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Review

Occurrence and quality characterisation of groundwater in hard rock terrains of Karnataka

S. C. Puranik

Department of Studies in Geology, Karnataka University, Dharwad – 580 007, India. E-mail: puranik_sc@yahoo.co.in.

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Hydrosphere is the term used to define all water bearing units of the earth. It is difficult to understand the occurrence and movement of water within subsurface. The physical and chemical characters of water vary within all the components of hydrologic cycle. Rainwater gets contaminated due to atmospheric pollution. Depending on soil characters the infiltering rain water gets contaminated. Aquifer is the term used to the litho units or set of litho units that store water within the available openings and yield water whenever recovered through wells. Openings are due to structural disturbance in case of consolidated formations in the form of fractures, cracks, joints and faults. They are due to the space between grains in case of unconsolidated and semi consolidated rocks. The alteration of rocks gives an opportunity to minerals to interact with the water that is available within subsurface. The contact time between groundwater and altered minerals in aquifers control the limit of dissolved solids in groundwater. This process of leaching of minerals into water changes the chemical characters of groundwater. The mineralogical characters of rocks and their intensity of weathering control the characters of the water. In the present article the characters of groundwater in rocks viz; granitic rocks, basaltic rocks, schistose rocks, sandstones, limestones, quartzites and laterites are discussed. The groundwater characters related to the aquifers close to sea coast and change of groundwater quality with respect to hydraulic gradient are discussed. Further, the impact of conjunctive use of surface and groundwater, dilution of groundwater by infiltration of rainwater and groundwater quality deterioration due to agricultural practice are also discussed. Human activities also played major role in changing groundwater quality.

Key words: Occurrence of groundwater, quality characters of groundwater, groundwater in hard rocks.

INTRODUCTION

Water occurs in three forms viz, vapour, liquid and solid. Hydrologic cycle is the term used to explain all forms of water. Hydrosphere is the term used to define all water bearing or possessing units of the earth. The different components of hydrologic cycle are evaporation, precipitation, surface runoff and infiltration.

It is simple to mitigate the surface water, but it is difficult to understand the occurrence and movement of water within subsurface because it is not visible to eyes. Even it is difficult to know its occurrence and movement through any modern technology.

In the present article the occurrence, movement and quality characters of subsurface water occurring in different geological environment are discussed.

GENERAL CHARACTERS OF WATER

Water is made up of two important elements viz, hydrogen and oxygen. These two together constitute 99.99% of water. Thus, chemically water means “H_2O”. The 0.01% constituents control the water quality. The constituents that are present in water other than ‘H’ and ‘O’ are Ca, Mg, Na, HCO_3, Cl and SO_4 as major ones. The secondary ones are Fe, K, CO_3 NO_3, F while Al, As, Ba, Br, Co, Cr, I, Ge, Zn, Pb, Mn, Ni are minor ones and Be, Bi, Ce, Ga, An, Ag, Sn, Y, Zr are tracers. The physical characters like colour, odour, and turbidity are also important in defining the water quality.

WATER QUALITY AND HYDROLOGIC CYCLE

The water from surface water bodies gets vaporized to atmosphere due to solar radiations leaving behind the salts. The vaporized part of water contains ‘H’ and ‘O’. This is converted into clouds and later returns to earth in the form of rains or snowfall. This is “precipitation”. This

Table 1. Chemical constituents and respective minerals.

Constituents	Minerals
Calcium: (Ca)	Plagioclase, pyroxenes, amphibolites, calcite, aragonite, dolomite, anhydrite, gypsum, apatite, wollastonite, fluorite, etc.
Magnesium: (Mg)	Olivine, biotite, hornblende, augite, calcite, dolomite, serpentine, talc, diopside, tremolite. etc.
Sodium: (Na)	Plagioclase, clay minerals, nepheline, sodalite, stilbite, glucophane etc
Potassium: (K)	Orthoclase, microcline, biotite, lucite etc.
Chloride: (Cl)	Sodalite, micas, horhblende, chlorite, apatite.
Sulphate: (SO_4)	Pyrite, gypsum, barite.
Bicarbonate and Carbonate	Atmospheric carbon dioxide, some evaporates,

process is similar to that of distillation. Thus, precipitated water should be pure form of water. Due to atmospheric pollution these days, the rain water gets contaminated with many constituents before it reaches the earth surface. Once the precipitated water reaches the earth surface it starts flowing. In this process of the movement from one place to other the flowing water dissolves soluble components and carries insoluble components in suspended form. This converts the water into contaminated one. Depending on soil's physical and chemical characters, the infiltrated rain water gets more mineralized or changes its chemical and physical characters.

OCCURRENCE AND CHARACTERS OF GROUNDWATER IN HARD ROCK AREAS

The infiltrated rainwater gets into subsurface and it is stored in the openings available in the rock formations. "Aquifer" is the term used for the litho units or set of litho units that store water within the available openings and yields water whenever recovered through wells.

The infiltration of groundwater depends on quantity of rain, soil characters (both physical and chemical) and number and concentration of openings in the rock units. The sandy soil helps faster infiltration than clayey soil. Depending upon the soluble constituents in soil, the infiltering water changes its quality. More number of openings helps to store large quantity of water in rock formations. The storage capacity of rocks or set of rock formations depends on the intensity and density of openings play an important role. The openings in rocks mean the space between the particles in case of unconsolidated and semi consolidated rocks. In case of consolidated (Hard) rocks the openings mean the factures, joints, shear zones and fault planes. All these together can be called as "openings" in hard rocks or consolidated rocks. Such openings are normally created by earth movement i.e. structural disturbances and/or orogenic activities. Such openings in hard rocks are called as "secondary openings" because they have developed after the formation of rocks.

The groundwater in hard rock terrains normally occurs under water table or unconfined conditions. In some sedimentary or volcanic rocks the groundwater occurs under unconfined and confined conditions. The openings are available from surface to deep into the crust. These serve as conduits to transmit and store water. The groundwater in highly fractured limestone/quartzite/ sandstones which are bounded by impervious shaly or clayey formations the groundwater occurs under "confined" or "semi confined" conditions. The groundwater moves both vertically and horizontally depending upon openings.

MINERALS IN ROCK FORMATIONS AND THEIR IMPACT ON WATER QUALITY

The quality of subsurface water or groundwater generally depends on the type of minerals available in the rock formations. The disintegration is the physical breakdown of rocks and minerals. These do not get dissolved into surrounding groundwater immediately or easily. The total contact time of disintegrated minerals and water cause chemical alteration of minerals. Such chemically altered minerals easily dissolve into the groundwater causing chemical change in the groundwater causing chemical change in the quality. This process of altering of minerals in rocks and their dissolution into water is a continuous process till the water is in circulation within the subsurface.

At this point of time it is very important to know the properties of the minerals and their chemical composition. Under normal geological conditions the flow direction of groundwater is parallel to the topography of the region. The direction of movement of subsurface depends on "hydraulic gradient". The hydraulic gradient is the slope of flow of subsurface water. The movement of subsurface water is very slow when compared to the movement of surface water or streams. The flow rate of water in rivers is 20 - 50 cm/s. The groundwater flow rate is a few centimeters per day. In gravelly formations it is 15 cm/day. Therefore, the availability of groundwater for recovery from subsurface is possible. Owing to the characters of minerals the chemical characters of the groundwater are controlled.

Table 1 list out the minerals and constituents that could

Table 2. Chemical analysis of groundwater from granitic rocks.

Rocks	Ca	Mg	Na	K	HCO_3	CO_3	Cl	SO_3	TDS	TH	pH
Unaltered Granitic rock	30	08	200	01	348	-	42	11	419	144	7.4
Weather Granitic rock	202	16	590	05	234	24	130	411	4288	144	7.9

(Values are in mg/l except pH).

Table 3. Chemical analysis of groundwater from basaltic rocks.

Rock	Ca	Mg	Na	K	HCO_3	CO_3	Cl	SO_3	TDS	TH	pH
Basalt	55	04	204	02	192	-	100	16	240	156	7.38
Vesicular Basalt	96	14	50	02	273	-	90	227	3900	224	7.20

(Values are in mg/l accept pH).

Table 4. Chemical analysis of groundwater from schistose rocks.

Rock	Ca	Mg	Na	K	HCO_3	CO_3	Cl	SO_4	TDS	TH	pH
Schist	255	154	25	15	172	-	72	16	400	215	7.2

(Values are in mg/l except pH)

be leached into water from weathered minerals and rocks(Todd, 1980).

CASE STUDIES

In the foregoing pages, the groundwater quality variations in different rocks and in different environments are discussed.

Granitic rocks

In this study all acidic igneous plutonic rocks are considered as `granitic rocks'. The groundwater available in unaltered granite rocks is normally of good quality. The total dissolved solids in the water are less than 500 mg/l. When these rocks are altered and minerals like plagioclase, orthoclase micas etc. decompose and easily dissolve in water depending upon the contact time between water and minerals. The total dissolved solids in such groundwater ranges from 3000 - 8000 mg/l. Here the groundwater occurs under unconfined conditions. Table 2 shows the chemical analyses of groundwater from less weathered granitic rocks and highly weathered granitic rock (Abbi, 1991; Modi, 2001). The weathered granitic rocks have more concentration than unaltered granitic rocks.

Basaltic rocks

The groundwater in fractured basalts is softer than the amygdaloidal basalts because of presence of minerals viz; zeolites and calcite in the cavities. These minerals are more susceptible for easy dissolution in groundwater. Here the groundwater occurs under unconfined, semi-confined and confined conditions (the Deccan Basalts of Southern India). Due to the presence of easily soluble minerals in vesicular basalts they have higher concentrations of constituents than basalts.

Table 3 shows the chemical analyses of groundwater from basalt and vesicular basalt (Modi, 2001).

Schistose rocks

There are varieties of schistose rocks from simple chlorite schists (low metamorphic rocks) to granulites (high grade metamorphic rocks). Their chemical composition and mineralogy vary widely. Depending on the mineralogy and intensity of weathering and the contact time with water the chemical characters of groundwater vary. Here the groundwater occurs under unconfined conditions. Table 4 shows the chemical analyses of groundwater from schistose rock (Vastrad, 1987).

Quartzites, sandstones and limestones

There are variations in chemical characters of groundwater in all these rocks. The groundwater is mostly softer within quartzites and sandstones when compared to those within limestones. Quartz is the major component in quartzites and sandstones, which do not easily alter but only disintegrate and its dissolution in water is small.

Table 5. Chemical analysis of groundwater from sandstone and limestone.

Rock	Ca	Mg	Na	K	HCO_3	CO_3	Cl	SO_4	TDS	TH	pH
Sandstone	82	38	07	-	250	26	43	62	128	320	7.6
Limestone	178	125	110	-	288	82	606	62	2680	392	8.1

(Values are in mg/l except pH).

Table 6. Chemical analysis of groundwater from laterites.

Rock	Ca	Mg	Na	K	HCO_3	CO_3	Cl	SO_4	TDS	TH	pH
Laterite	30	03	03	-	120	-	21	04	237	90	7.6

(Values are in mg/l except pH).

Table 7. Total dissolved solid values of groundwater samples.

One km. away from coast	Two kms. away from coast	Three kms. away from coast
928	787	371
383	357	284
1144	180	144

(Values are of TDS in mg/l).

The calcite and dolomite in limestone readily dissolves in water causing water quality variation. Here the groundwater occurs under unconfined and semi unconfined conditions. The limestones have higher concentrations of constituents than sandstone due to easily soluble minerals in limestones. Table 5 shows the chemical analyses of groundwater from sandstone and limestone [Modi, 2001].

Laterites

The laterites are secondary rocks formed by the alteration of original rocks through the process of residual concentration in semi arid climatic conditions. The laterites are iron rich with less quantity of aluminous material. The soluble constituents are transported during their formation. Thus, there will be no soluble constituents available in laterites that can get into water. Therefore, the quality of water in lateritic terrain is normally good. Here the groundwater occurs in unconfined conditions. Table 6 shows the chemical analyses of groundwater from laterite [Didgur, 2003].

Aquifers close to the coast

In case of aquifers close to coast usually groundwater occurs under unconfined conditions. Due to excess withdrawal of fresh water, the subsurface movement of sea water into the coastal aquifers and cause salinization of the aquifers. This is `Sea water intrusion'. Table 7 shows changes in the values of total dissolved solids in coastal aquifers [Didgur, 2003]. The groundwater close to sea coast has higher total dissolved solids value when compared to those inland.

Hydraulic gradient and groundwater quality

The subsurface movement of water is usually from the area of recharge to the area of discharge. The area of recharge and the area of discharge must be identified in a basin. During the movement of groundwater from the place of recharge to the place of discharge the quality of water changes depending upon lithologic characters (natural) and also due to anthropogenic activities. Table 8 shows the change in hydrogeochemical facies (Abbi, 1991; Back's, 1966; Hydrochemical facies classification) of water from the area of recharge to the area of discharge in a basin which has 100 km length and covers an area of 1100 sq. kms approximately. The chemical characters of groundwater from the area of recharge are significantly different from those from the area of discharge.

Conjunctive use of surface water and groundwater

The groundwater within highly weathered and altered granites is normally saline with TDS values are more than2000 mg/l. In such cases it is advised to use both soft

Table 8. Hydrochemical facies of groundwater at different elevations.

Facies in the area of recharge above 700 mts. msl.	Facies in the area between 700 – 600 mts. msl.	Facies in the area of discharge below 600 mts. msl.
Ca + Mg – Na + K	Ca + Mg – Na + K	Na + K – Ca + Mg
Na + K - Ca + Mg	Na + K - Ca + Mg	Na + K
HCO_3 - Cl + SO_4	HCO_3 - Cl + SO_4	Cl + SO_4 – HCO_3
Cl + SO_4 – HCO_3	Cl + SO_4 – HCO_3	Cl + SO_4

Table 9. Total dissolved solid values of groundwater and diluted samples.

Original TDS value	4 times dilution	6 times dilution	8 times dilution
6251	3423	2025	1117
3562	1117	768	628
3283	978	698	559
3143	943	634	
2479	733	524	

(Values are of TDS in mg/l).

Table 10. Fluoride values of groundwater.

Pre monsoon		Post monsoon	
‘F’ content	TDS content	‘F’ content	TDS content
3.34	1200	2.73	951
2.16	1988	1.16	700
3.30	4355	1.57	1600
2.30	3032	1.64	1100
4.25	2152	3.78	1000
4.05	1868	2.93	500
5.80	1019	3.42	600
1.64	1196	0.52	600
5.26	2004	3.02	900
3.42	1389	1.75	1200

(Values are in mg/l).

surface water and hard subsurface water together. Such use of both surface as well as subsurface water is called as `Conjunctive use of water’. This method helps in minimal use of surface water and use of saline water. If this is not followed the water table in such areas will raise and the area will be converted into a water logged area or marshy land. Table 9 shows the change in the content of total dissolved solids when it is mixed with fresh water in different proportions [Abbi, 1991]. In the areas of high saline groundwater conjunctive use of surface and groundwater is advisable.

In-situ dilution of groundwater

The saline groundwater can be diluted by artificial recharge. The artificial recharge methods include construction of barriers or percolation pits etc within the streams. These structures help in infiltration of fresh surface water into ground. Such infiltrated of fresh water dilutes the saline groundwater. This is called “insitu dilution”. Table 10 shows the “Fluoride” content and TDS content of groundwater [Gangadhar Murthy, 2006]. The table shows lower values of ‘F’ and TDS in post monsoon samples. Thus, the recharge of rain water helps in insitu dilution of groundwater.

Agricultural practice and groundwater quality

Farmers use large quantity of chemical fertilizers for good yield of crops and irrigate with large quantity of water. Crops absorb required quantity of fertilizers and the unused ones infilter into subsurface and join aquifer system contaminating groundwater. Unknowingly such contaminated groundwater is used for agriculture. This is called ‘return irrigation water’. Such reuse of used water is harmful to crops and also to human. It is essential to educate farmers in this regard.

Conclusion

The above discussion reveals that the major cause for the change in the chemical characters of groundwater within different rocks depend on the mineralogical characters of rock formations where the groundwater is stored and recovered. This is to say that the chemical characters of water depend on the natural environment where the groundwater is stored. The interference of man has played a major role in altering the chemical nature of groundwater and contaminates it. The anthropogenic activities on the surface of the earth have changed its surface as well as the groundwater quality. These activities include rural and urban liquid and solid waste disposals, industrial effluents and unhealthy agricultural practices. Thus, it is very interesting to know the occurrence and quality in hard rocks.

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