

Hydrogeochemistry of groundwater in a part of the hard rock terrain of central India

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Abstract Hydrogeochemical investigations have been carried out to determine the sources of dissolved ions in groundwater in a part of the hard rock terrain of central India. The high concentration of SiO_2 and various geochemical signatures reflect the weathering of minerals. The groundwater chemistry favours the formation of clay minerals due to evaporation. The positive saturation index of calcite and the higher ratio of Mg/Ca and Na/Ca also support the occurrence of evaporation. The evaporation enhances the concentration of ions in groundwater during the summer. The high content of sulphate and chloride in some groundwater, and the occurrence of kankar in the area suggest a long history of evaporation. Greater ion concentrations in the groundwater of the post-monsoon period compared with the pre-monsoon period indicates the increasing addition of leachates into the groundwater from the soil and anthropogenic activities, which leads to a deteriorating quality of groundwater. The Gibbs diagram shows that the groundwater chemistry is controlled by rock weathering to some extent and that evaporation is a dominant factor leading to the deterioration of the quality of groundwater in the area.

Key words hydrogeochemistry; groundwater; terrain; central India

INTRODUCTION

Agriculture is a dominant sector in the economic development of countries like India because it is the source of sustenance for the majority of the population and contributes 46% of the gross national product (Singh, 1983). The development of agriculture is a key factor and, hence, irrigation is indispensable to improve the agrarian economy. In India, about 90% of groundwater is utilised for irrigation. (Bobbá *et al.*, 1997). The conjunctive use of groundwater and surface water would eliminate water scarcity; therefore, efforts are focused on locating the potential zones of groundwater. However, the quality of groundwater in the study area has received little attention. Sporadic investigations on the quality of groundwater and its impact show a reduction in crop yields and human health. Interrelated hydrogeological processes should be evaluated prior to control or improvement of water quality and should suggest alternative water supply schemes. The present study, therefore, focuses on the hydrogeochemical processes in a hard rock terrain of central India.

STUDY AREA

The study area covers an area of 750 km^2 extending between latitudes $24^\circ 15'$ to $24^\circ 38'$ N and longitudes $78^\circ 57'$ to $79^\circ 14'$ E in the Sagar District, Madhya Pradesh, India.

The climate is semi-arid with extremely hot summers; the average monthly temperature varies from 15°C in January to 45°C in May. The average annual rainfall is about 1000 mm. The major part of the rainfall occurs during June to September. Physiographically, it is a low lying flat terrain, with a few inselbergs, gently sloping towards the northeast. It is drained by the Bila River, which is a major tributary of the Dhasan River. About 400 km² of the area is irrigated by water from the Bila Dam. The drainage pattern is dendritic. Streams become dry except during the rainy season. The area has both surface and subsurface water irrigation resulting in recirculation of groundwater.

GEOLOGY AND HYDROGEOLOGY

The geology of the area has been described by Rajarajan (1978) and Roday *et al.* (1989). Most of the area is part of the Archaean Bundelkhand granite complex which consists of coarse-grained granites and gneisses cut by pegmatite, aplite and epidiorite dykes. The complex is overlain by the Proterozoic Bijawar groups outcropping in the east of the area, and the arenaceous Vindhyan supergroup, also of Proterozoic age, outcrops in the south (Nagvi & Rogers, 1987)

The wells sampled during the study are situated in the Bundelkhand granite complex. The fresh granites and gneisses have very low porosity and permeability, but they weather to produce high porosity and low permeability sandy clays. In the dug well sections in some parts of the area, the junction between the fresh and weathered granites is observed to be extensively fractured rock. Pumping tests at such locations suggest permeabilities to be of the order of 30–40 m/d. However, in the majority of locations, the weathered profile is only about 5–10 m thick and the zone of higher permeability is not sufficiently thick to yield more than 15–20 m³/d. Abstraction is normally done using 3–5 m diameter dug wells for domestic and the occasional irrigation supply, and some tube wells with hand pumps also exist. The dug wells pierce the weathered zones and have a total depth of 7–10 m.

As often in such systems, no real regional flow can be identified. Flow systems are relatively local in scale compared with the scale of well separation and, in addition, the only data available are from actively pumped wells in a strongly seasonal system. Water levels during May–June 2006, when the current study was undertaken, ranged between 5–8 m below ground level. Such shallow aquifers having limited storage and afford little protection from the effects of irrigation in a rural population almost completely dependent upon groundwater for domestic supplies.

METHODOLOGY

Seventeen surface post-monsoon water samples and 95 groundwater samples were collected from the dug wells of the Bundelkhand complex during May–June 2006 and October–November 2006. The surface water samples were taken from tanks, canals and rivers. Each sample was analysed at the University of Saugor, Sagar, for major species (Na⁺, K⁺, Ca²⁺, Mg²⁺, Cl⁻, SO₄²⁻, HCO₃⁻ and NO₃⁻) using the standard methods

of APHA (1992) which involved flame photometry (Na^+ , K^+ , Ca^{2+}), titration for (HCO_3^- , Cl^- , Mg^{2+}) and spectrophotometry (SO_4^{2-}). Temperature, pH and electrical conductivity were measured in the field.

RESULTS AND DISCUSSION

Sources of major ions

Table 1 gives a summary of the chemical analyses of the surface water samples. The data are plotted on a Piper diagram in Fig. 1(a). Surface waters were of very good quality for irrigation with EC ranging from 300 to 400 $\mu\text{s}/\text{cm}$. They had low to moderate alkalinity at pH of around 8; Cl^- varied from 20 to 40 mg/L with about an equivalent amount of Na^+ . NO_3^- was low (0.2–0.3 mg/L) as was SO_4^{2-} (25–35 mg/L).

Table 2 and Fig 1(b) give a summary of the chemical analysis of groundwater samples. Groundwater quality in general is good though at places it is more mineralized than the surface water with EC averaging around 630 $\mu\text{s}/\text{cm}$ (210–1560 $\mu\text{s}/\text{cm}$) in the pre-monsoon period. The dissolved ions in groundwater samples are generally governed by the lithology, velocity and quantity of groundwater flow, nature of geochemical reactions, solubility of salts and human activities (Karnath, 1991, 1999; Bhatt & Saklani, 1996). The concentration of carbonate is caused by the CO_2 present in the soil zone formed from the weathering of parent materials. The weathering is caused by the alternate wet and dry conditions characteristic of the semi-arid climate of the area. The value of PCO_2 is higher in groundwater than in the atmosphere as a result of the decay of organic matter and respiration in the soil zone. The HCO_3^- derives from the dissolution of the silicate minerals orthoclase, plagioclase, hornblende, diopside, hypersthene, olivine and biotite of country rocks by carbonic acid. The hydro-geochemical reactions dictate that the groundwater in the area will

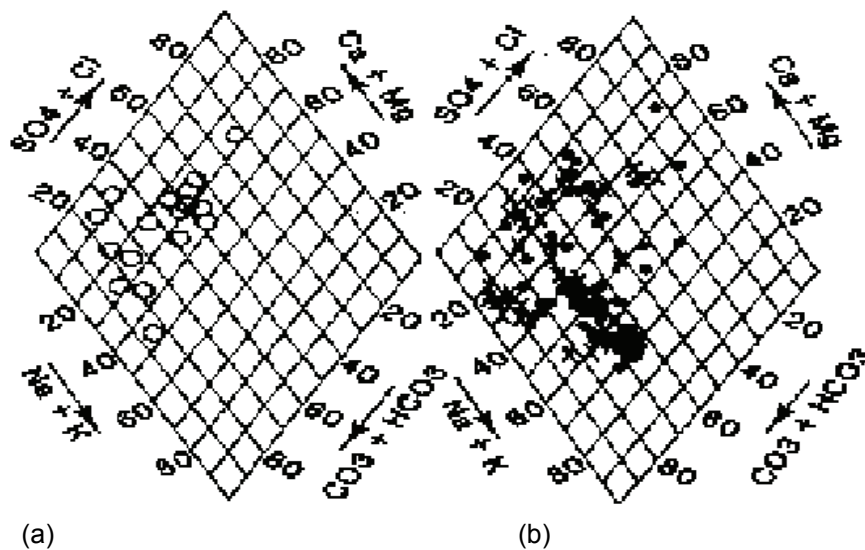


Fig. 1 Piper diagram representation of: (a) surface water samples, and (b) groundwater samples.

Table 1 Average values of the chemical constituents of surface water.

Constituent	Unit	Canal water ^a	Tank water ^b	River water ^a
Temperature	°C	25	25	24
pH		7.95	8.19	8.08
EC at 25°	µS/cm	310	299	400
TDS	mg/L	198	191	257
Total hardness	mg/L	54	78	95
Calcium	mg/L	28	35	40
Magnesium	mg/L	18	13	24
Sodium	mg/L	19	22	28
Potassium	mg/L	9.2	14	4
Bicarbonate	mg/L	82	120	183
Chloride	mg/L	43	39	24
Sulphate	mg/L	35	31	25
Nitrate	mg/L	0.32	0.23	0.29
Cl/SO ₄		1.22	1.23	0.97
HCO ₃ /Cl		1.90	3.06	7.58
SAR		0.65	0.80	0.87

^aAverage of five samples. ^bAverage of seven samples.

Table 2 Summary of groundwater chemistry (mg/L).

Constituent	Season	Maximum	Minimum	Mean	Median	Std. dev.	Coeff. std dev.
pH	a	9.2	7.15	8.19	-	-	-
	b	9.3	7.20	8.25			
EC at 25°C (µS/cm)	a	1560	210	885	612	281	0.44
	b	1638	220	929	642	294	0.46
TDS	a	1000	134	567	415	17	0.44
	b	1050	142	596	435	19	0.46
Total hardness	a	425	32	228	94	9.1	0.06
	b	445	34	240	99	9.5	0.063
Calcium	a	170	16	93	37	36	0.65
	b	178	17	98	39	38	0.68
Magnesium	a	97	03	50	21	14	0.52
	b	102	04	53	23	15	0.54
Potassium	a	41	12	21.5	5.14	6.4	0.89
	b	43	2	22.5	5.40	6.7	0.93
Sodium	a	180	10	95	51	5.2	0.07
	b	190	12	101	54	5.45	0.073
Bicarbonate	a	560	10	285	311	10.4	0.03
	b	588	12	300	327	11.2	0.031
Chloride	a	200	6	103	52	4.2	0.06
	b	210	6	109	55	4.4	0.063
Sulphate	a	200	3.6	118	19	45	1.22
	b	210	38	125	20	47	1.28
Nitrate	a	25	0.02	12.51	1.17	3.40	2.36
	b	27	0.02	13.63	1.22	3.57	2.47
Silica	a	20	0.02	1.34	1.11	3.45	2.20
	b	25	0.04	1.44	1.17	3.40	2.36

Season—a: Pre-monsoon, b: Post-monsoon.

acquire cations besides SiO_2 . An excess of alkalinity of the waters has been balanced by alkalis ($\text{Na}^+ + \text{K}^+$). The excess of alkaline earth elements ($\text{Ca}^{2+} + \text{Mg}^{2+}$) over HCO_3^- in some samples reflects an extra source of Ca^{2+} and Mg^{2+} ions. The dominance of Na^+ suggests that the ions result from silicate weathering and/or dissolution of soil salts.

Groundwater in the study area has a higher ratio of $\text{Mg}^{2+}/\text{Ca}^{2+}$ and $\text{Na}^+/\text{Ca}^{2+}$. This supports the occurrence of evaporation, whereas the excess of Na^+ over Cl^- in some samples reflects silicate weathering (Stallard & Edmonds, 1983) and also suggests that the higher concentration of alkalis is from sources other than precipitation (Singh & Hasnain, 1999). The precipitation of CaCO_3 can be assessed in terms of a Saturation Index (S.I.) using a simple thermodynamic approach. The S.I. has a positive value indicating supersaturation with respect to CaCO_3 (Table 3). The high value of PCO_2 (Table 3) in the soil zone suggests a loss of CO_2 during the flow of groundwater. This cause an increase in pH and results in the supersaturation of CaCO_3 . The high content of SO_4^{2-} and the occurrence of kankar suggest a long history of evaporation influence on exchange processes and generally indicates the excess of alkalis over alkaline earth elements, which also favours formation of montmorillonite and chlorite.

Table 3 Hydrogeochemical signatures in groundwater of the study area.

Chemical parameter	Mean values
Mg:Ca	0.80
Na:Ca	1.05
PCO_2	4.14
Si(CaCO_3)	0.98
Na:Cl	0.90
Na:K	4.30

The Gibbs diagram (Fig. 2) suggests that chemical weathering of the rock forming minerals and, to some extent, evaporation, are dominant factors that control the groundwater chemistry of the area. This is expected, as evaporation greatly increases the concentration of ions formed by chemical weathering leading to higher salinity. Anthropogenic activities also lead to an increase in Na^+ , Cl^- and TDS (Hem, 1991; Karnath, 1999). The plot of samples on the Gibbs diagram is typical of a semi-arid/arid climate and a strong influence of evaporation on groundwater chemistry.

Greater concentration of ions in the groundwater of the post-monsoon compared with the pre-monsoon period indicates the increasing addition of leachates into the groundwater from the soil and from anthropogenic activities, which leads to a deterioration of groundwater quality.

MECHANISMS CONTROLLING GROUNDWATER QUALITY

In natural water–rock interactions with carbonic acid, the groundwater acquires ions in various proportions. Loss of groundwater caused by evapotranspiration results in the transfer of salts from groundwater to the soils. Such soil serves as a source of dissolved ions, is involved in the formation of kankar and is important to clay mineralogy.

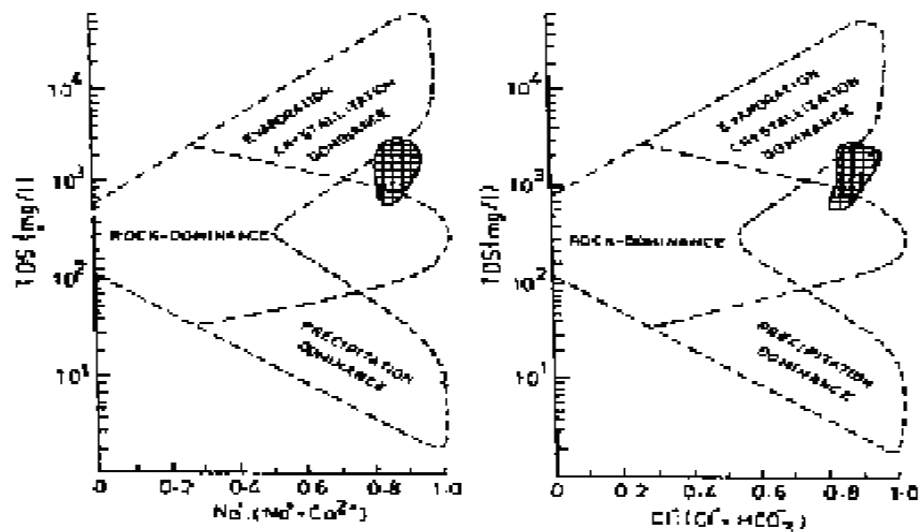


Fig. 2 Mechanisms governing groundwater chemistry (after Gibbs, 1970).

Anthropogenic activities also increase the ion concentration (TDS, Na^+ Cl^- , SO_4^{2-} and NO_3^-), especially during the post-monsoon period when the water table is nearer to the surface. Changes in the ionic concentration between the pre-and post-monsoon period signify active infiltration which can affect the salt content of wells within a short period. As entry of dissolved ions into the aquifer system is caused by percolation, they mix with groundwater and flow laterally. Mixing of high TDS with low TDS water along the flow path also promotes leaching of salts present in the soil zone during vertical recharge from rainfall and return seepage from irrigation, and results in poor groundwater quality. This, in turn, reduces agricultural productivity and affects health.

CONCLUSIONS

The study has provided significant information on the development of groundwater quality in part of the hard rock terrain of central India. High values of SiO_2 and Na:Cl in groundwater suggest a meteoric origin. The high concentration of SiO_2 and various geochemical signatures suggest the contribution of ions from the weathering of minerals. The chemical composition of the groundwater is in equilibrium with the clay minerals because of evaporation, the important role of which is suggested by the positive saturation index of CaCO_3 and the high ratios of Mg/Ca and Na/Ca. The evaporation increases the concentration of ions in the soil during the summer. The high SO_4^{2-} and Cl^- in some groundwater and kankars (CaCO_3) in the area suggest a long history of evaporation. The seasonally poor quality of groundwater is caused by the addition of leachates from the soils in the monsoon. The high concentration of SO_4^{2-} , Cl^- , NO_3^- and K in a few samples also indicates an anthropogenic impact on groundwater quality. The Gibbs diagram shows that the groundwater chemistry is controlled by rock weathering to some extent, and that evaporation is a dominant factor leading to poor groundwater quality.

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