Geospatial Analysis of Groundwater Quality in Ludhiana District, Punjab, India

ABSTRACT

This paper presents a geospatial analysis of the groundwater quality of Ludhiana district, Punjab, India. The groundwater samples were collected from 99 locations by grid based sampling 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^{-}) and water quality index (WQI) was used to evaluate the groundwater quality of the study area for both pre-monsoon and post-monsoon periods. The concentration of total hardness exceeded the permissible limit of 200 mg/l during both periods. The WQI coupled with the spatial maps indicated that merely (1%) of the total study area had access to good water quality and rest of the study area fell under i.e. poor, very poor and unsuitable for drinking purpose during pre-and post-monsoon periods. The geographical information system (GIS) based groundwater quality mapping presented could be potential tool for groundwater quality mapping and management.

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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. It is assessed that around the greater part of the total populace relies upon the groundwater (Mohrir et al., 2002); though around 1 billion individuals are straightforwardly subject to the groundwater resource in Asia alone (Foster, 1995). Groundwater is the vertebral segment of India's farming, industrial and drinking water security in provincial and urban regions. Unfortunately, majority of the Indian groundwater resource has been weakened because of the release of effluent from pits, releases of residential wastewater in defective channels, improper management of sanitary landfills, over exploitation of 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). A steady and large-scale groundwater depletion in the northern India was reported by (Tiwari et al., 2009). These types of activities show deep impact on groundwater sources and human health (Bharti et al., 2013; Bhutiani et al., 2016).

In Punjab, more than 83% of land is under agriculture where, overall 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 12.76 lakh tubewells (both electric and diesel operated) in Punjab (CGWB, 2014). Recent study found that decay of groundwater quality because of anthropogenic exercises is expanding at an alarming rate in many pieces of the Punjab (Kaur et al., 2016). Also, one latest study reveals that anthropogenic chemicals have influenced the general groundwater of Malwa region in Punjab and it isn't appropriate for drinking (Suthar et al., 2018). The concentration of trace metals like Uranium and Arsenic in both shallow and deep aquifers were noticed by various researchers (Hundal et al., 2009; Singh et al., 2011). The nature of groundwater likewise relies upon on various formations present in the geologic strata of the region. The source of ions in groundwater is diversified in nature and the groundwater quality shifts with profundity and time range in shallow and deep aquifers (Mishra and Mishra, 2006; Brindha et al., 2012). Present examination is completed in Ludhiana district of Punjab, India, as Ludhiana is one of the rapidly growing industrial city of Punjab which is known to be most affected by pollution (Singh et al., 2013). The point contamination sources (Budha Nullah) obviously decayed the water quality of river Sutlej, which thus influenced the groundwater in the encompassing zones (Sharma et al., 2017). GIS has been recognized to be a viable tool in managing such dynamic systems (John et al., 2006). Geostatistics and GIS have been demonstrated as effective tools for efficient planning and the executives of the groundwater resources (Chen et al., 2004). The geostatistical procedures are helpful for breaking down intrinsic vulnerabilities of groundwater frameworks and can be utilized in groundwater estimation issues,

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including interpolation and differentiation (ASCE, 1990; Mtetwa et al., 2003; Junge et al., 2010). Various studies (Sadat et al., 2014; Khan et al., 2017; Syed et al., 2017) have appeared extraordinary blend utilization of GIS and WQI for assessing groundwater quality. The primary target of this study is to analyse the current spatial variation in groundwater quality of Ludhiana district, Punjab using the WQI coupled with geospatial techniques.

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2. METHODOLOGY

2.1 Study Area

Punjab State is spanned by three major rivers; the Ravi, the Beas and the Satluj which are the part of Indus river basin. Ludhiana district falls in heart of Punjab and is bounded between North latitude 30° 33' and 31° 01' and East 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 3767 sq. km. The absolute populace of the district according to 2011 census data is approximately 35 lakh in which rural population comprises 15.3 lakh and urban population comprises 19.3 lakh. Hot tropical steppe, dry-hot and semi-arid with very hot summer and cold winters is the characteristic climate of the region. The region experiences south west monsoon from the last week of June to the end of September. This contributes about 78% of annual rainfall where in July and August are the wettest months. Rest 22% of rainfall is received during non-monsoon period. The district area is occupied by Quaternary Indo-Gangetic alluvium. The subsurface lithological setting of the area comprises sand, silt, clay and kankar in various proportions. For the present study to assess the quality of groundwater, samples have been collected from 99 locations from the depth ranging 10 m to 150 m. The geographical locations of all the sampling points are shown in Figure 1.

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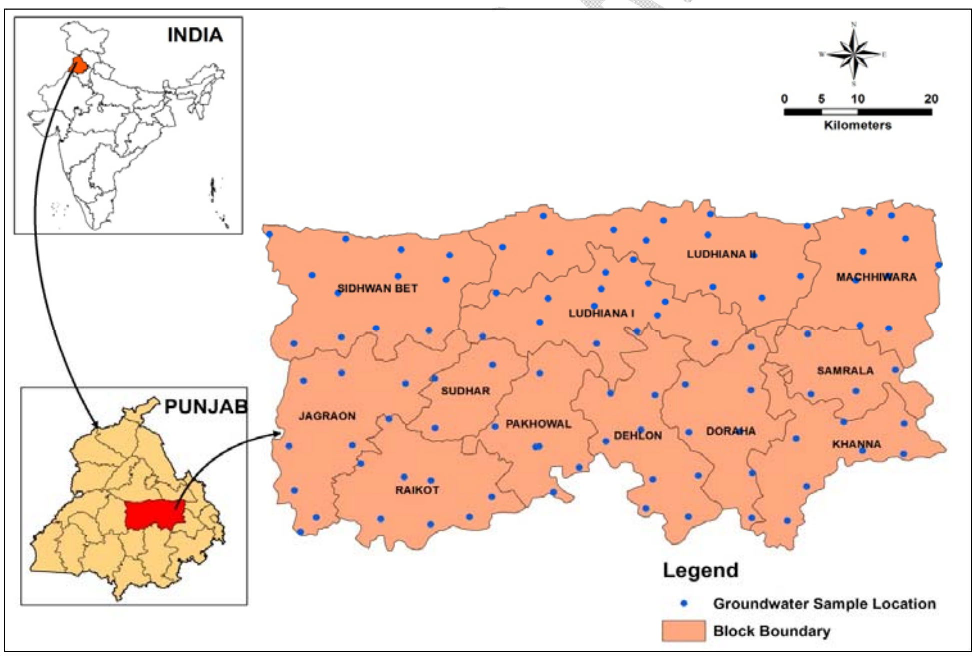

Figure 1 Study Area and Groundwater Sampling Locations

2.2 Sample Collection and Analysis

For this examination, 99 groundwater samples for both pre-monsoon (April-May) and post-monsoon (November-December) of 2018 periods have been collected by grid based sampling method with 7x7 km grid of Ludhiana district, Punjab. The groundwater samples were collected from tubewells and hand pumps. Pre-washed glass bottles were used for sampling and rinsed with sample water during filling and marking. The water from aquifer was drained for 5-7 minutes before the collection of samples. The samples were put away at a temperature of 4˚C and analysed inside seven days of sampling. The physicochemical parameters incorporating 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 examination of groundwater quality exhibited here is compared with the acceptable limit of drinking water quality stipulated by Bureau of Indian Standards (BIS 2012).

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2.2 Groundwater Quality Mapping

For groundwater quality mapping, tubewells locations have been used to prepare the spatial map of the tubewells for 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. Various researchers demonstrated that in groundwater studies, remote sensing and GIS was a proficient tool (Krishnamurthy et al., 1996; Saraf and Chaudhary, 1998; Murthy, 2000). IDW works on the assumption that are near each other are more similar than those that are more distant 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.

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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 in the following steps.

The calculation of WQI was made (Rown, 1972) by using the following equation:

$$WQI = \sum_{i}^{n} WiQi \,/\, \sum_{i}^{n} Wi$$

Calculation of Quality rating scale (Q_i)

The quality rating for each parameter is calculated as

$$Q_i = 100\,[(V_i - V_o) / (S_i - V_o)]$$

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 pH =7.0)

Calculation of Unit weight (W_i)

Unit weight for each parameter is calculated as

$$W_i = K/S_i$$

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

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

Weightage (w_i) assigned to each parameter is according to its relative significance in water in a scale of 1-5 in Table 1.

Table1 Weights of parameters vis-a-vis acceptable values

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 spatial variation in groundwater quality parameters of Ludhiana district during the pre- and post-monsoon periods are thus analysed by generating the thematic data layers. Figures 2 (a) and (b) indicate the spatial variation in 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).

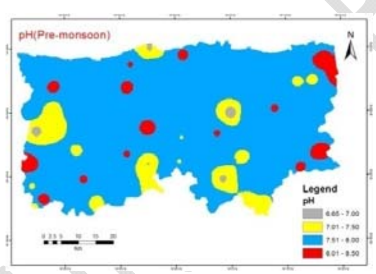

Figure 2(a)

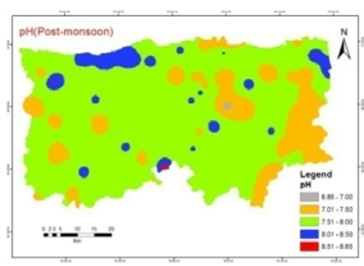

Figure 2(b)

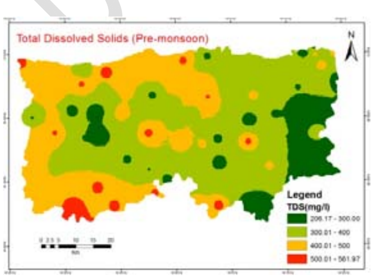

Figure 3(a)

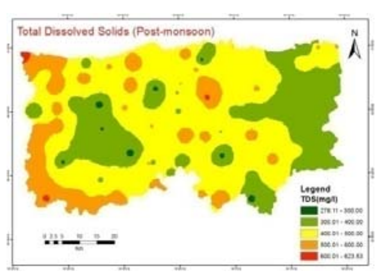

Figure 3(b)

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 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). Figures 3(a) and 3(b) shows the spatial variation of TDS. The exceeding limit of TDS is mainly because of agricultural, industrial and anthropogenic activities in the study area.

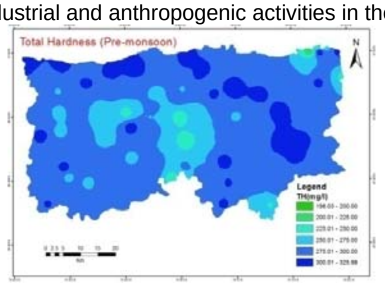

Figure 4(a)

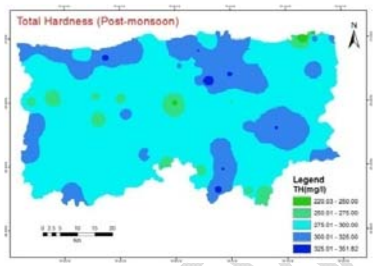

Figure 4(b)

The TH value ranges from 198 to 326 mg/l and 267 to 352 mg/l during pre-and post-monsoon periods, respectively. The spatial variation map given in Figures 4(a) and 4(b) of total hardness 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 is attributed due to presence of calcium and magnesium.

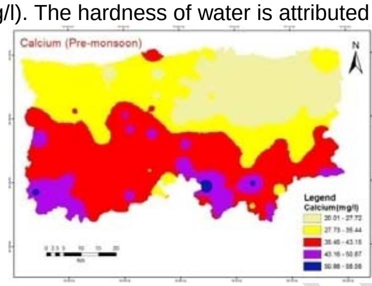

Figure 5(a)

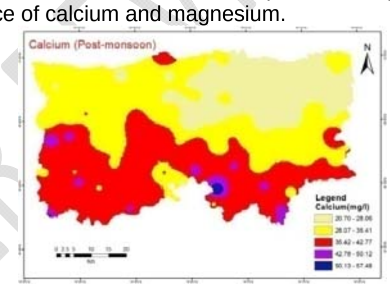

Figure 5(b)

The value of calcium during both periods ranges between 20 to 58.6 mg/l and 20.7 to 57.5 mg/l. The spatial variation map illustrated in Figures 5(a) and 5(b) shows that whole study area within the acceptable limit according to (BIS 2012).

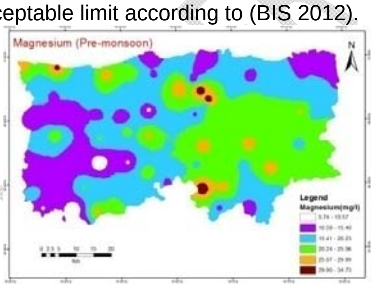

Figure 6(a)

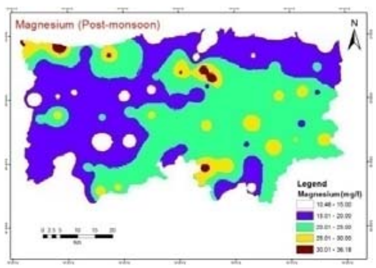

Figure 6(b)

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 both periods. The spatial variation map Figures 6(a) and 6(b) of magnesium shows that 95.9% and 92.9% of the study area during both periods are within the acceptable limit. Due to relative abundance of rocks, in groundwater calcium content is more than the magnesium content.

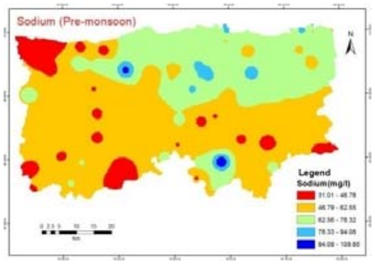

Figure 7(a)

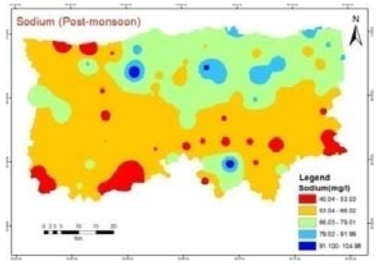

Figure 7(b)

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

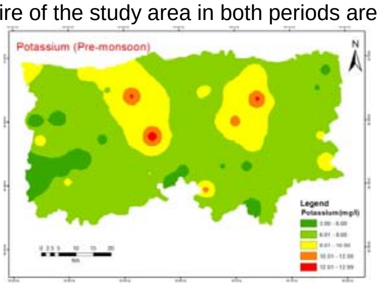

Figure 8(a)

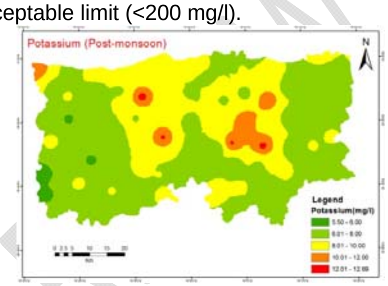

Figure 8(b)

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

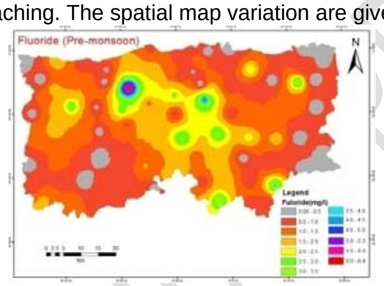

Figure 9(a)

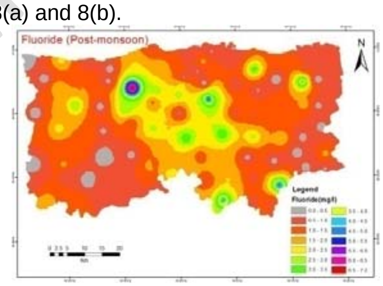

Figure 9(b)

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 periods, respectively. 43.4% and 48.4% of the study area during both periods are above the acceptable limit (>1.0 mg/l). Figures 9(a) and 9(b) shows the spatial variation of fluoride. The concentration of fluoride may be due to geological and surface discharges in the study area.

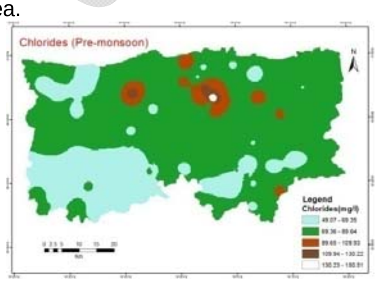

Figure 10(a)

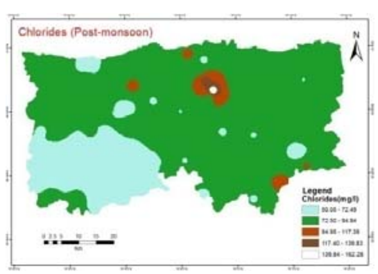

Figure 10(b)

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

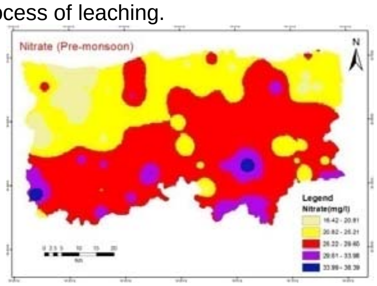

Figure 11(a)

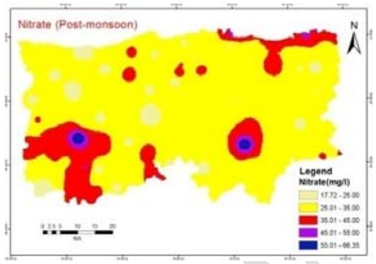

Figure 11(b)

Nitrate concentration in groundwater varies from 16.41 to 38.41mg/l and 17.72 to 66.45 mg/l for both periods. The spatial variation map illustrated in Figures 11(a) and 11(b) shows that the entire 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.

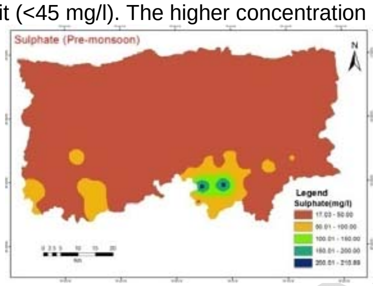

Figure 12(a)

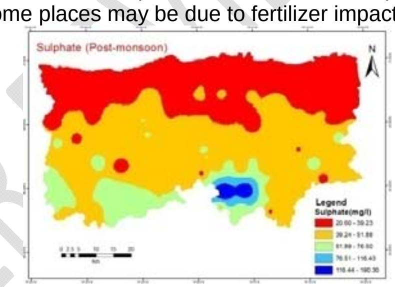

Figure 12(b)

Sulphate concentration ranges between 17 to 211 mg/l during pre-monsoon period and 20.57 to 190.4 mg/l during post-monsoon period. The spatial variation maps of the study area are shown in Figures 12(a) & 12(b).

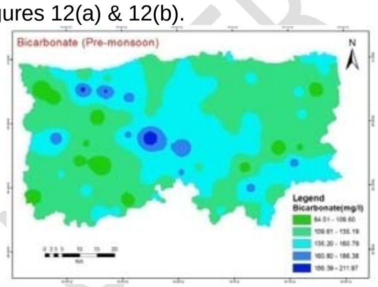

Figure 13(a)

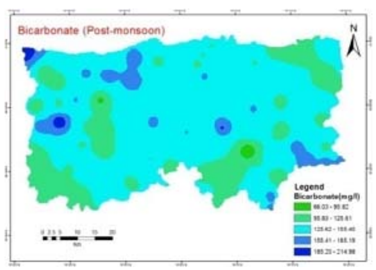

Figure 13(b)

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. Figures 13(a) and 13(b) shows the spatial variation of bicarbonate, for the whole study area are within the acceptable limit (<500 mg/l) during both periods.

3.1 WQI

The quality of groundwater was assessed through water quality index and was determined by using weighted arithmetic water quality index method. The unit weight and quality rating for each parameter were calculated and WQI of the sampling points was determined during pre-and post-monsoon periods. 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 periods of Ludhiana district 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

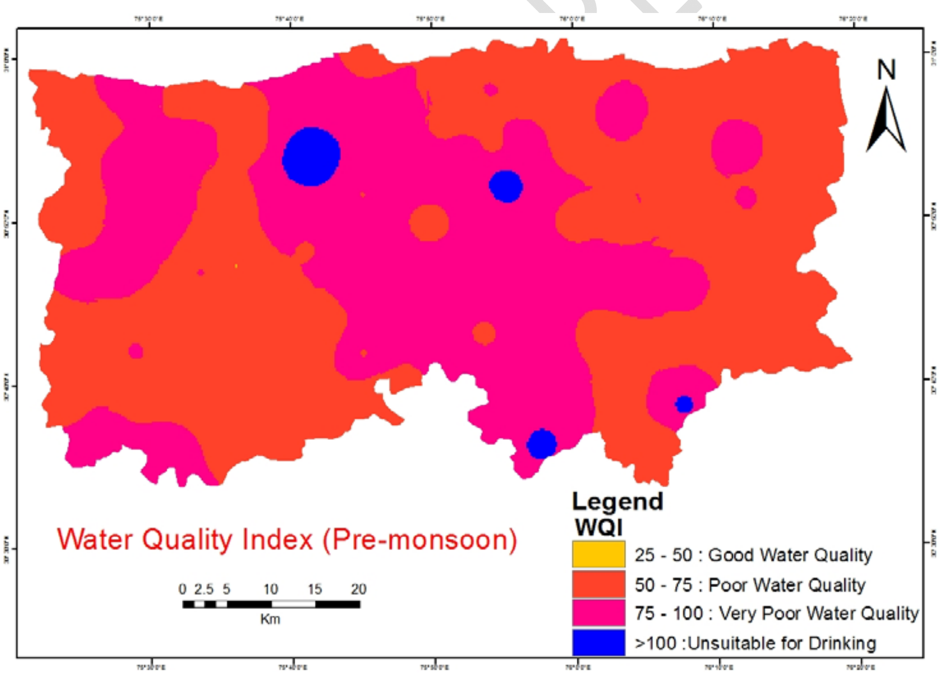

Figure 14(a)

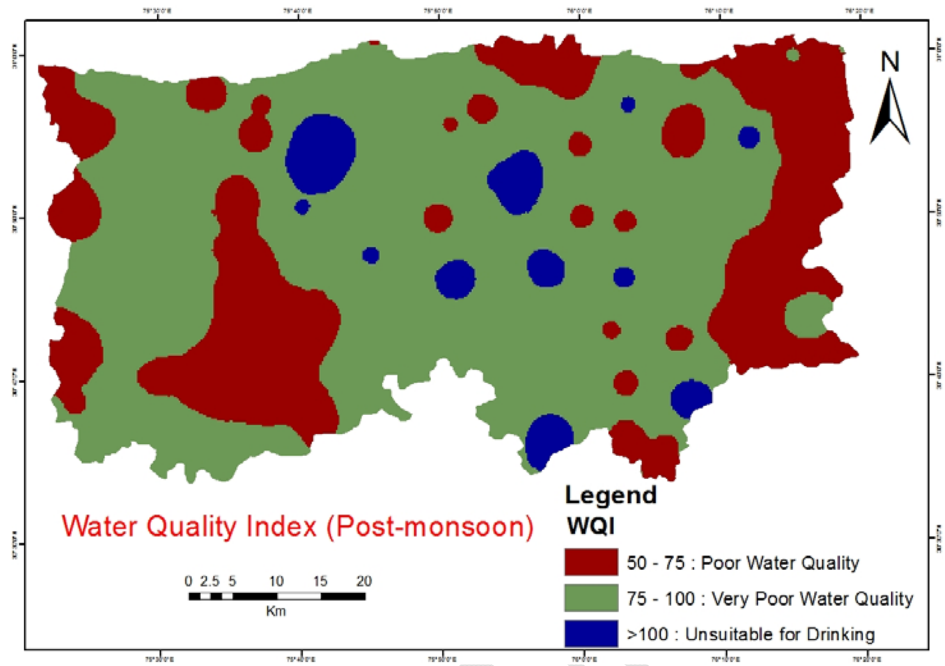

Figure 14(b)

4. CONCLUSION

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

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