ASSESSMENT OF SURFACE WATER QUALITY OF BANGLADESH USING WATER QUALITY INDICES (WQI) AND THEIR CORRELATION WITH SOCIOECONOMIC FACTORS

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ABSTRACT

Around 10,000 years ago, human settlements and their waste led to unprecedented concentrations of people in villages and towns, which caused disruption to the aquatic ecosystem. This trend has been exacerbating at an alarming rate due to different types of human interventions such as industrialization, infrastructure development, deforestation, agricultural activity, etc. To quantify the degree of pollution and to analyze the pollution patterns of waterbodies, different kinds of Water Quality Indices (WQI) have been applied all over the world to analyze the pollution of a specific waterbody. However, the application of the WQI for analyzing the impact of different socio-economic factors on the water quality of a developing country like Bangladesh requires further attention. As such, under this study, the WQI of different monitoring stations of the Department of Environment (DoE) located in 3 lakes and 44 rivers across Bangladesh were estimated using the Weighted Arithmetic Water Quality Index (WAWQI). Furthermore, the impact of different socio-economic factors such as population, household numbers, literacy rate, and number of economic establishments on water quality were analyzed through regression analysis. The water quality data of different stations were collected during 2017-2019. Five parameters (pH, DO, BOD, COD, and TDS) were used to calculate the Water Quality Indices in each of the stations. The indices were then aggregated for each district and different socioeconomic data of the districts were collected from the Bangladesh Bureau of Statistics (BBS). The results of the study show that the majority of Bangladesh's surface water bodies have poor water quality and are not fit for human consumption without treatment. The results also suggest that an increase in the population, number of households, and number of economic establishments has a negative impact on the water quality. The impact of population, household number, and economic activities on WQI can be expressed as the equations respectively: $WQI = 55.94 + (1.67\times10^{-6})\times$Population; $WQI = 56.42 + (5.99\times10^{-6})\times$Household Number; and $WQI = 57.29 + (2.76\times10^{-5})\times$Number of Establishments. The R^2 values for these three relations are found as 0.315, 0.295, and 0.181 respectively. No significant correlation is observed between literacy rate and WQI. Therefore, water literacy among mass people is necessary along with ordinary literacy to improve water quality. It is essential to monitor domestic sewage and industrial discharge into waterbodies and enforce laws and regulations strictly to prevent surface water pollution. Improving water quality will also benefit from the adoption of appropriate solid waste management practices and the restriction of open dumping of industrial and domestic solid waste and sludge. For a better evaluation of the WQI of the waterbodies, more consistent sampling over the years and an increasing number of monitoring stations with more parameter analysis can be helpful.

Keywords: *Water Quality Index, Surface Water Quality, Bangladesh, Socio-Economic Factors*

1 INTRODUCTION

The demand of water is rising quickly because of recent economic growth and population rise. Safe drinking water can be obtained by groundwater withdrawal, surface water treatment, and rainwater harvesting. Presently, groundwater serves as the main supply of drinking water for 97% of Bangladesh's population and is also used extensively for industrial and agricultural purposes (LGED, 2022). Bangladesh withdraws about 32 km^3 of groundwater a year, which is around 4% of the world's total groundwater extraction (Hanasaki et al., 2018). The country's groundwater table is fast declining as a result of such excessive extraction and this rate is about 0.1 to 0.5 meters per year (Dey et al., 2017; Shamsudduha et al., 2009). Therefore, the use of surface water sources for different purposes including domestic supply has become an important concern of the respective authorities. However, the challenge of using surface water for domestic and other purposes is the quality of the surface water and its treatment. High organic and other toxic pollutant in surface water requires massive treatment technologies and high cost. Therefore, it is important to understand the factors that affect the surface water quality. The quality of water can be affected by both man-made and natural factors. Water quality is naturally impacted by lithology, geology, vegetation, climate, and time. In densely populated areas, anthropogenic activities have an impact on non-natural elements of water quality through a variety of means, including household activities, industry, agriculture, animal husbandry, mining, power generation, and forestry field practices (Lobato et al., 2015). The idea is that pollution levels rise in direct proportion to the complexity of economic and human activity, which affects aquatic ecosystems and the availability of safe water to drink.

The Water Quality Index (WQI) model is one of several methods that have been created to assess data on water quality. Large temporally and spatially changing water quality datasets can be analyzed using WQI models, which are based on aggregation functions, to yield a single value (WQI) that represents the quality of the water body. Water management and supply organizations find them appealing since they are very simple to use and they simplify complicated water quality datasets into a single, easily comprehensible value (Uddin et al., 2021). Numerous WQI models have been created, differing in terms of their structure, the parameters considered and their weightings, and the sub-indexing and aggregation techniques employed. The most often used WQI models are the CCMEWQI (Canadian Council of Ministers of Environment Water Quality Index), NSFWQI (National Sanitation Foundation Water Quality Index), OWQI (Oregon Water Quality Index), and WAWQI (Weighted Arithmetic Water Quality Index) models. Among them, the WAWQI is an appropriate and straightforward method, that may be used to characterize both surface and subsurface water quality and includes several quality parameters into a single mathematical equation (Chandra et al., 2017). Several studies apply different WQI models to assess both the surface and groundwater quality of Bangladesh. WQI was examined and assigned by Iqbal et al., (2019) for the assessment of groundwater quality in Bangladesh. Saha et al., (2018) evaluated the assignment of WQI for groundwater quality evaluation in Sathkhira district. Chowdhury et al., (2022) computed WQI using WAWQI, CCMEWQI, and NSFWQI to study the water quality of the Shitalakshya River. Mallick et al., (2021) studied the water quality of 10 major rivers of Bangladesh using the water quality data (DO, BOD, pH, and SS) of DoE collected during 2010-2016 and developed a WQI for a limited number of parameters. Till date, analyzing the surface water quality status of the whole of Bangladesh with recently available data has not been done yet. Identifying possible factors governing the surface water quality and their correlation with WQI is also understudied in Bangladesh, though several such studies are available for other countries. Afriana et al., (2022) studied the impact of economic agglomeration on WQI in Indonesia and found that water quality is affected significantly with the increase of economic agglomeration. Kustanto (2020) studied the role of socioeconomic factors (i.e., GDP per capita, the number of micro and small-scale manufacturing establishments, the workforce, and foreign direct investment) on water quality and found that these factors significantly affect water quality. In this study, the WQI of the DoE sampling locations throughout Bangladesh has been assessed with the recent data from 2017 to 2019 using the WAWQI method. The WQI at the district level is also computed to illustrate the relationship between WQI and socioeconomic variables such as population, number of households, literacy rate, and number of businesses. The study's conclusions will assist policy makers and authorities in comprehending potential influences on Bangladesh's water quality and in formulating appropriate plans for improving it.

2 METHODOLOGY

The Flow Chart of the methodological approach of this study is shown in Figure 1.

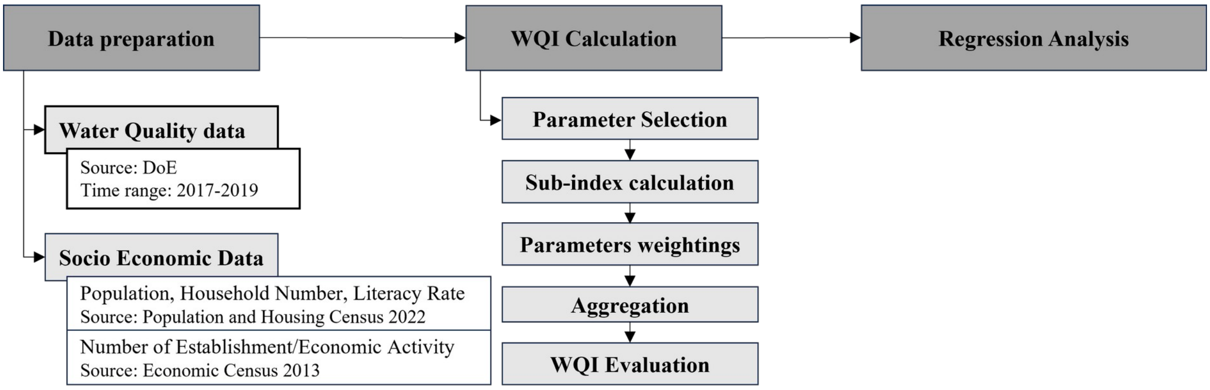

Figure 1: Methodological approach of the study

2.1 Data Preparation

For assessing the water quality status of the surface waterbodies of Bangladesh, water quality data of the major rivers and lakes between 2017 and 2019 was collected from the Department of Environment (DoE), Bangladesh. Water quality data of 169 sampling points in 47 surface water bodies including 44 rivers and 3 lakes distributed over 30 districts of Bangladesh was organized and prepared for calculation of WQI. Yearly mean values of the parameters in every monitoring station are considered to calculate the WQI value of a station in a single year. Thus, there were a total of 169 individual WQI values for 169 sampling points during the time 2017-2019 by doing a simple average of the WQI of 3 years. To show the effect of different factors on WQ, the indices were then aggregated for 30 individual districts (having at least one sampling point on their boundary during 2017-2019). District-wise data on population, household number, and literacy rate was collected from the Population and Housing Census 2022: National Report (Volume 1) (BBS, 2023). District-wise data on economic activities or the total number of establishments was collected from the report of Economic Census, 2013 (BBS, 2015).

2.2 Water Quality Index Calculation

The weighted arithmetic WQI method was applied to classify the water quality of surface water of Bangladesh for drinking use. The detailed calculation procedure of this method is discussed in the following subsections.

2.2.1 Parameter Selection

Parameter selection is an important part of calculating any WQI, as the generation of sub-indices depends on it. The parameter selection procedure can be applied to three different systems (Sutadian et al., 2016). Such as fixed systems, open systems, and mixed systems. In a fixed system, WQI is confined to a few sets of parameters, and there is no provision for adding new parameters, even if it becomes useful and necessary. On the other hand, an open system enables the user to combine their preferred and required criteria. The mixed system includes the core fixed parameters needed to calculate the final index as well as new parameters that can be incorporated based on user selections. Since many factors affect the quality of water, many parameters are advised to be used for determining WQI in different methods. These parameters fall into five categories: oxygen level, eutrophication, health aspects, physical qualities, and dissolved compounds (Tyagi et al., 2020). The parameters in this study are chosen depending on the research aims and data availability, as the study is based on secondary data. DoE measured a total of 12 parameters (Physical and Chemical only) and there is no measurement of bacteriological parameters (i.e., total coliform) and Nutrients (i.e., Nitrogen and Phosphorous). Therefore, in this study, we have selected five parameters (pH, DO, BOD, COD, and TDS) that are most significant for analyzing the impact of anthropogenic activity on water quality. During the calculation of WAWQI, a single faulty parameter value may affect the entire story of the Water Quality Index. Therefore, even though data is available, some parameters were left out. For instance, the study does not include Electrical Conductivity (EC), because natural factors like lithology, geology, climate, etc., may cause EC values in coastal rivers to be so high that they may change the general scenario for evaluating the effects of anthropogenic influences. When computing WAWQI, some other studies also used a limited set of parameters for the specific objectives. For instance, Khan et al. (2021) employed three parameters - DO, BOD, and total coliform - to assess the effects of residential sewage discharge directly into the Gomti River in India during the COVID-19 lockdown period, when there was a possible risk of faecal-oral transmission. The WQI of surface water samples from the Mahi, Sabarmati, Narmada, and Tapi rivers in Gujarat, India, was assessed by Nihalani & Meeruty (2021) using five parameters: pH, DO, BOD, nitrate, and total coliform.

2.2.2 Sub-Index Calculation

Quality rating or sub-indices of the parameters, Q_i is calculated according to the equation (1).

$$Q_i = \{(V_i - V_0)/(S_i - V_0)\} * 100 \quad (1)$$

Where, V_i is the estimated value of the i^{th} parameter; V_0 is the ideal value of the parameter in pure water; S_i is the standard permissible value of the i^{th} parameter for drinking water according to WHO guidelines.

2.2.3 Parameter Weightings

Unit weight for the i^{th} parameters is calculated according to equation (2).

$$W_i = \frac{K}{S_i} \quad (2)$$

Where, K is a proportional constant which can be calculated according to equation (3).

$$K = \frac{1}{\sum (1/S_i)} \quad (3)$$

2.2.4 Aggregation

The final WQI value is calculated by aggregating subindices and weights using an additive function as shown in equation (4).

$$WQI = \frac{\sum W_i Q_i}{\sum W_i} \quad (4)$$

Where, W_i is the weightage of the i^{th} parameter, Q_i is the quality rating or sub-index value of the i^{th} parameter.

2.2.5 WQI Evaluation

The calculated WQI values were then evaluated for describing the quality status of the waterbodies considered as a source of drinking water. Table 1 shows the water quality rating according to the Weighted Arithmetic Water Quality Index.

Table 1: Water quality rating as per weighted arithmetic water quality index method (Brown et al., 1972; Tokatli, 2019)

WQI Level	Water Quality Status	Usage Possibilities	Rating
0-25	Excellent	Drinking, irrigation, industrial	A
26-50	Good	Drinking, irrigation, industrial	B
51-75	Poor	Irrigation, industrial	C
76-100	Very poor	Irrigation	D
Above 100	Unsuitable	Proper treatment is required	E

2.3 Regression Analysis

Linear regression analysis of the data is performed to see the effect of different factors like population, household number, literacy rate, and economic activity on water quality (WQI) individually. The general equation for the linear regression model is shown in equation (5).

$$Y = \beta_0 + \beta_1 X + \varepsilon \quad (5)$$

Here, Y is the dependent variable (in this case WQI), X is the independent variable (i.e., population, household number, literacy rate, and number of establishments), β_0 and β_1 are the population parameters of the regression coefficients, and ε is the error variable.

The significance of the correlation between the dependent and independent variables was tested considering the significance level as 0.05 (value of α).

3 RESULT AND DISCUSSIONS

3.1 WQI Calculation

DoE water quality data from 2017 to 2019 are used for calculating WQI. Five water quality parameters including pH, DO, BOD, COD, and TDS were used. Detailed statistics of the water quality data from 2017 to 2019 are given in Table 2. High TDS and COD values were observed in some sampling points situated in the coastal region or near an industrial effluent.

Table 2: Statistics of the DoE water quality data (2017-2019)

WQ Parameters	Mean	SD	Max	Min
pH	7.51	0.38	9.35	4.6
DO	5.09	2.21	12.4	0
BOD	6.17	10.25	86	0
COD	65.39	88.52	1371	2.4
TDS	1041.25	2645.31	18640	9

Using the weighted arithmetic WQI approach, the WQI of 169 sampling points of the DoE is determined for the years 2017, 2018, and 2019. The box and whisker plot (Figure 2) displays the statistical data, which includes the medians, ranges, and outliers of the estimated WQI for each of these three years separately as well as averaging them. The median did not significantly change between 2017 and 2018, yet from 2018 to 2019, there was a slight increase. Therefore, it can be noted that the quality of the water has declined over time. The 2017 datasets have a wider range than the 2018 datasets. Additionally, the range is greater in 2019 than it was in 2018.

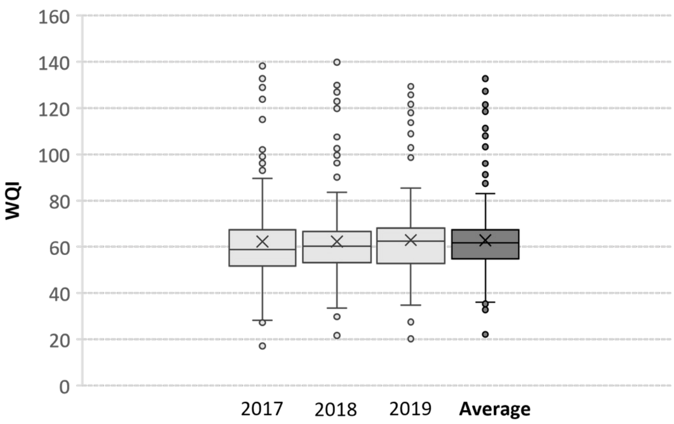

Figure 2: Water Quality Indices of the sampling points from 2017 to 2019

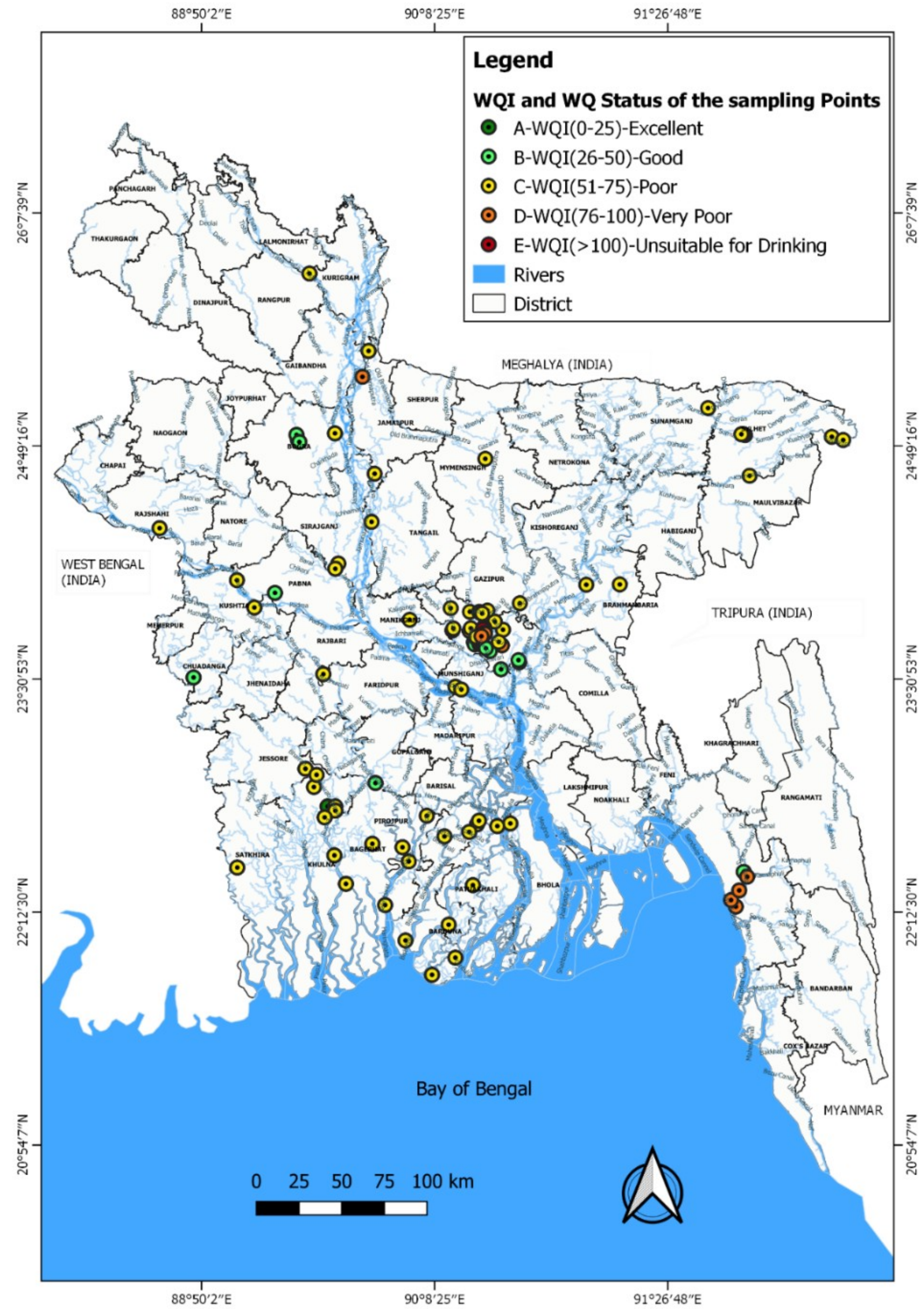

Figure 3: Water Quality Indices in different surface water monitoring stations of Bangladesh (average of 2017, 2018, and 2019)

Figure 3 shows a map of Bangladesh's surface water quality status (average of 2017, 2018, and 2019) based on DoE sampling stations spread across 44 rivers and 3 lakes. The majority of surface water stations have poor water quality (Rating-C) which can be used for irrigation and industrial purposes. Additionally, some stations have very poor (Rating-D) water quality, and some stations have unsuitable (Rating-D) water quality which requires proper treatment for use. Most of these worst stations are situated in and around Chattogram city and Dhaka city where huge number of industrial or domestic wastewater effluents exist. From the map, it can also be observed that some sampling points in and around Dhaka city show good water quality status (Rating B). Such results may occur as the study did not account for seasonal variation and instead considered the yearly mean value of the parameters while calculating WQI. High flow in some rivers during the monsoon season may improve their water quality. Therefore, taking seasonal variation into account and calculating the WQI for both the dry and wet periods separately can help to provide a more realistic scenario of the water quality of the stations.

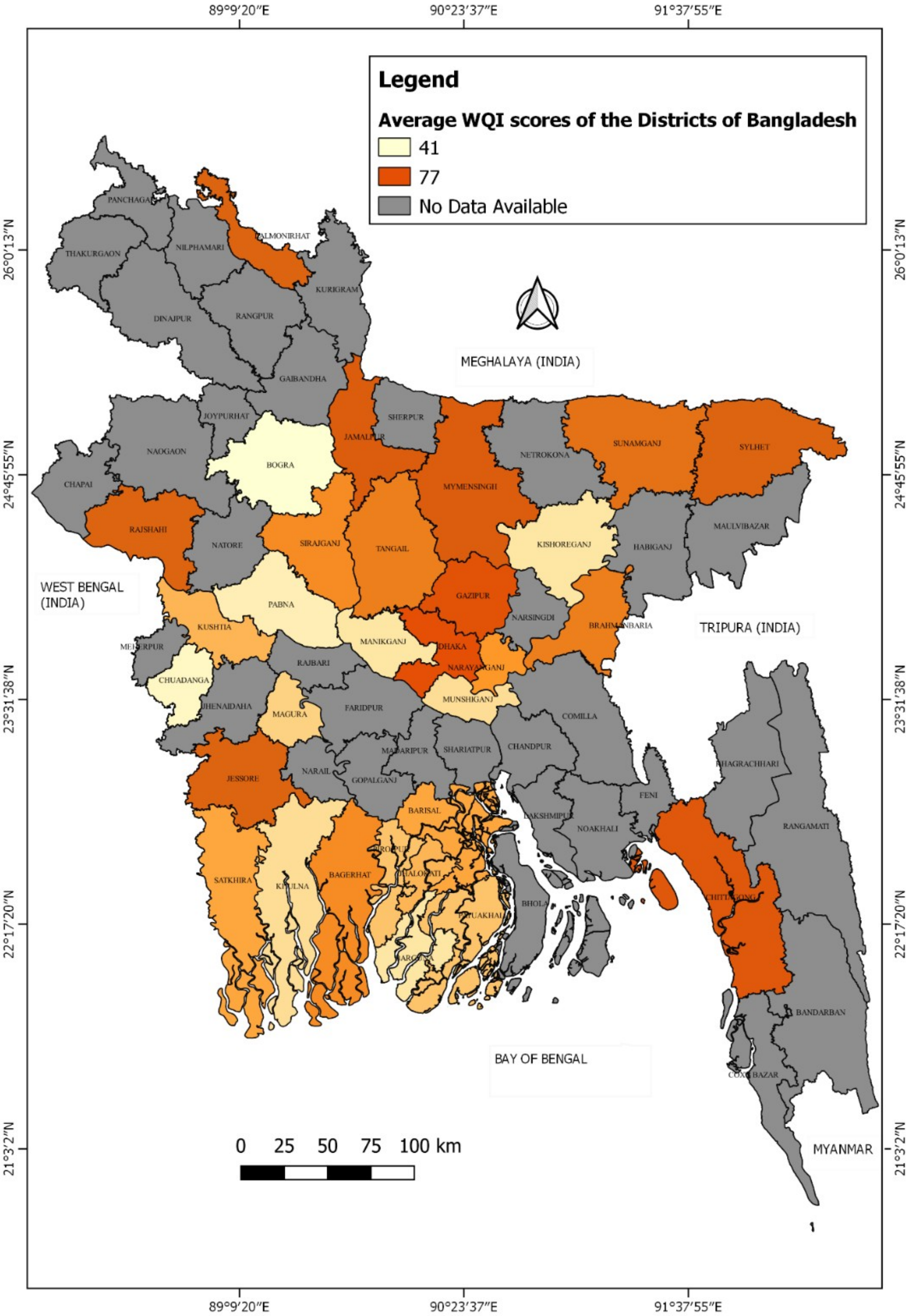

Figure 4: Average Water Quality Indices in different districts of Bangladesh

A map depicting Bangladesh's surface water quality condition per district is shown in Figure 4. Each district is assigned a WQI score once all the points located within it have been compiled and their scores averaged. As a result, for thirty districts with at least one sampling point within their administrative boundaries, thirty distinct WQI scores were assigned. The range of the district's WQI scores varies from 41 to 78. Districts with high WQI scores include Dhaka, Chattogram, Gazipur, Jessore, Lalmonirhat, and others. These districts are typically densely populated and have a high level of economic activity. Therefore, an increase in anthropogenic activity may have the potential to worsen the quality of the water. The next subsection analyses these impacts. It is observed that some districts have many sampling locations while other districts only have one. Additionally, certain sampling locations may be situated close to the administrative boundaries of other districts. As a result, there is a possibility of deviations from the actual scenario while determining and comparing the districts' WQI.

3.2 Effects of Different Factors on Water Quality

There are many reasons for the deterioration of surface water quality. Among them, different kinds of anthropogenic activities have the most significant impact. The rapid growth of population and economic developments are responsible for the generation of more wastewater from households, hospitals, industries, and any other types of establishments. Open dumping of solid waste in the open land and waterbodies by unaware people may also have a significant impact on water quality deterioration. Education and awareness among people may reduce such activities. In this study, effort was made to show the impact of some such factors on water quality through regression analysis. The summary of the outcomes of all the regression analysis are shown in Table 3.

Table 3: Summary of all the regression analyses results

Variable	Coefficients		R^2	Significance			Type of Correlation
	β_0	β_1		p	Status		
Population	55.94	1.67×10^{-6}	0.315	0.001	$p<0.05$	Significant	Positive
Household number	56.42	5.99×10^{-6}	0.295	0.002	$p<0.05$	Significant	Positive
Literacy rate	46.49	0.19	0.021	0.445	$p>0.05$	Not Significant	No Correlation
Economic activity	57.29	2.76×10^{-5}	0.181	0.019	$p<0.05$	Significant	Positive

3.2.1 Effect of Population on Water Quality

Bangladesh is one of the most densely populated countries in the world. The country has a population of over 160 million people, of which 31.51% reside in urban areas (BBS, 2023). Anthropogenic activities are also high where number of populations is high. It is general to have the impact of such activities on surrounding ecosystems, especially on aquatic ecosystems. In this study, a positive correlation between WQI and the population of a district is found. Figure 5 shows the relationship between population and WQI. The relation can be expressed as equation (6).

$$WQI = 55.94 + \left(1.67 \times 10^{-6}\right) \times Population \tag{6}$$

The R^2 value is 0.315 which indicates that the independent variable (population) explains 31.5 % of the variability of the dependent variable (WQI). The result also shows that the independent variable (population) statistically significantly predicts the dependent variable (WQI), $F(1, 28) = 12.9$, $p < 0.05$ (i.e., the regression model is a good fit for the data).

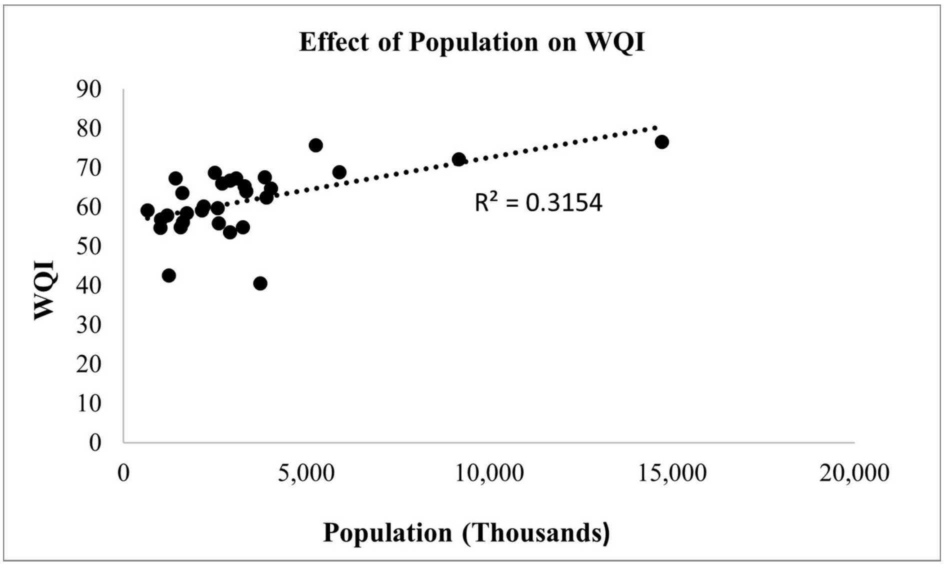

Figure 5: Effect of Population on Water Quality Index

3.2.2 Effect of Household Number on Water Quality

Every household is a unit of waste generation, both solid waste and wastewater. In many cases in a developing country like Bangladesh, the generated solid waste is dumped in open land in absence of a proper management system. Wastewater is sometimes treated through sewerage system but there is a common habit of the city dwellers to dispose of their wastewater into a surface water body. Thus, there is a huge possibility of having a relationship between household numbers and WQI. In this study, a positive correlation between the number of households in the districts and their WQI scores is found as well. Figure 6 shows the relationship between the number of households and WQI. The relationship is similar to the relationship that exists between the population and WQI. The relation can be expressed as equation (7).

$$WQI = 56.42 + \left(5.99 \times 10^{-6}\right) \times Household\,Number \tag{7}$$

The R^2 value is 0.295 which indicates that the independent variable (household number) explains 29.5 % of the variability of the dependent variable (WQI). The result also shows that the independent variable (household number) statistically significantly predicts the dependent variable (WQI), F (1, 28) = 11.7, $p < 0.05$ (i.e., the regression model is a good fit for the data).

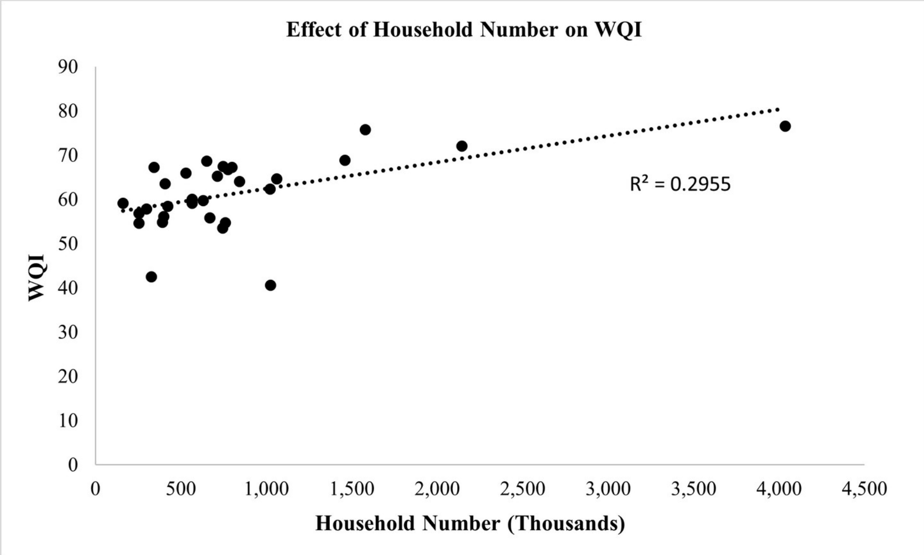

Figure 6: Effect of Household Number on Water Quality Index

3.2.3 Effect of Literacy Rate on Water Quality

The percentage of a population that can read and write is known as its literacy rate. A high proportion of literacy suggests that a significant portion of the population is knowledgeable and capable of gaining access to resources and information that can enhance their quality of life. A low rate of literacy may indicate other societal problems, such as poverty or limited access to school. Therefore, it is expected that literate people will be knowledgeable about all facets of community development as well as concerns associated with water. They will behave in a way that prevents them from taking actions that harm ecosystems. So, there may be a possibility of having a relation between WQI and literacy rate. Unfortunately, in this study, it was found that no such significant relationship between them exists. The result shows that the independent variable (literacy rate) statistically does not significantly predict the dependent variable (WQI), $F(1, 28) = 0.6$, $p > 0.05$ (i.e., the regression model is not a good fit for the data). The R^2 value is 0.021 which indicates that the independent variable (literacy rate) explains only 2.1 % of the variability of the dependent variable (WQI). Figure 7 shows the plot of WQI against the literacy rate. It is clear from the outcomes that only an increase in literacy rate is not enough for the improvement of water quality. The people should also be aware of gaining water-related knowledge, attitudes, and behaviours which is sometimes termed as “Water Literacy” by the academicians.

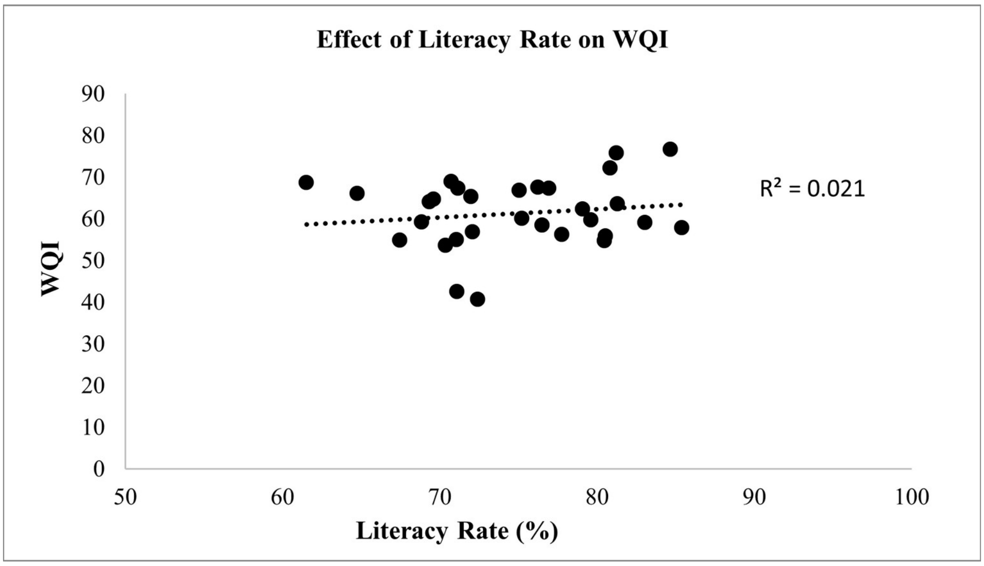

Figure 7: Effect of Literacy Rate on Water Quality Index

3.2.4 Effect of Economic Activity on Water Quality

Rapid economic growth in Bangladesh also increased the development of more economic establishments. Major economic activities in Bangladesh include- wholesale and retail trade, motor vehicles repairing; accommodation and food service activities; transportation and storage; manufacturing; education; and other economic activities (BBS, 2015). Most of the economic establishments are the source of wastewater and different kinds of pollutants that may pollute the surrounding surface water bodies. In this study, it was found that a positive correlation between WQI and number of total establishments in a district exists. Figure 8 shows the relationship between the number of total economic establishments and WQI. The relation can be expressed as equation (8).

$$WQI = 57.29 + \left(2.76 \times 10^{-5}\right) \times Number\ of\ Establishments \tag{8}$$

The R^2 value is 0.181 which indicates that the independent variable (number of economic establishments) explains 18.1 % of the variability of the dependent variable (WQI). The result also shows that the independent variable (number of economic establishments) statistically significantly predicts the dependent variable (WQI), $F (1, 28) = 6.18$, $p < 0.05$ (i.e., the regression model is a good fit for the data).

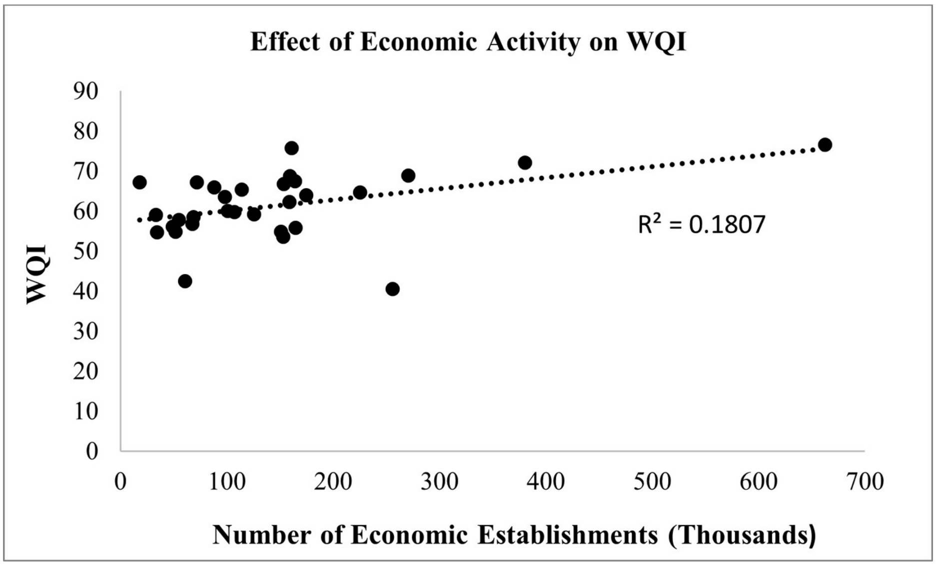

Figure 8: Effect of Economic Activity on Water Quality Index

3.3 Limitations and Future Opportunities

This study has some limitations regarding data availability and resource constraints. Five physio-chemical water quality parameters were selected in this study for calculating WQI considering data availability. Some important parameters such as total coliform, nitrate, phosphate, heavy metals, Electrical Conductivity (EC), etc. were not considered in this study. Considering more parameters to calculate WQI is helpful to find the more appropriate water quality status as every parameter has some significant role in defining water quality status. Again, the study used the yearly mean value of the parameters for calculating the WQI of a sampling point. Some stations may have high seasonal variability compared to others which may affect the final WQI scores after aggregating them district-wise. Though water quality data from 2017 to 2019 is used to calculate the WQI of the districts, district-wise socio-economic data is not found for the same period. This may have some effect on the actual relationship between WQI and the socio-economic factors. However, to the best of the author's knowledge, this study is the first attempt to develop the WQI of the surface water bodies distributed all over Bangladesh and their correlation with socio-economic factors. This work can be expanded by considering more socio-economic factors and more comprehensive datasets. Seasonal variation can be explored in future research with more updated datasets from DoE and BBS.

4 CONCLUSIONS

The study's findings indicate that most of Bangladesh's surface water bodies have poor water quality and are not directly drinkable without treatment. The findings also imply that a rise in the number of people, households, and economic establishments has a detrimental effect on the quality of the water. Such an effect is caused by the open disposal of household and industrial solid waste as well as the increased discharge of wastewater from households and businesses into surface water bodies. Ordinary literacy cannot alter such human tendencies; widespread development of water literacy is necessary. The authorities in Bangladesh should take the appropriate actions to restrict the unwanted dumping of solid waste and the discharge of sewage and industrial waste to improve the quality of the country's surface water. With a more stringent dataset and methodology selection, future research can concentrate on a wider range of issues influencing water quality.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to Mr. Md. Sohel Masud, Director, Water Supply, Sanitation, and Urban Water Management Division, Institute of Water Modelling (IWM) for his valuable guidance during the study. The authors are also grateful to Mr. Mohammed Solaiman Haider, Director, Department of Environment (DoE), for his invaluable support regarding surface water quality data and other guidance.

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