Physicochemical quality monitoring of groundwater for drinking purposes in rural Ujjain, Central India: findings of a 2-year longitudinal study

Surya Singh¹ · Vivek Parashar² · Madhanraj Kalyanasundaram³ · Shweta Khare^{2,4} · Manju R. Purohit^{4,5} · Cecilia Stålsby Lundborg⁴ · Vishal Diwan^{1,4}

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Abstract

Rampant use of groundwater for drinking purposes in several parts of the world has raised the concern over its quality. Owing to increasing population, overuse, and pollution of surface water sources, the use of groundwater has increased to considerable extent. Despite this, little attention is paid towards the monitoring of groundwater resources to assess their suitability for drinking purposes. To assess the groundwater quality in rural areas of Ujjain District of Madhya Pradesh, India, in order to check its suitability for drinking purpose, water quality analysis was done at seven time points during the two study years in six villages of Ujjain District, Central India. A total of 868 groundwater samples from 124 households were collected, and standard analytical methods were employed for analysis. Overall groundwater quality of the area is good and qualified for drinking. However, occurrence of high amount of dissolved solids (> 800 mg/L) and hardness (> 400 mg/L) is the issue of concern, as long-term use of such water might result in variety of health ailments, such as kidney stones and atopic dermatitis in children. Regular monitoring and long-term surveillance of drinking water sources are necessary to keep track of the changes occurring in the system.

Keywords Drinking water quality · Groundwater · Long-term surveillance · Rural India · Ujjain

1 Introduction

Water is one of the most essential requirements for living beings. Out of the total water present over the earth's surface, only 3% is freshwater available for living beings [1]. Moreover, out of this 3%, much of the water is ice-locked and/or underground. Therefore, the remaining meagre amount of available freshwater needs to be used very judiciously. Nevertheless, an ever-increasing population, rapid industrialization, and pollution have led to the contamination of most of the water resources, be it surface water or

groundwater [2–4]. Therefore, in order to have the accurate assessment for suitability of water resources, various methodologies and tools are being used across the globe [5–8]. It has been reported that in developing countries, around 90% of wastewater is directly discharged in surface water sources without any treatment [9, 10]. This might be due to low awareness, lack of resources, and financial constraints. As far as India is concerned, approximately 70% of the country's water resources are polluted, indicating the seriousness of the issue [11]. Also, most of the groundwater resources are contaminated with various hazardous

✉ Vishal Diwan, vishal.diwan@ki.se; vishal.diwan@icmr.gov.in | ¹Division of Environmental Monitoring and Exposure Assessment (Water and Soil), ICMR – National Institute for Research in Environmental Health, Bhopal 462 030, India. ²Department of Public Health and Environment, R.D. Gardi Medical College, Ujjain 460 001, India. ³Division of Environmental Health and Epidemiology, ICMR – National Institute for Research in Environmental Health, Bhopal 462 030, India. ⁴Department of Global Public Health, Health Systems and Policy (HSP): Medicines Focusing Antibiotics, Karolinska Institutet, 171 77 Stockholm, Sweden. ⁵Department of Pathology, R.D. Gardi Medical College, Ujjain 460 001, India.

metals/metalloids, such as arsenic, cadmium, lead, and manganese [12–16] that make the water unfit for use.

Water quality in the Indian state of Madhya Pradesh has rarely been assessed. It has been reported that the water in the state suffers due to significant mining activities and agricultural nonpoint source pollution [17, 18]. Moreover, heavy metal pollution has also been reported from drinking water sources in the state [19]. Various religious activities and associated mass bathing events further add to the pollution problem [20–23]. Emerging issues, such as the occurrence of antibiotic-resistant bacteria, have also been reported as being traced to illicit discharge of hospital waste in the city [24, 25]. After recognizing water pollution as a public health problem, the government initiated various national-level programmes, such as the National Water Quality Monitoring Programme, to monitor and maintain water quality under its central- and state-governed institutions; however, satisfactory results could not be achieved. Various limitations of the existing monitoring system, especially in rural areas, have led to uncertainty regarding the quality of groundwater used for drinking purposes among rural households. Hence, in order to make an assessment of household drinking water quality, this study was conducted in the Ujjain District of Central India where water availability and quality are a concern [26, 27].

There are a number of physicochemical parameters that are necessary to meet certain standards, in order to make water fit for use. In India, the Bureau of Indian Standards (BIS) provides limits for various parameters (Appendix 1). Therefore, water samples collected from Ujjain city in Central India were assessed for quality and compared with BIS standards. To make a comparative assessment, standards given by the World Health Organization (WHO) were also considered (Appendix 1). Statistical analysis was done, and based on the outcome; relevant preventive measures have been suggested.

2 Materials and methods

2.1 Setting

This study was undertaken in the Ujjain District of the Indian state of Madhya Pradesh. Ujjain is one of 52 administrative districts and has a population of 0.52 million with approximately 60% living in rural areas [28]. The total literacy rate is 73.55% and female literacy is 60.7%. Of the total population, 21.3% live below the poverty line [28, 29]. The population is mostly engaged in agriculture and related occupations. The infant mortality rate is 59 per thousand, while the maternal mortality ratio is 268 in the Ujjain District (Annual health survey 2010–11) [30], which

is higher than the national average (viz. 30 per thousand and 130, respectively).

The present study is a part of an ongoing project that has been previously described in detail [31]. The data collection for this study occurred in parallel with data collected from children as described and presented elsewhere. In short, six out of the 60 villages were selected from the Demographic Surveillance Site of R.D. Gardi Medical College, Ujjain. A simple random method was used to select households with children from 1 to 3 years of age from a village that fulfilled the inclusion criteria of the previous study [31].

2.2 Design and sample collection

This study used a repeated cross-sectional design. Water samples were collected in seven rounds from the selected households of the six villages, as shown in Fig. 1. In each village, two drinking water samples from separate major sources were also collected.

The samples were collected during the pre-monsoon (May 2015, June 2016), monsoon (August 2014, August 2015, September 2016) and post-monsoon (January 2015, January 2016) seasons from 2014 to 2016 from various abstraction sources in clean polyethylene bottles and preserved by adding an appropriate reagent [15, 32]. All the samples were stored in sampling kits maintained at 4 °C and brought to the laboratory for detailed physicochemical analysis. The sampling was done by trained research assistants.

All the chemicals used in the analysis were of analytical grade (Merck). Deionized water was used throughout the study. All glasswares and other containers used for the analysis were thoroughly cleaned by soaking them in detergent, followed by a soaking in 10% HNO₃ for 48 h and finally rinsed with deionized water several times prior to use.

2.3 Sample analysis

An analysis of various organoleptic and physicochemical parameters was carried out in order to evaluate groundwater quality. Temperature was measured using a thermometer with an accuracy of 0.1–0.2 °C. The pH was measured using a handheld digital pH meter (Thermo Fisher Scientific, Mumbai, India). Conductivity was measured using a digital conductivity meter (611-El, Electronic India, Parwanoo, India). A digital TDS meter (AM-TDS-01, Aquasol Digital, Rakiro Biotech Systems, India) was used for measuring the total dissolved solids.

Physicochemical parameters were analysed using standard methods [15, 32]. Chloride, hardness (total, calcium, and magnesium), alkalinity, nitrate nitrogen, and

Fig. 1 Groundwater sampling sites in Ujjain, Central India. Note: The map shows clockwise, India, Madhya Pradesh, and Ujjain District, respectively, and studied villages. The map in this figure was created by the authors for use in this manuscript

Orthophosphate (OP) were measured through titration methods. The quantification of chemical constituents was based upon the calibration curves of standard solutions of respective constituents. These analyses were carried out in the Central Research Laboratory of R.D. Gardi Medical College, Ujjain.

2.4 Statistical analysis

Data were entered in Microsoft Excel and analysed using IBM SPSS Statistics 25.0 (IBM Corp. Armonk, NY, USA). Descriptive statistics were calculated. The observed values were compared with the standard reference values (BIS values). Differences in the mean values of the parameters across the study period (seven rounds over a 2-year period; *i.e.*, temporal variation) and the differences in the values between the villages (*viz.* geographical variation) were studied. Factorial repeated measures ANOVA was used to test the existence of significant temporal and geographical variation among the measured parameters.

2.5 Ethical considerations

The study was approved by the institutional ethics committee of R.D. Gardi Medical College (No: 2013/07/17-311). Informed consent was obtained from concerned household heads for taking drinking water samples. Consent was also obtained from respective local village leaders for collecting water samples from drinking water sources.

3 Results

3.1 Study samples

A total of 868 water samples from 124 households were collected and analysed, out of which only 29 households consistently used water from the same source. The most commonly used water source was the hand pump followed by well. It was also noted that many households frequently changed drinking water sources from one to another. The main reason for this seemed to be the

availability of water and ease of access in different seasons (Table 1).

3.2 Physicochemical properties of water

Among all the analysed parameters, total dissolved solids (TDS), total hardness, calcium hardness, and magnesium hardness were found to be exceeding the defined BIS limits (Appendix 1). These parameters were also beyond the limits in the source water itself, and therefore high values in the household water were evident (Table 2).

The variations of these four parameters were plotted for each round (Fig. 2). It can be seen that in each round, the values are significantly higher than the BIS acceptable limits for these parameters. Moreover, variation in the water quality is also evident among different rounds or seasons. The ANOVA analysis showed that the above-mentioned four parameters are beyond acceptable limits (Appendix 2). There was a significant difference found among the water quality of the considered villages. A significant

difference was found to be existing in the water quality during different seasons as well. No correlation was found in the water quality variation among the villages and seasons (Appendix 2).

4 Discussion

Long-term follow-up was undertaken in rural households of Ujjain for assessing the quality of drinking water. Organoleptic and physicochemical parameters in the collected water samples were evaluated and compared with drinking water quality standards [33, 34]. Results showed that some of the parameters, viz. total dissolved solids (TDS), total hardness, calcium hardness, and magnesium hardness, exceeded the desired acceptable levels prescribed by BIS. Moreover, it was surprising that this phenomenon was common for all six villages. Other parameters were found well within the acceptable limits. It is noteworthy that there is no pattern in the increase of values over time for the particular parameters.

The acceptable limit for TDS is 500 mg/L for drinking purposes [33, 34]. Levels of TDS were found to exceed the acceptable limit in all the villages in every season. Moreover, a sharp decline could be observed in TDS values for all villages in the samples collected in the third round (pre-monsoon: May 2015). This can be explained, as during the dry season there is no seepage of silt and/or dissolved solids in the groundwater. Upon the arrival of the monsoon season, a large amount of water laden with silt seeps off the ground and mixes with the water beneath it, thus making it rich in dissolved solids. Hence, there is a dip in the curve in the pre-monsoon season

Table 1 Sample collection and source of water

Villages	Number of households	Total no. of water samples collected during the study period
Village 1	25	175
Village 2	26	182
Village 3	23	161
Village 4	23	161
Village 5	15	105
Village 6	12	84
Total	124	868

Table 2 Descriptive statistics of physicochemical parameters (cumulative data) in source water and household drinking water

Parameters (unit)	Statistical parameters			
	Source drinking water	Household drinking water		
	Mean	Min	Max	Mean $\pm$ SD
pH	7.35 $\pm$ 0.32	6.00	9.50	7.52 $\pm$ 0.5
Temperature ($^{\circ}$ C)	25.82 $\pm$ 3.65	7.70	38.00	24.84 $\pm$ 4.59
TDS (mg/L)	967.81 $\pm$ 129.28	209.0	2700	834.73 $\pm$ 292.34
Conductivity (mS/cm)	3.96 $\pm$ 5.82	0.34	3.62	1.3578 $\pm$ 0.47
Turbidity (NTU)	6.32 $\pm$ 8.39	BDL	34.80	1.0941 $\pm$ 2.19
Chloride (mg/L)	228.74 $\pm$ 31.07	20.98	704.30	185.94 $\pm$ 127.50
Total hardness (mg/L)	544.43 $\pm$ 102.09	86	1286	435.89 $\pm$ 197.73
Calcium hardness (mg/L)	251.78 $\pm$ 100.77	16.8	861	215.53 $\pm$ 125.95
Magnesium hardness (mg/L)	292.65 $\pm$ 47.34	1.1	949.8	220.36 $\pm$ 146.94
Methyl orange alkalinity (mg/L)	290.29 $\pm$ 53.67	20	610	275.25 $\pm$ 132.1
Nitrate nitrogen (mg/L)	31.95 $\pm$ 4.64	12.45	46.78	28.38 $\pm$ 11.36
Orthophosphate (mg/L)	0.28 $\pm$ 0.16	0.011	2.346	0.16 $\pm$ 0.19

BDL below detection limit

(a)

Effect of time on TDS*: $F(6) = 82.75$, p Value = 0.001;
Effect of village on TDS*: $F(5) = 13.52$, p Value = 0.001

(b)

Effect of time on Total hardness*: $F(6) = 26.55$, p Value = 0.001;
Effect of village on Total hardness*: $F(5) = 23.19$, p Value = 0.001

(c)

Effect of time on Ca hardness*: $F(6) = 54.78$, p Value = 0.001;
Effect of village on Ca hardness*: $F(5) = 11.45$, p Value = 0.001

(d)

Effect of time on Mg hardness*: $F(6) = 18.23$, p Value = 0.001;
Effect of village on Mg hardness*: $F(5) = 47.70$, p Value = 0.001

Fig. 2 Water quality parameters exceeding the BIS limits in selected villages in Ujjain—**a** total dissolved solids (TDS), **b** total hardness, **c** calcium hardness, and **d** magnesium hardness. * The effect of mul-

tipale time points and different villages on the parameters was calculated by 'factorial repeated measures ANOVA'

(Fig. 2a, which again rises back during monsoons. It may also be observed in Fig. 2a that, although the TDS values are exceeding acceptable limits, the values are well below the permissible limit. So, in the absence of any alternative source, water obtained from this source may be consumed for drinking purposes. Similarly, values of total, calcium, and magnesium hardness are also exceeding the acceptable limits (200 mg/L, 75 mg/L, and 30 mg/L, respectively) [33, 34]. Nevertheless, for all these parameters, the values are comparatively high in the first, fourth and seventh rounds of samples, viz. for the monsoon seasons (Fig. 2). It is due to the fact that the monsoon season results in

a rapid dissolution of carbonate and bicarbonate rocks, thus releasing the carbonate and bicarbonate ions in the surrounding water, which are responsible for hardness in the water. It is to be noted that values exceed not only the acceptable limits, but also permissible limits for calcium and magnesium hardness (200 mg/L and 100 mg/L, respectively).

Water quality variation among seasons is found to be significant as rains in the monsoon season bring a high amount of dissolved and suspended solids, which are absent during pre- and post-monsoon seasons. Moreover, rains result in a faster dissolution of rocks, thus releasing

Table 3 Comparison of average values of the assessed physiochemical parameters between the villages across the study period

Parameters (Unit) (BIS acceptable limits)	Rounds	Villages					
		1 (Mean $\pm$ SD)	2 (Mean $\pm$ SD)	3 (Mean $\pm$ SD)	4 (Mean $\pm$ SD)	5 (Mean $\pm$ SD)	6 (Mean $\pm$ SD)
pH (6.5–8.5)	1	8.20 $\pm$ 0.60	7.26 $\pm$ 0.30	7.48 $\pm$ 0.27	7.26 $\pm$ 0.11	7.87 $\pm$ 0.43	7.51 $\pm$ 0.27
	2	8.75 $\pm$ 0.76	7.64 $\pm$ 0.33	7.76 $\pm$ 0.28	7.38 $\pm$ 0.42	8.01 $\pm$ 0.37	7.64 $\pm$ 0.55
	3	7.58 $\pm$ 0.39	7.40 $\pm$ 0.49	7.45 $\pm$ 0.17	7.33 $\pm$ 0.22	8.03 $\pm$ 0.31	7.72 $\pm$ 0.23
	4	7.82 $\pm$ 0.161	7.66 $\pm$ 0.36	7.40 $\pm$ 0.19	7.37 $\pm$ 0.14	7.79 $\pm$ 0.27	7.69 $\pm$ 0.37
	5	7.44 $\pm$ 0.29	7.34 $\pm$ 0.33	7.30 $\pm$ 0.29	6.96 $\pm$ 0.41	7.55 $\pm$ 0.25	7.37 $\pm$ 0.46
	6	7.76 $\pm$ 0.38	7.43 $\pm$ 0.29	7.72 $\pm$ 0.25	7.28 $\pm$ 0.17	7.95 $\pm$ 0.31	7.62 $\pm$ 0.26
	7	7.16 $\pm$ 0.29	7.08 $\pm$ 0.44	6.80 $\pm$ 0.21	7.35 $\pm$ 0.22	7.13 $\pm$ 0.30	6.86 $\pm$ 0.43
Temperature (°C) (NA)	1	28.44 $\pm$ 1.66	27.65 $\pm$ 0.83	27.67 $\pm$ 1.24	27.09 $\pm$ 0.60	26.8 $\pm$ 1.01	26.67 $\pm$ 1.23
	2	20.4 $\pm$ 4.55	21.81 $\pm$ 3.69	18.82 $\pm$ 2.63	21.51 $\pm$ 4.24	21.87 $\pm$ 3.96	18 $\pm$ 3.02
	3	24.04 $\pm$ 2.34	24.73 $\pm$ 2.44	23.58 $\pm$ 1.32	24 $\pm$ 2.70	23.4 $\pm$ 1.18	23.08 $\pm$ 2.15
	4	27.96 $\pm$ 0.96	27.27 $\pm$ 0.91	28.29 $\pm$ 0.86	27.69 $\pm$ 0.76	27.8 $\pm$ 1.15	27.25 $\pm$ 0.62
	5	16.04 $\pm$ 3.81	21.57 $\pm$ 5.61	15.68 $\pm$ 4.04	21.96 $\pm$ 2.82	15.87 $\pm$ 3.14	19.25 $\pm$ 3.84
	6	29.76 $\pm$ 1.97	28.12 $\pm$ 2.08	28.95 $\pm$ 1.56	27.91 $\pm$ 1.12	28.33 $\pm$ 1.54	29.25 $\pm$ 1.48
	7	27.76 $\pm$ 0.86	25.19 $\pm$ 2.55	25.74 $\pm$ 2.36	27.91 $\pm$ 2.27	26.4 $\pm$ 1.55	27.75 $\pm$ 0.75
TDS (mg/L) (500 mg/L)	1	1240 $\pm$ 211	913 $\pm$ 266	800 $\pm$ 200	972 $\pm$ 162	1120 $\pm$ 267	811 $\pm$ 197
	2	1120 $\pm$ 228	825 $\pm$ 175	750 $\pm$ 186	818 $\pm$ 128	1081 $\pm$ 348	698 $\pm$ 174
	3	525 $\pm$ 158	564 $\pm$ 146	524 $\pm$ 94	582 $\pm$ 119	705 $\pm$ 114	425 $\pm$ 84
	4	925.2 $\pm$ 54.99	810 $\pm$ 235	829.58 $\pm$ 62.15	1305.21 $\pm$ 314.56	918.67 $\pm$ 298.50	678.33 $\pm$ 193.12
	5	884.8 $\pm$ 339.49	779.42 $\pm$ 182.51	698.64 $\pm$ 204.79	996.78 $\pm$ 249.71	1088.67 $\pm$ 504.82	707.5 $\pm$ 257.46
	6	857.6 $\pm$ 323.69	739.23 $\pm$ 189.02	639.55 $\pm$ 112.43	912.61 $\pm$ 188.38	1128 $\pm$ 392.56	590 $\pm$ 118.53
	7	832.8 $\pm$ 273.74	759.62 $\pm$ 217.32	770.87 $\pm$ 151.79	815.22 $\pm$ 121.44	978.67 $\pm$ 335.99	637.5 $\pm$ 99.51
Conductivity (mS/cm) (NA)	1	1.97 $\pm$ 0.39	1.48 $\pm$ 0.44	1.31 $\pm$ 0.34	1.59 $\pm$ 0.27	1.85 $\pm$ 0.44	1.37 $\pm$ 0.32
	2	1.83 $\pm$ 0.38	1.33 $\pm$ 0.30	1.23 $\pm$ 0.32	1.37 $\pm$ 0.22	1.79 $\pm$ 0.59	1.14 $\pm$ 0.30
	3	0.96 $\pm$ 0.26	0.94 $\pm$ 0.28	0.86 $\pm$ 0.15	0.95 $\pm$ 0.20	1.15 $\pm$ 0.2	0.7 $\pm$ 0.13
	4	1.52 $\pm$ 0.09	1.32 $\pm$ 0.39	1.36 $\pm$ 0.10	2.15 $\pm$ 0.53	1.51 $\pm$ 0.51	1.11 $\pm$ 0.32
	5	1.45 $\pm$ 0.56	1.18 $\pm$ 0.29	1.09 $\pm$ 0.32	1.46 $\pm$ 0.42	1.78 $\pm$ 0.62	1.12 $\pm$ 0.43
	6	1.39 $\pm$ 0.53	1.21 $\pm$ 0.31	1.05 $\pm$ 0.19	1.51 $\pm$ 0.31	1.85 $\pm$ 0.66	0.98 $\pm$ 0.19
	7	1.37 $\pm$ 0.46	1.25 $\pm$ 0.37	1.23 $\pm$ 0.31	1.35 $\pm$ 0.20	1.61 $\pm$ 0.57	1.04 $\pm$ 0.18
Turbidity (NTU) (1–5 NTU)	1	0.41 $\pm$ 0.30	0.68 $\pm$ 0.58	1.25 $\pm$ 0.44	0.68 $\pm$ 0.55	0.52 $\pm$ 0.56	0.29 $\pm$ 0.14
	2	0.19 $\pm$ 0.35	1.03 $\pm$ 1.49	0.89 $\pm$ 0.72	0.21 $\pm$ 0.22	0.70 $\pm$ 0.84	3.33 $\pm$ 1.92
	3	0.61 $\pm$ 0.73	0.40 $\pm$ 0.53	3.19 $\pm$ 6.95	0.42 $\pm$ 0.40	0.43 $\pm$ 0.36	2.75 $\pm$ 1.12
	4	0.19 $\pm$ 0.13	0.85 $\pm$ 1.46	1.01 $\pm$ 0.91	0.16 $\pm$ 0.09	0.32 $\pm$ 0.26	6.13 $\pm$ 5.30
	5	1.39 $\pm$ 1.34	1.44 $\pm$ 1.30	2.93 $\pm$ 2.49	1.9 $\pm$ 2.25	1.79 $\pm$ 0.78	1.71 $\pm$ 1.11
	6	0.45 $\pm$ 0.46	3.37 $\pm$ 3.98	3.86 $\pm$ 2.47	0.32 $\pm$ 0.16	3.35 $\pm$ 1.57	4.38 $\pm$ 2.66
	7	0.22 $\pm$ 0.26	0.92 $\pm$ 1.29	0.47 $\pm$ 0.46	0.13 $\pm$ 0.16	0.38 $\pm$ 0.44	0.58 $\pm$ 0.40
Chloride (mg/L) (250 mg/L)	1	418.79 $\pm$ 75.80	145.85 $\pm$ 73.67	96.15 $\pm$ 44.41	153.17 $\pm$ 49.58	248.02 $\pm$ 146.03	80.84 $\pm$ 61.3
	2	441.72 $\pm$ 100.36	173.44 $\pm$ 88.33	96.57 $\pm$ 63.47	127.57 $\pm$ 65.09	354.84 $\pm$ 240.25	58.86 $\pm$ 22.49
	3	275.72 $\pm$ 41.95	106.29 $\pm$ 43.33	99.71 $\pm$ 35.41	123.70 $\pm$ 65.74	307.76 $\pm$ 217.49	55.69 $\pm$ 12.99
	4	283.64 $\pm$ 33.42	181.98 $\pm$ 66.03	148.02 $\pm$ 31.04	258.00 $\pm$ 69.47	209.35 $\pm$ 138.01	161.34 $\pm$ 147.54
	5	270.57 $\pm$ 97.67	142.24 $\pm$ 60.99	118.62 $\pm$ 69.47	159.62 $\pm$ 64.38	242.22 $\pm$ 147.99	95.07 $\pm$ 62.59
	6	266.29 $\pm$ 65.03	129.06 $\pm$ 55.40	93.12 $\pm$ 31.04	149.89 $\pm$ 34.69	237.93 $\pm$ 91.05	60.02 $\pm$ 7.83
	7	236.36 $\pm$ 126.21	141.93 $\pm$ 99.42	126.22 $\pm$ 52.08	249.32 $\pm$ 45.70	199.25 $\pm$ 148.92	108.81 $\pm$ 90.34

Table 3 (continued)

Parameters (Unit) (BIS acceptable limits)	Rounds	Villages					
		1 (Mean $\pm$ SD)	2 (Mean $\pm$ SD)	3 (Mean $\pm$ SD)	4 (Mean $\pm$ SD)	5 (Mean $\pm$ SD)	6 (Mean $\pm$ SD)
Total hardness (mg/L) (200 mg/L)	1	416.79 $\pm$ 296.21	546.69 $\pm$ 173.61	473 $\pm$ 111.91	660.96 $\pm$ 119.54	523.73 $\pm$ 186.25	531.67 $\pm$ 191.47
	2	245.28 $\pm$ 232.28	412.77 $\pm$ 179.52	375.58 $\pm$ 178.92	582.43 $\pm$ 127.82	434 $\pm$ 153.62	428.67 $\pm$ 119.97
	3	422.88 $\pm$ 240.91	411 $\pm$ 143.03	349.33 $\pm$ 66.20	504.96 $\pm$ 151.07	318.67 $\pm$ 97.88	370.5 $\pm$ 85.58
	4	389.36 $\pm$ 17.88	432.69 $\pm$ 129.75	397.42 $\pm$ 73.09	735.91 $\pm$ 104.43	393.2 $\pm$ 95.23	336.33 $\pm$ 126.58
	5	450.32 $\pm$ 320.91	469.23 $\pm$ 148.04	404.87 $\pm$ 132.49	763.13 $\pm$ 162.95	337.73 $\pm$ 131.36	481.67 $\pm$ 218.80
	6	472.96 $\pm$ 186.18	376 $\pm$ 114.31	388.61 $\pm$ 90.44	525.13 $\pm$ 123.77	358.4 $\pm$ 87.78	398 $\pm$ 61.05
	7	247.76 $\pm$ 143.56	333.46 $\pm$ 107.67	357.48 $\pm$ 87.19	617.13 $\pm$ 139.22	212.67 $\pm$ 81.76	235 $\pm$ 75.86
Calcium hardness (mg/L) (75 mg/L)	1	331.83 $\pm$ 199.77	332.28 $\pm$ 117.58	267.49 $\pm$ 86.52	297.56 $\pm$ 39.18	252.7 $\pm$ 120.34	296.1 $\pm$ 99.32
	2	201.94 $\pm$ 142.76	277.44 $\pm$ 82.04	196.53 $\pm$ 106.08	260.67 $\pm$ 92.97	222.04 $\pm$ 101.43	212.98 $\pm$ 69.55
	3	224.03 $\pm$ 83.82	158.47 $\pm$ 74.54	127.14 $\pm$ 29.11	90.3 $\pm$ 47.99	102.48 $\pm$ 56.99	106.93 $\pm$ 38.79
	4	275.18 $\pm$ 62.71	196.51 $\pm$ 54.09	280.86 $\pm$ 58.19	251.82 $\pm$ 146.06	125.16 $\pm$ 32.27	130.02 $\pm$ 27.84
	5	354.56 $\pm$ 210.41	290.45 $\pm$ 116.44	242.59 $\pm$ 85.79	404.57 $\pm$ 96.72	172.48 $\pm$ 61.20	291.2 $\pm$ 142.99
	6	272.49 $\pm$ 133.11	147 $\pm$ 75.82	135.86 $\pm$ 44.02	130.84 $\pm$ 41.12	113.68 $\pm$ 26.04	118.48 $\pm$ 16.72
	7	182.7 $\pm$ 97.81	169.86 $\pm$ 68.52	180.6 $\pm$ 58.53	170.00 $\pm$ 94.26	63.42 $\pm$ 33.60	87.32 $\pm$ 41.39
Magnesium hardness (mg/L) (30 mg/L)	1	84.96 $\pm$ 109.69	214.41 $\pm$ 84.73	205.51 $\pm$ 57.74	363.39 $\pm$ 116.34	271.03 $\pm$ 106.29	235.57 $\pm$ 122.61
	2	43.34 $\pm$ 91.29	135.33 $\pm$ 108.29	179.06 $\pm$ 84.54	321.76 $\pm$ 101.53	211.96 $\pm$ 123.23	215.69 $\pm$ 111.60
	3	198.85 $\pm$ 228.62	252.53 $\pm$ 124.43	222.21 $\pm$ 46.21	414.66 $\pm$ 156.90	216.19 $\pm$ 96.12	263.58 $\pm$ 87.56
	4	114.18 $\pm$ 67.49	236.18 $\pm$ 113.03	116.54 $\pm$ 44.48	484.09 $\pm$ 164.30	268.04 $\pm$ 100.86	206.31 $\pm$ 129.63
	5	95.75 $\pm$ 120.40	178.78 $\pm$ 60.05	162.27 $\pm$ 68.26	358.56 $\pm$ 112.78	165.25 $\pm$ 152.83	190.47 $\pm$ 82.33
	6	200.46 $\pm$ 125.40	229 $\pm$ 65.15	252.75 $\pm$ 74.10	394.29 $\pm$ 107.25	244.72 $\pm$ 74.73	279.53 $\pm$ 49.86
	7	65.06 $\pm$ 50.55	163.60 $\pm$ 71.95	176.88 $\pm$ 52.22	447.12 $\pm$ 116.94	149.25 $\pm$ 73.30	147.68 $\pm$ 43.08
Methyl orange alkalinity (mg/L) (NA)	1	101.18 $\pm$ 91.03	271.62 $\pm$ 82.28	226 $\pm$ 38.62	377.65 $\pm$ 52.76	296.8 $\pm$ 86.06	257 $\pm$ 49.41
	2	70.8 $\pm$ 105.73	301.85 $\pm$ 105.01	206.83 $\pm$ 90.95	462.09 $\pm$ 69.58	318.67 $\pm$ 146.45	385.5 $\pm$ 95.07
	3	197.52 $\pm$ 104.55	362.69 $\pm$ 94.30	146.5 $\pm$ 29.01	441.48 $\pm$ 107.83	227.2 $\pm$ 100.76	371.5 $\pm$ 111.24
	4	273.6 $\pm$ 51.83	312.15 $\pm$ 50.13	361.08 $\pm$ 68.66	511.57 $\pm$ 64.12	414.53 $\pm$ 95.29	356.33 $\pm$ 62.10
	5	164.24 $\pm$ 118.01	251.46 $\pm$ 74.82	259.13 $\pm$ 77.64	428 $\pm$ 84.58	267.87 $\pm$ 147.22	266.67 $\pm$ 62.36
	6	207.92 $\pm$ 71.44	288 $\pm$ 72.82	205.48 $\pm$ 58.21	419.83 $\pm$ 75.64	263.06 $\pm$ 76.69	368.33 $\pm$ 127.53
	7	167.52 $\pm$ 64.91	194 $\pm$ 58.12	152 $\pm$ 68.07	242.35 $\pm$ 67.92	236.67 $\pm$ 78.66	217 $\pm$ 100.55
Nitrate–nitrogen (mg/L) (45 mg/L)	1	–	–	–	–	–	–
	2	32.99 $\pm$ 6.91	26.42 $\pm$ 4.83	18.6 $\pm$ 4.71	30.79 $\pm$ 4.04	31.12 $\pm$ 15.36	17.78 $\pm$ 1.14
	3	29.41 $\pm$ 7.85	30.38 $\pm$ 6.03	22.38 $\pm$ 3.29	27.49 $\pm$ 4.47	19.03 $\pm$ 4.45	18.05 $\pm$ 1.50
	4	37.41 $\pm$ 4.94	31.96 $\pm$ 5.49	28.38 $\pm$ 4.43	37.72 $\pm$ 6.34	32.15 $\pm$ 6.95	24.51 $\pm$ 5.36
	5	34.83 $\pm$ 6.94	22.74 $\pm$ 4.32	20.35 $\pm$ 5.20	25.26 $\pm$ 7.75	27.69 $\pm$ 5.48	27.13 $\pm$ 4.24
	6	27.6 $\pm$ 11.65	27.47 $\pm$ 7.73	25.39 $\pm$ 4.48	35.23 $\pm$ 6.45	28.96 $\pm$ 5.78	22.13 $\pm$ 2.73
	7	29.57 $\pm$ 4.68	31.48 $\pm$ 10.58	39.01 $\pm$ 45.35	25.32 $\pm$ 1.84	30.20 $\pm$ 11.49	27.13 $\pm$ 4.34
Orthophosphate (mg/L) (NA)	1	–	–	–	–	–	–
	2	0.17 $\pm$ 0.18	0.12 $\pm$ 0.09	0.09 $\pm$ 0.02	0.15 $\pm$ 0.15	0.17 $\pm$ 0.10	0.03 $\pm$ 0.01
	3	0.12 $\pm$ 0.17	0.21 $\pm$ 0.32	0.16 $\pm$ 0.07	0.45 $\pm$ 0.37	0.06 $\pm$ 0.01	0.03 $\pm$ 0.01
	4	0.09 $\pm$ 0.05	0.14 $\pm$ 0.19	0.16 $\pm$ 0.06	0.17 $\pm$ 0.09	0.08 $\pm$ 0.03	0.17 $\pm$ 0.08
	5	0.19 $\pm$ 0.19	0.05 $\pm$ 0.04	0.09 $\pm$ 0.01	0.09 $\pm$ 0.05	0.29 $\pm$ 0.57	0.08 $\pm$ 0.02
	6	0.23 $\pm$ 0.12	0.19 $\pm$ 0.15	0.25 $\pm$ 0.11	0.1 $\pm$ 0.03	0.32 $\pm$ 0.15	0.19 $\pm$ 0.06
	7	0.11 $\pm$ 0.08	0.28 $\pm$ 0.29	0.31 $\pm$ 0.23	0.08 $\pm$ 0.02	0.29 $\pm$ 0.33	0.08 $\pm$ 0.04

NA, Limit not defined

dissolved constituents in the groundwater. It causes differences in the water quality during different seasons. Differences in the water quality among villages (Table 3) might be the outcome of local and geogenic factors. Such seasonal variations have also been reported in earlier studies of Ujjain [35].

High values of TDS and hardness (total, calcium, and magnesium) indicate the presence of various cations and salts, which is common in the case of groundwater. Bicarbonates, calcium, and magnesium are important elements for the high values of these parameters. It is known that calcium and magnesium are essential cations for health, as these are involved in many biochemical processes of the body [36, 37]. It has also been reported that high levels of calcium in drinking water result in a low occurrence of dental caries [38], hypertension [39], and cardiovascular diseases [40, 41]. However, there are other studies which indicate that excess calcium sometimes may result in an increased risk of myocardial infarction among postmenopausal women [42]. The consumption of water having high hardness levels might promote urinary health issues, such as formation of kidney stones [43–45]. Moreover, there are several studies which depict the positive correlation between hard water and atopic dermatitis (eczema), especially in children [46–48]. Therefore, consumption of such water is recommended only after undergoing sufficient treatment.

The hardness in water can be reduced by various methods, such as reverse osmosis, filtration, and ion exchange mechanisms [49–51]. Another common approach to reduce hardness is precipitation, which can be achieved through lime, lime soda, or sodium hydroxide softening. In this process, anions (e.g., carbonate and/or hydroxide ions), are used to bind with cations present in water (Ca and/or Mg), which leads to their precipitation and subsequent removal. In the reverse osmosis method, water is forced to pass through a semi-permeable membrane under pressure, which results in softer water. In the ion exchange mechanism, hard water is allowed to pass through sodium rich exchange material (also called zeolite). In this process, sodium ions get replaced by the cations present in water, viz. Ca and Mg, thus reducing the hardness of water.

Safe and clean drinking water is essential for all living beings. The present study is an attempt to realize the importance of long-term monitoring of drinking water sources for better health and quality of life. The study not only assessed the groundwater quality in rural households, but also followed the same households for two consecutive years to observe whether there was any change over time. The findings resulted in a comprehensive picture about the groundwater condition of the studied area. Therefore, emphasis needs to be on long-term surveillance

for assessing changes in water quality over time. Long-term surveillance of drinking water parameters can further help in taking appropriate measures in time. The scope of the study can also be widened by including health-seeking data along with water quality, as it would help to build up cause–effect relationships, and various water-borne diseases can be prevented from occurrence. In order to facilitate this, local governments may also be engaged in water quality programmes, which can periodically examine water quality levels and take necessary action.

5 Conclusion

Drinking water quality in the rural areas of Ujjain, Madhya Pradesh in Central India, was monitored for the period of 2 years in different seasons. It was found that dissolved solids and hardness were exceeding recommended limits in the water samples, which might prove to be harmful for health in the long term. Thus, the present study emphasizes the importance of periodic water quality monitoring to witness changes in health and/or ecological outcomes. The authors recommend further studies to ascertain the health impact of long-term consumption of water with higher levels of dissolved solids and hardness. It is suggested that such water should be used for consumption only after applying necessary treatments. Moreover, it is established that long-term surveillance is necessary for maintaining the water quality, and hence this study might help upcoming researchers for planning and management of water quality programs.

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Compliance with ethical standards

Conflict of interest The authors state that they have no conflict of interest.

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Appendix 1: Indian and WHO drinking water quality standards

Parameters	Units	Indian Standards (BIS)		WHO Standards	
		Acceptable limit	Permissible limit	Acceptable limit	Permissible limit
pH	–	6.5–8.5	–	–	6.5–8.5
Temperature	°C	–	–	–	–
TDS	mg/L	500	2000	500	1500
Conductivity	mS/cm	–	–	–	–
Turbidity	NTU	1	5	–	–
Chloride	mg/L	250	1000	250	–
Total hardness	mg/L	200	600	100	500
Calcium hardness	mg/L	75	200	75	–
Magnesium hardness	mg/L	30	100	50	150
Methyl orange alkalinity	mg/L	–	–	–	–
Nitrate nitrogen	mg/L	45	–	50 (total nitrogen)	–
Orthophosphate	mg/L	–	–	–	–

Appendix 2: Statistical parameters total dissolved solids

Effect of independent variable (repeated measured) on outcome variable	DF*, F	p value
Main effects of time	6, 82.754	0.001
Main effects of village	5, 13.523	0.000

Post hoc analysis

*DF, degree of freedom

	Mean difference	95% CI of MD		p value
		Lower bound	Upper bound	
Time point 1 vs.				
T2	95.395*	25.946	164.844	.001
T3	412.368*	343.231	481.506	.000
T4	66.077	− 1.777	133.931	.064
T5	117.244*	27.282	207.205	.002
T6	165.215*	87.060	243.371	.000
T7	177.409*	101.320	253.498	.000
Time point 2 vs.				
T3	316.974*	257.970	375.977	.000
T4	− 29.318	− 103.322	44.686	1.000
T5	21.849	− 68.348	112.046	1.000
T6	69.820	− 6.595	146.235	.112
T7	82.014*	3.143	160.886	.034
Time point 3 vs.				
T4	− 346.292*	− 409.700	− 282.883	.000
T5	− 295.125*	− 382.579	− 207.671	.000
T6	− 247.153*	− 320.216	− 174.090	.000
T7	− 234.959*	− 303.361	− 166.558	.000
Time point 4 vs.				
T5	51.167	− 40.519	142.853	1.000
T6	99.139*	20.131	178.146	.003
T7	111.333*	28.988	193.677	.001
Time point 5 vs.				
T6	47.971	− 14.319	110.261	.385
T7	60.165	− 24.682	145.013	.621
Time point 6 vs.				
T7	12.194	− 65.802	90.190	1.000
	Mean difference	95% CI of MD		p value
		Lower bound	Upper bound	
Village 1 vs.				
5	− 81.4598	− 230.3295	67.4099	1.000
4	6.6131	− 125.0847	138.3109	1.000
6	271.8569*	111.7787	431.9350*	.000
3	203.0967*	68.1721	338.0212*	.000
2	151.3156*	23.6364	278.9949*	.008
Village 5 vs.				
4	88.0729	− 63.2045	239.3503	1.000
6	353.3167*	176.7790	529.8544*	.000
3	284.5565*	130.4617	438.6512*	.000
2	232.7755*	84.9833	380.5676*	.000

	Mean difference	95% CI of MD		<i>p</i> value
		Lower bound	Upper bound	
<i>Village 4 vs.</i>				
6	265.2438*	102.9240	427.5635*	.000
3	196.4836*	58.9070	334.0602*	.001
2	144.7026*	14.2240	275.1812*	.018
<i>Village 6 vs.</i>				
3	−68.7602	−233.7088	96.1884	1.000
2	−120.5412	−279.6178	38.5354	.375
<i>Village 3 vs.</i>				
2	−51.7810	−185.5158	81.9538	1.000
Total hardness				
Effect of independent variable (repeated measured) on outcome variable				
Main effects of time			6, 26.551	0.000
Main effects of village			5, 23.194	0.000
Post hoc analysis				
*DF, degree of freedom				
	Mean difference	95% CI of MD		<i>p</i> value
		Lower bound	Upper bound	
<i>Time point 1 vs.</i>				
T2	111.641*	50.268	173.015	.000
T3	128.541*	67.070	190.012	.000
T4	77.278*	21.001	133.554	.001
T5	43.083	−29.702	115.869	1.000
T6	107.612*	43.573	171.652	.000
T7	193.330*	132.661	253.999	.000
<i>Time point 2 vs.</i>				
T3	16.900	−43.814	77.613	1.000
T4	−34.364	−88.418	19.691	1.000
T5	−68.558*	−127.664	−9.452	.010
T6	−4.029	−57.473	49.415	1.000
T7	81.689*	23.006	140.371	.001
<i>Time point 3 vs.</i>				
T4	−51.263*	−97.323	−5.203	.016
T5	−85.457*	−150.946	−19.969	.002
T6	−20.928	−68.393	26.537	1.000
T7	64.789*	9.522	120.056	.009
<i>Time point 4 vs.</i>				

	Mean difference	95% CI of MD		<i>p</i> value
		Lower bound	Upper bound	
T5	−34.194	−94.448	26.060	1.000
T6	30.335	−7.813	68.483	.315
T7	116.052*	77.209	154.895	.000
<i>Time point 5 vs.</i>				
T6	64.529*	11.945	117.113	.005
T7	150.247*	85.812	214.681	.000
<i>Time point 6 vs.</i>				
T7	85.718	40.216	131.219	.000
	Mean difference	95% CI of MD		<i>p</i> value
		Lower bound	Upper bound	
<i>Village 1 vs.</i>				
5	8.956	−85.303	103.215	1.000
4	−249.794*	−333.180	−166.408*	.000
6	−20.106	−121.461	81.250	1.000
3	−8.177	−90.654	74.299	1.000
2	−48.679	−129.521	32.163	1.000
<i>Village 5 vs.</i>				
4	−258.750*	−354.534	−162.967*	.000
6	−29.062	−140.839	82.715	1.000
3	−17.133	−112.126	77.859	1.000
2	−57.635	−151.212	35.941	1.000
<i>Village 4 vs.</i>				
6	229.688*	126.914	332.463*	.000
3	241.617*	157.403	325.831*	.000
2	201.115*	118.501	283.729*	.000
<i>Village 6 vs.</i>				
3	11.929	−90.109	113.967	1.000
2	−28.573	−129.295	72.148	1.000
<i>Village 3 vs.</i>				
2	−40.502	−122.198	41.194	1.000
Calcium				
Effect of independent variable (repeated measured) on outcome variable			<i>DF*, F</i>	<i>p</i> value
Main effects of time			6, 54.779	0.000
Main effects of village			5, 11.449	0.000

	Mean difference	95% CI of MD		<i>p</i> Value
		Lower bound	Upper bound	
Time point 1 vs.				
T 2	67.869*	29.353	106.385	.000
T3	161.578*	121.130	202.025	.000
T4	86.539*	45.739	127.339	.000
T5	5.510	−43.337	54.357	1.000
T6	144.352*	103.506	185.199	.000
T7	155.403*	115.385	195.421	.000
Time point 2 vs.				
T3	93.709*	56.806	130.612	.000
T4	18.670	−16.047	53.386	1.000
T5	−62.359*	−99.643	−25.075	.000
T6	76.484*	40.348	112.620	.000
T7	87.534*	50.568	124.500	.000
Time point 3 vs.				
T4	−75.039*	−104.889	−45.189	.000
T5	−156.068*	−202.710	−109.425	.000
T6	−17.225	−45.644	11.194	1.000
T7	−6.174	−34.025	21.676	1.000
Time point 4 vs.				
T5	−81.029*	−127.562	−34.496	.000
T6	57.814*	25.318	90.310	.000
T7	68.864*	41.605	96.124	.000
Time point 5 vs.				
T6	138.843*	103.027	174.658	.000
T7	149.893*	107.733	192.054	.000
Time point 6 vs.				
T7	11.051	−18.702	40.803	1.000
	Mean difference	95% CI of MD		<i>p</i> value
		Lower bound	Upper bound	
Village 1 vs.				
5	113.089*	63.026	163.151	.000
4	33.973	−10.315	78.261	.350
6	85.794*	31.962	139.626	.000
3	62.256*	18.451	106.061	.001
2	38.795	−4.141	81.732	.117
Village 5 vs.				
4	−79.116*	−129.988	−28.243	.000
6	−27.295	−86.662	32.072	1.000
3	−50.832*	−101.285	−.380	.047

	Mean difference	95% CI of MD		p value
		Lower bound	Upper bound	
2	−74.293*	−123.993	−24.593	.000
Village 4 vs.				
6	51.821	−2.765	106.406	.079
3	28.283	−16.445	73.011	.909
2	4.823	−39.055	48.701	1.000
Village 6 vs.				
3	−23.537	−77.732	30.657	1.000
2	−46.998	−100.493	6.497	.144
Village 3 vs.				
2	−23.461	−66.851	19.930	1.000
Magnesium hardness				
Effect of independent variable (repeated measured) on outcome variable			DF*, F	p value
Main effects of Time			6, 18.226	0.000
Main effects of Village			5, 47.701	0.000
Post hoc analysis				
*DF, Degree of freedom				
	Mean difference	95% CI of MD		p Value
		Lower bound	Upper bound	
Time point 1 vs.				
T2	43.772*	10.998	76.547	.001
T3	−33.039	−75.205	9.128	.346
T4	−9.261	−42.347	23.825	1.000
T5	37.574*	2.319	72.828	.026
T6	−36.740*	−72.344	−1.136	.037
T7	37.927*	6.006	69.847	.007
Time point 2 vs.				
T3	−76.811*	−120.005	−33.617	.000
T4	−53.033*	−93.305	−12.761	.002
T5	−6.199	−38.438	26.041	1.000
T6	−80.513*	−112.224	−48.801	.000
T7	−5.846	−38.158	26.466	1.000
Time point 3 vs.				
T4	23.778	−21.662	69.217	1.000
T5	70.613*	26.391	114.834	.000
T6	−3.701	−48.665	41.263	1.000
T7	70.966*	24.307	117.624	.000

	Mean difference	95% CI of MD		<i>p</i> Value
		Lower bound	Upper bound	
<i>Time point 4 vs.</i>				
T5	46.835*	7.403	86.267	.007
T6	−27.479	−63.585	8.627	.415
T7	47.188*	15.781	78.594	.000
<i>Time point 5 vs.</i>				
T6	−74.314*	−107.626	−41.001	.000
T7	.353	−35.179	35.885	1.000
<i>Time point 6 vs.</i>				
T7	74.667	43.337	105.996	.000
	Mean difference	95% CI of MD		<i>p</i> Value
		Lower bound	Upper bound	
<i>Village 1 vs.</i>				
5	−104.133*	−168.955	−39.310*	.000
4	−283.767*	−341.113	−226.422*	.000
6	−105.899*	−175.603	−36.196*	.000
3	−70.435*	−127.155	−13.715*	.005
2	−87.475*	−143.070	−31.879*	.000
<i>Village 5 vs.</i>				
4	−179.635*	−245.506	−113.764*	.000
6	−1.767	−78.637	75.103	1.000
3	33.697	−31.630	99.025	1.000
2	16.658	−47.696	81.011	1.000
<i>Village 4 vs.</i>				
6	177.868*	107.188	248.547*	.000
3	213.332*	155.417	271.247*	.000
2	196.293*	139.478	253.107*	.000
<i>Village 6 vs.</i>				
3	35.464	−34.708	105.637	1.000
2	18.425	−50.842	87.692	1.000
<i>Village 3 vs.</i>				
2	−17.039	−73.223	39.144	1.000

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