Hydrochemical Characterization, Classification and Evaluation of Groundwater Regime in Sirsa Watershed, Nalagarh Valley, Himachal Pradesh, India.

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Abstract
Nalagarh valley is the southernmost expanse of Himachal Pradesh; belong to the rapid industrial belt of Baddi, Barotiwala and Nalagarh (BBN). The present investigation is to examine the suitability of groundwater quality for drinking purpose and factor prevailing hydrochemistry by collecting 32 groundwater samples during pre and post monsoon. The physical and chemical analyses result shows the parameters like Cl^-, HCO_3^-, SO_4^{2-}, NO_3^{2-} are well within desirable limit as per BIS. At some locations the concentration of pH, TH and Mg^{2+} exceeded the permissible limits and nearly 50% samples of EC, TDS, Ca^{2+} shows above the desirable limit of BIS which gives us cautions. Classification of hydrochemical facies of groundwater revealed that all the samples belong to the Ca^{2+}-Mg^{2+}-HCO_3^- water types. Based on the Soltan's Classification, the groundwater sample are categorized normal chloride, normal sulfate and normal bicarbonate water type. Base-exchange indices and meteoric genesis indices indicates majority of samples belongs to Na^+- HCO_3^- and shallow water percolating type are 93.75% and 90.63% respectively. According to Gibb's ratio, the entire water sample fall in the rock dominance field for both season.
Key words: Water resources, Groundwater Quality, Hydrochemical facies, Base-exchange indices, Gibb's ratio

1. Introduction

Water is essential to all forms of life and makes up 50-97% of the weight of all plants and animals and about 70% of human body. It is a fundamental force in ecological life-support systems on which sustainable, social and economic development depends. The demand of freshwater is increasing day by day with ever growing population, where surface water is not available, sufficient, convenient, or feasible for consumption, but groundwater potential is suitable in quantity or quality, for consumption. Groundwater is about 20% of the world resource of fresh water and widely used by industries, irrigation and for domestic purposes (Usha *et al*., 2011). The quality of groundwater depends upon overall proportional amount of different chemical constituents present in groundwater (Ghosh *et al.,* 2011). The development of industry and agriculture created a number of environmental problems including air and water pollution with their serious effects on human health (Wang *et al*., 2010; Patrick, 2003). Due to the vagaries of monsoon and the scarcity along with contamination of surface water, groundwater is being exploited on large scale in developing countries like India without proper attention to quality issues. Moreover, the groundwater table has declined over the decades resulting continuous reduced annual recharge, influencing the redox chemistry of the aquifers and soil-water interfaces, causing mobilization of several chemical constituent in the aquifer matrices. The composition of groundwater in a region can be changed through the operation of the processes such as evaporation and transpiration, wet and dry depositions of atmospheric salts, selective uptake by vegetation, oxidation/reduction, cation exchange, dissociation of minerals (soil/rock–water interactions), precipitation of secondary minerals, mixing of waters, leaching of fertilizers and manure, pollution of lake/sea, and biological process (Appelo and Postma, 1993). The type and extent of chemical contamination of the groundwater largely depend on the anthropogenic activities mainly by acid rains, fertilizers, industrial waste, garbage and domestic waste (Kaushik and Kaushik, 2006), the geochemistry of the soil through which the water flows prior to reaching the aquifers (Zuane, 1990). Since it is impossible to control the dissolution of undesirable constituents in the waters after they enter the ground (Johnson, 1979; Sastri, 1994), proper groundwater management is necessary for sustainable utilization. It was perceived that the criteria used in the classification of waters for a particular purpose considering the individual concentration do not find its suitability for other purposes, and better results can be obtained only by considering the combined chemistry of all the ions rather than individual or paired ionic characters (Handa, 1964, 1965; Hem, 1985).
Rapid industrialization and urbanization is taking place in the Nalagarh valley in last one decade, owing to the special packages of incentives granted by the Central government. This has led to the setting up of different manufacturing unit generating variety of effluent and waste product, hence adding loads of pollution to water resources and environment. The area under investigation has emerged as a major industrial hub and lies in the Baddi, Barotiwala and Nalagarh (BBN) industrial belt where intense industrial development takes place and large groundwater development is observed in industrial belt wherein fall of water level down to 6 meters have been perceived in some parts of valley (CGWB, 1998). As per Baddi Barotiwala Nalagarh Development

Authority report 2007, around 72% of industries in Nalagarh are processing without ETP's is a major threat to groundwater regime. The present communication is focused on the study of temporal changes in the groundwater quality to assess the intensity of pollution activity on it in the industrial area and to describe the hydrochemistry and suitability of groundwater for drinking purposes.

2. Study Area

The study area lies between Northern latitudes of 30°52' to 31°04' and Eastern longitudes of 76°40' to 76°55' with an aerial spread of 250 sq. Km. 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). Rainfall is the major source of recharge to groundwater. Other sources of the groundwater recharge body in the valley are chiefly affected through the influent stream seepage and percolation of surface precipitation and irrigation waters. So, surface water pollution is a great threat to groundwater quality.

2.1 Physiography and Climate

The study area can be divided into three distinct physiographic units:

1. Outer part of Lesser Himalayas representing the ridges confining to the NW flank of the valley,
2. Foot hills zone representing valley floor and the sub-dued hills along SW flank of the valley,
3. The alluvium plain encompasses Chandigarh and Ropar area.

The climate of the valley is sub-tropical type. The localities in the valley enjoy fine weather during winter months but during summer period, especially from May to July is very hot. The bulk of precipitation occurs only in the forms of rainfall. Southwest monsoon is active from late June to early September. The winter rains are well distributed from December to March. The annual rainfall varies from 900 mm to 1200 mm. However, the average annual rainfall is about 1046 mm with average of 56 rainy days.

2.2 Geology and Hydrogeology

The geology of the area is complex not from the stratigraphical point of view but for its tectonic complexities. Stratigraphically, the Nalagarh valley and its flanks are bounded by the tertiary formations and structurally they are highly disturbed. The rock types of the area can be broadly grouped into two tectonic zones striking and trending NW-SE direction. So, the direction of their tectonic zones position from North to South is as follows;

A) Belt of lower and middle Tertiary occurring along the NE flank of the valley (Para-autochthonous).

B) Belt of upper Tertiary confined to the valley and along its SW flank (Autochthonous). The contact of these zones is marked by a major fault (Nalagarh thrust).

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 is shown in 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 m below ground level. 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 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.

3. Materials and Methods

Water samples from 14 Tubewells, 7 Borewells, 5 Handpumps, 4 Springs and 2 wells were collected during May 2012 and October 2012 and were analyzed in laboratory. The water sampling has been carried out following the standard procedures. Good qualities, air tight plastic bottles with cover lock were used for sample collection and safe transfer to the laboratory for analysis. Analysis were done for pH and EC and the major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, HCO_3^{2-}, CO_3^{2-} and NO_3^{2-}) using standard method (APHA, 2002). Temperature, pH, EC were determined at the time of sampling in the site. The determinations of immediate parameters were made within 2 days after sampling. Ca^{2+}, Mg^{2+}, CO_3^{2-} and HCO_3^{2-} were analyzed by titration. Na^+ and K^+ were measured by flame photometry and NO_3^{2-} and SO_4^{2-} by U.V Spectrophotometer. HCO_3^{2-} and Ca^{2+}were analyzed within 24 hour of sampling.

4. Results and Discussion

32 groundwater samples were collected from the study area for physico-chemical analysis and their results have been presented in Table1. The brief details of quality parameters are as under:

4.1 pH

The pH value depicts the balance between acids and bases in water. The desirable and permissible limit for pH is

6.5 and 8.5 (BIS, 1991). The pH values of the groundwater samples in Nalagarh Valley ranges from 7.17 to 8.7 with a mean value 7.57 during per monsoon and varies from 7.07 to 8.07 with mean value of 7.19 during post monsoon indicating slightly alkaline in nature but suitable for drinking and industrial purposes. One pre monsoon sample pH value was beyond permissible limit i.e. tube well from village Chihra (8.7).

4.2 Electrical Conductivity (EC)

The term EC denotes the characteristics of a medium to passage of electricity and is a function of temperature, type of ions present and concentration of various ions (Walton, 1970). The groundwater samples having EC values less than 2000 micro Siemens/cm (µS/cm at 25^{o} C) is generally considered as fresh water. In the present study, EC values ranged between 500 µS/cm to 1513 µS/cm with average mean value 908.59 µS/cm in pre monsoon and varied between 440 µS/cm to 1348 µS/cm with mean value 807.59 µS/cm during post monsoon. Thus it indicates that the groundwater samples are fit for domestic as well as drinking purposes.

4.3 Total Dissolved Solids (TDS)

The total dissolved solids measures the total concentration of all mineral constituents dissolved in water and is related to the problem such as excessive hardness. The principal constituents are usually calcium, magnesium, sodium, and potassium cations and carbonate, hydrogen carbonate, chloride, sulfate, and nitrate anions. TDS concentrations in the groundwater vary 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 acceptable limits. The average mean values of TDS are 588.78 mg/L and 522.41 mg/l at pre and post monsoon. 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.

4.4 Total Hardness (TH)

Hardness of water is a measure of the total concentration of the calcium and magnesium ions expressed as calcium carbonate. As per drinking water specifications (BIS 1991), the desirable limit in the absence of alternative source of water is 600 mg/L. In the study area, the concentration of total hardness varies from 206mg/l to 622 mg/l with mean value of 380.56 mg/l during pre monsoon. During post monsoon the value of TH ranged from 186 mg/l to 772 mg/l with mean value of 380.56 mg/l. 6.25% of sample is above the permissible limit which is unfit for domestic and industrial purposes; hence water softening processes are required whereas 42.19% is above desirable limit which gives us caution(Fig. 4 and 5). The high degree of hardness in the study area may be attributed to the disposal of untreated/improperly treated sewage and industrial wastes into the Sirsa River and its tributaries.

4.5 Total Alkalinity

Total Alkalinity is the quantitative capacity of water sample to neutralize a strong acid to a designated pH. The most common source of the bicarbonate and carbonate in the groundwater is due to carbon dioxide generated through bacterial oxidation of the organic matter, leaching and dissolution of carbonate rocks. In the study area, total alkalinity in water samples varied between 60 mg/l and 196 mg/L during pre monsoon and the post monsoon varies from 62 to 204 mg/l which is within the permissible limit and therefore suitable for drinking purposes. Its mean values are 118.93 mg/L and 129.56 mg/l during pre and post monsoon respectively.

4.6 Chloride (Cl)

Chloride is one of the major inorganic anions in water and wastewater. Chloride in drinking water is not generally harmful to human being until present in higher in higher concentration. It is the most abundant anion in the human body and contributes significantly along with its associated cations, to the osmotic activity of the extra cellular fluid (DNHW, 1975). The chloride ion in the groundwater of the study area varied between 2.98 mg/l and 38.77 mg/l with mean value 14.6 mg/l during pre monsoon and varies from 3.98 mg/l to 39.76 mg/l with mean value 15.47 mg/l during post monsoon. The entire water samples are within the desirable limit of BIS. Thus, ground water in the area is fit for drinking purposes as far as chloride content is concerned.

4.7 Calcium (Ca)

Calcium is the most abundant of the alkaline-earth metals and is a major constituent of many common rocks minerals. Calcium is present in groundwater due to its easy solubility and abundance in most rock types. In drinking water, the desirable limit of calcium is 75 mg/l and permissible limit in the absence of alternative source of water is 200 mg/l as per BIS (1991) and WHO (1996). The amount of calcium in the groundwater of the study area ranges from 35.32 mg/l to 157.28 mg/l and from 27.55 mg/l to 138.59 mg/l for both pre monsoon and post monsoon which is within permissible limit. The averaged mean values for both pre and post monsoon are 74.01 mg/l and 15.47 mg/l respectively. 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.

4.8 Magnesium (Mg^{2+})

Magnesium is alkaline - earth metals and extensively occurred in the earth crust. It ranked eighth among the chemical elements in terrestrial abundance. The concentration of magnesium in groundwater is generally less than calcium due to slow dissolution of magnesium bearing minerals and greater abundance of calcium ions in earth's crust. The maximum permissible limit for magnesium is 100mg/l in drinking water supplies. The concentration of magnesium ranged between 20.64mg/l to 137.2 mg/l with mean value 56.7 during pre monsoon and between 31.72 mg/l to 172.82 mg/l with mean value 73.38 mg/l. 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 catharties and diuretics (Montgomery, 1985) as shown in Fig. 3 and 4. Thus, the water from these locations is unfit for domestic purposes. The higher concentrations are due to combination of weathering of minerals magnesite and dolomite and also from various industrial effluents, as these locations are vicinity to a cluster of several industries.

4.9 Nitrates

The application of excessive nitrogenous fertilizer to the agricultural fields cause leaching from the root zone by water percolating through the soil profile and ultimately accumulates in the groundwater. Excessive concentrations of nitrate in drinking water cause methemoglobinemia in small baby. Nitrate values of groundwater in the Nalagarh valley 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. The averaged mean values are 3.08 mg/l and 3.91 mg/l in both pre and post monsoon which is well within the desirable limit. Thus, the water is fit for domestic and industrial purposes.

4.10 Sodium (Na^+)

Sodium is the most abundant element of the alkali-earth group in the earth crust with average value 2.5%. In igneous rock, sodium is slightly more abundant than potassium, but in sediment, sodium is less abundant. BIS (1991) & WHO (1996) have not given any guideline limit for sodium in drinking water. Sodium concentration ranged between 12 mg/l to 99 mg/l with mean value 35.02 mg/l during pre monsoon. During post monsoon, the sodium content varies from 9.1 mg/l to 62.5 mg/l with mean value 29.45 mg/l.

4.11 Potassium (K^+)

In most natural water, the concentration of potassium is much lower than that of sodium. Potassium is an essential element for both plants and animals. Very high potassium concentration may be harmful to human nervous and digestive system. BIS (1991) & WHO (1996) have not prescribed any guideline limit for potassium in drinking water. Potassium concentration ranged between 0.9 mg/l to 8.9 mg/l with mean value 2.44 mg/l during pre monsoon and between 0.4 to 19 mg/l with mean value 2.06 during post monsoon. The concentration of potassium in the study area is very low. It is not feasible to assess the suitability of water for drinking purpose as no agency have given any standard with respect to potassium.

4.12 Sulphate (SO_4^{2-})

Suphate (SO_4^{2-}) can be naturally occurring or the result of municipal or industrial discharges. The principle natural sources include rock weathering, input from volcanoes and input from biological or biochemical process. Also, an additional major source is anthropogenic attributable to human activities like runoff, rainfall or dry fallout. The concentration of Sulphate varies from 9.98 mg/l to 27.01 mg/l with mean value 12.74 mg/l during pre monsoon and varies from 9.69 mg/l to 26.48 mg/l with mean value 13.28 mg/l during post monsoon. All the water samples are within the acceptable limit which depicts that water is good for drinking and domestic purposes.

4.13 Phosphate

Phosphorus additions to water bodies even in small amount can produce accelerated growth of algae and aquatic vegetation, thereby causing eutrophication of the aqueous system (Handa, 1990), the application of phosphatic fertilizers has increased the abundance of phosphate in the groundwater. The concentration of phosphate content in the groundwater sample varies from 0.01 mg/l to 0.95 mg/l with mean value 0.18 mg/l during pre monsoon and between 0.01 mg/l to 0.05 mg/l with mean value 0.025 mg/l during post monsoon. The concentration of phosphate in the groundwater is very low which depicts fit for domestic consumption.

5. 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 milliequivalent percentage differences between alkaline earth and alkali metals and between weak acidic anions and strong acidic anions would plot in one of the four possible sub-fields of the diagram. The square or rectangular field describes the overall character of the water. The diagram can be used to study various hydro chemical processes, such as base cation exchange, cement pollution, mixing of natural waters, sulphate reduction, saline water and other related hydro chemical problems (Chadha 1999). The chemical analyses data of all the samples collected from the study area have been plotted on

Chadha's diagram (Fig.5 & 6) and results have been summarized in Table 2. It is evident from the results, that during pre monsoon season all samples fall in Group 5 (Ca^{2+}-Mg^{2+}- 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.

6. Classification of Groundwater Samples

The groundwater occurs both in porous consolidated formation in valley area and fissured semi-consolidated formation belonging to Siwalik foothills (CGWB, 2007b). The groundwater level in the valley area is shallow and increases towards the hills with the rise of the land surface. Major ion chemistry in soft and hard rock fractured subsurface aquifer system indicates significant difference in mean content of many parameters. The ionic dominance pattern is in the order of $Mg^{2+} > Ca^{2+} > Na^+ > K^+$ among cations and $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$ among anions in both pre monsoon and post monsoon. Groundwater samples were classified according to total dissolved solid (McNeely et al, 1979). The entire samples are fresh and non saline water type during both season. Based on Cl^-, SO_3^{2-} and HCO_3^- concentration (Soltan, 1998), water samples are classified as normal chloride (<15 meq/l), normal sulphate (<6 meq/l) and normal bicarbonate (2-7 meq/l). Based on the Soltan's classification, all the groundwater samples both pre and post monsoon are of normal chloride type followed by normal sulfate and normal bicarbonate type which are given in Table 3.

6.1 Base–exchange indices (r1)

Matthess (1982) classified the properties of groundwater based on the predominant of chemical constituent of Na^+- SO_4^{2-} and Na^+- HCO_3^- type. The base-exchange indices were estimated using the following equation:

$$r1 = (Na^+ - Cl^-) / SO_4^{2-}$$

where r1 is the Base-exchange index and Na^+, Cl^- and SO_4^{2-} concentrations are expressed in meq/l. If r1 < 1, the groundwater sources are of Na^+- SO_4^{2-} type, while r1 > 1 indicates the sources are of Na^+- HCO_3^- type. According to the Base-exchange indices (r1) about 6.25% and 9.38% groundwater samples are classified as Na^+- SO_4^{2-} type during pre and post monsoon. The majority of the samples are identified as Na^+- HCO_3^- type during pre and post monsoon are 93.75% and 90.63% which can be attributed to the geological formations of this region (Table 3).

6.2 Meteoric genesis indices (r2)

The groundwater sources can also be classified based on meteoric genesis index into two types and can be evaluated using following equation (Soltan 1998):

$$r2= [(Na^+ + K^+) - Cl^- / SO_4^{2-}]$$

Where r2 is the Meteoric genesis index and the concentrations of Na^+, K^+, Cl^- and SO_4^{2-} are expressed in meq/l. If r2 < 1 the groundwater source is of deep meteoric water percolation type while r2 > 2 characterized by surface or shallow meteoric water percolation type. Based on r2 values, majority of the groundwater sources in the study area are of shallow meteoric water percolating type .Moreover all Na^+- HCO_3^- are surface or shallow meteoric genesis water in nature and Na^+-SO_4^{2-} type groundwater sample are of deep meteoric water and percolating type in nature. According to the meteoric genesis indices, the majority of groundwater sources belong to a surface or shallow meteoric water percolating type are 93.75% and 90.63% during pre monsoon and post monsoon whereas 6.25% and 9.37% belong to deep meteoric percolating water type in both season which is shown in Table 3.

7. Mechanism Controlling Groundwater Chemistry

Gibbs (1970) proposed a diagram to understand the relationship of chemical component of water from their respective aquifer dispositions. Ramesam and Barua (1973) have carried out similar research work in the northwestern regions of India. Based on Gibbs diagram, there are three major mechanisms that regulate the chemistry of the groundwater: 1) Evaporation Dominance, 2) Precipitation Dominance and 3) Rock Dominance. Gibbs ratio are calculated by following formulae given below.

$$\text{Gibbs Ratio I Cation} = [(Na^+ + K^+) / (Na^+ + K^+ + Ca^{2+})]$$

$$\text{Gibbs Ratio II Anion} = [Cl^- / (Cl^- + HCO_3^-)]$$

Where all the ion concentrations are expressed in meq/l. In the present study, Gibbs ratios of the water samples are plotted against their respective total dissolved solids to assess the functional sources of dissolved chemical constituent whether the mechanism of controlling groundwater chemistry is due to rock dominance or evaporation dominance or precipitation dominance (Fig 7 to 10). It is observed that the density of distribution of all samples are confined to central rock dominance category indicating the chemistry of groundwater of Nalagarh valley is mainly controlled by the interaction existing between the litho units and the percolating water into the subsurface domain.

8. Conclusion

The groundwater samples collected from industrial belt of Nalagarh valley, were appraised for their chemical composition and suitability for drinking purpose. The results showed the parameters like HCO_3^-, Cl^-, NO_3^{2-}, SO_4^{2-} were within the desirable limit according to WHO and BIS. In about 50% samples EC, TDS, TH, Ca^{2+} and Mg^{2+} were above the desirable limit which gives us caution for deterioration of water quality in near future and being unfit for domestic consumption. In few samples pH, TH and Mg^{2+} exceeded permissible limit which may be due to their close vicinity to the industrial units, besides contribution from geological formation, interaction with sewage and intensive agriculture practices may also be the probable sources. High pH can be attributed to dissolution of higher level of alkalinity mineral causing scaling up in the water distribution system and industrial appliances. It was witnessed that there was direct correlation between TH and Mg^{2+} values as the groundwater in this region was moderately to very hard in nature indicating the presence of HCO_3^- , Ca^{2+} and Mg^{2+} salts. The hydrochemistry of groundwater revealed that the HCO_3^-type of water predominated anion, and Ca^{2+}- Mg^{2+} type dominated cations during pre and post monsoon periods. 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. Based on the Soltan's classification, the groundwater samples (both pre and post monsoon) are of normal chloride, normal sulfate and normal bicarbonate water types. Base-exchange indices (r1) and Meteoric genesis indices (r2) indicates majority of the groundwater sample belong to Na^+-HCO_3^- and shallow meteoric water percolation type in both season are 93.75% and 90.63% and the rest are Na^+- SO_4^{2-} and Deep meteoric water percolating type. Moreover, Gibbs ratio indicated that the chemistry of the groundwater was effectively controlled by central rock dominance, the interaction between the chemical weathering of rock minerals of the region and the subsurface water. Hence, it can be concluded that the overall quality of groundwater is regulated by lithology besides other forms of local environment activities. There is increasing awareness among the people of the study area to maintain the good groundwater quality and the present study may prove to be useful step in achieving the same.

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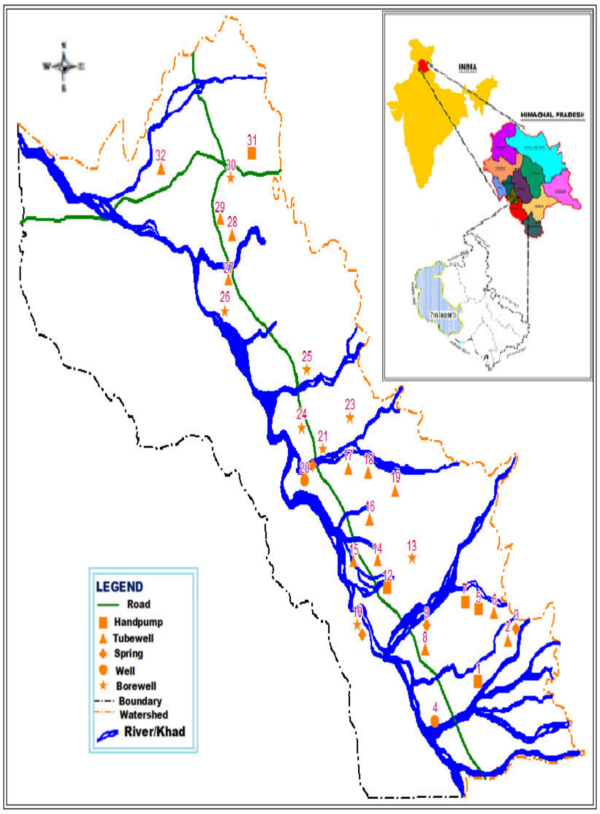

Fig. 1 Map showing the Study Area and Sampling Location

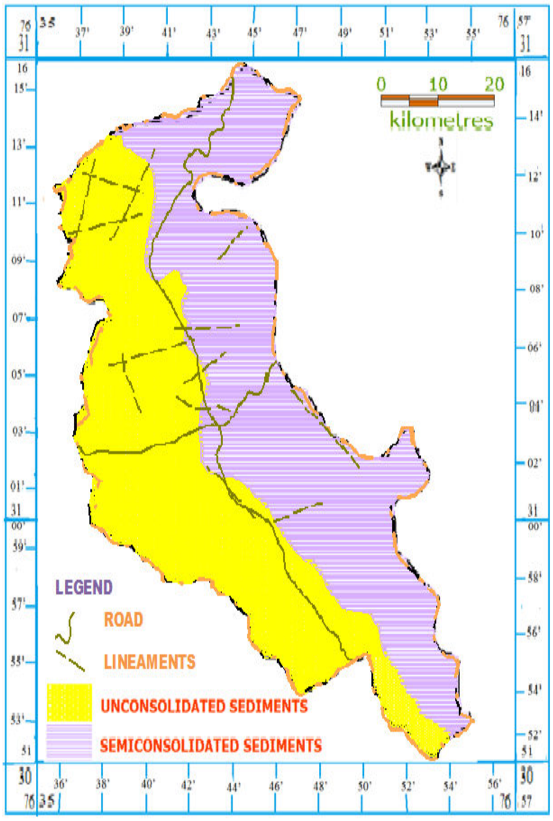

Fig. 2 Hydrological formation in the Study Area

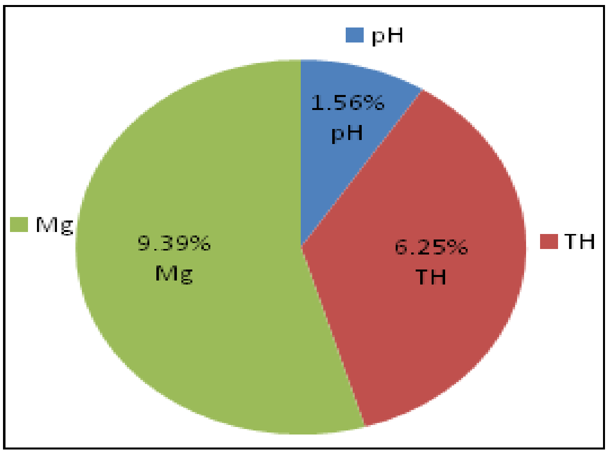

Fig. 3 Pie chart showing parameters exceed BIS Permissible Limit

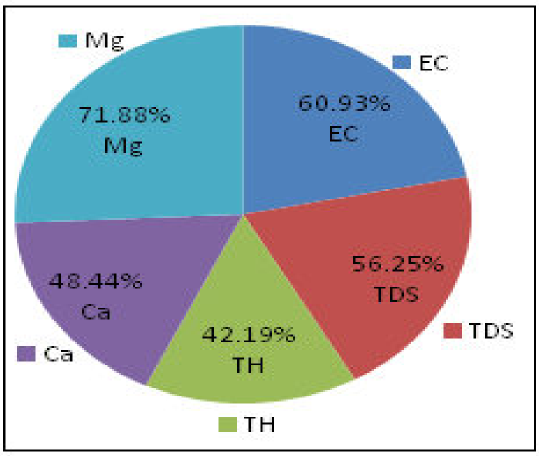

Fig. 4 Pie Chart showing parameters above BIS Desirable Limit

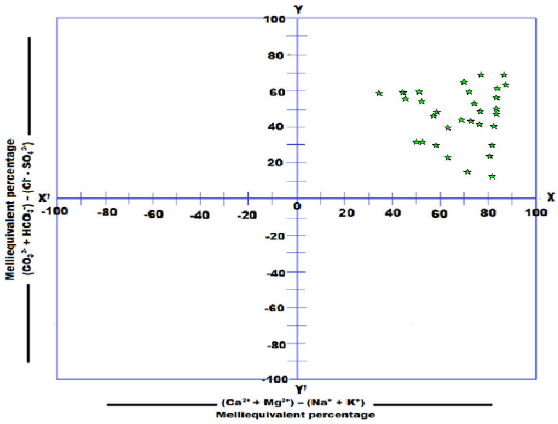

Fig. 5 Chadha Diagram for groundwater facies during pre monsoon

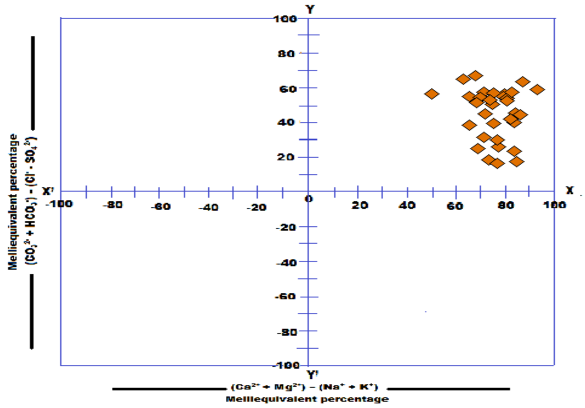

Fig. 6 Chadha Diagram showing groundwater facies during post monsoon

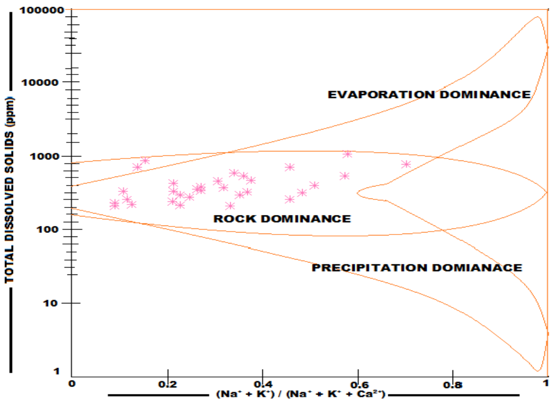

Fig. 7 Gibb's ratio (cations) for groundwater sample during pre monsoon

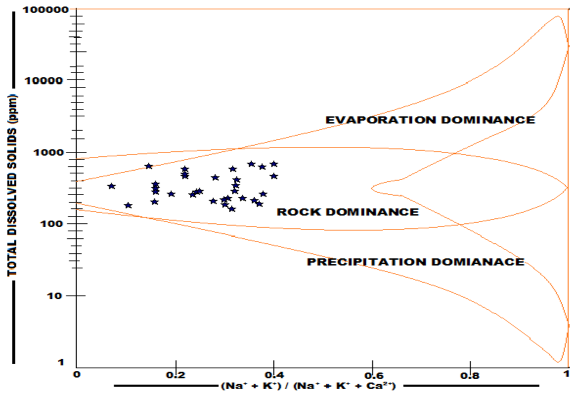

Fig. 8 Gibb's ratio (cations) for groundwater sample during post monsoon

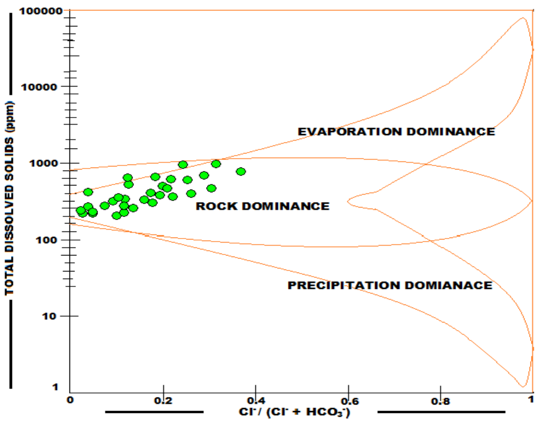

Fig. 9 Gibb's ratio (anions) for groundwater sample during pre monsoon

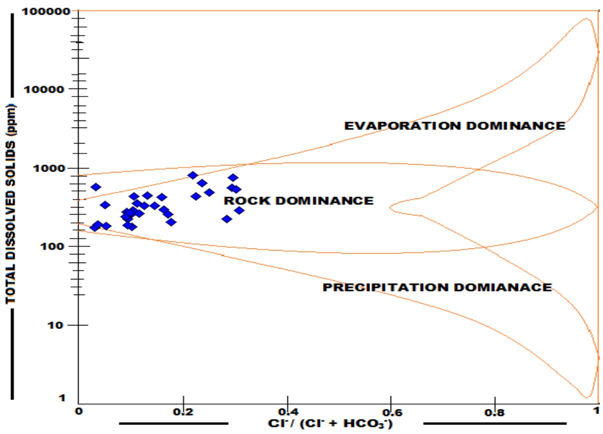

Fig. 10 Gibb's ratio (anions) for groundwater sample during post monsoon

Table1. Analytical Results of Groundwater Samples during Pre and Post monsoon, 2012.

Sl. No.	Parameters	No. of Samples analyzed	Pre monsoon				Post monsoon				Sample above desirable limit (%)	Sample above permissible limit (%)
			Range		Mean Value	Std Deviation	Range		Mean value	Std Deviation		
1	pH	32	7.17	8.7	7.57	0.35	7.03	8.07	7.19	0.23	NIL	1.56
2	EC	32	500 µS/cm	1513 µS/cm	908.59 µS/cm	284.08	440 µS/cm	1348 µS/cm	807.59 µS/cm	270.84	60.93	NIL
3	TDS	32	324 mg/l	992 mg/l	588.78 mg/l	185.35	284 mg/l	875 mg/l	522.41 mg/l	175.49	56.25	NIL
4	TH	32	206 mg/l	622 mg/l	306.38 mg/l	86.95	186 mg/l	772 mg/l	380.56 mg/l	155.33	42.19	6.25
5	TA	32	60 mg/l	196 mg/l	118.93 mg/l	28.95	62 mg/l	204 mg/l	129.56 mg/l	31.09	NIL	NIL
6	Cl^-	32	2.98 mg/l	38.77 mg/l	14.6 mg/l	21.69	3.98 mg/l	39.76 mg/l	15.47 mg/l	36.72	NIL	NIL
7	Ca^{2+}	32	35.32 mg/l	157.28 mg/l	74.01 mg/l	22.02	27.55 mg/l	139.59 mg/l	79.8 mg/l	12.09	48.44	NIL
8	Mg^{2+}	32	20.64 mg/l	137.2 mg/l	56.7 mg/l	1.51	31.72 mg/l	172.82 mg/l	73.38 mg/l	3.20	71.88	9.39
9	NO_3^{2-}	32	0.49 mg/l	6.27 mg/l	3.08 mg/l	28.66	0 mg/l	18.92 mg/l	3.91 mg/l	28.44	NIL	NIL
10	Na^+	32	12 mg/l	99.9 mg/l	35.02 mg/l	9.19	9.1 mg/l	62.5 mg/l	29.45 mg/l	9.64	NIL	NIL
11	K^+	32	0.9 mg/l	8.8 mg/l	2.44 mg/l	1.52	0.4 mg/l	19 mg/l	2.06 mg/l	4.28	NIL	NIL
12	SO_4^{2-}	32	9.98 mg/l	27.01 mg/l	12.74 mg/l	3.32	9.69 mg/l	26.48 mg/l	13.28 mg/l	3.99	NIL	NIL
13	PO_4^{2-}	32	0.01 mg/l	0.95 mg/l	0.18 mg/l	0.19	0.01 mg/l	0.05 mg/l	0.025 mg/l	0.01	NIL	NIL

Table 2. Summarized Results of Chadha's Classification

Classification/ Type	Sample Number	
	Pre monsoon	Post monsoon
Group 1 (Ca^{2+}- Mg^{2+}-Na^+- K^+)	-------	--------
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^-)	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17, 18,19,20,21,22,23,24,25,26,27,28,29,30,3 1,32	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,1 8,19,20,21,22,23,24,25,26,27,28,29, 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^-)	----------	-----------

Table 3 Classification of Groundwater according to different Criteria

Sample No.	Pre monsoon								Post monsoon							
	Cl^-		HCO_3^-		SO_4^{2-}		Base-exchange (r1)	Meteoric genesis (r2)	Cl^-		HCO_3^-		SO_4^{2-}		Base-exchange (r1)	Meteoric genesis (r2)
	meq/l	Class	meq/l	Class	meq/l	Class			meq/l	Class	meq/l	Class	meq/l	Class		
1	0.17	Normal	1.57	Normal	0.21	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.11	Normal	1.90	Normal	0.27	Normal	Na^+-HCO_3^-	Shallow Meteoric
2	0.08	Normal	1.41	Normal	0.26	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.17	Normal	1.86	Normal	0.31	Normal	Na^+-HCO_3^-	Shallow Meteoric
3	0.14	Normal	2.26	Normal	0.30	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.20	Normal	1.77	Normal	0.35	Normal	Na^+-HCO_3^-	Shallow Meteoric
4	0.08	Normal	1.87	Normal	0.22	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.45	Normal	2.03	Normal	0.28	Normal	Na^+-HCO_3^-	Shallow Meteoric
5	0.48	Normal	0.98	Normal	0.22	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.20	Normal	1.80	Normal	0.30	Normal	Na^+-SO_4^{2-}	Deep Meteoric
6	0.17	Normal	1.93	Normal	0.21	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.17	Normal	2.26	Normal	0.25	Normal	Na^+-HCO_3^-	Shallow Meteoric
7	0.28	Normal	1.67	Normal	0.24	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.31	Normal	2.13	Normal	0.25	Normal	Na^+-HCO_3^-	Shallow Meteoric
8	0.2	Normal	1.48	Normal	0.23	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.20	Normal	1.80	Normal	0.28	Normal	Na^+-HCO_3^-	Shallow Meteoric
9	0.31	Normal	2.16	Normal	0.24	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.28	Normal	2.10	Normal	0.29	Normal	Na^+-HCO_3^-	Shallow Meteoric
10	0.08	Normal	1.64	Normal	0.21	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.11	Normal	1.67	Normal	0.26	Normal	Na^+-HCO_3^-	Shallow Meteoric
11	0.36	Normal	1.93	Normal	0.28	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.28	Normal	3.08	Normal	0.36	Normal	Na^+-HCO_3^-	Shallow Meteoric
12	0.48	Normal	2.0	Normal	0.25	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.42	Normal	1.93	Normal	0.30	Normal	Na^+-HCO_3^-	Shallow Meteoric
13	1.04	Normal	2.29	Normal	0.26	Normal	Na^+-SO_4^{2-}	Deep Meteoric	1.12	Normal	2.13	Normal	0.31	Normal	Na^+-SO_4^{2-}	Deep Meteoric
14	0.79	Normal	2.13	Normal	0.28	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.99	Normal	2.13	Normal	0.32	Normal	Na^+-HCO_3^-	Shallow Meteoric
15	0.67	Normal	2.03	Normal	0.29	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.62	Normal	2.30	Normal	0.35	Normal	Na^+-HCO_3^-	Shallow Meteoric
16	0.8	Normal	1.7	Normal	0.21	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.17	Normal	1.70	Normal	0.26	Normal	Na^+-HCO_3^-	Shallow Meteoric

6Sample No.	Pre monsoon								Post monsoon							
	Cl^-		HCO_3^-		SO_4^{2-}		Base-exchange (r1)	Meteoric genesis (r2)	Cl^-		HCO_3^-		SO_4^{2-}		Base-exchange (r1)	Meteoric genesis (r2)
	meq/l	Class	meq/l	Class	meq/l	Class			meq/l	Class	meq/l	Class	meq/l	Class		
17	0.42	Normal	1.57	Normal	0.25	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.79	Normal	1.80	Normal	0.29	Normal	Na^+-HCO_3^-	Shallow Meteoric
18	0.56	Normal	1.41	Normal	0.24	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.31	Normal	1.70	Normal	0.30	Normal	Na^+-HCO_3^-	Shallow Meteoric
19	1.09	Normal	1.77	Normal	0.26	Normal	Na^+-SO_4^{2-}	Deep Meteoric	0.76	Normal	1.83	Normal	0.31	Normal	Na^+-SO_4^{2-}	Deep Meteoric
20	0.5	Normal	2.29	Normal	0.28	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.42	Normal	2.79	Normal	0.34	Normal	Na^+-HCO_3^-	Shallow Meteoric
21	0.36	Normal	1.18	Normal	0.26	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.39	Normal	1.02	Normal	0.27	Normal	Na^+-HCO_3^-	Shallow Meteoric
22	0.34	Normal	1.64	Normal	0.27	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.28	Normal	2.20	Normal	0.33	Normal	Na^+-HCO_3^-	Shallow Meteoric
23	0.22	Normal	1.9	Normal	0.24	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.22	Normal	2.00	Normal	0.28	Normal	Na^+-HCO_3^-	Shallow Meteoric
24	0.36	Normal	1.77	Normal	0.27	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.34	Normal	1.64	Normal	0.32	Normal	Na^+-HCO_3^-	Shallow Meteoric
25	0.42	Normal	2.88	Normal	0.37	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.81	Normal	2.95	Normal	0.46	Normal	Na^+-HCO_3^-	Shallow Meteoric
26	0.22	Normal	1.97	Normal	0.26	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.34	Normal	2.2	Normal	0.33	Normal	Na^+-HCO_3^-	Shallow Meteoric
27	0.34	Normal	2.20	Normal	0.27	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.28	Normal	2.16	Normal	0.31	Normal	Na^+-HCO_3^-	Shallow Meteoric
28	0.56	Normal	2.20	Normal	0.32	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.81	Normal	2.36	Normal	0.44	Normal	Na^+-HCO_3^-	Shallow Meteoric
29	0.56	Normal	2.62	Normal	0.36	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.45	Normal	2.39	Normal	0.42	Normal	Na^+-HCO_3^-	Shallow Meteoric
30	0.45	Normal	3.21	Normal	0.38	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.67	Normal	2.66	Normal	0.68	Normal	Na^+-HCO_3^-	Shallow Meteoric
31	0.75	Normal	2.49	Normal	0.56	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.90	Normal	2.29	Normal	0.67	Normal	Na^+-HCO_3^-	Shallow Meteoric
32	0.59	Normal	2.20	Normal	0.32	Normal	Na^+-HCO_3^-	Shallow Meteoric	0.50	Normal	3.34	Normal	0.39	Normal	Na^+-HCO_3^-	Shallow Meteoric