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RESEARCH PAPER

Assessment of Groundwater Based Public Drinking Water Supply System of Kamrup District, Assam, India using a Modified Water Quality Index

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ABSTRACT
This work aims to assess the Water Quality Index (WQI) of the groundwater-based public drinking water supply system of Kamrup District (Rural) of Assam, India. For assessing WQI, water samples have been collected, both raw water and treated water, from seventy-eight public drinking water supply projects over the district for comprehensive physicochemical analysis. The WQI was calculated based on the weightage derived from the literature survey and based on the doctors' weightage. The derived WQI showed that the water quality falls from poor to very poor quality. However, the concentration of the water quality parameters except Iron, Fluoride, and Manganese are within the permissible limit in all the water supply projects. It shows that the WQI calculated based on the weightage derived, as stated above, is not displaying the actual water quality of the supplied water. As such, a modified method is proposed to calculate the WQI of the supplied water considering the permissible limit of the parameters in deriving the weightage for the parameters. The WQI values calculated using the modified method falls in the range of good water quality to poor water quality and shows the true water quality of the supplied water. The statistical analysis of the water quality parameters and WQI shows that the WQI has a very high correlation with Manganese with a coefficient of correlation value of 0.86, followed by 0.4 with Chloride and 0.34 with Fluoride.

KEYWORDS: Water quality; groundwater; Drinking Water; Kamrup.

INTRODUCTION

Water is one of the essential commodities and a precious national asset that has been exploited than any other natural resource. Around 70 percent of the earth is covered with water, but only one percent of them are usable for human consumption. The water for domestic and industrial purposes can be supplied from the available surface water sources as well as from the groundwater. Groundwater is the most vital resource for millions of people for both drinking and irrigation uses (Delgado et al., 2010; Raju et al., 2015; Raju et al., 2015; Ghalib 2017; Mohammadi et al., 2017; Yousefi et al., 2018). At the same time, it is challenging to have a perennial surface source for the implementation of the water supply schemes. As such, the Govt. of Assam has implemented several groundwater-based water supply schemes for the rural areas of the state. The schemes are running at several parts of the state for supplying drinking water.

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The quality of water must be considered in any assessment of water resources (Anon 1993). Although scientific measurement is used to define water quality, it is not easy to say about the quality of the water as good or bad. Therefore, the water quality is related to particular use only. Drinking water is the water that is safe to drink as well as to use for food preparation without risk of health problems. According to the WHO organization, about 80% of the diseases in human beings are caused due to the lack of pure drinking water (Ramakrishnaiah et al.,2009). The quality of groundwater depends on the nature of the soil and the rock masses present along the pathway of the groundwater saturation zone (Olayinka et al., 1999; Foster et al., 2000; Chidambaram et al., 2008, Das and Bhattacharjya 2020). However, as observed, the groundwater quality deteriorates due to residential, industrial, commercial, agricultural, and other anthropogenic activities together with natural conditions (Foster et al., 2002; Nair et al., 2015). The water quality of any specific area or specific source can be assessed by using physical, chemical, and biological parameters. The values are harmful to human health if they exceed the defined limit (*Bureau of Indian Standards, Specification for drinking water. IS: 10500, New Delhi, India* 2012; *Guidelines for Drinking-water Quality, Fourth Edition, World Health Organization ISBN 978 92 4 154815 1* 2012; *Guide Manual: Water and Waste Water, Central Pollution Control Board, New Delhi* 2013). The Water Quality Index (WQI) is an effective way to communicate information on the quality of water to the concerned citizen and policymakers. The use of individual quality parameters to describe water quality is not easily understandable to the common public. (Akoteyon et al., 2011; Bharati & Katyal 2011). Therefore WQI can reduce the quality parameters into a single value that expresses the overall quality in a simplified and logical form (Babaei Semiromi et al., 2011).

Horton (1965) proposed a method for evaluation of WQI values ranking the categories of water as excellent, poor, very poor, and unsuitable for use. These categories are easily understandable for decision-makers and consumers. There are various methods to derive WQI values (Tyagi et al., 2013). Usually, weighted WQI values are calculated in which the parameters have been assigned a weight according to their relative importance in the overall quality of water. Many studies have been carried out regarding the application of the weighted WQI approach in groundwater quality assessment (Sahu & Sikdar 2008; Ketata et al., 2012; Alastal et al., 2015; Kawo & Karuppannan 2018; Rabeiy, 2018). All these methods to derive WQI values are similar, the only difference being the number and type of parameters considered and their corresponding weights.

Many researchers have studied the quantification of water quality using the Water Quality Index (WQI). Assessment of WQI for the groundwater in Tumkur Taluk of Karnataka, India, was done by (Ramakrishnaiah et al., 2009). After evaluation of the WQI values, they finally concluded that the groundwater of the area needs some degree of treatment before human consumption. (Krishan et al., 2016); (Patl & Patil 2013); (Chandra et al., 2017); (Yogendra & Puttaiah, 2008); (Chaturvedi & Bassin 2010) etc. also done similar works in different areas. The only difference is the number and type of parameters used and their corresponding weight. Shweta Tyagi et al. (2013), in their work "Water Quality Assessment in Terms of Water quality Index" reviews some of the important water quality assessment, their mathematical structure, merits, and demerits of the methods. Besides, they highlight and draw attention towards the development of a new and globally accepted water quality index that represents a reliable picture of water quality. (Tirkey et al., 2013) also reviewed the different water quality indices. They presented a list of selected studies carried out worldwide using water quality indices. (Pei-Yue et al., 2010), on their work regarding groundwater quality assessment, entropy weight was calculated and assigned to different parameters for calculating WQI values.

The purpose of this study is to assess the suitability of the groundwater-based public drinking water supply system of Kamrup district, Assam, India base on computed WQI values. The WQI is initially calculated based on the weightage derived from the literature survey and also from DCMG Opinion Survey. However, the evaluation of the results shows that the resulted WQI values do not display the actual water quality of the supplied water. As such, a new method is proposed for calculating the WQI of the supplied water considering the permissible limit of the parameters in deriving the weightage of the parameters.

MATERIALS AND METHODS

Kamrup (Rural) district (Fig. 1) lies between 25.46N and 26.49N latitude and between 90.48E and 91.50E longitude and has a total area of 3105 sq. km. The perennial tributaries like Puthimari, Digaru, Kulshi, Singra, etc., are passing through the district and join the river Brahmaputra. As per the 2011 census of Govt. of India, the total population of the district was 1,517,542 and population density is 490 per sq. km. The annual rainfall of the district ranges between 1500 mm to 2600mm. The major soil groups identified in the district are recent riverine alluvial soils, old riverine alluvial soils, old mountain valley alluvial soils, and laterite red soils. The economy of the district is based on industry and agriculture. The total cultivators in the district are 207262, out of which 150921 are small and marginal farmers. The literacy rate of the district is 70.95 %. Fig. 1 shows the district boundary along with the locations of the water supply projects considered in the study.

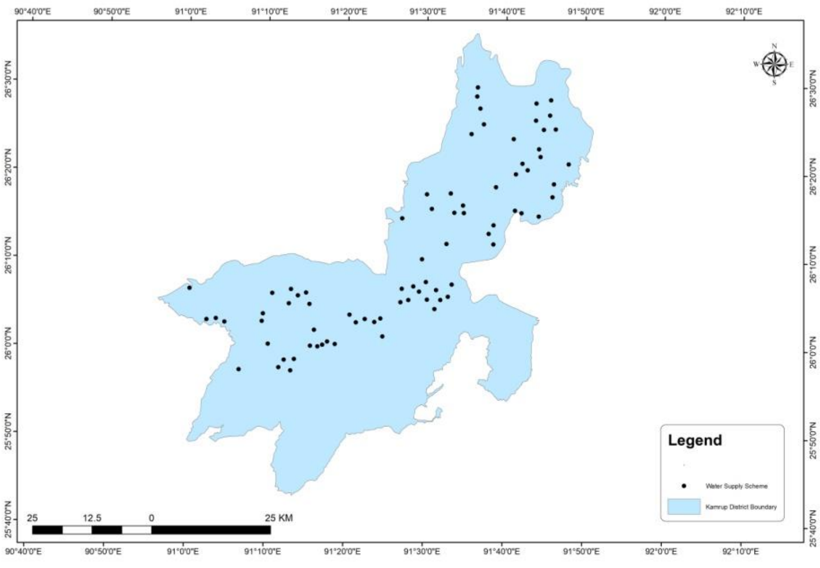

Fig. 1. Kamrup district showing the rural water treatment plants

Water samples were collected from seventy-eight groundwater-based Public Water Supply schemes implemented by the Assam Public Health Engineering Department. The samples were collected in pre-cleaned plastic polyethylene bottles for physicochemical analysis during the year 2017. Before sampling, all the sampling containers were washed and rinsed thoroughly with the groundwater to be taken for analysis. For each water supply scheme, two numbers of water samples (raw water and treated water) are collected for testing. Raw water has been aerated, followed by rapid sand filtration, then disinfection at the storage level and distributed to beneficiaries.

All the one hundred and fifty-six numbers of water samples collected from different water supply schemes were tested in the district level laboratory of the Public Health Engineering Department. The samples were tested for twelve numbers of parameters generally done in regular testing of water samples observing the standard procedure followed by the department. The parameters are Iron, Alkalinity, Turbidity, Calcium Hardness, Total Dissolved Solids, Chloride, Fluoride, Total Hardness, Nitrate, pH, Manganese, and Magnesium. The chemical parameters of the raw water samples for different water supply schemes are plotted on the map prepared by GIS (Geographical Information System as shown in Fig.2 and Fig. 3.

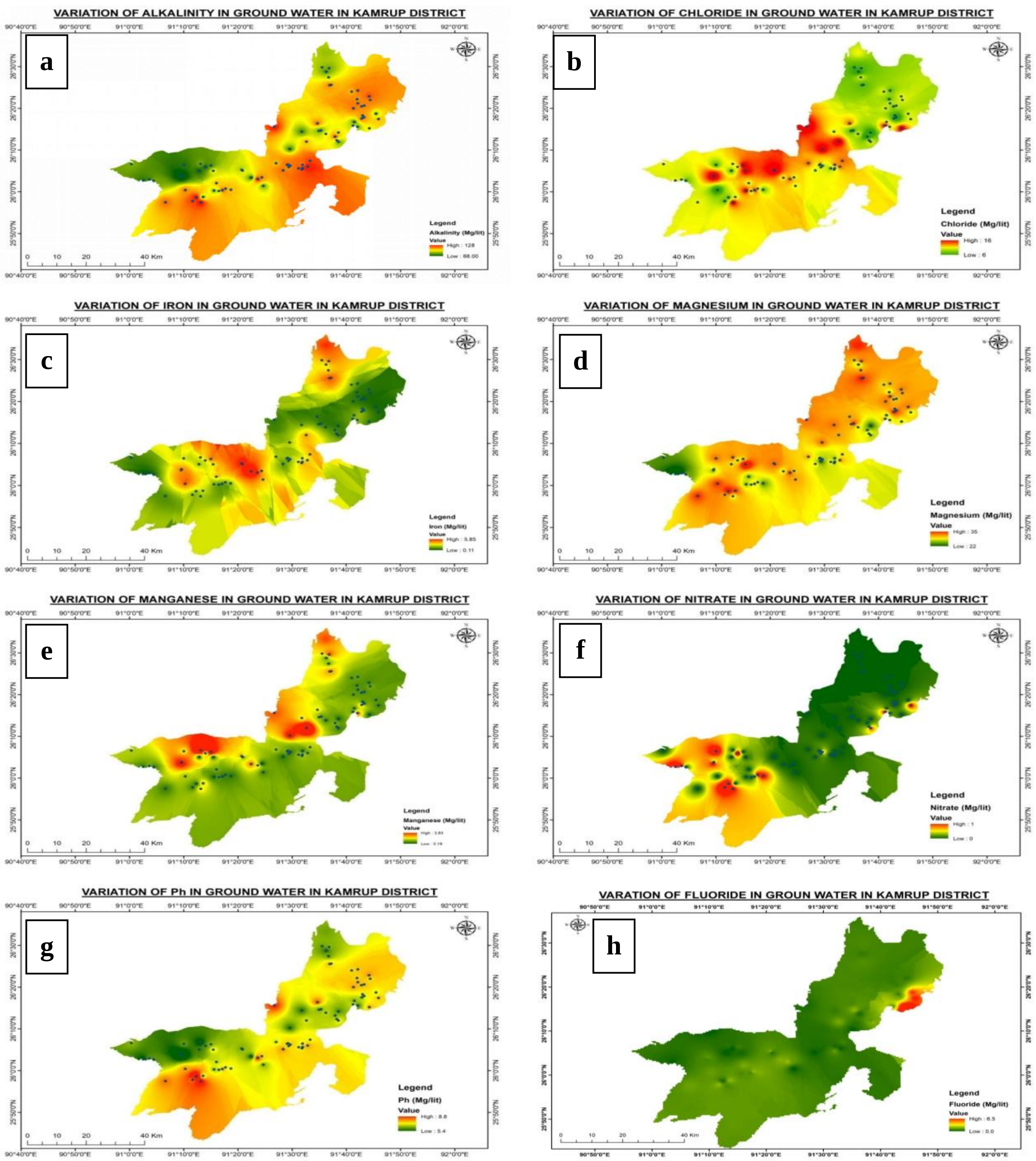

Fig. 2. Map showing the distribution of various parameters in groundwater (a) Alkalinity, (b) Chloride, (c) Iron, (d) Magnesium, (e) Manganese, (f) Nitrate, (g) pH, (h) Fluoride

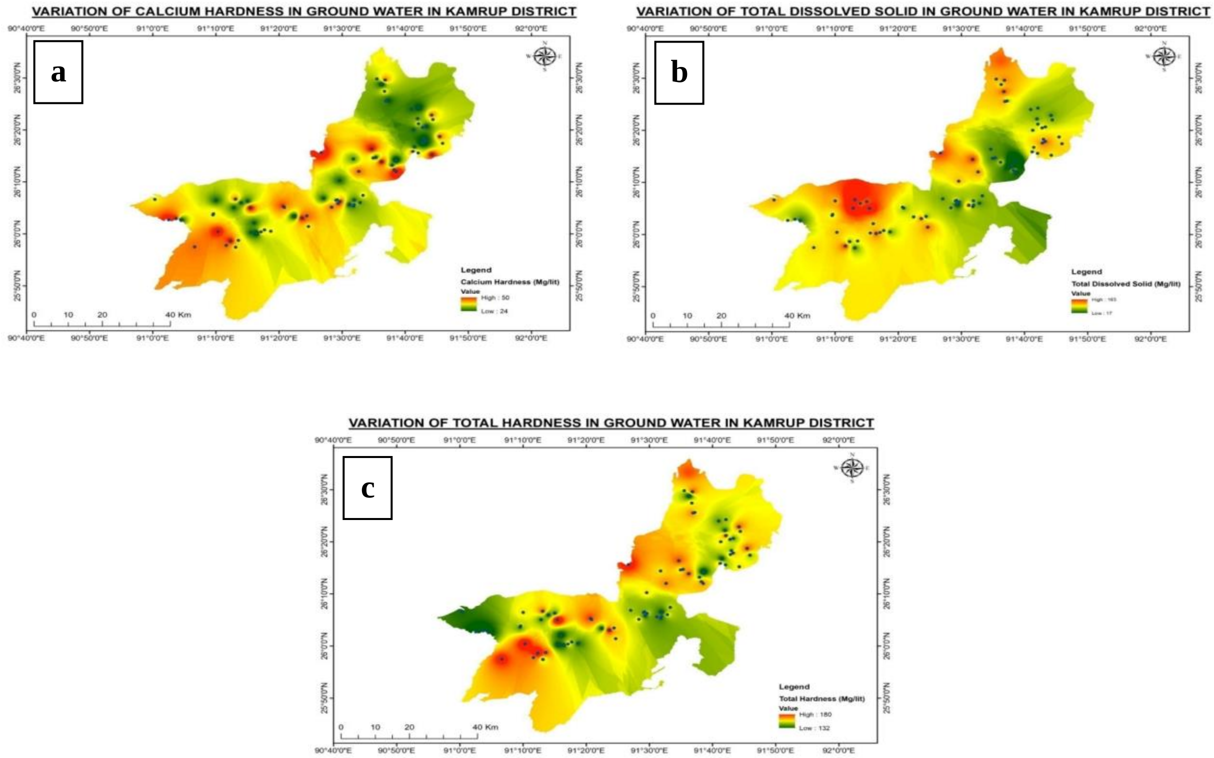

Fig. 3. Map showing the distribution of various parameters in groundwater (a) Calcium hardness, (b) Total dissolved solid, (c) Total hardness

Fig. 4 shows the box plot of the water quality parameters used in the study. It may be observed that the maximum concentration of Alkalinity is 128.0 mg/L, and the minimum value is 68.0 mg/L. In the case of Chloride, the maximum concentration is 16.0 mg/L, and the minimum value of 6.0 mg/L found in the Bhitarkhola public water supply scheme. The box plots of the other parameters like Iron, Magnesium, Manganese, Nitrate, $P^{H,}$ and Fluoride show that the maximum and minimum values of the parameters found in raw water as Iron ranges between 5.85mg/L to 0.11 mg/L, Magnesium ranges between 35.0mg/L to 22.0mg/L, Manganese ranges from 3.48 mg/L to 0.19 mg/L, Nitrate ranges between 1 mg/L to 0, pH value ranges between 8.33 to 6.30 and fluoride ranges from 6.5 mg/L to 0. The box plot of hardness parameters like Calcium hardness, the maximum and minimum values found in raw water are 50 mg/L and 24 mg/L, respectively. In the case of total dissolved solids, it ranges between 165 mg/L to 17 mg/L, and for the case of total hardness, the maximum and minimum values are 180 mg/L and 132 mg/L, respectively.

The standards of drinking water quality recommended by the Bureau of Indian Standards (BIS) have been considered for computing water quality Index (WQI) values from the laboratory test data of the physicochemical parameters. The following steps are followed for the computation of WQI values. First, each of the twelve parameters has been assigned a weight (w_i) according to their relative importance in water quality for drinking purposes. The weightage has been assigned based on the literature survey in the range of 1 to 5 (Table 1). The maximum weight of 5 has been assigned to the parameter Nitrate due to its more significance in water quality assessment. The high concentration of Nitrate can cause methemoglobinemia (Blue baby syndrome), which is excessively found in newborn infants. On the other hand, as it itself may not be harmful, Magnesium has assigned a weight of 1. The weight of the remaining parameters has been assigned according to their relative importance in the drinking water. The relative weight W_i is computed using. 1

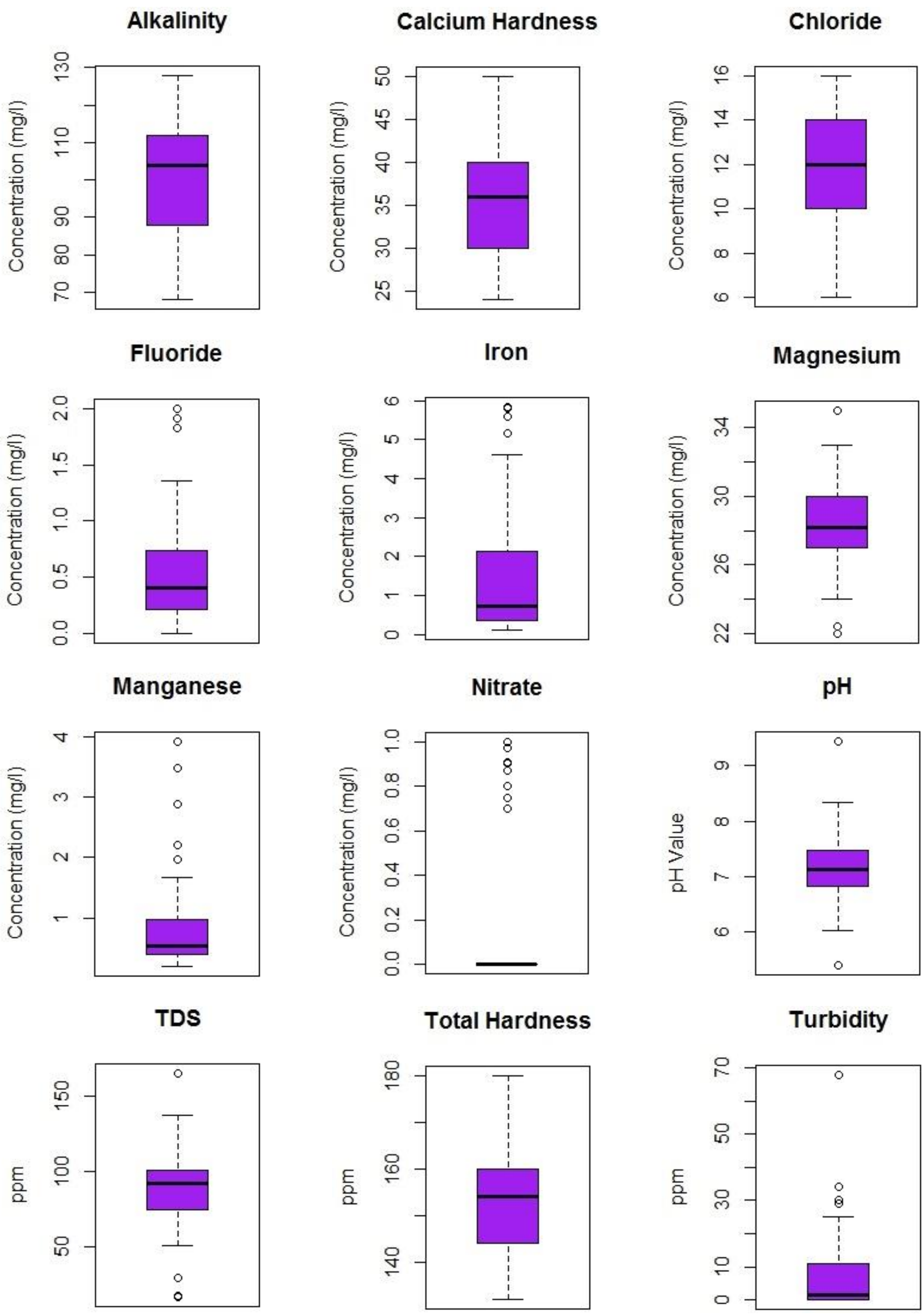

Fig. 4. Box plot showing the values of different quality parameters of raw groundwater

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

Where, W_i is the relative weight, w_i is the weight of each parameter, and n is the number of parameters.

Table 1. BIS value, weight, and relative weight of different parameters

Sl. No.	Parameter	BIS value	Weight (w_i)	Relative Weight (W_i)
1	Iron	0.3 Mg/L	3	0.0857
2	Alkalinity	200 - 600 Mg/L	2	0.0571
3	Turbidity	1 - 5 NTU	3	0.0857
4	Calcium	75 - 200 Mg/L	2	0.0571
5	Total Dissolved solid	500 - 2000 Mg/L	4	0.1143
6	Chloride	250 - 1000 Mg/L	3	0.0857
7	Fluoride	1 – 1.5 Mg/L	4	0.1143
8	Total Hardness	200 – 600 Mg/L	2	0.0571
9	Nitrate	45 Mg/L	5	0.1429
10	pH	6.5 – 8.5	4	0.1143
11	Manganese	0.1 - 0.3 Mg/L	2	0.0571
12	Magnesium	30 - 100 Mg/L	1	0.0286
			$\sum w_i = 35$	$\sum w_i = 1$

In addition to assigning weight to the different physicochemical parameters from the literature survey and by considering the significance of the parameters in the overall water quality, an opinion survey conducted by the author among the doctors in the Department of Community Medicine, Guwahati (DCMG), Assam, India for giving weightage to the different parameters. They have valued the different parameters ranging from 1 to 10 in terms of risk to human health. From the survey data, the relative weight of different parameters has been calculated. Table 2 shows the relative weight calculated based on the literature survey and the DCMG opinion survey.

To bring the water quality parameters on the same scale, the parameters have been normalized using Eq. 2. The result is multiplied by 100 to make it a whole number.

$$q_i = 100 \times max\left[\left|\frac{C_i - S_i}{C_{imax} - S_i}\right|, 0\right] \quad (2)$$

Where C_i is the concentration of ith parameters (mg/L), $S_i$is the Indian drinking water standard of the ith parameter (mg/L), and C_{imax} is the permissible concentration of the ith parameters (mg/L), N is the number of parameters. The WQI values of different water supply schemes are calculated by using Eq. 3.

$$WQI = \sum_{i=1}^{n} w_i q_i \quad (3)$$

After the calculation of the WQI values of different water supply schemes, the values are grouped (Table 3) according to the status of the water quality (Chatterji and Raziuddin, 2002).

Table 2. Comparative statement of relative weights

Sl. No.	Parameter	Relative Weight (W_i)	
		DCMG Survey	Literature Survey
1	Iron	0.078	0.0857
2	Alkalinity	0.079	0.0571
3	Turbidity	0.101	0.0857
4	Calcium	0.075	0.0571
5	Total Dissolved solid	0.097	0.1143
6	Chloride	0.075	0.0857
7	Fluoride	0.102	0.1143
8	Total Hardness	0.086	0.0571
9	Nitrate	0.094	0.1429
10	pH	0.0897	0.1143
11	Manganese	0.063	0.0571
12	Magnesium	0.062	0.0286

Table 3. Water quality classification based on WQI value

Water quality Index Level	Water quality Status	Number of Schemes	
		DCMG opinion Survey	Literature Survey
0-25	Excellent water Quality	0	0
26-50	Good water quality	0	0
51-75	Poor water quality	15	33
76-100	Very poor water quality	63	45
More than 100	Unsuitable for drinking	0	0

The evaluation of the results shows that the computed WQI values are in the range of poor quality water to very poor quality water. According to opinion survey conducted by the author among the doctors in the Department of Community Medicine, Guwahati (DCMG) 15 numbers of schemes fall in the category of supplying poor quality water and 63 numbers with very poor quality water. But according to literature survey, 33 numbers of schemes fall in the category of supplying poor quality water and 45 numbers with very poor quality water. However, it has been observed that all the parameters except Iron, Fluoride, and Manganese are within the permissible limit. In some of the projects, Iron and Manganese concentration are slightly higher than the permissible value. In the case of fluoride, its value exceeds the limit only in five numbers of projects. This shows that the WQI calculated using the weight as discussed above is not reflecting the actual water quality of the supplied water. As such, to have a more realistic picture, a new method for evaluating WQI values is proposed considering the maximum permissible value of the parameters. In the proposed method, we have assigned a weight of 0.30, if the concentration of the parameter within the permissible limit. A linear relation is then used to assign the weightage beyond the permissible limit. Fig. 4 (a-l) shows the variation of weightage for the parameters considered in the study.

The water quality indices of different supply schemes are evaluated using Eq. 4, and the result is multiplied by 100 to convert the WQI values to the whole number

$$WQI = \frac{1}{N} 100 * \sum max\left[\left| \frac{C_i * 0.3}{S_{imax}} \right|, 0.3 \right] \quad (4)$$

Where C_i is the concentration of ith parameters (mg/L), S_{imax} is the maximum value as per the Indian drinking water standard for the ith parameters (mg/L), N is the number of parameters.

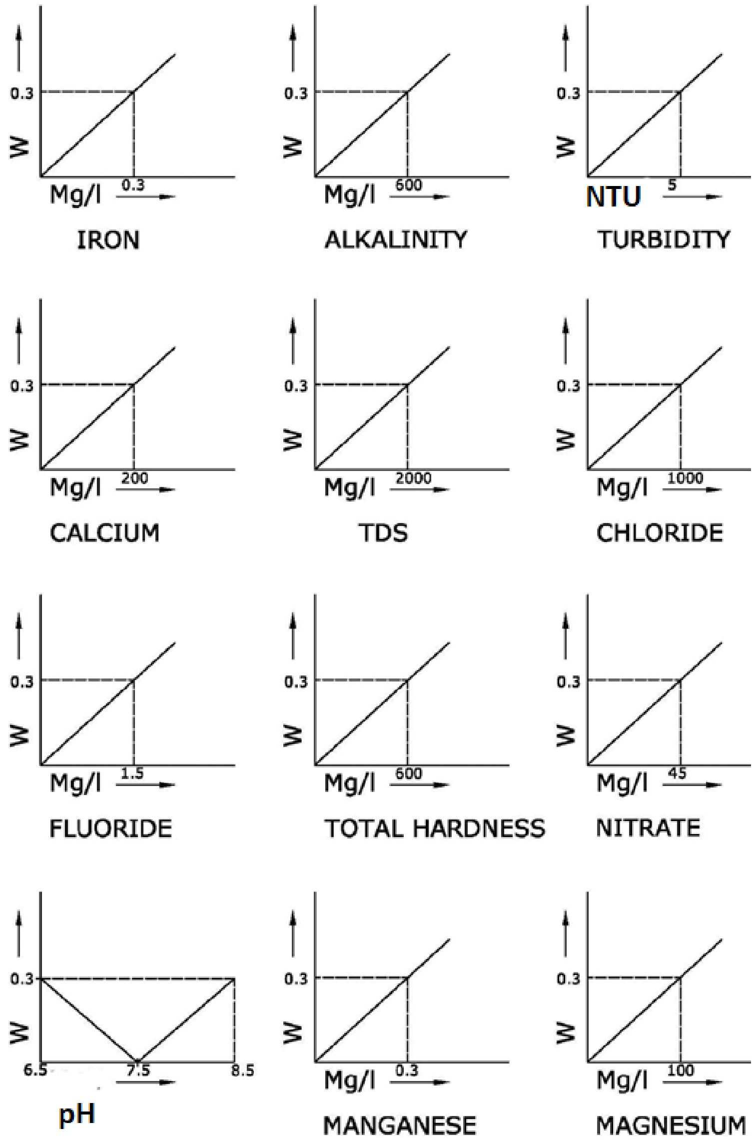

Fig. 5. The variation of weightage of different parameters as per the proposed method

After calculating the WQI values of the water supply projects, they are grouped (Table 4) according to the status of water quality proposed for the new method. When the WQI is 0.3, it indicates that all the water quality parameters are with the permissible limits. If it is more than 0.3, it suggests that the concentration is more than the allowable limits for one or more parameters.

Table 4. Water quality classification based on WQI value as per the proposed method

Water Quality Index Level (%)	Water quality Status	Number of Schemes
<=30	Good Water Quality	47
31-60	Poor Water Quality	31
61-90	Very Poor Water Quality	0
More than 90	Unsuitable for Drinking	0

RESULTS AND DISCUSSIONS

The WQI values for treated water are evaluated by considering 12 (Twelve) nos of Physicochemical parameters for seventy-eight locations of water supply schemes. The assessed WQI values using the weightage obtained from the DCMG opinion Survey ranges from 69 to 96. The index calculated by using the literature survey is ranging from 66 to 89. It gives some general ideas regarding possible problems with water for a particular reason (Tewari et al., 2010). The WQI values of different water supply projects using both the weightage are shown in Fig. 6. Again, it is observed that in DCMG opinion Survey, some parameters have been assigned more weightage in comparison to their relative importance in the overall quality of water. The WQI values calculated by considering both the weightage shows higher values, and the water quality falls in the range of poor water quality to very poor water quality. But the concentration of the parameters except Iron, Fluoride, and Manganese are within the permissible limit in all the water supply projects. Iron in groundwater occurs naturally. As the water moves through the underground rock formations, some of the Iron dissolves and accumulates in aquifers which serve as a source for groundwater. It is not hazardous to health, but it is considered a secondary or aesthetic contaminant. While considering raw water, 82.05% of the schemes are found to be contaminated beyond the permissible limit. Iron concentration in raw water is found maximum to the tune of 5.85 mg/L in the Aggumi water supply scheme in the Chaygaon development block. But in the case of supplied water, 35.89% of the schemes are found contaminated with Iron beyond the permissible limit. A maximum of 1.60 mg/L of Iron concentrations in supplied water is found in the Sapathuri water supply scheme in the Rampur development block. But in most of the Iron contaminated schemes supplying water, it just crosses the permissible value of 0.30 mg/L but within 1.0 mg/L. Although in some of the water supply projects, the Turbidity value for raw water is found beyond the permissible limit, it comes to the desirable after treatment. The value of the chemical parameters like Alkalinity, Calcium Hardness, Total Dissolved Solids, Chloride, Total Hardness, Nitrate, pH, and Magnesium are found within the permissible limit both in raw and treated water. Out of seventy-eight water supply schemes considered under the study, fluoride is found beyond the permissible value only in five nos of schemes under the Bezera development block. It is known from the department that in all the Fluoride contaminated schemes, water has been extracted from rock boring type of deep tube well. This has been done due to the unavailability of a water-bearing sandy layer, i.e., the confined aquifer in that area. In all other seventy- three locations of schemes, water has been extracted from a confined aquifer. Fluoride is beneficial for human health for the prevention of dental cavities. If the concentration of fluoride exceeds the permissible value, it can cause dental fluorosis, and a much higher concentration result in skeletal fluorosis (Shah et al., 2008). Moreover, Nitrate, the other most harmful chemical parameter, has been found within the permissible limit in all the projects and even up to a maximum value of 1mg/L. The high concentration of Nitrate in drinking water is toxic and causes blue baby diseases in children and gastric carcinomas (Gilly et al., 1984; Alam et al., 2012). In some of the schemes, Manganese concentration is found beyond the permissible limit both for raw and treated water. But this concentration is not so high. So, the above information regarding poor to very poor quality of water is not reflecting the true water quality of the supplied water and will give some negative impact regarding supplied water. Therefore, a new method for evaluating WQI value is being proposed.

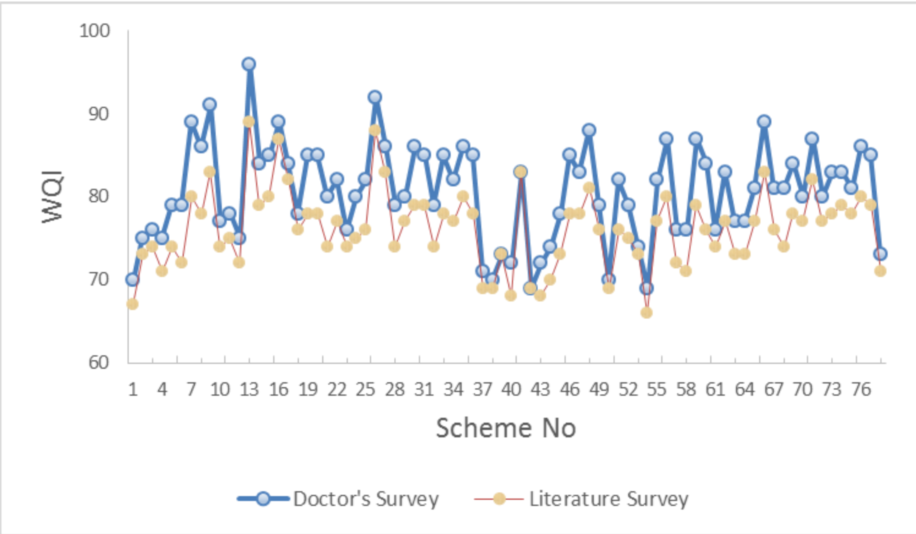

Fig. 6. Water Quality Index values calculated using Doctor's and literature survey

In the proposed method, a weight of 0.30 is being considered if the concentration of the parameters is within the permissible limit. The WQI values evaluated by observing this method fall in the range of good water quality to poor water quality. The water quality indices of different water supply schemes as per the newly proposed method are plotted on the map prepared using GIS (Fig. 7). According to the proposed method, out of seventy-eight locations of water supply projects considered in the study, forty-seven numbers were found supplying good quality water and thirty-one numbers with poor quality water. This poor quality of water is mainly due to high values of Iron, Manganese, and specially Fluoride in Schemes Sl no 14 to 18 (Fig. 6). Only in Sl no 19 to 24 (Fig. 6), all the projects are supplying good quality water, whereas, in Sl no 14 to 18 (Fig. 6), all the projects are supplying poor quality water. This poor-quality water can easily be used for drinking purposes by applying the normal filtration process at the domestic level. But, the poor quality water with more Fluoride concentration, especially in Sl no 14 to 18 (Fig. 6), RO filtration process, is required before human consumption.

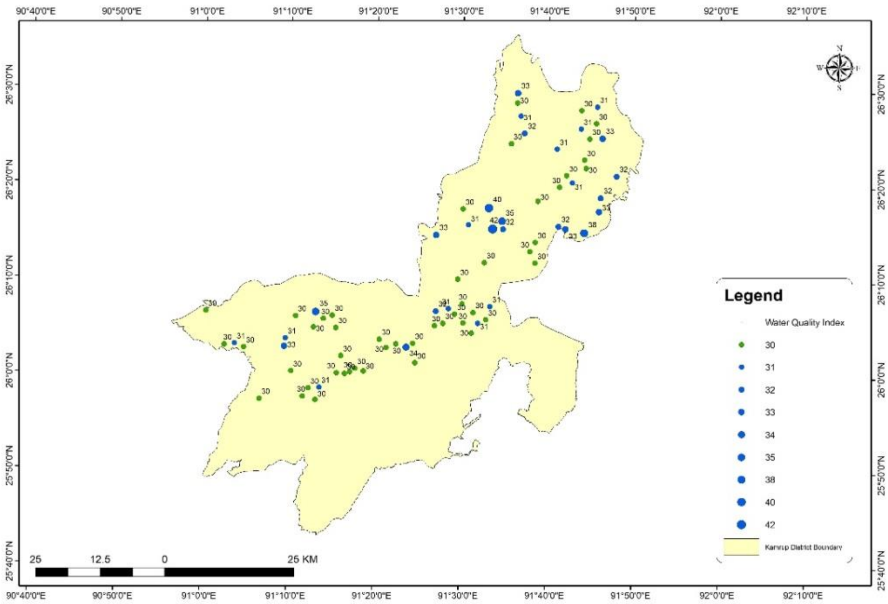

Fig. 7. Map showing WQI values using the proposed method

Statistical analysis is carried out to study the correlation between the water quality parameters and WQI calculated using the proposed method. Fig. 8 shows the scatter plot and correlation matrix of physicochemical parameters and WQI. It can be observed that there is a significant positive correlation among Chloride, Calcium hardness, Manganese, Alkalinity, and pH value. A high positive association has been observed between Manganese and Total hardness with a coefficient of correlation value of 0.81. The other positive correlations are Chloride and Calcium hardness with a coefficient of correlation value of 0.35, Chloride, and Manganese with a coefficient of correlation value of 0.32, etc. On the other hand, Alkalinity is negatively correlated with TDS with a coefficient of correlation value of -0.38. The correlation between the WQI and the water quality parameters shows that the WQI has a significant positive relationship with Manganese, Chloride, Fluoride, Calcium hardness, TDS, pH, etc. Among all these water quality parameters, the WQI has a very high correlation with Manganese with a coefficient of correlation value of 0.86, followed by 0.4 with Chloride and 0.34 with fluoride.

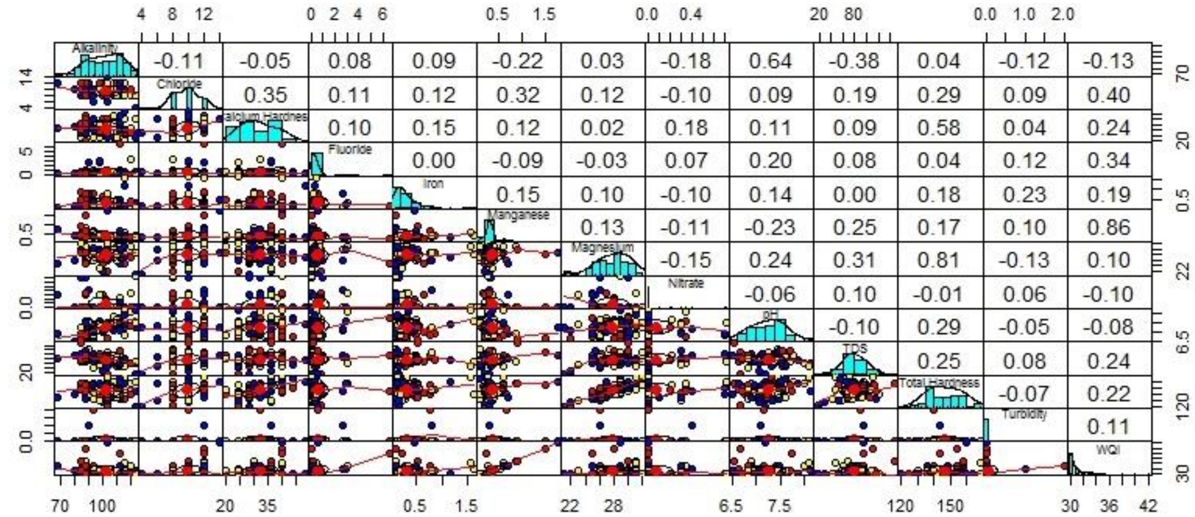

Fig. 8. Scatter plot and correlation matrix of physicochemical parameters and WQI

CONCLUSIONS

From the field test results, it has been observed that almost all the parameters of the public water supply distribution system are within the permissible limit. In some of the water supply projects, only Iron, Manganese, and Fluoride have been found beyond the permissible limit. The study shows that the assignment of weight is very crucial in deriving a convincing water quality index of drinking water supply schemes. It shows that the weight calculated by using the literature survey and DCMG opinion Survey provides wrong information about the water quality of the supplied water. The new method proposed in this study provides a logical value that reflects the true water quality. The WQI evaluated with the proposed method falls in the category of good water quality and poor water quality. This poor quality water can easily be used for drinking purposes applying the normal filtration process at the domestic level, as Iron and Manganese are not shown harmful to human health. But, the poor quality water with more Fluoride concentration, especially in Bezera Development Block, RO filtration, may be applied before human consumption. As fluoride has been detected in the rock-boring type of deep tub well, it is advisable to stop the rock-boring type of deep tube well for the implementation of a water supply scheme. At the same time, we should go for perennial surface sources for the implementation of the water supply projects in the areas where groundwater has been found contaminated with fluoride. The method has been applied at the Kamrup district of Assam, India. However, it can be used for any other location in the world.

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The authors declare that no funding has been used for the study.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and falsification, double publication and/or submission, and redundancy, has been completely observed by the authors

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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