Geospatial Analysis of Groundwater Quality in Ludhiana, Punjab (India)

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ABSTRACT

This paper presents a geospatial analysis of the groundwater quality of Ludhiana, Punjab, India. The groundwater samples were collected from 99 locations using grid based sampling procedure and analysed for parameters viz. pH, total dissolved solids (TDS), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), fluoride (F^{-}), chloride (Cl^{-}), nitrate (NO_3^{-}), sulphate ($SO^{2}_{4}{}^{-}$) and bicarbonate (HCO_3^{-}). Sampling was done during both pre-monsoon and post-monsoon periods. Water quality index (WQI) was used to represent the groundwater quality of the study area. The WQI coupled with the spatial maps indicated that merely (1%) of the total study area had good groundwater quality and the rest of the study area fell under poor, very poor and unsuitable for drinking purpose. The geographical information system (GIS) based groundwater quality mapping presented in this paper could be a potential tool for groundwater quality management.

Keywords: Groundwater quality; Water quality index; Geospatial techniques; GIS

1. INTRODUCTION

Water is one of the essential resources on earth. Groundwater is a key natural resource for fulfilling the needs of inhabitants. Groundwater is the vertebral segment of India's farming, industrial and drinking water security in rural as well as urban regions. Unfortunately, quality of the Indian groundwater resources is deteriorated because of the release of effluent from pits, releases of residential wastewater in defective channels, improper management of sanitary landfills, over-exploitation for irrigation, urban runoff, intense nitrogenous fertilizers used in agriculture, contaminated industrial sites and industrial discharges (Singh, 2000; Vijay et al., 2011; Kumar et al., 2016). These types of activities are reported to have impact on groundwater sources and human health (Bharti et al., 2013; Bhutiani et al., 2016). A steady and large-scale groundwater depletion in the northern India was reported by (Tiwari et al., 2009).

In Punjab (India), more than 83% of land is under agriculture where, the entire state is highly reliant on groundwater throughout the year (Garduno et al., 2011). Groundwater, basically from tube wells and bore wells have been the significant resource for millions of people in Punjab. There are around 1.3 million tubewells (both electric and diesel operated) in Punjab. Deterioration of groundwater quality because of anthropogenic activities is reported expanding at an alarming rate in many parts of Punjab (Kaur et al., 2016). Also, a recent study indicated that chemicals from anthropogenic wastes influenced the general groundwater quality of Malwa region in Punjab making it inappropriate for human consumption (Suthar et al., 2018). The concentration of trace metals like Uranium and Arsenic in both shallow and deep aquifers were also reported (Hundal et al., 2009; Singh et al., 2011). The nature of groundwater relies on various geological formations present in the region. The geostatistical procedures are found useful for breaking down intrinsic vulnerabilities of groundwater frameworks and can be utilized in groundwater estimation issues, including interpolation and differentiation (Krishnamurthy et al., 1996; Saraf and Chaudhary, 1998; Murthy, 2000; Mtetwa et al., 2003; Junge et al., 2010). Geographical information system (GIS) is proven as a potential tool in managing dynamic systems like the groundwater systems (Chen et al., 2004; John et al., 2006). Several studies have demonstrated the use of indexing concepts like water quality index (WQI) coupled with geospatial techniques in analysing the groundwater quality (Sadat et al., 2014; Khan et al., 2017; Syed et al., 2017). The primary objective of this study was to analyse

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the current groundwater quality of Ludhiana, Punjab (India). It was also attempted to analyse the spatial variation of groundwater quality in the area.

2. METHODOLOGY

2.1 Study Area

Punjab (India) is spanned by three major rivers; the Ravi, the Beas and the Satluj which are part of Indus river basin. Ludhiana district located in the heart of Punjab is bounded between latitude 30° 33' and 31° 01' and longitude 75°25' and 76° 27'. The Satluj shapes the fringe of the district Ludhiana in the North with Jalandhar and Hoshiarpur areas. The geographical area of the district is around 3767 sq. km. The population of the district according to 2011 census data is approximately 3.5 million with 1.5 million rural and 2.0 million urban (Punjab, 2011). The region experiences south west monsoon from the last week of June to the end of September. This contributes about 78% of the annual rainfall. The remaining 22% of the rainfall is received during non-monsoon period. The subsurface lithological setting of the area comprises sand, silt, clay and kankar in various proportions. The geographical positions of all the sampling locations are shown in Figure 1.

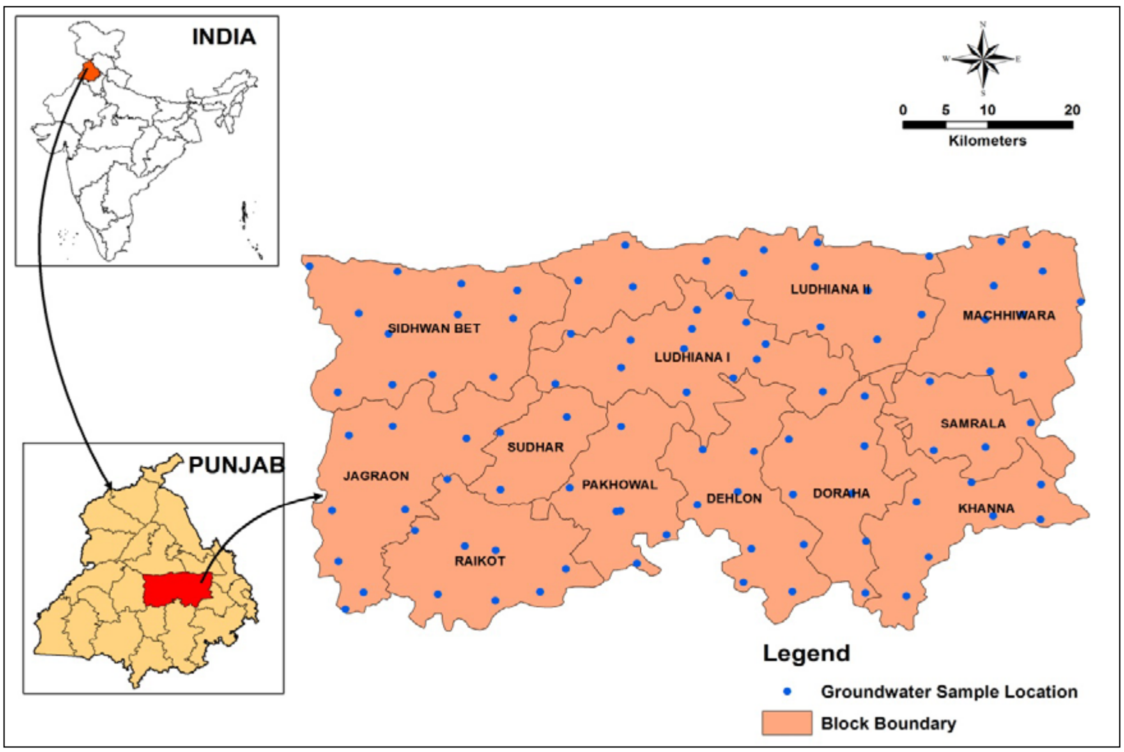

Figure 1 Study area and sampling locations

2.2 Sample Collection and Analysis

99 groundwater samples for both pre-monsoon (April-May) and post-monsoon (November-December) periods of 2018 were collected by grid based sampling method with 7 x 7 km grid of the study area. The groundwater samples were collected from tubewells and hand pumps. Pre-washed glass bottles were used for sampling and are rinsed with sample water before filling. The water from the sampling well was drained for 5 - 7 minutes before the collection of samples. The samples were stored at a temperature of 4˚C and analysed within seven days of sampling. The physicochemical parameters including pH, total dissolved solids, hardness, calcium, magnesium, sodium, potassium, sulphate, bicarbonate, chloride, nitrate and fluoride were analysed. The pH and TDS were measured using digital tester HI98129 (Hanna, Romania). Total hardness and chlorides were determined by titration method as described in American Public Health Association (APHA 2017). Flame Photometer was used for determining calcium, sodium and potassium as given in (APHA 2017). Sulphate, nitrate and

fluoride were measured spectrophotometrically as per methodology in (APHA 2017). Magnesium is determined with the help of Atomic Absorption Spectrophotometer (AAS4141 by ECIL) as described in (APHA 2017). The results of the examination of groundwater quality obtained were compared with the standards of drinking water quality prescribed by the Bureau of Indian Standards (BIS 2012).

2.2 Groundwater Quality Mapping

For groundwater quality mapping, tubewells locations were marked on the spatial map of the entire study area using ArcGIS version 10.4. After preparing the spatial map, thematic data layers for all the parameters pH, TDS, TH, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, F^{-}, Cl^{-}, NO_3^{-}, $SO^{2}{}_4^{-}$ and HCO_3^{-} were generated. For spatial variations of groundwater quality, Inverse Distance Weighted (IDW) interpolation technique was utilized in ArcGIS 10.4 environment. IDW works on the assumption that the points near are more similar than those that are more distant or separated. To predict a value for any unmeasured location, IDW uses the measured values surrounding the prediction location. The measured values closest to the prediction location have more influence on the predicted value than those farther away.

2.4 Estimation of WQI

Horton (1965) proposed the first water quality Index for assessing the quality of natural water bodies. The WQI method has been widely used by the various researchers, Jasmin and Mallikarjuna (2013) analysed the physicochemical parameters through the development of drinking water quality index (DWQI). WQI is valuable and unique rating to depict the overall water quality status in a single term was assessed by (Tyagi et al., 2013). WQI is calculated by weighted arithmetic water quality index method using the following steps.

The WQI was estimated using the equation (1) (Rown, 1972)

$$\mathrm{WQI} = \frac{\sum_{i}^{n} W_i Q_i}{\sum_{i}^{n} W_i} \tag{1}$$

Where, w_i = Unit weight of each parameter
Q_i = Quality rating of each parameter
n = number of parameters

Quality rating scale (Q_i) is described as shown in equation (2)

$$Q_i = 100 * \frac{(V_i - V_o)}{(S_i - V_o)} \tag{2}$$

Where, v_i = estimated concentration of i^{th} parameter in the analysed water
v_o= ideal value of this parameter in pure water
v_o = 0 (except for pH where v_o =7.0)

Unit weight (w_i) for each parameter was calculated by using equation (3)

$$w_i = \frac{K}{S_i} \tag{3}$$

Where, K = proportionality constant $= \frac{1}{\sum_{i=1}^{n} S_i}$

S_i = recommended standard value of i^{th} parameter

Weightage (W_i) assigned to each parameter according to its relative significance in water in a scale of 1 - 5 as given in the literature is presented in Table 1.

Table1 Weightage of parameters vis-a-vis standards

Parameter[1]	Weight age (W_i)	Unit Weight (w_i)	BIS Standards (S_i)
pH	5	0.125	6.5-8.5
TDS	5	0.125	500
TH	4	0.100	200
Ca^{2+}	3	0.075	75
Mg^{2+}	2	0.050	30
Na^{+}	3	0.075	200
K^{+}	3	0.075	-
F^{-}	5	0.125	1.0
Cl^{-}	4	0.100	250
NO_3^{-}	3	0.075	45
SO_4^{-}	2	0.050	200
HCO_3^{-}	1	0.025	500
	$\sum W_i$=40	**$\sum w_i$=1**	

[1]All parameters are expressed in mg/l, except pH

3. RESULTS AND DISCUSSION

The water quality of the study area for various parameters identified is depicted in figures 2 through 13.

Figures 2 (a) and (b) indicate the spatial variation of pH during the pre-and post-monsoon period in the study area. The pH varied from 6.65 to 8.50 and 6.85 to 8.65 during pre-and post-monsoon period, respectively. However, the pH is found to be close to the standards (BIS 2012).

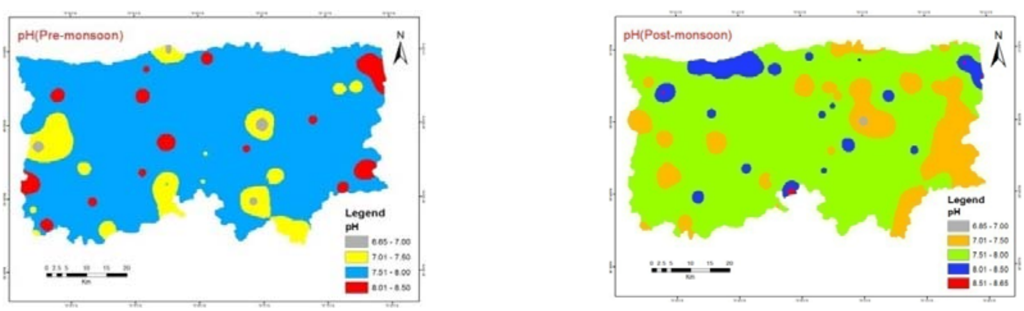

Figure 2 (a) and 2 (b) Spatial variation of pH

Figures 3 (a) and (b) show the spatial variation of TDS in the study area. The value of TDS in groundwater varies from 206 to 561 mg/l during pre-monsoon period and 278 to 623 mg/l during post-monsoon period. The spatial variation map shows that 86.8% and 63.6% of the study area are below the (BIS 2012) acceptable limit (< 500 mg/l) during both periods. 13.1% and 36.3% of the study area during both periods are above the acceptable limit (> 500 mg/l). The exceeding limit of TDS could be because of agricultural, industrial and anthropogenic activities in the study area.

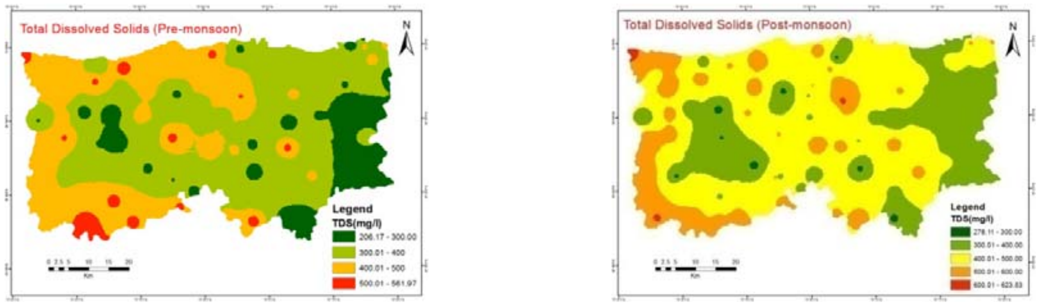

Figure 3 (a) and 3 (b) Spatial variation of total dissolved solids

The spatial variation of TH is given in Figures 4 (a) and 4 (b). TH value ranges from 198 to 326 mg/l and 267 to 352 mg/l during pre-and post-monsoon period, respectively. TH variation shows that 98.9% and 100% of the study area during both periods are above the acceptable limit (> 200 mg/l). The hardness of water may be attributed due to presence of calcium and magnesium.

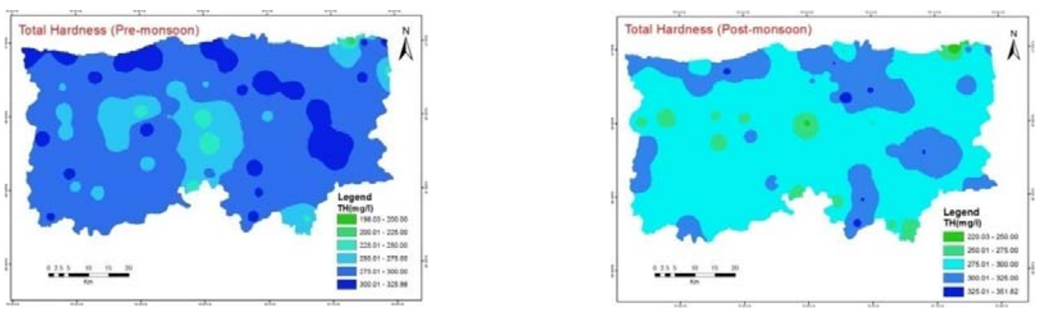

Figure 4 (a) and 4 (b) Spatial variation of total hardness

Figures 5 (a) and 5 (b) illustrate the spatial variation of calcium in the study area. The value of calcium ranges between 20 to 58.6 mg/l and 20.7 to 57.5 mg/l during both period, respectively. All the values are within the acceptable limit according to (BIS 2012).

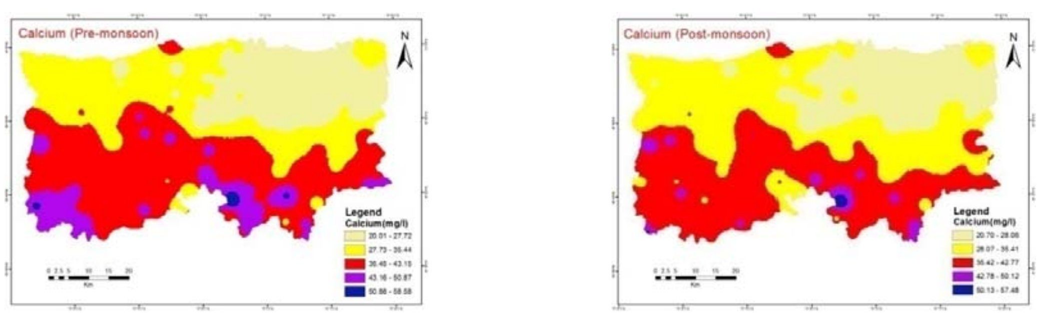

Figure 5 (a) and 5 (b) Spatial variation of calcium

Figures 6 (a) and 6 (b) indicate the spatial variation of magnesium. The acceptable limit of magnesium is 30 mg/l and its values ranges between 5.74 to 34.74 mg/l and 10.48 to 36.23 mg/l during pre-and post-monsoon period, respectively. 95.9% and 92.9% of the study area during both periods are within the acceptable limit.

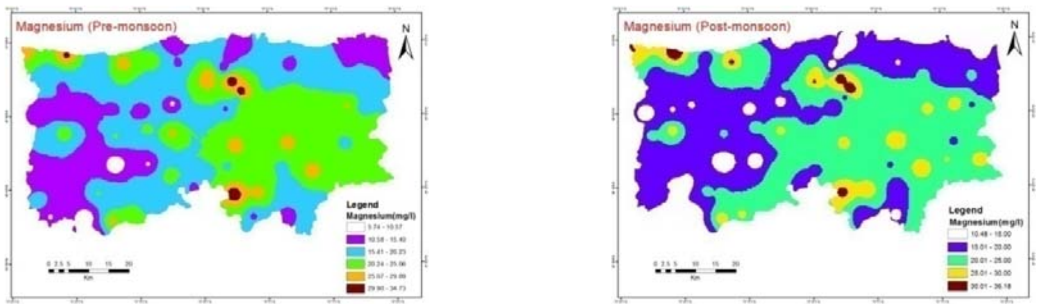

Figure 6 (a) and 6 (b) Spatial variation of magnesium

Figures 7 (a) and 7 (b) reveals the spatial variation of sodium. The sodium concentration in the area varied from 31 to 110 mg/l and 40 to 105 mg/l during pre-and post-monsoon period, respectively. The entire of the study area in both periods are within the acceptable limit (< 200 mg/l).

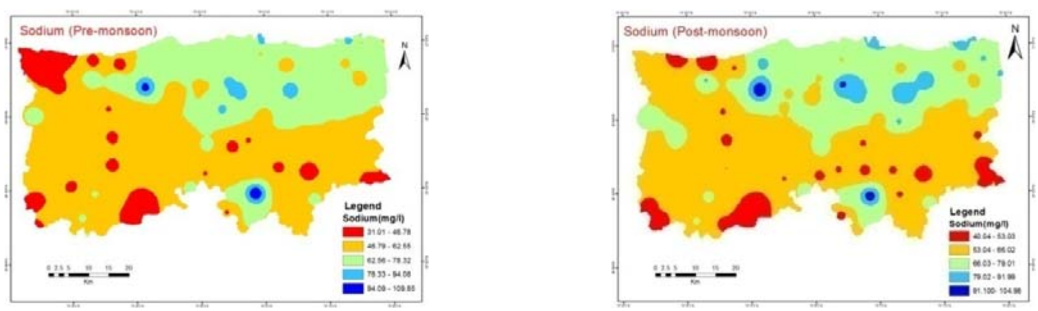

Figure 7 (a) and 7 (b) Spatial variation of sodium

The spatial variation of potassium is given in Figures 8 (a) and 8 (b). The potassium concentration varied from 3 to 13 mg/l and 5.5 to 12.7 mg/l during pre-and post-monsoon periods, respectively. The higher concentration of potassium in both periods may be due to rain water, use of fertilizers and industrial pollution leaching.

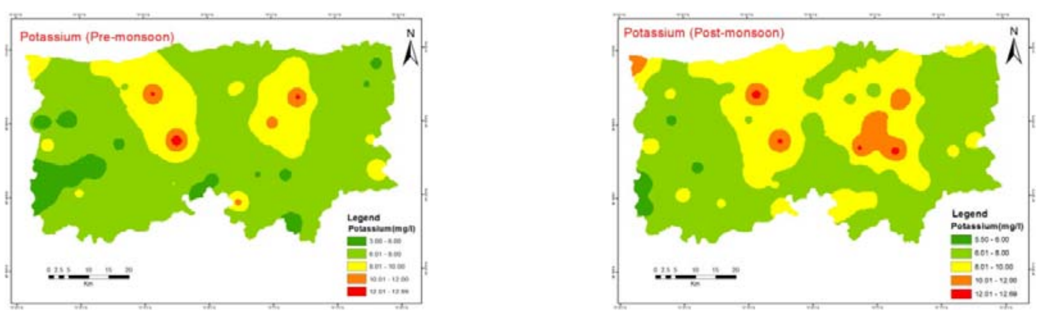

Figure 8 (a) and 8 (b) Spatial variation of potassium

Figures 9 (a) and 9 (b) show the spatial variation of fluoride. The fluoride concentration in the entire study area ranges between 0 to 6.5 mg/l and 0 to 7.3 mg/l during pre-and post-monsoon period, respectively. 43.4% and 48.4% of the study area during both periods are above the acceptable limit (> 1.0 mg/l). The concentration of fluoride may be due to geological and surface discharges in the study area.

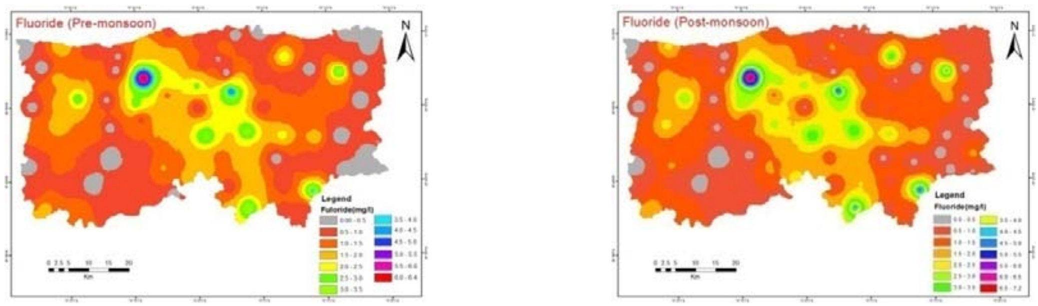

Figure 9 (a) and 9 (b) Spatial variation of fluoride

The spatial variation of chloride is given in Figures 10 (a) and 10 (b). It shows that the chloride concentration in the study area is within the acceptable limit (< 250 mg/l) during both periods of study. Higher concentration of chloride in water plays the significant role in the process of leaching.

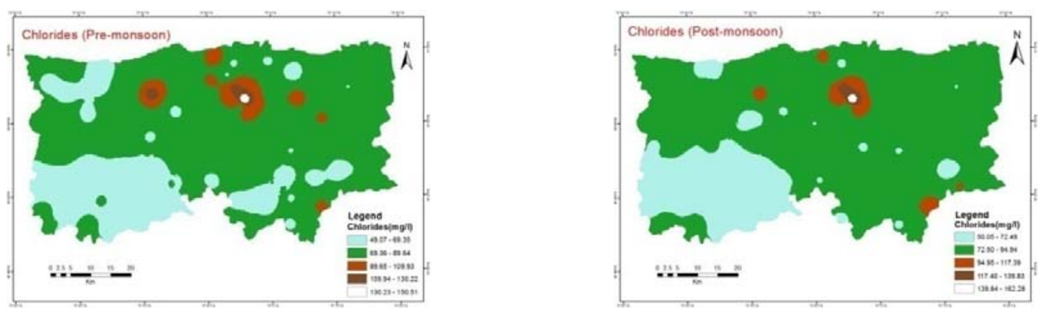

Figure 10 (a) and 10 (b) Spatial variation of chlorides

Figures 11 (a) and 11 (b) show the spatial variation of nitrate. The concentration of nitrate in groundwater varies from 16.41 to 38.41mg/l and 17.72 to 66.45 mg/l for both periods, respectively. Whole of the study area during pre-monsoon period and 94.8% study area during post-monsoon period are within the acceptable limit. Only 6.1% of the study area during post-monsoon period is above the acceptable limit (< 45 mg/l). The higher concentration of nitrate at some places may be due to fertilizer impacts.

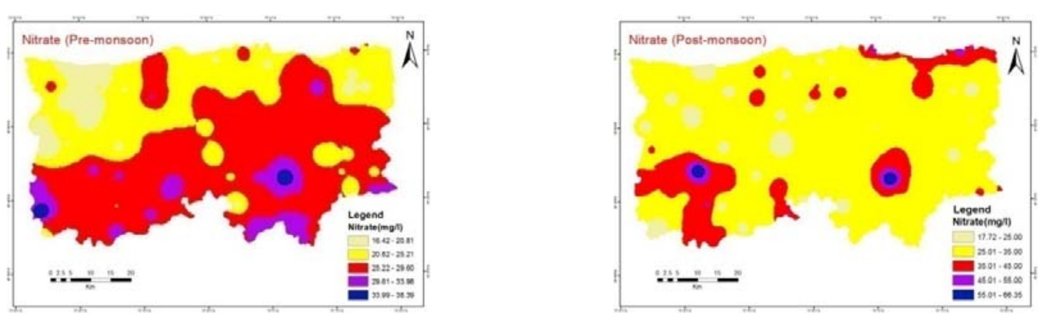

Figure 11 (a) and 11 (b) Spatial variation of nitrate

Figures 12 (a) & 12 (b) show the spatial variation of sulphate. The concentration of sulphate ranges between 17 to 211 mg/l during pre-monsoon period and 20.57 to 190.4 mg/l during post-monsoon period. A marginal increase was depicted during pre-monsoon period, this may be due to industrial waste activities.

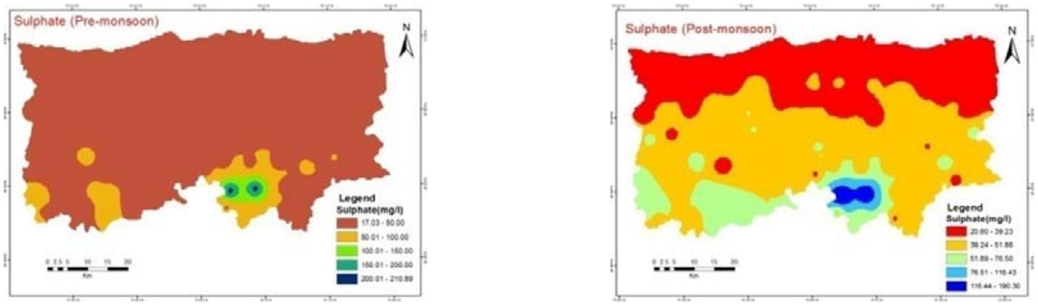

Figure 12 (a) and 12 (b) Spatial variation of sulphate

Figures 13 (a) and 13 (b) demonstrate the spatial variation of bicarbonate. The concentration of bicarbonate ranges between 84 to 212 mg/l during pre-monsoon period and 66 to 215 mg/l during post-monsoon period. The spatial variation of bicarbonate, for the whole study area is within the acceptable limit (< 500 mg/l) during both periods.

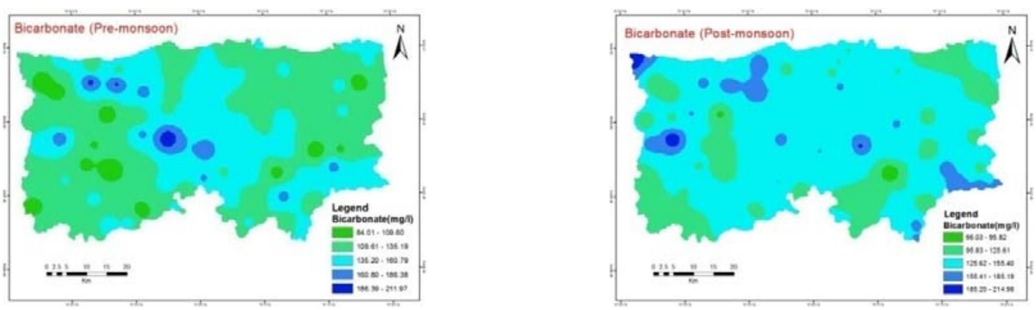

Figure 13 (a) and 13 (b) Spatial variation of bicarbonate

3.1 WQI

The quality of groundwater was assessed through water quality index and was determined by using weighted arithmetic water quality index method as explained in equation (1). The WQI values were then interpolated using Inverse Distance Weighted (IDW) method in GIS environment to achieve the WQI maps of the study area. The WQI ranged from 49.90 to 150.13 during pre-monsoon period and 57.46 to 164.04 during post-monsoon period. The categorized WQI values for the entire study area are presented in Table 2. The WQI map of pre-and post-monsoon period of the study area are shown in Figures 14 (a) and 14 (b).

The spatial variation of water quality indexing for the entire study area shows that there is no excellent water quality during both of the periods. Merely 1% of the study area is under Good water quality during the pre-monsoon period. The WQI map shows that the poor water quality, very poor water quality and unsuitable for drinking was respectively, 58.6%, 35.4% and 5.0% during pre-monsoon period. However, during post-monsoon period poor water quality, very poor water quality and unsuitable for drinking was respectively, 43.4 %, 44.4%,12.2% of the study area. The change in groundwater quality may be due to normal geological phenomena due to industrial activities, increased population, urbanization, agricultural practices and leaching of wastewater into the aquifer system.

Table 2 Rating of water quality index

Sr. No.	WQI Value	Rating of water Quality
1.	0-25	Excellent water quality
2.	25-50	Good water quality
3.	50-75	Poor water quality
4.	75-100	Very Poor water quality
5.	Above 100	Unsuitable for drinking purpose

Source : (Brown et al., 1970; Goher et al., 2014)

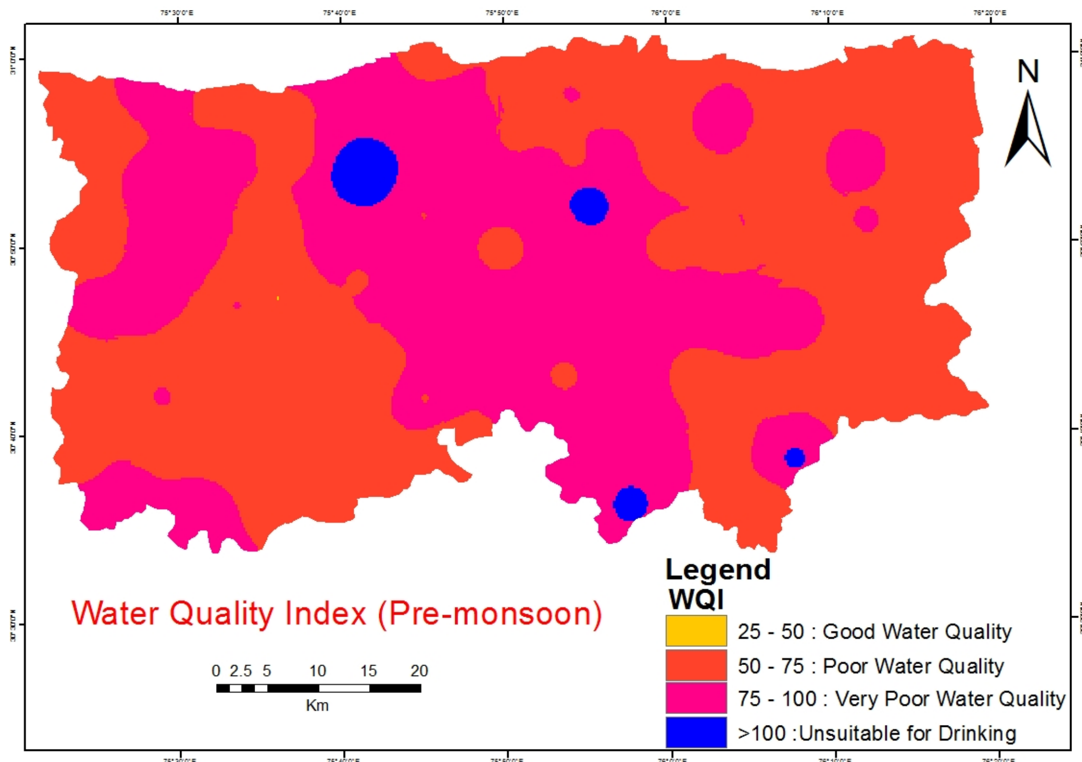

Figure 14 (a) Spatial variation of WQI (Pre-monsoon)

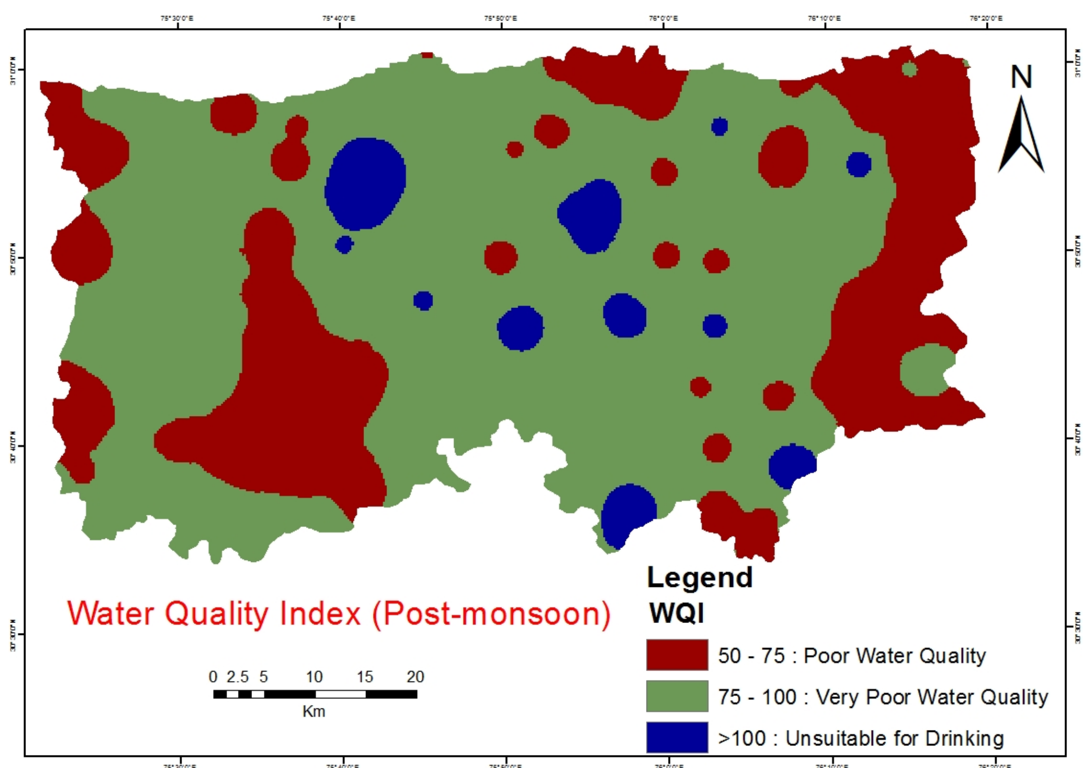

Figure 14 (b) Spatial variation of WQI (Post-monsoon)

4. CONCLUSION

In Ludhiana (India), groundwater is the major source of water for accomplishing the daily needs and the quality of this source of water has deteriorated by human and industrial activities. The spatial variation of WQI shows that 58.6% and 43.4% of the study area during the pre and post monsoon period, respectively fall under poor water quality and 40.4% and 56.6 % of the study area during the pre and post monsoon periods, respectively fall under the category of not suitable for drinking. Groundwater in the entire study area can be categorised as very hard. The parameters like magnesium, nitrate, total dissolved solids and fluoride exceed the permissible limit as prescribed by the BIS. The study shows the spatial variation in the groundwater quality using geospatial techniques and the maps so developed herein shall facilitate development of proper strategies to control and manage water quality.

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