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Study of quaternary aquifers in Ganga Plain, India: Focus on groundwater salinity, fluoride and fluorosis

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Abstract

In marginal and central alluvial plains (Ganga Plain) of India, the inland salinity is continuously increasing, canal network and arid to semi-arid climatic conditions that led to excessive evapotranspiration concentrates the salt in soil and thereby escalating the groundwater salinity. In Mat Tahsil, Mathura district (Ganga Plain) study on shallow and deep aquifer salinity and fluoride was carried out in August 2001 and 2004.

Groundwater salinity in some parts is more then 4000 $\mu\Omega^{-1}$/cm. This region is severely affected by endemic fluorosis due to consumption of fluoride-contaminated water. Analysis of F^-, Na^+, K^+, Cl^- and HCO_3^- was carried out at 30 sites of dugwells and borewells. Result shows that there is a variation and continuous escalation in the groundwater salinity and fluoride concentration in deep and shallow aquifers on the basis of analysis. Classification of salinity levels was carried out in 2001 and 2004. The deep aquifers (borewells) are found more saline as compare to the shallow aquifers (dugwells) while F^-, Na^+, K^+, Cl^- and HCO_3^- shows high concentration in shallow aquifers. The fluoride concentration in the groundwater of these villages showed values from 0.1 to 2.5 mg/l, severe enough to cause dental and skeletal fluorosis among the inhabitants, especially children of these villages. One of the major effects of inland salinity in this region is from saline groundwater, which is reaching the land surface and causing soil salinisations and water logging in the NE and SE parts of Mat block.

Keywords: Quaternary aquifer; Groundwater salinity; Fluoride content increase; Critical block; Hydraulic conductivity; Ganga Plain; Infiltration

1. Introduction

Salinity is considered as one of the complex process, which is directly or indirectly associated with the local or regional geological features and climatic conditions. It has been estimated that over 1.90 lakh km^2 area in parts of India (Haryana, Delhi, Uttar Pradesh, Karnataka, Punjab, Rajasthan, Gujarat and Tamil Nadu) is affected by inland salinity in Groundwater (EC > 4000 $\mu\Omega^{-1}$). Saline/brackish water resources up to the depth of 450 m below the ground level in alluvial areas and 100 m below ground level in hard rock areas have been estimated to be of the order of 1164 BCM [1]. Majority of the areas of western UP are facing the problem, of inland salinity, which is increasing inflow of saline groundwater into surface waters and salinisation of groundwater resources. A detail of state wise inland salinity in groundwater is shown in Table 1. While fluoride, which is one of the most abundant chemical after Cl among the halogens [2] have been extensively studied [3–5] and fluoride related health and environmental concerns have reached an alarming proportion in several regions of the world. In India, the problem of excessive fluoride was first reported in 1937 in the state of Andhra Pradesh [6] and the recent study shows approximately 62 million people including 6 million children suffer from fluorosis because of consumption of water containing high concentrations of fluoride [7]. Many studies have found fluorosis to be invariably associated with high concentrations of fluoride in drinking water [8,9]. High oral intake of fluoride results in physiological disorders, skeletal and dental fluorosis, thyroxine changes and kidney damage [10,11]. Fluorides accumulate in bones and teeth as fluorapatite and causes bone to become brittle [12,13].

Bureau of Indian Standards [14] has suggested that the permissible limit of fluoride in drinking water should be 1 mg/l,

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Table 1
Estimated area affected by inland salinity in groundwater—EC > 4000 $\mu\Omega^{-1}$ (source: Ray Sinha, SP, 2004)

Serial number	State	Total area of the state (km^2)	Area underlain by saline groundwater (km^2)	Percentage
1	Haryana	44,212	11,438	25.87
2	Punjab	50,353	3,058	06.07
3	Delhi	1,485	140	09.43
4	Rajasthan	342,239	141,036	04.12
5	Gujarat	196,024	24,300	12.40
6	Uttar Pradesh	294,411	1,362	00.46
7	Karnataka	191,791	8,804	04.59
8	Tamil Nadu	130,058	3,300	02.54
9	Total	1,250,573	193,438	15.47

which is lower than the limit of 1.5 mg/l suggested by WHO in 1984. According to WHO, 1971, permissible limit for fluoride in drinking water is 1.0 mg/l [15], whereas USPHS, 1962 [16] has set a range of allowable concentrations of fluoride in drinking water for a region depending on its climate conditions because the amount of water consumed and consequently the amount of fluoride ingested being influenced primarily by the air temperature [17–19]. Table 2 shows the maximum allowable fluoride concentrations as established by USPHS. Accordingly, the maximum allowable concentration of fluoride in drinking water in Indian conditions comes to 1.4 mg/l while as per Indian standards it is 1.5 mg/l. [20].

The Mat Tahsil, which is suffering from inland salinity and excessive fluoride in groundwater is situated in Mathura district, mainly located in the marginal alluvial plain, with some portion falling in the central alluvial plain of the Ganga Plain. The Mat Tahsil area with its three blocks, i.e. Naujhil, Mat and Raya is situated in the eastern part of the Mathura district. Naujhil and Mat blocks were recognized as a critical (dark) block and Raya was marked as a semi-critical (grey) block in 1998 by the state groundwater department. The study area is characterized by the Vindhyan Group strata (sandstone, shales and limestone) in the subsurface, which are overlain by a thick pile of unconsolidated sediments of the Ganga Plain. Mostly the groundwater is saline to highly saline in nature. Based on geophysical surveys, only 260 km^2 areas has been demarcated for fresh groundwater out of the total area of Mathura district, i.e. 3811 km^2, in the west of Yamuna river, down to a depth of 50 m bgl [21].

In view of the persistent problem of inland salinity and concentration of fluoride and fluorosis and other chemicals in the groundwater and its impact on environment, the present study was undertaken to evaluate and determine the possible factors controlling variation and escalation of groundwater salinity, fluoride and associated chemical constituents of the water in two types of Quaternary aquifers in alluvial Plains.

2. Study area

Mat Tahsil belongs to the eastern Mathura district, which is a rapidly growing industrialized district. The main industries in the region are petroleum refineries, alcohol, food processing, soft drinks, textiles, nitrogen fertilizers, metallic products, electrical machines, wood paper and plastic products. Mat Tahsil area is situated, between 27°05′N and 27°50′N latitude and 77°30′E and 78°00′E longitude at 180 m above sea level. The study area has a semi-arid to arid climate with an average monthly temperature varying from of 38 to 46 °C in summer and 25 to 32 °C in winter. The average weather conditions allow recognising six well-marked traditional seasons, i.e. spring (March–April), summer (May–June), monsoon (July–August), sharada (September–October), hemanta (November–December) and winter (January–Februray). The average annual rainfall variation is between 550 and 650 mm. The thickness of the alluvial cover around the study area varies between 200 and 250 m. In the lower part just above the basement, thick horizons of arkosic gravel-coarse sand are present. They are followed by clay–kankar succession with thin, fine sand intercalations. The topmost 10 m are invariably made up of clay with kankar and distinct calcrete horizons [22]. Agricultural activities in the region are quite intensive, about 70% of the land in the plain is irrigated. The major crops grown in the region are grains vegetables, sugar-beet and fruits. The rapid growth of the population and the industry in the region increases the water demand causing a reduction in water quality, which is a serious problem.

Table 2
Different ranges of the maximum allowable fluoride concentrations as per USPHS

Annual averages of maximum daily air temperature (°C)	Recommended fluoride concentration (mg/l)			Maximum allowable fluoride concentration (mg/l)
	Lower	optimum	Upper	
10–12	0.9	1.2	1.7	2.4
12.1–14.6	0.8	1.1	1.5	2.2
14.7–17.7	0.8	1.0	1.3	2.0
17.8–21.4	0.7	0.9	1.2	1.8
21.5–26.2	0.7	0.8	1.0	1.6
26.3–32.5	0.6	0.7	0.8	1.4

3. Objectives and scope

The main aim of the present study is to develop an understanding of the behavior of inland salinity and fluoride in the aquifers and its escalation in the groundwater of Mat Tahsil and to address the problems posed by these two parameters in the area. This study has two main objectives: (I) evaluation of the salinity levels in shallow and deep aquifers and its variation and escalation levels based on the monitoring done, in August 2001 and 2004 and (II) to evaluate the fluoride concentration along with other major constituents of groundwater such as Na^+, K^+, Cl^-, and $HCO_3{}^-$ in shallow and deep aquifers in August 2001 and 2004. This work is likely to give information for understanding and help in finding solution to the water quality problems related with inland salinity and fluoride in the alluvial plain.

4. Methodology

The electrical conductivity and pH of fifty samples each of shallow dugwells and deep borewells was analysed on the spot. While, sixty sample, 30 from the dugwell and 30 from the borewell in close proximity were collected for comparative study and monitoring in August 2001 and 2004 (Fig. 1). The dugwells range in depth from 10 to 20 m and the borewells range from 60 to 120 m. In most cases, the samples collected from borewells were pumped for several hours prior to sampling. The groundwater samples were collected in glass bottles after rinsing with the sample water. The sample bottles were immediately sealed using rubber stoppers and aluminium protective caps crimped by a hand-held crimping device. The salinity in aquifers was classified on the basis of their electrical conductivity. The total salt content stated in terms of electrical conductivity is an

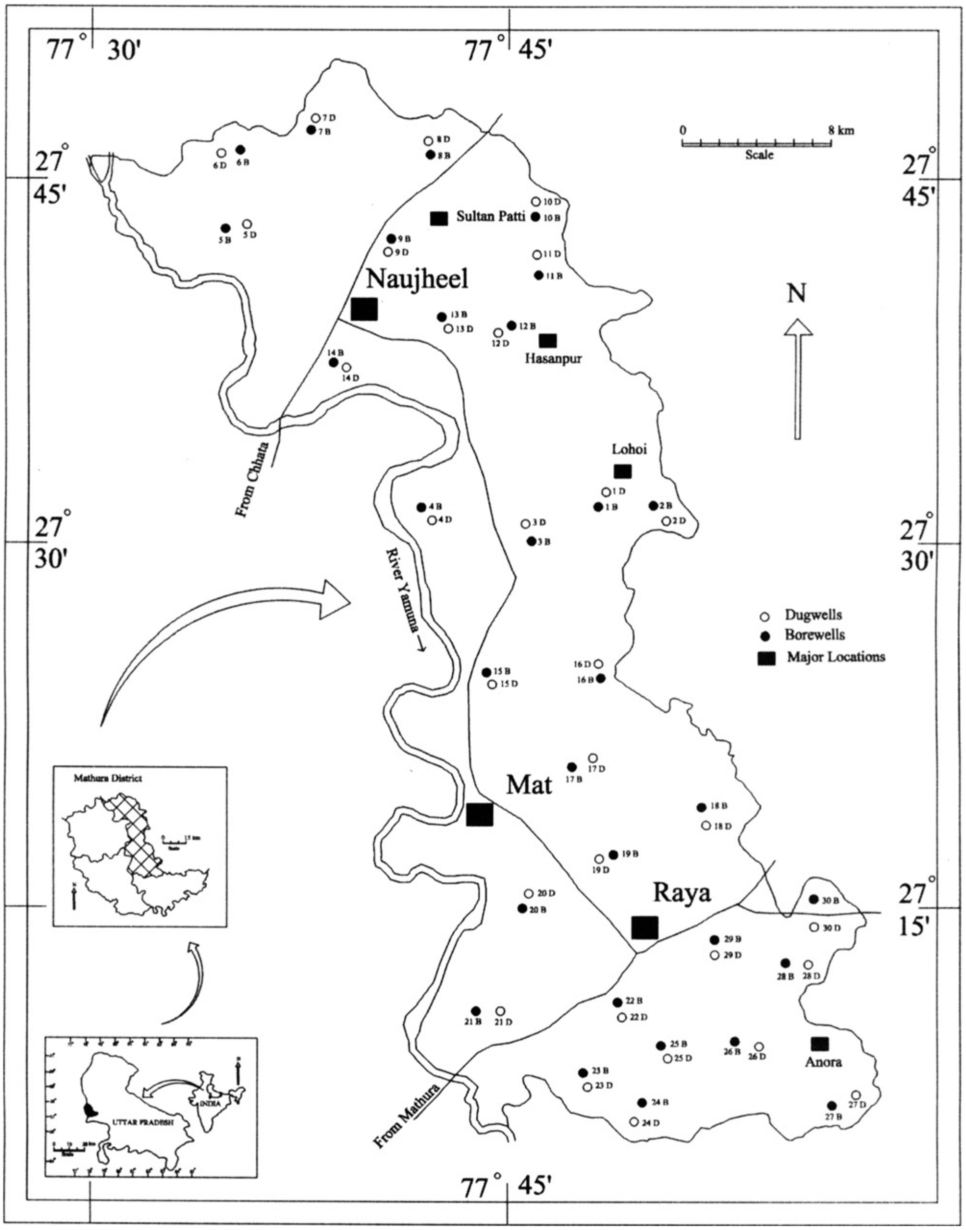

Fig. 1. Mat Tahsil, showing the locations of the dugwells and borewells.

Table 3

Chemical composition of groundwater in the study region in August 2001and 2004, D = dugwells (all concentrations are expressed in mg/l except pH)

Dugwell samples number shown in figure	pH		HCO_3^-		TDS		K^+		Na^+		Cl^-		F^-	
	August 2001	August 2004	August 2001	August 2004	August 2001	August 2004	August 2001	August 2004	August 2001	August 2004	August 2001	August 2004	August 2001	August 2004
1D	7.2	7.2	412	450	986	1086	5	7	150	170	210	220	0.4	0.6
2D	8.1	8.1	389	410	1250	1300	11	15	184	164	245	270	1.2	1.3
3D	7.0	7.2	524	550	1420	1500	6	5	160	192	310	325	1.4	1.8
4D	7.4	7.5	624	620	865	910	9	11	220	240	325	340	1.8	2.3
5D	7.6	7.4	687	710	1560	1500	8	10	125	150	280	300	1.0	1.0
6D	7.3	7.0	623	650	2100	2200	14	15	154	165	384	370	0.9	1.1
7D	6.9	7.3	589	610	1450	1800	16	16	167	180	410	420	1.5	1.8
8D	7.9	7.6	512	550	1100	1400	21	25	210	230	278	315	1.2	1.5
9D	7.2	7.5	654	640	1050	1250	7	10	200	210	265	270	1.5	1.7
10D	8.1	8.0	745	755	1520	1500	26	25	146	165	382	390	1.7	1.5
11D	8.4	8.1	398	400	1430	1630	13	15	143	150	450	480	1.4	1.4
12D	7.5	7.8	569	590	840	1250	20	22	120	115	470	480	1.6	1.9
13D	7.0	7.3	512	540	780	980	11	14	110	135	351	365	0.8	1.2
14D	6.8	7.5	452	450	1090	1050	17	19	280	275	296	300	1.4	1.5
15D	7.1	7.6	498	475	1040	1100	9	10	240	260	247	245	1.6	1.9
16D	7.0	7.4	434	440	1020	1200	16	15	265	275	236	210	1.8	1.6
17D	7.2	7.6	541	540	1100	1540	24	28	240	250	348	356	1.0	1.2
18D	8.0	8.2	458	450	950	1280	21	20	310	290	397	410	1.1	1.4
19D	7.2	7.6	541	560	1200	1670	20	22	325	350	459	470	0.5	0.8
20D	7.6	7.8	587	570	1260	1380	14	15	210	200	254	260	0.8	1.1
21D	7.9	8.0	387	390	1500	1650	7	10	180	215	355	370	0.7	0.9
22D	7.5	7.7	423	480	1460	1550	10	13	370	385	510	550	1.5	1.7
23D	6.9	7.4	485	510	1570	1500	15	16	256	265	345	380	1.7	2.0
24D	7.5	7.8	467	480	1320	1470	9	12	340	250	450	455	1.3	1.6
25D	8.1	8.0	326	350	1530	1700	15	15	180	295	356	380	1.5	1.7
26D	8.4	8.3	375	390	1150	1300	13	15	240	270	265	270	1.6	1.9
27D	8.0	8.1	472	485	1650	1600	15	18	120	130	354	370	1.4	1.5
28D	7.3	7.5	518	550	1600	1950	24	23	185	200	410	450	1.7	2.5
29D	7.2	7.9	462	470	1280	1500	28	25	135	150	398	410	1.2	1.5
30D	8.4	8.2	570	610	1360	1400	19	17	260	280	327	400	1.3	1.5

Table 4
Chemical composition of groundwater in the study region in August 2001 and 2004 *B* = borewells (all concentrations are expressed in mg/l except pH)

Borewells samples numbers shown in figure	pH		HCO_3^-		TDS		K^+		Na^+		Cl^-		F^-	
	August 2001	August 2004	August 2001	August 2004	August 2001	August 2004	August 2001	August 2004	August 2001	August 2004	August 2001	August 2004	August 2001	August 2004
1B	7.0	7.0	410	450	650	950	2	4	100	110	200	280	0.2	0.4
2B	7.6	8.0	340	380	1100	1280	7	9	150	170	210	220	1.0	1.4
3B	7.2	6.9	250	270	1200	1440	3	7	80	125	230	285	1.1	1.3
4B	7.1	7.6	380	410	700	850	5	8	150	165	180	210	0.9	1.1
5B	7.0	7.3	375	425	1250	1300	4	6	75	77	240	250	1.2	1.3
6B	7.1	6.8	513	550	1310	1510	10	12	110	114	310	307	0.5	0.7
7B	6.5	7.4	480	510	940	950	12	18	105	135	150	165	1.2	1.2
8B	7.5	7.2	425	480	850	980	11	10	125	195	170	180	1.0	1.4
9B	7.0	7.0	482	470	900	1210	5	7	160	162	210	240	1.1	1.4
10B	7.2	7.9	525	550	1380	1650	12	14	170	200	250	265	1.3	1.5
11B	7.8	7.6	195	240	1100	1180	5	8	90	140	170	190	1.2	1.4
12B	7.3	7.2	292	310	525	725	9	11	70	150	290	310	1.3	1.6
13B	6.8	6.9	328	355	700	840	5	7	50	75	230	265	0.2	0.5
14B	7.0	7.1	350	378	980	1250	7	9	190	165	250	275	1.4	1.6
15B	7.3	7.7	322	340	850	1150	4	7	95	110	140	242	1.1	1.3
16B	7.1	7.2	350	330	810	980	9	12	100	113	155	192	1.2	1.3
17B	6.9	7.5	250	275	700	850	15	18	122	145	212	250	0.6	0.9
18B	7.5	7.8	322	365	850	1100	10	13	135	160	248	270	1.0	1.1
19B	7.3	7.0	380	410	1100	1150	9	14	180	175	311	380	0.1	0.6
20B	7.4	8.1	360	390	1150	1460	12	15	153	195	125	150	0.3	0.5
21B	7.5	7.9	250	275	1250	1430	4	8	85	192	210	225	0.2	0.4
22B	7.2	7.5	244	295	1380	1490	6	10	155	210	195	295	0.7	0.9
23B	7.1	8.0	295	325	1210	1400	12	14	196	224	165	230	1.6	1.8
24B	7.3	7.4	310	318	980	1340	9	11	220	265	245	290	1.1	1.2
25B	8.0	7.9	275	312	1150	1270	14	16	140	218	248	295	1.2	1.4
26B	8.0	8.1	310	350	980	1250	10	11	210	230	170	190	1.3	1.8
27B	7.5	7.6	240	280	1340	1500	12	15	100	122	210	250	1.1	1.5
28B	7.1	7.9	380	365	1280	1480	18	20	125	180	250	278	1.5	1.5
29B	7.0	7.5	280	310	850	1050	10	17	115	125	320	325	1.4	1.7
30B	7.9	8.2	315	300	1150	1380	7	11	220	250	240	235	0.9	1.6

important criterion for many uses of water including municipal water supply, industrial water supply and water used for irrigational purposes. The international standard for drinking water with respect to total dissolved solids, recommended by WHO, is 1500 mg/l as maximum permissible level. The same standard is used to classify the groundwater quality in aquifers.

Fluoride in water samples was analyzed by using the SPADNS colorimetric method. A calibration standard ranging from 0 to 0.4 mg F^-/L was prepared by diluting an appropriate volume of standard F^- solution. To 50 ml of standard solution, 10.0 ml the SPADNS reagent was added and mixed well. The spectrophotometer (Perkin-Elmer model LAMBDA 40) was set at wavelength of 570 nm, and a calibration graph was prepared from different standard F^- concentrations. When the graph gave a straight line, the instrument was considered ready for measurement of F in the samples. The other chemical constituents (Na^+, K^+, Cl^-, and $HCO_3{}^-$) were also determined in the laboratory following APHA-AWWA-WPCF [23] procedures. The total dissolved solid was calculated using formula given by Todd [24]. The Tables 3 and 4 present the details of the chemical constituents determined in dugwells and borewells, respectively.

5. Results and discussion

In rocks and soils generally salt is present in crystalline structures with the ions packed together in a regular array. Salt those are water soluble separates into individual ions or groups of ions when they dissolve. The most common naturally occurring ions found in groundwater, surface water and soils includes sodium, chloride, bicarbonates, calcium, magnesium, etc. The solubility of different salts in water varies markedly and this determines the case at which they can be moved from one part of the landscape

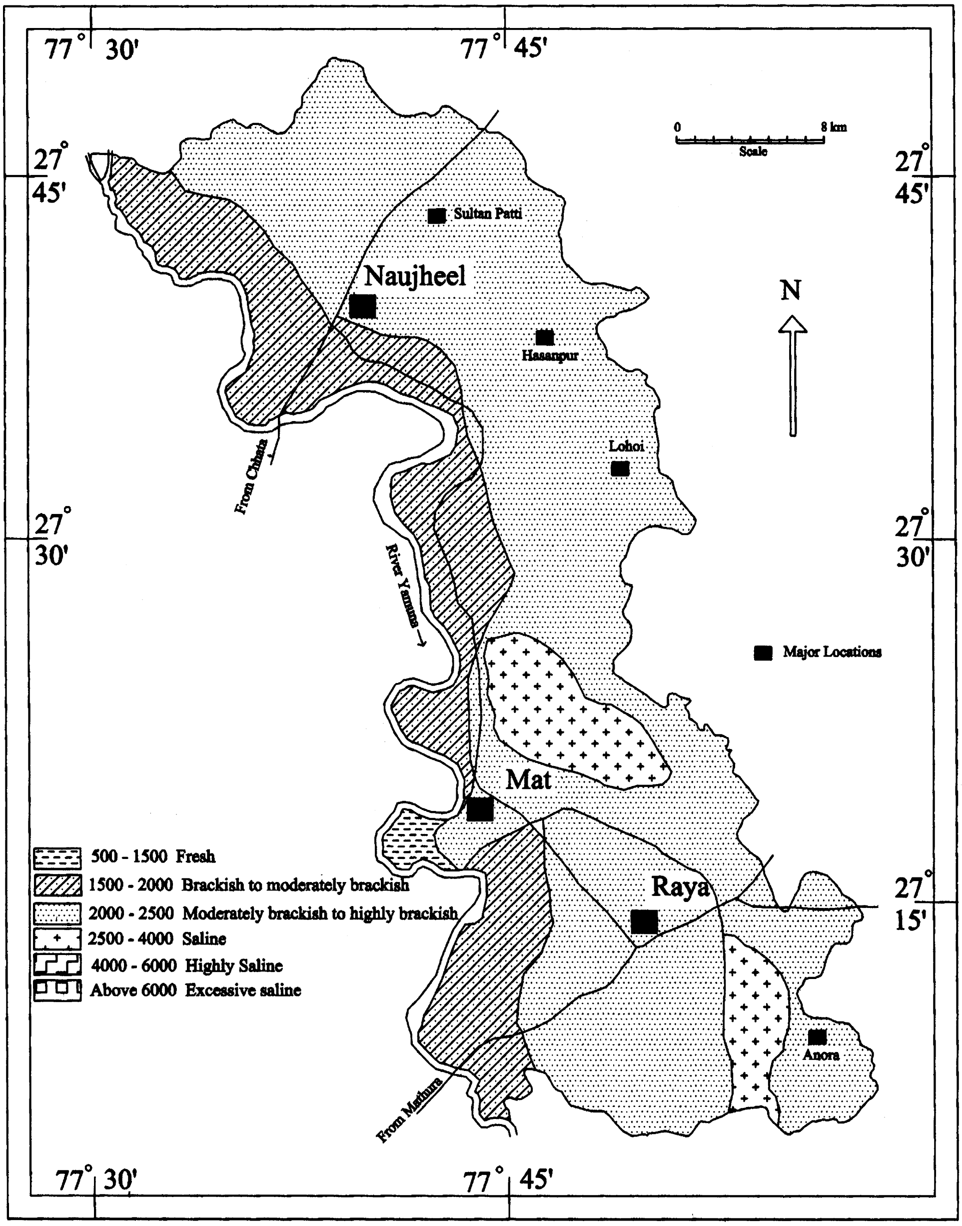

Fig. 2. Water quality of shallow aquifers in the study area in August 2001.

to another. The present study area affected by inland salinity, sodium chloride and calcium carbonates are the dominant salts.

Further most of the rivers of the marginal and central alluvial Plains (Ganga Plain) originate from Himalayan mountain ranges where there is generally high precipitation. Usually in mountains the concentration of TDS is low and the two major rivers that are river Yamuna and Ganga flows through the arid and semi-arid regions of marginal and central alluvial plains. In these areas the concentration of salt through evaporation rises. When the same water is diverted for irrigation through canal network the salt concentration is amplified by evapotranspiration, which increase inland salinity and thereby increase in groundwater salinity [25]. Thus the canal network and the arid climatic conditions are one of the major reasons for continuous escalation in the salinity.

Figs. 2 and 3 show the water quality classification in shallow aquifers in year 2001 and 2004, based on the electrical conductivity; Figs. 4 and 5 represents the same study carried out for the deep aquifers in the year 2001 and 2004. The figures show that the groundwater quality of the shallow aquifer has deteriorated over time. The water in these aquifers was found ranging from brackish to highly brackish and saline in few pockets in 2001, but in 2004; highly brackish and saline areas have escalated sharply. Figs. 4 and 5 represents the same classification for deep aquifers, in which water was found to be highly brackish to saline in 2001; in 2004 it was found to be highly brackish to saline in majority of portions but in some portions it was found to be highly saline in nature. The variation and escalation in salinity level has been found less in deep aquifers as compared to the shallow aquifers over time. But the deep aquifers are more saline

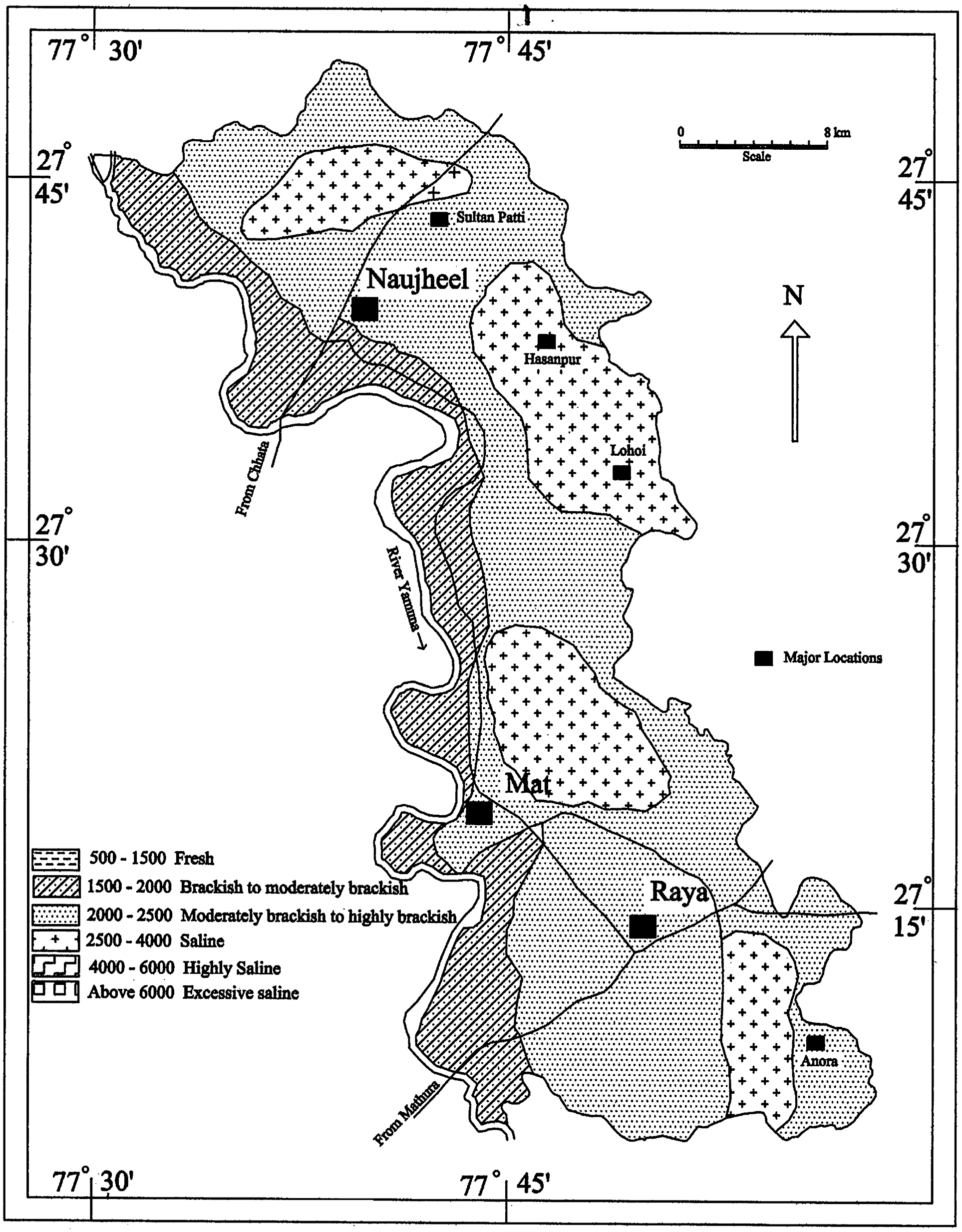

Fig. 3. Water quality of shallow aquifers in the study area in August 2004.

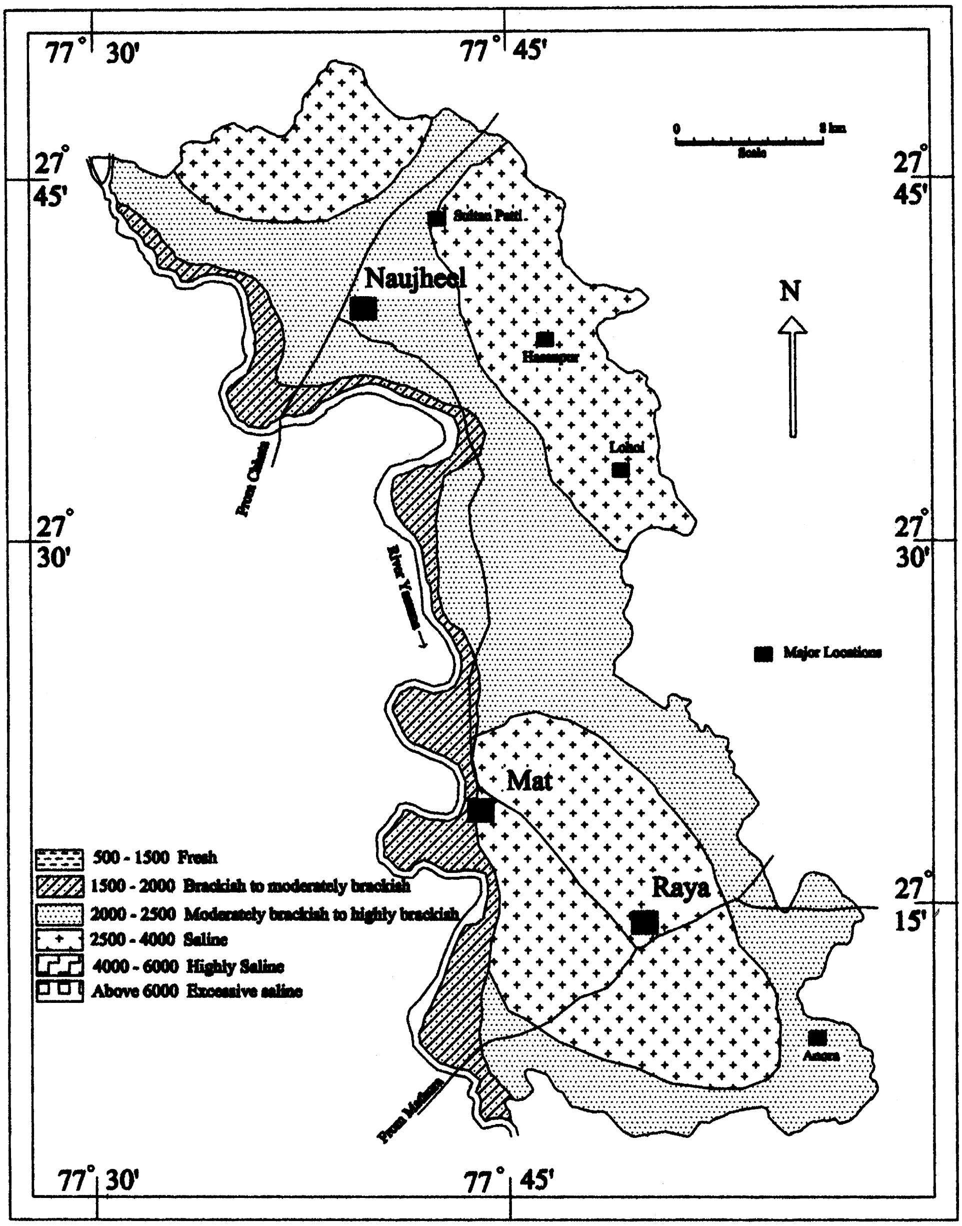

Fig. 4. Water quality of deep aquifers in the study area in August 2001.

as compared to the shallow aquifers. Most of the deep aquifers in the study area were found to be confined to semi-confined in nature in geoelectrical investigations, aquifers of such nature possess some hydrostatic pressure and whenever these aquifers were drilled for borewells, the pressure caused the upward movement of water, leading to deterioration of shallow aquifers [26]. Thus the excessive drillings of borewells and high yield tubewells are probably causing deterioration of water quality in shallow aquifers in the region as dugwells shows deterioration in water quality after nearby drilling of borewells within 6–12 months of time. Besides that the major impact of dryland salinity in the region is from saline groundwater's reaching the land surface and causing soil salinisation and water logging, while in some areas, salt leached from the surface accumulates in unsaturated zone between the soil surface and the groundwater table.

The study area belongs to the quaternary sediments. These sediments are characterized by fining upward cycles of sand, silt and clay and contain organic matter (up to 6.0 wt.%) [27] and $CaCo_3$ concretions called kankar. These kankar's also escalate dryland and groundwater salinity. Another factor for escalation in the salinity in groundwater of the study area is the irrigation-induced salinity, which is caused by increased, leakage of water from the surface into groundwater due to over-irrigation, and impaired drainage, which also enhanced inland salinity.

A critical study of the analytical data of 30 groundwater samples of dugwells and 30 samples of borewells shown in Tables 3–4 indicate the behavior of fluoride in the study area. The chemical analysis of the August 2001 data reveals that fluoride was marginally higher in the shallow dugwells than in the deep borewells, but other chemical constituents such as Na^+, K^+, Cl^-, and HCO_3^- show minor changes between dugwell

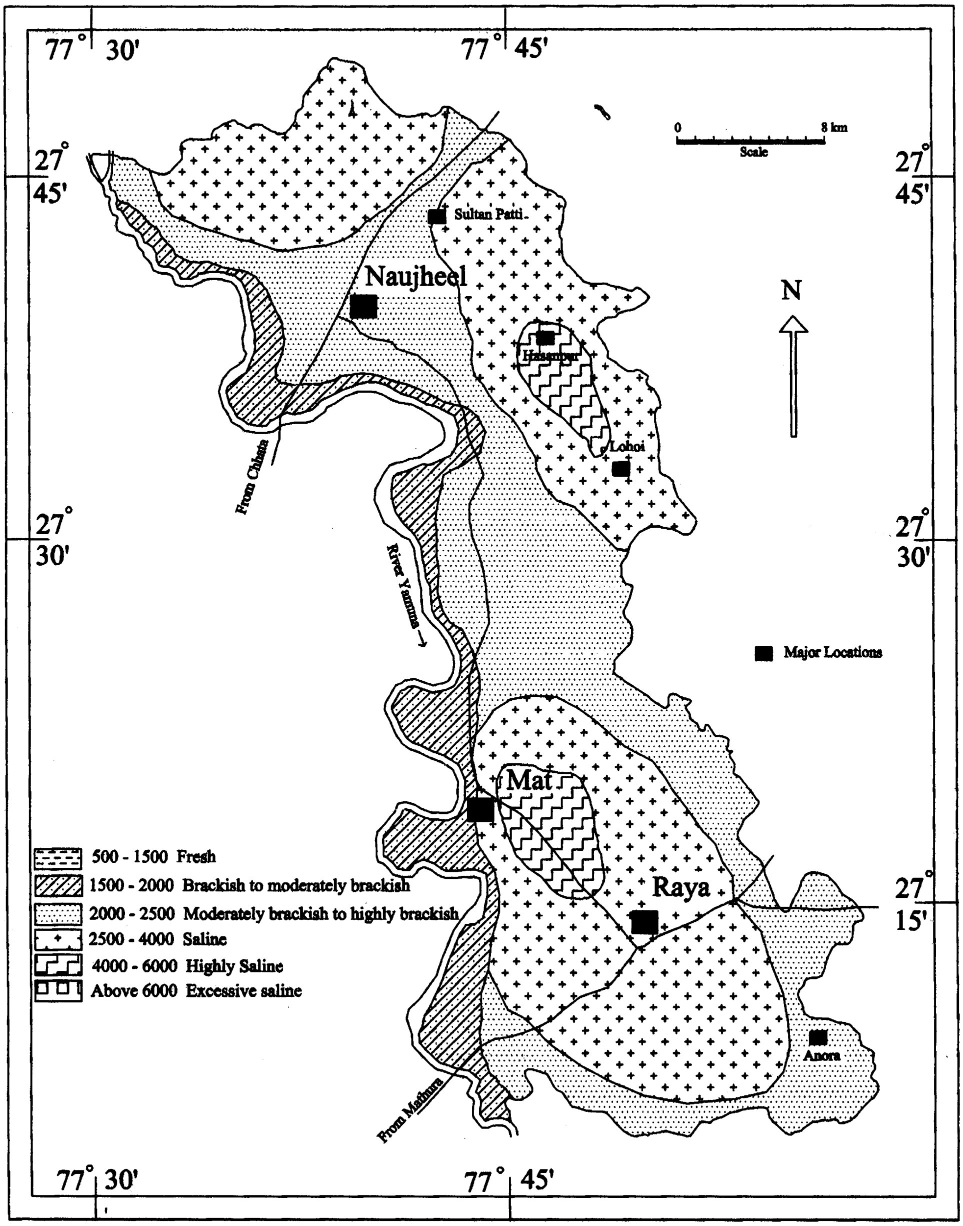

Fig. 5. Water quality of deep aquifers in the study area in August 2004.

and borewell samples. The analysis later carried out in August 2004 for the same dugwell and borewell samples indicate variations and escalation in fluoride and other chemical constituents. A comparison of the two sets of data indicates that during 3 years the average F content has increased from 0.1 to .6 mg/l. The rise in F content along with other chemical constituents is more in the shallow dugwells than in the deep borewells. The changes in these parameters between the waters of two types of aquifers are believed to result from the interplay of the following factors.

The study area shows the frequent alteration of mud and clay layers in the subsurface lithology and fluoride is commonly encountered in clay minerals as F is strongly absorbed by soil. The weathering of the alkaline sedimentary rocks (especially shales) release fluoride in soil and groundwater [28,29]. As mentioned above the entire study area is underlain by the Vindhyan formations mainly consisting of sandstone, shales and limestone, which could yield large concentration of F after weathering. They may be the possible source of the continuous escalation of F content both in the shallow and deep aquifers.

As the mud and clay layers frequently occur in the study area, they enable the waters to have a long residence time with the aquifer materials, which leads to leaching of the soil horizons. This increases the concentration of Na^+, K^+, Cl^-, and $HCO_3{}^-$ making the shallow aquifers richer in these chemicals as compared to deep aquifers. In addition, the extremely low hydraulic conductivity between the shallow and deep zones also suggests that the recharge sources for both deep and shallow zones are different otherwise both the aquifers would have similar fluoride content.

Furthermore the cations, like sodium and potassium occur in high concentration in the shallow aquifers because cations in a groundwater solution have a tendency to become absorbed into the surfaces of clay minerals. This occurs because the clay mineral surfaces tend to have many naked negative electrical charges that can react with the positive ions, moreover, the anions like chlorides and bicarbonates are in low concentration in comparison to cations because anions are much less likely to be absorbed owing to the relative scarcity of positive electrical sites on the clay minerals. Also, some ions are too large to be effectively absorbed [30]. This seems to be a major factor for the high concentration of Na^+, K^+, Cl^-, and $HCO_3{}^-$ in shallow aquifers in comparison to deep ones.

In the August 2001 analysis, the concentration of fluoride in majority of the locations was within the permissible limits in Naujheel and Raya blocks. At Mat block however it was above the permissible limits in 50% locations. By August 2004, about 80% locations of Mat and approximately 50% locations of Raya and Naujheel blocks showed the fluoride level above the permissible limits. Dental fluorosis in the children in Mat block (Kapoor village) especially mottling and pitting of teeth have became a common feature among the children and adults because of the excessive intake of fluoride either through naturally occurring fluoride in the water of dugwells or borewells, water fluoridation, toothpaste or other sources. As dental fluorosis generally occurs during the stage of enamel formation it is seen by all sides as the first visible sign that an overdose of fluoride has occurred in the children during this vulnerable period. More surprisingly many children afflicted with dental fluorosis are also suffering from gastrointestinal, respiratory, skin, bone and muscle diseases in the region, which could be because of dental fluorosis. In Mat block the dental fluorosis (DF) was detected in more then 40% of the population in several villages. Dental fluorosis is more common among the children. While skeletal fluorosis is more common among the people having ages more than 50 years. The constituents such as sodium, potassium, chloride and bicarbonates play a vital role in higher life forms. Both deficiency and excess of these constituents might be harmful. Effects associated with the impact of these ions on human health greatly depend on total intake through various media such as water, air and food.

6. Conclusion

The study reveals escalation and variation of groundwater salinity in shallow and deep aquifers; the canal network and the climatic conditions are the major reason for continuous escalation in groundwater salinity. Moreover irrigation-induced salinity is also a problem in some areas. The dryland salinity is increasing inflow of saline groundwaters into surface waters and salinisation of groundwater resources. Majority of the water samples collected from Mat Tahsil do not meet the water quality standards prescribed for fluoride concentration and other quality parameters. The areas with high fluoride content have been identified, and the possible causes for its variation and escalation have been investigated. The poor hydraulic conductivity between the shallow and deep zones also causes the variation of fluoride and other chemical constituents between the two types of aquifers. The dugwell water is not suitable for consumption without any prior treatment. A hand pump attached filter based on Nalgonda technology or activated alumina adsorption [20] and defluoridation of groundwater using activated charcoal prepared from wheat husk and fly ash obtained from a thermal power plant [31] might be the solution to this problem.

Studies on groundwater quality monitoring in aquifers can help in identifying safe aquifer zones for drinking water and provide solution to the quality problems in groundwater by means of hydrogeological and geochemical data.

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