GRADING OF TUBE WELL WATER DEPENDING ON PHYSICOCHEMICAL PARAMETERS AND MANAGEMENT PRACTICES OF FRESH WATER IN KACHUA UPAZILA, BAGERHAT: INDICES BASED APPROACH

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ABSTRACT

Coastal belt of Bangladesh faces a severe fresh water crisis due to different climatic hazards (flooding, cyclone, tidal surges), salinity intrusion and groundwater pollution. Bagerhat, a coastal district of Bangladesh has faced a severe water crisis in recent years. The objective is to grade the tube well water based on water quality index (WQI), heavy metal evaluation index (HMEI), heavy metal pollution index (HMPI), hazard index (HI) of 12 selected physicochemical parameters and to know the current fresh water management practices. Baruikhali (ward no. 3) village of Kachua Upazila (Bagerhat District) has been purposively selected to perform the study. 45 groundwater samples are collected from 45 tube wells (<80 feet depth) to assess 12 parameters including chromium, manganese, iron, nickel, copper, zinc, cadmium and lead through Flame Atomic Absorption Spectrophotometer in the Laboratory of University of Rajshahi. In addition, 6 in-depth interviews are also incorporated to validate the laboratory data as well as to know the overall management practices of fresh water in the designated village. Data are analyzed through SPSS and the map is prepared with ArcGIS. WQI claims that about 8.89% samples are graded into the category 'excellent', followed by 'good' (35.36%), 'poor' (11.11%), 'very poor' (24.44%), 'unsuitable' (20%) respectively. HMEI also reports the grade of water as 'no effect' (13.33%), 'slightly affected' (24.44%), 'moderately affected' (20%), 'strongly affected' (33.33%) and 'seriously affected' (8.89%). HMPI classifies the degree of gradation of water as 'no effect' (20%), 'slightly affected' (18.29%), 'moderately affected' (15.56%), 'strongly affected' (26.67%), 'seriously affected' (8.89%) respectively. HI for infants are found that about 42.22% samples are safe and 57.78% are unsafe; followed by 28.89% safe and 71.11% unsafe for child; 68.89% safe and 31.11% unsafe for adults. Spatial distribution of WQI, HMEI, HMPI and HI show that south western areas of the study village are highly contaminated with the heavy metals. In-depth interviews report that people are suffered from severe fresh water crisis in the pre-monsoon season (February-May) almost every year. Furthermore, they also claim that almost every year saline water enters into this area in the pre-monsoon season which accelerates agricultural cultivation as well as negatively impacts on biodiversity. All in-depth interview participants agreed that rainwater harvesting can reduce this fresh water crisis at least four months of the year. Finally, urgent actions (facilitate rainwater harvesting, re-excavation of ponds, maximum utilization of surface water, protect fresh water ponds, etc.) will be taken for ensuring continuous supply of fresh water round the year in the study area.

Keywords: *Tube wells, health concerns, heavy metals, water quality, rainwater harvesting*

1. INTRODUCTION

Bangladesh is a South Asian emerging developing country in the world. This country has served improved water sources to its more than 97% of the total population (Hossain et al., 2021; WHO and UNICEF, 2015) but less than 40% of the total population inadequately managed this service and about 50% of the supplied water is reported as contaminated with heavy metals, salinity or microbial pathogens (Khan et al., 2023; Hossain et al., 2022; World Bank, 2018). The distributions of the water sources differ spatially, hydro-geologically, topographically and also hard to reach zones (Mondal, 2015). Therefore, achieving Sustainable Development Goals (SDG) for Bangladesh needs special attention to the hard-to-reach water deficit zones (Hossain et al., 2021). Besides, less than one percent (0.26%) of total global accessible water sources (surface/ groundwater) (Rasheed, 2011) are polluted or contaminated with several pesticides, chemicals, toxic substances, biological parameters, etc. (Parvin et al., 2022; Khan, 2022; Rampley et al., 2020; Proshad et al., 2020). Pollutants in fresh water is an alarming issue in developing countries like Bangladesh (Sarker et al., 2019; Alidadi et al., 2019).

Bangladesh is facing acute water pollution for its continuous increase of industrial zones and expansion of rapid urbanization with concrete structures. The water quality has been deteriorated due to anthropogenic and natural causes (Khan and Paul, 2023a). Industrial and agricultural sources have caused extensive heavy metals both in surface and groundwater (Khan and Farha, 2022; Alam et al., 2020; Islam et al., 2018). In addition, flash flood and poor sanitation and drainage system increases fecal coliform and different pathogens in the surface water that is detrimental to human and environment health (Khan and Paul, 2023b; Parvin et al., 2022; Khan and Hossan, 2021; Sarker et al., 2019). Cities are provided water supply from groundwater in most of the cases (Zuthi et al., 2009) and rural areas are depended upon groundwater abstracted from tube wells and surface water collected from wells, ponds, rivers, canals, etc. Urban rivers are also linked with water quality due to common practices of liquidating of untreated household and industrial waste into the water bodies that leads to the rise of hazardous metals in the river water (Hasan et al., 2014; Zakir et al., 2013).

Groundwater contamination and salinity in the coastal zones are one of the major problems in Bangladesh as well as in the world (Shaibur et al., 2023; Khan et al., 2023). Several studies have been conducted to measure the suitability of water quality in various coastal zones of Bangladesh. Previous study shows in Satkhira (Khan and Paul, 2023a; Das et al., 2021; Das et al., 2019; Shaibur et al., 2019a), Bhola (Shaibur et al., 2023), Khulna (Khan and Paul, 2023a; Mahmud et al., 2020; Islam et al., 2017), Cox's Bazar (Deeba et al., 2021), Patuakhali (Ravenscroft et al., 2013), Bagerhat (Khan, 2022) Jashore (Ghosh et al., 2020; Sarwar et al., 2020; Shaibur et al., 2019b) Districts in Bangladesh. Almost all these studies grade and classify the water quality based on their determined parameters and some of the research reports that coastal groundwater is mostly saline and people are forced to drink this water due to unavailable fresh water. The study has tried to identify the gradation of the water into different classes based on the selected four indices. We have purposively determined the study area as Baruikhali village (Ward no. 3) of Kachua Upazila of Bagerhat District because this area faces severe fresh water crisis in the pre monsoon and winter seasons of the year. Besides, this area is located in the interior coastal belt of the country. Considering the above mentioned background, the objectives of this research are to grade the tube well water and identify the existing fresh water management practices in the study area.

2. METHODOLOGY

2.1 Study Area

The south-western coastal district Bagerhat is declared as the exposed (shoreline) area depending upon the salinity, tidal fluctuations and cyclone risk (PDO-ICZMP, 2003). This district consists of nine upazilas. Kachua Upazila is purposively identified as the research area from these nine upazilas upazila. Besides, about 85.66% household's consume tubewell water for drinking and other purposes in Bangladesh (BBS, 2022) and 58.4% households (HH) of Kachua Upazila (54% of Kachua Sadar

Union and 33% of east Baruikhali village) consume this water for the same purposes (BBS, 2011). East Baruikhali (Ward no. 3) villages from Kachua Sadar Union are also nominated purposively due to severe fresh water crisis and unavailability.

2.2 Samplings, Collection Procedure and Focus Group Discussions

Total 45 water samples from 45 sampling sites are collected from east Baruikhali village of Kachua Upazila between 11-15 March 2022 (Fig. 1). These locations are identified based on the highest water use from tube wells declared by local respondents which cover almost the entire study area. Water samples are collected in a new plastic bottles that are pre-washed and rinsed several times with distilled water and dried out for more than 36 hours. After that, the bottles are marked with lebel carefully and prepared for collecting samples. The bottles are completely filled up and ensured that air bubbles are fully absent inside the bottles that help to prevent oxidation reaction during transportation. Samples are preserved in a closed icebox and transported to the laboratory within 24 hours of collection. Samples are preserved in a refrigerator <4ºC up to accomplish the experiment. In addition, 6 indepth interviews are conducted to understand the management practices with a determined checklist that is arranged in a chronological way and it continues for about 40-50 min.

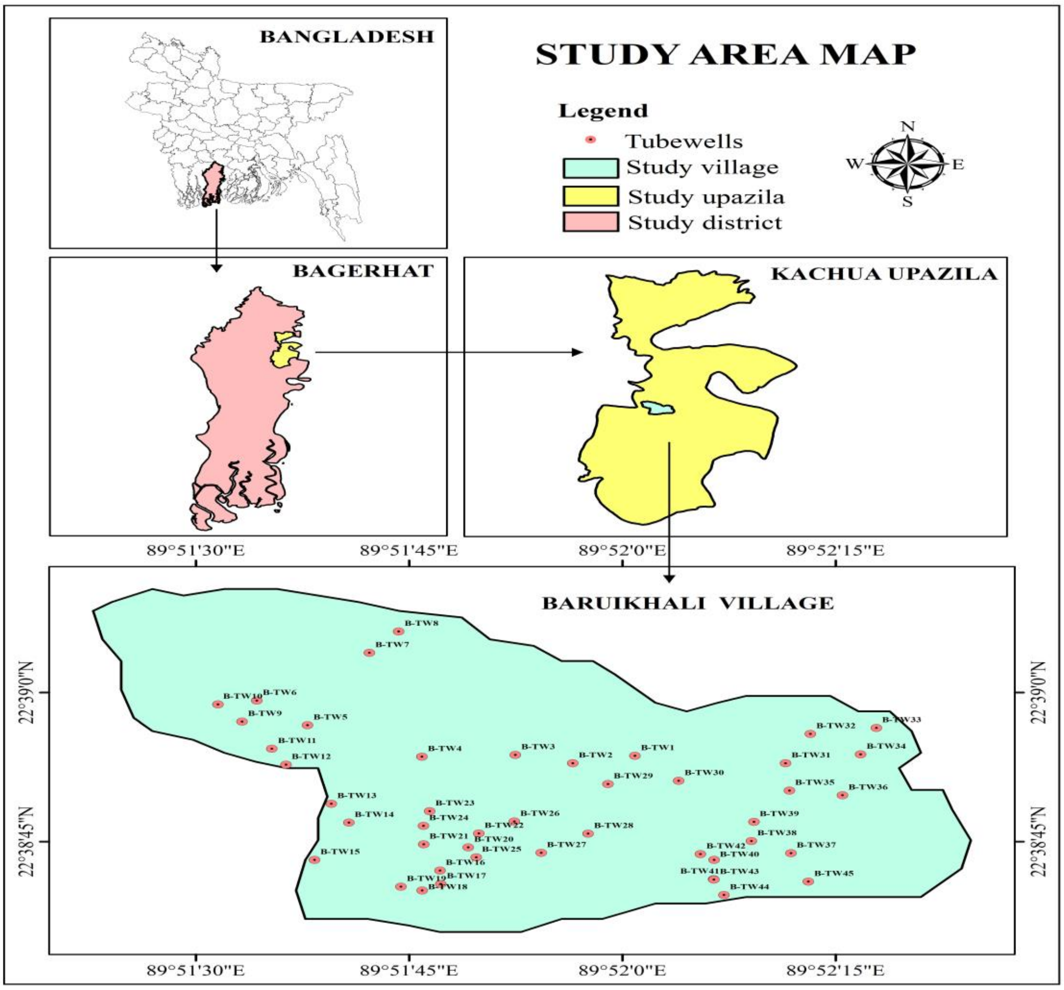

Figure 1: Study area map with tube wells position

2.3 Determination of Water Indicators

Total 12 indicators (Table 1) are tested to perform the study. TH and Cl concentrations of collected samples are measured by using ethylenediaminetetraacetic acid (EDTA) and $AgNO_3$ titration method respectively. Other trace metals, Cr, Mn, Fe, Ni, Cu, Zn, Cd and Pb are determined by using flame Atomic Absorption Spectrophotometer (AAS), Shimadzu Corporation, Japan. All trace metals are prepared in the Institute of Environmental Science (IES) water laboratory and AAS of Central Science Laboratory (CSL) of University of Rajshahi is used to measure the concentrations. The details of the parameters are depicted in Table 1 that is used for the whole writings. The units are also measured by parts per million (ppm) for all the parameters.

Table 1: Measurement procedure of parameters with tolerable limit set by WHO and ECR

Parameter	Symbol	Method	Testing	WHO	ECR
Chloride	Cl	Titration	IES	250	150-600
Total hardness	TH	Titration	IES	500	200-500
Potassium	K	AAS	CSL	12	12
Calcium	Ca	AAS	CSL	75	75
Chromium	Cr	AAS	CSL	0.05	0.05
Manganese	Mn	AAS	CSL	0.1	0.1
Ferrous	Fe	AAS	CSL	0.3	0.3-1.0
Nickel	Ni	AAS	CSL	0.07	0.1
Cupper	Cu	AAS	CSL	2.0	1
Zinc	Zn	AAS	CSL	3-5	5
Cadmium	Cd	AAS	CSL	0.003	0.005
Lead	Pb	AAS	CSL	0.01	0.05

Note: WHO represents World Health Organization and Environmental Conservational Rules (ECR) 1997 values are used as the standard value (S_i) for index formulation.

2.4 Data Analysis and Index Formulation

Data are analyzed by using Statistical Package for the Social Sciences (SPSS, v. 22.0). Water quality index (WQI), heavy metal evaluation index (HMEI) and heavy metal pollution index (HMPI) are measured by considering 12 indicators and hazard index (HI) is formulated from 8 indicators.

Table 2: Gradation of water quality

WQI	Water Quality	Grade	Possible use
<25	Excellent	A	Drinking, irrigation and industrial
26-50	Good	B	Drinking, irrigation and industrial
51-75	Poor	C	Irrigation and industrial
76-100	Very poor	D	Irrigation
>100	Unfit for drinking	E	Should not be used without treatment

2.4.1 Water Quality Index

WQI determines the gradation of water for using several purposes. It was first introduced by Horton and advanced by Brown et al. (1972). This procedure has been used worldwide by numerous scientists (Khan and Paul, 2023a; Jahan et al., 2022; Mahmud et al., 2020) respectively. Scientists (Shahriar and Moniruzzaman, 2022; Ram et al., 2021; Brown et al., 1972) have classified the water quality into five categories based on WQI as stated herewith (Table 2). WQI is measured by a weighted arithmetic method of 12 parameters by which grade the degree of purity of tube well water by Eq. (1) with the help of Eq. (2)-(4).

$$WQI = \frac{\sum_{i=1}^{n=12} Wi * Qi}{\sum_{i=1}^{n=12} wi} \quad (1)$$

$$Q_i = 100 * \frac{Vi - Vo}{Si - Vo} \quad (2)$$

$$W_i = \frac{K}{Si} \quad (3)$$

$$K = \frac{1}{\sum_{i=1}^{n=12} \frac{1}{Si}} \quad (4)$$

Here, V_i = measured concentration of i^{th} indicator; V_o = the ideal value of pure water = 0; S_i = standard value taken from ECR (1997), such as K=12 ppm; W_i is the unit weight that is calculated by equation no. 3. K is constant.

2.4.2 Heavy Metal Evaluation Index and Heavy Metal Pollution Index

HMEI is calculated for assessing and grading drinking water quality as well as overall quality of water based on heavy metals that exist in the sample water which is measured by Eq. (5) (Deeba et al., 2021; Sheykhi and Moore, 2012). HMPI is also a controlling assessment procedure for water quality based on the heavy metal concentrations. This index is calculated by Eq. (6) which has been commonly used by various researchers in the world (Bakan et al., 2010; Prasad and Kumari, 2008a; Prasad and Mondal, 2008b; Edet and Offiong, 2002; Mohan et al., 1996). It is assessed by considering the weighting of each selected parameter. The weighting value determines the relative importance of each parameter and is calculated inversely proportional to the recommended value by Bangladesh standard (ECR, 1997).

$$\text{HMEI} = \sum_{i=1}^{n} \frac{\text{Hc}}{\text{Hmac}} \quad (5)$$

$$\text{HMPI} = \frac{\sum_{i=1}^{n} WiQi}{\sum_{i=1}^{n} wi} \quad (6)$$

$$Qi = \sum_{i=1}^{n} \frac{|(Mi-Ii)|}{(Si-Ii)} * 100 \quad (7)$$

Here, H_C = determined value and H_{mac} = the highest tolerable concentration recommended by ECR (1997). Q_i is the sub-index; W_i = unit weighting and calculated by inversing S_i; n = number of indicators. M_i = the monitored value; I_i = the standard limits; S_i = the standard value taken from ECR (1997). HMEI and HMPI are graded into several types (Deeba et al., 2021; Sheykhi and Moore, 2012). Based on the result of our study, HMEI and HMPI classification are modified (Table 3) to differenciate one tube well to another.

Table 3: Gradation of water quality based on HMEI and HMPI

HMEI classification			**HMPI classification**		
HMEI	Degree of pollution	Grade	HMPI value	Degree of pollution	Grade
<2	No effect	A	<50	No effect	A
2 - 3	Slightly affected	B	51 - 100	Slightly affected	B
3 - 4	Moderately affected	C	101 - 200	Moderately affected	C
4 - 5	Strongly affected	D	201-300	Strongly affected	D
>5	Seriously affected	E	>300	Seriously affected	E

Table 4: Non-carcinogenic effects of heavy metals due to life time consumption (Khan and Paul, 2023a)

Sl.	**Metals**	**Reference dose (RfD)**
1	Chromium (Cr)	3×10^{-3}
2	Manganese (Mn)	1.4×10^{-1}
3	Ferrous (Fe)	3×10^{-1}
4	Nickel (Ni)	2×10^{-2}
5	Cupper (Cu)	5×10^{-3}
6	Zinc (Zn)	3×10^{-1}
7	Cadmium (Cd)	5×10^{-4}
8	Lead (Pb)	3.6×10^{-3}

2.4.3 Health Risk Assessment

Health risk assessment (HI) is calculated based on the ingestion of contaminated drinking water by Eq. (8) provided by USEPA (1989). It is measured by considering the lifetime average daily dose (LADD) of ingestion through drinking water (ppm/kg/day).

$$\text{LADD} = \frac{(\text{C}*\text{IR}*\text{ED}*\text{EF})}{(\text{BW}*\text{AT})} \quad (8)$$

$$\text{LADD} = \frac{(\text{C}*\text{IR})}{(\text{BW})} \quad (9)$$

$$\text{HI} = \sum_{1}^{n} \frac{LADD}{RfD} \quad (10)$$

Here, C=concentration of trace metals; IR=ingestion rate [.25, 1.5 and 3 liters per day for infant (<12 months), child and adult respectively (Hossain et al., 2020; Brindha et al., 2016)]; EF=exposure (days/year); ED=mean year; BW=body weight (6.9, 18.7, 57.5 kg for infant, child and adult respectively), and AT=average days (Khan and Paul, 2023a; Vetrimurugan et al., 2017). The researcher seems that this water is consumed 365 days in the mean year (ED) by the people. For this reason, EF = ED = AT. So, we have used the simplified Eq. (9) of LADD. HI is calculated by following USEPA (1989) guidelines as given Eq. (10) where reference dose (RfD) for an indicator is taken from Khan and Paul (2023a) stated in Table 4. The gradation of HI is divided into safe (HI<1) and unsafe (HI>1).

2.4.4 Indepth Interview

Besides the laboratory experiments, the researcher conducts indepth interviews to know the current fresh water management practices in the study area. The indepth interview participants are selected based on the experience and involvement of water management committee who are union parisad member, local potable water suppliers, school teacher living more than 20 years in this village. The predetermined checklist is composed with 10 questions related with water management including seasonal impacts.

3. RESULTS AND DISCUSSIONS

Gradation of Groundwater

The study reveals the gradation of tube wells in the study area are depicted in Table 5. Here, it is reported that the mean of WQI, HMEI, HMPI, HI_{Infant}, HI_{Child} and HI_{Adult} are 67.9 (grade C, poor), 3.373 (grade C, moderately affected), 142.762 (grade C, moderately affected), 1.888 (unsafe), 2.099 (unsafe), 1.473 (unsafe) respectively. The ranges of these indices are 11.28-149.28, 0.896-5.967, 35.21-396.27, 0.329-3.694, 0.608-3.895, 0.258-4.259 respectively that indicate there are several sampling station's water are very harmful for human consumption. Individually, WQI reveals that about 9 samples of tube well water (out of 45) are graded as 'E' that indicate one fifth of the surveyed tube well water is unfit for drinking and should not be used without treatment. Another 11 samples of tubewell water are revealed as 'very poor' or graded as 'D' and it can be used for irrigation purposes (Table 5). About 5 samples of tube well water quality are found as 'poor' which are graded as 'C' in the study area which can be utilized for irrigation and industrial purposes. Followed by, 15 and 4 samples of tubewells water quality are graded as 'B' and 'A' which is 'good' and 'excellent' that can be used for drinking and irrigation or industrial purposes respectively. HMEI of the study reveals that about 4 samples of tubewell water are graded as 'E' and it can seriously affect the human body as it contains heavy metals in high range (5.239-5.874). About one third (15 out of 45) of the samples of tube well water is graded as 'D' as these are found strongly contaminated with heavy metals and can be strongly affected on human health. Likewise, HI reports that 18, 13 and 31 water samples are determined as safe for infant, child and adult respectively (Table 5).

Table 5: Gradation of degree of pollution for tube well water based on WQI, HMEI, HMPI and HI

Sl.	WQI	Grade	HMEI	Grade	HMPI	Grade	HIInfant	HIChild	HIAdult
1	53.24	C	2.364	B	63.34	B	0.561	0.783	0.894
2	72.38	C	2.684	B	86.07	B	0.873	0.841	0.652
3	64.37	C	2.511	B	78.56	B	0.893	0.608	0.324
4	87.21	D	4.008	D	201.34	D	2.326	2.657	2.351
5	77.34	D	3.054	C	134.25	C	2.654	2.304	0.698
6	79.12	D	3.215	C	139.81	C	2.458	2.009	0.665
7	43.72	B	1.357	A	111.32	C	2.652	2.963	0.987
8	48.38	B	2.054	B	121.91	C	2.398	2.897	0.698
9	46.21	B	2.016	B	108.36	C	2.327	2.651	0.321
10	91.06	D	4.231	D	214.38	D	2.086	2.009	2.961
11	98.57	D	4.422	D	235.31	D	2.568	2.304	2.637
12	113.23	E	4.556	D	253.05	D	2.099	2.819	3.578
13	145.32	E	5.874	E	387.29	E	3.504	3.215	4.259
14	149.28	E	5.967	E	396.27	E	3.694	3.631	4.004

15	132.57	E	5.328	E	347.28	E	3.561	3.578	3.541
16	134.58	E	5.239	E	339.91	E	3.251	3.895	2.961
17	109.23	E	4.332	D	239.51	D	2.983	2.998	3.008
18	101.67	E	4.431	D	213.37	D	2.907	2.851	3.228
19	106.89	E	4.536	D	283.64	D	2.637	2.654	3.688
20	83.07	D	4.329	D	203.07	D	2.005	2.314	3.641
21	37.89	B	2.321	B	39.23	A	0.587	0.873	0.521
22	33.38	B	2.637	B	35.21	A	0.329	0.964	0.903
23	48.02	B	2.964	B	51.09	B	0.698	0.802	0.805
24	48.29	B	2.953	B	52.31	B	0.893	2.005	0.752
25	75.39	D	4.512	D	200.05	D	1.992	2.361	2.315
26	89.54	D	4.229	D	219.04	D	2.129	2.597	2.354
27	17.32	A	0.896	A	39.67	A	0.796	0.706	0.879
28	11.28	A	1.294	A	37.82	A	0.778	0.776	0.563
29	25.36	B	3.224	C	60.58	B	2.654	2.689	0.804
30	24.82	A	1.548	A	43.28	A	0.886	0.809	0.604
31	57.61	C	3.208	C	69.37	B	0.965	2.118	0.368
32	43.09	B	3.235	C	72.38	B	2.324	2.213	0.258
33	48.65	B	3.012	C	101.23	C	2.651	2.568	0.954
34	43.25	B	3.118	C	107.94	C	2.368	2.342	0.865
35	26.38	B	2.142	B	49.84	A	0.991	0.862	0.354
36	28.65	B	3.128	C	58.38	B	0.851	2.113	0.52
37	29.73	B	3.783	C	63.28	B	0.756	2.105	0.842
38	79.34	D	4.009	D	98.04	B	2.567	2.118	0.328
39	75.54	D	4.116	D	95.31	B	2.651	2.351	0.874
40	22.24	A	1.557	A	37.08	A	0.938	0.861	0.694
41	98.59	D	4.631	D	276.23	D	2.368	2.981	0.867
42	106.57	E	4.562	D	298.34	D	3.054	3.586	0.951
43	68.31	C	4.007	D	72.15	B	0.568	2.003	0.964
44	32.58	B	1.857	A	39.04	A	0.779	0.773	0.873
45	47.39	B	2.356	B	49.37	A	0.932	0.892	0.982
Mean	67.9		3.373		142.762		1.888	2.099	1.473

Comparison of Indices among Various Gradations

Different indices are graded into several classes which determine that the water sources are possible to use or not and possible human health impacts. The WQI reports that highest 35.36% samples are graded into 'B' which are known as good for drinking, irrigation or industrial production, followed by 11.11, 24.44 and 20% of samples are found as poor, very poor and unfit for drinking and graded as 'C', 'D' and 'E' respectively. However, only 8.89% of tube well samples are graded as 'A' which are excellent for drinking, irrigation or even for industrial purposes.

Table 6: Comparison of indices among different gradation of tube well water

Indices	Class	Grade	Percent
WQI	<25	A	8.89
	25-50	B	35.36
	50-75	C	11.11
	75-100	D	24.44
	>100	E	20.00
HMEI	<2	A	13.33
	2-3	B	24.44
	3-4	C	20.00
	4-5	D	33.33
	>5	E	8.89

HMPI	<50	A	20.00
	51-100	B	28.88
	101-200	C	15.36
	201-300	D	26.67
	>300	E	8.89
HIinfant	HI<1	Safe	42.22
	HI>1	Unsafe	57.78
HIchild	HI<1	Safe	28.89
	HI>1	Unsafe	71.11
HIadult	HI<1	Safe	68.89
	HI>1	Unsafe	31.11

The HMEI reveals that majority (33.33%) of the tube well samples are graded as 'D' which indicate strongly affected water sources in the study village. Followed by about 8.89, 20 and 24.44% of samples are graded as 'E', 'C' and 'B' that indicate seriously, moderately and slightly affected by heavy metals. Yet, the study explores that only 13.33% of samples are calculated as grade 'A' which have no effect at all. In terms of HMPI, the study calculated the highest 26.67% tube well samples are graded as 'D' which indicate that these tube wells water are strongly affected with heavy metals. About 20, 28.88, 15.36 and 8.89% water samples are graded as 'A', 'B', 'C' and 'E' which reveal as no effect, slightly, moderately and seriously affected (Table 6). Lastly, HI reveals that about 57.78 and 71.11% samples are unsafe for infant and child. Though, 68.69% of water samples are safe for adults. Overall, HI indicates that the tubewell sources are risky for the infant and child in the study village.

Spatial Distribution of the Indices

The spatial distribution of WQI, HMEI, HMPI, HI_{infant}, HI_{child}, and HI_{adult} of tubewell water sources are visualized by using Arc GIS 10.4 software. The selected indicators (TH, K, Ca, Cr, Mn, Fe, Ni, Cu, Zn, Cd, Pd) are found in the sample tube well sources which are released to the water through different anthropogenic and natural processes. Fig. 2 reveals the distribution of indices and it helps to identify the location of the contaminated/polluted tube wells. In addition, heavy metals distribution and movement in groundwater are influenced by the fundamental environmental factors as well as the particular metal occurrence (Habib et al., 2020; Hasan et al., 2023). This study reveals the distribution of heavy metals based on the indices. Individually, WQI distribution reveals that water quality of the south-western part of the study village is highly contaminated with heavy metals as ranged between 133.39-149.25 that may create severe health risk than the north-eastern part (11.288-26.617). The water quality gradually deteriorates from north-eastern to south-western part of the village. HMEI spatial distribution represents the similar patterns as of WQI. The northern part of the village is safer than other parts with HMEI between 0.8969-1.46 (Fig. 2). HMPI distribution also reveals the same results as of WQI and HMEI. It also indicates heavy metals pollution in the south-western part of the village and deteriorates from north-eastern to south-western area. HI_{adult} reveals similar spatial variation in respect of WQI, HMEI and HMPI. It reveals that the north-eastern part has less contaminated risk factors than the south-eastern part. Yet, HI_{infant} and HI_{child} spatial variation reveal the higher risk factors in south-western part of the study village but a quite different variation has also been observed. HI_{infant} also claims low risk factors in the middle part than eastern and southern part of the village. Again, a similar pattern has been observed for HI_{child} distribution. The spatial distribution of indices reveals that the south-western tube well sources are highly contaminated or polluted through heavy metals and these tube wells will be harmful for the respondents who rely on these sources.

Fresh Water Management Practices

Almost every year of the pre-monsoon season, saline water enters into the village which inundate crop lands and damage the crops, fresh water pisciculture or fisheries, biodiversity loss and imbalance of ecosystem. For this reason, proper fresh water management practice will be the best practice to reduce these issues in the study village. Almost all indepth interview participants report that rainwater harvesting can be an alternative way to reduce the severe crisis of fresh water for at least four months. The summary of the interviews is depicted herewith.

a. In the rainy season, people are using rainwater for different purposes in the study area but in the winter season, people mostly depend on potable jar water which is very costlier for them and sometimes collect from far away. The interviewee's report that the village people suffer from fresh water crisis from February-May (pre-monsoon season). The people expect government initiatives which are also revealed by Rahman et. al. (2017) in a study of coastal belt. Government may provide plastic containers (5000/7000 litres) to all families which can reduce water scarcity in both seasons (rainy and winter).

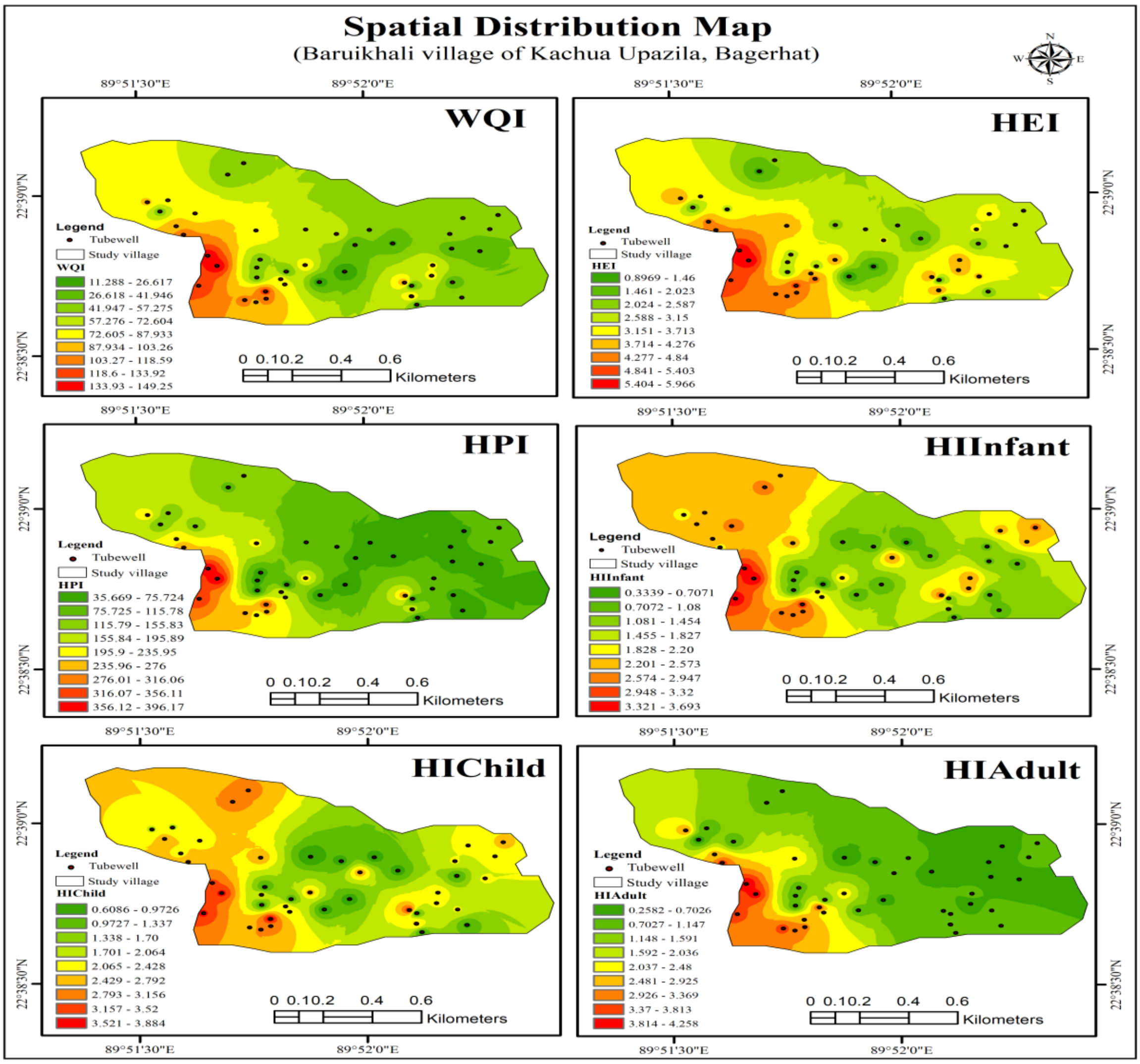

Figure 2: Spatial distribution of different indices

b. The study argues that installing new pond sand filter (PSF) shall be the alternative water source to reduce fresh water scarcity. Moreover, PSF is a recognized as efficient system which can be easily operated in the coastal belts of Bangladesh (Khan and Paul, 2023c; Hossain, et al., 2022; Rahman et. al., 2017). But this system faces challenges because installing authority (Department of Public Health Engineering) cannot take the responsibility of post-operative services. For enriching the fresh water availability in the study site, the local authorities such as, government bodies and local/international NGOs need to come forward to minimize the issues which are reported by the interviewees. The study also claims that pipe line water facilities need to be enhanced to reduce the fresh water crisis.

c. Participants recommend that the protected ponds need to be paved with concrete dams in order to conserve fresh water throughout the year which are fully filled with rainwater in the rainy season that can be stored by structural development and should be used round the year. This may a feasible option but also challenges to restrict the washing cloth with detergent and soaps.

d. The participants also recommend that solar powered PSF may be a solution to fresh water conservation practice. By the help of solar power, the electric cost will be minimized and respective pond water could be able to use for several purposes round year. However, respondents claim that salinity intrusion is another cause of fresh water crisis in the study village. For solving this barrier, re-excavation of rivers may solve the problem. Finally, fresh water management practice by raising awareness in the study area will reduce the fresh water crisis. Moreover, a reservoir can be made by digging small ponds or re-excavating of ponds that may provide fresh water to the study regions of Bangladesh.

e. Lastly, all the participants agreed that PSF will be cost effective and sustainable option in the study area that supports fresh water round the year.

CONCLUSION

The study grades the tube wells water depending upon WQI, HMEI, HMPI and HI respectively based on 12 physicochemical parameters and finally addresses the fresh water management practices. WQI reveals that about 8.89, 24.44 and 20% samples are graded as excellent, very poor and unsuitable. HMEI claims about 13.33, 20 and 33.33% samples are graded as no effect, moderately affected and strongly affected. HMPI also reports that about 26.67% are graded as strongly affected. HI claims as 31.11% (unsafe) for adult, 71.11% (unsafe) for child and 57.78% (unsafe) for infant in the study village. The study also reveals the spatial distribution of the indices claim that higher concentrations of heavy metals are mainly found in the south-western part of the study village and tub wells are safer in the north-eastern part. The indepth interview participants report that salinity intrusion is now impacting the study village in different phases throughout the year in the pre-monsoon season and study area inundated with saline water. Majority of the participants report that rainwater harvesting can be an alternative way to reduce the severe crisis of fresh water. In addition, setting up PSF, pipeline facilities, rainwater reservation, re-excavation of ponds and rivers, paved reserve ponds, solar powered PSF and awareness raising may be enhanced to minimize the problem in the village. Therefore, (N)GOs need to come forward to take proper actions for solving this problem.

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