Article

Geospatial Assessment of Ground Water Quality and Associated Health Problems in the Western Region of India

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Abstract: Groundwater constitutes a significant component of freshwater resources in India being vital for its economy and domestic water security. The quantity, quality and accessibility of water resources forms the basis of balanced socio-economic development and its optimum utilization cannot be sustained unless its quality is assessed. The current study tries to access the quality and suitability of groundwater for drinking purposes in western drier parts of India in the state of Rajasthan. Based on collected data, selected hydro-geochemical parameters, the quality of water has been determined and Water Quality Index (WQI) have been prepared using GIS applications. Applying the Inverse Distance Weighting method, WQI values for 89 villages in the area have been computed, which ranged between 71.23 and 447.39. While 68% of the region had “poor water quality”, only 32% is sustained as ‘good water’ for consumption. The fluoride content ranging between 1.66 and 8.60 mg/L and TDS > 1000 mg/L with average pH levels > 7 (8–9 pH) were found to be very high amongst all the 12 water quality parameters taken for the study. The northeastern region with a WQI value of >250 had the worst water quality. Furthermore, the existing water quality is also examined for influencing two water borne diseases, i.e., gastroenteritis and fluorosis in the region. The study thus establishes that the majority of groundwater in the region is beyond the permissible safer consumption limits, and a large population of the region, which is directly dependent on groundwater sources, is prone to water borne health hazards. A significantly high correlation was observed between Specific Water Quality Parameters in the region and prevalence of gastroenteritis (and fluorosis diseases with $R^2 = 0.530$ and $R^2 = 0.813$, respectively).

Keywords: WQI; water quality; fluorosis; gastroenteritis; GIS; TDS

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1. Introduction

Groundwater is an indispensable renewable resource found on earth, significant for supporting habitat, maintaining hydrological balance as well as sustaining human needs [1,2]. It constitutes crucial components of freshwater resources globally, fulfilling water requirements of millions of living organisms. Water also forms an integral part of many other natural resources too; hence, optimum utilization of related natural resources remains uncertain with degrading water quality. In nature, the quality of groundwater is believed to be cleaner from surface water, since it is recharged, recycled and filtered through biological, natural processes which keeps it free from contamination and pollution [3]. The quality of groundwater is subjected to various factors like forms of water, quantity of atmospheric precipitation, recharged water quality, inland/surface water, physio-chemical

properties of soil and several subsurface geo-chemical processes [4,5]. The chemical alteration in the groundwater also relies on factors such as duration of residence, seepage of contaminated surface water, salinity and several anthropogenic causes [6–9]. The quality, quantity and accessibility of groundwater is requisite for holistic, sustained socio economic and environmental development since it caters to the water needs of sectors across spheres of life.

In India, groundwater is considered the most dependable source as agriculture and drinking water demands are heavily met by it [10,11]. The main source of replenishable groundwater recharge in India comes from rainfall which accounts for nearly 67% of the total recharge annually. However, the recharge of groundwater is greatly affected by seasonal, temporal and spatial variation in annual rainfall, manifested through vast spatial variability in the availability and quality of groundwater in India [12]. Increasing population requirements, urbanization, industrialization, modern agricultural practices and non-uniform water extraction practices have accelerated degradation, depletion and contamination of groundwater resources, which have raised concerns regarding its quality and quantity. Unfortunately, water contamination and degrading quality of groundwater sources have posed severe threat to human health also wherein 80% of water borne diseases in developing countries like India can be associated with appalling drinking water quality and unhygienic conditions [13–16].

The depleting water quality has also been observed to impact the activity of microbial pathogens, which in turn can affect the prevalence and transmission dynamics of water-borne diseases to a greater extent [17]. This is evident through falling groundwater levels, contamination of aquifers, and increasing prevalence of water borne diseases over the past few decades. Contaminated aquifers, shrinking water sources and growing water scarcity problems are destabilizing India's capacity to ensure farm productivity, economic growth, safeguard public health, secure social stability and maintain environment functionality [18]. Since water quality is indicative of environmental fitness, and is closely woven with various socio-economic aspects. Its qualitative assessment is therefore, assertive to ensure environmental sustenance, long-term viability and water security for humans as well [19,20].

Appropriate water quality assessment and health management measures need reliable quantitative information. GIS has evolved as an efficient tool for assimilating, analyzing and exhibiting spatial data which can be utilized for numerous monitoring, planning and resource management purposes [3]. With the ability to use spatial data according to desired needs and in diversified domains within integrated environment, GIS has emerged as a significant platform for resource management studies. Its accuracy in exploratory data analysis, its visualization, as well as model building capacity has enabled it to address multidimensional resource management challenges including water [21]. It can be used to analyze spatial distribution of groundwater, problems associated with its quality, assessing its vulnerability to pollution, distribution of associated diseases and at-risk populations and to facilitate targeted interventions for resource management. It also provides an ideal platform for converging information in relation to the environment and population aspects and manipulating spatial data into different forms as per the geo-social requirements. Therefore, GIS can be seen as the most appropriate multispectral spatial analysis tool, which can be applied in almost all areas (even real time data analysis) where spatial information has to be retrieved and analyzed [22]. The study therefore also attempts to highlight the potential of geographical information system based geo-statistical techniques in assessing groundwater quality of the region and investigating the water-borne diseases susceptibility based on water quality indexing [17].

Furthermore, the study also intends to investigate the association of drinkable water quality and its influence on human health in the region, with respect to two diseases in particular, i.e., gastroenteritis and fluorosis. The study may therefore prove beneficial in assessing existing gross water resource quality and its suitability for human consumption. In

addition, it aims to identify the association between existing water quality and water borne diseases/ prevailing health hazards in the given or similar geographical environment [23].

2. Methodology

2.1. Study Area

The research area for this particular study covers Phagi Block, located in the south-western region of Jaipur district, in the state of Rajasthan (India) located between latitudes $26^{\circ}30'22''$ N to $26^{\circ}43'15''$ N and longitudes $75^{\circ}23'56''$ to $75^{\circ}42'35''$ E. It is surrounded in the South by Tonk district and occupies an area of 146,790 ha (Figure 1). The region has a mild slope with clay loam soil and semi-arid topography. The region has high relative temperatures throughout the year with dry arid weather conditions. The average annual precipitation is around 640 mm with summer maximum which makes availability of surface water shorter and existence of non-perennial river systems. Due to scarce availability of surface water, more than 50% of the people in the region rely on groundwater resources for their needs [24–26]. However, with degrading water sources, the predominance of water borne diseases can be observed in the region [27,28]. Two parameters (Fluoride and Total Dissolved Solids) were found to have an increase in concentrations, due to which study area is more prone to diseases like fluorosis and gastroenteritis. The concentration of the elements in drinking water has been assessed as per the permissible limits set by the Bureau of Indian Standards (BIS10500-2003) [29].

Figure 1. Study Area—Location map (Source—Primary Data).

2.2. Process and Method

The cross-sectional study includes groundwater sample collection from well sites, primary and secondary data related to sanitation, drinking water availability, diseases, etc. The random stratified sampling method has been used to choose the primary households for the study. Water quality data for the year 2018–2019 have been collected from Ground Water Department, Jaipur (India) for 89 villages in the area and additional water sample were collected from randomly chosen 16 well sites in the area at a regular interval during the same time period (Figure 2). All water samples were collected in thoroughly rinsed and sterilized bottles and were then assessed through chemical laboratory analysis based on twelve (12) physio-chemical parameters for drinking purposes as delineated by the Bureau of Indian Standards [29]. Based on this, the WQI was calculated using Weighted Arithmetic Index Method [30–32] for each of the 89 villages in the area. Several groundwater characteristics, especially its chemical characteristics, have been chronicled around the world [33–37]. By preparing the Water Quality Index (WQI) or Groundwater Quality Index (GWQI based on the collected groundwater samples and data) [38], the overall water quality of the region has been assessed.

Figure 2. Water sample location sites (16 well locations, Phagi Block, Rajasthan, India (Source —Primary Data).

GIS platforms and geo-spatial analysis techniques have also been used to encapsulate the spatial variation in groundwater quality of Phagi Tehsil, Rajasthan (India). A spatial database of the study has been prepared with village boundary maps, and point vector files were generated using village Water Quality Index data of 89 Villages of the area and

GPS location of 16 well sites in the region. These points have been used as input in spatial interpolation using the IDW method in the ArcGIS 9.3 platform. The method evaluates the value of cells based on the estimated average value of sample data points in the neighborhood of each processing cell in the GIS environment. Close proximity of the point towards the centre determines more influence of the value in the averaging process. The technique has been used in several studies for preparing/presenting spatial distribution of the attributes using GIS tools [39–41]. Once the WQI is prepared, the values are thereafter classified into 5 quality categories ranging from ‘excellent’ to ‘unsuitable’ water quality and WQI index maps have been prepared. Using overlay analysis, several data sets have been merged and reclassified to acquire the desired outcome maps to facilitate spatial analysis of water resources in the area.

Epidemiological data focusing on gastroenteritis and fluorosis have been collected from ‘Patient Record form’ available at 5 (five) primary Health centers (PHC) located in the assessment area namely—Phagi, Madhorajpura, Chauru, Renwal, Nimera PHCs. In addition, 8–12 villages in the area were served by each PHC; therefore, all the villages under one PHC were dissolved to form a single polygon conforming the service area of the respective PHC in the selected study region. Therefore, the (PHC’s) are depicted by 5 polygons—Phagi, Madhorajpur, Chauru, Renwal, Nimera—in the region while showcasing disease prevalence of fluorosis and Gastroenteritis diseases. The chemical concentrations of the entire sample lying in a PHC have been averaged and association between specific disease incidence and level of relevant physio-chemical parameters in the groundwater have been quantified using correlation and linear regression analysis. The overall methodological design adopted for the research is represented in the flow diagram in Figure 3.

Figure 3. Research methodology flowchart.

2.3. Water Quality Index Generation for Drinking Purposes

Knowledge of several parameters associated with the quality of water is essential to interpret or make accurate prediction of its quality and suitability in any area [42]. WQI has emerged to be a very efficient, effective and beneficial method in determining the overall quality of water. Assessment of Water Quality Index requires the conversion of large, spatially complex water quality data into conveniently understandable information which can be applied to the number of resource management practices. Therefore, WQI has been

widely used as an indicator of groundwater quality in any area [3] WQI has been determined for sample locations on the basis of twelve (12) physio-chemical parameters of water quality for human consumption as directed by Bureau of Indian Standards [29] (Table 1).

Table 1. Indian BIS standards for drinking water quality; all variables are in (mg/L) except pH (unitless) (Source—Indian Standard (BIS10500/1991).

Chemical Parameter (mg/L)	Indian Standard (BIS10500/1991)
TDS	500
pH	6.5
Bicarbonate	-
Phosphate	-
Sodium	200
Calcium	75
Nitrate	45
Fluoride	1.0
Chloride	200
Total hardness	200
Sulphate	-
Potassium	-

In the study, the Weighted Arithmetic Index Method [43] has been applied to calculate WQI. Here, the water quality parameters are multiplied by their weighting factor and thereafter calculated using simple arithmetic means [44,45]. Parameters like TDS, fluoride, nitrate and sulphate have been allocated the maximum weight, i.e., 5 (five) due to their predominance and high relative presence in the water samples collected.

The following three steps have been used for determining WQI:

- (1) Step 1: Each of the given 12 parameters has been assigned a weight (W_i) according to its relative presence in water for assessing the overall water quality particularly for human consumption (Table 2).
- (2) Step 2: By applying the following equation, the relative weight (W_i) has been calculated

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

where:

- W_i = Relative weight;
- wi = Weight of each parameter;
- n = The number of parameters.

- (3) Step 3: Based on the guideline laid down by BIS 10500 (1991), every individual parameter is given a specific value by dividing its concentration in an individual water sample by its corresponding standard designated by BIS, and the obtained results have been multiplied by 100 to generate a quality rating scale (qi)

$$qi = (C_i \times S_i) \times 100 \quad (2)$$

where,

- qi = Quality rating;
- C_i = Concentration of each chemical parameter in each sample in mg/L;
- S_i = The water standard for drinking for each chemical part.

For each individual parameter, the Sub Index (SI) is calculated first, which is thereafter used to determine the final Water Quality Index, based on the formula given below:

$$SI_i = W_i \times q_i \quad (3)$$

$$W = \sum SI_i \quad (4)$$

where:

- SI_i = Sub index of i th parameter.

Table 2. Relative weight of chemical parameters.

Chemical Parameter (mg/L)	Indian Standard (BIS10500/1991)	Weight (w_i)	Relative Weight (W_i)
TDS	500	5	0.117
pH	6.5	4	0.097
Bicarbonate	-	1	0.023
Phosphate	-	1	0.023
Sodium	200	5	0.117
Calcium	75	5	0.097
Nitrate	45	2	0.047
Fluoride	1.0	5	0.117
Chloride	200	4	0.121
Total hardness	200	4	0.121
Sulphate	-	1	0.023
Potassium	-	4	0.033
		$\sum w_i = 41$	$\sum W_i = 0.936$

Based on the application of these steps, the Water Quality Index values are calculated which range from 71.23 (lowest) to 447.39 (highest). These values are further categorized into 5 classes (Table 3) to evaluate the condition of water quality within the region and for generating the water quality spatial distribution map.

Table 3. Water Quality Index (WQI) categories.

S.NO	Water Quality Index	Water Quality
1	0–100	Excellent
2	100–200	Good
3	200–300	Poor
4	300–400	Very poor
5	>400	Unsuitable for drinking

2.4. Map Generation

The obtained non-spatial (attribute) and spatial data are merged together for generating WQI maps, spatial distribution maps, etc. Chorochromatic thematic maps have been prepared to demarcate areas displaying spatial variation in water quality, concentration of chemicals and water borne diseases in the area using the GIS platform.

3. Results and Discussion

3.1. Evaluating Water Quality for Drinking Purposes

The assessment of groundwater quality is imperative for inspecting the usability and suitability of water for different purposes especially for human consumption. The

qualitative evaluation of water in the area has been conducted based on the analysis of several physiochemical characteristics and WQI assessment. It depends on several characteristics like biological, physical, and chemical components to evaluate water's suitability for human consumption and other purposes [46]. Based on an index number, a single score is obtained through summation of various parameters associated with water quality. Therefore, WQI is indicative of groundwater quality in general as well as in determining its suitability for human consumption in particular.

3.1.1. Levels of Primary Physicochemical Parameters Determining the Overall Quality of Water in the Study Area

- **pH Level** is an important functional parameter of water quality. The optimum pH level standard requirement should fall within the range of 6.5 to 8.5 [3]. However, as per BIS standards, the upper permissible pH level limit for drinking purposes has been standardized to 8.5 pH value with overall range of 6 to 9. While the villages in the western, southwestern region of Phagi like Nimera and Chauru had pH ranging between 6 to 7, it increases on moving from the southwestern region to Central and Northern regions with villages like Phagi and Renwal, having maximum pH between 8 to 9, which is slightly alkaline in nature. However, the pH values of the region are observed to be within permissible limits of BIS (i.e., between 6 to 9).
- **Fluoride (F^-)**: Fluoride is a monatomic anion found naturally in water with the chemical formula F^- . Fluoride is primarily sourced from water in the human diet. Therefore, much of the difference in total fluoride intake is dependent on the compositional variability of water [47]. The existence of fluoride in groundwater is generally dissolved from geological formation [48]. While excessive intake of fluoride is often associated with dental fluorosis, excessive exposure to fluoride may lead to crippled skeletal fluorosis [49]. However, in the case of fluoride, the excess and deficiency both can be detrimental to human health; therefore, its optimum consumption is essential for balanced growth. The optimal intake of fluoride accepted widely ranges from 0.05 to 0.07 mg/kg of the total body weight [50]. It was observed that the Phagi region has an overall higher concentration of fluoride, which ranged between 1.66 to 8.60 mg/L, and was way above the BSI prescribed standards (fluoride 1.0 mg/L) for drinking water in India. The fluoride concentration was highest in the Central and North Eastern region with more than a 3.90 mg/L concentration. More than 70% of the study area is badly affected by fluoride in drinking water (Figure 4A).
- **Total Dissolved Solids (TDS)**: refers to the overall accumulation of total dissolved mineral compositions in water. The levels of TDS in water depend on many natural, physiological factors, rock structures, rainfall, soil type, etc. as well as human induced factors like mining, increased discharge of solids into the water, water extraction levels, etc. [3]. The study shows higher TDS against the permissible limit of 500 mg/L, allocated by BIS. In fact, except for a few villages in the southern part of the region (Nimera village) which have TDS below 500 mg/L, most of the villages in the Central, Western and Northern part of the Block, show a very high concentration of TDS ranging more than 1500 mg/L. Almost 70% of the region's water is found "unsuitable for drinking purposes" owing to its high TDS concentrations > 1000 mg/L. High TDS concentration pockets are located along the central, northeastern and southwestern part within the region (Figure 4B).

Figure 4. Spatial distribution of TDS (A) and Fluoride (B) concentration in Phagi Tehsil (Source—Primary Data).

3.1.2. Water Quality Index (WQI) Analysis

Since WQI is a summative compilation of several biophysical characteristics of water, it is indicative of its holistic quality. The computed WQI values for the whole study region range between 71.23 to 448.39 with overall higher WQI values and high spatial variability. Low WQI distribution, i.e., below 100 WQI value (synonymous to ‘excellent water ‘quality’) is observed in the southern, southwestern region (Chauru, Nimera region). The value increases on moving towards the central, northern and northeastern regions (Phagi, Renwal, Madhorajpura), where the WQI values exceeds the 250 range and is considered of “Poor” to “Very Poor” quality, and inappropriate for human consumption. Certain village pockets even had >400 WQI values which were categorized as regions having water ‘Unsuitable for Drinking’. Nearly 66% of the samples from the region either were in Poor, Very Poor or Water Unsuitable for Drinking category as per WQI. In fact, 18.57% samples with > 400 WQI values fall under “Water unsuitable for drinking” category and only 31.42% samples with (less than) < 100 WQI values were considered of “Good Water Quality”. Areas with WQI values in between 300 to 400 indicate that water should be used with caution, particularly where the prevalence of water borne health hazards is higher (Figure 5).

The analysis, therefore, reveals high spatial variations in water quality within the study area. While the central and northeastern regions of the study area show very high values (>400) on the Water Quality Index, indicating that the water is “unfit” for drinking, the southern regions have lower values (<100) showing that water is suitable for drinking. The most “unsuitable water for drinking” was observed in Phagi and Renwal regions with highest values on WQI index exceeding >400 with 402.03 and 404.07 WQI values respectively).

Figure 5. Water quality map using WQI of 89 Villages in the Phagi Tehsil (Source—Primary Data).

3.2. Water Quality and Disease Prevalence

The prevalence of the waterborne diseases can be observed globally, with predominance in developing countries. The contamination of community water systems and outbreak of water borne diseases have the potential to affect large population consumer groups [51]. Water is considered safe for drinking and domestic purposes, when it is not only pleasant to taste, but also free from harmful chemical and pathogenic agents [52]. Accessibility to clean drinking water significantly affects poor and vulnerable people, especially those living in developing regions of the world [53].

In recent years, higher dependence on groundwater resources for domestic as well as economic purposes have led to constant degradation in quality of water with subsequent prevalence of water borne health hazards. Microbial contamination is very common in many developing countries affecting all water sources including piped [54]. The assessment of disease prevalence and concentration in the area is established on the disease case record data of fluorosis and gastroenteritis collected from five Primary Health Centers of the region (Table 4).

Table 4. PHC wise incidence of diseases and concentration of selected chemicals in groundwater (mg/L).

PHC	Chemical Concentration		Percentage of Cases with Disease Incidences 2018–2019	
	Fluoride	TDS	Fluorosis	Gastroenteritis
Phagi	3.38	2034	3.87	2.98
Madhorajpura	1.48	2175	3.09	4.52
Chauru	1.90	1897	1.99	4.85
Renwal	2.7	3134	3.50	10.03
Nimera	1.4	1905	1.50	2.80

3.2.1. Fluorosis

Fluoride, which is primarily sourced from water, has beneficial and detrimental effects on human health [55]. While its excess consumption/exposure is related to dental and skeletal fluorosis, its deficiency may cause tooth decay and osteoporosis [56,57]. Therefore, optimal intake of Fluoride is essential for the balanced development of human beings. Its intake through water plays a vital role in accessing its net consumption adequacy in many settings [58,59]. The health hazards associated with fluoride are often based on either contamination of groundwater with excess fluoride (F), with profusion occurring from geological crust or consumption of unsafe (untreated, unfiltered) groundwater having higher content of fluoride by the communities generally drawn through open wells, hand pumps and tube wells [60].

Communities consuming safe water ($F^- < 1.0$ mg/L) have comparatively lesser chances of fluorosis, as compared to the ones consuming water with higher fluoride content ($F^- > 1.0$ mg/L). The study area has a very high concentration of fluoride ranging between 1.66 to 8.60 mg/L and has a higher concentration of people suffering from fluorosis. The data collected from the PHC's of the study region reveal that disease samples collected from northern, northeastern and central regions show a higher concentration of fluorosis with Phagi and Madhorajpura PHC's having the highest percentage of 3.87% and 3.90, respectively, of the total fluorosis cases in the region in 2018 (Figure 6A). In fact, Phagi PHC is most affected by fluorosis followed by Renwal. The higher concentration of fluorosis cases can be linked to a higher fluoride concentration in water in the region. The value of R^2 between fluorosis and fluoride is observed to be 0.81, (Figure 6B) reflecting significantly higher positive association between the prevalent disease (i.e., fluorosis) and presence of fluoride (chemical parameter taken) in the groundwater of the region.

Figure 6. Percentage of Fluorosis cases recorded. (A) linear regression analysis between fluorosis cases and fluoride content in water (B).

3.2.2. Gastroenteritis

Nearly 90% of diarrheal deaths worldwide can be associated with inadequate sanitation, poor hygiene and overall unsafe water consumption practices [61]. The pathogenic microorganisms, their toxic exudates, and other contaminants together may cause conditions leading to gastroenteritis. Several incidences of viral gastroenteritis outbreaks, related to unsafe drinking practices, consumption of unsafe water and exposure to contaminated water have been reported worldwide [62–64]. The drinking water available in the region has low water quality; therefore, the prevalence for gastroenteritis is widespread in the region, with pockets of high concentration. The maximum concentration of gastroenteritis cases was observed in the northeastern section of the region in the given year. Spatial distribution of the diseases reveals that the highest incidences of gastroenteritis were reported

from PHC Renwal (10.03) followed by Chauru (4.85) and Madhorajpura (4.52) within the region (Table 4 and Figure 7). Statistical computation identifies the value of R^2 as 0.530, which highlights a positive association between gastroenteritis disease and an existing chemical parameter (TDS) concentration in groundwater (Figure 7B).

Figure 7. Percentage gastroenteritis incidences cases recorded (A); linear regression analysis between gastroenteritis cases and TDS content in water (B).

Different parameters of water quality with respect to disease prevalence i.e., fluorosis and gastroenteritis were found to be strongly interrelated within the area with the exception of small pockets in southern and southeastern regions. A high correlation was observed between disease prevalence and 12 water chemical parameters, with two parameters (Fluoride & TDS) showing maximum correlation.

Therefore, a visual comparison of the hydro-chemical concentration map with a disease distribution map indicates that the areas having a high concentration of specific chemicals exceeding the standard limit prescribed by BIS corresponds with the areas of high disease incidence (Figures 4 and 5). Regression analysis further validates the fact, establishing a positive correlation between existing water quality and prevalence of selected water borne diseases in the particular area. Therefore, a strong association between concentration of specific physio-chemical parameters in groundwater and prevalence of respective diseases can be observed in the region.

4. Conclusions

The systematic study carried out using spatial analysis tools on the GIS platform to assess the chemical characteristics of drinking water quality on health concludes that deteriorating water quality is a major problem in the Phagi Block located in Jaipur, Rajasthan (India). The integration of various thematic layers using ArcGIS 9.3 GIS software has proved beneficial in determining groundwater suitability for drinking purpose and in highlighting prevailing water borne health hazards in the region. Assimilation and integration of spatial data at various stages of the work conducted on the GIS platform generated thematic and spatial distribution maps of the study region. The generated Thematic assessment substantiated the results of degrading water quality in the region and prevailing health hazards in the region.

Statistical analysis reveals a strong positive association between disease prevalence/distribution and spatial pattern in concentration of physio-chemical parameters taken for groundwater analysis in the area. The WQI for 89 samples have been calculated using the Inverse Distance Weighting (IDW) method, wherein WQI values range between 71.23 to 447.39. Nearly 90% of the water samples exceeds the 200 WQI value, which is the

highest permissible limit for drinking water in India as per BIS drinking water standards. This signifies that the maximum percentage of water available for human consumption pertains to 'poor quality' in the region. The higher values of the WQI are primarily due to a relatively higher concentration of Fluoride and TDS in the groundwater. Chemical characteristics of groundwater in the study area indicate an alkaline nature of water. The "Poor Quality" groundwater is primarily concentrated in the central, northern and northeastern region of the block. The region is dominated by a range of economic activities (industries, agriculture, etc.) directly corresponding to higher concentrations of fluorides and TDS in the groundwater.

The study highlights that the population depending directly on groundwater drinking sources is prone to the health problems like fluorosis and gastroenteritis therefore encourages simple water purification measures like filtration and boiling before consumption. The northeastern region with a high score of more than 250 WQI value is the most severely affected zone in the whole region with quality ranging from 'Poor' to 'Water Unfit for Drinking Purposes'. It also shows higher reported cases of fluorosis and gastroenteritis within the whole region. Within the study area, Phagi and Renwal regions are observed to be most affected by poor standards of drinking water quality and showcase predominance the two diseases. Regression analysis further validates the observations establishing a positive correlation between concentration of diseases and quality of water. Therefore, the prevalence of water borne diseases like fluorosis and gastroenteritis and many other waterborne health hazards in the region may be attributed to poor groundwater quality with a higher concentration of fluoride and TDS in the groundwater.

The study also highlights the need for a definite strategy and guidelines pertaining to groundwater quality, quantity and accessibility management using quick, reliable technology. It thus highlights the potential of GIS for analyzing groundwater quality and its impacts on human health, which is imperative for effective planning of water quality management and healthcare systems. The study may therefore prove beneficial in effectively assessing the overall quality of groundwater resources available, provisions of clean, safe drinking water, management of water borne diseases, sensitizing and promoting safe drinking practices, in the given or similar geographical environment.

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Abbreviations

WQI	Water Quality Index
GWQI	Groundwater Quality Index
IDW	Inverse Distance Weighting
BIS	Bureau of Indian Standards
TDS	Total Dissolved Solids
pH	Power of Hydrogen
IDW	Inverse Distance Weighting
PHC	Primary Health Centers

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