Assessment of Groundwater Quality in Kaliakair Upazila of Gazipur in Terms of Water Quality Indices

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Abstract. In the present study, the suitability of groundwater for drinking and irrigation purposes was analyzed in Kaliakair upazila. Thirty (30) groundwater samples from Kaliakair upazila were collected and examined for pertinent water quality indicators. To estimate the water quality index (WQI) for the drinking purpose, various parameters such as pH, TH, TDS, EC, F^-, Cl^-, Fe, NO_3^-, SO_4^{2-}, As, Alkalinity, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cu, Cd, Ni, Zn and Mn were considered. In the WQI for irrigation, various irrigation indices, SSP, SAR, RSBC, PI, MHR and KR were employed. The WQI for drinking purposes was observed from 15.51 to 76.78, with an average of 27.67 for all samples found fit for drinking purposes. Five classifications have been established for drinking water based on WQI: excellent, good, poor, very poor, and unfit for drinking. The ArcGIS map shows that approximately 90% of the study area had an excellent index, while only 10% in the southwest region had a good index. That means all study areas of DWQI remained within the standard limit. The WQI for irrigation purposes was observed from 11.63 to 75.12, with an average of 38.52 for all samples found fit for irrigation purposes. Irrigation water has been classified into four groups based on WQI: excellent, good, permissible, and unfit for irrigation. After analysis of the inverse distance weighting (IDW) method in the ArcGIS map, it can be seen that the southwest region is more suitable for irrigation purposes.

Keywords: Water quality index, Groundwater, Drinking water, Irrigation, GIS.

1 Introduction

Sustainable groundwater quality is important for drinking, irrigation and household purposes. In Bangladesh, groundwater quality has grown to be a significant concern [1]. Groundwater (GW) serves as the main supply of water for industrial, municipal, agricultural, and drinking purposes in Bangladesh [2]. The unplanned urbanization and quickly expanding industry have made matters worse over time in terms of deterioration. The groundwater (GW) level in Gazipur district and its peri-urban areas is drastically declining [3]. Water quality is being negatively impacted by the startling increase in industrialization

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[4]. This upazila is one of the major textile and dyeing industrial areas in Gazipur district. That type of industry uses a huge amount of groundwater. For this reason, some GW-related problems can arise, like water quality and GW level [5]. In recent times, different studies have revealed that the concentration of iron and manganese rapidly increased in GW and that the suitability of GW go down [6]. Pollution of groundwater is a great threat to human health and the biodiversity of the environment. In Bangladesh, groundwater is the only source of high-quality water, despite the relatively low rate of contamination. Over the past twenty years, Bangladesh has seen an increase in the availability of drinking water; nonetheless, the negative health effects of contaminated water persist [7]. Groundwater quality is continuously monitored and assessed, which serves to protect the environment and save lives. In this study, the groundwater quality for drinking and irrigation purposes will be evaluated by water quality indices. The procedure of evaluating the quality of groundwater is intricate. Based on hydrochemical data, the WQI has been developed to evaluate groundwater quality and its susceptibility to contamination. WQI was computed using the load assignment method to establish drinking water standards.

The objective of the study is to assess the present status of GW quality of the Kaliakair upazila and mapping WQI for drinking and irrigation purposes by using ArcGIS.

2 Methodology

The groundwater samples were collected during January and February 2024, in the dry season. Thirty pre-selected groundwater sampling locations within the Kaliakair upazila were utilized to gather samples. The chosen pumping wells, whose depths ranged from 60 to 250 feet, were the sites from which the groundwater samples were taken. All water samples were collected using standard protocol and placed in high-density polypropylene (HDPP) bottles that had been previously cleaned. Using pre-washed plastic bottles, two sets of samples were taken from each location. Water samples were taken in plastic bottles following five minutes of continuous tube well pumping. Following collection, samples were labeled and then kept in a closed icebox right away. After that, the samples were taken to a lab for chemical analysis. The Inverse Distance Weight technique (IDW) will be used to create the spatial distribution maps of the water quality parameters for irrigation and drinking, and the analytical results will be utilized to create the numerical spatial distribution of the parameters using the ArcGIS 10.8 software.

2.1 Study Area

The study areas as well as groundwater sampling sites were selected at different places in one municipality and nine unions under Kaliakair Upazila. Kaliakair, an upazila of the Gazipur district, is located between 24.0750º N and 90.2167º E in central Bangladesh and has an area of 314.13 km^2. The Kaliakair upazila has one municipality and nine union parishad. There are 183 mauzas and 264 villages in this upazila. It is bounded by Gazipur Sadar and Sreepur upazilas on the east, Sakhipur and Mirzapur upazilas on the north, Savar and Dhamrai upazilas on the south, and Mirzapur upazila on the west [8].

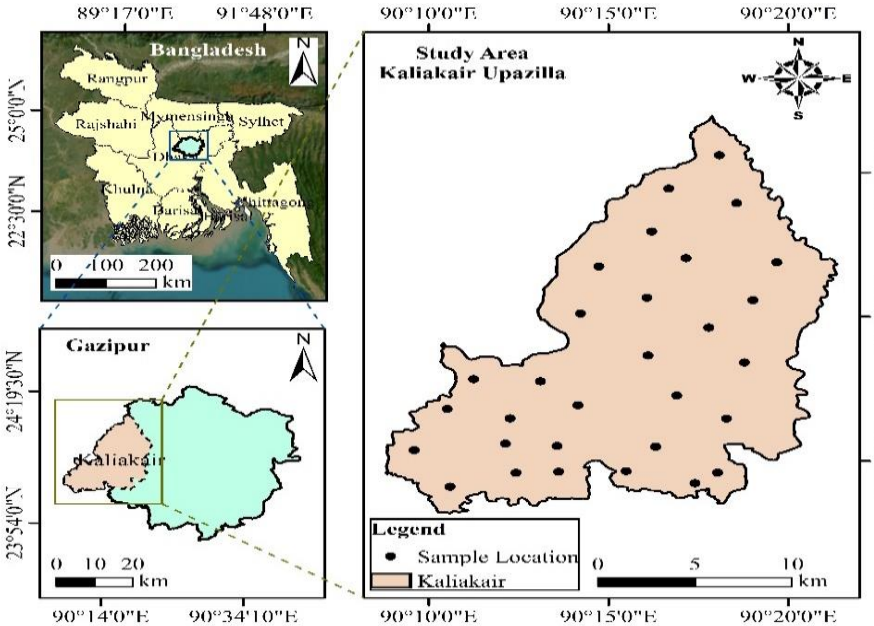


Fig. 1. Location map and sampling points in Kaliakair upazila

2.2 Water Quality Index

The WQI is a composite grading system that was developed to evaluate groundwater quality. The primary objective of the Water Quality Index (WQI) is to integrate extensive and intricate water quality data into a single quality index. Four steps were involved in calculating the DWQI and IWQI [9].

First step, A specific weight (wi) was allocated to each criterion based on its proportional importance in the drinking water quality measurement criteria.

Second step, The following formula was used to determine the relative weight (Rwi).

$$Rwi = wi/\sum_{i=1}^{n} wi \tag{1}$$

In this case, n is the total number of parameters, w_i is the weight of each parameter, and Rw_i is the relative weight. Next, a quality rating scale (q_i) was calculated for each parameter.

Table 1. DWQI computation, relative weight is allocated according to the proportion of the sample that is within the standard deviations [10,11,12].

Parameters	Standards limits	Sample within the standard limit		Weight (w_i)	Relative Wt. (W_i)
		Number	Percentage		
pH	6.5-8.5	28	93.33	4	0.085
TDS (mg/l)	1000	30	100	5	0.106
TH (mg/l)	500	30	100	3	0.064
EC (µs/cm)	1000	30	100	5	0.106
F^- (mg/l)	1	30	100	3	0.064
Cl^- (mg/l)	250	30	100	5	0.106
Fe (mg/l)	0.1	27	90	3	0.064
NO_3^- (mg/l)	45	30	100	5	0.106
Ca^{2+} (mg/l)	75	30	100	2	0.043
Mg^{2+} (mg/l)	30-35	30	100	2	0.043
Na^+ (mg/l)	200	30	100	2	0.043
K^+ (mg/l)	12	30	100	3	0.064
Zn (mg/l)	5	30	100	2	0.043
Mn (mg/l)	0.4	26	86.67	3	0.064
				$\sum = 47$	$\sum = 1$

2.3 Irrigation Water Quality Indices

Soluble Sodium Percentage (SSP). Increased Na concentration in the soil has an impact on the aggregation characteristics of the soil and acts as a dispersant to break up soil aggregates. The combination of Na^+ and Cl^- may hasten the formation of saline soil and lower the rate of infiltration. According to FAO, 1985 has prescribed 80 as an acceptable limit of SSP for Irrigation water.

$$\mathrm{SSP} = \frac{Na^+}{Ca^{2+}+Mg^{2+}+Na^++K^+} * 100 \tag{2}$$

Sodium Adsorption Ratio (SAR). Because the buildup of Na ions in the plant body interferes with photosynthetic activity, causing leaves to fall and affecting soil permeability, which weakens internal drainage, high SAR water lowers agricultural output [13]. According to FAO, 1985 has prescribed 26 as an acceptable limit of SAR for irrigation water.

$$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+}+Mg^{2+})}{2}}} \tag{3}$$

Residual Sodium Bicarbonate (RSBC). High levels of bicarbonate in irrigation water cause direct harm to leaves and fruits, whereas soil RSBC and pH were raised [14].

According to FAO, 1985 has prescribed 10 as an acceptable limit of RSBC for irrigation water.

$$\text{RSBC} = HCO_3^- - Ca^{2+} \tag{4}$$

Permeability Index (PI). When the typical rate of soil infiltration is noticeably decreased, it creates a permeability problem (PI) that prevents crops from receiving enough moisture. This PI is primarily responsible for two aspects of water quality: the water's salt content and the ratio of calcium to sodium in the water. Constant irrigation with mineral-rich groundwater can degrade soil quality and have an impact on seed germination [15]. PI evaluates the efficiency of the water in the soil system. According to FAO, 1985 has prescribed 25 as an acceptable limit of PI for irrigation water.

$$\text{PI} = \frac{Na^+ + \sqrt{HCO^-3}}{Ca^{2+} + Mg^{2+} + Na^+} * 100 \tag{5}$$

Magnesium Hazards Ratio (MH). Alkaline earth elements, specifically calcium and magnesium, are typically found in groundwater in an equilibrium state. Crop growth requires both calcium and magnesium divalent ions. They also establish the soil's physical properties, like friability and aggregation. The soil's ability to bind phosphorus may be reduced as well as salinity increased due to the increased concentration of calcium and magnesium ions (Joshi et al. 2009). According to FAO, 1985 has prescribed 50 as an acceptable limit of MH for irrigation water.

$$\text{MH} = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} * 100 \tag{6}$$

Kelly's Ratio (KR). The Kelley ratio was developed to assess the quality of irrigation water by comparing sodium ions to calcium and magnesium ions. Kelly (1963) proposed that the maximum KR for irrigation water should be 1.0. This shows a healthy tilth condition and the absence of any permeability issues in the soil, as well as a good balance of Na^+, Ca^{2+}, and Mg^{2+}.

$$\text{KR} = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \tag{7}$$

Table 2. Relative weight for the IWQI computation is assigned based on the percentage of the sample that falls within the standard limits [16].

Parameters	Standard value	Sample within the standard limit		Weight (w_i)	Relative Wt. (W_i)
		Number	Percentage		
SSP	80	30	100	2	0.143
SAR	26	30	100	1	0.071
RSBC	10	30	100	2	0.143

MH	50	30	100	5	0.357
KR	1	27	90	4	0.286
				∑ = 14	∑ = 1

Third step, It was calculated by dividing each water sample's concentration by the standard for that particular parameter as stated in the Bangladesh Environmental Conservation Rules, ECR 2023 guidelines. The result was then multiplied by 100. So, the equation of qi:

$$q_i = \frac{Ci}{Si} * 100 \tag{8}$$

where, C_i concentration (mg/l) and q_i quality rating for each chemical parameter in the water sample are shown here.

Fourth step, The DWQI / IWQI calculation using Equation:

$$WQI = \sum_{i=1}^{n} Rwi * qi \tag{9}$$

3 Results and Discussion

3.1 Drinking Water Quality Index (DWQI)

DWQI is a number that indicates the overall quality of water for drinking purposes and thus may prevent many diseases related to water consumption. The equations 1, 2, 3 are employed in order to ascertain the index. Table 1 shows the relative weights for DWQI. Drinking water has been divided into five groups based on the DWQI: excellent, good, poor, very poor, and unfit for drinking purposes.

Table 3. DWQI range and category classification depend on index value [11]

DWQI Value	Category of water	No. of Sample	% of Index Value
<50	Excellent	27	90
50–100	Good	3	10
100-200	Poor	-	-
200–300	Very Poor	-	-
>300	Unfit for drinking purposes	-	-

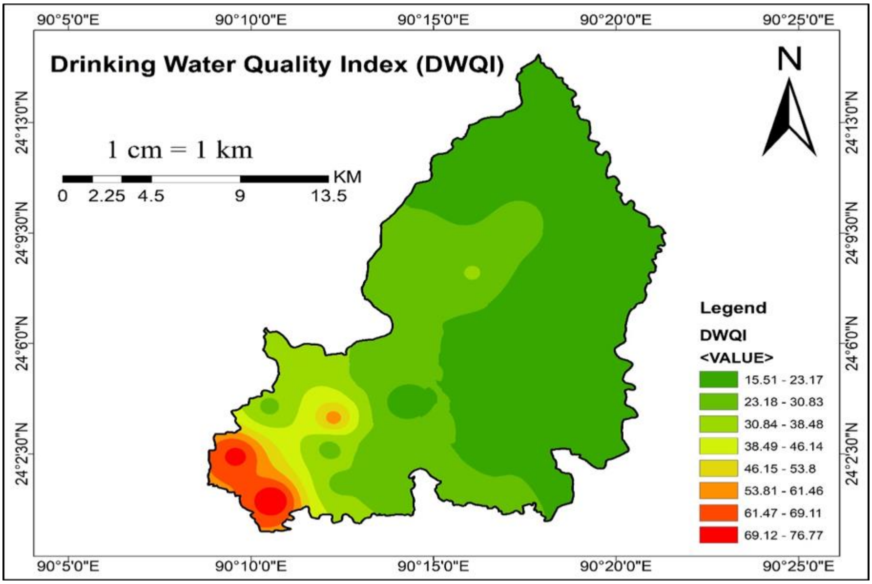


Fig. 2. Spatial distribution map for DWQI

IDW method of the ArcGIS 10.8 software were used to prepare the spatial distribution map. Figure 2 shows that approximately 90% of the study area had excellent index, while only 10% in the Southwest region had good index. That means all study areas DWQI remained within the standard limit. The DWQI of groundwater value from 15.51 to 76.77, with an average of 27.67 for all samples found fit for drinking purposes.

3.2 Groundwater Suitability for Irrigation Purpose

The mineralogical composition of the irrigation water has a major impact on the crop's yield rate. Crop productivity may be negatively impacted by irrigation water containing an excessive number of dissolved ions. The appropriate maintenance of dissolved ions in irrigation water in accordance with crop requirements should also be a priority [12]. The suitability of groundwater for irrigation in the test region has been assessed using the water quality index. Additionally, a number of irrigation appropriateness indicators, like SSP, SAR, RSBC, MH, KR, PI.

Soluble Sodium Percentage (SSP). In this study, it was seen that the minimum concentration value was been 12.62 in location S-18 (Pakrul, Dhaljora) and the maximum value was 47.45 in location S-01 (Talchala, Fulbaria) among the 30 locations in Kaliakair upazila. The average value was 29.91. The SSP was categorized in Table 4 as excellent, good, permissible, doubtful and unsuitable. According to the SSP index, all of the water samples that were collected were appropriate for irrigation, falling within the excellent (16.67%), good (73.33%), and permissible (10%) water quality categories.

Figure 3 shows that the soluble sodium percentage (SSP) map in Kaliakair upazila depends on the test value.

Sodium Adsorption Ratio (SAR). In this study, it was seen that the minimum concentration value was been 0.94 in location S-18 (Pakrul, Dhaljora) and the maximum value was 2.59 in location S-26 (Mouchak Sador) among the 30 sampling locations in Kaliakair upazila. The average value was 1.68. The SAR is categorized in Table 4 as excellent, good, doubtul, and unsuitable. In this study, 100% of the samples remained in the excellent category. Figure 3 shows that the sodium adsorption ratio (SAR) map in Kaliakair upazila depends on the test value.

Residual Sodium Bicarbonate (RSBC). In this study, it was seen that the minimum concentration value was been 0.09 in location S-18 (Pakrul, Dhaljora) and the maximum value was 1.26 in location S-14 (Board Ghor Bazar, Sutrapur) among the 30 sampling locations in Kaliakair upazila. The average value was 0.66. Table 4 classifies the RSBC as a safe, marginal and unsuitable category. In this study, 100% of the samples remained in the safe category. Figure 3 shows that the RSBC map in Kaliakair upazila depends on the test value.

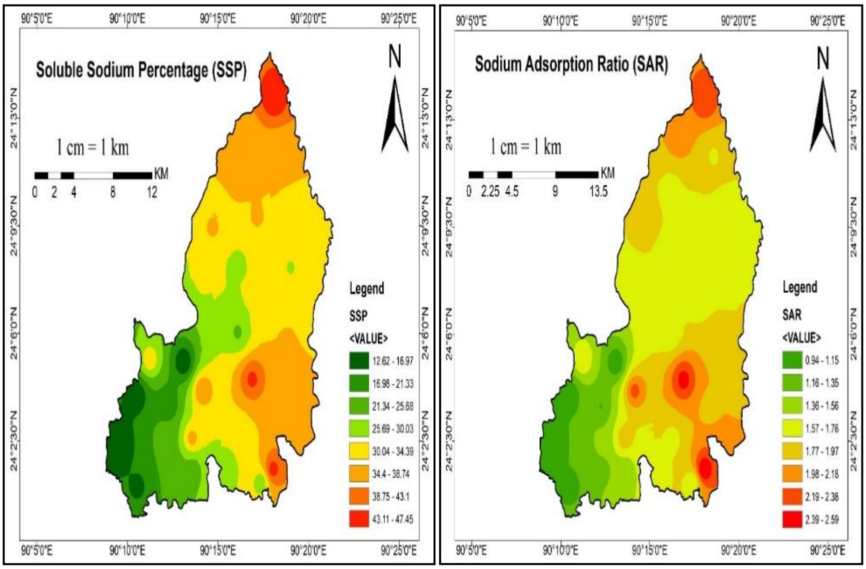
Permeability Index (PI). In this study, it was seen that the minimum concentration value was been 47.01 in location S-18 (Pakrul, Dhaljora) and the maximum value was 208.85 in location S-26 (Mouchak Sador) among the 30 sampling locations in Kaliakair upazila. The average value was 119.76. The PI is categorized in Table 4 as excellent, slightly good, and unsuitable. According to the PI index, all of the water samples that were collecte were fit for irrigation, falling into the excellent (83.33%) and slightly good (16.67%) water quality categories. Figure 3 shows that the permeability index (PI) map in Kaliakair upazila depends on the test value.

Magnesium Hazards Ratio (MH). In this study, it was seen that the minimum concentration value was been 6.59 in location S-18 (Pakrul, Dhaljora) and the maximum value was 47.66 in location S-14 (Board Ghor Bazar, Sutrapur) among the 30 sampling locations in Kaliakair upazila. The average value was 23.02. Table 4 classifies the MH as suitable and unsuitable category. In this study, 100% of the samples remained in the suitable category. Figure 3 shows that the magnesium hazards ratio (MH) map in Kaliakair upazila depends on the test value.

Kelly's Ratio (KR). In this study, it was seen that the minimum concentration value was been 0.15 in location S-18 (Pakrul, Dhaljora) and the maximum value was 1.16 in location S-01 (Talchala, Fulbaria) among the 30 sampling locations in Kaliakair upazila. The average value was 0.54. Table 4 classifies the KR as suitable and unsuitable category. Among all the samples, 90% were suitable and 10% were unsuitable with respect to the KR index. Figure 3 shows that the kelly's ratio (KR) map in Kaliakair upazila depends on the test value.

Table 4. Classification of groundwater using irrigation indices [16]

Parameter/ Indices	Values	Category	No. of samples	% of sample
SSP	<20	Excellent	5	16.67
	20-40	Good	22	73.33
	40-60	Permissible	3	10
	60-80	Doubtful	-	-
	>80	Unsuitable	-	-
SAR	<10	Excellent	30	100
	10-18	Good	-	-
	18-26	Doubtful	-	-
	>26	Unsuitable	-	-
RSBC	<5	Safe	30	100
	5-10	Marginal	-	-
	>10	Unsuitable	-	-
PI	>75	Excellent	25	83.33
	25-75	Slightly Good	5	16.67
	<25	Unsuitable	-	-
MH	<50	Suitable	30	100
	>50	Unsuitable	-	-
KR	<1	Suitable	27	90
	>1	Unsuitable	3	10



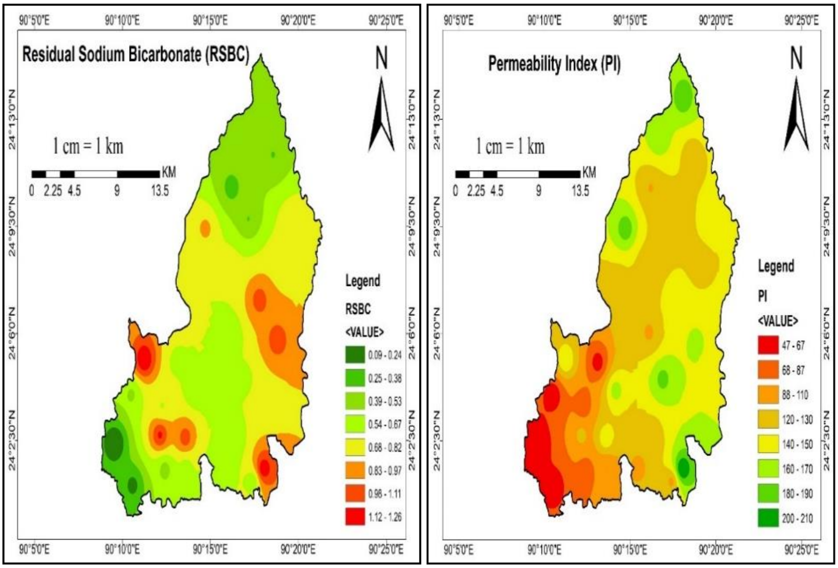


Fig. 3. Spatial distribution of various indices SSP, SAR, RSBC & PI

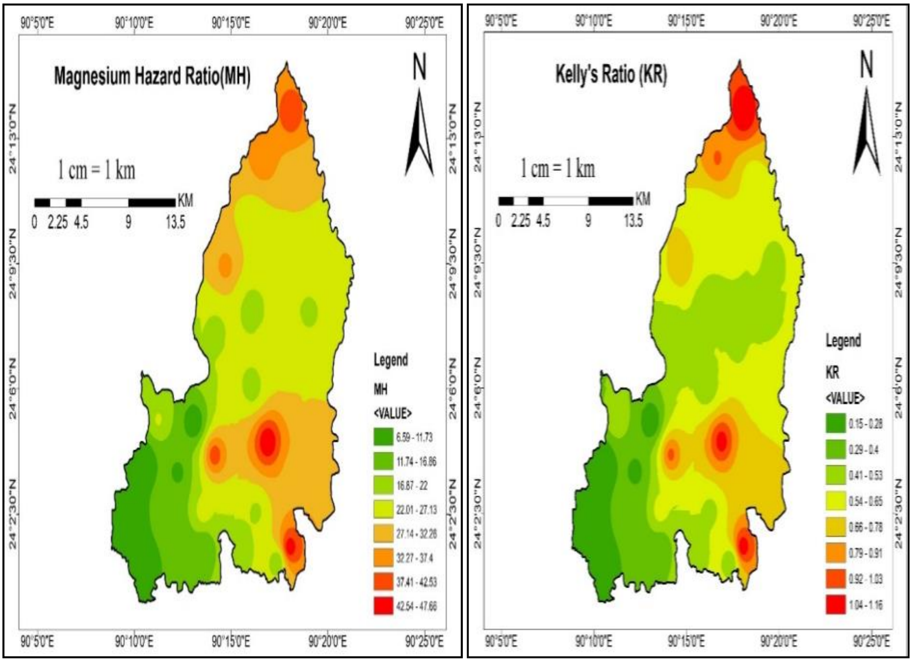


Fig. 4. Spatial distribution of various indices MH & KR.

3.3 Irrigation Water Quality Index (IWQI)

The WQI is a composite grading system that was developed to evaluate groundwater quality for irrigation. Consolidating vast and intricate water quality data into a single quality index is the main objective of the WQI [17]. FAO (1985) standard limits for irrigation indices and water quality parameters provide the basis of the entire computation. When determining the IWQI, a total of six (6) water quality indices are considered. The equations 1, 2, 3 are employed in order to ascertain the index. Table 2 shows the relative weights for irrigation water quality index (IWQI).

Table 5. IWQI range and category classification depend on Index value

IWQI Value	Category of water	No of Sample	% of Index
<150	Excellent	30	100
150–300	Good	-	-
300-450	Permissible	-	-
>450	Unfit for Irrigation purposes	-	-

IDW tools of the ArcGIS 10.8 software were used to prepare the spatial distribution map. Figure 4 shows that the irrigation water quality index (IWQI) map in Kaliakair upazila depends on the index value.

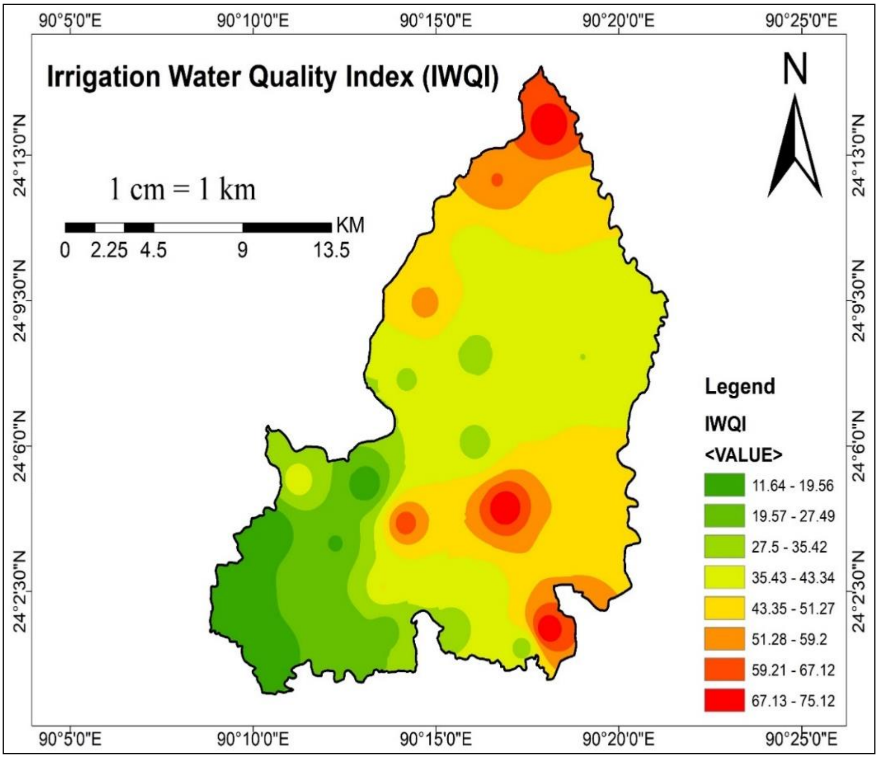


Fig. 5. Spatial distribution map for IWQI

The IWQI value in groundwater ranged from 11.64 to 75.12, with an average of 38.52 for all samples found fit for irrigation purposes. After analysis of the IDW method in ArcGIS map, it can be seen that the southwest region is more suitable for irrigation purposes. As Mn is not considered in IWQI for this reason, the southwest region shows a more suitable zone.

4 Conclusions

One of the most important elements for maintaining life is groundwater. The current study ascertains the physicochemical properties of groundwater in the Kaliakair upazila and assesses its suitability for agricultural and drinking uses. Thirty (30) tubewells were sampled, chemical parameters were evaluated, and the WQI was calculated in order to examine the water quality. To calculate the WQI for drinking purposes, table 1 displays a number of parameters, including pH, TDS, TH, EC, F^-, Cl^-, Fe, NO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, Zn and Mn were considered. The drinking-quality index (WQI) ranged from 15.51 to 76.78, with an average of 27.67 for all samples deemed suitable. In order to calculate the WQI for irrigation, a number of parameters, including $Ca^{2+,}$ Mg^{2+}, Na^+,

K^+, and HCO_3^- were considered. Several water quality indices, i.e., SSP, SAR, RSBC, PI, MH and KR indices are applied to assess the IWQI. For irrigation applications, the WQI ranged from 11.63 to 75.12, with an average of 38.52 for all samples deemed suitable. According to the results, 100% of the samples belong to the excellent index. Finally, the parameter test values were used to create WQI map by using the IDW method in ArcGIS 10.8 software. The ArcGIS map shows that approximately 90% of the study area had an excellent index, while only 10% in the Southwest region had a good index for drinking water. After analysis of the IDW method in the ArcGIS map, it can be seen that the southwest region is more suitable for irrigation purposes. The ArcGIS map also shows that 100% of the study area had an excellent index for irrigation water. It is expected that the findings of this study will provide better insights for water planners monitoring irrigation water quality management in Kaliakair upazila.

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