Effect of irrigation on groundwater chemistry in the lower Chambal Command area, Madhya Pradesh, India

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Abstract The study area is a part of the Chambal and Sind River basin, in the Bhind and Morena districts of Madhya Pradesh, India. It is irrigated by the Chambal canal system. The area comprises alluvium in which groundwater occurs under unconfined and semi-confined conditions. To determine the effect of irrigation on groundwater chemistry, 45 groundwater samples from a non-irrigated area, and 45 samples from an irrigated area, were collected during May–June 1998 from the existing dug wells. The major cations and anions were determined from the samples. The statistical analysis of these data suggests that irrigation does have an effect on groundwater chemistry. At the 99% confidence level, the concentrations of the chemical constituents are much higher in the irrigated area than the non-irrigated area. These areas are identical except in their agricultural development. Although most of the groundwater samples are of good quality for irrigation purposes, some of them are unsuitable for irrigation. The processes associated with surface water irrigation and involved in modifying the concentration of chemical constituents in groundwater are evaporation and transpiration, mineral dissolution, dissolution of fertilizers, mixing with existing groundwater, CO_2 uptake and ion exchange. In addition, calcite precipitation is likely to be a control on Ca and HCO_3 concentrations at several stages. Although the method has only examined one "snap shot" in time, the approach to data analysis adopted here is simple enough to be incorporated as routine following field collection of data but it is representative of a longer-term average.

Key words Chambal District, Madhya Pradesh, India; effect; groundwater chemistry

INTRODUCTION

In India irrigation is required for extensive agricultural production. One of the more difficult problems associated with irrigation is the assessment of long-term effects on groundwater quality; possible problems include build-up of agrochemicals and increase in the concentration of ions due to evapotranspiration. To assess these problems, modelling methods have been suggested by FAO/UNESCO (1973), Goldsmith (1986), Radstake *et al.* (1988) and Tellam *et al.* (1989). However, an extensive database is required for these methods; short-term predictions can easily be in error (Konikow & Persons, 1985). A alternative method is to use comparative studies of adjacent irrigated and non-irrigated areas, provided all other conditions are similar. Such a method lacks the potential predictive power of modelling, but does avoid the main problems of modelling mentioned above and gives some degree of warning of potential problems.

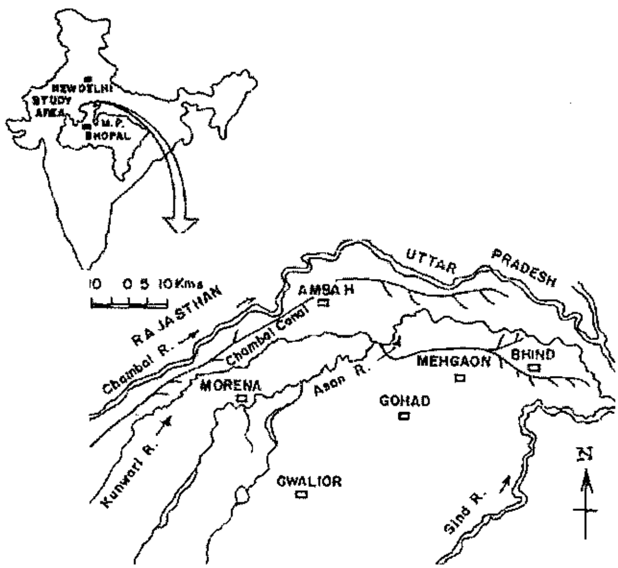

Fig. 1 Location of the study area.

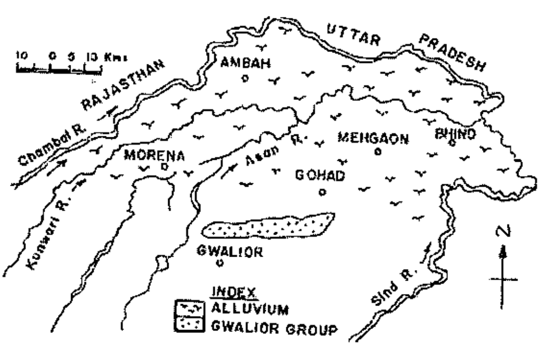

Fig. 2 Geology of the study area.

In the study area, the second method was applied in an alluvial area of the lower Chambal district of Madhya Pradesh. Emphasis is given to the use of simple statistical analyses of standard water quality parameters.

STUDY AREA

The study area encompasses parts of the Chambal and Sind river basins (Fig. 1). It is irrigated by the reservoir of the Gandhi Sagar dam but the tail-end areas do not receive sufficient surface water for irrigation because of insufficient water in the reservoir.

Large-scale irrigation commenced around 1978. It covers an area of about 750 km^2. Physiographically, it is a low-lying flat terrain, gently sloping towards the northeast. The area is semiarid (Thornthwaite, 1955) with average rainfall of about 800 mm occurring mainly from June to September. The temperature reaches a maximum of around 44°C in the hot season and a minimum of around 18°C in the cool season.

The main crops in the rainy season are paddy and sorghum, whereas wheat and grain dominate in the winter. In the non-irrigated area, crops are grown only during the wet season. Fertilizers and pesticides are used in the irrigated area.

HYDROGEOLOGY

The geology of the area (Fig. 2) has been studied by Heron (1922), Saxena (1975) and Chourasia (1984). The area is covered by the alluvium, which is underlain by the rocks of the Gwalior group.

The wells sampled during the study are situated in the alluvium Pumping tests suggest the permeability to be of the order if 60–80 m day^{-1}. The dug wells pierce the alluvium with total depths ranging from 10 to 20 m. Water levels during May–June 1998, when the current study was undertaken, ranged from 5–8 m below ground level. Abstraction of groundwater is normally done from 3–5 m diameter wells for domestic and the occasional irrigation supply. Tube wells and hand pumps also exist in the area.

WATER SAMPLING AND ANALYSIS

Fifteen surface water samples and 90 groundwater samples were collected from dug wells in the study area during May–June 1998. The surface water samples were taken from canals (five), tanks (seven) and rivers (three). Sampling locations are shown in Fig. 3.

All samples were analysed at the Dr H. S. Gour University, Sagar, for major cations and anions (Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^- and NO_3^-) using the standard methods of the American Public Health Association (APHA, 1992). A variety of techniques was used to analyse the samples: flame atomic absorption (Na^+, Ca^{2+}, Mg^{2+}, K^+), auto-titration (HCO_3); auto-analyser (NO_3), and ion chromatography (Cl^-, SO_4^{2-}). Conductivity, pH, and water temperature were measured in the field.

RESULTS AND DISCUSSION

Surface water samples Table 1 summarizes the chemical analyses of the surface water samples; the data are also plotted on a Piper diagram in Fig. 4(a). The waters were of very good quality for irrigation with electrical conductivities ranging from 299 to 400 S cm^{-1}; pH varies from 7.95 to 8.19; Cl^- varies from 24 to 43 mg l^{-1} with about an equivalent amount of Na^-; NO_3^- was low (0.23–0.32 mg l^{-1}) and SO_4^{2-} ranged 2.5–3.5 mg l^{-1}.

Groundwater samples Table 2 and Fig. 4(b) give a summary of the chemical analysis of all the groundwater samples. The groundwater quality in general was good,

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

No.	Constituents	Measurement unit	Canal water[a]	Tank water[b]	River water[c]
1.	Temperature	°C	25°C	25°C	24°C
2.	pH	–	7.95	8.19	8.08
3.	EC at 25°C	S cm^{-1}	310	299	400
4.	TDS	mg l^{-1}	198.36	191.34	256.6
5.	Total hardness	mg l^{-1}	54	78	95
6.	Calcium	mg l^{-1}	28	35	4
7.	Magnesium	mg l^{-1}	18	13	24
8.	Sodium	mg l^{-1}	19	22	28
9.	Potassium	mg l^{-1}	9.2	14	4
10.	Bicarbonate	mg l^{-1}	82	120	183
11.	Chloride	mg l^{-1}	43	39	24
12.	Sulphate	mg l^{-1}	35	31	25
13.	Nitrate	mg l^{-1}	0.32	0.23	0.29

[a] Average of five samples. [b] Average of seven samples. [c] Average of three samples.

Table 2 Summary of chemistry of all 90 groundwater samples.

Constituents	Unit	Maximum	Minimum	Mean	Standard deviation, σ	Coefficient of σ
pH	–	9.2	8.2	8.7	–	–
Temperature	°C	26	24	25	–	–
EC at 25°C	S cm^{-1}	3533	494.4	998	281	0.44
TDS	mg l^{-1}	2261	316.4	638	27	0.05
Total hardness	mg l^{-1}	435	135	285	10.1	0.06
Calcium	mg l^{-1}	180	30	105	38	0.66
Magnesium	mg l^{-1}	90	10	50	16	0.54
Sodium	mg l^{-1}	10	4	7	6.4	0.92
Potassium	mg l^{-1}	180	10	96	6.2	0.09
Bicarbonate	mg l^{-1}	775	165	418	15.7	0.04
Chloride	mg l^{-1}	277.9	20	125	5.2	0.07
Sulphate	mg l^{-1}	212	25	90	45	1.24
Nitrate	mg l^{-1}	50	10	30	3.40	2.38

though averaged over the irrigated and non-irrigated areas. It was more mineralized than the surface waters with electrical conductivities ranging 496–3533 S cm^{-1}. The groundwater was more alkaline (average pH 8.2) and had higher Cl^-, SO_4^{2-} and NO_3^- concentrations (averages of 125, 90 and 30 mg l^{-1}, respectively).

STATISTICAL ANALYSIS

Of the 90 groundwater samples obtained, 45 were from the irrigated area and 45 from the non-irrigated area. For the two areas, Table 3 lists a selection of values for the minimum, maximum, mean and standard deviation.

Deviation for electrical conductivity, total dissolved solids, SO_4^{2-}, Cl^-, NO_3^- and HCO_3^-. However, further examination of the data revealed that most of the constituents are better approximated by a lognormal distribution than by a normal

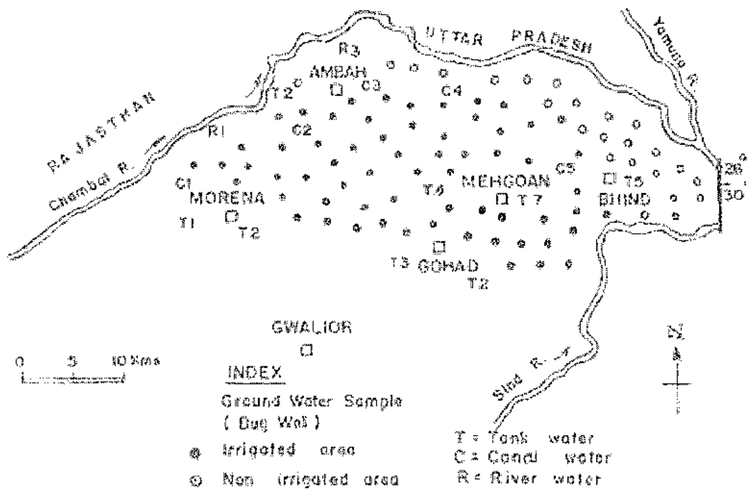

Fig. 3 Map of the surface and groundwater sampling points.

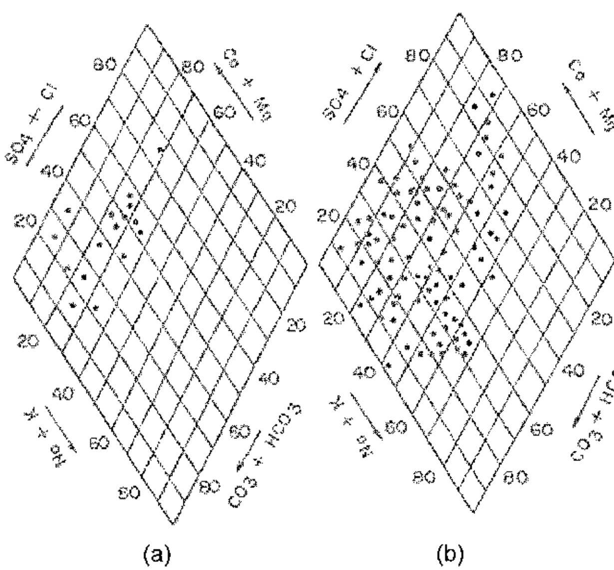

Fig. 4 Piper diagram showing ion concentrations in (a) surface and (b) groundwater.

distribution. Figure 5 indicates that SO_4^{2-}, NO_3, Na^+ and possibly HCO_3^- and Mg^{2+} concentrations were higher in the irrigated area. Electrical conductivity and total dissolved solids also appeared to be higher.

Table 4 and Fig. 6 show the result of simple linear regression involving logarithmic values of all variables except HCO_3 (similar results were obtained using

Table 3 Summary of chemical constituents of groundwater samples grouped according to well location

Area	No. of samples	Parameter	EC at 25°C S cm^{-1}	In mg l^{-1} TDS	SO_4	NO_3	Cl	HCO_3
Irrigated	45	Min.	1626.1	1040.1	100	30	157.5	530
		Max	3533.0	2261.1	212	50	277.9	775
		Mean	2579.5	1650.9	156	40	217.7	652.5
		Standard deviation	23.15	16.14	7.55	1.97	6.56	6.05
Non Irrigated	45	Min.	494.4	316.4	25	10	20	165
		Max	1414.0	904.9	90	20	100	203
		Mean	954.2	310.6	57.5	15	60	184
		Std dev.	14.02	9.25	1.55	2.5	2.09	2.75

Table 4 Correlation matrix (linear correlation coefficients).

	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	NO_3^-
Irrigated								
Na^+	1	−0.05	−0.19	0.25	0.50	−0.08	0.65	−0.03
K^+		1	0.48	0.21	0.24	0.38	0.28	0.30
Ca^{2+}			1	0.05	0.09	0.56	0.34	0.38
Mg^{2+}				1	0.54	0.06	0.39	−0.20
Cl^-					1	0.26	0.55	−0.03
SO_4^{2-}						1	0.09	0.13
HCO_3^-							1	0.14
NO_3^-								1
Non-irrigated								
Na^+	1	0.24	−0.21	0.38	0.53	0.10	0.44	−0.28
K^+		1	0.43	0.16	0.61	0.40	0.42	−0.05
Ca^{2+}			1	0.39	0.50	0.70	0.56	−0.06
Mg^{2+}				1	0.39	0.45	0.71	0.13
Cl^-					1	0.73	0.56	−0.24
SO_4^{2-}						1	0.53	−0.12
HCO_3^-							1	0.03
NO_3^-								1

All data logarithmically transformed except HCO_3; confidence limits r 99% - 0.35 (irrigated area), 0.43 (non-irrigated area); r 95% - 0.28 (irrigated area), 0.33 (non-irrigated area).

linear values of all variables). The correlation matrices are complex, showing a tight interrelationship of all parameters except NO_3 in the non-irrigated area. In the irrigated area, the variables split into two almost unrelated groups: K-Ca-NO_3-SO_4 and Cl-Na-HCO_3-Mg.

The factor/correspondence and cluster analysis was not attempted (though it might yield useful information) because cluster analysis is influenced by local conditions (e.g. NO_3 reduction, non-fertilization, non-irrigation, etc.).

The statistical analysis suggests that irrigation did have an effect on groundwater quality in the study area. Cl^-, SO_4^{2-} HCO_3^-, NO_3^-, Na^+, K^+, Ca^{2+} and Mg^{2+} concentrations are higher in the irrigated area. This increase in concentration of ions is due to processes such as mineral dissolution, ion exchange, mixing with existing groundwater, CO_2 uptake, evaporation and transpiration, and dissolution of fertilizers.

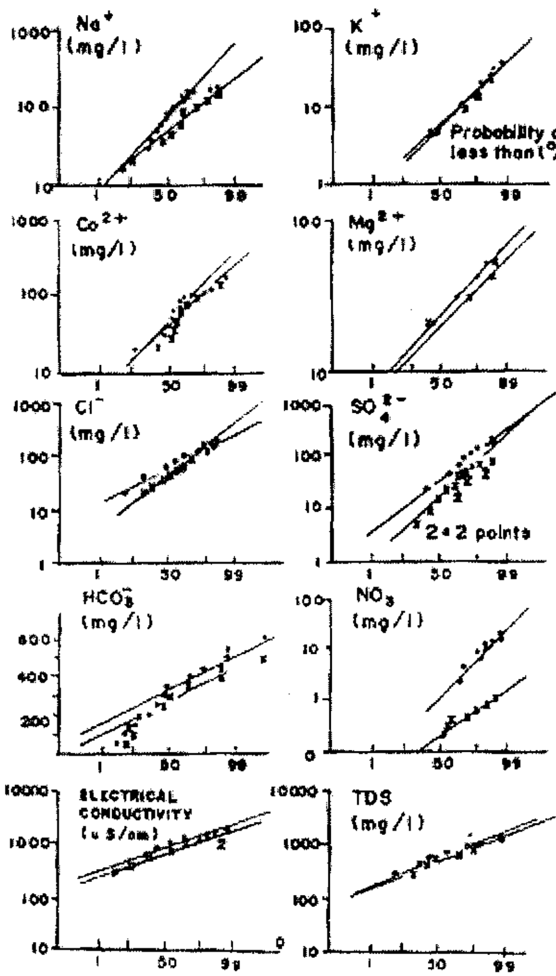

Fig. 5 Concentration *vs* probability plots of groundwater samples from non-irrigated (•) and irrigated (×) plots.

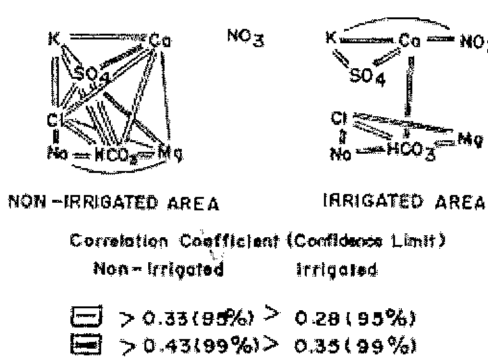

Fig. 6 Diagrammatic representation of the correlation matrix in Table 4.

CONCLUSION

Simple statistical analyses were applied to compare the groundwater of the alluvial area of the lower Chambal Command, one area being irrigated with surface water, the second area non-irrigated. It was assumed that the areas were identical except in their agricultural development. It is suggested that the simple method applied has been useful in identifying from standard (sparse) data the effects of irrigation in a rather complex system, and its application in similar regions elsewhere would allow a broad impression of the effects of irrigation to be accumulated. In addition, the method is simple enough to be carried out routinely by the appropriate groundwater authorities. Monitoring of this nature is particularly important in locations where groundwater is used for irrigation and the dissolved constituents are continually recycled. However, care needs to be taken that the areas being compared are, except for their agricultural development, identical as far as can be ascertained in terms of their geology, climate, hydrogeology and hydrology. The results of the present study confirm that the concentrations of Cl, SO_4^{2-}, NO_3^-, HCO_3^-, Na^+ K^+, TDS, and EC are higher in the irrigated area. It demonstrates that irrigation has affected the groundwater quality.

Acknowledgements The author wish to thank Professor S. N. Pandey, Head of the Department of Applied Geology, Dr H. S. Gour University, Sagar (M.P.) for providing the necessary facilities to carry out this work.

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