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Groundwater Quality in Maharashtra, India : Focus on Nitrate Pollution

INDRANI GUPTA+, ABHAYSINH SALUNKHE, NANDA ROHRA AND RAKESH KUMAR

Groundwater Survey and Development Agency (GSDA), Central Ground Water Board (CGWB) and Maharashtra Pollution Control Board (MPCB) have been carrying out groundwater quality monitoring at about 1407 monitoring locations in various districts of Maharashtra state in India. The groundwater quality data for pH, TDS, total hardness, sulphate, flouride and nitrate were compared with BIS: 10500:2004-2005 standards for drinking purpose. The results show that nitrate pollution is becoming more prevalent in groundwater of Maharashtra. Water quality data during the period 2007-2009 show that 544 locations out of 1407 locations exceeded 45 mgl^{-1}, the allowable NO_3 level for drinking water. About 227 locations exceeded nitrate level beyond100 mgl^{-1}. At 87 talukas in 23 districts of Maharashtra the NO_3 levels exceeded the standard in all samples monitored during 2007-2009. The Buldana district with highest locations (27) had nitrate above 100 mgl^{-1} followed by Amravati (24) and Akola (20) districts. At 7 talukas in 4 districts, fluoride was found above permissible limit of 1.5 mgl^{-1}, 100% of the time. 2 talukas in 2 districts of Maharashtra showed 100% non compliance of pH as per BIS standard of 6.5-8.5 mgl^{-1}. The districts having good to excellent quality of groundwater were Bhandara, Gondia, Kolhapur, Mumbai city, Mumbai Suburban, Nandurbar, Raigad, Ratnagiri, Satara, Sindhudurg, Thane and Washim. Vaijapur taluka in Aurangabad, Sinnar in Nashik and Kalambh taluka in Osmanabad have very poor water quality. Paithan taluka in Aurangabad, Shegaon taluka at Buldhana district, Amolner taluka at Jalgaon district and Jafrabad in Jalna district have water unsuitable for drinking.

Key words: *Groundwater quality, nitrate, Maharashtra*

1. Introduction

Groundwater plays a crucial role as a decentralized source of drinking water for million rural and urban families. Groundwater can have some dissolved forms of chemicals, which may be unacceptable due to their chronic health effects, taste and aesthetic reasons. According to some estimates, groundwater accounts for nearly 80 percent of the rural domestic water needs, and 50 percent of the urban water needs in India. Groundwater is generally less susceptible to contamination and pollution when compared to surface water bodies. Also, the natural impurities in rainwater, which replenish groundwater systems, get removed while infiltrating through soil strata. But, in India, where groundwater is used intensively for irrigation and industrial purposes, a variety of land and water-based human activities have been causing pollution to this precious resource. Its over-exploitation is causing aquifer contamination in certain instances, while in certain other cases, its unscientific development within sufficient knowledge of groundwater flow dynamic and geo-hydro chemical processes has led to its mineralization. The pollution of groundwater from diffuse sources, such as agriculturally derived nitrate, sewerage, organic garbage, livestock excreta, etc can pose risks to human health[1]. The commonly observed contaminants, such as arsenic, fluoride and iron are geogenic, whereas contaminants such as nitrates, phosphates, heavy metals etc. owe their origin to various human activities including domestic sewerage, agricultural practices and industrial effluents.

In this study, the groundwater quality data for Maharashtra, India (**Fig. 1**) monitored by Groundwater Survey and Development Agency (GSDA), Central Ground Water Board (CGWB) and MPCB were evaluated. The concentrations of significant parameters, viz. pH, TDS, total hardness, sulphate, flouride and nitrate were compared with BIS: 10500:2004-05 standards for drinking water[2]. Water quality index for these sites were calculated.

2. Study area

Maharashtra is located in the northern center of peninsular India, bordered by the Arabian sea to the west, Gujarat and the Union Territory of Dadra and Nagar Haveli to the northwest, Madhya Pradesh to the northeast, Chhattisgarh to the east, Karnataka to the south, Andhra Pradesh to the southeast, and Goa to the southwest. The state extends between the latitudes 15.6° North and 22.1° North and longitudes 72.6° East and 80.9° East. The

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Fig. 1 : A map of Maharashtra (India) indicating various districts

state covers an area of 307,731 km^2 (118,816 sq mi) or 9.84% of the total geographical area of India.

The Western Ghats also known as Sahyadri, are a hilly range running parallel to the coast, at an average elevation of 1,200 m. To the west of these hills lie the Konkan coastal plains, 50–80 km in width. To the east of the Ghats lies the flat Deccan Plateau. The third important region is the Satpura hills along the northern border, and the Bhamragad-Chiroli-Gaikhuri ranges on the eastern border form physical barriers preventing easy movement. These ranges also serve as natural limits to the state. The Western Ghats form one of the three watersheds of India, from which many South Indian rivers originate, notable among them being Godavari River, and Krishna, which flow eastward into the Bay of Bengal, forming one of the greatest river basins in India.

Maharashtra has typical monsoon climate, with hot, rainy and cold weather seasons. Tropical conditions prevail all over the state, and even the hill stations are not that cold. Mean temperature of western Maharashtra is 26-27ºC. Rainfall in Maharashtra differs from region to region. Thane, Raigad, Ratnagiri and Sindhudurg districts receive heavy rains of an average of 2000 mm annually. But the districts of Nasik, Pune, Ahmednagar, Dhule, Jalgaon, Satara, Sangli, Solapur and parts of Kolhapur get rainfall less than 500mm. Rainfall particularly concentrates to the Konkan and Sahyadrian Maharashtra. Central Maharashtra receives less rainfall. However, under the influence of the Bay of Bengal, eastern Vidarbha receives good rainfall in July, August and September.

The western Maharashtra comprising of Eastern half of Pune, Satara and Sangli, Solapur, Osmanabad, Beed and Ahmednagar has hot semi-arid ecosystem with black soil medium and deep black soils as inclusion. The districts of Nasik, Jalgaon (western part), Aurangabad, Northern hilly part of Ahmednagar, Jalna, Parbhani, Nanded and Latur have hot semi-arid ecosystem with shallow black soils (deep and medium black soils as inclusion). The eastern Maharashtra comprising of Buldana, Akola, Amravati and Yavatmal has hot semi-arid ecosystem with deep black soil (shallow and medium black soils as inclusion). Satara, Sangli, western part of Pune, Kolhapur (eastern part) have hot dry sub humid ecosystem with shallow black soils and deep black soils as inclusions.

3. Water quality index

For computing WQI of groundwater the relative weight of chemical parameters as considered by Ramakrishnaiah *et al*.[3], is modified and the modified relative weights of selected parameters are given in **Table 1.** The maximum weight of 5 has been assigned to the parameter nitrate due to its major importance in water quality assessment.

A quality rating scale (q_i) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the BIS:10500,(2004-05) and the result is multiplied by 100:

$$q_i = (C_i / S_i) \times 100 \quad (1)$$

where q_i is the quality rating, C_i is the concentration of each chemical parameter in mgl^{-1}, and S_i is the Indian drinking water standard for each chemical parameter in mgl^{-1} according to the guidelines of the BIS:10500 (2004-2005).

Table 1: Relative weights of chemical parameters

Parameter	BIS Standards	Weight (w_i)	Relative weight (W_i)		
			Original weights *	without Mn	without Fe and Mn
pH	6.5-8.5	4	0.09756	0.10811	0.12121
TH	300-600	2	0.04878	0.05405	0.06061
Calcium	75-200	2	0.04878	0.05405	0.06061
Magnesium	30-100	2	0.02439	0.05405	0.06061
Bicarbonate	244-732	3	0.07317	0.08108	0.09091
Chloride	250-1,000	3	0.07317	0.08108	0.09091
TDS	500-2,000	4	0.09756	0.10811	0.12121
Fluoride	1-1.5	4	0.09756	0.10811	0.12121
Manganese	0.3	4	0.09756		
Nitrate	45	5	0.12195	0.13514	0.15152
Iron	0.3-1.0	4	0.09756	0.10811	
Sulphate	200-400	4	0.09756	0.10811	0.12121

* Ramakrishnaiah *et al*.

Table 2 : Water quality classification based on WQI value*

WQI value	Water quality
<50	Excellent
50-100	Good
100-200	Poor
200-300	Very poor
>300	Unsuitable for drinking

* Ramakrishnaiah *et al.*

For computing the WQI, the sub index SI is first determined for each parameter, which is then used to determine the WQI as per the following equation:

$$SI_i = W_i \cdot q_i \qquad (2)$$

n

$$WQI = \sum_{i=1}^{n} SI_i \qquad (3)$$

where n is the number of parameters. The computed WQI values are classified into five types, "excellent water" to "water, unsuitable for drinking"[3].

4. Results and discussion

To compare the suitability of water for drinking purposes, the values are compared with the Bureau of Indian Standards (BIS 10500, 2004-05) for different parameters in drinking water. **Table 3** denotes the districts of Maharashtra with number of talukas having 100% exceedance of significant parameters of groundwater quality with drinking water standards (Indian).

Nitrate pollution

The results show that nitrate pollution is severe in Maharashtra. About 544 locations out of 1407 locations exceeded 45 mgl^{-1}, the allowable limit for drinking water. About 227 locations exceeded 100mgl^{-1}. At 87 talukas in 23 districts of Maharashtra the NO_3 levels exceeded the standard in all samples monitored during 2007-2009. The Buldana district with highest locations (27) had nitrate content above 100 mgl^{-1} followed by Amravati (24) and Akola (20). Districts like Ahmednagar, Akola, Amravati, Aurangabad, Beed, Bhandara, Buldhana, Chandrapur, Dhule, Gadchiroli, Gondia, Jalgaon, Jalna, Latur, Nagpur, Nanded, Nashik, Osmanabad, Parbhani, Pune, Sangli, Solapur, Wardha, Washim and Yavatmal have shown nitrate concentrations exceeding 100 mgl^{-1}.

Greater NO_3^- intake reduces the oxygen carrying capacity in the blood by binding to hemoglobin, causing a condition referred to as methemoglobinemia[4] or blue baby syndrome which may cause mortality by asphyxiation especially in new born infants. Infants less than six months of age are at higher risk due to the presence of bacteria in their digestive systems that speed the binding process. A population-based case-control study in Nebraska found long-term consumption (30 years) of community water with average levels of nitrate 4 mgl^{-1} was positively associated with a two-fold risk for non-Hodgkin's lymphoma[5]. Continuous consumption of water containing high nitrate may cause several health hazards in animals, e.g. gastrointestinal cancer, alzheimer disease, vascular dementia, absorptive, secretive functional disorders of the intestinal mucosa, multiple sclerosis, non-Hodgkin's lymphoma, hypertrophy of thyroid, etc. NO_3 level between 45-89 mgl^{-1} is generally safe for human adults and livestock but should not be used for human infants. NO_3 levels between 89-176 mgl^{-1} are generally acceptable for human adults and all livestock unless food or feed sources are very high in nitrates. NO_3 level between 177-440 mgl^{-1} is dangerous for human adults and young livestock and probably acceptable for mature livestock if feed is low in nitrates. Above 440 mgl^{-1} water should not be used. **Fig. 2** indicates the frequency distribution of pre-monsoon nitrate concentration

Table 3: Number of talukas with 100% exceedance of significant parameters during 2007-2009

District	NO_3	TH	F	TDS	pH
Aurangabad	6	1		1	
Amravati	2	1	1	1	
Beed	6	3			
Bhandara	2				
Buldhana	7	1			
Chandrapur	4	1	4		
Dhule	1				
Gadchiroli	4	1			
Hingoli	1				
Jalgaon	7	2		2	
Jalna	6	5		1	
Kolhapur	1				
Latur	1	1			
Mumbai	4				
Nagpur	3	1	1		
Nanded	6	2	1		
Nashik	4	2			
Osmanabad	9	1			
Raigad		1		1	1
Sangli	5	2			1
Solapur	6	4			
Thane	1				
Wardha	1				
Total	**87**	**29**	**7**	**6**	**2**

Table 4: District wise correlation matrix for different groundwater parameters

District	N		SO_4^{-2}	NO_3^-	F^-	District	N		SO_4^{-2}	NO_3^-	F^-
Ahmednagar	**41**	Cl^-	0.67**	0.69**	0.35**	**Akola**	**107**	Cl^-	0.70**	0.25**	0.43**
		SO_4^{-2}		0.24	0.55**			SO_4^{-2}		0.23*	0.43**
		NO_3^-			0.07			NO_3^-			0.06
Amravati	**178**	Cl^-	0.77**	0.53**	0.078	**Aurangabad**	**15**	Cl^-	0.84**	0.89**	0.53**
		SO_4^{-2}		0.77**	0.17*			SO_4^{-2}		0.98**	0.39
		NO_3^-			0.02			NO_3^-			0.53*
Beed	**17**	Cl^-	0.57	0.77	0.26	**Bhandara**	**21**	Cl^-	0.92**	0.82**	0.01
		SO_4^{-2}		0.55	0.4			SO_4^{-2}		0.87**	-0.02
		NO_3^-			0.31			NO_3^-			-0.05
Buldhana	**116**	Cl^-	0.65**	0.57**	-0.05	**Chandrapur**	**39**	Cl^-	0.63	0.48	0.05
		SO_4^{-2}		0.43**	0.12			SO_4^{-2}		0.49	0.28
		NO_3^-			-0.27			NO_3^-			-0.1
Dhule	**16**	Cl^-	0.93**	0.81**	0.49	**Gadchiroli**	**42**	Cl^-	0.58	0.69	0.01
		SO_4^{-2}		0.7**	0.32			SO_4^{-2}	1	0.63	0.05
		NO_3^-			0.32			NO_3^-		1	0.14
Gondia	**27**	Cl^-	0.78	0.69	-0.01	**Jalgaon**	**35**	Cl^-	0.92**	0.91**	0.07
		SO_4^{-2}	1	0.86	0.14			SO_4^{-2}	1	0.82**	0.01
		NO_3^-		1	-0.08			NO_3^-		1	-0.1
Jalna	**18**	Cl^-	0.49**	0.82**	-0.01	**Latur**	**21**	Cl^-	0.23	0.42	-0.33
		SO_4^{-2}	1	0.37	0.4			SO_4^{-2}	1	0.67**	0.04
		NO_3^-		1	-0.01			NO_3^-		1	-0.12
Nagpur	**36**	Cl^-	0.06	0.15	-0.03	**Nanded**	**21**	Cl^-	0.92**	0.6**	0.4
		SO_4^{-2}	1	0.37*	-0.29			SO_4^{-2}	1	0.73**	0.35
		NO_3^-		1	-0.22			NO_3^-		1	0.22
Nashik	**30**	Cl^-	0.92**	0.6**	0.4	**Osmanabad**	**11**	Cl^-	0.88**	0.87**	0.22
		SO_4^{-2}	1	0.73**	0.35			SO_4^{-2}	1	0.92**	0.12
		NO_3^-		1	0.22			NO_3^-		1	0.32
Parbhani	**13**	Cl^-	0.95**	0.74**	-0.21	**Pune**	**40**	Cl^-	0.76**	0.59**	0.58**
		SO_4^{-2}	1	0.73**	0.02			SO_4^{-2}	1	0.41**	0.52**
		NO_3^-		1	-0.34			NO_3^-		1	0.43**
Sangli	**25**	Cl^-	0.52**	0.08	0.11	**Solapur**	**43**	Cl^-	0.67**	0.45**	0.37
		SO_4^{-2}	1	0.09	0.1			SO_4^{-2}	1	0.17	0.29
		NO_3^-		1	-0.21			NO_3^-		1	-0.05
Wardha	**39**	Cl^-	0.31	0.80**	0.03	**Washim**	**71**	Cl^-	0.59**	0.38**	-0.06
		SO_4^{-2}	1	0.27	-0.15			SO_4^{-2}	1	0.44**	-0.01
		NO_3^-		1	-0.07			NO_3^-		1	-0.11

Note: ** Correlation is significant at 0.01 level (2-tailed)
* Correlation is significant at 0.05 level (2-tailed)

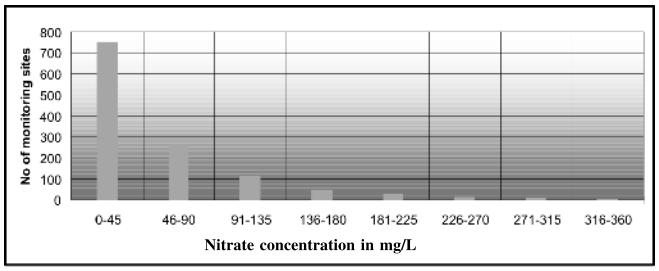

Fig. 2 : Frequency distribution of premonsoon NO_3^- concentration in groundwater of Maharashtra

in Maharashtra. **Fig. 3** shows the contour maps of pre-monsoon nitrate concentration in different districts of Maharashtra.

In India, localized occurrence of nitrate (>45 mgl^{-1}) in groundwater has been observed in Andhra Pradesh, Bihar, Chattisgarh, Delhi, Goa, Gujarat, Haryana, Himachal Pradesh, Jammu & Kashmir, Jharkhand, Karnataka, Kerala, Maharashtra, Madhya Pradesh, Orissa and Punjab[6-10].

The heavy use of nitrogenous fertilizers in cropping system is a large contributor to anthropogenic nitrogen in

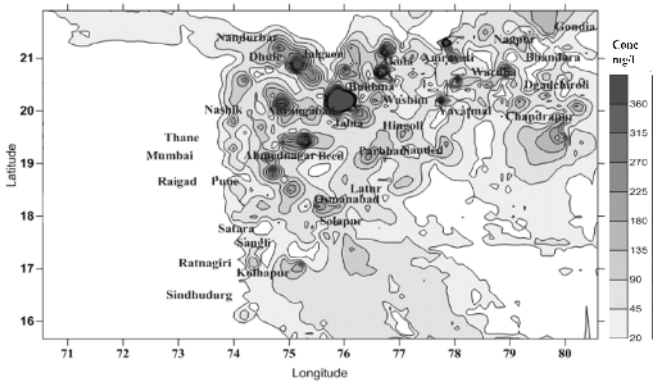

Fig. 3 : Contour map of nitrate in the premonsoon season

groundwater world wide[6,11]. Non-agricultural sources of nitrogen are septic systems and leaking municipal sewers, un-sewered sanitation in densely populated areas or from point sources such as irrigation of land by sewage effluents. Some chemical and micro-biological processes, such as nitrification and denitrification also influence the nitrate concentration in groundwater.

Water contaminated with nitrate can be treated so that it meets drinking standards. Treatments are expensive, however, and include processes, such as reverse osmosis, deionization, and distillation. Boiling, softening, or disinfection will not reduce the nitrate content of water.

Total hardness

Groundwater in 30 talukas in 17 districts showed total hardness exceeding the permissible limit (600mgl^{-1}) 100% of the time. Hard water is not a health hazard. In fact, the National Research Council (National Academy of Sciences)[12] states that hard drinking water generally contributes a small amount toward total calcium and magnesium human dietary needs. In some instances, where dissolved calcium and magnesium are very high, water could be a major contributor of calcium and magnesium to the diet. However, hard water is a nuisance because of mineral buildup on fixtures and poor soap and/or detergent performance. Hard water interferes with almost every cleaning task from laundering and dishwashing to bathing and personal grooming. Water flow may also be reduced by deposits in pipes.

Flouride pollution

The groundwater quality monitored by GSDA and CGWB during the period 2007-2009 showed that 7 talukas in 4 districts (Amravati, Chandrapur, Nagpur and Nanded) have fluoride levels above permissible limits of 1.5 mgl^{-1}, 100% of the time. The major health problems caused by fluoride are dental fluorosis, teeth mottling, skeletal fluorosis and deformation of bones in children as well as in adults. The major sources of fluoride in groundwater are fluoride-bearing rocks such as fluorspar, cryolite, fluorapatite and hydroxylapatite. The fluoride content in the groundwater is a function of many factors such as availability and solubility of fluoride minerals, velocity of flowing water, temperature, pH, concentration of calcium and bicarbonate ions in water, etc.

Total dissolved solids

TDS is an indicator of aesthetics. The analysis revealed that 6 talukas in 5 districts of Maharashtra had 100% exceedance of permissible limit. An elevated level of TDS, by itself, does not indicate that the water presents a health risk. However, elevated levels of specific ions included in the TDS measurement, such as magnesium, calcium, nitrate could present health risks. The concentration of the dissolved ions may cause the water to be corrosive, salty or brackish taste, result in scale formation, and interfere and decrease efficiency of hot water heaters. For aesthetic reasons, a limit of 2000 mgl^{-1} as permissible limit has been established as part of the BIS: 10500 (2004-2005).

pH

Two talukas in two districts of Maharashtra (Raigad and Sangli) showed 100% non compliance of BIS: 10500 (2004-2005) standard of 6.5-8.5 mgl^{-1}.

SO_4^{2-}

The average sulphate level for three years 2007-09 in 22 monitoring locations out of 1406 locations was more than 400mgl^{-1}, the permissible limit for sulphate in groundwater. 88 locations had sulphate levels more than 200 mgl^{-1}, the desirable limit for drinking water. The districts which had sulphate levels more than 400mgl^{-1} are Ahmednagar, Akola, Amravati, Aurangabad, Buldhana, Chandrapur, Jalgaon, Jalna, Raigad, Sangli and Solapur. Sulphate is a naturally occurring ion in almost all kinds of water bodies. At higher concentration $SO_4^{2"}$ may cause gastro-intestinal irritation particularly when Mg^{2+} and Na^+ are also present in drinking water resources.

Sources of NO_3^- contamination in groundwater

Table 4 presents the correlation coefficient matrix between major chemical parameters of groundwater of those districts with a nitrate problem. A very strong relationship was observed between $NO_3^{"}$ and $SO_4^{2"}$ levels in groundwater at Amravati (r = 0.77), Aurangabad (r = 0.98), Bhandara (r = 0.87), Dhule (r= 0.70), Jalgaon (r= 0.82), Latur (r= 0.67), Nanded (r= 0.73), Nashik (r= 0.73), Osmanabad (r= 0.92) and Parbhani (r= 0.73). The correlation coefficients are significant at 1% level. Such high correlation indicates the contamination of groundwater with nitrate and sulphate from point sources, i.e. fertilizers, sewage and animal wastes. While studying nitrate concentrations in groundwater of some rural areas of

Table 5 : Classification of groundwater quality of Talukas as excellent, good, poor, very poor and unsuitable for drinking

Sr. No.	District	Excellent	Good Water	Poor Water	Very Poor Water	Unsuitable for drinking
1	Ahmadnagar		Sangamner, Shrirampur	Akole, Karjat, Shrigonda		
2	Akola		Barshi Takli, Patur**	Akola**, Akot**, Balapur, Telhara, Murtizapur*		
3	Amravati	Anjangaon	Chandur Bazar, Chikhaldara, Amravati*, Anjangaon*, Dharni**	Chandur Railway, Morshi, Nandgaon Khandeshwar, Surji, Tiwasa, Achalpur*, Bhatkuli*, Daryapur*		
4	Aurangabad		Khultabad, Sillod	Aurangabad, Kannad	Vaijapur	Paithan
5	Beed		Ambejogai, Beed	Ashti, Gewrai, Kej, Parli		
6	Bhandara		Bhandara, Lakhani, Pauni			
7	Buldhana		Khamgaon, Chikhali*, Jalgaon jamod*, Mehkar*, Motala*	Deolgaon Raja, Sangrampur, Sindkhed Raja, Lonar**, Nandura*		Shegaon
8	Chandrapur		Chimur, Jiwati, Pombhuma	Brahmapuri, Mul, Nagbhid, Sawali		
9	Dhule			Dhule, Sindhkheda		
10	Gadchiroli		Dhanora, Etapalli	Mulchera, Chamorshi		
11	Gondia	Salekasa	Arjuni Moregaon, Deori, Goregaon, Sadak Arjuni, Tiroda			
12	Hingoli		Aundha (Nag), Basmatnagar, Sengaon	Hingoli		
13	Jalgaon		Bhusawal, Raver	Bhadgaon, Dharangaon, Mukainagar, Parola		Amalner
14	Jalna			Ambad, Parthur		Jafrabad
15	Kolhapur	Chandgad, Gadinglaj, Gaganbawada, Panhala	Ajra, Hatkanangale, Kagal, Kolhapur			
16	Latur		Nilanga, Chakur, Jalkot, Udgir	Ahmadpur		
17	Mumbai City		Bombay (Churchgate), Colaba, Deulwadi, Mahim, Mahroli (Chemur)			
18	Mumbai Suburban	Kurla				
19	Nagpur	Umred	Bhivapur, Hingna, Mouda, Nagpur, Parseoni	Kamptee, Ramtek		

Sr. No.	District	Excellent	Good Water	Poor Water	Very Poor Water	Unsuitable for drinking
20	Nanded		Kinwat, Mahur, Mukhed, Nanded, Biloli	Bhokar, Himayat Nagar		
21	Nandurbar		Akkalkuva, Nandurbar, Navapur, Taloda			
22	Nashik		Dindori, Igatpuri, Kalwan, Nashik, Yeola, Peinth		Sinnar	
23	Osmanbad		Lohara, Paranda, Tuljapur		Kalambh	
24	Parbhani		Jintur, Parbhani, Palam, Selu	Manwat		
25	Pune	Mulshi, Wadgaon (Maval), Wehle	Daund, Pune (Haveli), Junnar, Mawal, Purandar, Shirur	Baramati		
26	Raigad	Karjat, Khalapur, Mangaon, Mhasala, Roha	Raigad			
27	Ratnagiri	Chiplun, Dapoli, Guhagar, Khed, Mandangarh, Rajapur, Ratnagiri, Sangameshwar		Ratnagiri	Chiplun, Dapoli, Guhagar, Khed, Mandangarh Rajapur, Ratnagiri, Sangameshwar	
28	Sangli	Shirala	Atpadi, Miraj, Palus, Walwa	Islampur, Jath, Kavathemahankal		
29	Satara	Mahabaleswar	Khandala, Koregaon, Wai			
30	Sindhudurg	Devgad, Dodamarg, Kankavli, Kudal, Malvan, Sawantwadi, Vaibhavwadi, Vengurla				
31	Solapur	Sangoola		Barshi, Madha, Malshirs, Mohol, S. Solapur		

Sr. No.	District	Excellent	Good Water	Poor Water	Very Poor Water	Unsuitable for drinking
32	Thane	Shahapur, Wada	Dahanu, Jawahar, Mokhada, Palghar, Vasai			
33	Wardha		Ashti, Hinganghat, Karanja	Arvi		
34	Washim		Washim** Karanja*, Malegaon*, Manora*, Risod*, Mangrulpir*			
35	Yavatmal		Arni**, Mahagaon**, Ralegaon, Babhulgaon, Darwha**, Ghatanji*, Kalamb, Maregaon*, Ner*, Pusad*, Umarkhed**, Yavatmal*, Zari* Jamni*	Babhulgaon, Digras, Kelapur, Maregaon, Ner, Wani, Yavatmal		

*WQI calculated with Fe

** For some part of the Taluka, WQI is calculated with Fe and some without Fe

Rajasthan, Suthar *et al.*[10] also reported a significant relationship between NO_3^- and SO_4^{2-}. NO_3^- showed a good correlation with Cl^- contents at Amravati (r = 0.53), Aurangabad (r = 0.89), Bhandara (r = 0.82), Dhule (r= 0.81), Jalgaon (r= 0.91), Nanded (r = 0.60), Nashik (r = 0.60), Osmanabad (r= 0.87) and Parbhani (r= 0.74) as the correlation coefficient *r* was significantly higher. Similarly, SO_4^{2-}also exhibited a good relationship with Cl^- for groundwater samples from Amravati (r = 0.77), Aurangabad (r = 0.84), Bhandara (r = 0.92), Dhule (r= 0.93), Jalgaon (r= 0.92), Nanded (r= 0.92), Nashik (r= 0.92), Osmanabad (r= 0.88) and Parbhani (r= 0.95) which suggested the contribution of animal and human excreta deposition on groundwater contamination. The correlation matrix between important parameters of water suggests that major sources of NO_3^- and SO_4^{2-} in groundwater of this region were nitrogenous fertilizer, sewerage, animal waste, organic manure, etc.

Water Quality Index

Table 5 indicates a list of talukas belonging to the categories- excellent, good, poor, very poor and unsuitable for drinking based on the WQI calculated for the period 2007-2009. The districts which have good to excellent quality of groundwater are Bhandara, Gondia, Kolhapur, Mumbai city, Mumbai Suburban, Nandurbar, Raigad, Ratnagiri, Satara, Sindhudurg, Thane and Washim.Vaijapur Taluka in Aurangabad, Sinnar in Nashik district and Kalambh Taluka in Osmanabad have very poor water quality. Paithan Taluka in Aurangabad, Shegaon Taluka at Buldhana district, Amolner Taluka at Jalgaon District and Jafrabad in Jalna District have water quality unsuitable for drinking.

5. Conclusion

The correlation matrix between important parameters of water suggested that major sources of NO_3^- in groundwater of this region were nitrogenous fertilizer, sewerage, animal waste, organic manure, etc. Further detailed study is still required to trace out the potential contamination sources. Results thus indicate that this state may be a danger zone for NO_3^- toxicity risks in humans.

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