Chapter 12
Suitability of Groundwater for Drinking and Agricultural Use in Patna District, Bihar, India

Yash Aryan, P. Thambidurai, and Anil Kumar Dikshit

Abstract Groundwater is the most important source of freshwater, with nearly one-third of the world's population depending on it for drinking. The demand for groundwater has increased tremendously in developing countries, including India, due to the rapid growth of population, urbanization, and industrialization. The quality of groundwater is also important, along with the quantity. The present study highlights the scenario of groundwater in India and in the study area, which is Patna district in the state of Bihar. The study aims to evaluate the groundwater suitability for drinking and irrigation purposes. The chemical characteristics of groundwater samples at 37 locations were obtained from the Central Ground Water Board 2021 report. The study found that the groundwater samples in most parts of the study area were appropriate for drinking and irrigation purposes as most of the parameters such as pH, EC, TDS, and TH were within the maximum allowable limit or maximum permissible limit specified by WHO and BIS. The major anions and cations were found to be within the maximum limit permitted for drinking. The various parameters indicating the groundwater suitability for irrigation were found to be excellent to permissible range, while the magnesium hazard parameter was observed to be greater than 50% at 12 locations indicating groundwater samples were not desirable for irrigation. Although most of the above parameters were within the range, parameters such as coliform value and arsenic content are also equally important and need to be measured before declaring groundwater fit for drinking.

Keywords Agriculture · Drinking · Groundwater · Industrialization · Urbanization · Water quality

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1 Introduction

Water is an essential and vital resource for the existence of all life forms. Groundwater is the major source of freshwater for human life (Vignesh et al., 2021). Around one-third of the global population depends on groundwater for drinking water (Li et al., 2021). The presence of freshwater on the earth is estimated at around 36 Mkm^3; out of this, about 22% exists as groundwater (Sarath Prasanth et al., 2012). Groundwater availability has been taken for granted as it is a replenishable resource, resulting in the overexploitation of groundwater as a resource. The demand for groundwater has increased tremendously in developing countries, including India, due to the increase in population and growth of industries. The overexploitation of groundwater resulted in groundwater stress in many parts of India, along with degradation in the quality of groundwater mostly due to anthropogenic activities.

2 Groundwater Scenario in India

The extraction of groundwater is not uniform in different parts of India. The majority of extracted groundwater (90%) is used for irrigation, and groundwater supplies primarily support about 60% of the irrigated land in India (Chindarkar & Grafton, 2019). According to an assessment conducted by Central Ground Water Board (CGWB) in 2017, 432 billion cubic meters (bcm) was the total annual groundwater recharge, and 393 bcm was the annual extractable groundwater resource. The problem gets worsened due to the disparity in basin-wise water availability across the country because of variation in population density and uneven rainfall in the country. The availability of water in the Brahmaputra/Barak basin is very high, around 14,057 m^3/year/person, and very low in the Sabarmati basin (307 m^3/year/person). There are many basins like Pennar, Tapi, Mahi, etc., which are already water-stressed. In the study conducted by CGWB, 17% of blocks in various states (mainly Rajasthan, Punjab, and Haryana) were in an overexploited condition indicating the groundwater extraction exceeded the annually replenishable groundwater recharge, while 5% of blocks were in a critical stage where the groundwater extraction is between 90% and 100%. Around 14% of blocks fell under the semi-critical stage, with groundwater extraction between 70% and 90%, and 63% of the blocks had been categorized as safe, having groundwater extraction less than 70% (CGWB, 2020). The water level in India during pre-monsoon in 2018 was 5–10 m bgl (below ground level) in most parts of the country (Fig. 12.1). A few states such as Maharashtra, Odisha, Assam, and Andhra Pradesh had water level depth less than 2 m bgl in some of the locations. Most parts of Assam and some parts of Odisha, Andhra Pradesh, Uttar Pradesh, and Bihar showed a water level of 2–5 m bgl. The major western states and northwestern states such as Punjab, Haryana, Rajasthan, and Gujarat had a deeper depth to the water level of 10–40 m bgl or greater than 40 m bgl (CGWB, 2018). The groundwater level in India for pre-monsoon in 2018

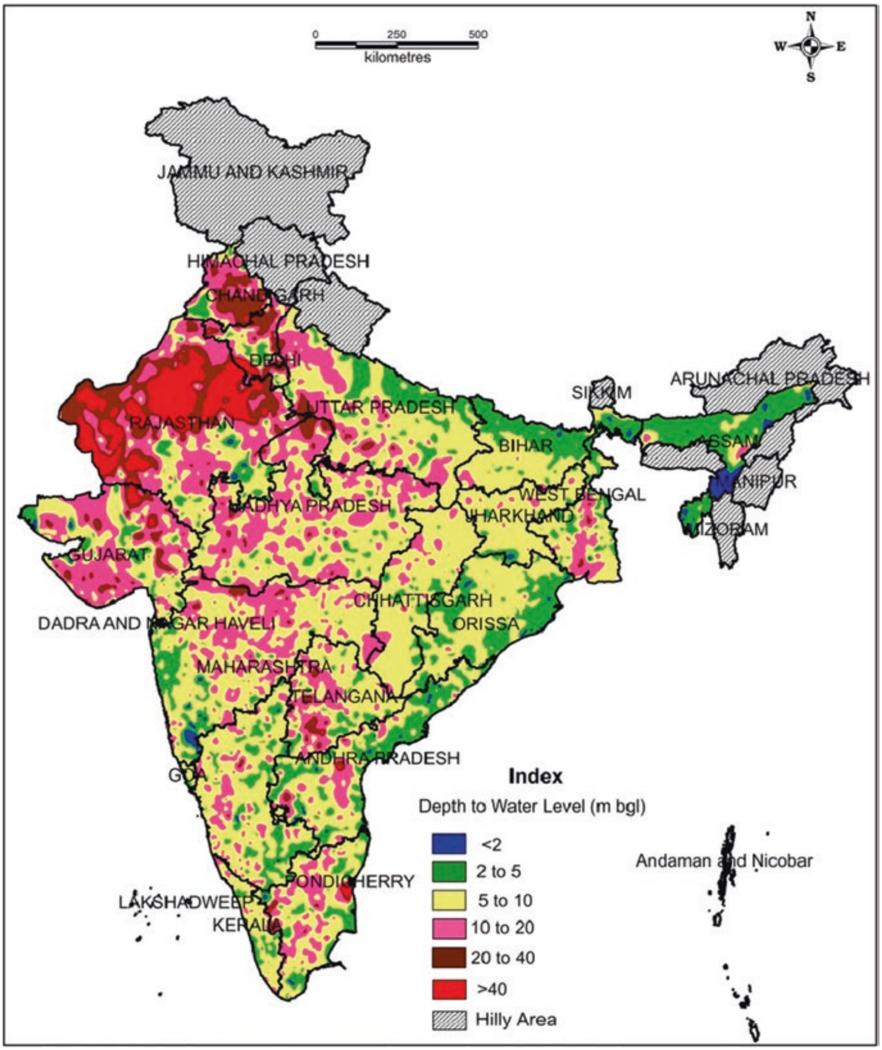

Fig. 12.1 Depth to water level map of pre-monsoon 2018

is shown in Fig. 12.2. Out of the total of 14,591 wells assessed, the majority of wells, around 5886 (41 %), had water levels in the range of 5–10 m bgl (CGWB, 2018). The fluctuations of water level during pre-monsoon in 2018 compared to pre-monsoon in 2017 have been shown in Fig. 12.3. The CGWB (2018) report revealed that water levels had both risen and fallen in the entire country. Out of 13,255 wells monitored, 6941 (52%) showed an increase in water depth, whereas 5721 (43%) showed a decrease. The water level did not change in the remaining 593 (4%) wells. Most of the wells showed fluctuation of 0–2 m. The water level rise was

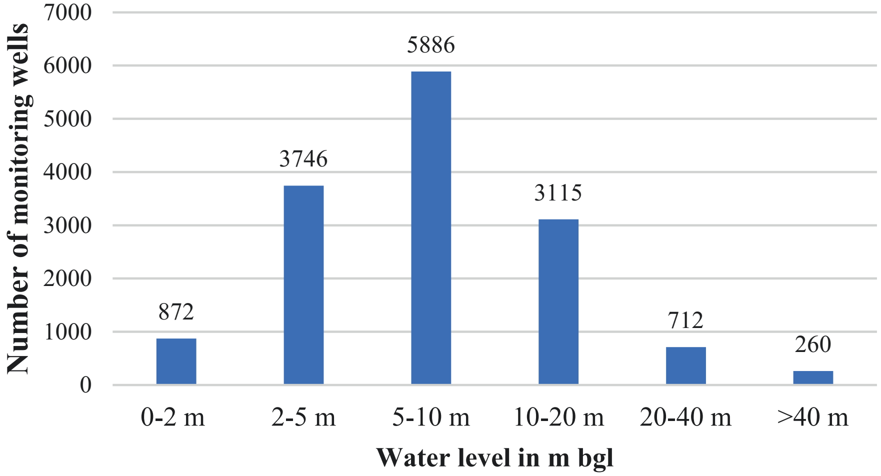

Fig. 12.2 Number of wells showing water level during pre-monsoon 2018

observed in the states of Jharkhand, Kerala, Meghalaya, Assam, Karnataka, Odisha, and parts of West Bengal, Maharashtra, and Tamil Nadu.

The fall of 0–2 m was seen in different parts of the states of Madhya Pradesh, Haryana, Bihar, Goa, Jammu and Kashmir, Chandigarh, Himachal Pradesh, Delhi, and Uttar Pradesh, while a fall of above 4 m prevailed in the states of Uttarakhand, Gujarat, Rajasthan, Chhattisgarh, Madhya Pradesh, Delhi, Goa, Gujarat, Telangana, and Madhya Pradesh. The wells showing water level depth during different periods, such as pre-monsoon, mid-monsoon, post-monsoon, and recession, have been presented in Fig. 12.4. It has been observed that once the monsoon starts, the wells are getting recharged, and more wells are coming under the range of 0–5 m bgl (Fig. 12.4). Whereas less variation in numbers has been observed in the wells having water level depth greater than 40 m bgl. The less variation in numbers of these wells may be attributed to the fact that these wells (>40 m bgl) mainly lies in the western states of India, having less rainfall, and hence these wells are not recharged from the rainfall to a great extent.

3 Groundwater Scenario in Bihar

Most of the parts of the state of Bihar have been blessed with plenty of water resources, but overexploitation and improper management of the groundwater have led to water scarcity in the state of Bihar. The administrative map of the state of Bihar is shown in Fig. 12.5.

According to the study conducted by CGWB in 2021, the water level out of the total of 209 wells monitored, 23 wells (11%) had water level of 0–2 m bgl observed in the northern part (Gopalganj, Siwan, Sitamarhi, and Muzaffarpur) and as patches

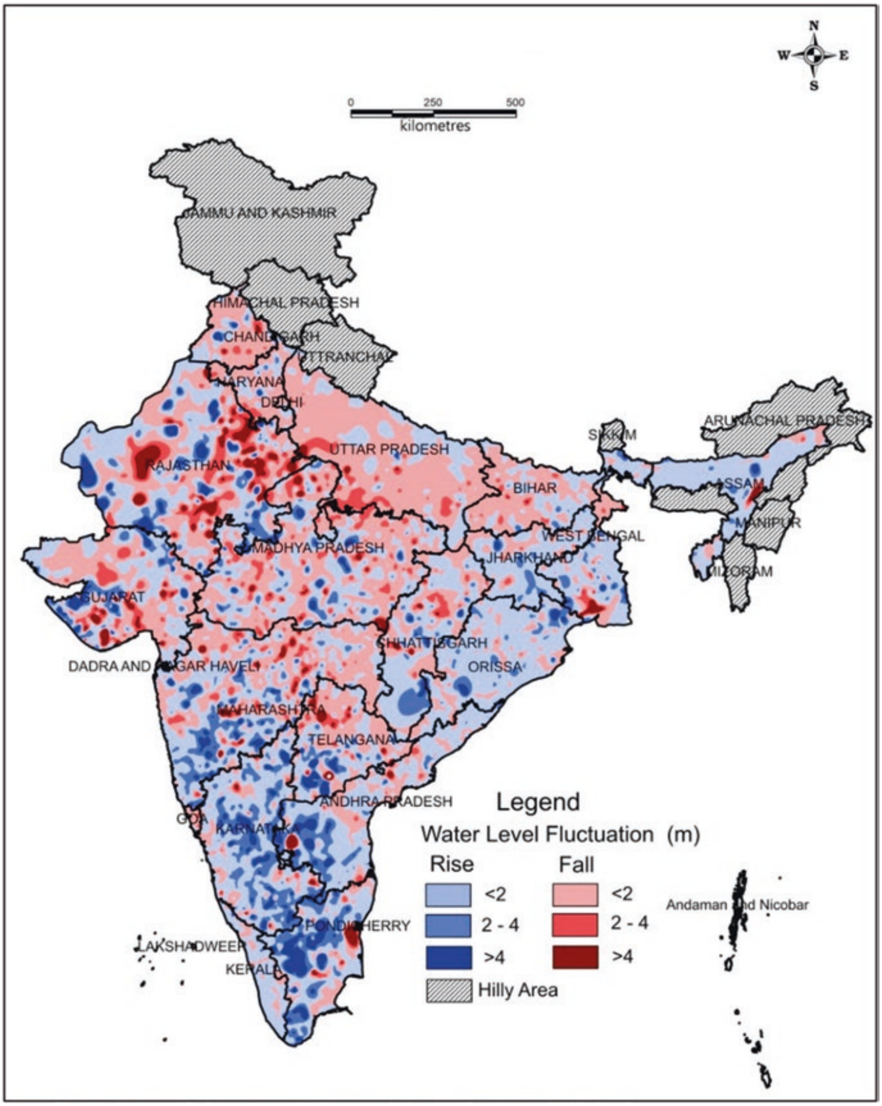

Fig. 12.3 Water level fluctuation during pre-monsoon 2017–2018

in the South Bihar Plain (SBP), while 96 wells (46%) fell in 2–5 m bgl water depth lied in the central part of Bihar (Saran, Vaishali, Arwal, Jehanabad, Gaya, Bhojpur, and Patna) and 90 wells (43%) had water level depth of 5–10 m bgl observed scattered in different districts of the state such as Bhojpur, Patna, Begusarai, Samastipur, Vaishali, Nalanda, and Nawada. During mid-monsoon (August 2020), a total of 327 wells were monitored. The water level depth during this period varied from 0.04 in Muzaffarpur to 11.00 m bgl in Nawada. The major number of wells ~86% across the

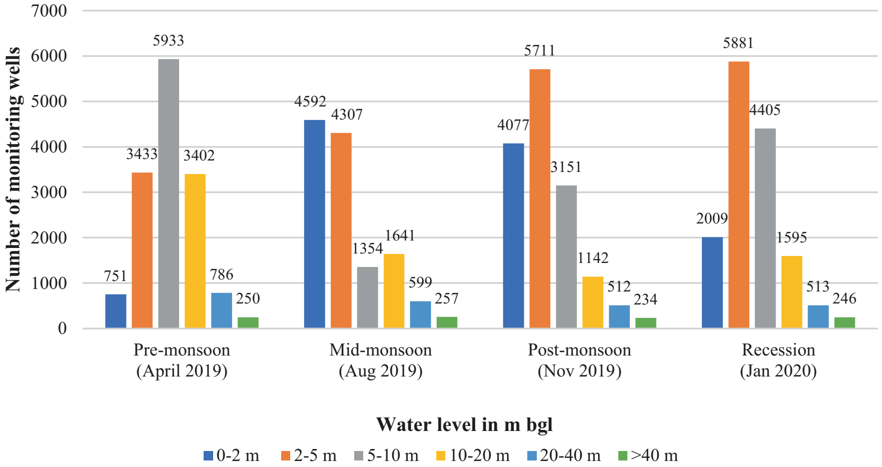

Fig. 12.4 Number of wells showing water level during different months

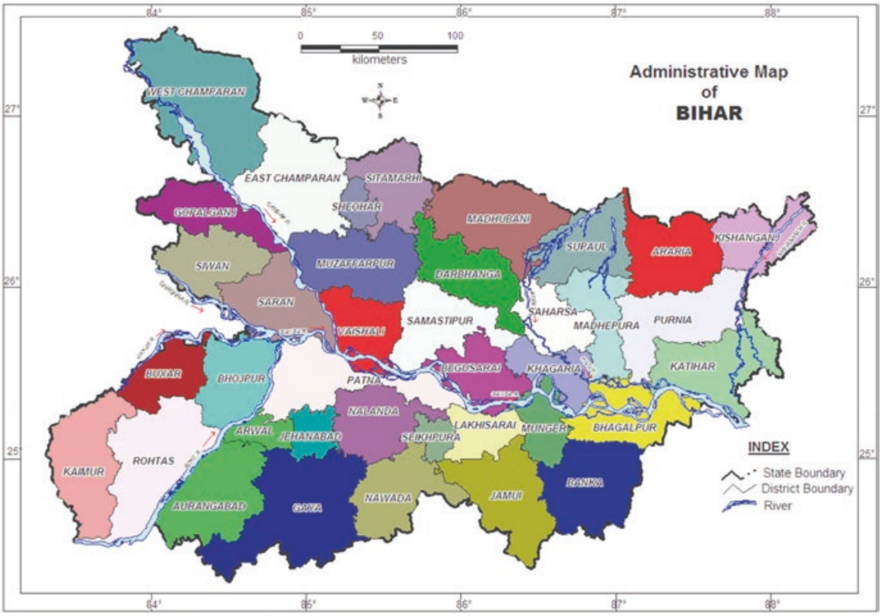

Fig. 12.5 Administrative map of Bihar state

state (except that some locations in Samastipur and Begusarai district) had water level depth ranging from 0 to 5 m bgl as the monsoon rainfall recharged the groundwater level rising the depth of water level in wells. Out of a total of 327 wells, 47 wells (13%) mostly in the Begusarai district, had a water level depth of 5–10 bgl, while water-level depth above 10 m bgl found only in 1 well located in Nawada. The shallow water level depth of range 0–2 m bgl was in Sitamarhi, Sheohar, Darbhanga, Madhubani districts, and many localized areas, mostly in NBP. About 12% of wells observed a water level of 5–10 m bgl, covering small areas at many locations of various districts such as Kaimur, Rohtas, Jamui, and Banka lying in SBP. The water level of above10 m bgl was found in about 15 numbers of wells (3%) present in the parts of Patna, Bhagalpur, Rohtas, Kaimur, and many other places as small patches. A total of 663 wells were monitored during the recession period (January 2020). The Muzaffarpur district had a minimum water level of 0.47 m bgl, while the Rohtas district had a maximum water level of 15.8 m bgl. In most regions of the state (64%), water levels were reported to be 2–5 m bgl. The water level in m bgl for different monsoon periods has been shown in Fig. 12.6. The number of wells having a water depth of 0–2 m bgl and 2–5 m bgl was observed to be increased during mid-monsoon and post-monsoon. This increase is completely justified due to the recharging of groundwater levels from the rainfall during the monsoon period.

3.1 *Seasonal Fluctuation*

The seasonal fluctuation showing rise and fall of water in wells (% of wells) has been shown in Fig. 12.7. A total of 180 wells were monitored to identify the variation in water level during August 2020 compared to May 2020. Out of a total of 180 wells, 176 wells (97%) showed a rise, and 4 wells (3%) showed a fall in the water table. Also, 181 wells were monitored to compare the fluctuations in water level in November 2020 compared to May 2020. The number of wells showing a rise was 157 (87%), and the number of wells showing a fall was 24 (13%). The wells

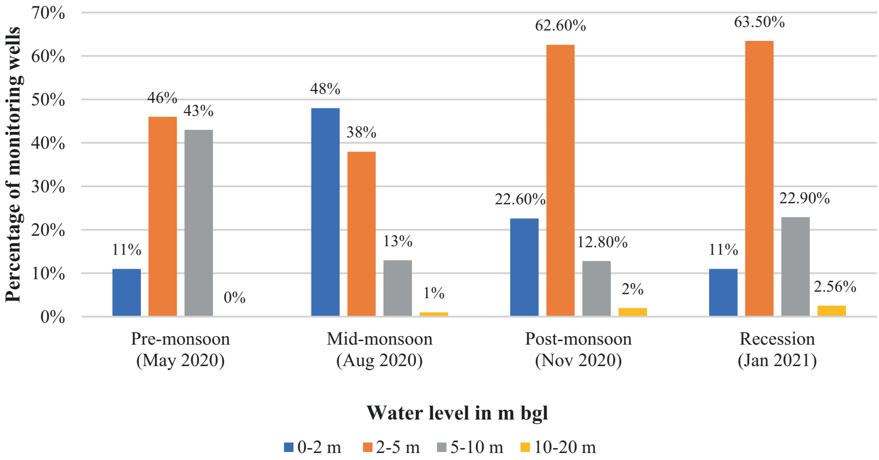

Fig. 12.6 Water level in wells during different periods in Bihar

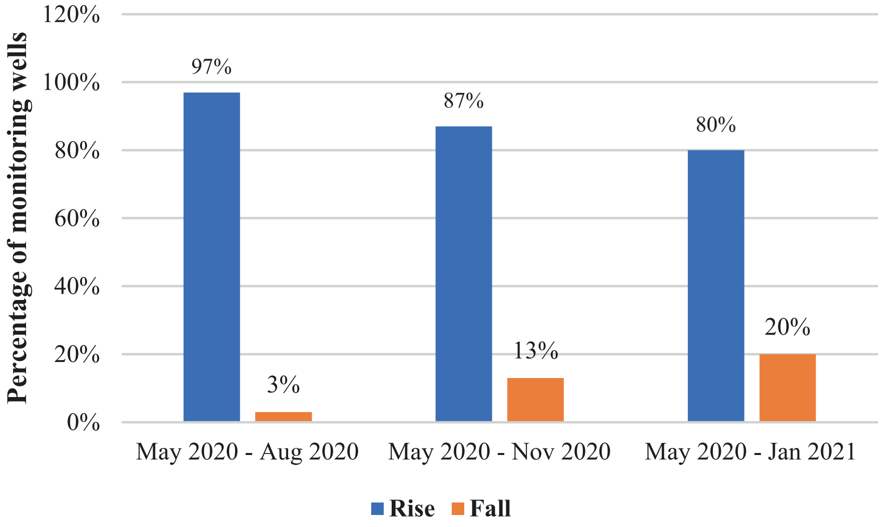

Fig. 12.7 Seasonal fluctuation in water level in Bihar state

showing falls were present in the major part of the Madhubani district and localized areas of Patna, Jehanabad, and Gopalganj districts.

Again, to compare the fluctuations in January 2021 compared to May 2020, a total of 184 wells were analyzed, and out of these, 147 wells (80%) observed a rise while 37 wells (20%) showed a fall in the water table. The falls were seen in the wells located in the Madhubani district and in patches areas of Gopalganj, Patna, Nawada, Nalanda, Bhojpur, and East Champaran districts.

3.2 *Annual Fluctuation*

The annual fluctuation in terms of the rise and fall of water level (% of wells) has been shown in Fig. 12.8. The monitoring wells represented a limited area of the state of Bihar during the assessment done for May 2019 to May 2020 indicated that 158 wells (91%) out of 174 wells showed a rise in the water level and covered the major part of the state while 16 wells (9%) indicated fall in the water level covering mainly parts of the Nalanda, Samastipur, Buxar and Begusarai districts. Similarly, water table variation between August 2019 and August 2020 showed that out of a total of 283 wells, 226 wells (80%) indicated a rise while 57 wells (20%) indicated a fall. The fall was observed mostly in districts located in SBP, such as Arwal, Aurangabad, and Jehanabad districts (Fig. 12.8). From November 2019 to November 2020, the wells were monitored in the entire state, and the analysis showed that out of a total of 582 wells, the number of wells indicating rise was 239 (41%) and 343 wells (59%) showed fall in the water level. Similarly, from January 2020 to January

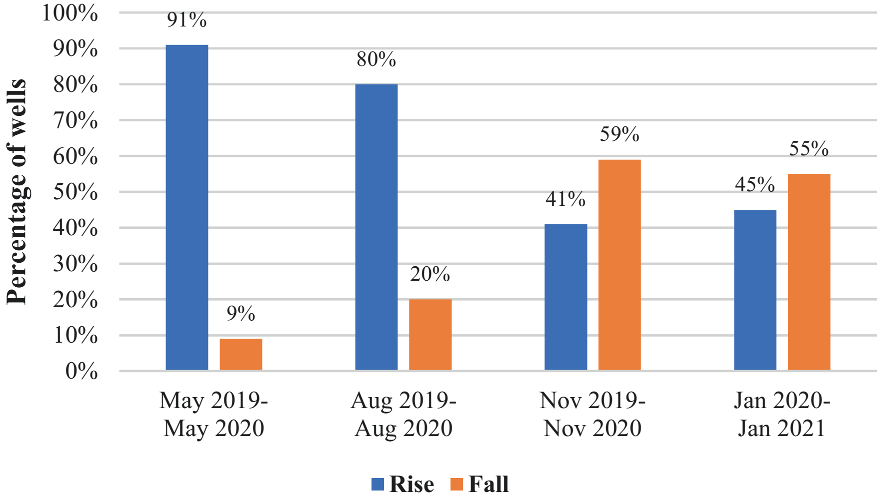

Fig. 12.8 Annual fluctuation in water level in Bihar state

2021, a total of 619 was analyzed, covering the whole state. Out of 619 wells, 277 wells (45%) indicated a rise, while 343 wells (55%) indicated a fall in the water level (Fig. 12.8).

3.3 *Decadal Fluctuation*

The decadal fluctuation in terms of the rise and fall of the water table (% of wells) has been shown in Fig. 12.9. The water-level fluctuation in May 2020 related to the decadal mean of May had been reported and a total of 202 wells were analyzed, covering a limited area of the state of Bihar. Out of a total of 202 wells, 175 wells (86%) showed a rise in the water level while 27 wells (14%) indicated a fall in the water level, covering mainly parts of the Samastipur, Begusarai, Nalanda, Nawada, Sitamarhi, and Bhojpur districts. Similarly, variation in water depth between August 2010 and August 2020 showed that out of a total of 320 wells, 253 wells (79%) indicated a rise while 67 wells (21%) indicated a fall mostly observed in major parts of Begusarai, and some parts of Saran, Vaishali, Bhojpur, Nalanda, Arwal, Aurangabad, Nawada, East Champaran, and Gaya district (Fig. 12.9). From November 2010 to November 2020, 626 wells were monitored in the entire state, and the analysis showed that out of a total of 626 wells, the number of wells indicating rise was 396 (63%), and 230 wells (37%) showed fall in the water level. The falls were observed mainly in the areas of East Bihar, covering various districts such as Supaul, Araria, Kishanganj, Purnea, Katihar, Banka, Jamui, Munger, and in some areas of West Champaran, East Champaran, Kaimur, Buxar, Rohtas, Arwal, and Aurangabad. Similarly, from the decadal mean of January 2011 to January 2021, a

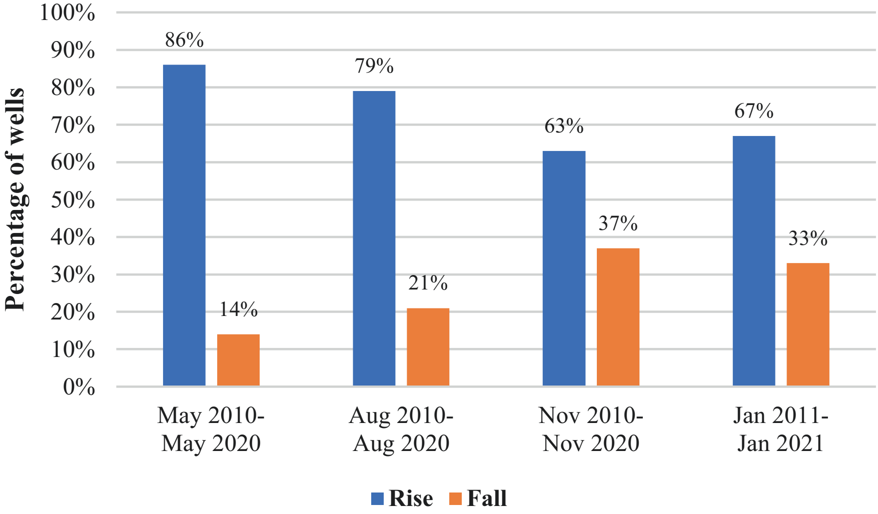

Fig. 12.9 Decadal fluctuation in water level in Bihar state

total of 627 were analyzed, covering the whole state. Out of 627 wells, 418 wells (67%) indicated a rise, while 209 wells (33%) indicated a fall in the water level (Fig. 12.9).

3.4 Groundwater Contamination

Groundwater contamination is a global challenge as everyone must have access to sufficient and affordable clean water for drinking and other purposes. The rapid population, urbanization, and industrialization resulted in severe groundwater contamination, posing a major problem all over the world. The groundwater contaminants are mainly geogenic in nature. The natural mineral deposits within the Earth's crust dissolve, resulting in contamination, but now, the release of contaminants of anthropogenic origin from industries and various other human activities has worsened the scenario. The contamination of groundwater is different from surface water contamination as it is not visible, and resource recovery is difficult at the current level of technology (Li et al., 2021). The groundwater contaminants are generally colorless and odorless, and their impact on human health is chronic (Chakraborti et al., 2015). Groundwater pollution can negatively impact human health and environment and can create social issues among citizens. The high levels of chemical constituents in drinking water, such as fluoride, metals, nitrate, etc., adversely affects the human health and leads to soil contamination. Contamination of groundwater also reduces freshwater availability, causing conflicts among citizens and leading to socio-economic crises and even wars (Li et al., 2021).

The major challenges and concerns in India are groundwater contamination from arsenic, fluorides, and nitrates. Several studies have been performed in the field of groundwater contamination from these contaminants in various parts of India (Ahamed et al., 2006; Thapa et al., 2019; Suthar et al., 2009; Chakraborti et al., 2016). Arsenic contamination affected 107 countries all over the world, having concentrations beyond the maximum limit of 10 ppb specified by WHO (Shaji et al., 2021). In terms of population, around 200 million people all over the world have been adversely affected by arsenic contamination above the specified limit of WHO (Jha & Tripathi, 2021). Asia has the highest number of reports (32), followed by Europe (31) and then Africa (20). South Asia, including India, appears to be the worst affected by arsenic groundwater contamination. Shaji et al. (2021) stated that over 50 million population in India is exposed to arsenic groundwater contamination. A total of 17 states and one union territory in India have been reported to have arsenic values beyond the limit of 50 ppb specified by BIS. About 19% of the Indian population is at risk of arsenic poisoning (Shukla et al., 2020). The shallow aquifers from 10 states in India had reported high arsenic value in groundwater (>10 ppb), while deeper aquifers greater than 100 m are free from arsenic. The worst affected states are Bihar, West Bengal, Assam, and Tripura. More than 10 million people in rural Bihar are exposed to the high level of naturally occurring arsenic, covering 46% of the geographical area (Chakraborti et al., 2016). Chakraborti et al. (2016) found that the magnitude of the arsenic contamination in the groundwater was severe in the Patna district, and around 61% of analyzed tube wells in five blocks of Patna had arsenic above 10 μg/l. The groundwater of the Bhojpur district in Bihar was also found to have arsenic concentrations higher than 50 ppb in most of the groundwater samples (Maity et al., 2020). Chronic arsenic exposure causes arsenicosis and various other adverse effects on human health, such as liver damage, cancer, and coronary heart disease. The fluoride contamination exceeding 1.5 mg/l is affecting around 260 million worldwide. Globally, citizens of around 25 nations are exposed to adverse health effects due to the high concentration of fluoride (Jha & Tripathi, 2021). Mostly, the reason for high fluoride is geogenic in nature, and fluoride content in the groundwater in India has been increasing mainly due to the excessive withdrawal of groundwater. Around 62 million people are exposed to the risk of excess fluoride contamination in India (Jha & Tripathi, 2021). The groundwater in many states (Odisha, Rajasthan, Haryana, Punjab, Gujarat, West Bengal, Bihar, Gujarat, Uttar Pradesh, and Andhra Pradesh) of India has high fluoride concentrations. The concentration of fluoride in groundwater in Rohtas district in Bihar varied from 0.10 to 2.50 mg/l, while groundwater contamination due to fluoride in Gaya district (Bihar) varied from 0.19 to 14.4 mg/l. At the same time, the fluoride value in the groundwater of Bhagalpur district (Bihar) ranged from 0.00 to 1.34 mg/l. The low concentration (0.5–1.0 ppm) is necessary as it prevents dental caries, while a high concentration of fluoride causes fluorosis, while prolonged exposure to high fluoride content of above 4 ppm causes calcification in bones resulting in the formation of osteoporosis and osteosclerosis.

Nitrate contamination in drinking water is widely spread contaminations globally (Thapa et al., 2019). The sources of nitrate contamination in the groundwater are mainly the application of fertilizer, unlined drainage, sewerage lines, and human and animal wastes. There are various studies on nitrate contamination in groundwater performed in various parts of India, such as Thapa et al., (2019), Ahamad et al. (2018), and Ahada and Suthar (2018). The groundwater of Gharbar village in Jharkhand, India, had nitrate contamination from 34.10 to 319.10 mg/l, which is much more than the specified limit of 45 mg/l as per BIS (Thapa et al., 2019). The groundwater in Varanasi, Uttar Pradesh, India, was found to have nitrate content ranging from 40.32 to 78.97 mg/l, and around 80% of the groundwater samples exceeded the specified limit of 45 mg/l (Ahamad et al., 2018). Similarly, the groundwater nitrate concentration in the southern district of Punjab, India, varied from 38.45 to 198.05 mg/l, and over 92% of sites showed a high level of nitrates exceeding the specified limit (Ahada & Suthar, 2018). 26% of groundwater samples of Nirmal province in the South exceeded the specified limits and were found to have a significantly high nitrate concentration (Adimalla et al., 2018). The groundwater nitrate concentration in the rural areas of Rajasthan, India, also exceeded the specified limits and ranged from 7.10 to 82.0 mg/l (Suthar et al., 2009). The risk of nitrate-contaminated groundwater was also found in Anantapur District in Andhra Pradesh, India, where 65% of groundwater samples had nitrate content higher than the specified limit examined during the pre-monsoon (Reddy et al., 2009). The existing studies revealed that the problem of high nitrate content in the groundwater is prevailing in most parts of India. The high nitrate content has numerous adverse health effects such as methemoglobinemia in infants and causes gastric cancer and thyroid gland hypertrophy, respiratory trouble and multiple sclerosis in adults.

4 Study Area

The study area is Patna district, located in South Bihar alluvial plains. It is located at an elevation of 174 feet on the southern bank of Ganges'. It is surrounded by the Samastipur and Saran districts in the north, Begusarai in the east, and Bhojpur in the west, and the river Ganges separates it from the Vaishali district. The present study area lies between 25°21′45.83"N, 85°42′19.54″E, and 25°28′22.78"N 83°51′51.40″E. The climate of the district is extreme in nature, with high temperatures during summer and low temperatures during winter. The monsoon starts in June and lasts till September. The Patna district lies in the flat region, having a high presence of alluvium, making it fertile for agricultural use (Chettry & Surawar, 2021). Despite its location on the banks of the Ganges, water needs of the city are fulfilled entirely by underground aquifers (Saha et al., 2014). The water level ranged from 0.54 m bgl to 8.92 m bgl during the pre-monsoon period (May 2020) in the Patna district, while during mid-monsoon (August 2020) ranged from 0.12 m bgl to 5.03 m bgl. Similarly, the water table varied from 1.82 m bgl to a maximum of 11.47 m bgl during the post-monsoon (November 2020) and during the recession (January 2021) ranged from 0.78 m bgl to 7.99 m bgl (CGWB, 2021). The decadal mean variation of the water table between January 2011 and January 2021 revealed a rise in the water table in 87% of wells and a decline in 13% of wells (CGWB, 2021).

5 Methodology

The physicochemical and ion-related data for groundwater samples in the Patna district have been taken from CGWB (2021). A total of 35 dug wells known as hydrograph network stations (HNS) were examined in the district. These HNSs were monitored for pre-monsoon, mid-monsoon, post-monsoon, and recession periods. The present study assessed the suitability of groundwater for drinking and irrigation purposes by comparing the physicochemical and ion concentration data of groundwater samples in the study area to the water quality parameters specified by the World Health Organization (WHO, 2004) and the Bureau of Indian Standards (BIS 2012). The groundwater samples were collected in airtight polypropylene bottles having capacity of 1 L and standard American Public Health Agency (APHA) (2017) and BIS methods were adopted to analyze the samples for basic parameters. Various parameters included in the study were pH, EC, TDS, TH, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, NO_3^{-}, SO_4^{2-}, and F^{-}. Coliform and arsenic were not within the scope of study. The data published in the report (CGWB, 2021) were verified, and error balance percentage of the analyzed geochemical data of the water samples was within the range of acceptability (±5%).

6 Results and Discussion

This section evaluates and discusses the appropriateness of groundwater in the Patna district for drinking and irrigation, considering significant physicochemical characteristics such as pH, electrical conductivity (EC), total dissolved solids (TDS), and so on, as well as major ions such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, NO_3^{-}, SO_4^{2-}, and F^{-} .

6.1 Suitability for Drinking Purposes

The physicochemical characteristics and values of the major ions present in groundwater samples of different locations in the Patna district have been presented in Table 12.1. All the values are in mg/l except for the pH and EC values. The range of physicochemical parameters value in the study area is shown in Table 12.2.

Table 12.1 Physicochemical characteristics of groundwater in the study area

S.No.	Block	pH	EC (μs)	TDS	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	NO_3^{-}	SO_4^{2-}	F^{-}
1	Bihta	7.38	1649	1072	420	130	23	150	60	622	142	51	49	0
2	Paliganj	8.23	908	590	170	24	27	103	35.6	476	18	14	21	0.3
3	Dulhin bazar	8.29	841	547	355	80	38	30	1.49	238	89	48	45	0
4	Bikram	8.1	980	637	245	58	24	104	15.1	348	60	51	61	0.2
5	Bikram	7.5	463	301	205	24	35.2	13	0.49	234	11	1	5.2	0.112
6	Abarh	7.91	518	337	175	42	17	33	2.91	252	15	0	7.5	0.257
7	Bihta	8.05	327	213	135	26	17	10	1.58	166	9	0	3.9	0.211
8	Phulwari	7.82	578	376	215	40	27.9	22	2.07	301	25	0	6.1	0.27
9	Bakhtiyarpur	8.23	621	404	155	10	31.6	57	2.94	332	23	0	16.6	0.09
10	Bihta	8.07	654	425	170	36	19.4	40	37.12	228	48	41.3	18.1	0.17
11	Barh	8.19	946	615	220	8	48.6	94	0.09	572	8	0.2	4.6	0.78
12	Bihta	8.06	560	364	200	38	25.5	23	2.61	289	10	1.4	9.9	0.28
13	Daniyawan	7.95	515	335	190	36	24.3	20	1.19	295	4	0	3.1	0.36
14	Danapur	8.02	376	244	150	28	19.4	15	1.57	221	2	0	2.5	0.37
15	Punpun	8.0	464	302	165	32	20.7	17	1.62	271	6	0	4.3	0.16
16	Bikram	8.1	497	323	205	32	30.4	9	1.07	320	3	0	2.2	0.3
17	Dulhinbazar	8.16	398	259	160	34	18.2	12	1.02	197	9	3	4.4	0.14
18	Phulwari	7.87	839	545	300	58	37.7	43	10.21	443	26	2.7	13.6	0.38
19	Naubatpur	8.05	504	328	200	26	32.8	19	2.09	283	10	0	3.3	0.4
20	Fatuha	8.07	655	426	260	16	53.5	49	2.81	301	39	12.8	10.1	0.11
21	Danapur	7.99	664	432	255	42	36.5	22	1.95	381	13	5.4	6.8	0.3
22	Maner	7.9	729	474	250	48	31.6	36	4.75	264	80	14.7	27.8	0.3
23	Danapur	8.15	416	270	190	34	25.5	5	1.82	228	3	0	2.6	0.4
24	Patna Sadar	8.08	554	360	205	40	25.5	19	2.87	338	10	0	6.7	0.33
25	Maner	8.18	1033	671	435	52	74.1	30	8.21	480	104	5	24.5	0.43

S.No.	Block	pH	EC (μs)	TDS	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	Cl^-	NO_3^-	SO_4^{2-}	F^-
26	Maner	7.98	986	641	380	54	59.5	28	6.4	449	52	18.5	21.5	0.49
27	Mokama	8.03	736	478	265	38	41.3	48	2.66	351	41	0.2	24.3	0.25
28	Bikram	8.07	511	332	185	34	24.3	22	1.84	197	67	0	3.9	0.33
29	Patna Sadar	7.94	819	532	280	50	37.7	42	1.89	264	110	0	16.6	0.19
30	Mokama	8.18	474	308	150	28	19.4	34	2.43	221	16	0	11.3	0.48
31	Maner	8.32	401	261	175	30	24.3	13	1.86	209	15	0	4.4	0.26
32	Bikram	8.2	400	260	150	20	24.3	15	1.3	240	5	0	3.1	0.39
33	Phulwari	8.11	418	272	140	22	20.7	25	1.93	252	6	0	3.4	0.35
34	Patna City	8.06	439	285	190	22	32.8	22	2.82	240	12	0	6.6	0.14
35	Barh	8.0	509	331	200	36	26.7	20	1.74	308	9	4.5	4.9	0.5
36	Barh	7.96	538	350	194	28	30.2	23	4.4	308	0	0	0	0
37	Naubatpur	8.06	590	384	235	40	32.8	24	1.14	308	13	0	0	0

[a] All units are in mg/l except pH and EC

Table 12.2 The range of physicochemical parameters in the study area

Sl. No.	Water quality parameters[a]	WHO standards 2004		Indian standard (BIS 10500, 2012)		Range in the study area
		Most desirable limit	Max. allowable limit	Highest desirable	Max. permissible	
1	pH	6.5	8.5	6.5–8.5	6.5–9.5	7.38–8.32
2	EC (μs/cm)	1500	–	–	–	327–1649
3	TDS	500	1500	500	2000	213–1072
4	TH (as $CaCO_3$)	100	500	300	600	135–435
5	Ca^{2+}	75	200	75	200	8.0–130
6	Mg^{2+}	50	150	30	100	17.0–74.1
7	Na^+	–	200	–	200	5.0–150
8	K^+	–	12	–	–	0.09–60
9	HCO^-_3	–	–	–	–	166–622
10	Cl^-	200	400	200	400	0.0–142
11	F^-	1.00	1.5	1.00	1.5	0.0–0.78
12	NO^-_3	–	50	–	45	0.0–51.0
13	SO^{2-}_4	200	400	200	400	0.0–61.0

[a] All units are in mg/l except pH and EC

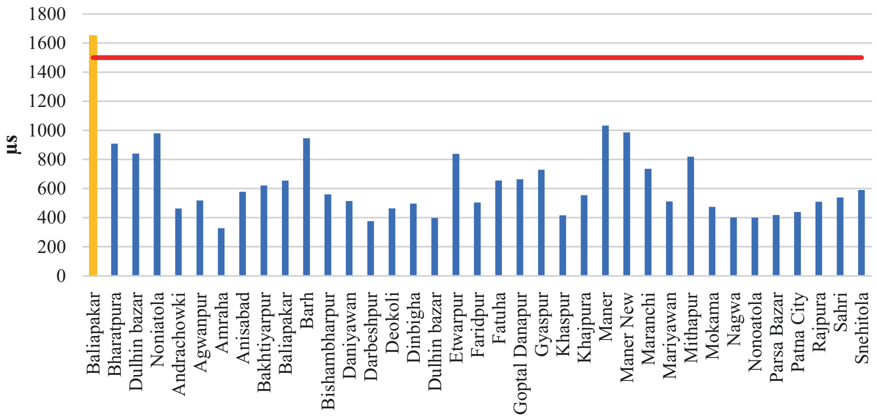

Fig. 12.10 EC values in the groundwater samples of different locations in the Patna district

pH

The quantitative measure of the basicity or acidity of an aqueous solution is called pH. The pH of drinking water must be within the standard limit of 6.5–8.5 mentioned by the WHO and BIS. The pH of groundwater samples of the study area ranged from 7.38 to 8.32, with the average value of 8.03 indicating that the groundwater was somewhat alkaline or basic in character. The alkaline nature of groundwater in the Patna district can be attributed due to the absence of any major industry in the study area.

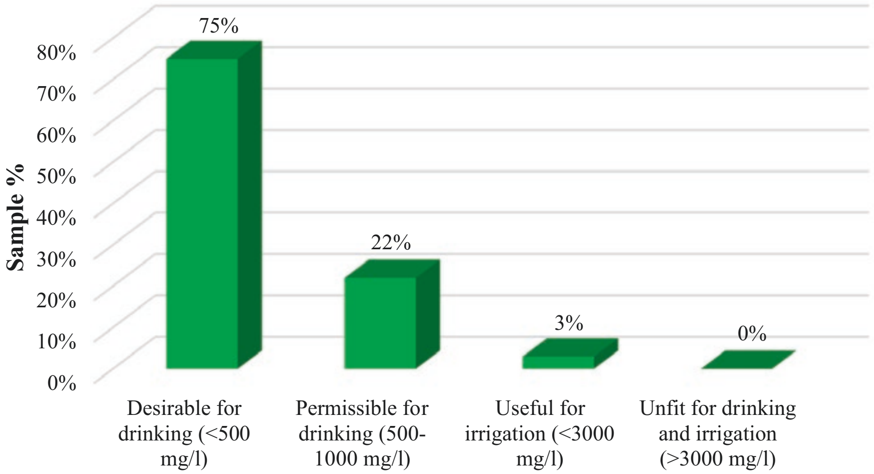

Fig. 12.11 Groundwater quality in the study area based on TDS

Electrical Conductivity

Electrical conductivity (EC) refers to the capacity of water to carry electricity. It varies directly with the variation of dissolved material in the water. According to WHO (2004), the recommended level in drinking water is 1500 μhos/cm. The EC of groundwater in the Patna district varied from 327 to 1649 μs at 25 °C, having an average of 635.40 μs. The EC values of groundwater samples of different locations are shown in Fig. 12.10. The EC was found to be within the desirable limit as mentioned by WHO (2004) in all the study area at all locations except one. The location is Baliapakar in block Paliganj of Patna district with an EC of 1649 μs. The low values of EC in the research region indicated groundwater samples with less dissolved salts. The high value of EC at one location in the study area may be due to some anthropogenic causes. The EC value less than 1500 μmhos/cm is classified as type I where enrichment of salts is low; type II, when EC is between 1500 and 3000 μmhos/cm in which the enrichment of salts is medium; and type III, when EC > 3000 μmhos/cm having high enrichments of salts. According to the aforementioned classification, 97% of groundwater samples are classified as type I, which has little salt concentration, while 3% of total groundwater samples under type II have medium salt enrichment.

Total Dissolved Solids

Total dissolved solids (TDS) in groundwater is the overall concentration of dissolved solids. TDS majorly include inorganic salts such as potassium, calcium, sodium, carbonate, and bicarbonate. According to WHO, the highest recommended TDS level is 500 mg/l, while the maximum is 1500 mg/l. As per BIS, the acceptable level is 500 mg/l, but the maximum permitted is 2000 mg/l. TDS values ranged from 213 to 1072 mg/l, having an average of 413 mg/l in the study area. Out of the total 37 locations, TDS values at 28 locations are found to be within the highest desirable

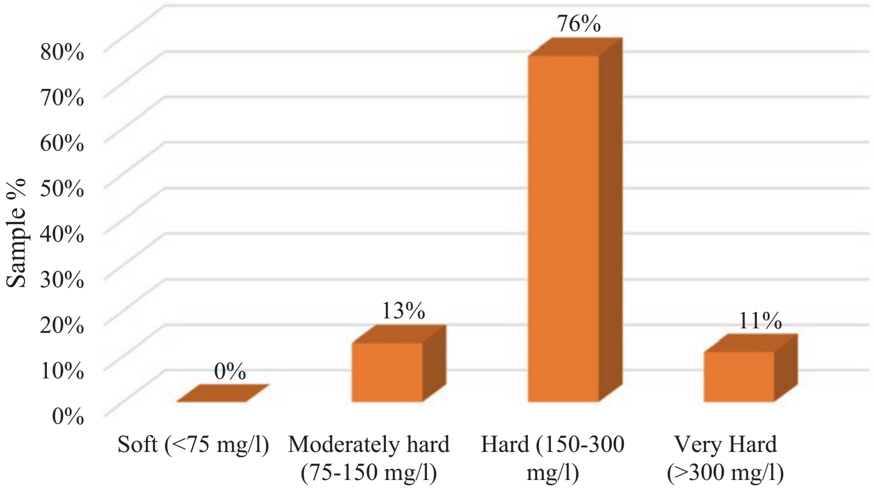

Fig. 12.12 Groundwater quality for drinking in the study area based on TH

or acceptable limit, while TDS at the remaining 9 locations falls under max allowable or permissible limit. TDS values have not exceeded the permissible limit at any of the locations in the Patna district. The reason for high TDS values at some locations may be the percolation of sewage into the groundwater or the leaching of salts from the soil. Groundwater has been classified based on TDS values by Davis and De Wiest (1966). Based on this classification, it was found that 75% of the groundwater samples (TDS < 500 mg/l) are fit for drinking, while 22% of the samples (500–1000 mg/l) are permissible for drinking (Fig. 12.11).

Total Hardness

Total hardness (TH) is the amount of dissolved magnesium and calcium in the water. The TH values varied from 135 to 435 mg/l, having an average of 221 mg/l in the Patna district. As per WHO (2004), the most desirable limit of hardness is 100 mg/l, and the maximum allowable limit is 500 mg/l, while BIS (2012) specifies 300 mg/l as the highest desirable limit and 500 mg/l as the maximum permissible limit. The hardness at all the locations of the research area was found to be greater than the most desirable limit (100 mg/l) as specified by WHO, while none of the locations had hardness values greater than the maximum allowable limit. According to BIS (2012), 4 out of a total of 37 sites had hardness levels higher than the highest recommended limit of 300 mg/l. None of the locations had hardness values greater than the maximum permissible limit. Based on TH, Sawyer and McCarthy (1967) classified groundwater. According to this classification, none of the groundwater samples was soft (TH < 75 mg/l); 13% were moderately hard (75–150 mg/l); 76% were hard (150–300 mg/l) while 11% were very hard (TH > 300 mg/l) (Fig. 12.12).

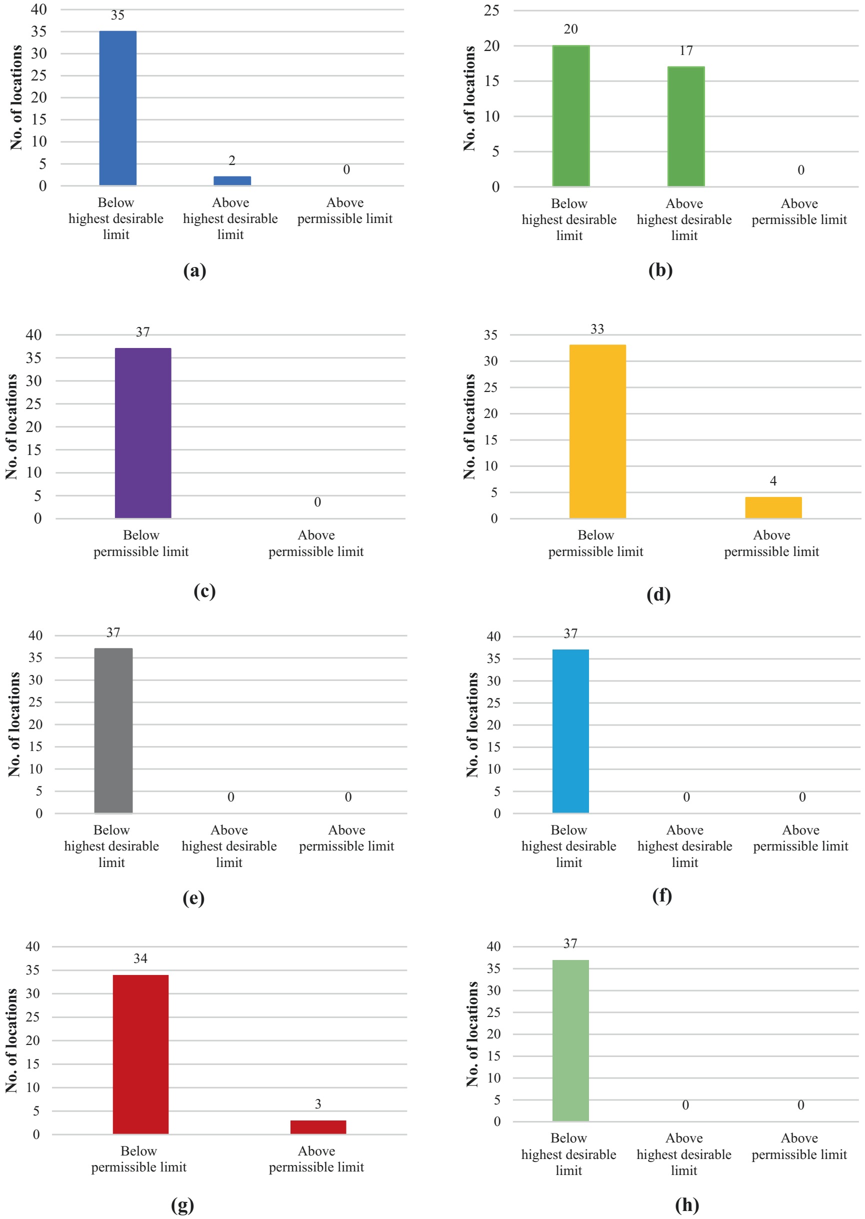

Fig. 12.13 Concentration in the groundwater of (**a**) Calcium (Ca^{2+}), (**b**) Magnesium (Mg^{2+}), (**c**) Sodium (Na^{+}), (**d**) Potassium (K^{+}), (**e**) Chloride (Cl^{-}), (**f**) Flouride (F^{-}), (**g**) Nitrate (NO_3^{-}), and (**h**) Sulfate (SO_4^{2-})

Calcium and Magnesium

The Ca and Mg are present mostly in the form of bicarbonates and to a less extent in the form of chloride and sulphate. When the groundwater comes in contact with certain rocks and minerals, these minerals get dissolved, releasing calcium and magnesium. Ca and Mg deficiency in drinking causes oncological diseases, gastrointestinal, respiratory systems, and cardiovascular diseases (Rapant et al., 2017). The Ca^{2+} concentration in groundwater samples ranged from 8 mg/l to 130 mg/l having an average 38 mg/l. As seen in Fig. 12.13a, the value of Ca^{2+} exceeded the most or highest desirable limit of 75 mg/l at two of the locations in the study area, while at the rest 35 locations, the value was within the highest desirable limit (<75 mg/l). In the study area, none of the locations exceeded the value of the maximum allowable or maximum permissible limit (>200 mg/l) of Ca^{2+}. Similarly, the value of Mg^{2+} varied from 17 mg/l to 74.1 mg/l with an average of 31 mg/l (Fig. 12.13b). Out of total 37 locations, 20 locations had Mg^{2+} value below highest desirable limit (< 30 mg/l). The value of Mg^{2+} at 17 locations (46%) in the study region surpassed the value of the highest desired limit of 30 mg/l as per BIS (2012) while at all the locations, the value of Mg^{2+} was within the maximum permitted limit of 100 mg/l as specified in BIS (2012). When compared to the most desirable limit of 50 mg/l specified by WHO, the value of Mg^{2+} exceeded at 3 locations out of a total of 37 locations in the study area.

Sodium and Potassium

Sodium is present in most groundwater and is a highly reactive alkali metal. The source of sodium in groundwater is the rocks containing sodium compounds which dissolve to release sodium in groundwater. The various health issues due to high Na-concentrated groundwater intake are hyperosmolarity, high blood pressure, oedema, and not suitable for agricultural use. The Na content of the groundwater samples in the Patna district varied from 5 mg/l to 150 mg/l. Na content in the groundwater was found to be within the limit of maximum allowable or maximum permissible limit (<200 mg/l) as specified by WHO and BIS and none of the locations had groundwater sapmles exceeding the highest permissible limit (> 200 mg/l) (Fig. 12.13c). The K content in the groundwater across the locations in the study area varied from 0.09 to 60 mg/l having an average value of 6.31 mg/l. The K content in the groundwater was found to be in low concentrations (< 10 mg/l) in most of the locations, while at 5 locations out of 37 locations, the concentration was found to be more than 10 mg/l. As per WHO, the maximum allowable limit is 12 mg/l, and the K concentration at 4 locations exceeded the above limit (>12 mg/l) (Fig. 12.13d). Whereas groundwater samples from 33 locations had K concentration below permissible limit (<12 mg/l). The high potassium content in a few locations can be attributed due to the leaching of potassium through the soil into the groundwater from the use of fertilizer containing potassium.

Bicarbonate

Bicarbonate is present in the groundwater majority due to the carbonate rocks such as limestone and dolomite. The reaction involved between carbonate rocks and carbon dioxide in the aqueous environment produces an alkaline environment. The bicarbonate concentration varied from 166 mg/l to 622 mg/l. The oxidizing organic matter in the aquifer can be the reason for the high bicarbonate content (Saha et al., 2019).

Chloride and Fluoride

The sources of chloride in the groundwater are intrusion of saltwater, municipal and industrial effluents, weathering, leaching of sedimentary rocks and soils, etc. (Karanth, 1987). Usually, chlorides do not have adverse effects on human health, but the sodium part of table salt may lead to heart and kidney disease. The groundwater sample had chloride concentrations ranging from 0 to 142 mg/l. The chloride content across all the locations was found to be within the most desirable limit (<200 mg/l) specified by WHO and BIS (Fig. 12.13e). The source of fluoride in the groundwater is mainly geogenic in nature (Ram et al., 2021; Karunanidhi et al., 2020), resulting from the presence of added minerals such as pyroxene, and biotite, fluorite, and apatite in the rocks (granite and hornblende). These minerals release fluoride ions into groundwater during silicate weathering and dissolution processes. Industries that use fluoride minerals as raw material, such as brick and ceramics manufacture, mining, and pottery, also contribute to the occurrence of fluoride in groundwater (Yadav et al., 2019). Fluoride intake in small quantities (<0.5 mg/l) is recommended as it reduces dental caries, whereas intake of higher concentrations (>1.5 mg/l) leads to fluorosis (Jha et al., 2013). Fluoride concentrations in groundwater and various sources of water are causing severe concerns in India (Mukherjee & Singh, 2018). The high fluoride-contaminated groundwater exists in 20 states out of a total of 29 states of India (Subba Rao et al., 2020). The groundwater samples in the study region had fluoride concentrationss varying from 0 to 0.78 mg/l which is well below the maximum permissible limits of 1.5 mg/l and also below highest desirable limit (<1 mg/l) specified by the WHO and BIS (Fig. 12.13f).

Nitrate and Sulfate

The presence of nitrate in the groundwater in higher concentrations is a common and alarming problem all over the world, including in India. The various sources of nitrate contamination are leaching and oxidation of nitrogenous compounds, fixation, intensive agriculture, and unsewered sanitation. The maximum allowable limit of nitrate is 50 mg/l specified by WHO and 45 mg/l specified by BIS (Adimalla, 2020). In India, the nitrate concentration is generally higher than the specified limit in the intensively cultivable states such as Delhi, Maharashtra, Punjab, Haryana, Andhra Pradesh, West Bengal, Rajasthan, Uttar Pradesh, and Delhi (Suthar et al., 2009). The intake of groundwater containing a high concentration of nitrate above the specified limit causes several health problems such as methemoglobinemia, increases the risk of certain cancers, and impacts fetal development during pregnancy (Mathewson et al., 2020). The consumption of groundwater containing high nitrate content is also harmful to animals causing various diseases such as gastrointestinal cancer, vascular dementia, Alzheimer's disease, multiple sclerosis, absorptive, and hypertrophy of the thyroid (Suthar et al., 2009). Above 13 million people in India are drinking water having nitrate above the maximum allowed limit of 50 mg/l (Adimalla, 2020). The nitrate level in the study area's groundwater ranged from 0 mg/l to 51 mg/l, with an average of 7.42 mg/l. The value of nitrate in groundwater is below 10 mg/l across 30 locations (81%) out of 37 locations. Whereas nitrate content at four locations was found to be higher than 40 mg/l out of which three locations had nitrate content in the groundwater above the specified maximum

Table 12.3 Na%, SAR, MH, and KR values of groundwater samples

S. No.	Block	Location	Na%	SAR	MH	KR
1	Paliganj	Baliapakar	48.99	3.2	15.03	0.98
2	Paliganj	Bharatpura	61.19	3.4	52.94	2.02
3	Dulhin bazar	Dulhin bazar	15.82	0.7	32.20	0.25
4	Bikram	Noniatola	50.14	2.9	29.27	1.27
5	Bikram	Andrachowki	12.44	0.4	59.46	0.22
6	Abarh	Agwanpur	30.06	1.1	28.81	0.56
7	Bihta	Amraha	14.84	0.4	39.53	0.23
8	Phulwari	Anisabad	19.07	0.7	41.09	0.32
9	Bakhtiyarpur	Bakhtiyarpur	45.18	2.0	75.96	1.37
10	Paliganj	Baliapakar	44.19	1.3	35.02	0.72
11	Barh	Barh	48.19	2.7	85.87	1.66
12	Bihta	Bishambharpur	21.06	0.7	40.16	0.36
13	Daniyawan	Daniyawan	19.16	0.6	40.30	0.33
14	Danapur	Darbeshpur	18.70	0.5	40.93	0.32
15	Punpun	Deokoli	19.14	0.6	39.28	0.32
16	Bikram	Dinbigha	9.43	0.3	48.72	0.14
17	Dulhinbazar	Dulhin bazar	14.58	0.4	34.87	0.23
18	Phulwari	Etwarpur	26.21	1.1	39.39	0.45
19	Naubatpur	Faridpur	18.09	0.6	55.78	0.32
20	Fatuha	Fatuha	29.75	1.3	76.98	0.71
21	Danapur	Goptal Danapur	16.53	0.6	46.50	0.28
22	Maner	Gyaspur	25.28	1.0	39.70	0.45
23	Danapur	Khaspur	6.56	0.2	42.86	0.08
24	Patna Sadar	Khajpura	18.06	0.6	38.93	0.29
25	Maner	Maner	14.79	0.6	58.76	0.24
26	Maner	Maner new	15.41	0.6	52.42	0.25
27	Mokama	Maranchi	28.94	1.3	52.08	0.61
28	Bikram	Mariyawan	21.40	0.7	41.68	0.38
29	Patna Sadar	Mithapur	25.11	1.1	42.99	0.48
30	Mokama	Mokama	33.95	1.2	40.93	0.72
31	Maner	Nagwa	15.00	0.4	44.75	0.24
32	Bikram	Nonoatola	18.55	0.5	54.85	0.34
33	Phulwari	Parsa bazar	28.92	0.9	48.48	0.59
34	Patna city	Patna city	21.36	0.7	59.85	0.40
35	Barh	Rajpura	18.61	0.6	42.58	0.32
36	Barh	Sahri	22.24	0.7	51.89	0.40
37	Naubatpur	Snehitola	18.53	0.7	45.05	0.33

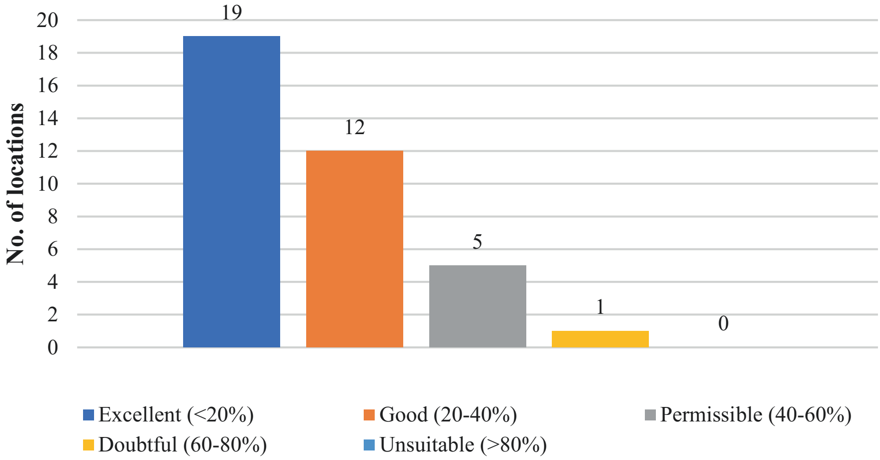

Fig. 12.14 Groundwater quality for irrigation in the study area based on sodium percentage

permitted limit (>45 mg/l) as specified by WHO and BIS (Fig. 12.13g). The nitrate concentration in the groundwater samples at 34 locations found to be below permissible limit (<45 mg/l). The sources of sulfate in the groundwater are both natural and anthropogenic. The natural sources include deposition from the atmosphere, sulfate mineral dissolution and oxidation, and sulfide mineral oxidation, while the anthropogenic sources include power plants, coal mines, power plants, metallurgical and phosphate refineries (Miao et al., 2012). The intake of sulfate higher than the specified limits causes diarrhea in humans. The recommended sulfate limit in groundwater is 200 mg/l, but the allowed maximum is 400 mg/l, as specified by WHO and BIS. Sulfate levels in groundwater in the study region varied from 0 to 61 mg/l, with an average of 12.43 mg/l. The sulfate content in groundwater did not reach the highest recommended limit (<200 mg/l) in any of the study area locations (Fig. 12.13h).

6.2 Irrigation Suitability

The groundwater suitability for irrigation purposes has been assessed based on various salinity indices such as sodium percentage (Na%), sodium absorption ratio (SAR), magnesium hazards (MH), and Kelly's ratio (KR). The calculated values of various water quality parameters to be used for irrigation of the groundwater samples in the study area are shown in Table 12.3.

Sodium Percentage (Na%)

The presence of excess sodium in groundwater combines with carbonates forming alkaline soils, while a combination of sodium with chlorine causes saline soils resulting in reduced permeability of the soil, affecting the plant or crop growth adversely. The sodium percentage was calculated using the equation below (Rao & Latha, 2019):

$$Na(\%) = \left(\frac{\mathrm{Na}^{+} + \mathrm{K}^{+}}{\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^{+} + \mathrm{K}^{+}} \right) \times 100 \tag{12.1}$$

The water used for irrigation should have a sodium percentage of less than 60%. The sodium percentage varied from 6.56% to 61.19% (Table 12.3). The sodium percentage was within the suitable range in all the locations of the Patna district except at Paliganj block in Bharatpura. Wilcox (1955) categorized the suitability of groundwater for irrigation based on Na%. According to this classification, groundwater samples of 19 locations had excellent suitability for irrigation purposes, while groundwater samples of 12 locations were of good category for irrigation. The groundwater samples at five locations fall in the permissible category based on sodium percentage, whereas the groundwater sample of one location fall in the doubtful category. There were no groundwater samples under the not suitable category for the irrigation purpose based on sodium percentage (Fig. 12.14).

Sodium Absorption Ratio (SAR)

SAR is a measure of water quality used for irrigation because the concentration of sodium reduces soil permeability (Todd, 1959; Richards, 1954). The SAR values in the samples of groundwater in the Patna district ranged from 0.2 to 3.4, indicating that the groundwater is observed to be of an excellent category as SAR values are less than 10 and can be used for irrigation (Table 12.4).

Magnesium Hazard (MH)

The presence of magnesium and calcium ions is essential as they cause friability of soil. However, high content of magnesium and calcium increases the pH of soil causing phosphorus loss. The groundwater having MH < 50% is suitable for irrigation (Szabolcs & Darab, 1964):

$$MH = \left(\mathrm{Mg}^{2+} \times 100\right) / \left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}\right) \tag{12.2}$$

Table 12.4 Classification of groundwater as per SAR values

Water quality	SAR values	Number of samples
Excellent	<10	37
Good	10–18	–
Permissible	18–26	–
Doubtful	>26	–

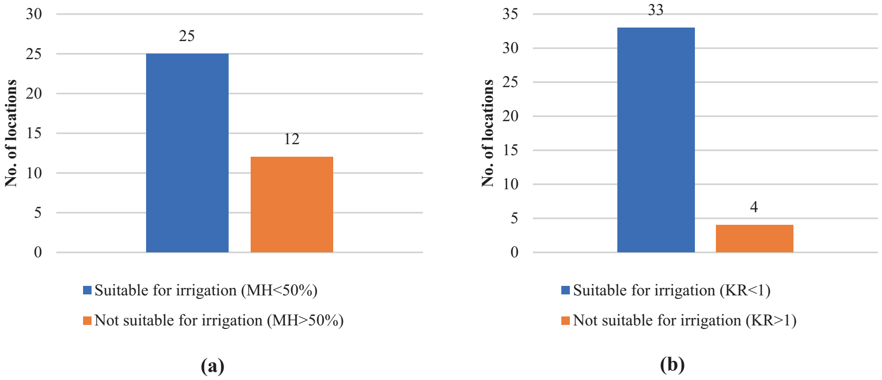

Fig. 12.15 Groundwater quality for irrigation in the study area based on (**a**) magnesium hazard values and (**b**) Kelly's ratio values

The MH values in the groundwater samples varied from 15.03 to 85.87% (Table 12.3). In the study area, the groundwater samples at 12 locations (32%) had MH values above 50% and are considered not suitable for irrigation with respect to magnesium concentration in the groundwater, as shown in Fig. 12.15a.

Kelly's Ratio (KR)

Kelly ratio value also indicates the suitability of the groundwater for irrigation purposes and is expressed as Kelley (1951):

$$KR = \left(\frac{\mathrm{Na}^{+}}{\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}}\right) \tag{12.3}$$

where the cations concentration is in mg/l.

KR values <1 indicate groundwater to be of good quality and suitable for irrigation, while KR >1 indicates groundwater is not suitable for irrigation. The KR values in the groundwater sample of the study area varied from 0.08 to 2.02. Out of the total 37 locations, 33 locations groundwater samples were suitable for irrigation as KR <1, while groundwater samples at 4 locations were not suitable for irrigation as KR >1 (Fig. 12.15b).

7 Conclusions

The groundwater in most parts of the Patna district was suitable for drinking, as most parameters were within the specified limits of WHO and BIS. The pH was found to be within range in all the locations while EC value exceeded in one location (Baliapakar in Paliganj). TDS was also within the specified limit, while TH values did not exceed the maximum allowable limit. The foremost anions and cations such as Ca^{2+}, Na^{+}, Mg^{2+}, Cl^{-}, F^{-} and $SO^{2-}{}_4$ were found to be within the maximum permissible limit, while K^{+} concentration exceeded the maximum allowable limit at four locations [Baliapakar (Paliganj), Bharatpura (Paliganj), Noniatola (Bikram), and Baliapakar (Paliganj)] in the study area. The concentration of $NO^{-}{}_3$ surpassed the maximum permitted level of 45 mg/l stipulated by BIS in 3 of the 37 research locations [Baliapakar (Paligang), Dulhin Bazar, and Noniatola (Bikram)]. Although most of the above parameters were within the range, parameters such as coliform value and arsenic content are also equally important and need to be measured before declaring groundwater fit for drinking. The majority of the groundwater in the study area was acceptable for irrigation as per the presence of Na% at all the locations was within the permissible range except for one location (Bharatpura in Paliganj), the SAR values also fall in the excellent category. The KR value was more than 1 in the groundwater samples at four locations [Bharatpura (Paliganj), Barh, Bakhtiyarpur, Noniatola (Bikram)] indicating unsuitable for irrigation, whereas the study found that the MH values of the groundwater were high in a few locations. The MH values were observed to be greater than 50% at 12 locations [Barh, Fatuha, Bakhtiyarpur, Patna City, Andrachowki (Bikram), Maner, Faridpur (Naubatpur), Bikram, Palihanj, Maranchi (Mokama), Sahri (Barh)] indicating groundwater samples were not suitable for irrigation.

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Declaration All the authors of this manuscript do not have any competing interests.

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