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Socio-economic effect on socially-deprived communities of developing drinking water quality problems in arid and semi-arid area of central Rajasthan

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Abstract Rajasthan is well known for its Great Thar desert. Central Rajasthan has an arid to semi-arid environment. The area faces either scarcity of water or poor quality of drinking water. In some areas water is transported 2 km or more, which uses time, energy and money. Rich people have their own sources, which is restricted for use by others. Such conditions are affecting socially-deprived communities, both socially and economically. Groundwater is a major source of drinking water due to the unavailability of surface water. There is a lack of groundwater quality knowledge in the community and the data available is hard to understand by consumers. The CCME Water Quality Index is a tool to simplify the water quality report by rating the water on quality standards. It provides meaningful summaries of overall water quality and trends, which is accessible to non-technical lay people. In the present study the objective is to examine the groundwater quality of six districts (Ajmer, Bhilwara, Pali, Rajasamand, Nagaur and Jodhpur), centrally located in Rajasthan, with arid and semi-arid conditions. CCME WQI is also evaluated to produce quality data in a form to be understood by the community. A total of 4369 groundwater sources in 1680 villages from six districts (76 546 km^2) were collected and examined. Results are outlined in the Bureau of Indian Standards (BIS: 10500, 2012) and 2952 sources are unsafe for drinking. According to CCME WQI groundwater of 93 villages is poor, 343 villages are marginal, and 369 villages are fair in quality. Toxicological studies of unsafe drinking water and their remedial measures are also discussed. A tentative correlation between prevailing water-borne diseases and quality parameter has also been shown.

Key words groundwater; water quality index; fluoride; nitrate; central Rajasthan, India

INTRODUCTION

Water quality is an important factor to monitor environment changes which are strongly associated with social and economic development. The evaluation of water in the developing countries has become a critical issue in recent years, especially due to the concern that freshwater will be scarce in the near future. Water from a certain source may be good enough for domestic or industrial use without any treatment, but it may not be suitable for drinking. It may be good for irrigating certain crops, but not for other crops.

It is estimated that about 21% of communicable diseases in India are water related (Brandon *et al.* 1995). The water quality issue is now being recognized in India as a major crisis. In most parts of the country, the water supplied through groundwater is beset with problems of quality (CGWB Report 2002).The over dependency on groundwater has led to 66 million people in 22 states being at risk due to excessive fluoride, and around 10 million at risk due to arsenic in six states (Husain *et al.* 2003, 2013, Ghosh 2007). In addition, there are problems due to excessive salinity, iron, nitrates and others (Desai 1990). Around 195 813 inhabitants are affected by poor water quality due to chemical parameters (CPCB 1999). It has been estimated that once pollution enters the subsurface environment it may remain concealed for many years, becoming dispersed over wide areas of groundwater aquifers and rendering groundwater supplies unsuitable for consumption and other uses. The rate of depletion of groundwater levels and deterioration of groundwater quality is of immediate concern in rural areas of the country. The increased dependency on groundwater has made water conservation the top priority in water management studies.

Groundwater occurs almost everywhere beneath the Earth surface. It is not in a single widespread aquifer, but in thousands of local aquifer systems and compartments that have similar characters. Knowledge of the occurrence, replenishment, and recovery of groundwater has special significance in arid and semi-arid regions due to the discrepancy in monsoonal rainfall, insufficient surface waters and over drafting of groundwater resources. Groundwater quality depends on the quality of recharged water, atmospheric precipitation, inland surface water, and on sub-surface geochemical processes. Temporal changes in the origin and constitution of the recharged water, hydrologic and human factors, may cause periodic changes in groundwater quality. Water pollution not only affects water quality, but also threatens human health, economic development, and social prosperity (Milovanovic 2007).

STUDY AREA

Rajasthan is the largest state in India, covering an area of 34.22 million hectares, i.e. 10.5% of the country's geographical area, but sharing only 1.15% of its water resources. Most of the state (60–75%) is arid or semi-arid. Western Rajasthan is arid to semi-arid, with low and erratic rainfall, high summer temperatures, low humidity and high-velocity wind, a negative water balance and acute water deficit. In the eastern part of the state, the climate is semi-arid to sub-humid with relatively better rainfall, low velocity wind, and higher humidity. Groundwater is overexploited in many districts of the state. The study area includes six centrally located districts of Rajasthan which covers 76 546 km^2. The study area is shown in Fig. 1 and detail including physical, geological and hydrogeological characteristics is given in Table 1.

Fig. 1 Study area.

Table 1 Detail of the study area (physical, geological and hydrogeological)**.**

District	Location Latitude	Longitude	Area km^2	Population 2011 Urban	Rural	Hydrogeology
Rajsamand	24º43′–26º01′	73º28′–74º28′	4655	183 820	972 777	Alluvium, Schist/phyllite, Gneiss, Slate, Granite, Quartzite
Ajmer	25º38′–26º58′	73º54′–75º22′	8481	1 035 410	1 547 642	Alluvium, Schist, Gneiss, Granites, Limestone and Phyllite
Jodhpur	25º51′–27º37′	71º48′–73º52′	22850	1 264 614	2 422 551	Quaternary alluvium, Sandstone, Rhyolite, Granite, Schist and Phyllite.
Nagaur	26º25′–27º40′	73º10′–75º15′	17718	637 204	2 670 539	Quaternary Alluvium, Sandstone, Limestone, Granite, Schist and Phyllites.
Pali	24º45′–26º29′	72º47′–74º18′	12387	460 006	1 577 567	Alluvium, Limestone, Gneiss, Sandstone, Schist, Phyllite, Slate, Granite and Shale
Bhilwara	25º01′–25º58′	74º01′–75º28′	10455	512 654	1 895 869	Alluvium, Gneiss, Schist, Phyllite, Slate, Limestone, Sandstone and Shale

QUALITY CRITERIA

In view of the direct consumption of water by people, domestic water supply is considered to be the most important use of water. Drinking use has been given first priority on utilization of water resource in the National Water Policy. In India, agencies like the Bureau of Indian Standards (BIS) and Indian Council of Medical Research (ICMR) have formulated drinking water standards. According to BIS 10500 (2012), standard values for the basic parameters covered in this paper are given in Table 2.

Table 2 Drinking Water Standards (BIS:10500:2012).

S. No	Quality parameter	Unit	Requirement*	Permissible limit#
1	pH		6.5-8.5	No relaxation
2	Total Dissolved Solids	mg/L	500	2000
3	Total Hardness	mg/L	200	600
4	Chloride	mg/L	250	1000
5	Nitrate	mg/L	45	No relaxation
6	Fluoride	mg/L	1.0	1.5
7	Calcium	mg/L	75	200
8	Magnesium	mg/L	30	100
9	Alkalinity	mg/L	200	600

*Acceptable limit; # In the absence of an alternative source.

WATER QUALITY INDEX

The communication and reporting of ambient water quality data to the average person without compromising the technical integrity of the data, has always been a challenging task. However, reporting of water quality has been made easier in recent years by the development and availability of the Canadian Council of Ministers of the Environment (CCME) Water Quality Index (WQI). It was developed with the intent of providing a tool for simplifying the reporting of water quality data (CCME 2001). It is a tool that provides meaningful summaries of water quality data that are useful to technical and policy individuals, as well as the general public interested in water quality.

The application of the CCME WQI requires Water Quality Guidelines (WQGs). The model essentially consists of three measures of variance from selected WQGs (scope, frequency, amplitude) that combine to produce a value between 0 and 100 that represents the overall water quality. A minimum of four variables must be sampled at least four times to be used in the calculation of index values. The calculation is done in the following steps:

F_1 (scope)

F_1 represents the percentage of variables that do not meet their objectives at least once during the time period under consideration (failed variables), relative to the total number of variables measured:

$$F_1 = \left(\frac{Number\ of\ Failed\ Variables}{Total\ Number\ of\ Variables}\right) \times 100$$

F_2 (frequency)

F_2 represents the percentage of individual tests that do not meet the objectives (failed tests):

$$F_2 = \left(\frac{Number\ of\ Failed\ Tests}{Total\ Number\ of\ Tests}\right) \times 100$$

F_3 (amplitude)

F_3 represents the amount by which failed test values do not meet their objectives. It is calculated in three steps:

– ***Step 1 Calculation of Excursion**:* The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an ‘‘*excursion*’’ and is expressed as follows.
When the test value must not exceed the objective:

$$excursion_i = \left(\frac{Failed\ Test\ Value_i}{Objective_j}\right) - 1$$

For the cases in which the test value must not fall below the objective:

$$excursion_i = \left(\frac{Objective_j}{Failed\ Test\ Value_i}\right) - 1$$

– ***Step 2 Calculation of Normalized Sum of Excursions*** The normalized sum of excursions *nse* is the collective amount by which individual tests are out of compliance. This is calculated by summing the excursions of individuals’ tests from their objectives and dividing by the total number of tests.

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{Numbers\ of\ Tests}$$

– ***Step 3 Calculation of F_3*** It is calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (*nse*) to yield a range between 0 and 100.

$$F_3 = \left(\frac{nse}{0.01nse + 0.01}\right)$$

CCME Water Quality Index

Once the factors have been obtained, the index itself can be calculated by following equation:

$$CCMEWQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right)$$

The factor of 1.732 arises because each of the three individual index factors can range as high as 100. This means that the vector length can reach $\sqrt{100^2 + 100^2 + 100^2} = \sqrt{30000} = 173.2$ as a maximum. Division by 1.732 brings the vector length down to 100 as a maximum; 0 represents the “worst” water quality and 100 represents the “best” water quality. These numbers are divided into five descriptive categories to simplify presentation (Table 3).

Table 3 CCME Water Quality Index categorization.

Quality of water	CCME-WQI value	Description
Excellent	95–100	water quality is protected with a virtual absence of threat or impairment; conditions are very close to natural or pristine levels
Good	80–94	water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
Fair	65–79	water quality is usually protected, but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
Marginal	45–64	water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
Poor	0–44	water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

METHODOLOGY

Groundwater samples (4369) were collected from 1680 habitations. After the collection, the samples were preserved as per the requirement of the parameters to be analysed**.** Determination of pH and conductance was performed on site using a portable meter. For the other parameters, samples were preserved by adding an appropriate reagent and brought to the laboratory in sampling kits maintained at 4ºC for detailed chemical analysis. The physicochemical analysis was performed following standard methods (APHA 2012).

RESULT AND DISCUSSION

District-wise statistics of groundwater chemistry are presented in Table 4.

pH values in the study area were within the recommended limit (6.5–8.5). The water in the area is normal to saline and Total Dissolved Solids (TDS) ranges from 110 to 36920 mg/L. High fluoride (up to 30 mg/L) in the area is due to leaching of fluoride rich minerals (fluorite) and rocks (viz. granite and gneiss) dominantly present in the study area (Srinivasamoorthy *et al*. 2007). The easier accessibility of rainwater to weathered rock, long-term irrigation processes, semi-arid climate, and long residence time of groundwater enriches the fluoride in the groundwater of the area (Srinivasamoorthy *et al*. 2008). Nitrate is higher (up to 800 mg/L) may be due to leaching from plant nutrient and nitrate fertilizers (Freeze and Cherry 1979, Madison and Brunett 1984). District-wise, the three habitations with the maximum concentrations of fluoride, nitrate and TDS are presented in Table 5.

CCME WQI in all districts is calculated and is shown in Table 6. Figure 2 shows a contour map for WQI in the study area. WQI in the study area ranges from 20.43 to 100. The minimum WQI is found in Salwa Kalan of Mandore block of Jodhpur District.

Table 4 Statistics of groundwater chemistry.

District	Fluoride		Nitrate		TDS		Chloride		TH		Calcium		Magnesium		Alkalinity	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Rajsamand	0.2	7.5	10	120	227	4540	50	2240	50	1770	8	840	6	648	84	970
Ajmer	0.2	15.1	4.0	791	190	22600	20	13800	50	8640	8	2840	4.8	850	71	1210
Jodhpur	0.1	30.0	0.2	800	120	36920	10	18900	70	9970	12	880	10	900	30	1360
Nagaur	0.1	25.0	10	677	149	16100	11	5950	50	3800	12	1040	12	1728	62	1270
Pali	0.2	23.2	2.0	240	170	11200	20	5150	70	4800	8	1080	4.8	648	60	1400
Bhilwara	0.1	19.5	0.1	700	110	29000	20	19800	60	9400	8	2040	4.8	1320	60	900

Values in mg/L.

Table 5 Top three habitations with maximum concentration of contaminants.

District	Fluoride		Nitrate		TDS	
	Value	Habitation	Value	Habitation	Value	Habitation
Rajsamand	7.5	Sadri	120	Sakarda	4540	Aidena
	6.3	Kushal Pura	100	Chokri	3208	Ghosundi
	5.9	Sadri	95	Aidena	3170	Sakarawas
Ajmer	15.1	Goyla	791	Paner	22600	Para
	12.1	Katsoora	757	Hathi Khera	20100	Jooniya
	8.7	Goyla	751	Khatoli	5090	Kanpura
Jodhpur	30	Chowkari Kalla	800	Khatiyasni	36920	Soorpura
	18	Bhavi	600	Kheri Salwa	19110	Hariyada
	19.4	Tilwasani	500	Daikara	19010	Dhundhara
Nagour	25	Alakh Pura	677	Gogelao	16100	Chhapra
	22.2	Ganthilasar	610	Loonsara	11250	Barani
	14.8	Ganthilasar	526	Manjhee	10300	Gogelao
Pali	23.2	Khor	240	Parasla Kalan	11200	Dhani
	20.3	Chotila	220	Sewari	11200	Deeri
	19.4	Anandpur Kalu	180	Neepal	10325	Roopawas
Bhilwara	19.5	Balapura	700	Palri	29000	Sangariya
	16.0	Amarwasi	500	Rayla	24300	Bansera
	15.0	Barantiya	500	Ban Ka Khera	23700	Kanechhan Khurd

All the values in mg/L

Table 6 Classification of habitations based on CCME WQI.

District	No. of Village	No of Samples	WQI Factors (Max) F_1	F_2	F_3	WQI Min	Excellent (95–100)	Good (80–94)	Fair (65–79)	Marginal (45–64)	Poor (<45)
Rajsamand	162	418	71.43	40.91	32.12	51.70	43	65	35	19	0
Ajmer	224	623	88.89	50	77.97	35.46	13	89	55	54	13
Jodhpur	236	575	88.89	70	74.87	20.43	28	86	47	52	23
Nagaur	429	1154	88.89	67.86	71.97	21.34	34	146	118	97	34
Pali	294	804	88.89	74.07	64.68	26.60	56	105	67	54	12
Bhilwara	335	795	88.89	60	80.96	30.79	93	117	47	67	11
Total	**1680**	**4369**	**71.43**	**41**	**81**	**20.43**	**267**	**608**	**369**	**343**	**93**

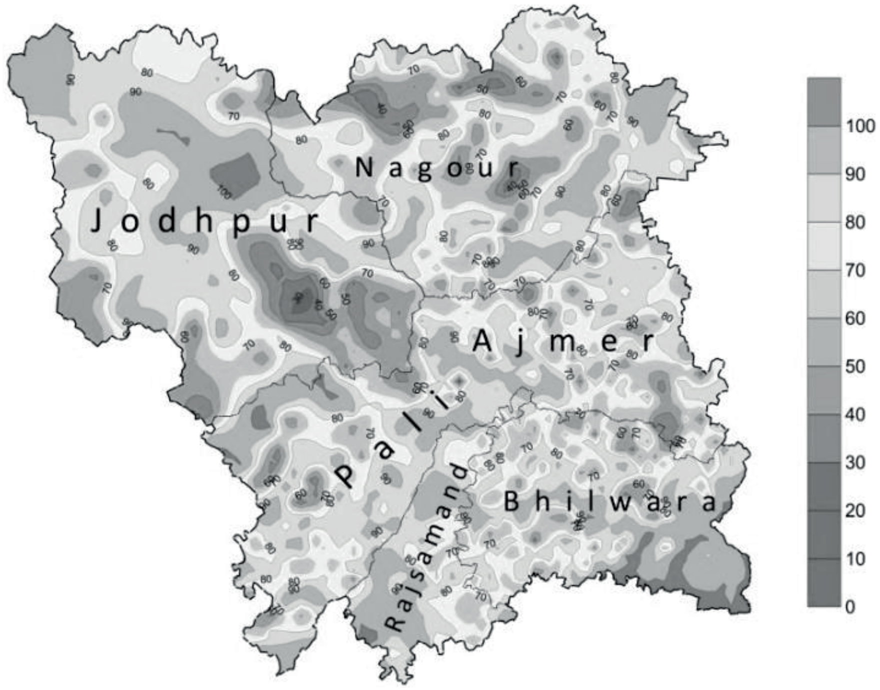

Fig. 2 Contour map for study area.

From the results it is clear that Rajsamand district has no habitations with poor groundwater quality; however, 19 habitations are marginal and 35 are fair in quality. The most quality affected district is Nagaur with 34 habitations in poor, 97 habitations in marginal and 118 habitation in fair category of CCMEWQI. Only 34 habitations are in the excellent category. F_1 (Scope) represents the number of parameters failed in a habitation. In the study area in all districts except Rajsamand, 88.89 % parameters were found above standard limit for a habitation. F_2 (frequency) represents number of tests failed for a habitation. In Pali district it is maximum, where 74.07% tests are failed for a habitation. F_3 (Amplitude) represents the amount which is higher than the standard limit. In Bhilwara district the values are 80.96% above the standard for a habitation.

CONCLUSION

The results indicate that most of the water quality parameters were beyond the permissible limits. The overall view of the Water Quality Index of the present study zone had a low WQI value indicating poor water quality. A total of 70% parameters were found unsafe in the area, with at least 50% failed test results. No district can be marked safe for use of groundwater among the six districts. Central government is now concentrating on the 78% rural population by launching a national program, "National Rural Drinking Water Program" with a target to provide safe and sustainable drinking water. The first priority is focused on the coverage of quality affected habitations.

REFERENCES

APHA (2012) *Standard Methods for the Examination of Water and Wastewater* (20th edn). American Public Health Association. Washington, DC.

Brandon, C and Homman, K. (1995) The cost of inaction: Valuing the economy wide cost of environmental degradation in India. Asia Environmental Division, World Bank, October, 07, memo.

CCME (2001) Canadian water quality guidelines for the protection of aquatic life. Water Quality Index 1.0, Technical Report. In Canadian environmental quality guidelines, 1999; Canadian Council of Ministers of the Environment, Winnipeg.

CGWB (2002) Technical Report. Central Groundwater Board of India, 38.

CPCB (1999) Water Quality status and statistics1996–97.Central Pollution Control Board, New Delhi.

Desai, B. (1990) *Pollution in India: Law and Enforcement*. Lancers Books, New Delhi.

Freeze, R. A. and Cherry, J. A. (1979). *Groundwater*. New Jersey: Prentice Hall.

Ghosh, A. (2007) Current knowledge on the distribution of arsenic in groundwater in five states of India. *J. Environ. Sci. Health*. Part A 42, 1–12.

Husain, I., *et al.* (2003) Fluoride in Drinking Water and Health Hazards: Some Observations of Fluoride Distribution in Rajasthan. In: *Environmental Scenario for 21st Century* (ed. by S. K. Agarwal), 355–374. APH Publishing Corporation.

Hussain, J., Husain, I. and Arif, M. (2013) Fluoride contamination in groundwater of central Rajasthan, India and its toxicity in rural habitants. *Toxicological & Environmental Chemistry* (95)6, 1048–1055 (DOI: 10.1080/02772248.2013.832545).

Madison, R. J. and Brunett, J. O. (1984) Overview of the occurrence of nitrate in ground water of the United States, in National Water Summary. *US Geological Survey, Water Supply Paper 2275*.

Milovanovic, M. (2007) Water quality assessment and determination of pollution sources along the Axios / Vardar River, Southeastern Europe. *Desalination* 213, 159–173.

Srinivasamoorthy, K., *et al.* (2007) Control of rock weathering on the chemical composition of groundwater in Salem District, Tamilnadu, India. *International Journal of Physical Sciences* 19(3), 367–378.

Srinivasamoorthy, K., *et al.* (2008) Identification of major sources controlling Groundwater Chemistry from a hard rock terrain – a case study from Mettur taluk, Salem district, Tamilnadu, India. *Journal of Earth System Sciences* 117(1), 49–58.