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Abstract
Geographical Information System (GIS) based groundwater quality mapping has been carried out with the help of hydrochemical data of Jammu district, Jammu and Kashmir State. Groundwater quality for drinking water purposes was analyzed by considering the WHO (2004) and ISI (1991) standard. A total of 100 samples were collected from different geological formations of the study area. The groundwater samples were analyzed for the major chemical constituents viz. Ca$^{2+}$, Mg$^{2+}$, Na$^+$, K$^+$ (cations); HCO$_3^-$, Cl$^-$, F$^-$, SO$_4^{2-}$, NO$_3^-$, SiO$_2$ (anions); pH, EC, TDS. In the study it is found that 80 samples in the pre-monsoon and 85 samples in the post-monsoon were under the hard water category (Sawyer and McCarty 1967). The purposes of this investigation were to provide an overview of present groundwater quality to determine spatial distribution of groundwater quality parameters and to map groundwater quality in the study area by using GIS. The ArcGIS 9.2 was used for generation of various thematic maps and ArcGIS spatial analyst to produce the final groundwater quality map. An interpolation technique, ordinary kriging, was used to obtain the spatial distribution of groundwater quality parameters. Five thematic maps with parameters such as TH, TDS, Ca$^{2+}$, Mg$^{2+}$ and NO$_3^-$ having desirable and undesirable classes were integrated using the overlay method and groundwater quality map for drinking purposes has been prepared. A salinity hazard map was also prepared after generating contours which show the regions with low, medium and high salinity hazards. The groundwater quality for drinking purposes was integrated with groundwater quality of irrigation purposes by spatial analysis. Integrating groundwater quality for drinking purposes and irrigation purposes pictorially representation shows desirable zone for drinking, desirable zone for irrigation purposes, desirable zones of both drinking and irrigation purpose and undesirables for drinking or irrigation purposes.

Keywords
Groundwater quality, GIS, Integration analysis, Jammu district, J&K, India

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Introduction
Groundwater is one of the most important natural resources required for the human consumption, domestic purposes, irrigation, industrialization, urbanization etc. As groundwater is the largest available source of fresh water, it has become crucial not only to find out groundwater potential zones, but also to monitor and conserve important resource. Groundwater is a most precious and important resource on the earth of limited extent. No other resources on the earth, is more versatile, vital and abundant than groundwater. It is vital for the existence of all forms of life, for human consumption, for industrial and agricultural activities of civilization. Rapid growth of population, expansion of irrigation and increasing trend of industrialization have contributed towards rising demand for groundwater in Jammu district. This paper analyses various chemical parameters of groundwater in the study area to find out its usability for domestic, industrial and agricultural purposes. The hydrogeochemical study reveals the zones and quality of water that are suitable for drinking, agricultural and industrial purposes. Further, it is possible to understand the change in quality due to rock water interaction or any anthropogenic influence. GIS technology provides suitable alternatives for efficient management of large and complex databases and it also provides the appropriate platform for convergent analysis of diverse data sets for decision making in groundwater management, planning and groundwater quality mapping.

In the present study, ground water quality mapping has been carried out in Jammu district, J&K State. Hydrochemical study seeks to determine the origin of the chemical composition of groundwater and the relationship between water and rock chemistry, particularly as they relate to groundwater movement. The purposes of this paper is to review certain methods for interpreting water analysis or for summarizing the water quality of an area under study or illustrating water quality characteristics on maps. Geographical or other methods may not suffice completely to establish relationship sought by the hydrologist in a water quality study, whereas GIS is quite valuable in pointing out features of analysis and arrays of data which need closer study. Generally more detailed study of water quality problems requires the participation of geochemist. Principles of graphical and numerical interpretation of chemical analysis of water are based on the relationship of ions, or groups of ions forming a chemical constituent of water. A single graph will not give all information such as concentration of ions, comparison of the proportions of ions, classification of water types, identification of mixed water of different composition to rock type. The choice of the presentation depends on the anticipated use and the type and quality of the analytical data. Hydrochemical study reveals the zone and the quality of water that is suitable for drinking, industrial and agricultural purposes. Further, it is possible to understand the change in quality due to rock water interaction or any type of anthropogenic influence. Groundwater often consists of eight major Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, Cl^-, F^-, SO_4^{2-}, NO_3^-, SiO_2. Hence
hydrochemical studies can be conducted by analyzing water samples based on these components. The chemical parameters that are taken into consideration are hydrogen ion concentration, specific conductance, total dissolved solids (TDS), and all major cations and anions. The purpose of the study is to understand the groundwater quality and pictorially represent it using the geographic information system. GIS is an effective tool for storing large volume data that can be correlated spatially and retrieved for the spatial analysis and integration to produce the desirable output. GIS has been used by scientist of various disciplines for spatial queries, analysis and integration for the last three decades (Burrough and McDonnell 1998). Numbers of studies were conducted to determine potential sites for groundwater exploration in diverse geological set ups using remote sensing and GIS techniques (Saraf et al. 1998; Choudhary et al. 2009; Magesh et al. 2012). Most of the groundwater studies based on GIS are concentrated on the preparation of hydrogeomorphological maps, interpretation of lineaments and integrated terrain analysis. Groundwater quality analysis has been made by a number of workers from time to time in the different rock terrain in the different area (Krishnamurthy and Srinivas 1995; Kamraju 1997; Srivastava et al. 1997; Srivastava and Battacharya 2000; Sreedevi et al. 2005; Pandian et al. 2007; Md. Surabuddin et al. 2008).

The GIS based quality mapping has been studied by using quality analysis data (Rao et al. 2003; Anbazhagan and Nair 2004; Singh et al. 2008). Bilgehan and Ali (2010) evaluated the groundwater quality mapping in urban groundwater using GIS in the Konya city of Turkey and found that the southwest of the city has optimum groundwater quality, and, in general, the groundwater quality decreases south to north of the city. Schot and Pieber (2012) studied the spatial and temporal variation in the groundwater quality in shallow wetland in the Vecht river plain in the centre of the Netherlands. Rivett et al. (2012) also determined urban groundwater baseflow influence upon inorganic river-water quality in the river Tame headwaters catchment in the city of Birmingham, UK where sewage pollution was the major concern in the 19th century. Jasrotia et al. (2013) used GIS approach for groundwater potential and groundwater quality, find the desired and undesirable groundwater quality zones in the Western Doon Valley, Uttarakhand, India. Dushiyanthan et al. (2014) determined hydrogeochemical study of the groundwater sample along the eastern parts of the lower Vellar basin, it is observed that the most of the groundwater sample not exceeding the maximum permissible limit in their quality and signifies that possible ionic base reaction between Ca^{2+} and Na^{+}. This study was undertaken to delineate the zones of groundwater quality suitable for drinking and irrigation purposes in the Jammu district using the application of GIS technology.
Study area
The study area of Jammu district, approximately lies between latitude 32° 33' 07" - 33° 07' 30" N and longitude 74°27'00"-77°21'00" E and covers a total area of 3092 km² bounded by steep mountain in the north and outer plains in the south. The area enjoys subtropical to moist temperate climate with an average temperature of 2-20°C in winter and 30-47°C in summer. The average annual rainfall is about 1116 mm, subtropical climate and enjoys the SW, NW-SE type of monsoon. The study area falls in the sub-mountainous region at the foothills of the Himalayas. Siwaliks ranges rise gradually in the northern part of the district and merge with the Indo-Gangetic plains in the south (Figure 1).

Figure 1 Location map of the study area
The structure and lithology plays a major role in the evolution of the topography and drainage pattern of the area. The major physiographic slope is towards the southwestern direction i.e.,
towards the outer plains. The nals/ stream are seasonal and results in the flash floods immediately after the rains. The major rivers flowing through the hilly area of the district are the Basantar, the Chenab, the Jammu Tawi, and the Munawar Tawi. These rivers have their origin are quite to the north of the district boundary limit.

Geological Setting
The geological formation of the study area mainly comprises Siwalik rocks, exposed in uplifted thrust sheets, and an integral part of the compression zones involved in the collision of Indian and Asian plate tectonics. It is an extensive belt of fresh water molassic deposit all along the southern foothills of the Himalaya. The Siwalik Formation in the lithological, structure and morphological peculiarities depicts the characteristic features of Foreland zone constituting the low foothills of the Himalayas, generally designated as Sub-Himalayas took place in several intermittent phases which record Middle Miocene through Pleistocene synorogenic Foreland basin sedimentation. The similarity in composition between the boulder conglomerate of upper Siwalik and the recent gravel and pebble beds and their alike distribution indicate the same source of sediments transported along the similar drainage lines. However, on the basis of lithology, the study area has been divided into Upper Murree, Lower, Middle and Upper Siwalik Subgroups and alluvium of Jammu Formation (Figure 2) by Ranga Rao et al. (1988). The Kishanpur-Mandli thrust lies between the Upper Murree and Siwalik Formation where boulder conglomerate, silt and clay occur as a valley fill deposits. The Surinsar-Mastgarh anticline is NW-SE trending, the core of which is formed in the Lower Siwalik. The Middle and Upper Siwalik subgroup in the Jammu region is best exposed in the southern limb. The Upper Siwalik of the Jammu is subdivided into three members i.e. Purmandal Sandstone member, Nagrota silt member and Tawi conglomerate member. The Upper Siwalik sequence lies conformably over the Middle Siwalik subgroup. The Jammu formation consists of the sub mountainous deposits laid down in the form of piedmont alluvial plains in the front of the Upper Siwalik hill slope delimiting the northern margin of the plain. These deposits are reworked materials derived from the Upper Siwalik boulder conglomerate beds and comprises class supported deposits in the upper fan area, sheet like gravel and sandy deposits in the mid fan area, sand and clay deposit with thin gravel bands in the distal fan. These deposits finally intermingle with the alluvial silt down the slope of the piedmont area.
Methodology
In the present study, topographical map of Survey of India (SoI) on 1:50000 scale, digital data of Indian remote sensing satellite Resourcesat-2, sensor LISS-IV with spatial resolution of 5.8 m was used. The Survey of India toposheets and digital satellite data were geometrically rectified and georeferenced to world space coordinate system using digital image processing software (ERDAS IMAGINE Ver: 9.2 and Arc GIS 9.2. Groundwater samples of hundred dug wells and tube wells from different parts of the study area were collected during pre-monsoon and post-monsoon and analyzed for their geochemistry. The techniques and sample collection are followed in the study were those after the American Public Health Association (APHA 1992) and Manual of Central Pollution Control Board, New Delhi (MPCB 1997). The sampling of the ground water has been done during April-May 2007 and Oct-Nov 2007 using pre cleaned (acid washed) polyethylene containers of two liter capacity. The samples were collected from dug well and tube well extensively used for drinking and other domestic purposes. The pH, EC and TDS were measured at the site using pH, EC and TDS testers. The total hardness and calcium were estimated by the EDTA titrimetric method. Followed by the water quality analysis, thematic maps were digitized and generated in the GIS environment. Using GIS spatial analysis the groundwater quality potential suitable and unsuitable were delineated as shown in the flow chart (Figure 3).
Figure 3 Flow chart showing the methodology adopted in the study area

Chemical analysis
In the study area the monsoon continues for quite a long duration. It starts in June and continues up to the month of October. In the present study hundred dug wells and tube wells, samples were collected during pre-monsoon (April-May 2007) and post-monsoon (Nov-Dec, 2007). This analytical data can be used for the classification of water for utilitarian purposes, solving ascertaining various factors on which the chemical characteristics of water depend. For greater interpretability, the analytical data are represented in Piper-Trilinear plots. The Pipers Trilinear diagram is extensively used to understand problems concerning the geochemical evaluation of groundwater. The concentrations of major ions in groundwater samples collected in both seasons (Figure 4). The analytical data were used for the spatial analysis and integration for groundwater quality mapping. The groundwater samples collected study areas are colorless, odorless, and free from turbidity. However, these do not fall in the realm of chemical quality. The
chemically the water should be soft, low in dissolved in solids and free from poisonous constituents.

Figure 4 Piper-Trilinear diagram of groundwater in the study area

The diagram consists of three distinct fields- two triangular fields and a diamond shaped field. The percentage equivalents per mole (epm) values are used for the plot (Todd 1980). The overall characteristic of the water is represented in the diamond shaped field by projecting the position of the plots in the triangular fields. Different types of groundwater can be distinguished by their plotting position, occupying a certain sub area of the diamond shaped field. Piper's Trilinear diagram were made and reveals that water belongs to Ca$^{2+}$, Mg$^{2+}$, and HCO$^3-$, facies and the plot of the groundwater samples of pre-monsoon data and post-monsoon data falls in the fields 1,3 and 4 which suggest that alkaline earth exceeds alkalies and weak acids exceed strong acids respectively.

The calcium and magnesium are major cations in the study area for about 75-90% of the cations. Bicarbonate is the major anion for accounts for about 70-85% of the anions in the study area. The plotting of the chemical quality data in the present study shows the dominance of calcium bicarbonate. The Ca$^{2+}$, Mg$^{2+}$, and HCO$^3-$, indicate the temporary hardness, alkalinity and the total hydrochemistry are dominated by alkaline earths and weak acids. This can be explained in terms of concentration process, which is dominant during the post monsoon period when precipitation exceeds evaporation. The quality of the groundwater samples has been analyzed separately for the drinking and irrigation purposes. As there is no major industry in the study area, quality analysis for the industry is not significant. Groundwater quality for drinking water purposes was
analyzed by considering the WHO (1984) and ISI (1991) standards. It has been found that some samples show TH, TA, TDS, Ca$^{2+}$, Mg$^{2+}$, Na$^+$, above the desirable limit.

**Spatial analysis for groundwater quality**

The chemical quality of the groundwater largely depends on the nature of the rock formations, physiographic, soil environment, recharge, and draft conditions in which it occurs. The chemical composition of water is an important factor to be considered before it's used for domestic, irrigation or industrial purposes (Suresh et al. 1991). Groundwater quality gives a clear picture about the usability of the water for different purposes. There are specific standards for quality of water for different purposes. Drinking water should satisfy many quality criteria, as it is the most sensitive among various uses. The standard quality of drinking water has been specified by the WHO (2004) and ISI (1991). It has given the permissible and desirable limits for the presence of various elements in the groundwater. In the present study the area shows limited seasonal variation in groundwater quality. According to the chemical composition of groundwater of the study area the pH value is in the range of 5.9 to 8.5 indicating an alkaline nature. TDS, which is a measure of the total concentrations of dissolved salts, is between 70 and 780 mg/l with a mean of about 339.4 mg/l. The concentrations of TA and TH vary from 29.1-365.8 to 80-584 mg/l with a mean of 176.3 and 226.5 mg/l, respectively. The waters belongs to the soft (75 to 150 mg/l) to hard (150- 3000 mg/l) categories (Sawyer and McCarty 1967) that all the samples show TH > TA indicates non-carbonate hardness. To ascertain the suitability of groundwater for drinking and public health purposes, hydrochemical parameters of the study area are compared with the guideline recommended by WHO (2004) and ISI (1991) Table1 which shows that groundwater has partial suitability for drinking purposes and public health because the concentrations of TDS, TH, Ca$^{2+}$, Mg$^{2+}$, and NO$_3^-$ in the groundwater are observed to be more than the concentrations of recommended limits for drinking purpose. Electrical conductivity which defines the salinity also shows variation and falls in the three classes with low, medium and high hazard classes and these can be best studied with graphical diagram (Richard 1954). The distribution for irrigation water quality classification (after Richards 1954) given in Table 2. Overlay analysis was performed in generating the quality map where the various quality maps were overlaid one upon the other. It is based on the Boolean logic where only two values were assigned, I e ‘1’ and ‘0’ (Burrough and McDonnell 1998). In this context ‘1’ stands for desirable and ‘0’ for the undesirable quality.
Table 1 Comparison of the quality parameters of groundwater of the study area with WHO and ISI for drinking purpose.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Water Quality Parameters (Unit)</th>
<th>WHO (1984)</th>
<th>ISI (1991)</th>
<th>Concentration in study area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Highest Desirable limit</td>
<td>Max. Permissible limit</td>
<td>Highest Desirable limit</td>
<td>Max. Permissible limit</td>
</tr>
<tr>
<td>1.</td>
<td>pH</td>
<td>7.0</td>
<td>8.5</td>
<td>6.5</td>
</tr>
<tr>
<td>2.</td>
<td>TDS (mg/l)</td>
<td>500</td>
<td>1500</td>
<td>500</td>
</tr>
<tr>
<td>3.</td>
<td>Calcium (mg/l)</td>
<td>75</td>
<td>200</td>
<td>75</td>
</tr>
<tr>
<td>4.</td>
<td>Magnesium (mg/l)</td>
<td>50</td>
<td>150</td>
<td>30</td>
</tr>
<tr>
<td>5.</td>
<td>Potassium (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Sodium (mg/l)</td>
<td>200</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Bicarbonate (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Chloride (mg/l)</td>
<td>200</td>
<td>600</td>
<td>250</td>
</tr>
<tr>
<td>9.</td>
<td>Sulphate (mg/l)</td>
<td>200</td>
<td>400</td>
<td>150</td>
</tr>
<tr>
<td>10.</td>
<td>Nitrate (mg/l)</td>
<td>45</td>
<td>45</td>
<td>100</td>
</tr>
<tr>
<td>11.</td>
<td>Fluoride (mg/l)</td>
<td>1.0</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Total Hardness as CaCO₃ (meq/l)</td>
<td>100</td>
<td>500</td>
<td>300</td>
</tr>
</tbody>
</table>
Table 2 Irrigation water quality classification (after Richards, 1954)

<table>
<thead>
<tr>
<th>Water quality class</th>
<th>Electrical conductivity * (µs/cm)</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent (C1)</td>
<td>100-250</td>
<td>4</td>
</tr>
<tr>
<td>Good (C2)</td>
<td>250-750</td>
<td>89</td>
</tr>
<tr>
<td>Fair/Medium (C3)</td>
<td>750-2250</td>
<td>7</td>
</tr>
<tr>
<td>Poor/Bad (C4)</td>
<td>&gt;2250</td>
<td></td>
</tr>
</tbody>
</table>

GIS based groundwater quality mapping for drinking water

The quality of the groundwater samples has been analyzed for drinking and irrigation purposes. Groundwater quality for drinking water purposes was analyzed by considering the WHO (2004) standard. It has been found that some samples show TH, TDS, Ca\(^{2+}\), Mg\(^{2+}\), and NO\(_3^-\) above the desirable limit. These values were plotted in the respective samples locations and contours were generated using the simple method of triangulation and interpolation techniques. Water quality maps were generated for TH, TDS, and NO\(_3^-\) in the study area falling under desirable limit. A salinity hazard map was also prepared after generating contours. The salinity hazard map shows regions with low, medium and high salinity hazards.

Hardness

Water hardness is caused primarily by the presence of cations such as calcium and magnesium and anions such as carbonate, bicarbonate, chloride, and sulfate in water. The concentration of TDS from 80-584 mg/l in Jammu district which is within the maximum permissible limits as (WHO 2004, and ISI 1991) standards indicating that the groundwater is potable. The desirable limit of the total hardness is 300 mg/l. The concentration of total hardness above the desirable limit, encrustation in water supply structure and adverse effect on domestic uses. According to Sawyer and McCarty’s (1967) classification 80% samples fall under hard class during pre monsoon and 85% samples found under hard class during the post-monsoon water samples (Table 3). The concentration of total hardness in the Jammu district varies from 80-584 mg/l which is within the maximum permissible limits (1500mg/l). The desirable limit of the total hardness is 300 mg/l. The concentration of total hardness above the desirable limit may lead to the encrustation in water supply structure and adverse effect on domestic uses. Hardness concentration of different locations was plotted and using the triangulation method and the value were interpolated to generate contours. The contour map was imported into the GIS environment and a thematic layer was prepared as per the limit of the ISI (1991).
**Table 3 Classifications based on hardness by Sawyer and McCartly (1967)**

<table>
<thead>
<tr>
<th>Hardness CaCO₃ (ppm)</th>
<th>Water class</th>
<th>Pre-monsoon samples</th>
<th>Post-monsoon samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-75</td>
<td>Soft</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>75-150</td>
<td>Moderately</td>
<td>18</td>
<td>13</td>
</tr>
<tr>
<td>150-3,000</td>
<td>Hard</td>
<td>80</td>
<td>85</td>
</tr>
<tr>
<td>&gt;3000</td>
<td>Very Hard</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Total dissolved solids**

The total dissolved solids (TDS) is the total amount of solids in mg/l. Concentration of TDS is an important parameter in drinking water and other water quality standard. In the present study, the following relation between EC and TDS has been used for studying the TDS variation in groundwater (Raghunath 1987). Total dissolved solids (TDS) denote the various types of minerals present in water in the dissolved form. In natural water, dissolved solids are composed of mainly carbonates, bicarbonates, chlorides, sulfates, phosphates, silica, calcium, magnesium, sodium and potassium concentration of TDS are an important parameter in drinking water and other water quality standards. Carroll (1962) proposed four classes of water based on TDS value (Table 4) and the majority of water samples TDS in the study area falls in the fresh water class of Carroll classification. In the study area TDS values range from 70-780 mg/l which is within the maximum permissible limits as per the WHO (2004) and ISI (1991) standards indicating that the groundwater is potable. There is a slight increase of Total dissolved solids (TDS) in the post monsoon season as a result of dissolution of minerals from the overlying layers and weathered zones by water percolation. The overall characteristics of groundwater in the investigated area in the post-monsoon season, where the majority of the minerals is high due to the rock interaction, are also controlled by the contamination from extraneous sources.

**Table 4 Water quality classification based on TDS (Caroll, 1962)**

<table>
<thead>
<tr>
<th>TDS (mg/l)</th>
<th>Water quality</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-monsoon</td>
<td>Post monsoon</td>
</tr>
<tr>
<td>0-1000</td>
<td>Fresh water</td>
<td>100</td>
</tr>
<tr>
<td>1,000-10,000</td>
<td>Brackish water</td>
<td>100</td>
</tr>
<tr>
<td>10,000-100,000</td>
<td>Salty water</td>
<td></td>
</tr>
<tr>
<td>&gt;100,000</td>
<td>Brine water</td>
<td></td>
</tr>
</tbody>
</table>

**Calcium**

Calcium is most important cation in the study area and present as calcium bicarbonate and causes hardness in water. In study area the concentration of calcium in groundwater ranges from
38-176 mg/l within the permissible limits WHO (2004) and ISI (1991) indicating that the groundwater is potable. The concentration of calcium above the desirable limit causes encrustation in water supply structure and adverse effect on domestic uses. The absence of calcium in drinking water is also responsible for rickets and defective teeth, while presences of excess calcium cause hard water gout urinary problem.

**Magnesium**

Magnesium is also an important cation of groundwater. Geologically, magnesium rich minerals are associated with basic, ultra basic and ultramafic rocks of igneous and metamorphic characteristics. Accordingly, to ISI (1991) the maximum desirable limit of magnesium is 30 mg/l. Livingstone (1963) suggested that river water contains magnesium content varying between 1 and 50 mg/l. The concentration of magnesium from the 1.9-44 mg /l in the study area, which is within the maximum permissible limits as per the WHO (2004) and ISI (1991) standards indicating that the groundwater is potable.

**Nitrate**

The concentration of nitrate in groundwater in the study area 0.1-60 mg/l is within the maximum permissible limit (100 mg/l) as per the WHO (2004) and ISI (1991) standards indicating that the groundwater is potable. The Nitrate occurrence in groundwater is due to aerobic decomposition of nitrogen from organic matter. Nitrate from other sources like fertilizer, industrial effluents and septic tanks contribute nitrate in the form of pollutants.

**Spatial analysis for groundwater Quality mapping**

The chemical quality of the groundwater largely depends on the nature of the rock formations, Physiographic, soil environment, recharge, and draft conditions in which it occurs. The chemical composition of water is an important factor to be considered before it's used for domestic, irrigation or industrial purposes (Suresh et al. 1991). Groundwater quality gives a clear picture about the usability of the water for different purposes. There are specific standards for quality of water for different purposes. The standard quality of drinking water has been specified by world health organization WHO (1984) and ISI (1991). It has given the permissible and desirable limits for the presence of various elements in the groundwater. In the present study, the area shows limited seasonal variation in groundwater quality. On the other hand, it has also been revealed that some samples show TH, TDS, Ca$^{2+}$, Mg$^{2+}$, and NO$_3^-$ above the desirable limit. These values were plotted in the respective samples locations and contours were generated using the simple method of triangulation and interpolation techniques. Water quality maps were generated for TH, TDS, and NO$_3^-$ in the study area falling under desirable limit. A salinity hazard map was also prepared after generating contours. The salinity hazard map shows regions with low, medium and
Groundwater quality analysis for irrigation

Water quality soil types and cropping practices play an important role in irrigation. Agriculture is found to be one of the major land-use practices in the study area. Most of the cultivated lands in Jammu district are irrigated by groundwater either from dug wells or bore wells. Therefore, it is necessary to perform the analysis of chemical quality for irrigation purposes. The important chemical constituents that affect the suitability of water for irrigation are the total concentration of soluble salts, relative proportion of sodium to calcium. Water quality problems in irrigation include salinity and alkalinity. Excessive sodium content in the water makes it unsuitable for irrigation purposes. In addition to this the quantity of bicarbonates and carbonates in excess of the alkaline earth elements also influences the suitability of water for irrigation purposes.

Sodium Absorption Ratio (SAR)

The relative activity of sodium ion in the exchange reaction with soil is expressed in terms of a ratio known as sodium absorption ratio (SAR) which is an important parameter for determining the suitability of irrigation water. SAR is defined by
Na⁺
SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})}/2}
SAR concentration is in meq/l

The SAR value in groundwater of the study area ranges from 0.032 to 1.162 meq/l in pre-monsoon and 0.067 to 1.166 meq/l in post-monsoon, which indicates that no hazard of alkalinity (Richards’s 1954) is anticipated in the study area. The water is of excellent quality (Table 5) in the study area, according to the SAR classification of Bower (1978).

Table 5 Groundwater quality based on Sodium Absorption Ratio (SAR) (Herman Bouwer, 1978)

<table>
<thead>
<tr>
<th>SAR(epm)</th>
<th>Remark on quality</th>
<th>No. of sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Post monsoon</td>
</tr>
<tr>
<td>0 - 6</td>
<td>No problems</td>
<td>100</td>
</tr>
<tr>
<td>6 - 9</td>
<td>Increasing problems</td>
<td></td>
</tr>
<tr>
<td>&gt;9</td>
<td>Severe problems</td>
<td></td>
</tr>
</tbody>
</table>

Residual Sodium Carbonate (RSC)
When the sum of carbonate and bicarbonate is in excess of calcium and magnesium there occurs a complete precipitation.

RSC = (CO₃⁻+HCO⁻₃)-(Ca²⁺+ Mg²⁺) meq/l

In the RSC values in groundwater of the study area, the value of pre-monsoon period ranges from -0.56 to -0.11 meq/l and the values of post-monsoon period ranges from -5.66 to 0.036 meq/l. It implies that according to the values of RSC, the groundwater of the study area is excellent quality.

Salinity Hazard
Most of the ground water samples fall in the medium salinity hazard (C2) as per the salinity hazard (Richard’s 1954) in both the season, whereas in the low salinity zone (C1) a few samples are falling during the both seasons. In the high salinity zone seven samples fall during premonsoon and thirteen samples fall during the post monsoon season (Figure 6). The quality of water for irrigation purposes depends on the salinity and alkalinity. The EC value of the samples will give the salinity value of the area. The classification formulated by four degrees of risk using groundwater for irrigation given in Table 6. The average value of pre-monsoon and post-monsoon water samples from the study area fall into three classes of salinity hazards: Excellent (<250), good (250-750), and doubtful (>750). Contours were constructed and the entire study area was...
divided into these three classes and three classes polygons were digitized. The salinity hazard map shows that the majority of study area falls into the good category (Figure 7). The doubt calls mostly fall in the high area expect two pockets in the alluvial plain which may be due to local occurrence.

![Figure 6 Classification of Irrigation water (after, Richard, 1955)](image)

- samples of pre-monsoon and -- samples of post-monsoon periods

![Figure 7 Salinity hazard map](image)
Table 6 Classification for degree of risk of using groundwater for irrigation (Richard, 1954)

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI</td>
<td>Low salinity water (EC: &lt;250 µs/cm) can be used for the most soils with little likelihood of soil salinity development. Some leaching is required, but this occurs under normal irrigation practices except in soil of extremely low permeability.</td>
</tr>
<tr>
<td>C2</td>
<td>Medium salinity water (EC: 250-750 µs/cm) can be used if moderate amount of leaching occurs. Crops of moderate salt tolerance can be irrigated with this water without special practice.</td>
</tr>
<tr>
<td>C3</td>
<td>High salinity water (EC: 750-2250 µs/cm) cannot be used on soils of restricted drainage. Even with adequate drainage. Special management for salinity control may be required and crop of good salt tolerance can be selected.</td>
</tr>
<tr>
<td>C4</td>
<td>Very high salinity water (EC: &gt;2250 µs/cm) is not suitable as irrigation water under ordinary circumstances. It can be used only on crops that are very salt tolerant and only if special practices are followed, including provision for high degree of adverse effects.</td>
</tr>
</tbody>
</table>

**Integrated quality mapping**

The spatial integration for quality mapping was carried out using overlay analysis. The groundwater quality map for drinking purposes was integrated with the groundwater quality map for irrigation. Integrating groundwater quality for drinking purposes and the salinity map can pictorially represent groundwater zones favorable for drinking purposes, irrigation purposes, zones of both drinking and irrigation purposes, zones not favorable for either drinking or irrigation purposes (Figure 8). Prioritization of zones on the basis of quality for drinking and irrigation can be used for the planning and preservation of groundwater resources.
Conclusions
During the year 2007 monitoring and hydrochemical analysis were carried out in 100 observation wells. Ground water in the study area shows that alkaline earth (Ca\(^{2+}\), Mg\(^{2+}\)) exceeds alkalies (Na\(^+\) and K\(^+\)). The groundwater increases its major ion concentration in the post monsoon period in comparison to the pre-monsoon period. This is because of the precipitation and the environment, weathering in the study area. In the present study the GIS has successfully demonstrated its capability in groundwater quality mapping Jammu district. The integrated GIS study resulted in the development of an efficient and effective methodology of spatial data management and manipulation. The integration and analysis of various thematic maps and image data proved useful for the groundwater quality zones suitable for domestic purposes. The final output has given the pictorial representation of groundwater quality zones suitable or unsuitable for drinking and irrigation purposes in the watershed. From the hydrogeochemical analysis, it is inferred that the excess concentration of Ca\(^{2+}\), Mg\(^{2+}\), NO\(_3^-\), TH, TDS, and in the study area was falling under desirable limit and area falling under undesirable limit quality for drinking purposes. Similarly, considerable areas in the watershed are having salinity hazard map shows regions with low, medium and high salinity hazards the salinity hazard map shows that the majority of study area falls in the good category.

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