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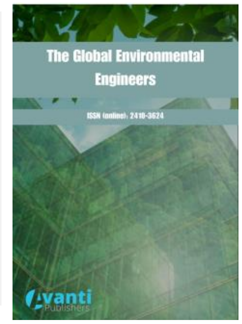

GIS-Based Evaluation of Pollution Sources and Water Quality Status in the Turag River, Bangladesh

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ABSTRACT

This study evaluates pollution sources and water quality status in the Turag River, Bangladesh, using Geographic Information System (GIS) techniques and Water Quality Index (WQI) assessment. The Turag River, classified as environmentally critical since 2009, faces severe degradation due to untreated industrial effluents from pharmaceutical facilities, textile mills, and manufacturing units located along its banks. Water samples were collected from nine strategic locations and analyzed for eight physicochemical parameters (pH, dissolved oxygen, biochemical oxygen demand, total suspended solids, turbidity, phosphate, nitrate, and temperature) using standard protocols. GIS-based spatial mapping revealed significant spatial heterogeneity in pollution levels, with BOD values (53-90 ppm, mean 73 ppm) and turbidity levels (40-80 NTU, mean 58.77 NTU) exceeding Department of Environment standards at all sampling sites. The calculated WQI values ranged from 35.14 to 38.83 (average 36.68), placing the river water quality consistently in the "Bad" category across all sampling locations. The northern section exhibited critical conditions for dissolved oxygen (3.4-3.5 ppm) and turbidity (75-80 NTU), while the southern segment showed elevated levels of BOD, phosphate, and nitrate. The consistently poor water quality classification indicates severe degradation, limiting usability to agricultural irrigation purposes only. These findings provide a foundation for developing targeted pollution control strategies and highlight the urgent need for comprehensive watershed management to restore this vital water resource.

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1. Introduction

Water is an indispensable natural resource with profound social and economic significance for human existence [1]. The sustainability of human life is fundamentally dependent on the availability of clean water resources [2]. Surface water and groundwater constitute the two primary sources of drinking water globally [3]. However, the accelerating deterioration of water quality in rivers, lakes, and other water bodies due to anthropogenic activities and natural processes poses a significant threat to both human wellbeing and ecosystem health [4, 5]. Most water sources in their natural state have become unsuitable for human consumption or other beneficial uses without appropriate treatment interventions [6-9]. This quality degradation stems from multiple factors, including rapid population growth, intensified urbanization, industrial expansion, and agricultural intensification, all of which have contributed to the diminishing availability of freshwater resources [10]. Although industrial water consumption is comparatively lower in volume, industrial effluents exert disproportionately adverse impacts on receiving water bodies. Additionally, more than three-quarters of water used for residential and commercial purposes returns as sewage, ultimately contaminating surface and groundwater resources [11]. In Bangladesh, approximately 15,000 m^3 of untreated chemical wastes are discharged daily into low-lying areas, natural canals, and major rivers, which serve as vital water sources for agriculture, aquaculture, and domestic use. The Turag River represents a critical water resource in this context. Originating from the Bangshi River in Gazipur and flowing through densely populated areas before merging with the Buriganga River near Mirpur in Dhaka, the Turag River has a catchment area of 999.74 km^2 located in the southern part of Modhupur [12]. Due to severe industrial pollution, the Department of Environment (DoE) classified the Turag River as environmentally critical in September 2009, highlighting the urgent need for intervention and management.

The rapid pace of urbanization and industrial development in Bangladesh over the past decade has generated serious environmental concerns. Water contamination by organic and inorganic pollutants has become particularly problematic as the development of sanitation infrastructure has not kept pace with urbanization, especially in developing countries like Bangladesh [13-15]. Consequently, point and non-point pollution sources have proliferated with the growth of industrial centers, resulting in the discharge of substantial volumes of untreated effluents into water bodies [16, 17]. Dhaka city is encircled by several rivers and canals, with the Turag, Buriganga, Dhaleshwari, Balu, and Shitalakhya being the most significant. Tongi, one of Dhaka's largest industrial zones, is situated along the banks of the Turag River. Beyond authorized industrial establishments, the riverbanks are lined with numerous unplanned, illegal, and semi-illegal structures, including residential buildings, commercial enterprises, and industries of various scales [18, 19]. Industrial land use predominates in the Tongi area, encompassing metal processing, clothing manufacture, jute processing, textile production, spinning, pharmaceutical manufacturing, and food production. Most industries in this region discharge effluents directly or indirectly into the Turag River without adequate treatment, causing significant deterioration of surface water quality. Furthermore, sewerage systems and municipal drainage channels have become repositories for solid, liquid, and chemical wastes, further polluting the riverbanks [20] Although the DoE has declared the Turag River an Ecologically Critical Area (ECA) and has conducted multiple water quality assessments [21], industrial facilities continue to discharge effluents and wastewater into the river, causing serious pollution [22].

While effluent treatment plants are mandated for industries generating hazardous waste, most industries in Tongi lack proper waste management facilities. These establishments dispose of untreated or partially treated effluents, posing substantial risks to public health and environmental integrity. The ecological balance of the river is shifting due to pollution, impacting fish populations and aquatic biodiversity. Communities residing near contaminated water bodies experience various health problems, including chronic illnesses, skin conditions, diarrhea, and respiratory issues. Rigorous monitoring of the Turag River's water quality is essential to prevent its further deterioration to the environmentally distressed state of the Buriganga River. Major pollution sources include consumer goods industries (soap and detergent manufacturers), garment factories, pharmaceutical companies, dyeing operations, textile mills, paint manufacturers, chemical factories, and steel workshops [20]. Previous water quality monitoring efforts have been inconsistent in parameter selection, making comparative analysis challenging [20, 22, 54]. Moreover, the Water Quality Index (WQI) represents a valuable and unique rating tool for assessing the overall health of water bodies and informing appropriate water treatment and management strategies. The WQI synthesizes the collective influence of various water quality parameters and effectively communicates water quality information to the public and policymakers [23-25]. As one of the most effective methods for describing water quality, the WQI can simplify complex datasets into comprehensible information, facilitating better understanding and decision-making.

This study aims to evaluate the pollution sources and water quality status of the Turag River using Geographic Information System (GIS) techniques and WQI assessment. The specific objectives include: (1) characterizing the physicochemical properties of the Turag River water at multiple sampling points; (2) identifying major pollution sources and their impacts on water quality; (3) calculating and spatially mapping the WQI to assess the overall health of the river; and (4) providing recommendations for pollution control and water quality improvement. The significance of this research lies in its comprehensive approach to water quality assessment, combining traditional water quality parameters with spatial analysis to provide a nuanced understanding of pollution dynamics in the Turag River. GIS-based methods offer superior visualization and spatial analytics capabilities that help in identifying pollutant hotspots and tracing contaminant pathways with high precision [26, 27] Likewise, the WQI framework simplifies complex datasets into actionable indices, enabling rapid, comparative evaluations of water quality across space and time [28, 29]. The findings will contribute to evidence-based policy formulation and intervention strategies aimed at restoring and protecting this vital water resource. By integrating GIS with WQI and statistical techniques, this research ensures a scientifically robust and practically implementable methodology for urban river pollution management—an approach validated in similar regional and international studies [30]. Additionally, the methodological framework developed in this study can be applied to other urban rivers facing similar pollution challenges, thereby enhancing water resource management practices in Bangladesh and similar developing countries.

2. Materials and Methods

2.1. Study Area

The Turag River functions as the principal upstream tributary of the Buriganga River in Bangladesh's fluvial network. Originating from the Bangshi River (a significant tributary of the Dhaleshwari River), the Turag flows through Gazipur before merging with the Buriganga River at Mirpur, Dhaka, with Tongi Khal establishing a hydraulic connection to the Balu River [31]. Geomorphologically, the Turag basin presents a distinctive semi-funnel configuration with a catchment situated in the central and southern portions of the Madhupur tract. The river flows north-to-south, extending approximately 40 miles in length with a maximum width of 15 miles, encompassing a total area of 999.735 km^2 [12]. This investigation was conducted in Tongi thana of Gazipur district, located 14 km north of Dhaka and 13 km south of Gazipur city center. The area represents an industrial corridor characterized by diverse manufacturing facilities—textile mills, dyeing operations, leather processing, pharmaceutical industries, and garment factories—all contributing to the complex pollution profile of the river. The Turag directly receives industrial effluents through multiple drainage channels that typically converge with the river 3-4 km downstream from discharge points [20].

Fig. (**1**) presents a comprehensive spatial visualization of the study area through four integrated components: (a) nine strategically placed sampling points that capture water quality variations along the river, (b) field-collected water samples for laboratory analysis, (c) an elevation profile highlighting topographic influences on hydrology and pollutant movement, and (d) a land use/land cover map showing industrial zones, urban areas, and other critical land categories near the river. Together, these elements offer a comprehensive understanding of the study area's environmental and anthropogenic characteristics. This spatial configuration underscores the Turag's vulnerability to anthropogenic contamination [19]. In addition, the DoE's designation of the Turag as an ECA emphasizes its environmental significance and the urgent necessity for evidence-based conservation strategies [21, 22].

2.2. Sample Collection

Water samples were collected from nine strategic locations along the Turag River where industrial effluents discharge into the waterway (Table **1**) on May 22, 2024. The sampling sites included: S1 (Beximco Pharma), S2 (SK+F), S3 (National Polymer Industries PLC), S4 (NOVARTIS), S5 (Ultra Washing and Dyeing Ltd), S6 (Drug

International Ltd), S7 (Meghna Group of Industries), S8 (KBPL Dyeing and Finishing Unit), and S9 (Creative Wash Limited). To ensure representative sampling and minimize bias, collection was conducted from the mid-stream at 8-10 inches depth, rather than from outlets or riverbanks. Samples were obtained in pre-labeled 250 ml and 500 ml plastic bottles for physicochemical analysis, with separate BOD bottles specifically designated for biochemical oxygen demand (BOD) testing. Bottles were immediately sealed to prevent atmospheric contamination and shielded with black polythene to protect against photochemical alterations. Each sample container was marked with a unique identification code indicating collection date, location coordinates, and sample number. The collected samples were transported to the laboratory with appropriate preservation protocols to maintain sample integrity for subsequent analytical procedures. Table **1** presents the industrial sources adjacent to each sampling

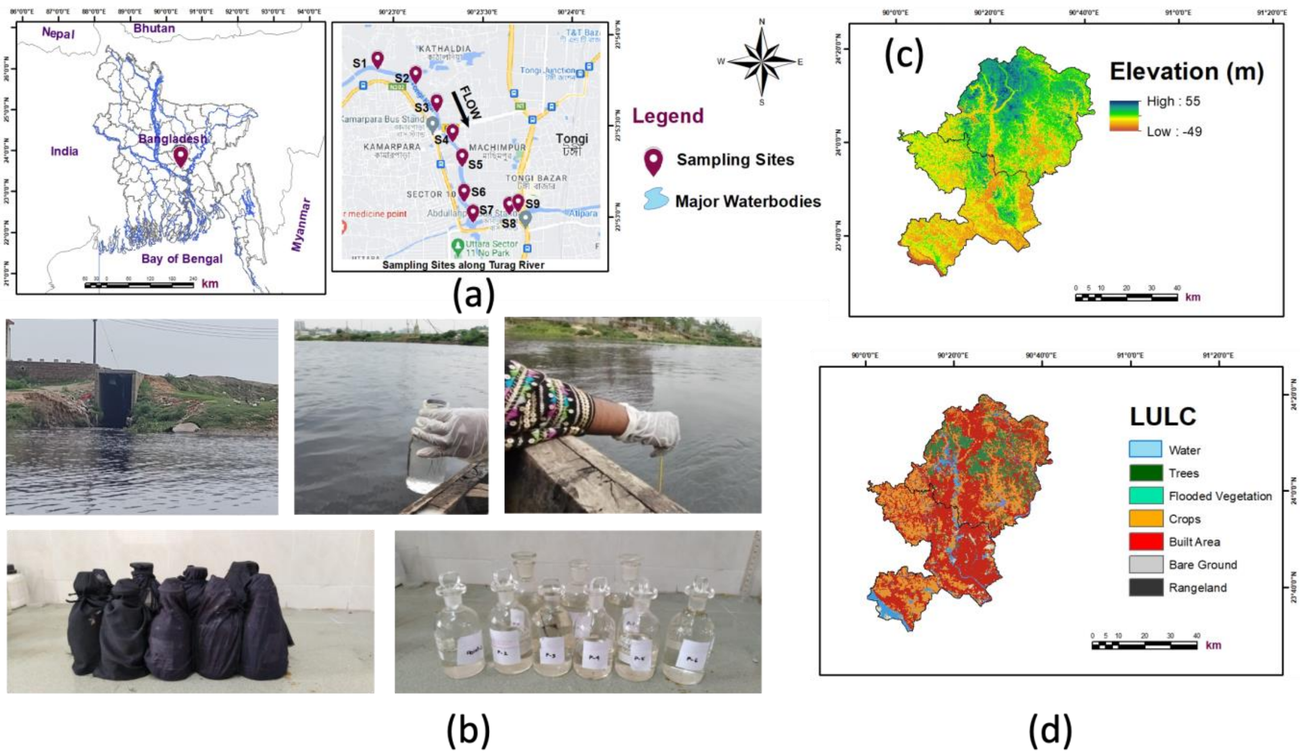

Figure 1: Study area overview: (**a**) sampling locations along the Turag River, Bangladesh; (**b**) field collection of water samples for laboratory analysis; (**c**) elevation profile of the river basin; and (**d**) land use/land cover (LULC) classification of the surrounding region.

Table 1: Industrial sources of pollution along the Turag River: sampling site identifications and locations.

Serial No.	Sampling Site	Location
S1	Beximco Pharma	Squib Road
S2	SK+F	
S3	National Polymer Industries PLC	
S4	NOVARTIS	
S5	Ultra Washing and Dyeing Ltd	
S6	Drug International Ltd	
S7	Meghna Group of Industries	Mill gate Road
S8	KBPL (Dyeing and Finishing Unit)	
S9	Creative Wash Limited	

site, representing major pollution contributors including pharmaceutical facilities, polymer industries, dyeing operations, and manufacturing units. The sampling was conducted during the pre-monsoon season, a period typically characterized by lower river discharge and higher pollutant accumulation. This timing was deliberately selected to capture peak pollution conditions; however, seasonal influences on water quality are acknowledged and warrant further investigation.

2.3. Selected Water Quality Parameters

This study utilized eight critical water quality parameters to assess the environmental status of the Turag River and calculate the WQI. The selection of parameters was based on their significance in determining overall water quality and their suitability for the National Sanitation Foundation Water Quality Index (NSFWQI) methodology. The parameters included pH, dissolved oxygen (DO), BOD, total suspended solids (TSS), turbidity, total phosphate (PO_4), nitrate (NO_3), and temperature. Physical and chemical analyses were conducted using standardized protocols and calibrated instrumentation as detailed in Table **2**.

Table 2: Analytical methods and instrumentation used for water quality parameter measurement.

Parameters	Unit	Methods /Instruments
pH (Hydrogen Ion concentration)	-	LUTRON YK-2005WA PH/ORP, DO, CD/TDS METER
DO (Dissolved Oxygen)	ppm	LUTRON YK-2005WA PH/ORP, DO, CD/TDS METER
BOD (Biological Oxygen Demand)	ppm	LUTRON YK-2005WA PH/ORP, DO, CD/TDS METER
TSS (Total Suspended solids)	ppm	HACH DR/870 Colorimeter
Turbidity	NTU	HACH DR/870 Colorimeter
PO_4 (Total Phosphate)	ppm	HACH DR 1900 Spectrophotometer
NO_3 (Nitrate)	ppm	HACH DR 1900 Spectrophotometer
Temperature	°C	Portable calibrated mercury thermometer

Parameters including pH, DO, BOD, TSS, and turbidity were measured at the Environmental Engineering Laboratory of the Department of Farm Structure and Environmental Engineering, while total phosphate and nitrate analyses were performed at the Bangladesh Fisheries Research Institute (BFRI). The analytical methods were selected based on their precision, reliability, and appropriateness for environmental water quality assessment. Electrochemical techniques were employed for pH and DO measurements using a calibrated LUTRON YK-2005WA meter. Colorimetric methods were utilized for TSS and turbidity determination via HACH DR/870 Colorimeter. Spectrophotometric analysis was conducted for phosphate and nitrate quantification using a HACH DR 1900 Spectrophotometer. Temperature was recorded on-site using a calibrated mercury thermometer to ensure accuracy in thermal characterization of the sampling points. These parameters collectively provide comprehensive insights into the anthropogenic impacts on the Turag River's water quality and serve as the foundation for spatial mapping and pollution source identification through the subsequent GIS-based analysis.

2.4. Water Quality Index (WQI)

The WQI methodology was initially developed by Horton [32] to quantitatively evaluate water quality in rivers. This approach provides a standardized numerical expression that reflects comprehensive water quality status through the integration of multiple parameters. Brown [33] and Deininger and Maciunas [34] subsequently refined this approach with the support of the National Sanitation Foundation (NSF), resulting in the widely adopted NSFWQI [35, 36]. The NSFWQI incorporates nine critical water quality parameters: DO, pH, BOD, Temperature, Total Phosphate, Nitrate, Turbidity, Total Suspended Solids, and Fecal Coliform [33, 37]. Table **3** presents the relative weight factors assigned to each parameter, reflecting their comparative significance in overall water quality assessment. These weightings, ranging from 0 to 1 with a sum of 1 when all parameters are considered, were established through extensive expert consultation and validation studies [38]. As noted by Thukral [39], a minimum of six parameters can be used for valid WQI calculation.

Table 3: Relative weight factors for water quality parameters used in Water Quality Index (WQI) calculation [38].

Parameter	Weight
Dissolved Oxygen	0.17
Fecal Coliforms	0.16
pH	0.11
Biological Oxygen Demand	0.11
Temperature	0.1
Total Phosphate	0.1
Nitrates	0.1
Turbidity	0.08
Total Suspended Solids	0.07

The mathematical expression for WQI calculation [23] is given by the following equation (1):

$$\mathrm{WQI} = \sum_{i=1}^{n} QiWi \tag{1}$$

Where Qi represents the sub-index for the ith water quality parameter, Wi denotes the weight associated with that parameter, and n indicates the number of parameters considered. The resulting WQI values range from 0 to 100, with higher values indicating superior water quality [40]. This standardized approach facilitates effective communication of complex water quality data to stakeholders and decision-makers.

2.5. Geographic Information System (GIS)-Based Spatial Mapping

The integration of GIS techniques in environmental monitoring incorporates essential spatial and temporal dimensions, enhancing evaluation and decision-making processes [25, 41, 42]. This study utilized ArcGIS 10.5 to analyze spatial distribution patterns of physicochemical parameters in the Turag River. We employed the deterministic inverse distance weighted (IDW) interpolation method to generate continuous spatial surfaces from discrete sampling points. This technique estimates values at unmeasured locations by calculating a weighted average of known values from surrounding points, with weights inversely proportional to distance. The selection of IDW as the interpolation method was justified by its demonstrated reliability and accuracy in hydrological studies. Islam [42] reported high predictive accuracy for water quality parameters sampled at 1 km intervals in the Old Brahmaputra River, Bangladesh. Their cross-validation analysis showed IDW achieved coefficient of determination (R^2) values ranging from 0.714 to 0.991 across various parameters, indicating strong correlations between observed and interpolated values. The method's effectiveness was further supported by consistently low Mean Absolute Error (MAE) values and Nash-Sutcliffe Efficiency (NSE) coefficients approaching 1 for most parameters. All raster maps depicting the spatial distribution of physicochemical parameters and WQI were standardized at 10 m × 10 m resolution in the present study. This facilitated the identification of pollution hotspots and spatial trends along the river course, providing a framework for visualizing water quality heterogeneity and identifying critical intervention areas.

3. Results and Discussion

3.1. Spatial Mapping of Physicochemical Attributes in the Turag River Water

The comprehensive analysis of water samples collected from the Turag River revealed significant variations in physicochemical parameters across sampling sites, as summarized in Table **4**. The measured values of these parameters were evaluated against the established standards set by the DoE to assess the river's water quality status. The pH values of the collected water samples ranged from 7.76 to 8.43 with a mean value of 8.09 (standard deviation, SD = 0.22), indicating mild alkalinity. This alkaline nature might be attributed to the presence of ions such as Ca, Mg, and Na in the water [43]. As shown in Fig. (**2a**), pH values exhibited relatively low variability across sampling sites, with the highest value (8.43) recorded at site S7 and the lowest (7.76) at site S5. While all measured pH values fell within the acceptable range (6-9) established by DoE standards [44]. persistent alkaline conditions may pose challenges for long-term irrigation applications. The spatial distribution depicted in Fig. (**3a**) reveals a gradient of increasing pH values in the northern section of the study area, particularly around the Meghna Group of Industries location.

Table 4: Summary of physicochemical parameters of water samples from the Turag River compared to Department of Environment (DoE) standards.

Chemical Composition and Parameters	Range	Average	Standard Deviation	DoE Standard (DoE, 1997)
pH	7.76-8.43	8.09	0.22	6-9
DO (ppm)	3.4-6.6	4.78	1.27	4.5-8
BOD (ppm)	53-90	73	13.76	≤ 50
TSS (ppm)	85-125	103.88	13.98	≤ 150
NO_3 (ppm)	1.29-2.89	1.86	0.47	≤ 10
PO_4 (ppm)	2.52-4.92	3.82	0.91	5-8
Turbidity (NTU)	40-80	58.77	13.79	≤ 10
Temperature (°C)	29-33	31.18	1.42	≤ 40

The DO concentrations ranged between 3.4 and 6.6 ppm with a mean value of 4.78 ppm (SD = 1.27). Fig. (**2b**) illustrates significant variations in DO levels, with notably higher concentrations (6.2-6.6 ppm) observed at sampling sites S7, S8, and S9, indicating relatively improved oxygenation in the southern segment of the study area. According to DoE standards, acceptable DO levels for surface water should fall between 4.5 and 8 ppm. The spatial mapping in Fig. (**3b**) reveals a distinct north-south gradient, with critically low DO levels in the northern portions (primarily at sites S1 and S4 with values of 3.5 and 3.4 ppm, respectively). Such depleted oxygen levels (below 5.0 ppm) can place aquatic life under considerable stress and impair natural stream purification processes.

The BOD values across sampling sites exhibited substantial variation, ranging from 53 to 90 ppm with a mean concentration of 73 ppm (SD = 13.76). As illustrated in Fig. (**2c**), the highest BOD values were recorded at sampling points S8 (90 ppm) and S7 (87 ppm), reflecting intense organic pollution from adjacent industrial discharges. Notably, all sampling locations exceeded the DoE permissible limit of 50 ppm, indicating significant organic pollutant loading throughout the river stretch. The spatial map (Fig. **3c**) shows a progressive southward increase, with peak concentrations in the southern reach. This trend likely results from cumulative industrial effluent from clusters of textile, dyeing, and washing factories concentrated between Tongi Mill Gate and Mirpur Bridge (S7–S9), as well as limited flow and dilution capacity downstream. Additionally, reduced current velocity in the semi-funnel-shaped southern stretch enhances pollutant retention and oxygen demand. Despite these high BOD levels, downstream DO concentrations were found to be relatively elevated. This suggests that physical and ecological compensatory mechanisms—such as channel widening, re-aeration, and natural attenuation—may partly offset the oxygen-consuming effects of organic loading. The elevated value at S9 (76 ppm) corresponds with effluent from Creative Wash Limited, which reportedly discharges high-strength wastewater rich in detergents, surfactants, and synthetic dyes. These readily biodegradable substances exert considerable oxygen demand, sharply elevating BOD and making the water unsuitable for safe disposal or irrigation use.

The BOD values across sampling sites exhibited substantial variation, ranging from 53 to 90 ppm with a mean concentration of 73 ppm (SD = 13.76). As illustrated in Fig. (**2c**), the highest BOD values were recorded at sampling points S8 (90 ppm) and S7 (87 ppm), coinciding with locations adjacent to the Meghna Group of Industries and

KBPL Dyeing facilities. Notably, all sampling locations exceeded the DoE permissible limit of 50 ppm, indicating significant organic pollutant loading throughout the river stretch. The spatial map (Fig. **3c**) shows a progressive southward increase, with peak concentrations in the southern reach. This pattern stems from: (i) dense clusters of

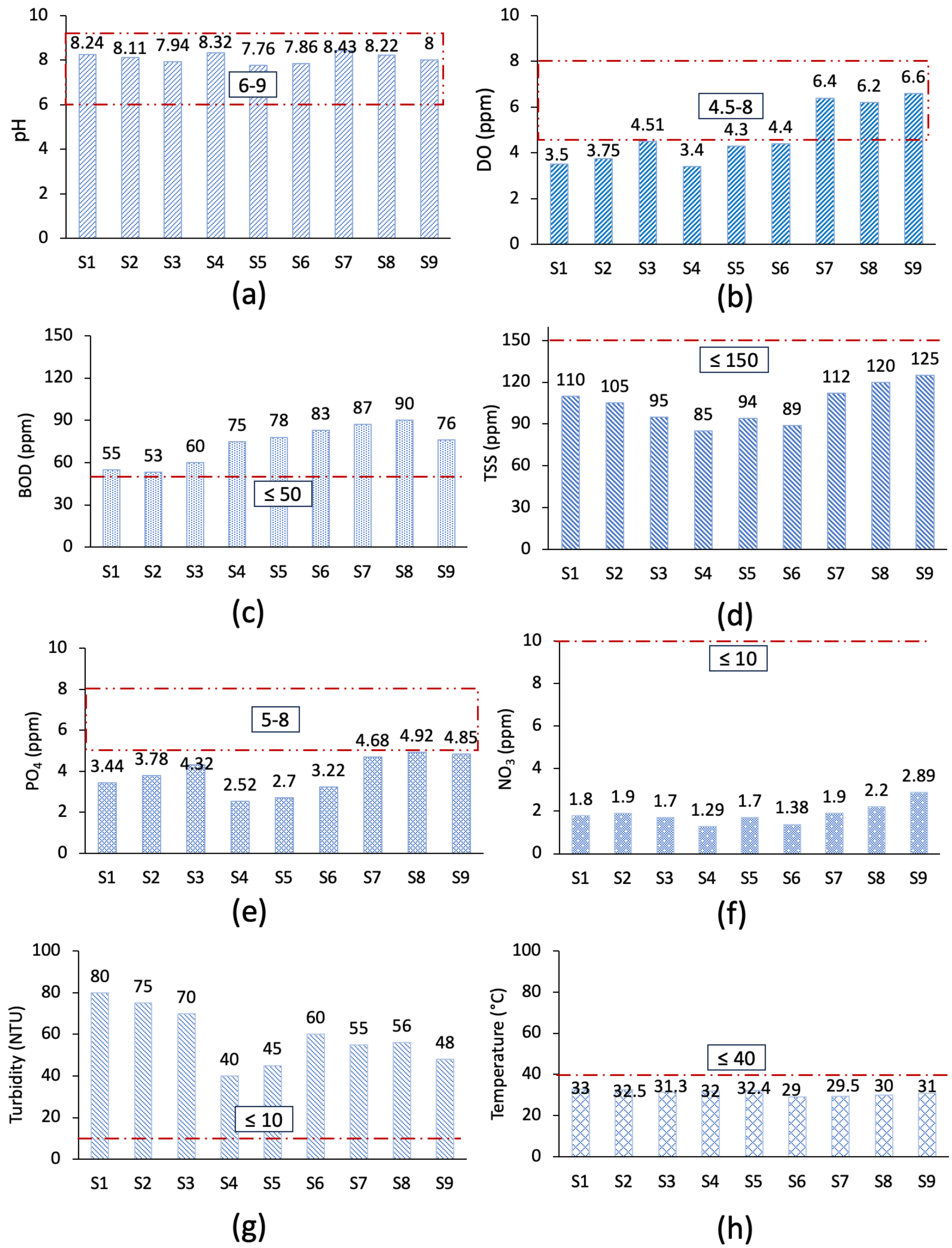

Figure 2: Measured physicochemical parameters at different sampling sites along the Turag River: (**a**) pH, (**b**) dissolved oxygen (DO), (**c**) biological oxygen demand (BOD), (**d**) total suspended solids (TSS), (**e**) phosphate (PO_4), (**f**) nitrate (NO_3), (**g**) turbidity, and (**h**) temperature; the red-dashed lines/rectangles indicate Department of Environment (DoE) standard limits, as referenced in Table **4**.

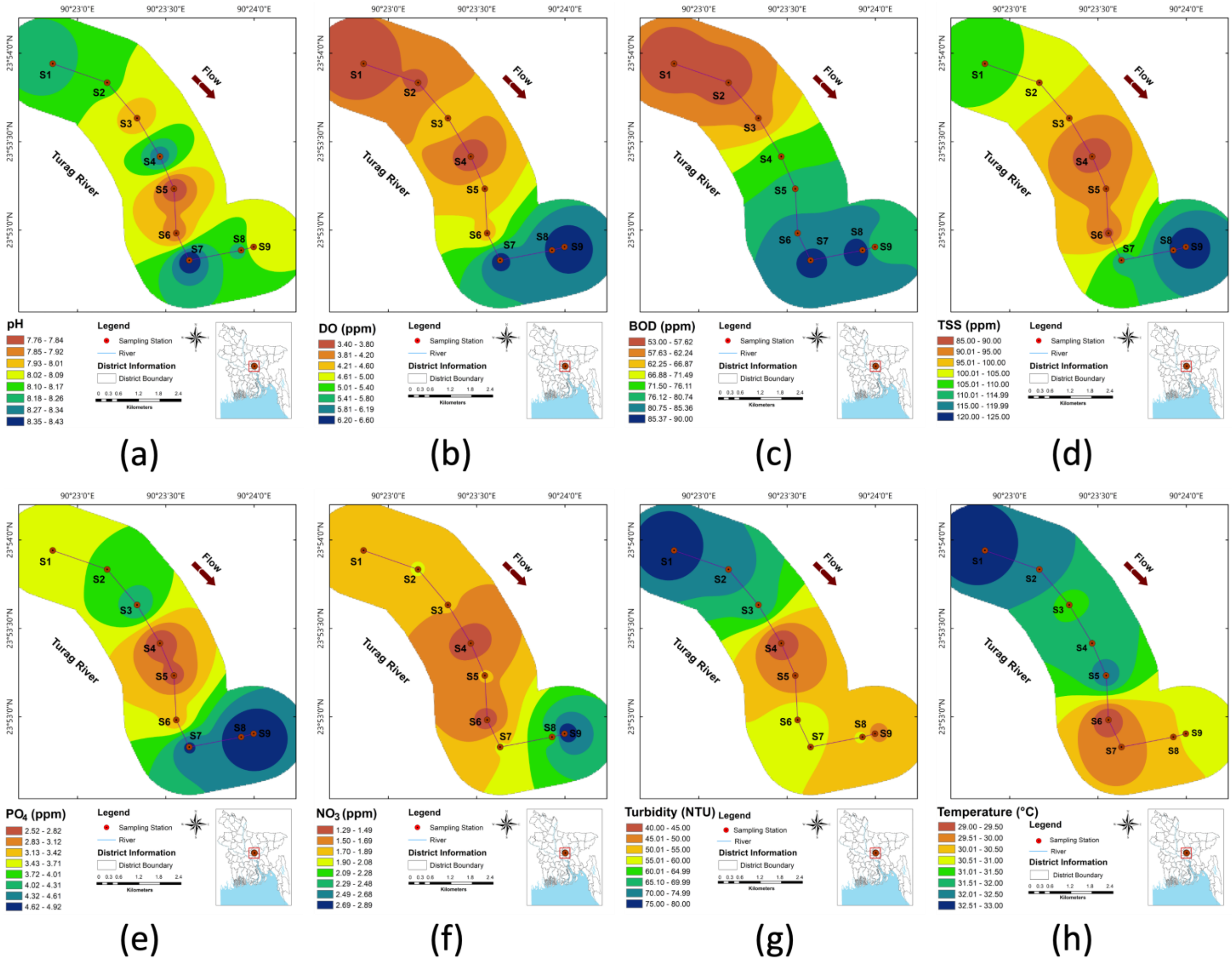

Figure 3: Spatial distribution maps of physicochemical parameters in the Turag River: (**a**) pH, (**b**) dissolved oxygen (DO), (**c**) biological oxygen demand (BOD), (**d**) total suspended solids (TSS), (**e**) phosphate (PO_4), (**f**) nitrate (NO_3), (**g**) turbidity, and (**h**) temperature.

textile and dyeing industries between Tongi Mill Gate and Mirpur Bridge (S7–S9), releasing untreated, oxygen-demanding effluents; (ii) reduced flow velocity in the semi-funnel-shaped southern stretch, which enhances pollutant settling and limits dilution; and (iii) seasonal backwater effects from the Buriganga River that impede downstream flushing. When interpreted together with the DO pattern, these results emphasize that high BOD alone does not invariably produce low DO if compensatory re-aeration and photosynthetic inputs are sufficiently strong in a given reach. Furthermore, the elevated value at S9 (76 ppm) reflects effluent from Creative Wash Limited, known for discharging high-strength wastewater containing detergents, surfactants, and dyes. These biodegradable compounds exert high oxygen demand, sharply elevating BOD and rendering the water unsuitable for discharge or irrigation.

Moreover, the TSS concentrations in the water samples ranged from 85 to 125 ppm with an average value of 103.88 ppm (SD = 13.98). As depicted in Fig. (**2d**), the highest TSS values were observed at site S9 (125 ppm) and site S8 (120 ppm), while the lowest concentration (85 ppm) was recorded at site S4. Although all measured TSS values remained below the DoE standard limit of 150 ppm, most samples contained TSS concentrations exceeding 100 ppm. The spatial distribution (Fig. **3d**) reveals heterogeneity, with hotspots in the southeast likely driven by: (i) high-density effluent discharges from nearby textile-washing facilities; (ii) geomorphic conditions favoring sedimentation due to lower channel gradient; and (iii) suppressed turbulence during the dry season, amplifying particulate deposition. Water containing more than 120 ppm of suspended solids typically contains minerals that impart a distinctive taste or render it unsuitable for human consumption.

The phosphate content of the tested samples varied from 2.52 to 4.92 ppm with a mean value of 3.82 ppm (SD = 0.91). Fig. (**2e**) reveals that the highest PO_4 concentrations were detected at sites S8 (4.92 ppm) and S9 (4.85 ppm), while the lowest value (2.52 ppm) was recorded at site S4. Although the measured phosphate levels remained within the DoE standard range (5-8 ppm), they exceeded the maximum permissible limit of 2.00 ppm for irrigation water as recommended by Ayers and Westcot [45]. The spatial distribution map (Fig. **3e**) indicates a pronounced increase in phosphate concentrations toward the southern segment of the river, particularly at locations near textile and dyeing facilities. Excessive phosphate in irrigation waters can adversely affect crop health by reducing chlorophyll content in leaves and diminishing sugar content [46]. In surface waters, sustained phosphate enrichment also accelerates eutrophication, triggering dense algal and cyanobacterial blooms that subsequently deplete dissolved oxygen, release harmful cyanotoxins (e.g., microcystins), and generate taste-and-odour compounds, all of which degrade drinking-water quality and pose acute risks to fish, livestock, and human health [47].

The nitrate concentrations in the analyzed samples ranged from 1.29 to 2.89 ppm with an average value of 1.86 ppm (SD = 0.47). As shown in Fig. (**2f**), the highest NO_3 level was measured at site S9 (2.89 ppm), while the lowest concentration (1.29 ppm) was found at site S4. All samples exhibited nitrate values well below the DoE standard limit of 10 ppm. The spatial distribution pattern depicted in Fig. (**3f**) reveals a general trend of increasing nitrate concentrations from north to south, with the highest levels corresponding to the southernmost sampling locations. The elevated nitrate concentration at S9 may be linked to the combined discharge of nitrogen-rich detergents and chemical additives used in washing operations at Creative Wash Limited, in addition to probable leaching of nitrate-containing compounds from improperly managed solid waste near the riverbank. Runoff from these sources during pre-monsoon events may contribute to localized nitrogen loading in the water column. Despite the relatively low nitrate concentrations compared to regulatory standards, it is important to note that elevated nitrate levels in drinking water can lead to health issues such as methemoglobinemia in infants and increased risk of gastric cancer. Beyond these acute effects, long-term ingestion of nitrate-laden water has been linked to thyroid dysfunction, adverse reproductive outcomes (e.g., neural-tube defects), and higher incidence of colorectal and bladder cancers in adults [48, 49]. Elevated nitrate can also act synergistically with phosphate to intensify eutrophication, indirectly exacerbating oxygen depletion and toxin release in receiving waters.

Turbidity values in the collected samples ranged from 40 to 80 NTU with a mean of 58.77 NTU (SD = 13.79). Fig. (**2g**) illustrates that the highest turbidity was recorded at site S1 (80 NTU), followed by site S2 (75 NTU), while the lowest value (40 NTU) was observed at site S4. All sampling sites significantly exceeded the DoE standard limit of 10 NTU. The spatial distribution map (Fig. **3g**) reveals a distinctive pattern with elevated turbidity levels in the northern section of the study area, particularly near pharmaceutical industries. High turbidity levels can adversely affect aquatic ecosystems by absorbing heat, thereby raising water temperature and consequently lowering DO levels. Additionally, suspended particles can prevent sunlight penetration, hindering photosynthesis in aquatic plants and potentially harming fish and their larvae. From an agricultural perspective, excessive turbidity can impair irrigation system performance by reducing soil hydraulic conductivity and promoting surface runoff. Although turbidity and TSS are generally positively correlated, their spatial trends diverge (Fig. **3d**, **3g**). This is likely due to differences in particle size and composition—finer colloids in the north increase turbidity, while coarser particles in the south contribute more to TSS but less to light scattering.

In addition, the water temperature measurements across sampling sites ranged from 29°C to 33°C with an average value of 31.18°C (SD = 1.42). As illustrated in Fig. (**2h**), the highest temperature was recorded at site S1 (33°C), while the lowest values were observed at sites S6 and S7 (29°C and 29.5°C, respectively). All temperature readings remained below the DoE standard upper limit of 40°C. The spatial distribution pattern shown in Fig. (**3h**) indicates a general decrease in temperature from north to south along the river course. This temperature decline aligns with zones of elevated pollutant concentrations, suggesting that increased pollution loads may locally suppress surface heating. The relatively elevated temperatures observed at certain locations may be attributed to the decomposition of organic matter by coliform bacteria, which generates excess heat and subsequently raises water temperature [50].

Overall, the spatial mapping of physicochemical parameters using GIS techniques (Fig. **3**) effectively highlights pollution hotspots and reveals spatial trends in water quality degradation along the Turag River. The interpolated surfaces demonstrate distinct spatial patterns for different parameters, with most contaminants showing concentration gradients that correlate with the distribution of industrial facilities. The northern section of the study area exhibits critical conditions for parameters such as DO and turbidity, while the southern segment shows elevated levels of BOD, phosphate, and nitrate. These spatial patterns provide valuable insights for identifying priority intervention areas and developing targeted pollution control strategies for the restoration of this vital water resource. Overall, the GIS-based spatial analysis incorporating elevation, vegetation, and land use indicates that low-lying, flatter areas—especially in the south—act as natural sinks for industrial effluents. In contrast, the elevated northern region experiences DO depletion and turbidity, likely due to steep industrial outflows and limited vegetative buffers. Dense riparian vegetation helps reduce runoff and filter pollutants, while the basin's semi-funnel geomorphology promotes downstream accumulation. These findings underscore the importance of topography, vegetation, and land cover in shaping pollutant transport—critical considerations for effective watershed and land-use planning.

3.2. Spatial Mapping of the Water Quality Index (WQI) in the Turag River

The WQI analysis provides a comprehensive assessment of the overall water quality status of the Turag River by integrating multiple physicochemical parameters into a single numerical value. As presented in Table **5**, the calculated WQI values for the nine sampling sites range from 35.14 to 38.83, with an average value of 36.68. The lowest WQI value (35.14) was recorded at sampling site S1 (Beximco Pharma), while the highest value (38.83) was observed at site S5 (Ultra Washing and Dyeing Ltd). Notably, sampling sites S6 (Drug International Ltd) and S4 (NOVARTIS) also exhibited relatively higher WQI values of 38.32 and 37.28, respectively.

Table 5: Water Quality Index (WQI) calculations for different sampling sites along the Turag River.

Sample ID	pH	DO (ppm)	BOD (ppm)	TSS (ppm)	PO_4 (ppm)	NO_3 (ppm)	Turbidity (NTU)	Temperature (°C)	WQI
S1	8.24	3.5	55	110	3.44	1.8	80	33	35.14
S2	8.11	3.75	53	105	3.78	1.9	75	32.5	36.40
S3	7.94	4.51	60	95	4.32	1.7	70	31.3	36.23
S4	8.32	3.4	75	85	2.52	1.29	40	32	37.28
S5	7.76	4.3	78	94	2.7	1.7	45	32.4	38.83
S6	7.86	4.4	83	89	3.22	1.38	60	29	38.32
S7	8.43	6.4	87	112	4.68	1.9	55	29.5	35.39
S8	8.22	6.2	90	120	4.92	2.2	56	30	36.07
S9	8	6.6	76	125	4.85	2.89	48	31	36.39
								WQI (Average)	36.68

According to the water quality classification system presented in Table **6**, the average WQI value of 36.68 places the Turag River water quality in the "Bad" category (WQI range: 25-49). This classification has significant implications for water usability, as water bodies with WQI values in this range have "limited usability" and are "appropriate only for agricultural irrigation purpose" [51-53]. The consistent placement of all sampling sites in the "Bad" category underscores the severe degradation of water quality throughout the studied river section.

The spatial distribution of WQI values across the study area, as visualized in Fig. (**4**), reveals distinct patterns of water quality variation along the Turag River. The pollution severity mapping shows a heterogeneous distribution of water quality, with notable spatial gradients in different sections of the river. The northern section of the study area, particularly near pharmaceutical industries (sampling sites S1, S2, and S4), exhibits some of the lowest WQI values, indicating more severe pollution conditions. This spatial pattern aligns with the findings presented in Section 3.1, where critical conditions for parameters such as DO (Fig. **3b**) and turbidity (Fig. **3g**) were also observed in the northern segment of the river. The central portion of the study area shows a slight improvement in WQI values, particularly at sampling sites S5 and S6, which recorded the highest WQI values among all sites. This localized improvement may be attributed to potential dilution effects or relatively lower pollutant loading in this section. However, even these "improved" values remain firmly within the "Bad" quality category, highlighting the pervasive nature of water pollution throughout the entire river stretch. Moreover, the southern section of the study area exhibits moderate WQI values, despite showing elevated levels of BOD (Fig. **3c**), phosphate (Fig. **3e**), and nitrate (Fig. **3f**) as discussed in Section 3.1. This apparent discrepancy can be explained by the compensatory effect of improved DO levels in this section (Fig. **3b**), which positively influenced the overall WQI calculation due to the higher weighting factor (0.17) assigned to DO in the NSFWQI methodology.

Table 6: Water quality classification system showing usability of water based on WQI values [51-53].

WQI Value	Quality Status	Water Usability Guidelines
90-100	Excellent	Suitable for drinking water supply without treatment; supports diverse aquatic ecosystems including sensitive species
70-89	Good	Requires conventional treatment for drinking water supply; appropriate for recreational activities including swimming
50-69	Medium	Requires advanced treatment processes for drinking water supply; suitable for livestock consumption
25-49	Bad	Limited usability; appropriate only for agricultural irrigation purpose
0-24	Very Bad	Not suitable for any standard uses; can only support a limited range of highly tolerant aquatic organisms

The consistently low WQI values across all sampling sites reflect the cumulative impact of multiple pollutants exceeding permissible limits, as evidenced by the physicochemical parameter analysis. Particularly significant are the extremely high BOD values (53-90 ppm) recorded at all sampling sites, which exceed the DoE standard of 50 ppm (Table **4**), indicating severe organic pollution throughout the river. Similarly, the turbidity levels (40-80 NTU) substantially exceed the DoE standard of 10 NTU at all sampling locations, further contributing to the degraded water quality status.

The spatial mapping of WQI values provides a valuable visualization tool for identifying priority intervention areas and assessing the overall health of the Turag River ecosystem. The consistently poor water quality classification across all sampling sites underscores the urgent need for comprehensive pollution control measures and ecosystem restoration efforts. These findings align with previous studies [16, 22] that have documented the severe degradation of the Turag River due to industrial pollution, reinforcing the DoE's designation of the river as an ECA [21]. Overall, the limitation of water usability to "agricultural irrigation purpose only" as indicated by the WQI classification has significant implications for water resource management and public health in the surrounding communities. However, even for irrigation applications, the elevated levels of certain parameters like BOD and turbidity may pose potential risks to crop health and soil quality in the long term. Therefore, appropriate treatment interventions and stringent pollution control measures are essential to improve the water quality status and restore the ecological integrity of this vital water resource.

3.3. Research Implications, Constraints and Future Pathways

The comprehensive GIS-based assessment of the Turag River's water quality has significant implications for environmental management and public health policy. The consistently "Bad" WQI classification across all sampling sites underscores the urgent need for stringent industrial effluent regulations and comprehensive watershed management strategies. The spatial mapping approach employed in this study offers a valuable decision-support tool for environmental authorities to identify critical pollution hotspots and prioritize intervention measures in resource-constrained contexts.

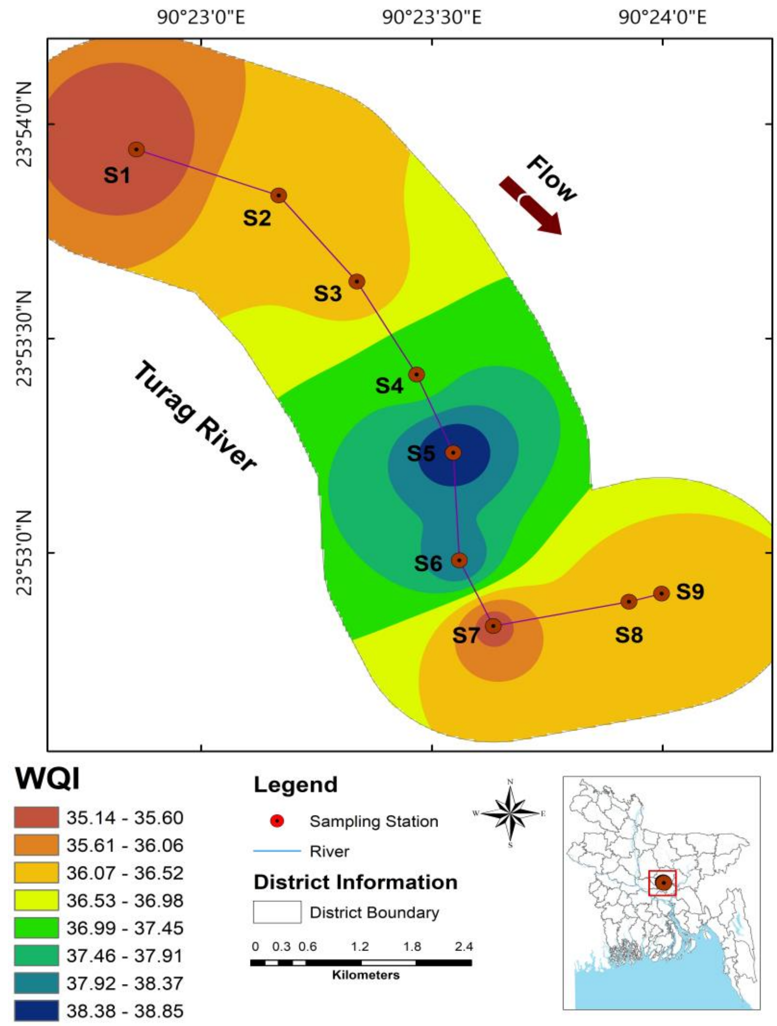

Figure 4: Spatial distribution of Water Quality Index (WQI) values across the studied section of the Turag River, showing pollution severity levels at different sampling locations.

Several methodological constraints warrant consideration when interpreting these findings. First, the sampling was conducted during a single season, potentially limiting the representativeness of the data across temporal variations. As noted in Section 2.2, the sampling took place during the pre-monsoon season to capture critical pollution loads under low-flow conditions. Nonetheless, the influence of seasonal variations—such as monsoonal dilution and dry-season concentration effects—should be systematically assessed in future studies to enhance temporal coverage. Seasonal fluctuations in precipitation, temperature, and industrial discharge patterns may significantly influence water quality parameters. Second, while the NSFWQI methodology employed is widely accepted, it considers a predetermined set of parameters with fixed weighting factors, which may not fully capture the specific pollution dynamics of the Turag River ecosystem. Finally, the study focused primarily on physicochemical parameters, excluding biological indicators such as fecal coliform, which could provide additional insights into ecological integrity and public health risks.

In response to these constraints, incorporating phytoplankton monitoring into future assessments is strongly recommended. Phytoplankton act as sensitive bio-indicators because their community structure, diversity and biomass rapidly reflect both short-term contaminant loads and long-term ecosystem stressors (e.g. eutrophication or toxic-algal events). Integrating phytoplankton data with NSFWQI outputs would therefore deliver a more conclusive and ecologically holistic picture of water quality, enabling regulators to detect pollution that may be missed by chemical analyses alone and to track recovery trajectories following remediation.

In addition, future research should consider measuring Gross Primary Productivity (GPP) and Net Primary Productivity (NPP) as complementary biological indicators to assess the ecological functioning and productivity status of the Turag River. These parameters provide valuable insights into autotrophic activity and organic matter fluxes, which are crucial for evaluating ecosystem health in conjunction with physicochemical metrics. However, due to the absence of chlorophyll-a or light-use efficiency data, GPP and NPP estimation was not feasible in the current study. Furthermore, future research should adopt multi-seasonal sampling regimes to better capture the spatiotemporal dynamics of pollution and water quality variability throughout the year [20, 54]. These campaigns should systematically quantify phytoplankton diversity indices (e.g. Shannon–Wiener), chlorophyll-a concentrations and functional group composition, thereby building a coupled physicochemical–biological dataset for the Turag River. The integration of additional parameters, particularly heavy metals and persistent organic pollutants, would enhance the comprehensiveness of the assessment [13, 25]. Furthermore, developing a customized WQI specifically calibrated for the unique pollution characteristics of Bangladesh's urban rivers could improve assessment accuracy [53]. Ultimately, this research establishes a robust baseline for long-term water quality monitoring and provides the scientific foundation for evidence-based policy interventions. The findings emphasize the critical need for enforcing existing environmental regulations, upgrading industrial effluent treatment infrastructure, and implementing holistic watershed management approaches to rehabilitate this vital water resource [18, 19].

4. Conclusion

The GIS-based assessment of the Turag River revealed severe water quality degradation throughout the studied section, with spatial mapping effectively identifying pollution hotspots and contamination gradients. The consistently "Bad" WQI classification (average 36.68) across all sampling sites reflects the cumulative impact of multiple pollutants exceeding permissible limits. Notably, TSS concentrations ranged from 85 to 125 ppm (average 103.88 ppm), phosphate content varied from 2.52 to 4.92 ppm (mean 3.82 ppm), and nitrate levels ranged from 1.29 to 2.89 ppm (average 1.86 ppm), with temperature measurements between 29°C and 33°C (average 31.18°C). The spatial distribution revealed distinct north-south gradients, with the northern section (near pharmaceutical industries) exhibiting critical dissolved oxygen conditions (3.4-3.5 ppm) and high turbidity (75-80 NTU), while the southern segment (near textile and dyeing facilities) showed elevated BOD (87-90 ppm), phosphate (4.85-4.92 ppm), and nitrate (2.2-2.89 ppm) levels. These patterns correspond to the distribution of industrial facilities, confirming their significant contribution to river pollution. The limitation of water usability to "agricultural irrigation purpose only" has profound implications for water resource management and public health in surrounding communities. We recommend implementing stringent industrial effluent regulations, upgrading treatment infrastructure, enforcing existing environmental laws, establishing continuous monitoring systems across seasons, and developing a comprehensive watershed management approach that addresses both point and non-point pollution sources to rehabilitate this vital water resource.

Conflict of Interest

The authors declare that they have no conflict of interest.

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References

[1] Kumar P. Simulation of Gomti River (Lucknow City, India) future water quality under different mitigation strategies. Heliyon. 2018; 4(12): e01074. https://doi.org/10.1016/j.heliyon.2018.e01074

[2] Zhang L. Different methods for the evaluation of surface water quality: The case of the Liao River, Liaoning Province, China. Int Rev Spat Plan Sustain Dev. 2017; 5(4): 4-18. http://dx.doi.org/10.14246/irspsd.5.4_4

[3] Paun I, Cruceru L, Chiriac FL, Niculescu M, Vasile GG, Marin NM. Water quality indices-methods for evaluating the quality of drinking water. In: Proceedings of the 19th INCD ECOIND International Symposium-SIMI 2016, "The Environment and the Industry"; 2016 Oct 13-14; Bucharest, Romania: p. 395-402. https://doi.org/10.21698/simi.2016.0055

[4] DeRamus HA, Clement TJ, Jeong CY, Berry JC. Comparison of beef cattle grazing management practices and their effects on runoff water quality in Louisiana. Glob J Agric Innov Res Dev. 2015; 2: 1-15. https://doi.org/10.15377/2409-9813.2015.02.01.1

[5] Tahmina B, Sujan D, Karabi R, Hena MKB, Amin KR, Sharmin S. Assessment of surface water quality of the Turag River in Bangladesh. Res J Chem Environ. 2018; 22(2): 49-56.

[6] Raymond F. Le problame dis ean dans le monde (Problems of water). UK: EB and Sons Ltd; 1992.

[7] Yasmin G, Islam D, Islam MT, Shariot-Ullah M, Adham AKM. Evaluation of groundwater quality for irrigation and drinking purposes in Barishal district of Bangladesh. Fundam Appl Agric. 2019; 4(1): 632-41. https://doi.org/10.5455/faa.301258

[8] Adham AKM, Islam MT. Numerical verification of groundwater suitability for irrigation around the subsurface da s2024020202m area of Miyako Island, Japan. Agro Environmental Sustainability. 2024; 2(2): 74-83. https://doi.org/10.59983/

[9] Tuli DH, Islam MT, Jahan N, Das N, Rahman MM, Adham AKM. Characterisation of power plant disposal water from two distinct regions in Bangladesh: A comparative assessment of irrigation feasibility. Asian J Water Environ Pollut. 2024; 21(6): 91-100. https://doi.org/10.3233/AJW240076

[10] Poonam T, Tanushree B, Sukalyan C. Water quality indices-important tools for water quality assessment: A review. Int J Adv Chem. 2013; 1(1): 15-28.

[11] Mukherjee S. Ground water pollution and emerging environmental challenges of industrial effluent irrigation: A case study of Mettupalayam Taluk, Tamilnadu. Madras School of Economics Working Paper. 2006; (7): 1-47. https://doi.org/10.2139/ssrn.1021153

[12] Uddin HM. Initial environmental impact assessment of the Turag-Buriganga naval transport [master's thesis]. Dhaka: Department of Geography and Environment, Jahangirnagar University; 2005.

[13] Sundaray SK, Panda UC, Nayak BB, Bhatta D. Multivariate statistical techniques for the evaluation of spatial and temporal variation in water quality of Mahanadi river-estuarine system (India)-A case study. Environ Geochem Health. 2006; 28(4): 317-30. https://doi.org/10.1007/s10653-005-9001-5

[14] Akoto O, Bruce TN, Darko G. Heavy metals pollution profiles in streams serving the Owabi reservoir. Afr J Environ Sci Technol. 2008; 2(11): 354-59.

[15] Ahmad MK, Islam S, Rahman S, Haque MR, Islam MM. Heavy metals in water, sediment and some fishes of Buriganga River, Bangladesh. Int J Environ Res. 2010; 4(2): 321-32.

[16] Mohammad G, Parinaz P, Mohammad MA, Mohammad Z, Hamid G, Seyyed AM, *et al*. Environmental impact assessment of the industrial estate development plan with the geographical information system and matrix methods. J Environ Public Health. 2012; 2012: 407162. https://doi.org/10.1155/2012/407162

[17] Ladwani KD, Manik VS, Ramteke DS. Impact of industrial effluent discharge on physico-chemical characteristics of agricultural soil. Int Res J Environ Sci. 2012; 1(3): 32-6.

[18] Khan SA, Ahammed SS, Rabbani KA, Khaleque MA. Water quality assessment of Turag River using selected parameters. IOSR J Environ Sci Toxicol Food Technol. 2020; 14(1): 61-6.

[19] Sadiqa H, Al-Amin M, Sarker MMH. Impact of urban wastes on water quality of Turag River [dissertation]. Dhaka: Bangladesh University of Engineering and Technology; 2021. https://doi.org/10.5281/ZENODO.5655206

[20] Rahman AKML, Islam M, Hossain MZ, Ahsan MA. Study of the seasonal variations in Turag river water quality parameters. Afr J Pure Appl Chem. 2012; 6(10): 144-8. https://doi.org/10.5897/AJPAC12.023

[21] DoE (Department of Environment). The general overview of pollution status of rivers of Bangladesh. Dhaka: Government of the People's Republic of Bangladesh, Ministry of Environment and Forest, Department of Environment; 2001.

[22] Mobin MN, Islam MS, Mia MY, Bakali B. Analysis of physicochemical properties of the Turag River water, Tongi, Gazipur in Bangladesh. J Environ Sci Nat Resour. 2014; 7(1): 27-33. https://doi.org/10.3329/jesnr.v7i1.22140

[23] Tyagi S, Sharma B. Water quality assessment in terms of water quality index. Am J Water Resour. 2013; 1(3): 34-8. https://doi.org/10.12691/ajwr-1-3-3

[24] Jahan N, Khan MB, Ali MA, Islam MT, Siddik MS. Spatial appraisal of groundwater quality for drinking purposes: A case study of Kalihati Upazila, Bangladesh. Fundam Appl Agric. 2020; 5(4): 521-36. https://dx.doi.org/10.5455/faa.129984

[25] Islam MT, Das N, Jahan N, Siddik MS, Mahmud K, Adham AKM. Utilizing geographic information system and indexing to evaluate irrigation suitability of groundwater in Kalihati Upazila, Bangladesh. Arch Agric Environ Sci. 2023; 8(3): 385-96. https://doi.org/10.26832/24566632.2023.0803017

[26] Latif M, Nasir N, Nawaz R, Nasim I, Sultan K, Irshad MA, *et al*. Assessment of drinking water quality using Water Quality Index and synthetic pollution index in urban areas of mega city Lahore: a GIS-based approach. Sci Rep. 2024; 14(1): 13416. https://doi.org/10.1038/s41598-024-63296-1

[27] Shukla BK, Gupta L, Parashar B, Sharma PK, Sihag P, Shukla AK. Integrative Assessment of Surface Water Contamination Using GIS, WQI, and Machine Learning in Urban–Industrial Confluence Zones

[28] Mishra AP, Singh S, Jani M, Singh KA, Pande CB, Varade AM. Assessment of water quality index using Analytic Hierarchy Process (AHP) and GIS: a case study of a struggling Asan River. Int J Environ Anal Chem. 2024; 104(5): 1159-71. https://doi.org/10.1080/03067319.2022.2032015

[29] Das A. Evaluation of surface water quality in Brahmani River Basin, Odisha (India), for drinking purposes using GIS-based WQIs, multivariate statistical techniques and semi-variogram models. Innov Infrastruct Solut. 2024; 9(12): 484. https://doi.org/10.1007/s41062-024-01780-3

[30] Pande CB, Tolche AD, Egbueri JC, Mohd Sidek L, Singh R, Mishra AP, *et al*. Implications of seasonal variations of hydrogeochemical analysis using GIS, WQI, and statistical analysis method for the semi-arid region. Appl Water Sci. 2025; 15(4): 80. https://doi.org/10.1007/s13201-025-02387-4

[31] Choudhury GA, Choudhury A. An assessment of water resources and flood management of Dhaka city. In: Water Resources Management and Development in Dhaka City. Dhaka: Goethe-Institut; 2004. p. 40-5.

[32] Horton RK. An index number system for rating water quality. J Water Pollut Control Fed. 1965; 37(3): 300-5. https://doi.org/10.1007/S12403-011-0040-0

[33] Brown RM, McClelland NI, Deininger RA, Tozer RG. A water quality index---Do we dare? Water & Sewage Works. 1970; 117(10): 339-43.

[34] Deininger RA, Maciunas JJ. Water quality index for public water supplies. Ann Arbor: Department of Environment and Industrial Health, University of Michigan; 1971.

[35] Abrahão R, Carvalho M, Da Silva WR, Machado TTV, Gadelha CLM, Hernandez MIM. Use of index analysis to evaluate the water quality of a stream receiving industrial effluents. Water SA. 2007; 33(4): 459-66. https://doi.org/10.4314/wsa.v33i4.52940

[36] Lumb A, Sharma TC, Bibeault JF. A review of genesis and evolution of water quality index (WQI) and some future directions. Water Qual Expo Health. 2011; 3: 11-24. https://doi.org/10.1007/s12403-011-0040-0

[37] Kumar D, Alappat BJ. NSF-Water Quality Index: Does it represent the experts' opinion? J Environ Eng. 2009; 135(1): 75-9. https://doi.org/10.1061/(ASCE)1090-025X(2009)13:1(75)

[38] Mutairi NA, Abahussain A, Battay AE. Spatial and temporal characterizations of water quality in Kuwait Bay. Mar Pollut Bull. 2014; 83(1): 1-5. http://dx.doi.org/10.1016/j.marpolbul.2014.04.009

[39] Thukral AK, Bhardwaj R, Kaur R. Water quality indices. Amritsar: Department of Botanical and Environmental Science, Guru Nanak Dev University; 2005.

[40] Uddin MG, Nash S, Olbert AI. A review of water quality index models and their use for assessing surface water quality. Ecol Indic. 2021; 122: 1-21. https://doi.org/10.1016/j.ecolind.2020.107218

[41] Das N, Rahman MM, Islam MT, Adham AKM. Assessing groundwater suitability for irrigation: A case study for Durgapur upazila of Bangladesh. Fundam Appl Agric. 2019; 4(3): 916-27. https://doi.org/10.5455/faa.45057

[42] Islam MT, Akash, Khatun MR, Jahan N, Islam MR, Partho DK, *et al*. Regional irrigation water quality index for the Old Brahmaputra River, Bangladesh: A multivariate and GIS-based spatiotemporal assessment. Results Eng. 2024; 24: 103667. https://doi.org/10.1016/j.rineng.2024.103667

[43] Rao BK, Panchaksharjah S, Patil BN, Narayana A, Kaiker DLS. Chemical composition of irrigation waters from selected parts of Bijpur district, Karnataka. Mysore J Agric Sci. 1982; 16(4): 426-32.

[44] DoE (Department of Environment). Guide to the Environmental Conservation Act 1995 and Rules 1997. Dhaka: Department of Environment, Bangladesh; 1997.

[45] Ayers RS, Westcot DW. Water quality for agriculture. FAO Irrigation and Drainage Paper 29 Rev. 1. Rome: Food and Agricultural Organization; 1985.

[46] Kirkham MB. Problems of using wastewater on vegetable crops. HortScience. 1986; 21(1): 24-7.

[47] Chorus I, Welker M. Toxic cyanobacteria in water: a guide to their public health consequences, monitoring and management. London: Taylor & Francis; 2021. https://doi.org/10.1201/9781003081449

[48] Elwood JM, van der Werf B. Nitrates in drinking water and cancers of the colon and rectum: a meta-analysis of epidemiological studies. Cancer Epidemiol. 2022; 78: 102148. https://doi.org/10.1016/j.canep.2022.102148

[49] Garcia Torres E, Perez Morales R, Gonzalez Zamora A, Rios Sanchez E, Olivas Calderon EH, Alba Romero JD, *et al*. Consumption of water contaminated by nitrate and its deleterious effects on the human thyroid gland: a review and update. Int J Environ Health Res. 2022; 32(5): 984-1001. https://doi.org/10.1080/09603123.2020.1815664

[50] Taiwo AM. Environmental impact of poultry farm operations on Alakata stream at Isolu in Abeokuta, Nigeria [master's thesis]. Abeokuta: Department of Environmental Management and Toxicology, University of Agriculture; 2010.

[51] Shokuhi R, Hosinzadeh E, Roshanaei G, Alipour M, Hoseinzadeh S. Evaluation of Aydughmush Dam reservoir water quality by National Sanitation Foundation Water Quality Index (NSF-WQI) and water quality parameter changes. J Health Environ. 2012; 4(4): 439-50.

[52] Habib AG, Khatami SH. Survey of the water quality of the Bahar County streams (Iran) by NSFWQI. Environ Conserv J. 2015; 4: 395-403. https://doi.org/10.36953/ECJ.2015.SE1646

[53] Uddin MG, Nash S, Olbert AI. A review of water quality index models and their use for assessing surface water quality. Ecol Indic. 2021; 122: 1-21. https://doi.org/10.1016/j.ecolind.2020.107218

[54] Meghla NT, Islam MS, Ali MA, Suravi, Sultana N. Assessment of physicochemical properties of water from the Turag River in Dhaka City, Bangladesh. Int J Curr Microbiol Appl Sci. 2013; 2(5): 110-22.