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Application of GWQI to Assess Effect of Land Use Change on Groundwater Quality in Lower Shiwaliks of Punjab: Remote Sensing and GIS Based Approach

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Abstract The groundwater resource is a multidimensional concept; it is defined by its location, its occurrence over time, its size, properties, conditions of accessibility, the effort required to mobilize it and therefore, all of which are to be considered in the context of demand. Groundwater, a renewable and finite natural resource, vital for man's life, social and economic development and a valuable component of the ecosystem, is vulnerable to natural and human impacts. There is a great need for the assessment and monitoring of quality and quantity of groundwater resource required at local level to develop an exact scenario of watershed. In this study qualitative assessment of groundwater was done and a ground water quality index criterion was used to understand the suitability of groundwater for irrigation and drinking purpose in the study area. A GIS based multicriteria analysis was done by assigning weight to different water quality parameters. The water quality was grouped into six classes from very good to unfit for drinking. It was found that the in most part of the study area the water quality varied from moderate to good except in some areas where it is poor to unfit. An assessment of change in landuse and landcover was done from the year 1989 using Landsat data to year 2006 using LISS III satellite data. The change in LULC was correlated with water quality data and it was found that the areas around which rapid urbanisation as well as industrialisation is taking place showed poor to unfit groundwater in terms of quality.

Keywords GWQI · Shiwaliks · GIS · LULC · Landsat · Groundwater

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1 Introduction

Groundwater is an important source of water supply throughout the world. Groundwater has become an essential commodity over the past few decades due to its increasing usage for drinking, irrigation and industrialisation. Rural India has started facing water crisis due to its increasing dependency on depleting groundwater supply. In many parts of India, especially in the arid- and semi-arid regions, due to vagaries of monsoon and scarcity of surface water, dependence on groundwater resource has increased tremendously in past few years. Viewed in the international perspective of '<1,700 m^3/ person/year' as water stressed and '<1,000 m^3/person/year' as water scarce, India is water stressed today and is likely to be water scarce by 2050 (Gupta and Deshpande 2004). Quality of groundwater is equally important as its quantity owing to the suitability of water for various purposes. Variation of groundwater quality in an area is a function of physical and chemical parameters that are greatly influenced by geological formations and anthropogenic activities (Subramani et al. 2005). The quality of surface water and soil characteristics play a major role in determining the composition and quality of the groundwater. The chemical properties of groundwater also depend upon the chemistry of water in the recharge area as well as on the different geochemical processes that are occurring in the subsurface. These geochemical processes are responsible for the seasonal and spatial variations in groundwater chemistry (Matthess 1982). Water Quality Index (WQI) can be defined as a parameter which reflects the overall water quality at a particular location i.e cumulative effect of different water quality parameters. WQIs for groundwater are described in the literature by various authors. Backman et al. (1998) used an index for evaluating the degree of groundwater contamination and verified its applicability in South-Western Finland and Central Slovakia. Soltan (1999) used WQI to indicate the quality of groundwater from ten wells located near the Dakhla Oasis in the Western Egypt. Many studies (Kim 2009; Babiker et al. 2007; Rivard et al. 2008) have been done on a regional scale with respect to groundwater quality and quantity. Remote sensing, because of its spatial and temporal coverage capabilities (Andreae 2002), has been important tool for studying Land Use Land Cover (LULC) changes (Anderson et al. 1976; Rasch 1994; Green et al. 1994; Kam 1995; Carlson and Azofeifa 1999; Luque 2000; Maselk et al. 2000; Yang and Lo 2002; Guerschman et al. 2003; Rogana and Chen 2004; Zsuzsanna et al. 2005). Anthropogenic or environmental conditions may lead to change in LULC pattern which can be discerned by using multi-temporal satellite image.

In the present study, the groundwater quality of Rupnagar district was evaluated from various deep aquifers (tube wells) and shallow aquifers i.e., hand pumps to understand the geochemistry of the aquifers. Impact of change in LULC was studied with respect to groundwater. A ground water quality index (GWQI) was generated for the entire study area to find the suitability of water for drinking and irrigation purpose.

2 Description of Study Area

The study area falls between north latitude 30°32′ and 31°24′ and east longitude 76°18′ and 76°55′ (Fig. 1). Satluj is the most important river of Rupnagar district; it

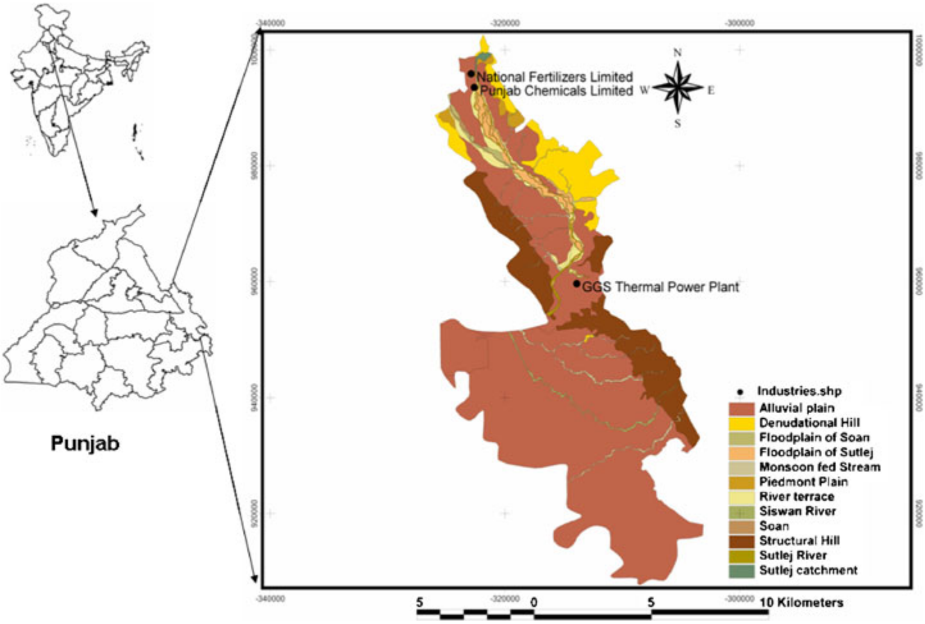


Fig. 1 Study area and its geomorphology

enters near Nangal, the place where it leaves the Himalayas. From Nangal onwards, it flows sluggishly through Anandpur Dun for a distance of about 60 km, leaving the Dun through an opening across the Shiwalik Hills near Rupnagar and entering the Punjab plain. The monthly average temperature in the district ranges from minimum of 4°C in winter to 45°C in summer. Relative humidity is high, averaging about 70% during monsoon. The annual rainfall in district averages around 775.6 mm from year 1901–2008. Physiographically the area can be divided into four subunits; Shiwalik hills, valleys, piedmont plain and alluvial flood plain. Shiwalik hills have general slope ranging from 25 to 60% and most of the hill area is under subtropical forest. The piedmont plain covers large area with slope 1% to 6% which is frequently intercepted by choes. This area is partly cultivated and partly under forest and wastelands.

The alluvial flood plain is marked with the confluence of Sutlej and Sirsa rivers with 1% to 3% slope. Most of the area covered by alluvial plain is used for agriculture. Geologically area has been divided in to two classes; Precambrian formations and recent formations (Quaternary). Even though majority of the study area is covered by Precambrian formation (charnockite), the western part of the area is under recent formation (sandy, silty and alluvium). The predominant rock types, charnockite and sandy silty alluvium are found in the central and western part of the study region. Geomorphology is associated with topographic landforms which in turn are related with runoff and infiltration. The underlying lithology, slope and the type of existing drainage pattern influences the quality of groundwater. Residual hills are spread along NE, SE and western part of the area. Residual hills are the end products of the process which reduces the original mountain masses into a series of scattered knolls standing on the pediplains. The central part of the study area is covered by valley flat which comprises of thin alluvial cover composed mostly of sand and silts. The alluvial plains occur mostly in the SW part of the study area.

2.1 Hydrogeology

The aquifers in the southern part of the study area is formed of Quaternary Alluvium while in the northern part the aquifers are mainly comprised of Shiwalik formation, Intermontane valleys and Kandi/Sirowal formation. From west to east the granular zones becomes less prominent and clay horizons with gravel or kankar become predominant. Groundwater occurs under phreatic condition in the shallow aquifers of Quaternary alluvium deposits, Intermontane valley and Kandi formation. Groundwater occurs under leaky confined to confined conditions in the deeper aquifers of alluvium. In the case of unconfined aquifers, the depth to water level varies from 2.7 to 10.3 m during pre-monsoon and 2.1 to 11.6 m during post-monsoon (CGWB 2007). Near the Shiwalik hills, groundwater occurs at greater depth when compared to alluvial plains where it occurs at shallow depth. Generally, the water level is deep in intermontane valley and slope towards central part of the valley. In the northern part, especially in the intermontane valley, groundwater flow is towards south and southeastern direction whereas in the southeastern part of the district, the groundwater flow is in the south and southwestern direction, which in turns reflects the topographic gradient.

3 Methodology

3.1 Water and Sediment Sampling

The study area was divided into grids of size 10×10 km^2 and representative groundwater samples were taken from each grid. Samples were collected on the basis of spectral signature as observed on satellite image from each grid. The pixels which contained stressed vegetation and also pixels which showed high soil moisture content were selected for sampling as it can be discerned as surface manifestation of groundwater and geology of the area. Twenty-two samples of groundwater were collected in polypropylene bottles during the month of January of the year 2007 from the adjoining areas of canals in Brahmapur, Anandpur Sahib, Nangal Town, Hardinamoh, Kharar, Chamkaur Sahib, Kurali, Morinda, Naya-Nangal and Sahibzada Ajit Singh Nagar and Rupnagar. Most of the groundwater samples were collected from dug wells, tube wells and hand pumps. Care was taken to discard water of first 20–25 strokes in order to minimize the impacts of iron pipes through which water was pumped out. A few water samples were also collected from the monitoring wells, particularly in Bera Chauta, Ahmedpur, Saijowal, Kharar, Rupnagar, Nupurbedi, Mianpur, Dheri, Dumewal, Bajrur, Ghoga (Fig. 2). The water samples were collected from nearly same depth (35∼40 m). The pH, Electrical conductivity and Total dissolved solids (TDS) meter (HANNA) were used to measure pH, EC and TDS in the field. The water samples collected were acidified for cation and heavy metal analysis and were stored in ice packed styrofoam boxes and brought to laboratory for further analysis. The samples were filtered using vacuum filtration unit

Fig. 2 Sampling locations

and analyzed using atomic absorption spectrophotometer (Thermo Fischer) using standard procedures as given in APHA (1995). Sediment samples were also collected from adjoining locations from where the water samples were collected and these samples were analysed using X-ray diffraction (PANalytical). The methodology adopted for the current study is shown in Fig. 3. The study was carried out with the help of topographic sheets, Garmin Global positioning system (GPS) and ground truthing. Toposheet were used to prepare the base map, drainage map to understand the general nature of the study area. GPS was used to map the location of each sampling site and finally the results were brought in GIS environment for further analysis.

3.2 Satellite Image Processing

The landsat image of the year 1989 procured from United States Geological Survey (USGS) and the Linear imaging scanning system (LISS) III (geo-coded) satellite image of December, 2006 acquired from National Remote Sensing Centre (NRSC), Hyderabad had been used for the present study. In addition, toposheets on 1:50,000 scales procured from Survey of India (SOI), Dehradun, were used for geo-referencing the satellite images. Initially, a thorough field survey of the study area was carried out for ground truthing. The geographical coordinates of various LULC

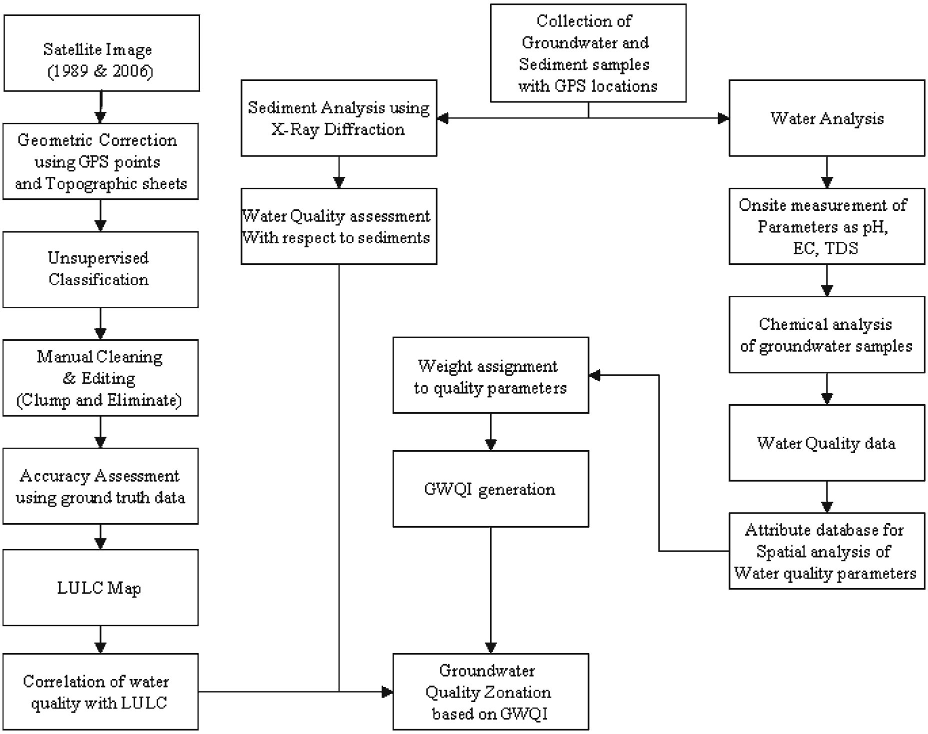


Fig. 3 Methodology adopted for the proposed study

classes were recorded using GPS. The geometric correction of the satellite image of the study area was further rectified by GPS points. The image was re-projected into World Geodetic System 1984 (WGS-84) spheroid and datum, zone 43 North of the UTM projection. The image of the study area was clipped by overlaying district boundary over the geo-referenced image. An unsupervised classification approach based on ISODATA clustering algorithm was used for classification of the satellite image using Erdas Imagine 9.1. In order to minimize the geometric and radiometric distortions, the first order polynomial model and nearest-neighbor re-sampling methods were applied. One hundred fifty spectral classes with 10 iteration and 95% convergence values were selected to perform unsupervised classification. The classified image was finally recoded into 12 classes (Fig. 4a, b).

The GIS based analysis of spatio-temporal behaviour of the groundwater quality in the study area was done using the Spatial Analyst module of ArcGIS 9.1. The interpolation technique used in the analysis is inverse distance weighted (IDW) method (Mueller et al. 2004; Tomczak 1998; Tabios and Salas 1985). Weights are computed by taking the inverse of the distance from an observation's location to the location of the point being estimated (Burrough and McDonnell 1998). The inverse distance can be raised to a power (e.g. linear, squared and cubed) to model different geometries (e.g. line, area, volume) (Guan et al. 1999).

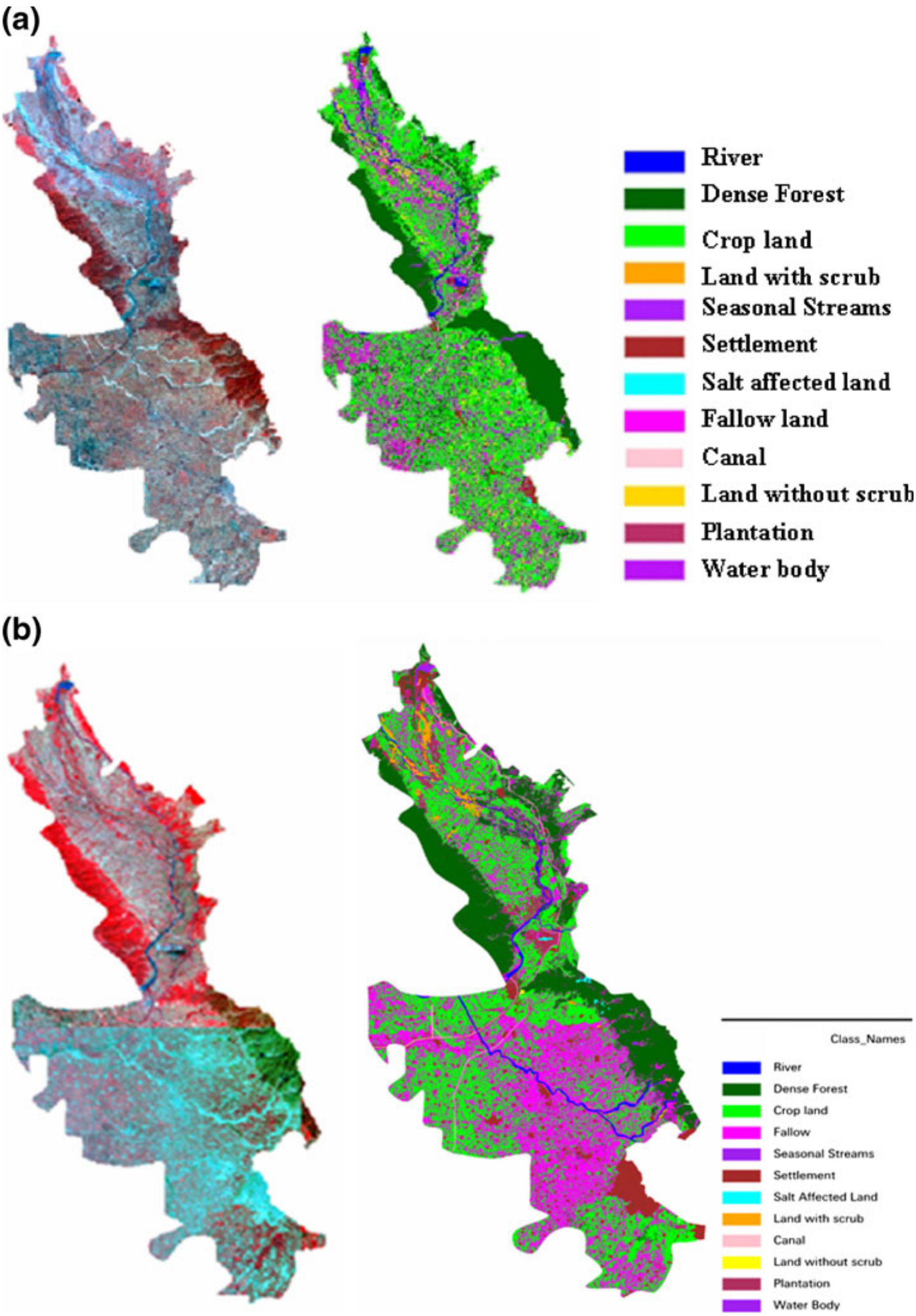


Fig. 4 **a** Landsat data of 1989 (bands 4, 3, 2 and 1) and land use/land cover of study area (based on unsupervised classification). **b** IRS LISS III data of 2006; bands 3, 2, and 1) and land use/land cover of study area (based on unsupervised classification)

4 Results and Discussion

When we compare the classified image for different LULC classes in the last two decades we come across certain observations that are alarming. The area covered by River, cropland, dense forest has decreased by 5.85 km^2, 191.25 km^2 and 152.22 km^2 respectively. The area under plantation, land without scrub, water body and seasonal streams shows a total decrease of 20.49 km^2, 39.03 km^2, 6.83 km^2 and 11.70 km^2 respectively (Table 1). The effect of gradually increasing influence of green revolution is continuously being manifested in the form of escalating area under salinisation; the total increase being registered is around 9.75 km^2 (Fig. 5). The accuracy assessment of the unsupervised classification was conducted and it was found that the accuracy of classified image was 88% derived from the error matrix, which can be considered good as per the criteria by Anderson et al. (1976). The portion on both the sides of Shiwalik ridge, locally called as “Kandi”, is used for cultivation while the portion near Nangal Dam and Nangal township, being made up of boulders, has been used for settlement and industrial uses. The scattered settlement is also present on Kandi tract. The lower portion of this surface away from the hills is intensively under cultivation. The portion adjacent to the hills, due to the inadequate supply of both surface and groundwater is not fertile and generally cropping is not done in this region. Recent flood plain being lowest in elevation and liable to annual flooding is rarely used for agricultural and settlement. Only small patches of cultivable land with thin and scattered settlement are present. Rest of the Kandi tract supports long grass or is left as fallow land being covered by swamps and elephant grass. Increase in population demands for increase in agricultural industrial products. This in turn calls for a better land use and management. The Shiwalik hills bordering the area and the Shiwalik ridge passing through it though is under forest but the forest is rapidly decreasing. Local inhabitants residing along the foot of these hills destroy much of the forest by cutting for burning wood. Moreover, the cattle, which are left loose to graze in these hills, are also destroying its vegetation. Net result is that these forests are gradually reducing in size, which in turn makes these hills an easy target to erosion. Nalas and khads passing through the shills carry more and more sediments year after year and deposit it in fertile land beyond these hills rendering them uncultivable. Thus sustainable planning for forest development and for the

Table 1 Area covered by LULC classes in year 1989 and 2006

Class	Area in km^2 in 1989	Area in km^2 in 2006
River	33.17	27.32
Settlement	17.56	111.23
Cropland	882.09	690.84
Fallow land	361.03	649.86
Dense forest	487.88	335.66
Salt affected land	11.70	21.46
Canal	13.66	13.66
Water body	17.56	10.73
Seasonal streams	33.17	21.46
Plantation	33.17	12.68
Land with scrub	17.56	52.69
Land without scrub	62.44	23.41

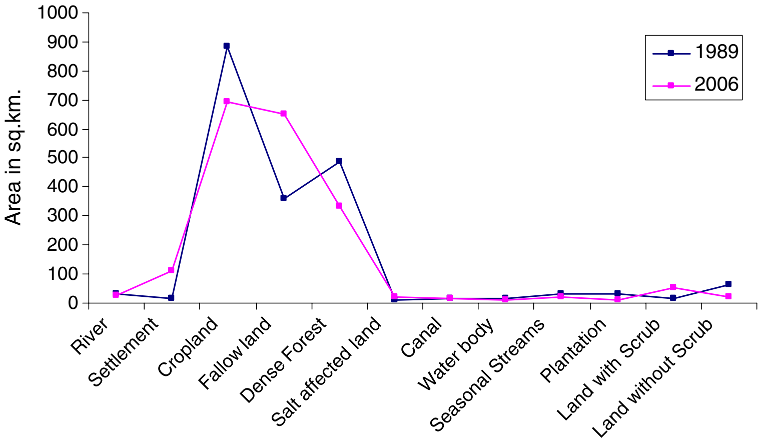


Fig. 5 Change in LULC classes from year 1989 to 2006

problem of silting and erosion is required. Pasture lands can be demarcated for cattle grazing and unauthorized wood cutting can be checked. New plantation of Khair and other economically profitable trees should be initiated. By taking the above mentioned precautions, this hilly terrain could be developed into forested area and the problems of silting and erosion along with landslides could be solved. Recent flood plain being the youngest surface in the area is still in the process of building up and is liable to annual flooding. It is covered by swamps and cut off meanders at places. Due to annual floods, recent floodplain is not suitable for agriculture. Therefore, it can be better developed as pasture land for cattle and can also be used for fodder cultivation. The area covered by swamps and cut off meanders can be developed into tanks for pisciculture.

4.1 Spatial Variation of Groundwater Quality

The water quality parameters that were analysed are given in Table 2. The pH of groundwater varied between 7.63 and 8.29. The highest pH was observed in the Gogha, which is 8.29. The electrical conductivity varied from 693.6 μS/cm and 1,295 μS/cm. The areas that had very high values for electrical conductivity are Chanalon, Landran, Bhalan. The concentration of bicarbonate in the study area varied from 169 ppm to 448 ppm. High values of bicarbonate are observed in some parts of Kharar, Bhalan, Dhair, Dheri, Bera Chaunta and Landran. Variations in nitrate concentrations were from 0.0 ppm to 80 ppm with 18.5 $\pm$ 24.18 ppm as the mean concentration of the various sampling sites in the study area. The concentration of nitrate exceeding the permissible limit (50 ppm, WHO) was observed in Nurpurbedi, Sandwan, Bhalan and Chanalon with the highest being in Sandwan (80 ppm). There were some other sites from where nitrate concentrations were close to the permissible limit—i.e. Landran (42 ppm), Saijowal (48 ppm) (Fig. 6).

The chromium concentration varied from 0.0 ppm to 0.37 ppm, the higher concentration of chromium was although observed at sites of Kubaheri, Bera Chauta, Mianpur, Sandawan, Chakdera and Hardinamoh (0.37 ppm) with Hardinamoh

Table 2 Water quality parameters that were analyzed

Samples	pH	EC	HCO_3	Cl	SO_4	NO_3	F	Ca	Mg	Na	K	TH	Cd	Cr	Cu	Fe	Mn	Pb	Zn
1	7.59	435.0	198.00	18.0	30.0	10.0	0.27	66.0	12.0	7.7	0.2	215.0	0.008	0.005	0.198	0.113	0.015	0.042	0.078
2	7.88	774.0	233.00	39.0	110.0	50.0	0.05	44.0	22.0	78.0	33.0	198.0	0.014	0.029	0.019	0.174	0.04	0.054	0.072
3	7.50	530.0	297.00	14.0	60.0	1.0	0.41	50.0	20.0	50.0	11.0	208.0	0.004	0.061	0.013	0.19	0.259	0.003	0.878
4	7.88	355.0	169.00	28.0	10.0	1.0	0.41	40.0	12.0	10.0	1.7	150.0	0.016	0.018	0.022	0.242	0.475	0.037	0.294
5	7.75	404.0	175.00	21.0	50.0	0.9	0.37	35.0	25.0	17.0	2.8	193.0	0.01	0.038	0.099	1.079	0.119	0.003	0.298
6	7.33	545.0	320.00	18.0	10.0	22.0	0.05	75.0	19.0	26.0	1.3	265.0	0.005	0.019	0.106	0.179	0.006	0.003	0.195
7	7.38	667.0	402.00	25.0	30.0	8.8	0.41	83.0	16.0	59.0	4.2	276.0	0.009	0.053	0.274	1.919	0.053	0.007	0.158
8	7.92	752.0	379.00	49.0	5.0	3.1	0.20	15.0	33.0	85.0	11.0	172.0	0.006	0.044	0.012	1.305	0.407	0.034	0.064
9	7.70	654.0	291.00	46.0	100.0	1.9	0.10	46.0	20.0	90.0	7.3	198.0	0.008	0.046	0.276	0.482	0.517	0.027	0.377
10	7.84	445.0	279.00	18.0	15.0	0.8	0.16	37.0	25.0	31.0	5.8	198.0	0.012	0.067	0.149	0.13	0.002	0.062	0.82
11	7.61	1,295.0	326.00	197.0	120.0	22.0	0.26	48.0	39.0	107.0	42.0	281.0	0.005	0.037	0.066	0.29	0.024	0.049	1.537
12	8.10	695.0	361.00	28.0	55.0	0.5	0.20	31.0	38.0	74.0	4.1	234.0	0.009	0.038	0.354	1.722	0.179	0.004	0.795
13	7.37	1,135.0	396.00	141.0	75.0	42.0	0.65	80.0	43.0	122.0	1.2	375.0	0.008	0.031	0.14	0.299	1.149	0.009	2.867
14	7.29	756.0	320.00	49.0	35.0	48.0	0.27	72.0	29.0	42.0	16.0	300.0	0.009	0.063	0.085	0.086	0.019	0.04	0.088
15	7.06	1,019.0	448.00	67.0	90.0	57.0	0.16	88.0	54.0	62.0	21.0	440.0	0.009	0.007	0.134	0.291	0.061	0.052	0.094
16	7.71	813.0	379.00	63.0	80.0	3.9	0.27	46.0	29.0	115.0	4.5	235.0	0.006	0.019	0.043	0.079	0.163	0.063	0.049
17	7.50	645.0	262.00	28.0	25.0	80.0	0.16	77.0	29.0	14.0	4.8	312.0	0.009	0.053	0.007	0.062	0.018	0.031	0.058
18	7.53	477.0	227.00	21.0	20.0	30.0	0.05	83.0	7.5	9.9	1.4	239.0	0.013	0.035	0.073	0.077	0.183	0.024	2.224
19	7.46	602.0	320.00	21.0	35.0	2.5	0.14	64.0	26.0	28.0	5.7	265.0	0.016	0.037	0.001	0.765	0.502	0.019	0.948
20	7.42	694.0	315.00	53.0	100.0	0.8	0.05	52.0	18.0	100.0	4.0	203.0	0.01	0.014	0.091	0.255	0.041	0.006	2.482
21	7.61	1,007.0	251.00	152.0	110.0	65.0	0.05	88.0	51.0	75.0	3.8	427.0	0.009	0.056	0.11	0.14	0.285	0.004	0.239
22	8.29	409.0	239.00	14.0	12.0	5.5	0.47	16.0	32.0	30.0	0.7	170.0	0.003	0.03	0.071	0.099	1.158	0.011	1.883
Minimum	7.06	355.00	169.00	14.00	5.00	0.50	0.05	15.00	7.50	7.70	0.20	150.00	0.00	0.01	0.00	0.06	0.00	0.00	0.05
Maximum	8.29	1,295.00	448.00	197.00	120.00	80.00	0.65	88.00	54.00	122.00	42.00	440.00	0.02	0.07	0.35	1.92	1.16	0.06	2.87
SD	0.29	249.25	75.88	49.36	38.27	24.95	0.16	22.60	12.20	36.94	10.77	78.98	0.00	0.02	0.10	0.55	0.34	0.02	0.88

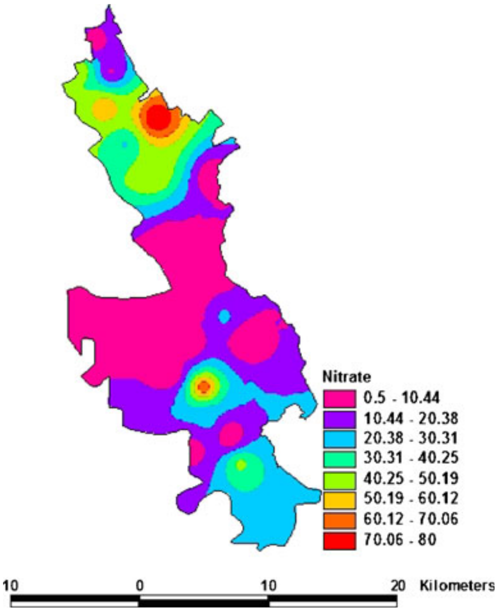


Fig. 6 Spatial variation of nitrate in the study area

showing the highest concentration (Fig. 7). The concentration of iron varied from 0.062 ppm to 7.919 ppm. Higher concentration was observed at Bhagwantpur, Bela, Dhair, Kharar and Ropar with Bhawantpur (7.919 ppm) being the highest. The concentration of manganese was very high at Gogha, Landran, Bhagwantpur

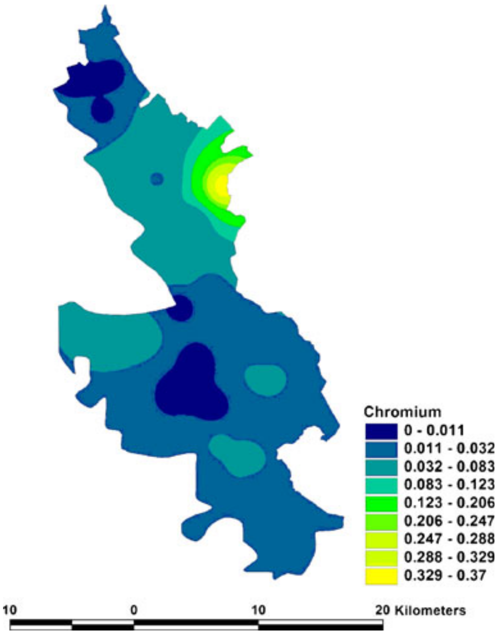


Fig. 7 Spatial variation of chromium in the study area

and Hardinamoh than the WHO standards (0.5 ppm) with Gogha reaching up to 1.158 ppm. The concentration of cadmium in the study area varied from a minimum of 0.003 ppm to a maximum of 0.016 ppm. The higher concentration of chromium was observed at Ahmedpur, Rurkihiran, Nupurbedi, Kubaheri, Kakrali and Dumewal with Rurkihiran and Ahmedpur being the highest (0.016 ppm).

4.2 Groundwater Quality in Relation to Agriculture

Out of the net irrigated area of 780 km^2 in Ropar district, only as 70 km^2 of land is irrigated by canals and rest by groundwater. Thus 91% of the total irrigated area is irrigated by groundwater by means of shallow and deep tubewells (CGWB 2007). The values observed for EC, which is used to express total concentration of dissolved solid, showed that at nine sampling locations the groundwater falls under medium salinity hazard showing that groundwater in these areas can be used for irrigation if dissolution coefficient of subsurface minerals is low or less leaching of minerals takes place while rest of the samples were in low salinity areas suggesting low leaching of minerals. The concentration of cadmium, manganese was found to be high at all the locations and nitrate, lead, iron was found to be high at some places suggesting high use of fertilizers and discharge of industrial effluents. Some sediment samples were analyzed using X-Ray Diffraction for the presence of minerals in the area and it was found that the presence of Iron, Copper, Chromium and Fluoride in groundwater is due to the leaching of minerals like Bornite (Cu_5FeS_4), Green cinnabar (Cr_2O_3), Hematite (Fe_2O_3), Burnt ochre (Fe_2O_3), Fluorite (CaF_2) (Fig. 8a, b). The mineral analysis was carried out to verify whether the source of ions/trace metals in groundwater is geogenic or anthropogenic. It was found that the chromium concentration is high in northern part of study area (Fig. 7) and the XRD data confirmed the presence of chromium which is not only anthropogenic but is also geogenic in origin. Similarly in southern part of the study area the concentration of Flouride (Fig. 9) was found to be high due to presence of fluorite.

Various plots like Piper (1944) trilinear diagram, Schoeller diagram (1965), radial plot have been used for expressing hydro-chemical facies of water i.e. water type. Water quality data was analysed through statistical distribution diagram such as Piper (1944) to understand hydro-chemical processes operating in the groundwater system that has resulted in the observed spatial and temporal variation in the groundwater quality constituents. The term hydro-chemical facies is used to describe the bodies of groundwater in an aquifer that differ in their chemical composition. The facies are a function of lithology, solution kinetics and flow pattern of groundwater through the aquifer. The tri-linear plot of chemical analysis on a Piper diagram (Fig. 10) shows that while a majority of groundwater samples belong to the bicarbonate type, a few samples (four in number) belong to the sulphate and chloride type. Among the cation facies, above 50% of the samples belong to the calcium type and a little fewer than 50% fall in the class of sodium and potassium type.

Although a higher proportion of samples are of calcium carbonate type, still we cannot undermine the significant presence of sodium and potassium carbonate type of facies in groundwater. A very minimal share also belongs to the chloride of calcium, sodium and potassium. The groundwater facies suggests that weathering of sodium-potassium containing minerals, industrial and agricultural activities and ion-exchange processes are major processes contributing to dominance of calcium,

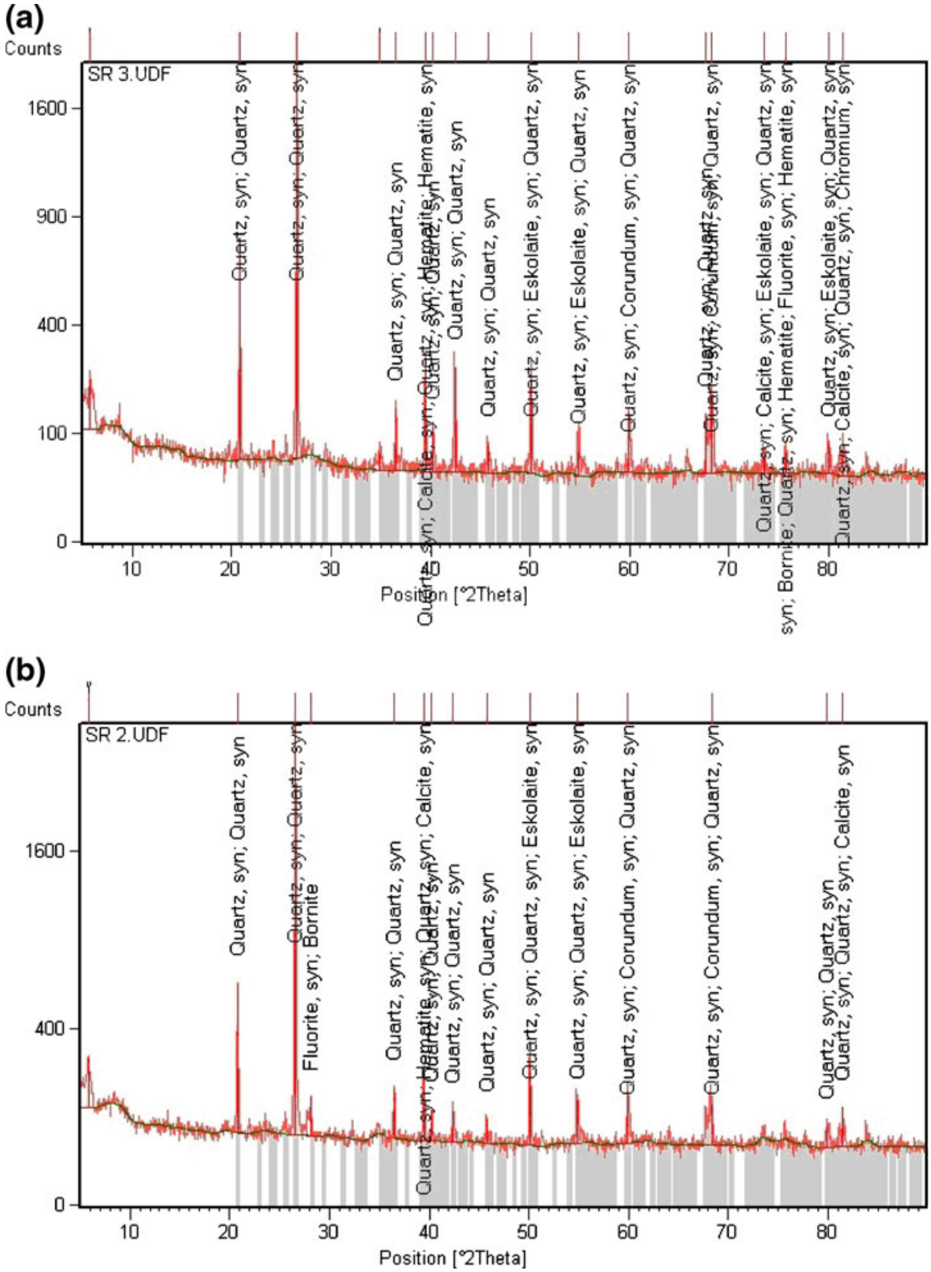
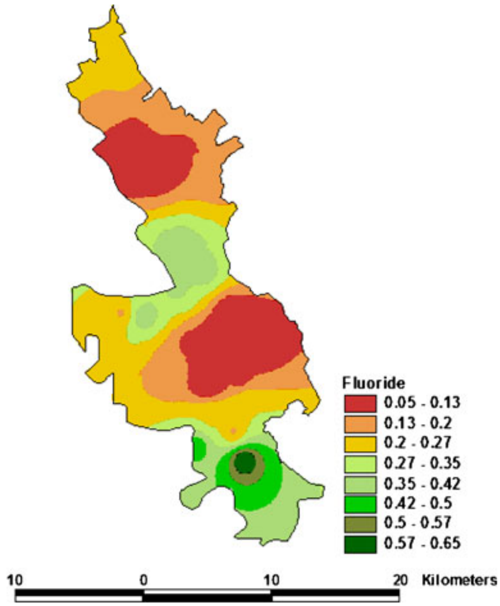


Fig. 8 **a** X-ray diffractogram of soil sample collected from N-W part of study area. **b** X-ray Diffractogram of soil sample collected from S-W part of study area

sodium and magnesium in the groundwater. Ion exchange of sodium and potassium by calcium and magnesium sorbed on the clay surface can cause their higher concentration in groundwater. The dissolution of gases and minerals, particularly CO_2 and CO_3 related compounds in the atmosphere and in the unsaturated zone

Fig. 9 Spatial variation of fluoride in study area



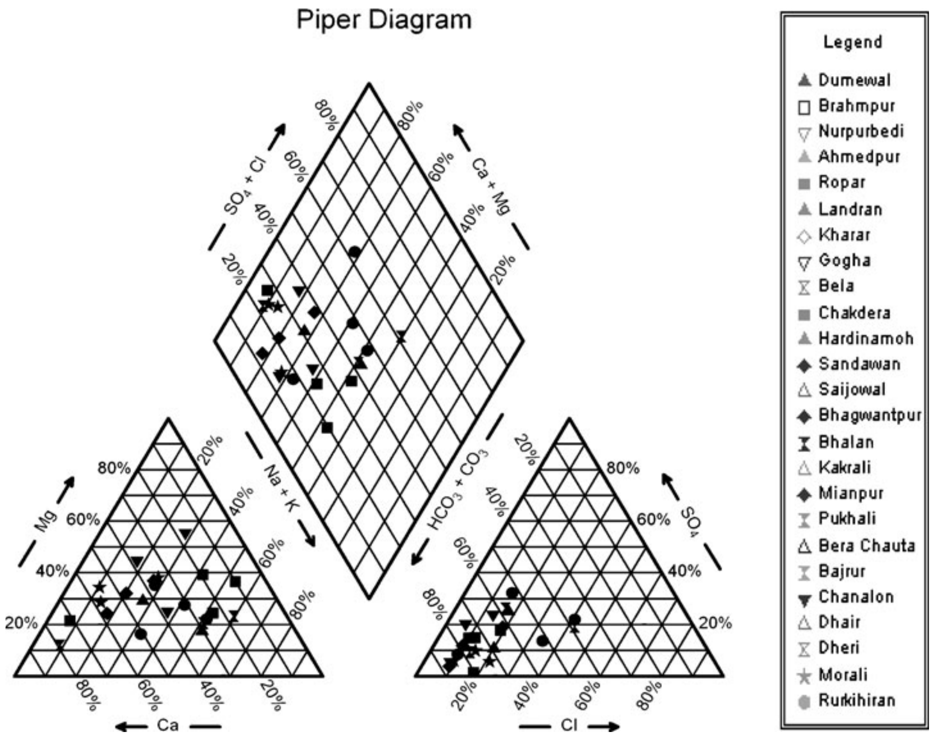


Fig. 10 Piper plot for water quality parameters

during precipitation and infiltration, would impart the bicarbonate character to the groundwater (Shanyengana et al. 2004). In addition to the above processes industrial and/or agricultural input of sodium and potassium also contributes to the increase of these ions in groundwater (Guo and Wang 2004). The areas near hills have dolomitic limestone and weathered lime overlying carbonate rocks. These weathered carbonate rocks might have reached groundwater during rainy season and recharged the groundwater thus imparting it carbonate character.

4.3 Evaluation of Water Quality Index

Ground Water Quality Index (GWQI) is a very useful and efficient method for assessing the quality of water. GWQI is a very useful tool for communicating the information on overall quality of water. To determine the suitability of the groundwater for drinking purposes, GWQI is computed adopting the following formula (Asadi et al. 2007).

$$GWQI = Anti\log\left[\Sigma W_{n=1}^{n} \log_{10} q_n\right] \tag{1}$$

Where,

Weightage factor (W) is computed using the following equation
$W_n = K/S_n$ and K, is the proportionality constant derived from,

$$K = \left[1/\left(\sum_{n=1}^{n} 1/S_i\right)\right] \tag{2}$$

S_n and S_i are the WHO/ICMR standard values of the water quality parameter.
Quality rating (q) is calculated using the formula,

$$q_{ni} = \left[\{(V_{\text{actual}} - V_{\text{ideal}})/(V_{\text{standard}} - V_{\text{ideal}}) \times 100\}\right] \tag{3}$$

Table 3 Water quality parameters and their WHO standards and assigned weights

Water quality parameter	WHO standard	Weight (W)
pH	8.5	0.1428
TDS	1,000	0.0012
Alkalinity	120	0.0101
Chloride	250	0.0048
Sulphate	250	0.0048
Nitrate	50	0.0242
Flouride	1.5	0.8090
Sodium	200	0.0060
Total hardness	300	0.0040
Cadmium	0.003	0.0725
Chromium	0.05	0.0435
Copper	2	0.0011
Iron	0.3	0.0073
Manganese	0.1	0.0044
Lead	0.01	0.2176
Zinc	5	0.0007

Table 4 Classification of ground water based on GWQI

Groundwater	GWQI
Very good	0–25
Good	25–50
Moderate	50–75
Poor	75–100
Very poor	100–125
Unfit	125 and above

q_{ni} Quality rating of i^{th} parameter for a total of n water quality parameters
V_{actual} Value of the water quality parameter obtained from laboratory analysis
V_{ideal} Value of that water quality parameter can be obtained from the standard tables. This value for pH is 7 and for other water quality parameters its zero
$V_{standard}$ World Health Organization standard of the water quality parameter (Table 3)

The groundwater was rated into very good, good, moderate, poor, very poor and unfit classes based on the GWQI values (Table 4). Most of the area was grouped under good to moderate except the areas such as Ghoga, Kharar, Rurkihiran, Bhalan, Saijowal, Dumewal and Nurpurbedi which belonged to poor to unfit class for drinking (Fig. 11). Bhalan, Saijowal, Dumewal and Nurpurbedi lie in the northern part of the study area, this area has shown high increase in the settlement in last two decades and the industries such as National Fertilizers Limited, Punjab Chemicals Limited are situated in this part of the study area.

The sewerage discharge from the Nangal settlement area and industries effluents are directed in the Satluj River which in fact recharges the unconfined aquifers in the area. The southern part of the study area lies near the Union Territory Chandigarh and it has shown tremendous increase in the built up area and several industries have

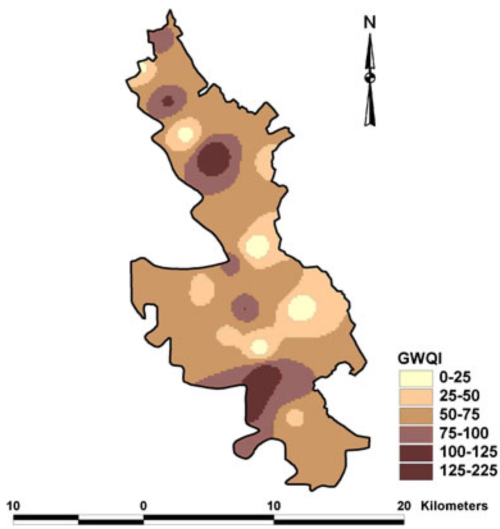


Fig. 11 Ground water quality index map

come up in last decade in this area. Thus polluting the groundwater resources in the study area through sewerage and industrial discharge respectively.

5 Conclusion

The groundwater quality of the study area is strongly influenced by effective weathering and leaching action of feldspars and magnesium calcite found in the litho-units of the study area along with anthropogenic activities like industrial effluents and phosphatic fertilizers in urban environments. The areas with water quality problems were identified based on GWQI index. In general, the quality of groundwater is good to moderate for drinking and irrigation purposes except in few areas where it is poor to unfit. However, the concentration of salts is reported more in the alluvial areas. The high salinity and high sodium concentration in soil may be attributed to improper use of fertilizers and contamination of dug wells. The development of thick soil cover has resulted in poor surface drainage. The water quality parameters suggest that the concentration of parameters such as nitrate, manganese, chromium are more than permissible limit of WHO in north western and southern parts of study area which is mostly covered by settlements. Due to improper sewerage system the quality of groundwater has deteriorated in northern and southern parts of the study area. Spatial distribution of water quality parameters was studied to see the localized influence of pollutants. Thus it can be inferred that integrated approach of remote sensing and GIS can be used as an effective tool to evaluate and quantify the impacts of land use/ land cover on groundwater quality so that pollution control measures can be carried out in holistic way.

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