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Assessment of groundwater quality using spatial variation technique

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ABSTRACT

Groundwater management is a potential solution to the global water crisis. We assessed the groundwater quality at Mettupalayam, Tamil Nadu, India, in order to determine its suitability for drinking. Groundwater samples were collected and their physicochemical characteristics such as pH, electrical conductivity (EC), total hardness (TH), total dissolved solids (TDS), Ca^{2+}, Mg^{2+}, $SO4^{2-}$ and Cl^{-} were determined and benchmarked with standard drinking water requirements. The variations of these parameters were presented spatially. The groundwater is generally brackish and hard; and of low alkalinity and high salinity. Consequently, the groundwater in most parts of the study area is unsuitable for drinking without treatment. It is recommended that point and nonpoint sources of groundwater pollution at Mettupalayam should be identified, monitored and managed in order to protect the groundwater.

KEY WORDS: Drinking water, environment, GIS, natural resources, pollution, water supply.

1. INTRODUCTION

Groundwater is an essential component of our life support system and its degradation has been an environmental concern (Adhikary, 2012; Cao, 2016). Groundwater contributes significantly towards the satisfaction of human water needs. Generally, groundwater is less-polluted compared to surface water. However, rapid population growth, urbanization, industrialization and agricultural activities are negatively affecting the quality of groundwater (Coetsier, 2008). Groundwater quality is fast deteriorating due to geogenic and anthropogenic activities (Yidana, 2012; Abida and Harikrishna, 2008; Ikhane, 2010; Adil, 2012; Wlodzimierz, 2013). For instances, some industries discharge untreated or partially-treated effluents into the sewers, drains and on land surfaces, thereby resulting in many environmental problems (Elkrail, 2012; Omonona, 2014). Soil layers and rock contain minerals, some of which get dissolved in groundwater as it passes through it. Harmful contaminants also get associated with groundwater through the process of seepage from surface water and biological activities. Runoff through farmlands wash down organic matters, mineral nutrients, fertilizers and pesticides; leachates from waste repositories; and wastewater discharge domestic activities; all contribute to increasing the contaminant levels in groundwater and thereby reducing its quality (CGWB, 2008). The chemical composition of groundwater is also affected by precipitation, geological structure, and mineralogy of watersheds, aquifers, and geological processes within the aquifer (Chenini and Khemiri, 2009; Aghazadeh and Asghar, 2010; Hosseini, 2014). All these affect the provision of safe drinking water, which is essential to the protection of public health and the environment.

The objective of this research work is to assess the groundwater quality at Mettupalayam, Tamil Nadu, India in order to determine its suitability for drinking and geographically map out pollution sensitive area.

Study Area and Sampling: Mettupalayam, which is the study area, is located in the foot hills of Nilgiris, India. The Bhavani River located in the foothills of Nilgiris is one of the perennial rivers in India. In recent years, many industries have been established at the aquifer boundary of Bhavani River, which is one of the sources of water to the people in the taluk. Other sources include borehole and hand-dug wells, and pipe-borne water. Mettupalayam is an important trading hub and transit centre for hill products. Mukherjee and Nelliyat (2006), reported that the groundwater quality at Thekkampatty, Jadayampalayam and Irumborai, which are villages in Mettupalayam, have been affected by industrial pollution.

This study was undertaken by randomly collecting 40 groundwater samples from open wells within Mettupalayam, India. The study area and the sample locations are presented in Figure.1. The samples were collected in plastic bottles, which had been cleaned with distilled water before being rinsed thoroughly with the collected groundwater.

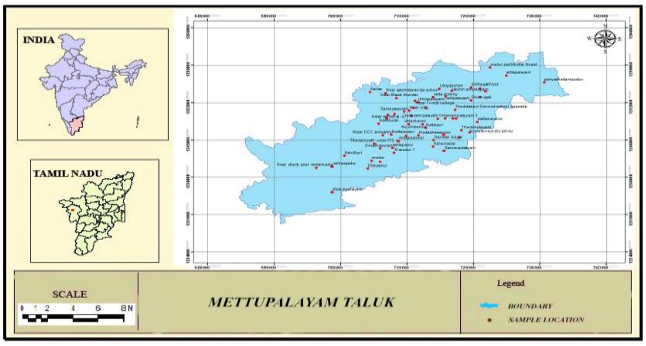

Figure.1. Study area and sample collection points

2. METHODS

The groundwater samples were analysed in accordance with standard methods recommended by American Public Health Association (APHA, 1998). The pH, total dissolved solids (TDS) and electrical conductivity (EC) were analysed on site using digital meters. Other parameters were determined in the laboratory. Calcium (Ca^{2+}) concentration was determined using eriochrome black T while the total hardness (TH) was determined using Versenate titration method. The concentration of Mg^{2+} was then determined by calculating the difference between TH and Ca^{2+} concentration. Chloride (Cl^{-}) and sulphate (SO_4^{2-}) was determined by titration method and turbidimetric method, respectively.

The results of the sampled groundwater (quality parameters) were the attribute data while the spatial variation of the results were developed using Inverse Distance Weighted (IDW) method of analysis (Mokarram, 2016). Spatial interpolation technique functions have been used in the present study to delineate the distribution of water pollutants (Mohammad, 2014). IDW analysis, which "is a deterministic interpolation that assigns values to locations based on the surrounding measured values and on specified mathematical formulas that determine the smoothness of the resulting surface" (ESRI, 2008), is best suited for a set of points that is dense enough to capture local surface variation. IDW method can be used efficiently with spatial data that have a normal distribution. The groundwater contaminations at unknown locations are determined, based on the distance and direction of the observation wells using spatial interpolation method (Akankpo and Igboekwe, 2012). Linear weighted combination of set of sample points is used to predict the cell value. The Weights are assigned based on the distance of input points from the output cell location. WQI is an important parameter used for the assessment and management of ground water. It was calculated by assigning rating scales and weightages to pH, EC, TH, TDS, Ca, Mg, SO_4 and Cl. The weightage of each parameter is assigned according to its relative importance in overall water quality. The geostatistical analyst extension with IDW algorithm in ArcGIS was used to interpolate the points and create the spatial distribution map. Spatial variation maps of major water quality parameters like pH, EC, TH, TDS, Ca, Mg, SO_4 and Cl were produced. For each of the maps, the study area was classified into three categories, such as good, moderate and poor quality.

3. RESULTS AND DISCUSSION

The physicochemical characteristics of water or groundwater can be used to determine its quality and suitability for purposes such as for drinking, irrigation, among others. The pH value of a water sample is used to determine whether it is acidic, neutral or alkalinic. The pH of the groundwater samples at Mettupalayam is generally alkalinic. However, the Bureau of Indian Standards (BIS, 2009) gives the permissible range of pH for drinking water to be 6.5 - 8.5. Consequently, pH values within this range was considered to be normal, those below it were considered to be acidic, while those above it were considered to be alkalinic. The distribution of the pH for the groundwater samples is presented in Figure.2. Most of the samples have their pH values within the normal or acceptable range, as clearly shown in Figure.2, while about 19.5% of the study area has its groundwater classified as being alkalinic. The minimum and maximum pH are 7.0 and 9.2, respectively; with the mean and median pH of the distribution being 8.1.

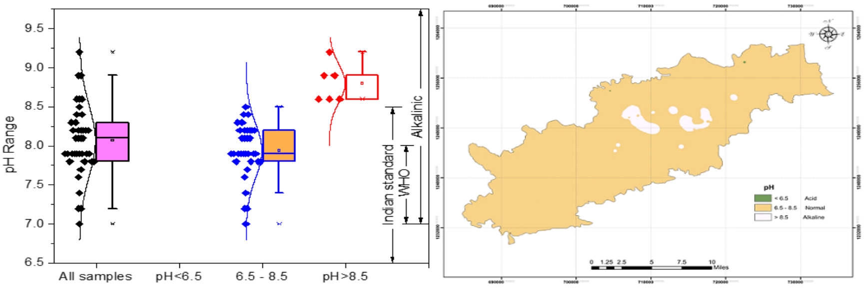

Figure.2. pH of the groundwater samples and its spatial distribution within the study area

The EC of water provides a measure of estimating its concentration of ions of dissolved salt (Selvakumar, 2014), which is responsible for its salinity and ability to conduct electricity. Consequently, it is related to TDS (Gnanachandrasamy, 2015). However, beyond a certain concentration (limit) of salt in water, EC no longer provides a direct proportionality to the amount of dissolved salt. The knowledge of the TDS in a water sample is, consequently, important. A graphical and spatial illustration of the distribution of the EC and TDS of the groundwater samples is presented in Figure.3 and Figure.4, respectively. In the study area, the minimum and maximum EC measured is 1.57 and 6.50 dS/m, respectively. This range of EC for the groundwater samples is generally unsuitable for drinking and can be categorized into water having high (0.75 – 2.25 dS/m) to very high (>2.25 dS/m) salinity hazard for irrigation. In plotting the spatial distribution of EC for the study area, the EC was classified in to three ranges: good (0.25-0.75 dS/m), moderate (0.75-2.25 dS/m) and poor (>2.25 dS/m). About 44% of the EC for the study area falls within the moderate category. This category is permissible for domestic and irrigation purpose. About 56% falls within the poor category, making the groundwater unsuitable for irrigation. The TDS of the groundwater samples ranges from 1110 – 4720 mg/l. The groundwater samples in the study area can be classified as brackish, since their TDS lie within 1000 – 10000 mg/l. In preparing the spatial distribution of TDS for the study area, the TDS was categorized into three classes: good (0 – 500 mg/l), moderate (500 – 2000 mg/l) and high (>2000 mg/l). Figure.4, consequently, show that the groundwater samples have moderate to high TDS. The high values of EC and TDS is most likely to have resulted from the persistent application of fertilizers in the study area, whose land area is predominantly used for farming.

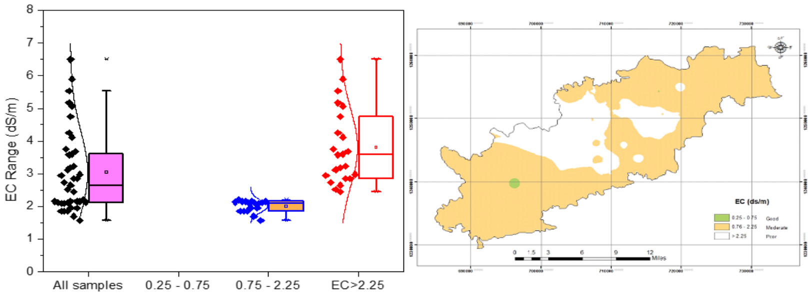

Figure.3. EC of the groundwater samples and its spatial distribution within the study area

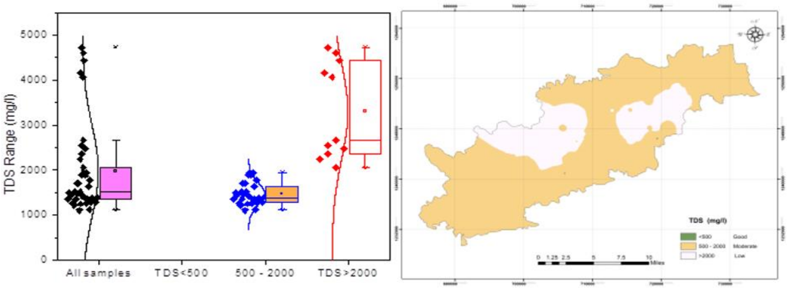

Figure.4. TDS of the groundwater samples and its spatial distribution within the study area

TH in water is due to carbonates, bicarbonates, chlorides and sulphates of calcium and magnesium dissolved in it (Basamba, 2013). A graphical and spatial illustration of the distribution of the TH of the groundwater samples is presented in Figure.5. The minimum and maximum TH obtained in the study area is 340 and 860 mg/l, respectively. Consequently, the groundwater samples are considered to be generally very hard (>300 mg/l). For the purpose of producing the spatial map of the distribution, The TH of the samples was categorized into good (<300 mg/l), moderate (300-600 mg/l) and poor (>600 mg/l). About 68% of the groundwater samples have their TH falling within the moderate (permissible) category. For domestic use TH up to 300 mg/l is not objectionable. From health point of view, TH even up to 600 mg/l is not of any concern but beyond that it may cause a laxative effect. For certain industries, however, water of zero hardness is required. Maximum value of hardness is observed in central part of the study area (Figure.5).

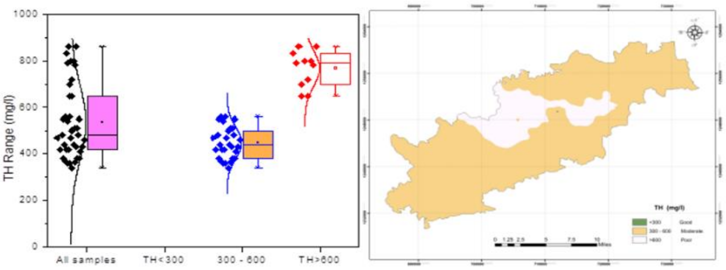

Figure.5. TH of the groundwater samples and its spatial distribution within the study area

Calcium is naturally present in water. It is a determinant of water hardness. The calcium content of groundwater samples in the study area varies from 108 mg/l to 356 mg/l. The graphical and spatial variation of Ca^{2+} in the study area is shown in Figure.6. About 71.3 % of the samples were within the permissible limits of less than 200 mg/l while 28.7 % of the samples exceeds this limit.

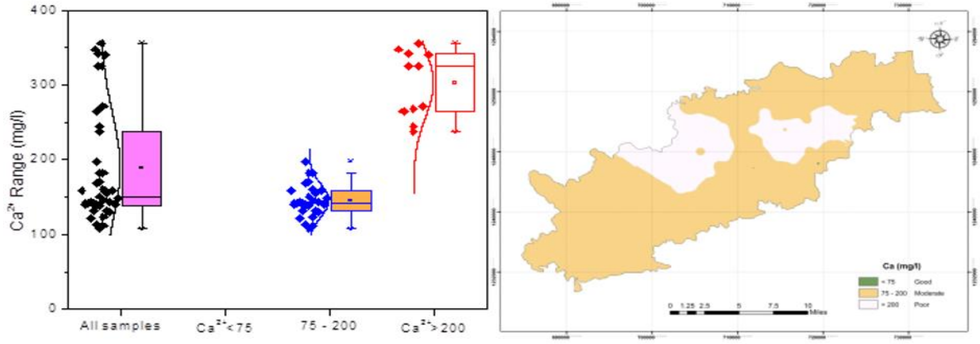

Figure.6. Ca^{2+} of the groundwater samples and its spatial distribution within the study area

A large number of minerals contain magnesium. Magnesium is washed from rocks and subsequently may end up in water in different ways. During the manufacture of plastics, magnesium is usually used as filler or for fire safety. Thus, magnesium can leach into groundwater from improper management of waste products, such as plastics, containing magnesium. A graphical and spatial illustration of the distribution of the Mg^{2+} of the groundwater samples is presented in Figure.7. The minimum and maximum Mg^{2+} obtained in the study area is 85 and 165 mg/l, respectively. The permissible limit for Mg^{2+} in drinking water, as per Bureau of Indian Standards, is 100 mg/l. Most of the samples in the study area have their Mg^{2+} concentrations to be beyond the permissible limit (Figure.7).

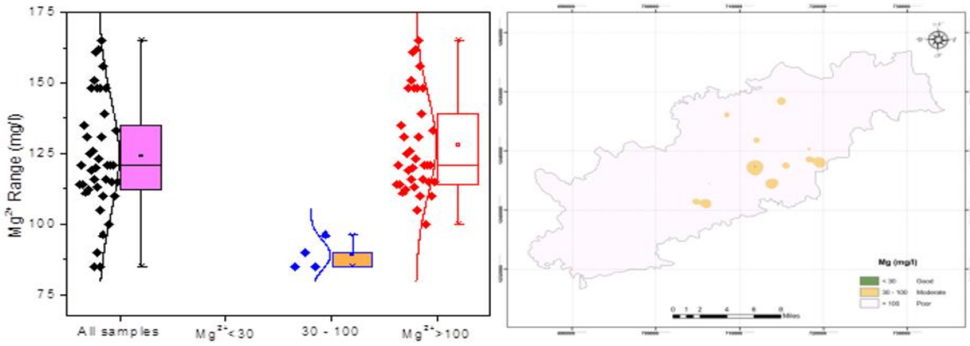

Figure.7. Mg^{2+} of the groundwater samples and its spatial distribution within the study area

Geological formation such as pyrite, lignite and coal contribute SO_4^{2-} to groundwater. A graphical and spatial illustration of the distribution of the $SO4^{2-}$ of the groundwater samples is presented in Figure.8. The SO_4^{2-} in the groundwater samples obtained from the study area ranges from 142 and 641 mg/l. For the purpose of producing the spatial map of the distribution, The SO_4^{2-} of the samples was categorized into good (<200 mg/l), moderate (200-400 mg/l) and poor (>400 mg/l). The permissible limit for SO_4^{2-} is 400 mg/l, as per BIS. Values exceeding this limit have causes gastrointestinal problem. About 91% of the groundwater samples have their SO_4^{2-} falling within the moderate (permissible) category. Particularly, the high presence of SO_4^{2-} was found in samples from Ramampalayam and Jadayampalayam area.

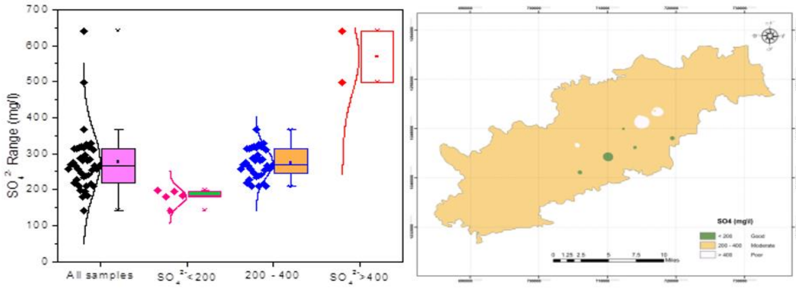

Figure.8. SO_4^{2-} of the groundwater samples and its spatial distribution within the study area

Chlorides are present in all drinking water supplies and can be present as sodium, magnesium or calcium salts (Sharma, 2013). High chloride in potable water is not harmful to humans but can corrode metal pipes and cause harm to plants. Soil porosity and permeability play an important role in chloride building-up in groundwater. The Cl^- of groundwater samples in the study area varies from 312 mg/l to 1085 mg/l. The graphical and spatial variation of Cl^- in the study area is shown in Figure.9. For the sake of taste, the permissible limit of Cl^- in drinking water is 250 mg/l. All the samples have their Cl^- levels exceeding this limit, making it unsuitable for direct use as drinking water. About 7% of the samples have their Cl^- content exceeding 1000 mg/l, which can be hazardous to plant life and as such unsuitable for irrigation purpose.

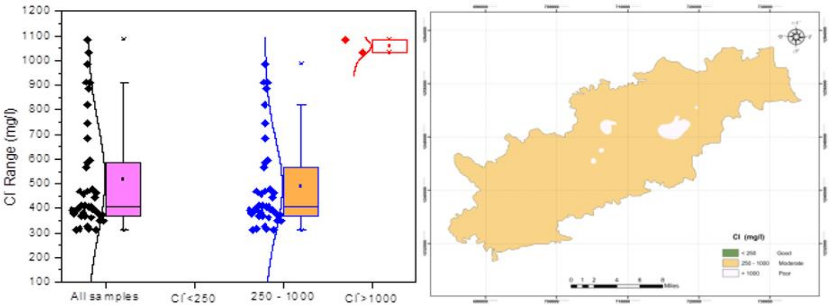

Figure.9. Cl^- of the groundwater samples and its spatial distribution within the study area

A GIS database proved to be a very useful tool for this groundwater study in order to make recommendations that will positively impact on the ecology, economic and socio-economic setup of the study area. To calculate the water quality index (WQI), weightages and ranking were assigned to water quality parameters (Table.1). The spatial variation maps of major groundwater quality parameters were integrated and groundwater quality map was prepared (Figure.10). The integrated map shows the details of pollution potential in the study area. Groundwater quality map of the study area reveals that the groundwater qualities in Alangombu, Ramampalayam, Sirumugai, Jadayampalayam and Thekkampatty villages are deteriorated as per thestandards (BIS, 2009).

Table.1. Weightages and ranking of water quality parameters

Criteria	Parameter range	Ranking	Weightages
pH	7.0 to 7.5	1	15%
	6.0-7.0 &7.5 to 8.5	2	
	<6 &>8.5	3	
Electrical conductivity (dS/m)	0-0.75	1	15%
	0.75-2.25	2	
	>2.25	3	
Total Hardness (mg/l)	0-300	1	15%
	300-600	2	
	>600	3	
Total Dissolved Solids (mg/l)	0-500	1	15%
	500-2000	2	
	>2000	3	
Calcium (mg/l)	<75	1	10%
	75-100	2	
	>100	3	
Magnesium (mg/l)	< 30	1	10%
	30-100	2	
	>100	3	
Sulphates (mg/l)	0-200	1	10%
	200-400	2	
	>400	3	
Chlorides (mg/l)	< 250	1	10%
	250-1000	2	
	1000	3	

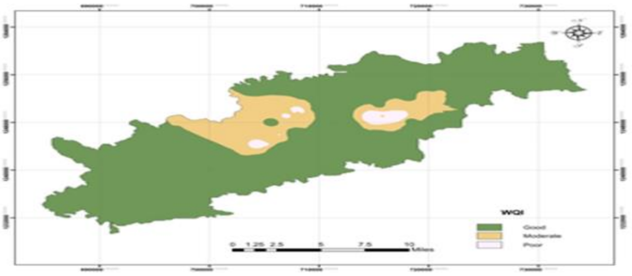

Figure.10. WQI for the groundwater samples and its spatial distribution within the study area

From the result 80.2 % of the area is within the permissible limit, 14.6 % of area is nearly polluted as per WQI and it is susceptible to pollution. The highly polluted area is 5.2% and this pollution was caused by contributions from industrial effluent discharge, urbanisation, improper solid waste disposal, sewage disposal and application of fertilizers. Aside the direct contamination of groundwater, these have also polluted groundwater through surface water bodies.

4. CONCLUSIONS

Based on the research it is concluded that an integrated weighted overlay model has been found very useful in delineating groundwater pollution sensitive area prospective zones. Continuous monitoring of zero discharge in industries should be ensured in sensitive areas. The untreated sewage and sewerage flowing in various open drains should be avoided. As a long term measure farmers should be educated about agricultural practices that promote the protection of the environment and public health. Considering terrain conditions and favourable zonation, the suitable artificial recharge structures are recommended.

The analytical results revealed the higher concentration of total hardness and total dissolved solids. Out of the 40 groundwater samples collected, the central part of Mettupalayam (comprising of Alangombu, Ramampalayam, Sirumugai, Jadayampalayam and Thekkampatty villages) shows a concentration of pollution-prone and polluted areas. The application of fertilizers, pesticides, herbicides by farmers and the discharge of industrial effluent were identified as the main contributors to the pollution of groundwater in the study area. Ventures which emphasis on total sanitation in rural areas, such as clean India project and waste management, should be strictly enforced in order to protect groundwater and thereby public health and environment.

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