COMPREHENSIVE ASSESSMENT AND SPATIAL MAPPING OF SURFACE WATER QUALITY FOR IRRIGATION USING GIS IN THE SOUTHEASTERN REGION OF BANGLADESH

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ABSTRACT

Water sources are susceptible to contamination due to various factors, including geological conditions, agricultural activities, industrial activities, and other human activities. In developing countries, like Bangladesh, water pollution remains a serious environmental concern and the rivers often exceed the water quality standards for agricultural, drinking, and industrial uses. Ensuring water safety is therefore critical. The purpose of this investigation was to assess surface water quality for irrigation purposes. In this study, a Water Quality Index (WQI) was estimated, and the spatial distribution of six surface water quality parameters was determined using Geographic Information System (GIS) techniques. Water samples were collected from different stations along the Karnaphuli and the Halda. The measured parameters include pH, chemical oxygen demand (COD), biochemical oxygen demand (BOD), total dissolved solids (TDS), Suspended Solid Particles (SS), and Dissolved Oxygen (DO). For the spatial distribution of the surface water quality parameters, the interpolation technique Inverse Distance Weighted (IDW) was applied using GIS tools. Results and analyses indicated a WQI value of 670 at the CUFT station, downstream portion of the Karnaphuli River, indicating highly polluted water. In contrast, the Halda River has the highest WQI value at Moduna Ghat station, which is 249, indicating an inferior quality status. The findings of this study are valuable for identifying significant contamination sources across different areas and subsequently help taking initiatives aimed at improving water quality. The study serves as a useful tool for ongoing water quality monitoring and management to prevent future pollution.

Keywords: *Water Quality Index (WQI),Spatial Mapping, Geographic Information System (GIS), Inverse Distance Weighted (IDW), BECR-2023*

1. INTRODUCTION

Water is the most crucial universal resource for sustaining life and is required in almost all human activities, including drinking, municipal use, irrigation to meet food needs, power generation, industrial use, navigation, and recreation. Water demand has increased over the years, leading to pollution and scarcity in many parts of the world. In many parts of the world, Rivers and Lakes show increasing levels of water pollution. This holds especially for developing countries undergoing economic expansion and population growth. Around 230 rivers flow through Bangladesh, including 54 international rivers. Urbanization is considered one of the main drivers of pollution in these rivers and water bodies (DoE, 2001). Many studies have shown that the quality of surface water of the country's rivers is becoming increasingly polluted and is at high risk (DoE, 1993).

Despite having many rivers, groundwater is the primary source of irrigation for cultivation in Bangladesh. A typical example is that 78% of the total irrigated area in Bangladesh's Northwest region is groundwater-fed (Hasanuzzaman et al., 2017; Mainuddin et al., 2020) due to a shortage of surface water. As a result, the levels of groundwater have been gradually falling down in many areas (Ahmad et al., 2014; Mojid et al., 2021). To increase production, the agricultural sector is being challenged by limited water availability (Djaman et al., 2018). In the coming decades, agriculture will continue to consume more water, and multi-dimensional groundwater use in the household and industrial sectors is also rising. Therefore, improving water productivity and quality, and managing its use, have become crucial for enhancing agricultural efficiency and safeguarding food security with the constraints of water resources.

Using surface water from rivers and lakes can be a solution to overcome this critical situation. However, to fully utilize surface water sources, the water quality must be known. In the southeastern region of Bangladesh, the main rivers are the Karnaphuli, Matamuhuri, Halda, Chingri, Sangu, Naf and also Kaptai Lake, which provide the region's surface water. However, these sources are currently in vulnerable condition due to various forms of pollution. The most important and prime seaport of Bangladesh is located at the estuary of the Karnaphuli River. Since independence, a huge number of chemical and fertilizer factories have been established on both riverbanks. The wastes from these factories are being dumped straightly into the river. Pollution of the Karnaphuli River also occurred due to oil leaking from ships and boats. A large number of studies have found an excessive waste assimilation capacity, which has already turned the river water unsuitable for fisheries, drinking, irrigation etc. The Tidal River Halda is considered the only natural breeding hub for carps in Bangladesh; however, this unique ecological activity is affected by the pollution of the Karnaphuli River. During dry season, sea water intrusion into Karnaphuli, Halda, Sangu, and Naf rivers will increase salinity and destroy their biodiversity due to rise in the sea level.

The Karnaphuli, Sangu, Halda, and Matamuhuri rivers and their tributaries have all been part of previous investigations in the region that frequently identified a "bad" to "medium" water quality status. Deterioration of water quality, pollution in water resources, and loss of aquatic plants and animals are the mojor critical environmental issues that require quick attention at both national and international scales (Sarwar et al., 2010; Susmith Kundu et al., 2024; Uddin et al., 2019). A study has examined the spatial distribution regarding the pollution of microplastic in the sediments of the Karnaphuli River Estuary (Rakib et al., 2022). The impact on Chittagong's public health has been studied due to heavy and toxic metal pollution in the Karnaphuli River (Ahmed et al., 2021). Hossen & Jishan (2018) determined the WQI at five different stations along the Halda River. Zuthi et al. (2020) assessed the quality of water of the Bamunshahi Canal, a tributary of the Karnaphuli River. In the southeastern region, no previous study has shown concentrations of water-quality parameters alongside the WQI.

The objective of this paper is to evaluate the WQI for sustainable irrigation and spatial mapping of the Karnaphuli and Halda rivers of Bangladesh. WQI is a simple method by the utilization of surveying the general water quality using a group of parameters that reduce the large amounts of information to a single number, usually dimensionless. Such index gives the general water quality status which can be of extraordinary help in the choice of a suitable water-treatment technique to address the pollution. This study aims to assess the current state of water quality by collecting samples from 9 key points from the rivers Karnaphuli and Halda, and analyzing 6 critical physicochemical and biological parameters like pH, DO, BOD, COD, TDS and SS with the standards as outlined in the Bangladesh Environmental Conservation Rules (BECR-2023).

The study then applied GIS-based IDW interpolation methods to develop a map for the spatial distribution of each parameter. Using WQI within a GIS platform could provide decision-makers with monitoring report data to understand surface water quality and support optimal use in the future as well. The outcome provides a valuable method for identifying the primary sources of pollution across the landscape. It will support pollution control efforts in specific regions and help with the long-term management of water resources for agriculture and other uses in those regions.

2. METHODOLOGY

2.1 Study Area

Karnaphuli and Halda are the two major rivers of Chattogram city, as shown in Figure 1, playing an important role in water supply, fisheries navigation, and the local ecosystem. The Karnaphuli River flows through Chattogram city, receiving both industrial and urban discharges, which influence the downstream water quality. The Halda River is one of Bangladesh's natural rivers for carp breeding, making it significant for sustainable fish production.

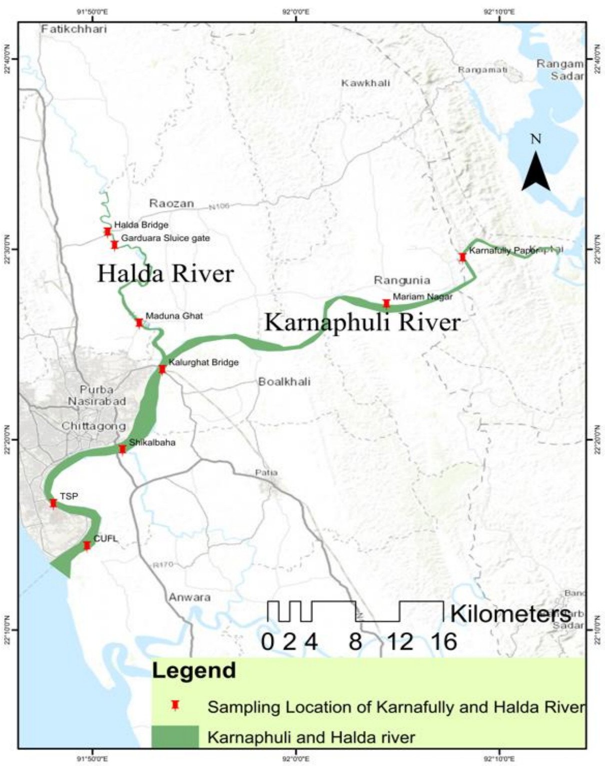

Figure 1: Location of study area with sampling points.

2.2 Sample Collection

The water quality parameter data for surface water samples were collected from two major rivers, Karnaphuli and Halda, comprising a total of nine sampling stations, as shown in Table 1 across these water bodies. Six key parameters were taken as consideration for determining the WQI. The physical and chemical parameters are pH, COD, BOD, TS, TDS, SS.

Table 1: Coordinates of the water collecting station

No	River	Sampling Station Name	**Coordinate**	
			Latitude	Longitude
1	Karnaphuli	CUFL	22.2390404	91.8288404
2		TSP	22.2760927	91.8012482
3		Shikalbaha	22.3232579	91.8579323
4		Kalurghat Bridge	22.3934168	91.8904595
5		Mariam Nagar	22.4509479	92.0741345
6		Karnafully Paper	22.4913719	92.1365639
7	Halda	Maduna Ghat	22.4340813,	91.8715864
8		Garduara Sluice gate	22.5022414	91.8514504
9		Halda Bridge	22.513834	91.8457122

2.3 Water Quality Index Calculation

WQI for the Karnaphuli and Halda was calculated using six parameters: pH, BOD, COD, DO, TDS, and SS. WQI was calculated using the weighted arithmetic WQI method (Horton, 1965), and then water parameters were multiplied by a weighting factor and aggregated using a simple arithmetic mean (Brown et al., 1970; Cude, 2001) by these three (1,2,3) equations:

$$Q_i = \frac{M_i - L_i}{S_i - L_i} * 100 \quad (1)$$

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

$$WQI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (3)$$

Where, Q_i is represented as the sub-index of the i^{th} parameter, w_i the unit weightage of the i^{th} parameter, n is the number of parameters included, M_i is the monitored value of the parameter, L_i is used for the ideal value and S_i is the standard value of the i^{th} parameter. The ideal value for dissolved oxygen (DO) = 14.6 mg/l and pH = 7, and for other parameters, it is taken equal to zero (0) (Abbasi & Abbasi, 2012; J. Tripathy & Sahu, 2005). The weightage unit (W_i) of each parameter was calculated a value inversely proportional to the standard of the World Health Organization (S_i) (World Health Organization, 2011). Table 2 classifies water quality into different categories based on the WQI range.

Table 2: WQI Categories and Corresponding Water Quality Ratings (Alsaqqar et al., 2015)

WQI Range	**< 50**	**50–100**	**100-200**	**200-300**	**300-400**	**>400**
Water Quality	Excellent	Good	Poor	Very Poor	Polluted	Very Polluted

2.4 Analysis the spatial distribution by GIS

In GIS, the IDW interpolation technique is a statistical method that produces a good variogram model, providing the most accurate attribute interpolations. This helps in choosing the best interpolation techniques based on how the natural attributes are distributed. The interpolation depends upon the spatial configuration of the empirical observations, rather than on an assumed model of spatial distribution Using WQI within a GIS platform could provide decision-makers with monitoring report data to understand surface water quality and support optimal use in the future as well. Figure 2 illustrates the complete methodological process followed in this study.

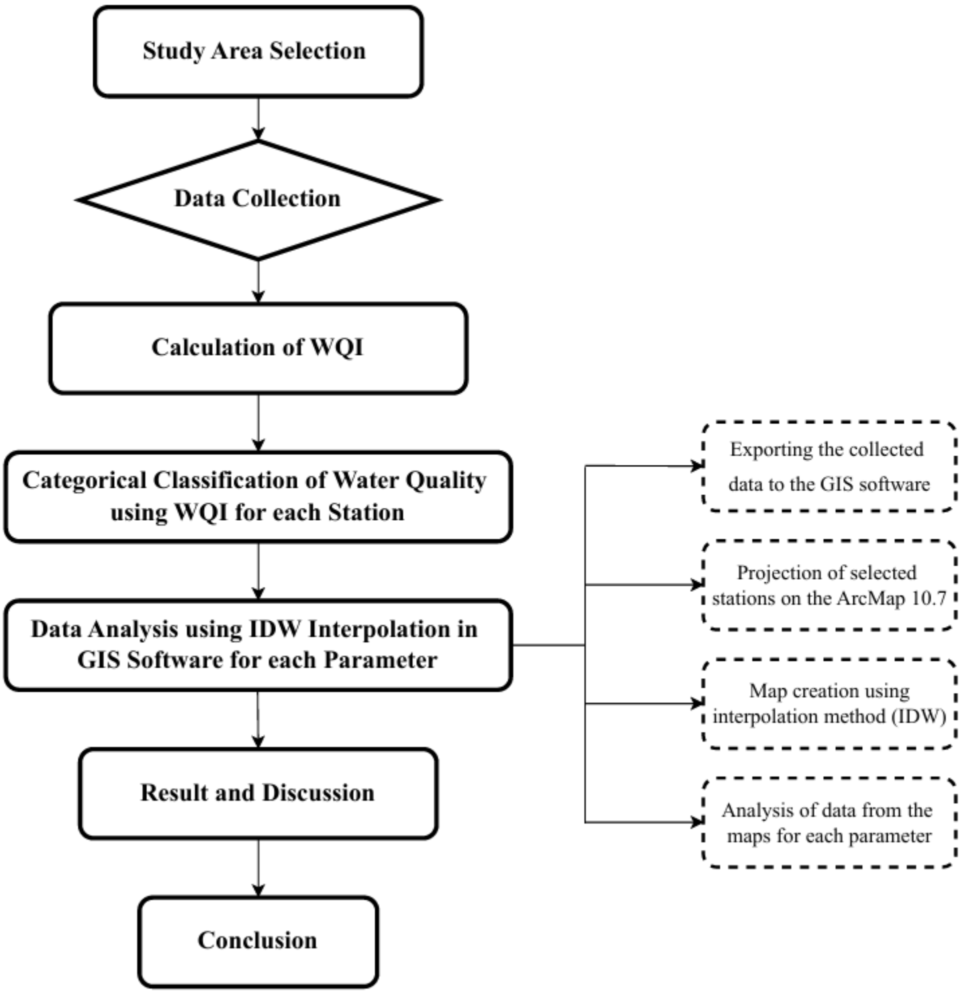

Figure 2: Flow chart of Methodology

3. RESULT AND DISCUSSION

The monthly WQI for the dry season nine station along the Karnaphuli and Halda rivers was determined using the weighted average method, based on six physicochemical parameters. This parameters value was taken from the Department of Environment, Surface and Ground Water Quality report 2023. This section represents the heat map for WQI, the water quality reference value, and the concentration of water quality parameters along the river body.

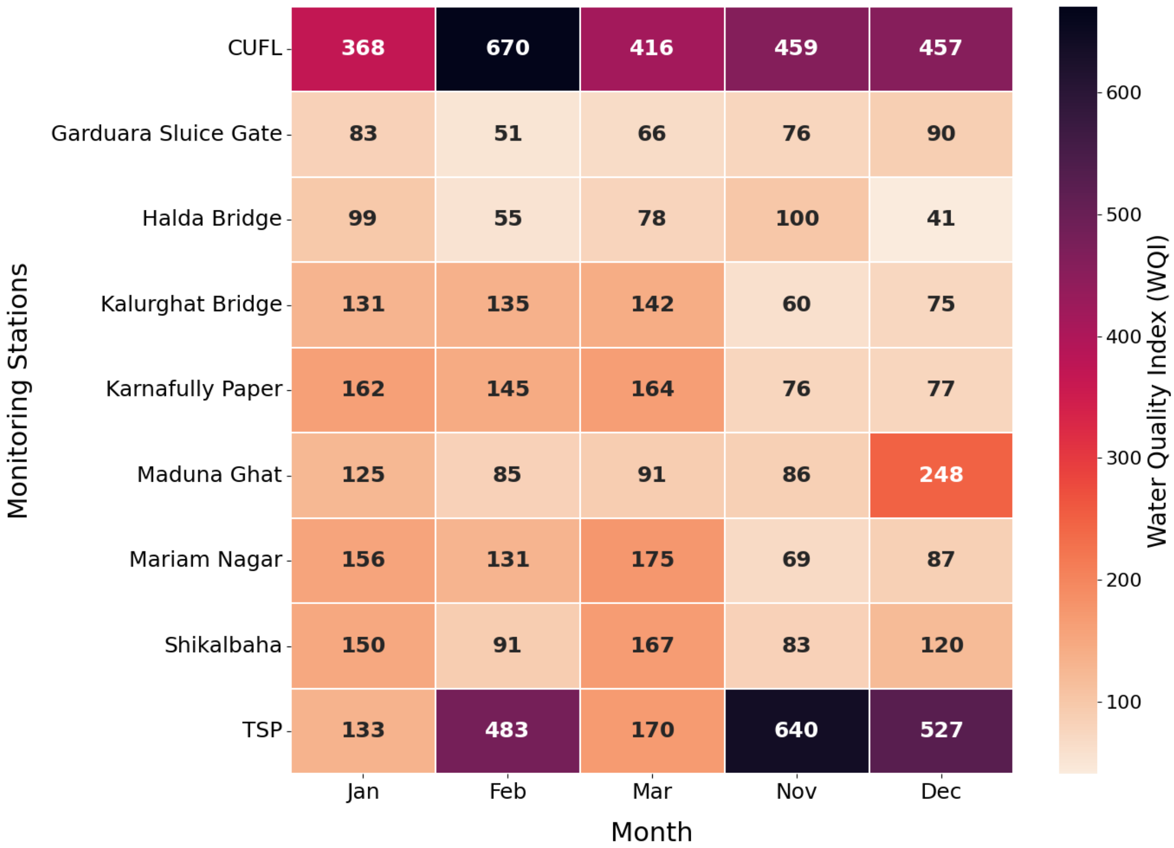

Figure 3: Spatiotemporal Variation of WQI in Karnaphuli River Basin

The heatmap visualized in Figure 3 displays the WQI values for nine monitoring stations over dry seasons. Color intensity indicates the WQI values shown on the right side of the figure. Lighter colors indicate lower WQI, while darker colors indicate higher WQI, potentially indicating worse water quality. Stations of CUFL and TSP on the Karnaphuli River show the highest WQI values, suggesting the poorest water quality. In contrast, the Halda River Maduna Ghat station shows a higher WQI. The months of February and November exhibit higher WQI values, indicating a deterioration in water quality.

Table 3: Reference Limits for River Water Quality Parameters (ECR, 2023)

Parameters	Standard Value	Ideal Value
PH	6.5-8.5	7
DO	5 or more mg/l	14.6 mg/l
BOD	12 mg/l	0
COD	100 mg/l	0
TDS	1000 mg/l	0
SS	10 mg/l	0

The standard values for each water quality parameter for irrigation purposes are taken from ECR 2023, shown in Table 3. The ideal values for pH are 7, DO is 14.6 mg/L, and for all other parameters, the values are zero (Cude, 2001b; J. K. Tripathy & Sahu, 2005).

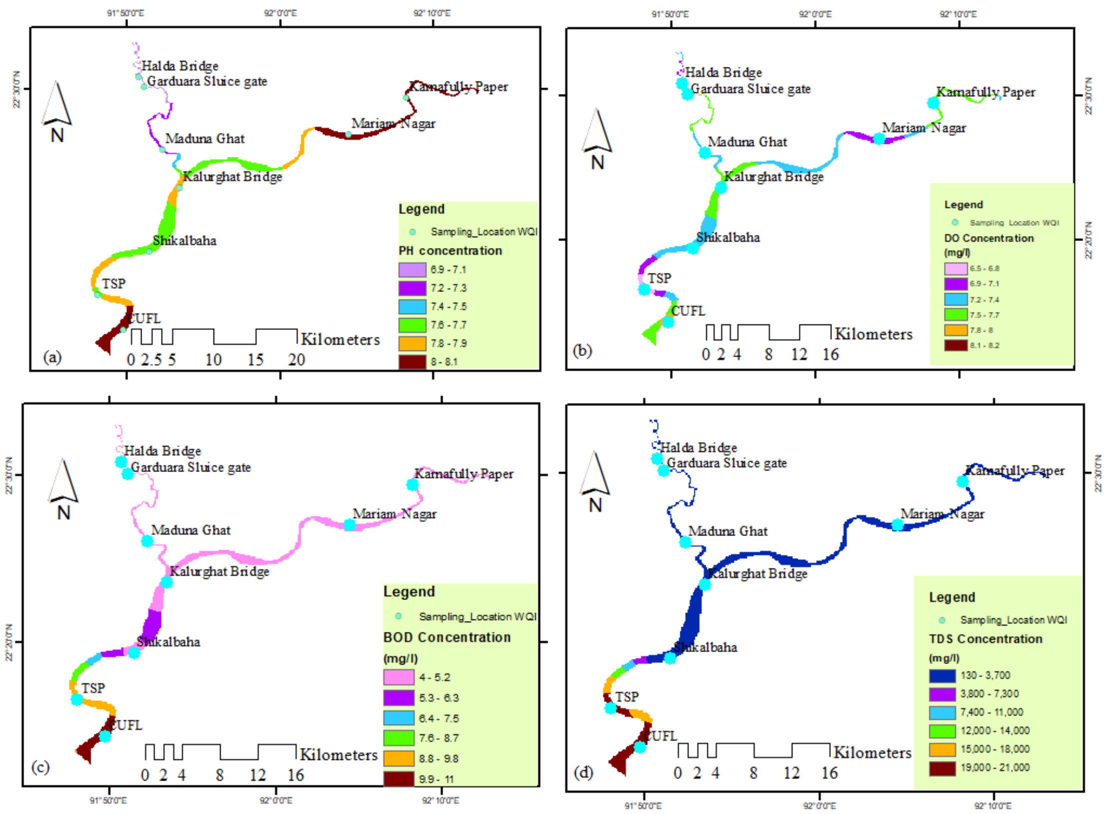

Figure 4: Spatial Distribution of Water Quality Parameters (a. pH, b. DO, c. BOD, and d. TDS) along the Karnaphuli-Halda River System.

Figure 4 shows the Spatial concentration of Water Quality Parameters for November, including pH, DO, BOD, and TDS, along the Karnaphuli-Halda River System. In 2023, during the dry season, the pH levels of sampling points on the Karnaphuli River varied from 6.69 to 8.1. Moreover, in the Halda River, PH varies from 6.08 to 7.26, while the standard for inland surface water is 6.5 to 8.5, as shown in Table 1. Similarly, DO, BOD, and TDS levels of the Karnaphuli and Halda river systems, which sequentially lie between 6.42 to 7.99, 5.02 to 8.46 and 3 to 14, 3 to 5 and 118 to 21500, 62.92 to 434.5, respectively. At the same time, the standard values of DO, BOD, and TDS range from 5 and more, 12 and 1000 mg/l for irrigation purposes.

4. CONCLUSIONS

This study assesses the suitability of water quality for irrigation purposes at nine stations along the Karnaphuli and Halda rivers. The key findings of this research indicate that water quality varies over time and across different locations. On the downstream side of the Karnaphuli River, at the CUFL and TSP location, the water quality is consistently poor. Additionally, at the Halda River, Moduna Ghat location, the water quality is worse and tends to deteriorate during November, February, and March for both rivers. Analysis for individual parameters like, the pH levels of both rivers lie within a safe range; however, the levels of DO, BOD, and TDS often fall outside the safe limits as set for irrigation water. Therefore, careful monitoring is necessary to ensure the sustainability of agriculture. Future work suggests a comprehensive study including additional water quality parameters from some more number of sampling locations for better presentation of WQI.

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DECLARATION

The authors utilized artificial intelligence tools, including ChatGPT (OpenAI, GPT-5.1) and DeepSeek (DeepSeek Inc., DeepSeek-V2), solely to improve the clarity and language of the manuscript.

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