Hydrochemical characterization, ionic composition and seasonal variation in groundwater regime of an alluvial aquifer in parts of Nalagarh valley, Himachal Pradesh, India

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doi:10.6088/ijes.6008

ABSTRACT

Around 72% industries in Nalagarh are processing without effluent treatment plants which is a major threat to groundwater regime. The present study is focused on hydrochemical characterization and seasonal variation of groundwater quality to assess the intensity of pollution in this industrial belt. At some locations the concentration of pH, total hardness and magnesium exceeded the permissible limits and other parameters like electrical conductivity, total dissolved solids, calcium, magnesium and bicarbonate showed above the desirable limit of Bureau of Indian Standard (BIS) that requires precautionary measures. Groundwater of the study area was assessed for irrigation purposes on the basis of Electrical Conductivity, Sodium Adsorption Ratio, Residual Sodium Carbonate, Percent Sodium, Kelley’s Ratio and Doneen’s Permeability Index all water samples were suitable for irrigation purpose respectively. The value of Magnesium Hazard indicates that 68.75% and 34.38% of water samples fall under “Harmful” class during both seasons respectively. Chadha’s diagram for geochemical classification and hydrochemical processes of groundwater for both seasons indicates that all the water samples are Ca2+–Mg2+–HCO3− type. The study reveals that the groundwater quality changed due to anthropogenic and natural influence such as industrial, agricultural, natural weathering process.

Key words: Industries, groundwater quality, total hardness, sodium adsorption ratio, kelly’s ratio, magnesium hazard

1. Introduction

Water quality studies are regarded as one of the thrust area in the water resources sector. In recent decades, exploitation of groundwater has increased considerably for agricultural and industrial purposes, because large sections of surface water regime are highly polluted by changing living standards of human being and landuse pattern. The composition of groundwater depends on the natural and anthropogenic processes which can alter these systems by contaminating them or modifying the hydrological cycle (Appelo and Postma, 1993; Singh, 2005 and Herojeet et al., 2013). Groundwater is about 20% of the world resource of fresh water and widely used by industries, irrigation and domestic purposes respectively (Usha et al., 2011). Presently, 85% of the water requirement for domestic use in rural areas, 55% for irrigation and over 50% for industrial and urban uses is met from groundwater (Ghosh and Sharma, 2006). Groundwater irrigation started with only 6.5 million
hectares in 1950-51 [Central Groundwater Board (CGWB), 1992], which was increased to 46.5 million hectares in 2000-2001 meeting about 70% of the irrigation water requirements of the country. This clearly indicates the growing pressure on groundwater resources. There is also growing concern on the deterioration of groundwater quality due to geogenic and anthropogenic activities (CGWB, 2010). The water used for irrigation purpose should be of such quality, which does not harm the soil and gives maximum crop yield (Patel and Desai, 2005). Groundwater resources in the alluvial regions are relatively more prone to contamination due to higher population densities and consequently intense agriculture and industrial activities in these areas [Environment Protection Agency (EPA), 1993].

The shallow character and high permeability of alluvial aquifers make them highly vulnerable to contamination (Helena et al., 2000; Singh et al., 2006). Nalagarh valley is the southernmost expanse of Himachal Pradesh, lies in the Baddi, Barotiwala and Nalagarh (BBN) industrial belt. The valley has been rated as fastest industrial development takes place in last decades, owing to the special concession given by the Central Government to State Government. This led to unplanned industrial activity leading to discharge of industrial effluent both treated and partially treated as well as untreated cause surface water pollution. Presently large development of groundwater is observed in industrial belts wherein fall of water level down to 6 meters have been observed in some parts of valley (Dhiman and Kumar, 1998), along with groundwater level depletion, vulnerability to groundwater pollution is major issues in the area. The present study carried out with the aim of understanding the groundwater quality and its suitability for domestic and irrigation purpose.

2. Study area

Nalagarh valley forms a South-Eastern narrow prolongation of a great outermost Himalayan intermountain valley area of about 230 sq. km. It lies between Northern latitudes of 30°52’N to 31°04’N and Eastern longitudes of 76°40’E to 76°55’E. The valley is having common border with Haryana towards south-east i.e. Kalka-Pinjor area and with Punjab towards south-west i.e. Ropar district (Fig.1). The depth of water level increases towards the hills with the rise of the land surface whereas shallow aquifer along the valley of Sirsa nadi (CGWB, 1975). The recharge of groundwater body is chiefly affected through rainfall, influent stream seepage and irrigation water. The valley lacks proper drainage system along with waste disposal facilities where sewage, both treated or untreated effluent are discharged into nallahs and other aquatic environment.

3. Materials and methods

Groundwater samples were collected from 14 Tubewells, 8 Dugwells, 5 Handpumps, 4 Springs and 2 wells were collected using grid method during May 2012 and October 2012. Good qualities, air tight plastic bottles with cover lock were used for sample collection and safe transfer to the laboratory for analysis. At the time of sampling, bottles were thoroughly rinsed two to three times with water to be sampled. The water sampling has been carried out following the standard procedures. Physical parameters like electrical conductivity (EC), pH, total dissolved solids (TDS) were measured on the spot at the time of sample collection using potable kit. Chemical analysis of major cations namely sodium (Na⁺), potassium (K⁺), calcium (Ca²⁺), magnesium (Mg²⁺) and anions namely sulphate (SO₄²⁻), chloride (Cl⁻), bicarbonate (HCO₃⁻), nitrate (NO₃⁻), phosphate (PO₄³⁻) for the examination of water and wastewater using standard method (APHA, 2002).
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Figure 1: Map showing sampling sites in the study area

3.1 Hydrogeology

Hydro-geologically, the unconsolidated valley fill or alluvial formation occurring in the valley area; semi-consolidated formations belonging to Siwalik group in the study area (Fig. 2). However, in valley area of Nalagarh, the ground water occurs in porous unconsolidated alluvial formation (valley fills) comprising, sand, silt, gravel, cobbles/pebbles. Ground water occurs both under phreatic & confined conditions. The thickness of such deposits is again restricted to 60 to 100 meters below ground level (mbgl) . Water table rises after monsoon period and intersects the ground surface at the contact between two terraces giving rise to a number of springs. Wells and tube wells are the main ground water abstraction structures. The depth of open dug wells and dug cum bored well in area ranges from 4.00 to 60.00 mbgl wherein depth to water level varies from near ground surface to more than 35 mbgl. However the yield of shallow aquifer is moderate with well discharges up to 10 liters per second (lps). Deeper semi-confined aquifers are being developed by tube wells ranging in depth from 65 to 120 m tapping 25-35 m granular zones. The well discharges vary from about 10 to 30 lps.

4. Results and discussions

The physical observations of 32 groundwater samples are colourless and odourless in natures which are given in the table 1. As per data obtained from the analysis (table 1), seasonal variation are more visible to those chemical parameters like pH, EC, TDS that may be attributed by over extracting of groundwater and declining of water table during pre monsoon. Whereas TH, Ca\(^{2+}\), Mg\(^{2+}\), HCO\(_3\)-, Cl\(^-\), NO\(_3\)- and PO\(_4\)\(^{3-}\) values were prominent in post monsoon period which might be due increase infiltration and recharge of aquifer by dissolution minerals, other anthropogenic activities and movement of water during monsoon period. The following interpretations were made from the result obtained for different parameters.
4.1 pH and Electrical Conductivity (EC)

pH of the water samples were slightly alkaline due to presence of carbonates and bicarbonates (Murhekar, 2011). The pH values of water samples varied between 7.17 to 8.7 during per monsoon and 7.07 to 8.07 during post monsoon were found within the limit (6.5-8.5) prescribed by BIS. 1.56% sample was beyond permissible limit. EC values ranged between 500 µS/cm to 1513 µS/cm and 440 µS/cm to 1348 µS/cm during pre and post monsoon were well within the permissible limits, fits for drinking and industrial purposes.

4.2 Total Dissolves Solid (TDS) and Total Hardness (TH)

The concentration of TDS varies from 324mg/l to 992 mg/l during pre monsoon and range between 284 mg/l to 875 mg/l in post monsoon among various locations and depths which are within permissible limits. 56.25% samples exceed the desirable limit of 500 mg/l indicating presence of slightly concentration of salts and related to the problem such as hardness. Total Hardness of groundwater ranged from 206mg/l to 622 mg/l and 186 mg/l to 772 mg/l during both seasons. 6.25% of sample is above the permissible limit which is unfit for domestic and industrial purposes whereas 42.19% is above desirable limit which gives us caution.

4.3 Calcium (Ca\textsuperscript{2+}) and Magnesium (Mg\textsuperscript{2+})

Calcium ranged between from 35.32 mg/l to 157.28 mg/l and 27.55 mg/l to 138.59 mg/l for both pre and post monsoon which is within permissible limit. However, 48.44% of water samples are above desirable limit, conditionally unfit for drinking purposes in case there is no alternative source of water supply. The magnesium concentrations varied between 20.64mg/l to 137.2 mg/l during pre monsoon and between 31.72 mg/l to 172.82 mg/l for post monsoon. Majority of water samples (87.5%) are above desirable limit and 9.38% exceed the permissible limit causes unpleasant taste to water and are laxative and its salts acts as
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There is a direct correlation where water samples Mg$^{2+}$ concentrations above permissible limit also have Total Hardness exceed permissible limit at the same location. Dissolved magnesium exceeds calcium in water once calcium precipitates after reaching super saturation and accounts for higher magnesium concentrations than calcium (Hem, 1991).

### Table 1: Analytical Result of Groundwater Samples as per BIS limit for Drinking Purpose

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Parameters</th>
<th>No. of Samples analyzed</th>
<th>BIS Limit</th>
<th>Pre monsoon Results</th>
<th>Post monsoon Results</th>
<th>No of Sample above Desirable Limit (%)</th>
<th>No. of Sample above Permissible Limit (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>pH</td>
<td>32</td>
<td>6.5 – 8.5</td>
<td>7.17 - 8.7</td>
<td>7.03 - 8.07</td>
<td>0.23</td>
<td>NIL</td>
</tr>
<tr>
<td>2</td>
<td>EC(µS/cm)</td>
<td>32</td>
<td>200</td>
<td>500 - 1513</td>
<td>284.08 - 440 - 1348</td>
<td>270.84</td>
<td>60.93</td>
</tr>
<tr>
<td>3</td>
<td>TDS(mg/l)</td>
<td>32</td>
<td>200</td>
<td>324 - 992</td>
<td>284 - 875</td>
<td>175.49</td>
<td>56.25</td>
</tr>
<tr>
<td>4</td>
<td>TH(mg/l)</td>
<td>32</td>
<td>600</td>
<td>206 - 622</td>
<td>186 - 772</td>
<td>155.33</td>
<td>42.19</td>
</tr>
<tr>
<td>5</td>
<td>Ca$^{2+}$(mg/l)</td>
<td>32</td>
<td>200</td>
<td>35.32 - 157.28</td>
<td>22.02</td>
<td>27.55 - 139.59</td>
<td>12.09</td>
</tr>
<tr>
<td>6</td>
<td>Mg$^{2+}$(mg/l)</td>
<td>32</td>
<td>100</td>
<td>20.64 - 137.2</td>
<td>1.51</td>
<td>31.72 - 172.82</td>
<td>3.20</td>
</tr>
<tr>
<td>7</td>
<td>Na$^+$ (mg/l)</td>
<td>32</td>
<td>----</td>
<td>12.0 - 99.9</td>
<td>9.19</td>
<td>9.1 - 62.5</td>
<td>9.64</td>
</tr>
<tr>
<td>8</td>
<td>K$^+$ (mg/l)</td>
<td>32</td>
<td>----</td>
<td>0.9 - 8.8</td>
<td>1.52</td>
<td>0.4 - 19</td>
<td>4.28</td>
</tr>
<tr>
<td>9</td>
<td>HCO$_3^-$ (mg/l)</td>
<td>32</td>
<td>600</td>
<td>60 - 196</td>
<td>28.95</td>
<td>62 - 204</td>
<td>31.09</td>
</tr>
<tr>
<td>10</td>
<td>Cl$^-$ (mg/l)</td>
<td>32</td>
<td>100</td>
<td>2.98 - 38.77</td>
<td>21.69</td>
<td>3.98 - 39.76</td>
<td>36.72</td>
</tr>
<tr>
<td>11</td>
<td>NO$_3^-$ (mg/l)</td>
<td>32</td>
<td>45</td>
<td>0.49 - 6.27</td>
<td>28.66</td>
<td>0.0 - 18.92</td>
<td>28.44</td>
</tr>
<tr>
<td>12</td>
<td>SO$_4^-$ (mg/l)</td>
<td>32</td>
<td>400</td>
<td>9.98 - 27.01</td>
<td>3.32</td>
<td>9.69 - 26.48</td>
<td>3.99</td>
</tr>
<tr>
<td>13</td>
<td>PO$_4^-$ (mg/l)</td>
<td>32</td>
<td>----</td>
<td>0.01 - 0.95</td>
<td>0.19</td>
<td>0.01 - 0.05</td>
<td>0.01</td>
</tr>
</tbody>
</table>

### 4.4 Sodium (Na$^+$) and Potassium (K$^+$)

The sodium concentrations are ranging between 12 mg/l to 99 mg/l and 9.1 mg/l to 62.5 mg/l with mean value 29.45 mg/l during both seasons. Potassium concentrations varied from 0.9 mg/l to 8.9 mg/l and 0.4 mg/l to 19 mg/l during pre and post monsoon. BIS (1991) & WHO (2006) have not prescribed any guideline limit for sodium and potassium in drinking water. The concentration of sodium and potassium in the study area is very low.

### 4.5 Alkalinity (HCO$_3^-$)

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Bicarbonate concentration varied between 60 mg/l and 196 mg/L and 62 to 204 mg/l during pre and post monsoon which is within desirable limit. Water samples are suitable for domestic and industrial uses as bicarbonate content is concerned. Normally in natural water as the pH value ranges from 7.0-8.0 would contain much more bicarbonates than carbonates (Chow, 1964).

4.6 Chloride (Cl⁻) and Sulphate (SO₄²⁻)

Chloride content ranged from 2.98 mg/l and 38.77 mg/l during pre monsoon and varies from 3.98 mg/l to 39.76 mg/l during post monsoon. The entire water samples are within the permissible limit of BIS. The Sulfate content in samples ranged from 9.98 mg/l to 27.01 mg/l and between 9.69 mg/l to 26.48 mg/l during pre and post monsoon, well within the acceptable limit which depicts fit for drinking purposes.

4.7 Nitrates (NO₃⁻) and Phosphate (PO₄³⁻)

Excessive concentrations of nitrate in drinking water cause methemoglobinemia in small baby. Nitrate values of groundwater samples varies from 0.49 mg/l to 6.27 mg/l during pre monsoon whereas during post monsoon between 0 mg/l to 18.92 mg/l which is well within the limit. The concentration of phosphate in water samples varies from 0.01 mg/l to 0.95 mg/l during pre monsoon and 0.01 mg/l to 0.05 mg/l for post monsoon. The concentration of phosphate in the groundwater is very low which depicts fit for domestic consumption.

<table>
<thead>
<tr>
<th>Table 2: Different criteria for suitability of groundwater for irrigation purposes.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameter</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Electrical Conductivity (µS/cm)</td>
</tr>
<tr>
<td>Sodium Adsorption Ratio</td>
</tr>
<tr>
<td>Sodium Residual Carbonate (meq/l)</td>
</tr>
<tr>
<td>Percent Sodium (%)</td>
</tr>
<tr>
<td>Kelley’s Ratio</td>
</tr>
<tr>
<td>Doneen’s Permeability Index (%)</td>
</tr>
<tr>
<td>Magnesium Hazard (%)</td>
</tr>
</tbody>
</table>

4.8 Water quality for irrigation purposes

The quality of water for irrigation varies substantially, depending principally upon the salinity, soil permeability, toxicity and some miscellaneous concerns such as excessive

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nitrogen loading or unusual pH of water. The irrigation water in the study area is classified on the basis of a) Electrical Conductivity (EC), b) Sodium Adsorption Ratio (SAR), c) Residual Sodium Carbonate (RSC), d) Percent Sodium (% Na), e) Kelley’s Ratio (KR), f) Doneen’s Permeability Index (PI), g) Magnesium Hazard (MH) as depicted in table 2.

4.9 Electrical conductivity (EC)

Electrical conductivity is related to salinity and it affects availability of water to crops. According to the classification suggested by Wilcox (1955), 31.25% water samples in the study area lie under good water class (250-750 µS/cm) and 68.75% under permissible class (750-2000 µS/cm) during pre monsoon and 50% lie under good class and 50% under permissible class during post monsoon. All the groundwater samples fall under good and permissible class, thus may be considered safe for irrigation purposes.

4.10 Sodium adsorption ratio (SAR)

Water having excess sodium has undesirable effects of changing soil properties and reducing soil permeability (Kelly, 1951). Sodium adsorption ratio (SAR) is an important parameter for determination of suitability of irrigation water (Todd, 1980) and is expressed as below:

\[ \text{SAR} = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})^2}} \]

The waters were classified in relation to irrigation based on the ranges of SAR values (U.S. Salinity Laboratory, 1954). In the present study SAR value range from 0.26 to 2.05 during pre monsoon and 0.21 to 1.11 for post monsoon.

4.11 Combined Effect of SAR and EC

The SAR and EC values of water samples of the study area were plotted in the graphical diagram of irrigated water (USSL, 1954). Accordingly, the entire water sample falls under C3-S1 (High Salinity with Low Sodium) i.e., 71.87% and 50% and C2-S1 (Medium Salinity with Low Sodium) i.e., 28.13% and 50% during pre monsoon and post monsoon (Fig.3).
Hence the waters tested in the study area are satisfactory for irrigation use in almost all soil types with slight chance of developing harmful levels of exchangeable sodium.

4.12 Residual sodium carbonate (RSC)

The carbonate and bicarbonate hazard on water quality can be determined in terms of Residual Sodium Carbonate (RSC) which is defined by the following equation (Eaton, 1950):

\[
RSC = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+})
\]

The concentrations of element are expressed in meq/l. According to Eaton (1950), on the basis of RSC value water quality is divided into three categories i.e. safe if RSC <1.25 meq/l, marginal quality if RSC 1.25–2.5 meq/l and unsuitable for irrigation if RSC >2.5 meq/l. In this study, RSC value varies from -12.47 meq/l to -3.71 meq/l during pre monsoon and -15.56 meq/l to -3.07 meq/l during post monsoon. It can be safely concluded that all water sample fall under safe category for irrigation during both season.

4.13 Percent sodium (% Na\(^+\))

Percent Sodium is another important factor to study sodium hazard and clogging of particles takes place there by reducing the permeability (Todd, 1980; Domenico and Schwartz, 1990). It is calculated by the following formula (Wilcox, 1955):

\[
\% \text{ Na}^+ = \left[ \frac{(\text{Na}^+ + \text{K}^+)}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+)} \right] \times 100
\]

The percent sodium values in the study area varied from 4.59 meq/l to 23.67 meq/l and 3.8 meq/l to 22.51 meq/l during both seasons.

4.14 Integrated effect of Percent Sodium and EC

From figure 4, it is observed that about 31.25% and 46.87% samples fall under excellent class and 68.75% and 53.13% fall under good class during pre and post monsoon. Hence, this gives a clear indication that all the groundwater in the study area is suitable for irrigation purposes.
4.15 Kelley’s ratio (KR)

Groundwater of the study area has also been classified according to Kelley’s ratio. The potential sodium problem in irrigation water could be reliably evaluated by using the following formula as calculated by Kelley et al., (1940) and Paliwal (1967).

\[
\text{Kelley’s ratio = } \frac{\text{Na}^+}{(\text{Ca}^{2+} + \text{Mg}^{2+})}
\]

Where all the concentrations are expressed in meq/l. The value of Kelley’s ratio is less than unity; the water is suitable for irrigation purposes: if it is two or more, the water is unsuitable for irrigation. According to this classification, the value of Kelley’s ratio varies from 0.066 to 0.483 during pre monsoon and 0.04 to 0.311 during post monsoon. Therefore, the water sample tested in the study area is less than unity, indicating the water is suitable for irrigation purposes and free from salinity hazard.

![Figure 5: Doneen’s permeability index for groundwater](image)

4.16 Doneen’s permeability index (PI)

The soil permeability is influenced by sodium, calcium, magnesium and bicarbonate contents of the soil (Chandu et al., 1995). Doneen’s (1964) has developed a criteria for examining the suitability of water for irrigation on soil based on permeability index (PI).

\[
\text{PI} = \frac{\text{Na}^+ + \sqrt{\text{HCO}_3^-}}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+)} \times 100
\]

Where all the ionic concentrations are expressed in meq/l. The PI values ranged between 9.53 % to 23.59 % during pre monsoon and 11.5 % to 45.46 %l for pre monsoon. In the present study, all the water sample fall in Class I category of Doneen’s chart which is fit for irrigation use as depicted in figure 5.

4.17 Magnesium hazard (MH)

Magnesium Hazard is an important parameter to evaluate the hazardous effect of Mg$^{2+}$ to irrigation water. Szabolcs and Darb (1964) proposed magnesium hazard for irrigation water, which is given by:

\[
\text{Mg}^{2+}
\]
MH= \frac{100}{\text{Ca}^{2+} + \text{Mg}^{2+}}

The degree of hazard effect would increase with the increase $\text{Mg}^{2+}/\text{Ca}^{2+}$ ratio. The effect of $\text{Mg}^{2+}$ Hazard will develop in the soil when the ratio exceeds 50 meq/l (Paliwal, 1972). In the present study, Magnesium Hazard varies from 20.08 % to 79.11 % during pre monsoon and 12.23 % to 62.97 % during post monsoon. Water samples falls under “Harmful” class were 68.75% and 34.38% during both seasons as shown in figure 6 and the remaining samples lies under the “No Probem” class.

![Figure 6: Graph showing magnesium hazard for groundwater](image)

### 4.18 Hydrochemical facies for groundwater

The hydrochemical facies of a particular place are influenced by geology of the area and distribution of facies by the hydro-geological controls. In the present study, the groundwater of the study area has been classified as per Chadha’s diagram (Chadha, 1999) and to identify the hydrochemical processes. The diagram is a somewhat modified version of Piper trilinear diagram (Piper, 1944) and the expanded Durov diagram (Durov, 1948). In Chadha’s diagram, the difference in milliequivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, is plotted on the X axis and the difference in milliequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) is plotted on the Y axis. The chemical analyses data of all the samples collected from the study area have been plotted on Chadha’s diagram (Fig.7) and results have been summarized in Table 3. It is evident from the results, that during pre monsoon season all samples fall in Group 5 ($\text{Ca}^{2+}$-$\text{Mg}^{2+}$-$\text{HCO}_3^-$). Almost similar trend was observed during post monsoon season also. The Chadha’s diagram has all the advantages of the diamond-shaped field of the Piper trilinear diagram and can be conveniently used to study various hydrochemical processes. Another main advantage of this diagram is that it can be made simply on most spreadsheet software packages.

### Table 3: Summarized Results of Chadha’s classification

<table>
<thead>
<tr>
<th>Classification/Type</th>
<th>Sample Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Group 1 ($\text{Ca}^{2+}$-$\text{Mg}^{2+}$-$\text{Na}^+$-$\text{K}^+$)</td>
<td>------</td>
</tr>
</tbody>
</table>
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| Group 2 (Na\(^+\)- K\(^+\)- Ca\(^{2+}\)- Mg\(^{2+}\)) | -------- | -------- |
| Group 3 (HCO\(_3\)- Cl\(^-\)-SO\(_4\)\(^{2-}\)) | -------- | -------- |
| Group 4 (SO\(_4\)\(^{2-}\)- HCO\(_3\)-Cl\(^-\)) | -------- | -------- |
| Group 5 (Ca\(^{2+}\)- Mg\(^{2+}\)- HCO\(_3\)) | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32 |
| Group 6 (Ca\(^{2+}\)- Mg\(^{2+}\)- Cl\(^-\)-SO\(_4\)\(^{2-}\)) | -------- | -------- |
| Group 7 (Na\(^+\)- K\(^+\)- Cl\(^-\)-SO\(_4\)\(^{2-}\)) | -------- | -------- |
| Group 8 (Na\(^+\)- K\(^+\)- HCO\(_3\)) | -------- | -------- |

(a) Pre monsoon          (b) Post monsoon

**Figure 7:** Diagram showing Hydrogeochemical classification of groundwater

5. Conclusion

The present investigation of quality of groundwater from 32 different locations from highly industrial area of Nalagarh valley shows that the parameters like HCO\(_3\)-, Cl\(^-\), NO\(_3\)-, SO\(_4\)\(^{2-}\) were within the desirable limit whereas EC, TDS, Ca\(^{2+}\) were above the desirable limit which
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required attention and regular monitoring. pH, TH and Mg\(^{2+}\) exceeds the permissible limit which can be negative impact on domestic and industrial purposes. It is observed that there is a direct correlation between TH and Mg\(^{2+}\) concentration above acceptable limit are found in the same sampling location which is vicinity to industrial plant. It was concluded that high amount of hardness in water indicates the presence of HCO\(_3^-\) of Ca\(^{2+}\) and Mg\(^{2+}\) salts. The overall groundwater quality is good and suitable for drinking and industrial purposes except for some selected sites. Water quality for irrigation purposes on the basis of SAR indicates excellent category of water. However, salinity and sodicity falls under C3-S1 and C2-S1 which is fit for irrigation to all soil types. As per RSC, % Na, Kelley’s ratio and Permeability Index, groundwater is suitable for irrigation. The toxicity due to magnesium hazard was observed in the study area, attributed by the dissolution of magnesium bearing minerals and industrial effluent. The result of Chadha’s diagram depicts all water sample belongs to the Ca\(^{2+}\)-Mg\(^{2+}\)-HCO\(_3^-\) water type with temporary hardness during both season respectively. It is recommended that water drawn from such sources should be properly disinfected before being used for drinking and other domestic applications. The study reveals that the groundwater quality changed due to anthropogenic and natural influence such as industrial, agricultural and natural weathering process.

6. References


3. BIS, (1991), Bureau of Indian Standards IS: 10500, Manak Bhavan, New Delhi, India.

4. CGWB, (2010), Groundwater quality in shallow aquifers of India, Faridabad, Central Groundwater Board, Ministry of Water Resources, Govt. of India.


7. CGWB, (1975), Report on the Groundwater Exploration in a part of Intermontane Sirsa Valley, Nalagarh Tehsil, Solan District Himachal Pradesh, Ministry of Irrigation, Govt. of India.


33. U.S. Salinity Laboratory, (1954), Diagnosis and improvement of saline and alkaline soils (p. 160), U.S. Dept.of Agriculture, Hand Book, No. 60.
