01	0.02	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.03
Copper(mg/l)	2	1.39	1.44	1.47	0.95	0.98	1.38	1.42	1.45	1.62	1.61
Iron (mg/l)	0.3	3.5	2.9	3.4	3.2	3.4	3.6	3.7	3.6	2.9	2.8
Turbidity (NTU)	5	22.8	22.4	22.1	21.9	21.7	22.3	22.6	22.7	22.7	22.6
Na+(mg/l)	200	2.5	2.8	2.9	3.1	3.1	3.5	3.7	3.7	3.9	3.9
K+(mg/l)	200	1.9	1.6	1.6	1.8	1.7	2.1	2.1	1.9	1.8	1.8
Ca2+(mg/l)	100	8.1	7.9	7.8	8.1	6.7	6.9	6.8	6.9	7.1	7.1
Mg2+(mg/l)	150	1.9	2.2	2.1	1.6	1.5	1.6	1.7	1.8	1.6	1.6
Cl-(mg/l)	250	9.5	9.6	8.9	8.8	8.9	9.1	8.9	9.1	9.1	9.1

(a) (b)

Figure 2: Water pollution scenario of Turag river after COVID-19

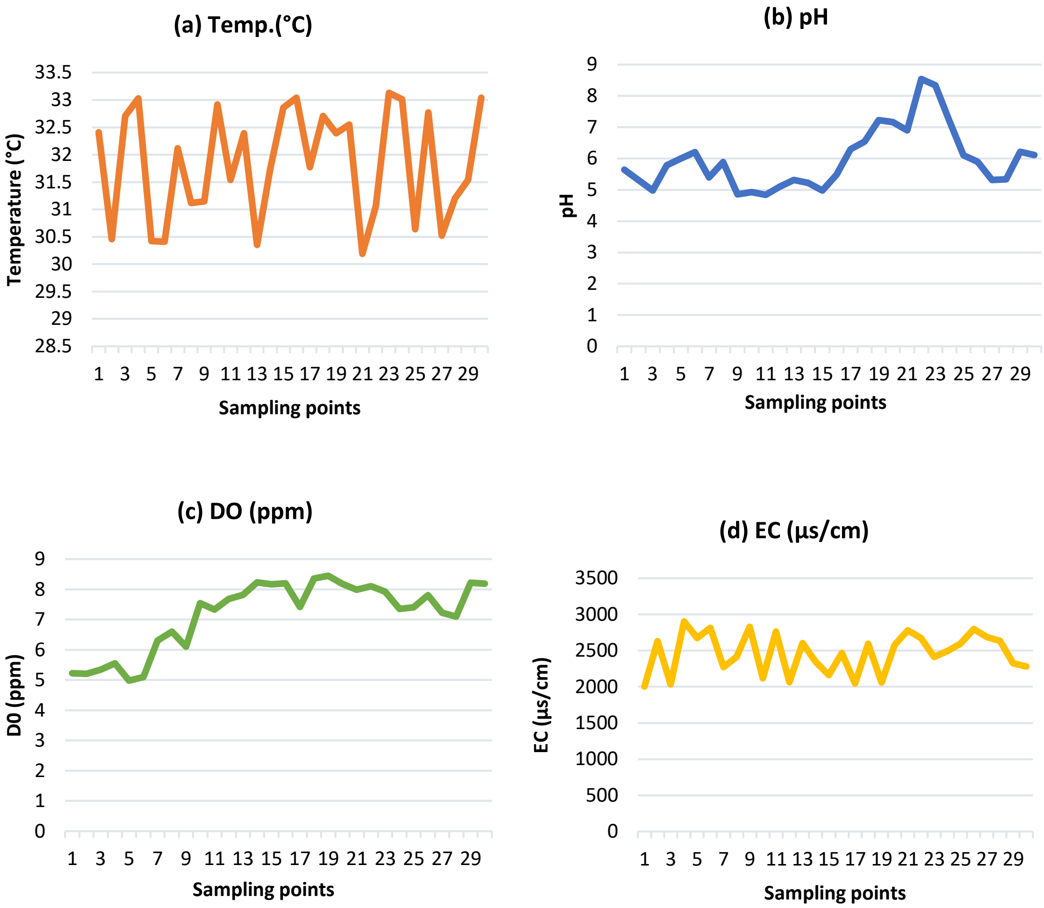


Figure 3: Station wise variation of physicochemical parameters of water

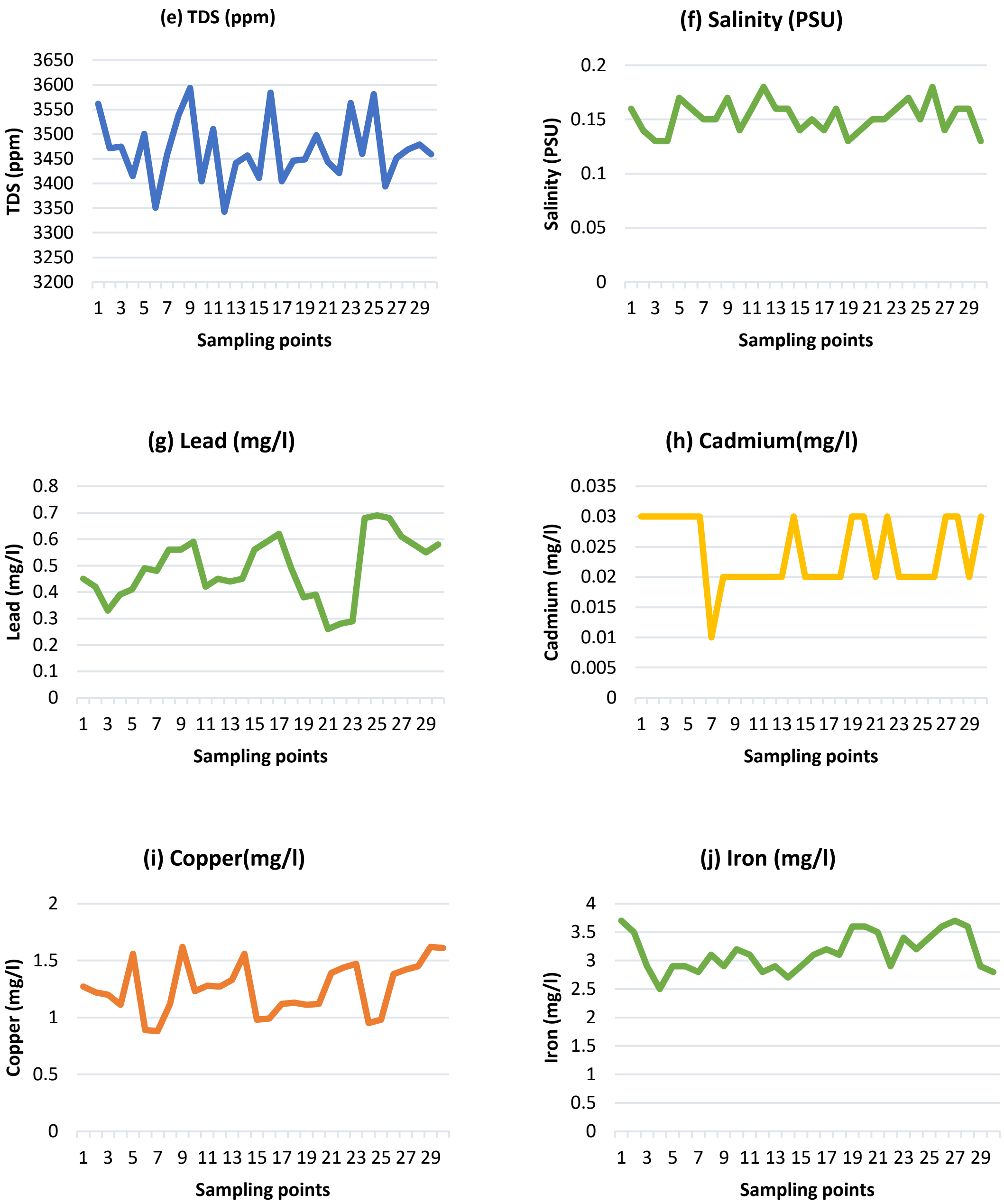


Figure 3: Station wise variation of physicochemical parameters of water (continued)

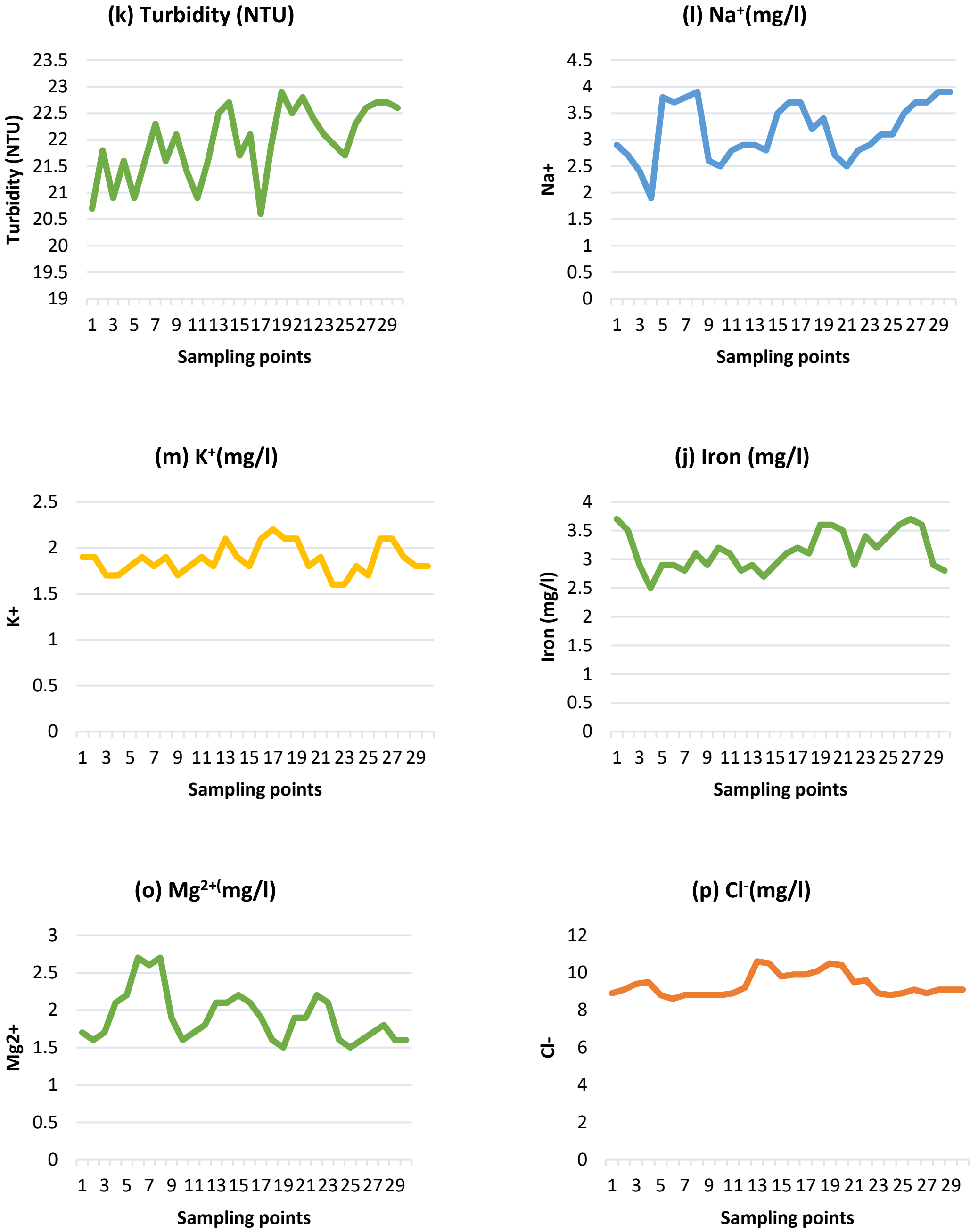


Figure 3: Station wise variation of physicochemical parameters of water (continued)

3.2 Correlation Matrix

The common method for figuring out and quantifying the relationship between two variables is the correlation coefficient. It is a basic statistical method for illustrating how reliant one variable is on another. The most likely common sources were identified using Pearson correlation to determine the variables that influence the link between the influencing water quality indicators and the components that contribute to the dispersion and transportation of contaminants in water bodies. - Strong connections are denoted by values of 1 and +1, respectively. There is no linear relationship between the variables, as shown by a value of 0. Similar behavior, interdependence, or a shared source are all suggested by a substantial positive correlation between metrics. The obtained correlation between various variables is mentioned below in the following table

Table 7: Correlation Matrix

	Temp.(°C)	pH	DO (ppm)	EC (µs/cm)	TDS (ppm)	Salinity (PSU)	Lead (mg/l)	Cadmium (mg/l)	Copper (mg/l)	Iron (mg/l)	Turbidity (NTU)	Na^{+}	K+	Ca2+	Mg2+	Cl-
Temp.(°C)	1.00															
pH	0.08	1.00														
DO (ppm)	0.29	0.33	1.00													
EC (µs/cm)	-0.46	0.11	-0.15	1.00												
TDS (ppm)	-0.04	0.02	-0.10	0.08	1.00											
Salinity (PSU)	-0.16	-0.03	-0.01	0.26	0.03	1.00										
Lead (mg/l)	0.11	-0.35	0.12	-0.04	0.04	0.18	1.00									
Cadmium(mg/l)	-0.14	0.11	-0.29	0.10	-0.09	-0.33	-0.30	1.00								
Copper(mg/l)	-0.21	0.01	0.13	0.15	0.14	0.24	-0.19	0.27	1.00							
Iron (mg/l)	-0.11	0.22	0.11	0.01	0.23	-0.02	0.11	0.13	-0.02	1.00						
Turbidity (NTU)	-0.09	0.29	0.57	0.25	-0.06	-0.03	-0.04	0.03	0.29	0.14	1.00					
Na+	-0.12	0.01	0.14	-0.15	0.00	0.13	0.50	-0.15	-0.04	0.08	0.14	1				
K+	-0.10	-0.20	0.22	-0.05	-0.20	0.01	0.33	-0.07	-0.16	0.34	0.07	0.40	1.00			
Ca2+	0.08	0.41	0.12	0.32	0.04	-0.04	-0.15	-0.09	0.12	0.06	0.02	-0.25	-0.22	1.00		
Mg2+	-0.22	0.04	-0.28	0.16	-0.07	0.07	-0.21	-0.13	-0.25	-0.44	-0.06	0.22	-0.14	-0.16	1.00	
Cl-	0.14	0.15	0.53	-0.16	-0.16	-0.28	-0.27	0.15	-0.05	-0.05	0.33	-0.17	0.40	-0.15	-0.07	1

3.3 Spatial variation of overall Water Quality Index (WQI)

Determination of WQI can help researchers and professional pretensioners to estimate the impact of numerous anthropogenic activities on surface water quality status (WQS). As multitude of surface water quality parameters can be represented using a single value thus its role in water quality management is very crucial. If WQI value is less than 50 (WQI<50) then water quality is considered to be excellent and if it exceeds 300, then the water is not suitable for drinking and requires proper treatment prior to using. In this study the WQI value was determined by integrating laboratory results obtained from total 30 sampling stations. At first the spatial variation of total 16 individual water quality parameters were mapped using ArcGIS 10.8 by kriging method. The generated maps help to identify the variation of each parameter at 30 different locations of TRB. It becomes quite easier for individuals to understand the variation of WQS at different locations through visualizations. Figure 3 below shows the spatial variation of 16 physicochemical parameters of water quality.

WQI map was generated after calculating WQI for each of the 30 sampling stations. It was very much alarming that all the stations depicted that WQS is not suitable for drinking which means these will require further treatment before using. Table 8 shows the unique values of WQI obtained from the sampling points. Only 10% of the stations show WQI value less than 300, 50% of the sample shows WQI value in between 300 and 400 and the remaining 40% values are above 400. Hence it is evident that each of the sampling stations depicted same pattern of failure to meet the standard requirements of water quality provided by WHO. The variety of pollutants and their consistent deviations from the guideline values indicate that the principal anthropogenic source of pollutants in the region is the main reason of degradation of water quality.

Table 8: Overall Water Quality Index of Turag River Basin

Name	WQI Level	WQS	Name	WQI Level	WQS	Name	WQI Level	WQS
S1	420.0118	NSD	S11	324.6876	NSD	S22	276.9596	NSD
S2	408.6038	NSD	S12	331.6799	NSD	S23	358.4301	NSD
S3	374.2737	NSD	S13	329.4097	NSD	S24	285.7299	NSD
S4	390.0225	NSD	S14	411.2657	NSD	S25	326.6988	NSD
S5	400.0792	NSD	S15	367.89	NSD	S26	414.1532	NSD
S6	425.6921	NSD	S16	379.3487	NSD	S28	412.8324	NSD
S7	260.8769	NSD	S18	389.8566	NSD	S29	471.5812	NSD
S8	369.6843	NSD	S19	347.2473	NSD	S30	461.0512	NSD
S9	367.988	NSD	S20	396.7567	NSD	S27	364.8611	NSD
S10	380.2385	NSD	S21	399.9582	NSD	S17	453.9737	NSD

*WQS = water quality status, * NSD = Not suitable for drinking

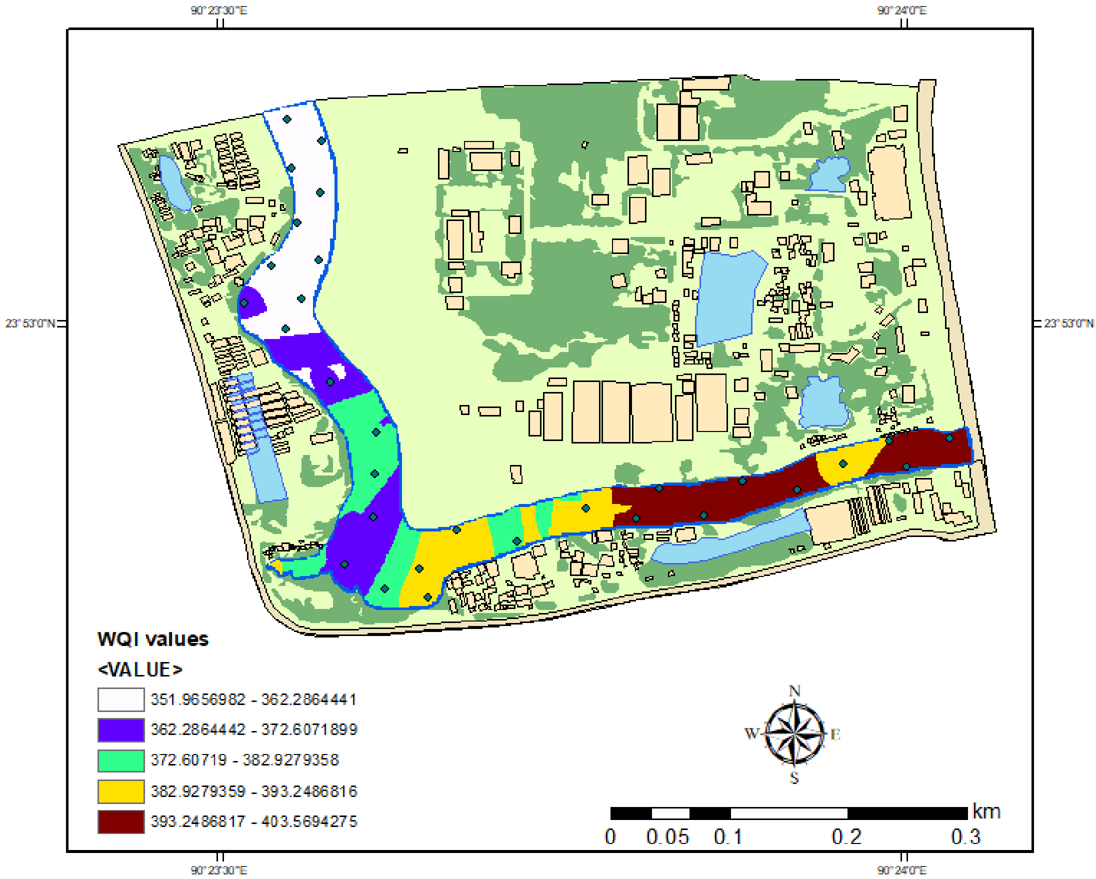
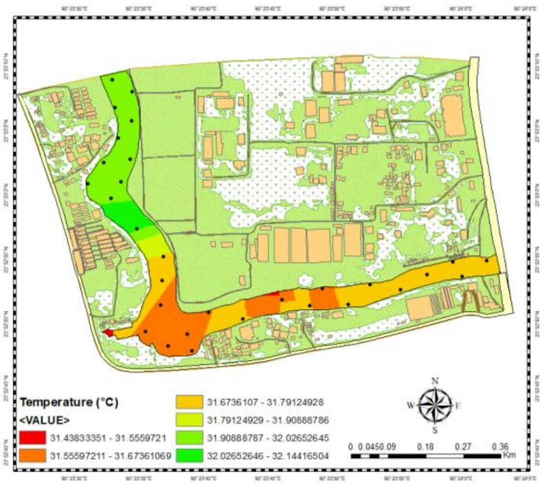


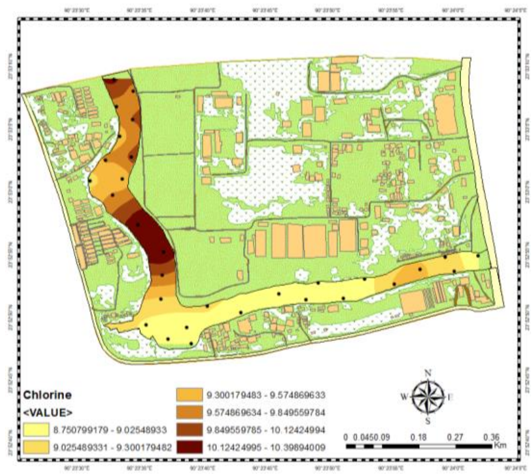
Figure 4: Overall Spatial variation of WQI throughout the thirty sampling stations in the Turag river basin (TRB)

(a)

(b)

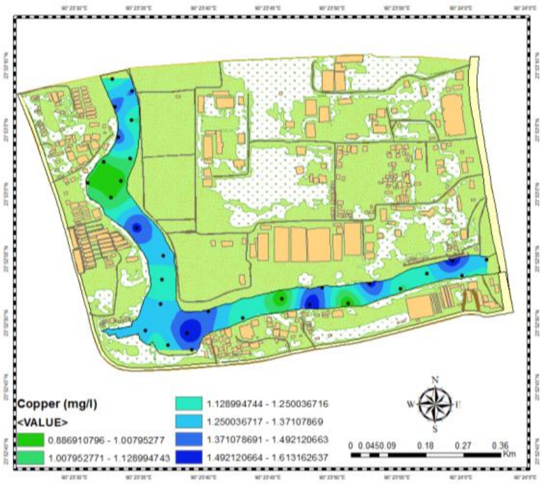


(c)

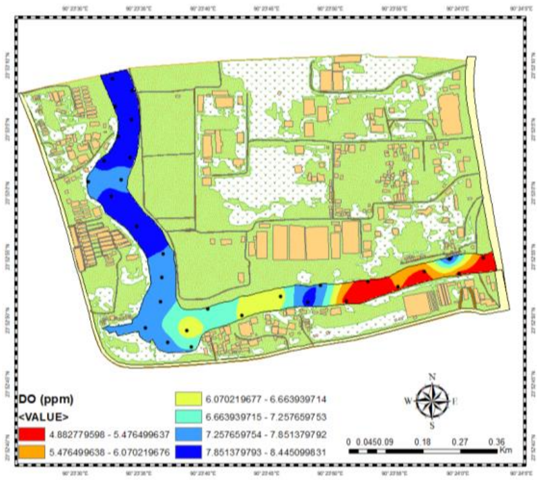


(d)

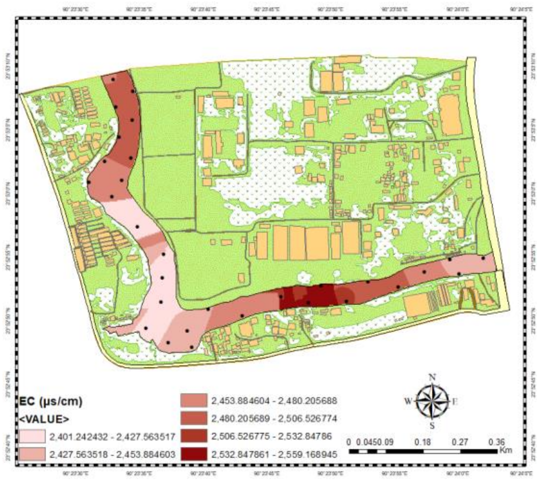
Figure 5: Spatial Variation of 16 water quality parameters



(e)



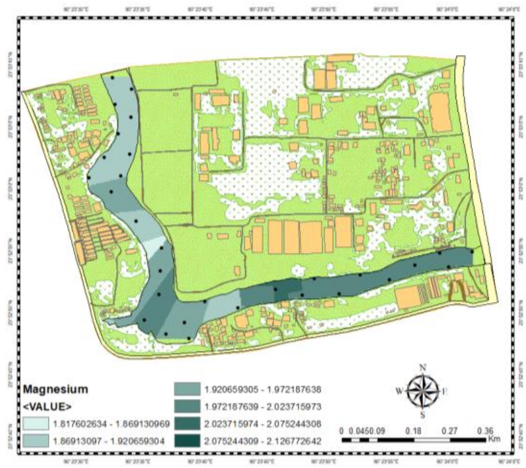
(f)



(g)

(h)

(i)

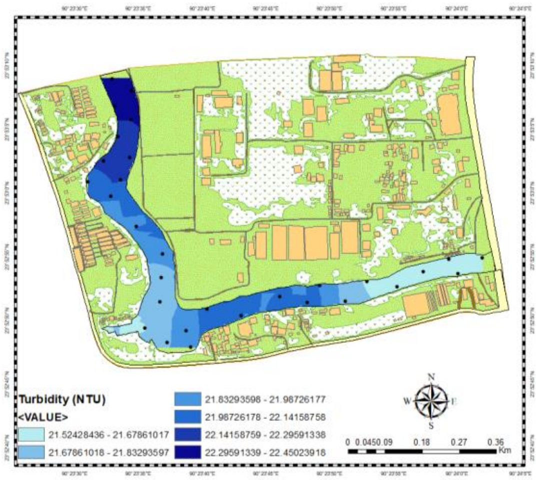


(j)

Figure 5: Spatial Variation of 16 water quality parameters (continued)

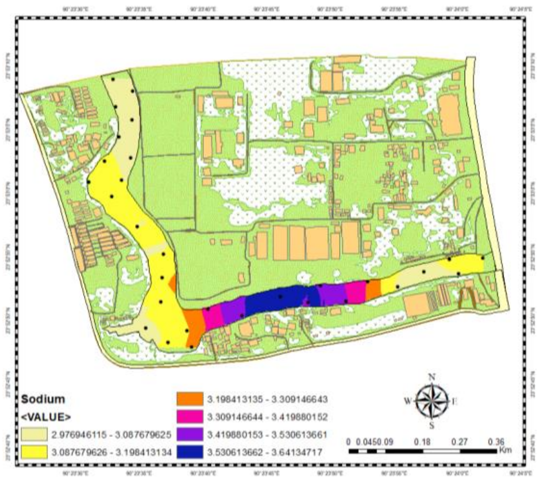
(k)

(l)

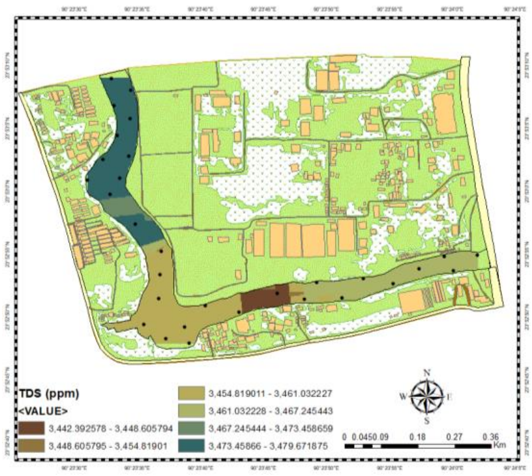


(m)

(n)



(o)



(p)

Figure 5: Spatial Variation of 16 water quality parameters (continued)

4. Discussion

A comprehensive understanding of the anthropogenic influences on the surface water catchment of the surrounding area can be gained by careful examination of the physical and chemical characteristics. Overall, the existing condition of the Turag was deemed unsatisfactory due to the presence of a large quantity of trash/litter, the direct discharge of municipal sewage, the presence of industrial discharge points, the absence of visible flow, the high rate of river encroachment, the high pollution load, and the absence of a river management system. Consequently, the restoration of the Turag River is crucial for ensuring that Dhaka has access to potable water. To restore water quality, the decrease of pollutant load through the establishment of efficient effluent and sewage treatment plants and continuous monitoring should be the top priority in conjunction with the installation of enhanced effluent treatment in industry, the natural flow of the Turag is essential for recovering water quality during the dry season (Whitehead et al., 2018). Barriers to ETP installation, such as the availability of ETP equipment on the local market and pro2cedural hurdles, should be reduced to encourage enterprises to fulfill environmental compliance. In addition, insufficient monitoring and law enforcement by government officials were recorded in textile companies. Prioritize the execution of the existing laws and effective governance including all stakeholders in order to ensure improved water sources for all (Tania et al., 2021; Uddin and jeong, 2021). It is necessary to ensure the prevention of illegal encroachment, the marking of river channel borders, and the dredging of severely narrow and shallow riverbeds. In addition to these recommendations, a frequent assessment of river quality and habitat survey is necessary to monitor river health with the goal of achieving SDG 6 by reducing pollution in the city of Dhaka**.**

5. Conclusion

The physicochemical study reveals that the majority of the water samples had concentrations that were higher than the permissible level. In this study effort, the WQI method and GIS-based spatial analysis were employed for the very first time to evaluate the water quality of the river Turag. This was the very first time either method had been applied. After computing 30 water quality indicators based on the samples obtained from the various stations, the water was given ratings ranging from "Good" to "Very Poor," with "Good" being the highest and "Very Poor" being the lowest. These ratings were based on the overall quality of the water. The WQI test determined that the quality of the water in the river is "Very bad," which is the lowest rating possible. The results of this research could serve as a basis for policymakers to build a plan for making more effective use of available water resources if they are taken into consideration.

6. Recommendations

Future research could investigate the following areas: (1) rationally and efficiently optimizing the existing water quality monitoring network through the spatial distribution of sample entropy and water quality risk to improve our understanding of the water quality risk and pollution in a basin; (2) developing more detailed indicators to more precisely identify specific driving factors; and (3) organically combining water quality automatic monitoring data with ozone monitoring data. It is general knowledge that water contamination cannot be completely halted, however it can be prevented by taking the following steps:

1.	Industrial polluters must be required by law to compensate for the higher expense of treating a body of water that they have contaminated.	6.	Industries should establish water treatment facilities to remove toxins from their effluents and wastewater before discharging them into streams.
2.	The disposal of municipal solid waste into the sewage system should be rigorously regulated, as should those who engage in such imprudent and careless behavior.	7.	Hospital wastes containing potentially hazardous substances should not be disposed of haphazardly or using municipal solid waste disposal methods.
3.	Illegal structures and their placement along the river must be demolished, and the free flow of river water must be guaranteed.	8.	Identify the polluter by involving a monitoring committee, then penalize him or her with a hefty fine or other appropriate sanction.
4.	For future management of the Turag river's aquatic environment, the government or municipal corporation should appoint a strong authority to monitor the river's water quality and take the required legal steps against the indiscriminate discharge of waste sewage and effluents.	9.	Bringing attention to the issue of water contamination through electronic media such as radio, television, and social media such as Facebook, Twitter, etc.
5.	The city corporation area is required to establish Sewage Treatment Plants for sewage purification prior to discharge.	10.	Application of property rights can help to ameliorate the WQS

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