GIS-Based Assessment and Characterization of Groundwater Quality in a Industrial City of Central Punjab, India

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ABSTRACT: The quality groundwater may be impacted by naturally occurring processes as well as by the activities directly attributable to human interventions in different environs. The complex biodiversity, physiographic setup coupled with prevailing hydrogeological set up attribute to water pollution in various parts of the State. Ludhiana district falls in central part of Punjab, India and it is well known for small and big scale industry hub in India. Different types of industry are set up in the Ludhiana and that can be badly effect the ground water quality. To analyse the effect of pollutants to in ground water, three blocks adjoining Ludhiana City are taken into consideration in which thirty two points are selected for ground water quality mapping. In the present study, the spatial variations in physicochemical quality parameters and heavy metals in groundwater of three blocks were analysed to determine the suitability through development of Water Quality Index (WQI) and Heavy Metal Pollution Index (HPI). The spatial variations maps are generated with the help of Geospatial analyst tool in ESRI Arc GIS. The suitability for drinking purpose was evaluated by comparing the physicochemical parameters of groundwater in the study area with drinking water standards prescribed by Bureau of Indian Standards (BIS). All the physicochemical parameters of groundwater except iron were found to be within the range as per BIS and the heavy metals such as Fluoride, Lead, Aluminium and Selenium were found to be almost more than the prescribed limits at all the stations. WQI and HPI maps shows that the ground water quality of these three blocks (Dehlon, Doraha and Khanna) were in very poor condition. The probable reason for the poor quality of ground water shown in HPI is due to heavy metal pollutants interacting with ground water through streams and nallah.

INTRODUCTION

Water is one of the most important substances on earth. All plants and animals must have water to survive. If there was no water there would be no life on earth. India is rich in water resources. Groundwater and network of rivers are the major sources that can fulfil the requirement of the country in all regions. Groundwater is well thought-out to be the most natural and fresh resource on earth which is used for drinking and irrigation purposes. Now these days ground water quality is badly affected by rapid industrialization and increasing human population, the stress on natural resources is increasing and their conservation is one of the major challenges for mankind. The quality of groundwater is as important as its quantity because it is the major factor in determining its suitability for drinking, domestic, irrigation and industrial purposes. The concentration of chemical constituents which is greatly influenced by geological formations and anthropogenic activities determine the groundwater quality. Both the agricultural and anthropogenic activities have resulted in deterioration of water quality rendering serious threats to human beings. As industrialization and use of chemicals on agricultural has increased that has been contributing significantly to groundwater contamination. Land use pattern has undergone a tremendous transformation in the state. During the recent years, there has been an increase in the area put to non-agricultural uses such as industrial sites, housing, transport systems, recreational purposes, irrigation systems, etc. The industrial effluents discharged into the natural environment are causing water pollution. Besides, a huge amount of municipal wastes is being generated and disposed off without any treatment. 73% of the total municipal solid waste is being generated in the 5 mega towns in the state i.e. Ludhiana, Jalandhar, Amritsar, Bathinda and Patiala. The state Punjab extends from the latitudes 29^o32'00" N to 32^o28'00" N and longitudes 73^o50'00" E to 77^o00'00" E and is bounded by Jammu and Kashmir in the north-east, by Himachal Pradesh in east and southeast, by Haryana in south, by Rajasthan in south and west and shares the international boundary with Pakistan on western side. The geographical area of Punjab is 50,362 sq. kms. Kaur (2016) has assessed the groundwater quality for drinking and irrigation purposes using hydro-chemical studies. The Deterioration of groundwater quality due to anthropogenic activities is increasing at an alarming rate in most parts of the Punjab.

STUDY AREA

The study area is the urban part of Ludhiana district of Punjab, India. It is located at 30.90^{0}N, 75.85^{0}E and location map with sampling points is shown in (Fig 1). The average rainfall of the district is 681 mm. The Satluj forms the border of the district in the North with Jalandhar and Hoshiarpur districts. Ropar and Fatehgarh Sahib Districts mark the eastern and south eastern boundaries. The geographical area of the district is 3767 sq. km. and the population of the district as per 2011 census is 3498739 (Rural: 1533401 & Urban: 1965338). The district is divided into 12 Blocks and the study area is focused on South-Eastern blocks of Ludhiana district namely Dehlon, Doraha and Khanna districts (Fig 1). The main reason of considering these blocks for the study is due to the highly urbanization and industrialization. The declining trend of ground water and increasing quality problem are major issues in this area of state.

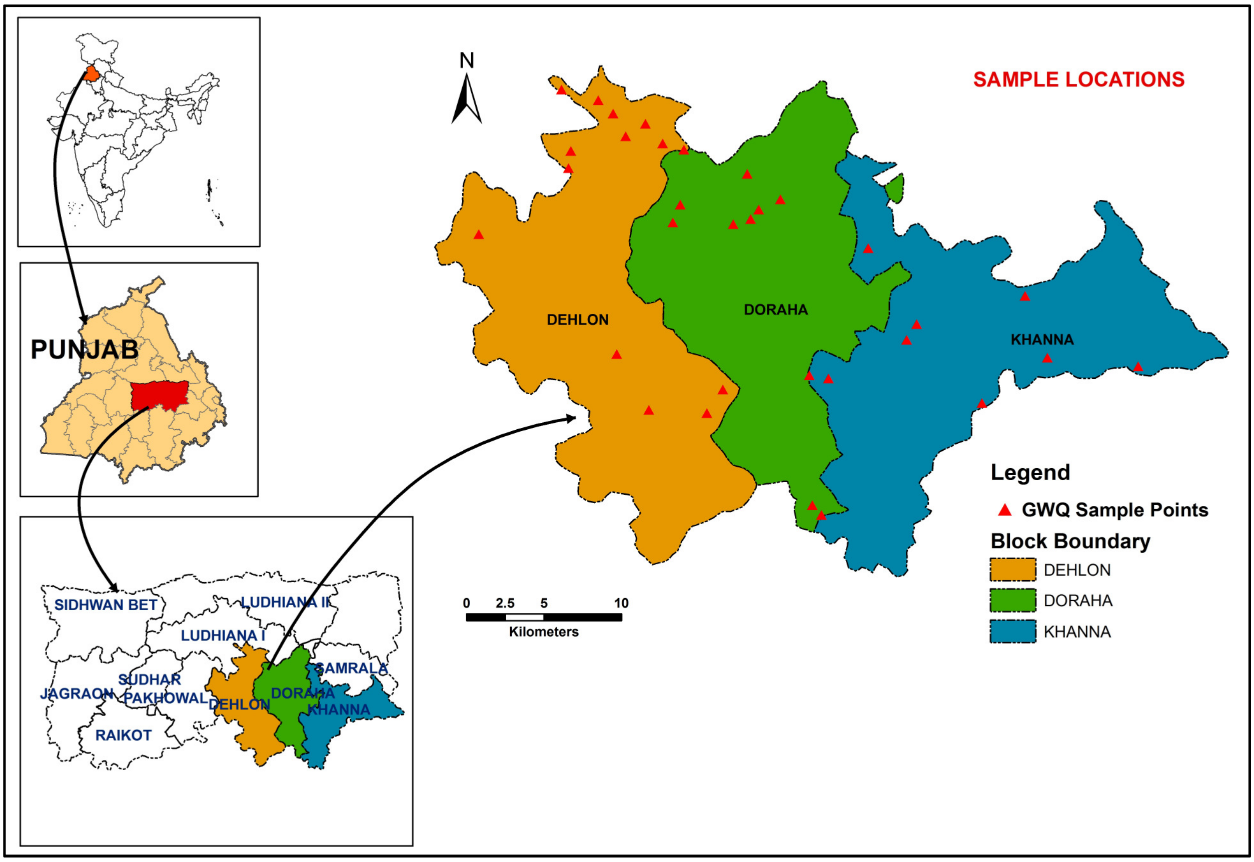

Fig 1 Map of the study area with sampling locations

OBJECTIVES

1. To study the spatial variation in groundwater quality of Ludhiana Industrial area.
2. To investigate the heavy metal concentration levels of groundwater in the region.

MATERIAL AND METHODS

In the present study, the spatial variations in physicochemical quality parameters and heavy metals in groundwater of three blocks, are analyzed on the basis of data available from Central Ground Water Board were determine its suitability through development of Water Quality Index (WQI) and Heavy Metal Pollution Index (HPI) maps. These maps are generated with the help of Arc Map GIS 10. The suitability for drinking purpose was evaluated by comparing the physicochemical parameters of groundwater in the study area with drinking water standards prescribed by Bureau of Indian Standards (BIS). GIS is most effective tool to provide better information of the consumers, policy makers and this helps for taking quick decision. For the spatial distribution map at first the corresponding topo sheets are geo-referenced. These toposheet were digitized in GIS platform to generate the base map of the three blocks i.e. Dehlon, Doraha and Khanna of district Ludhiana. The spatial distributions of WQI and HPI value were done with the help of spatial analyst module in Arc GIS 10 software. Inverse Distance Weighted (IDW) interpolation technique was used for spatial modeling. The water quality monitoring stations were located, and the water quality parameters of the stations were entered as attributes. The WQI and HPI are calculated by two methods i.e. Weighted Arithmetic Water Quality Index Method and Heavy Metal Pollution Index (HPI). Weighted arithmetic water quality index method classified the water quality according to the degree of purity by using the most commonly measured water quality variables. Tyagi (2013) assessed water quality in terms of water quality index (WQI) is valuable and unique rating to depict the overall water quality status in a single term. The method has been widely used by the various scientists and the calculation of WQI was made by using the following equation:

The quality rating scale (Qi) for each parameter is calculated by using this expression:

$$\mathbf{WQI = \Sigma\ Q_i\ W_i / \Sigma\ W_i}$$

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

Where;

V_i, is estimated concentration of i^{th} parameter in the analysed water

V_o is the ideal value of this parameter in pure water

V_o = 0 (except pH =7.0 and D.O. = 14.6 mg/l)

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

The unit weight (Wi) for each water quality parameter is calculated by using the following formula:

$$Wi = K/Si$$

Where, K = proportionality constant and can also be calculated by using the following equation: $K=1/\Sigma\ (1/Si)$

Table 1 The rating and grading of water quality according to this WQI

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

In computing the heavy metal pollution index a unit weightage (Wi) is considered which is inversely proportional to the recommended standard (Si) of the corresponding parameter. The drinking water standards for India (BIS 2012) were used for the metals for the calculations of Wi. Briefly, three classes have been demarcated as low (<15 HPI), medium (<15–30 HPI) and high (>30 HPI). The concentration limits [i.e. highest permissive value for drinking water (Si) and maximum desirable value (Ii) for each parameter] were taken from the Indian drinking water specifications (BIS 2012, IS:10500).

The heavy metal pollution index (HPI) model (Mohan, 1996) is given by equation

$$\mathbf{HPI} = \frac{\sum_{i=1}^{n} \mathbf{WiQi}}{\sum_{i=1}^{n} \mathbf{Wi}}$$

Where, Qi is the sub-index of the i^{th} parameter. Wi is the unit weightage of i^{th} parameter, and n is the number of parameters considered. The sub index (Qi) of the parameter is calculated by Eq.

$$Qi = \sum_{i=1}^{n} \{\mathbf{Mi(-)Ii}\} / (\mathbf{Si - Ii})$$

Where, Mi is the monitored value of heavy metal of i^{th} parameter, Ii is the ideal value of the i^{th} parameter and Si is the standard value of the i^{th} parameter. The sign (-) indicates numerical difference of the two values, ignoring the algebraic sign.

RESULTS AND CONCLUSIONS

The heavy metals are indestructible, insidious contaminants of the environment because of their non biodegradable nature and potential to cause adverse effect in human beings beyond certain level of exposure and absorption. Some of these metals are essential and required as nutrient for normal physiological function, as regular biochemical process in animals and plants, but their elevated levels in potable water, domestic wastewater and industrial effluent is a subject of serious concern due to their toxic properties. The heavy metals like Cadmium, Chromium and Lead are highly toxic to humans even in low concentration. Though Copper, Zinc and Iron are essential elements in human nutrition but these may be toxic with high concentrations, which also impart a bitter taste to water in concentration even well below the toxic level. The Deterioration of quality of ground water due to natural contamination from aquifers and overlaying soils is called geogenic contamination. This type of contamination occurs due to entrapped water reaction with the strata. Presence of high Lead, Selenium and Aluminum are usually a result of geogenic contamination as there are only a very few other source of these ions. All the heavy metals present in ground water may be due to effect of Ludhiana and Mandi Gobindgarh industry. The quality of groundwater was assessed through the WQI. The relative weight, quality rating, and sub index for each parameter were computed, and the WQI at the monitoring stations was determined. The WQI values were then interpolated using IDW method in GIS environment to obtain the WQI map of the area. The WQI ranged from 40.04 to 110.25. The water quality index maps of three blocks are shown in (Fig.2).

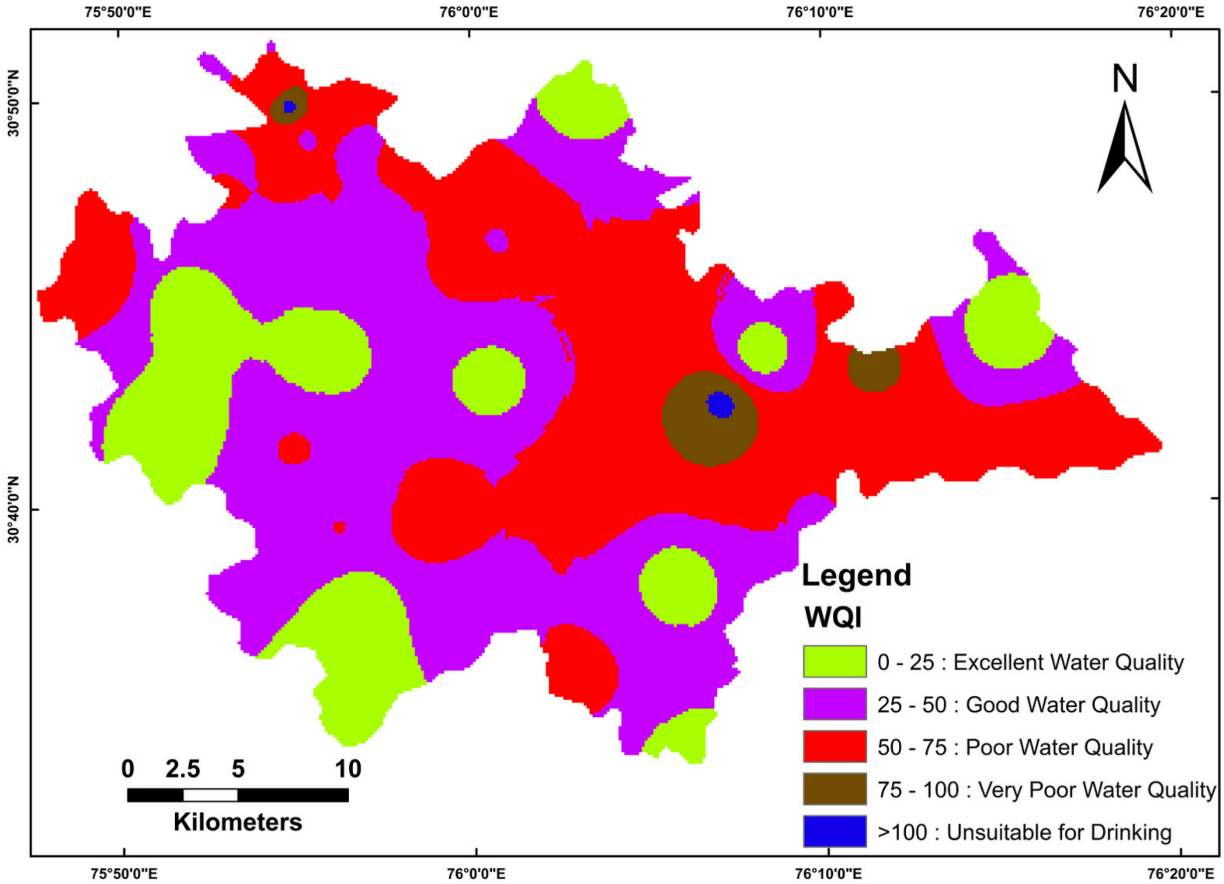

Fig 2 The water quality index map showing ranges of water quality

The WQI map was categorized based on the classification as presented in Table 1. The WQI maps revealed that the good water quality in (25 %) of the study area. The poor (52 %), very poor category (17 %) and unsuitable for drinking (6 %) of water quality in the study area may be due to leaching of ions, overexploitation of groundwater, direct discharge of effluents and agricultural impact.

The HPI shown in (Fig. 3) of the groundwater, the mean concentration value of the selected metals (Al, Se and Pb) have been taken into account. The values of HPI was to be found in the range of 0.287 - 214.2. The HPI values of the samples within study area were found at some stations above the critical pollution index (100). However, considering the classes of HPI, the low (<15 HPI), medium (<15–30 HPI) and high (> 30 HPI). The percentage (%) of HPI classes varied from low class (15.62 %), above high class (62.5 %) and above critical pollution index (25%) of study area come under above classes.

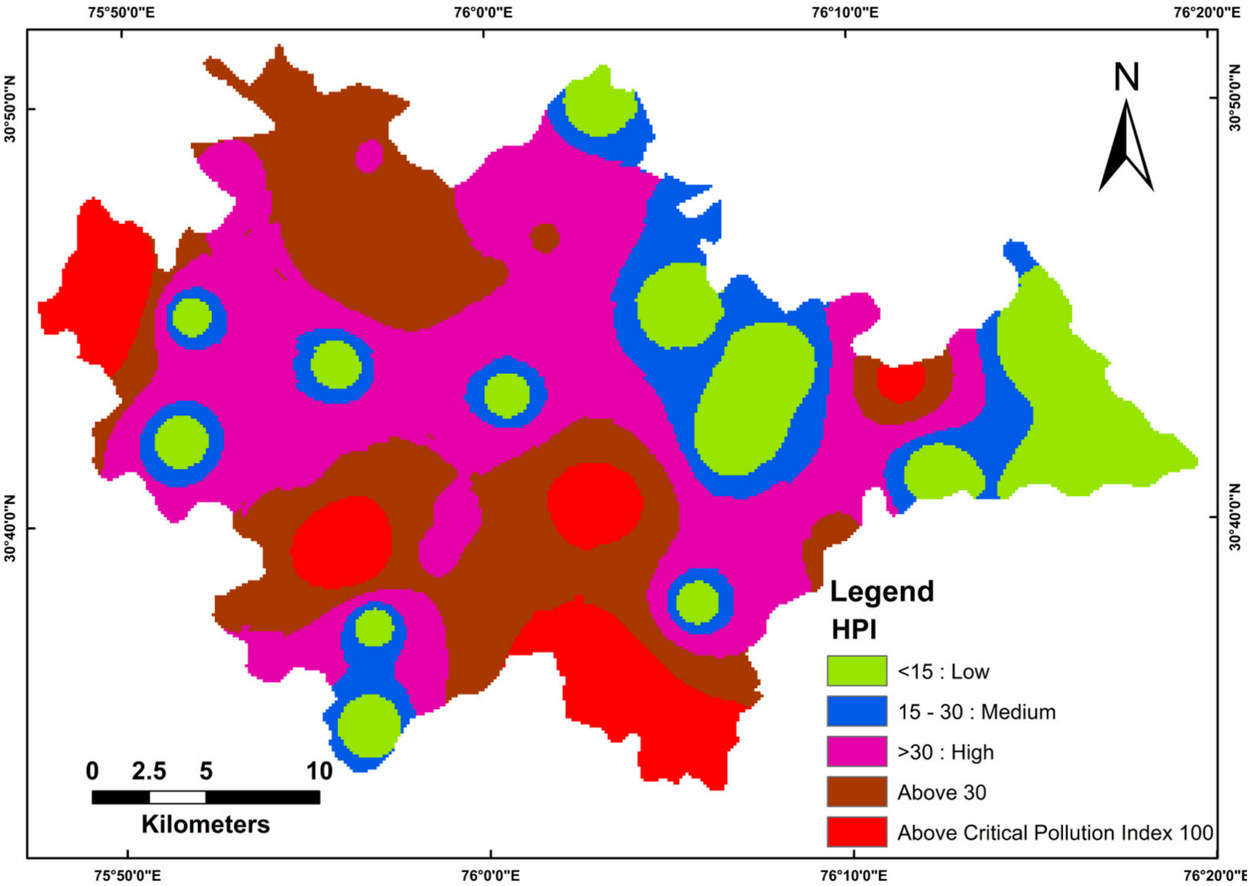

Fig 3 The HPI of the groundwater showing different categories of Pollution Index

The higher values of HPI have been found at sites Aluna Palla Basti, Aluna Miana, Kauri, Sirthala, Begowal and Siarh of Khanna, Doraha and Dehlon blocks of Ludhiana district. The higher values of HPI may be attributed mainly due to industrial activities, direct discharge of effluents and agricultural impacts. It may be noted that, in near future, the areas with permissible limits for drinking purpose may become “not permissible” due to mixing of heavy metals in ground water with passage of time.

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