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Identification of sea-water ingress using strontium and boron in Krishna Delta, India

V. K. Saxena*, N. C. Mondal and V. S. Singh

National Geophysical Research Institute, Uppal Road, Hyderabad 500 007, India

The distribution trends of trace elements over North and South Krishna delta were examined in relation to fresh-, brackish- and saline-water zonations. Strontium and boron have shown significant variations in fresh-, brackish- and saline-water environment. Strontium has shown a variation from 23 to 1500 µg/l in freshwater, 1650 to 2760 µg/l in brackish water and 1679 to 3180 µg/l in saline water. Similarly, boron has shown a variation from 71 to 199 µg/l in freshwater, 211 to 422 µg/l in brackish water and 695 to 2929 µg/l in saline water. The groundwater of these delineated zones when compared with the zonations of total dissolved solids are in good agreement. Therefore, strontium and boron could be used as sensitive chemical parameters responding to changes in fresh- to saline-water environment.

SEA-WATER intrusion in the delta region is widespread; it is not only occurs in India but in various parts of the world[1,2]. Such intrusion contaminates the fresh groundwater regime and also reduces the fertility of the soil, which in turn affects agricultural production[1,3–5]. Krishna Delta located in the southeast of India is known for high yields of agricultural production. Vijayawada, Guntur, Tenali, and Machilipatnam are the main townships located in this region. More than 70% of the population depends upon groundwater, for which hand pumps, dug wells and dug-cum-bore wells are used. During the past few decades, the rapid increase in sea-water intrusion has caused the transformation of fresh groundwater to brackish/saline water. Because of sea-water intrusion most of the fertile land has become wasteland and cultivation rate has also decreased[6]. Inhabitants of this region are facing water problem. The main sources of saline-water intrusion are: (i) changes of land use from agriculture to residential; and (ii) increase in the number of bore wells/dug wells and hand pumps. Thus, pumping of excessive groundwater may be a cause for the possible intrusion of sea-water in the delta region[7]. Hydrogeological and hydrochemical studies were carried out for the delineation of fresh groundwater aquifers and for the identification of fresh groundwater potential zones[3,8]. Attempts have been made to identify an economical and simple process, which can give preliminary information about sea-water intrusion in delta region. For this, strontium and boron have been considered for the delineation of fresh-, brackish- and sea-water intrusion. Strontium is a metal whereas boron is a non-metal; but both are quite abundant in sea-water[2,3]. This study has been carried out to observe the influence of strontium and boron on the groundwater of coastal regions as well as their correlation with the chemical parameters, which are commonly used for sea-water ingression studies. For the study, twenty-six groundwater samples were collected from the South and North Krishna Delta regions. These samples were collected in June 2000 (pre-monsoon) from dug wells, hand pumps and bore wells. The location of the sampling stations is shown in Figure 1. Chemical analysis of these water samples has been done for electrical conductivity (EC), total dissolved solids (TDS), pH, Na, K, Ca, Mg, Cl, HCO_3 and SO_4 and also various trace elements such as Sr, B, Cu, Zn, Fe and Ba. The chemical analysis was carried out using the method given by APHA[9,10]. The purpose of this communication is to extract the chemical parameters which can delineate the fresh-, brackish- and saline-water resources in the delta region.

The Krishna Delta is formed by the holy river Krishna, close to the Bay of Bengal in the east coast of India. The river Krishna originates from the Western Ghats near Mahabaleswar, Maharashtra. After covering a distance of

Table 1. Techniques used for chemical analysis of water samples

Sp. cond.	: Conductivity meter with selective electrode and sensor
TDS	: Gravimetric (evaporation) and total ionic counts
pH	: pH meter with selective electrodes
Na, K	: Atomic absorption spectrophotometer
Ca, Mg	: EDTA titro-metric and atomic absorption spectrophotometer
Cl	: Mohr titrametric and chloride metric
SO_4	: Spectrophotometer and gravimetric
HCO_3	: Acidimetric neutralization
Sr	: Atomic absorption and selective ion electrode
B	: Spectro-photometric and selective ion electrode
Cu, Zn, Fe and Ba	: Spectro-photometric and selective ion electrode

*For correspondence. (e-mail: vks_9020010@yahoo.co.in)

Table 2. Chemical composition of groundwater, Krishna Delta

Sample no.	Type of well	Depth (m)	EC	TDS	pH	Na	K	Ca	Mg	Cl	HCO_3	SO_4	Sr	B
1	DW	3.50**	1250	775	7.5	110	10	80	30	188	280	45	775	104
2	DW	4.50**	2300	1665	7.8	150	20	170	80	465	280	185	1665	369
3	HP	21.00*	2050	1230	7.8	140	22	170	75	460	275	140	1230	166
4	HP	18.00*	1950	1215	7.5	285	20	140	45	235	410	175	1215	147
5	DW	4.45**	2800	1915	7.5	485	25	100	75	785	325	140	1915	211
6	DW	4.80**	2100	1310	7.5	145	10	150	70	335	445	120	1310	199
7	DW	2.20**	4500	2760	7.8	750	32	85	105	960	360	480	2760	422
8	DW	1.92**	2300	1650	7.6	140	10	265	70	440	250	455	1650	238
9	HP	18.00*	2950	1785	7.9	400	25	100	80	775	325	70	1785	332
10	HP	28.00*	4416	3180	7.6	650	20	155	130	980	330	440	3180	2929
11	HP	22.00*	3343	2340	7.8	165	10	180	145	760	495	370	2340	366
12	DW	2.66**	2100	1315	7.6	160	10	170	45	355	435	85	1179	188
13	DW	10.5**	1250	830	7.6	100	10	105	50	250	255	55	306	102
14	DW	3.05**	1900	1200	7.5	160	15	90	70	450	350	175	902	127
15	DW	2.72**	3300	1980	7.9	345	20	125	140	750	385	275	1750	242
16	DW	1.44**	1850	1100	7.6	140	15	180	40	410	330	100	947	151
17	DW	4.21**	2100	1405	7.8	165	10	165	55	405	490	60	846	129
18	HP	16.00*	1450	915	7.5	95	20	105	40	205	270	160	840	156
19	HP	18.00*	2300	1435	7.8	160	10	160	82	305	550	75	983	159
20	DW	4.88**	1050	665	7.8	85	15	80	20	150	245	30	253	179
21	DW	1.44**	950	630	7.4	85	10	65	20	145	250	30	602	71
22	HP	20.00*	1450	900	7.6	70	10	120	25	275	210	35	23	94
23	DW	2.00**	2000	1440	7.9	180	15	175	70	405	505	60	1500	129
24	DW	1.98**	3250	2110	7.9	400	20	120	165	785	365	280	1790	284
25	DW	2.40**	1150	835	7.8	130	10	60	50	255	265	50	203	143
26	HP	22.00*	5050	3175	8.6	650	40	75	210	1160	475	545	1679	695

1, Peddaruru; 2, Kolluru; 3, Vellturu; 4, Ansalkudu; 5, Gurumula; 6, Narakun; 7, Induru; 8, Chibrolu; 9, Vallabha; 10, Chadalwada; 11, Reppale; 12, Tenali; 13, Kesarpalli; 14, Vijayawada; 15, Uppuluru; 16, Vyyuru; 17, Katuru; 18, Elarru; 19, Penamaru; 20, Kankipadu; 21, Royyuru; 22, Vall. puram; 23, Kapileswaram; 24, Nidumolu; 25, Chellapalle and 26 Kudali.
EC in μS/cm at 25°C; Sr and B in μg/l; pH at 25°C; Concentrations are in mg/l; DW, Dug well; HP, Hand pump; * indicates total depth of hand pump; **Depth of water table in dug wells.

Table 3. Basis of classification

Parameter	Freshwater	Brackish water	Saline water
TDS	< 1500	1500–3000	> 3000
Sr	< 1600	1600–5000	> 5000
B	< 200	200–500	> 500

TDS in mg/l, Sr and B in μg/l.

Table 4. Classification based on TDS, strontium and boron

Sample no.	TDS	Sr	B	Sample no.	TDS	Sr	B
1	F	F	F	14	F	F	F
2	B	B	B	15	B	B	B
3	F	F	F	16	F	F	F
4	F	F	F	17	F	F	F
5	B	B	B	18	F	F	F
6	F	F	F	19	F	F	F
7	B	B	B	20	F	F	F
8	B	B	B	21	F	F	F
9	B	B	B	22	F	F	F
10	S	B	S	23	F	F	F
11	B	B	B	24	B	B	B
12	F	F	F	25	F	F	F
13	F	F	F	26	S	B	S

TDS: mg/l, F, Freshwater, B, Brackish water and S, Saline water.

480 km in Maharashtra, 291 km in Karnataka and 510 km in Andhra Pradesh (a total distance of 1281 km) it emerges into the Bay of Bengal and forms a delta. A large number of townships such as Tenali, Vijayawada, Guntur, Machlipatnam, Nizampatnam and Repalle are located in the delta region. The right side of the Krishna river is known as North Krishna Delta and the left side is known as South Krishna Delta. Most of the soil of this delta region is alluvium. The flood basin on the right bank of the Krishna river is covered with black clay and grey clay underlain by brown silty clays and fine sands. Average rainfall is 1050 mm and annual temperature is 28°C.

Groundwater samples were collected in polythene bottles for the analysis of major cations and anions. Groundwater from each dug well was sampled at 0.5 m below the water-table. Hand pumps were run for 5 min before collection of the samples. The water sample was also colleted for trace elements. For this a 100 ml polythene bottle was used. Soon after collection of the sample, 1 ml HNO_3 was added and the sample bottle was kept air tight. Table 1 gives the instrumental/chemical techniques used for chemical analysis of water samples[11].

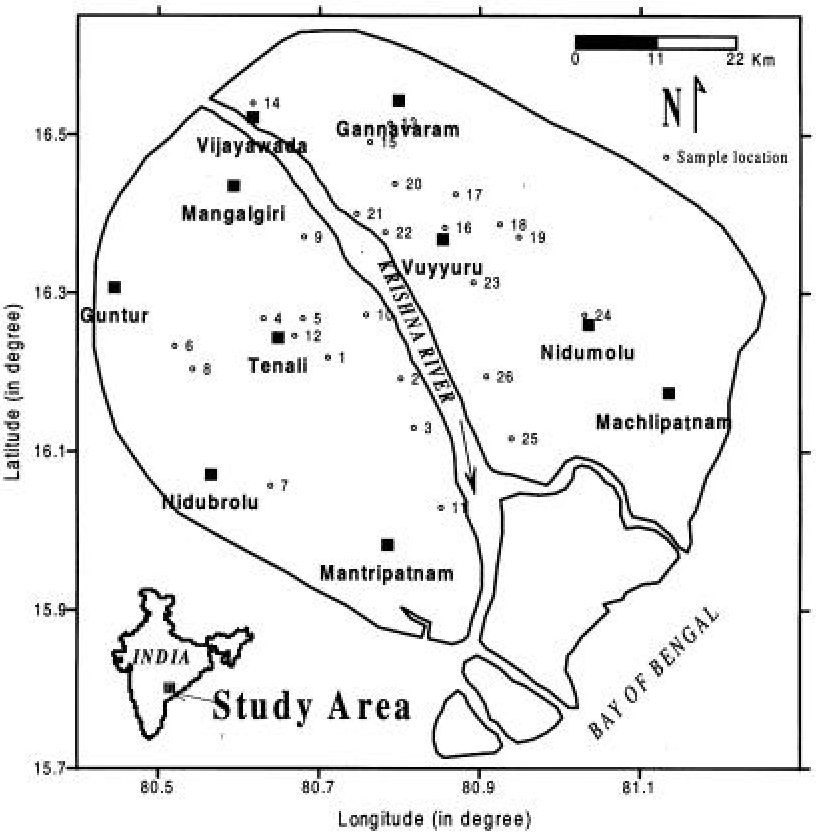

Figure 1. Location of groundwater, Krishna Delta.

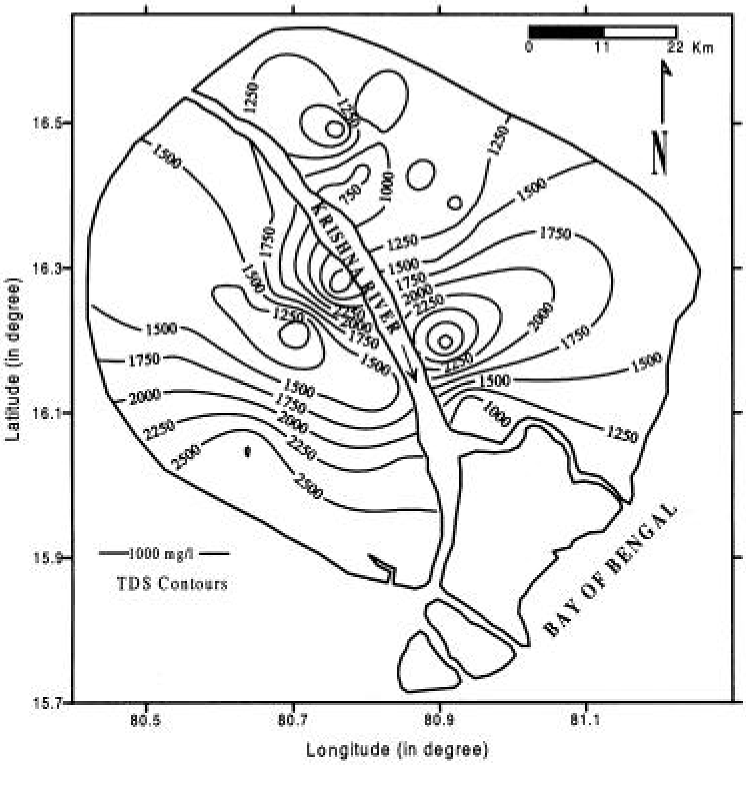

Figure 2. Contour of TDS.

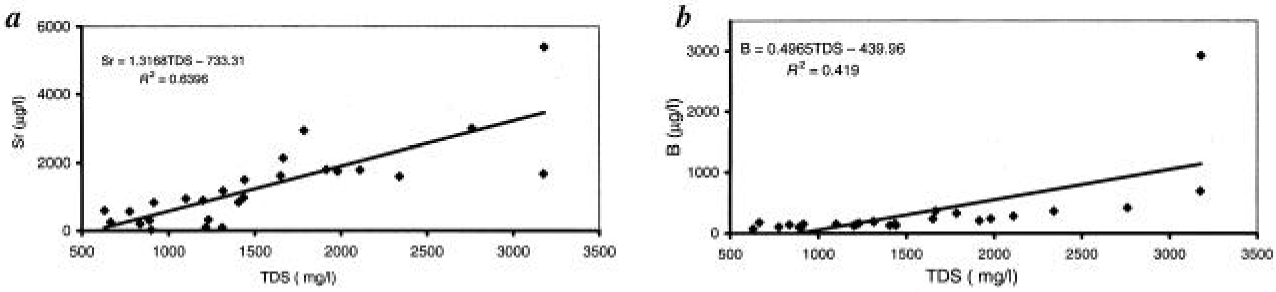

Figure 3. ***a***, TDS vs strontium, and; ***b***, TDS vs boron.

For the identification of fresh groundwater resources in the delta region, 26 groundwater samples were collected. Twelves samples were collected from South Krishna Delta and 14 from North Krishna Delta. The results are presented in Table 2. It can be seen from Table 2 that the groundwater is nearly neutral to mildly alkaline (pH: 7.4–8.6) and TDS varies from 630 to 3180 mg/l, this shows the different types of chemical characteristics of groundwater. Based on the dominance of cations and anions, the groundwater has been classified into NaCl, Na-Ca-Cl-HCO_3, Na-Mg-Cl-SO_4 and mixed type. Table 2 shows the concentration of various trace elements, and most of these are within the permissible limit of portable water[12–14]. Strontium and boron are the most dominating metallic trace elements in these groundwater samples. Fresh groundwater has been found in the villages, i.e. Peddaruru, Velluturu, Ansalkudu, Tenali, Kesarpali, Vijayawada, Vyyuru, Katuru, Elarru, Penamaru, Kankipadu, Royyuru, Vallavapuram, Kapileswaram and Chellapalle (Table 2). Figure 2 shows the contours of TDS; greater influence of sea-water intrusion has been observed in the South Krishna Delta, in particular the southeast region. Simultaneously, there is high concentration of TDS in the middle of the North Krishna Delta and also in the southwest part of the South Krishna Delta. This study indicates the preliminary water quality zonations on surface basis. The main groundwater types of this region are fresh, brackish and saline. Most of the groundwater has already become brackish/saline[6–8]. On synthesizing the chemical data as reported in Table 2, good correlations have been found between TDS and strontium (Figure 3 *a*), and TDS and boron (Figure 3 *b*). In general, strontium and boron were found to be less in fresh groundwater, but more in brackish and saline waters (Table 3). Strontium content in groundwater has been contoured; it has been found that the north side of the delta, mostly in the central part and close to Vyyurru–Royyuru–Elarru has comparatively less sea-water intrusion. But the groundwater near Nidumolu and Kudali has more in sea-water intrusion. In South Krishna Delta, the situation is little different because of high ingression rate observed in Chadalwada–Reppale–Induru tie-lines. Boron content of groundwater was also contoured; the activity of boron is greater towards the right side of the Krishna river in North Krishna Delta. In the middle part of the delta, sea-water intrusion is more. However, the withdrawal of water is also indicated to be more in this part. Freshwater zones identified by strontium and boron were compared (Table 4) with TDS. This indicated the applicability of strontium and boron as useful parameters for the delineation/identification of fresh groundwater resources in the delta region.

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Millennium-long ring-width chronology of Himalayan cedar from Garhwal Himalaya and its potential in climate change studies

Jayendra Singh, Ram R. Yadav*, Bhasha Dubey and Rajesh Chaturvedi

Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India

We report here a 1198-year long (AD 805–2002) ring-width chronology of Himalayan cedar (*Cedrus deodara*) from a site in Bhaironghati, Garhwal, Uttaranchal. This provides the longest record of ring-width chronology prepared so far using living tree samples from the Himalayan region. The forest from which the constituent samples were derived is a natural stand of mixed age. Many of the trees are several centuries old, with average age reaching 532 years. The ring-width chronology shows strong indirect relationship with mean monthly temperature from February to May. Strong temperature signal present in the series shows the potential of such long-term chronologies in developing climatic reconstructions useful for evaluating the recent climatic changes under the background influence of increasing concentration of greenhouse gases.

UNDERSTANDING the causes and mechanisms of the earth's climate variability requires developing high-resolution proxy records of climate spanning several centuries and millennia[1]. The proxy records spanning millennia and beyond, available thus far, are largely restricted to high-latitude Northern and a few from the Southern Hemisphere[1,2]. However, for the Himalayan region, which is climatically important, such long-term records are not yet available, except for the lone tree-ring-width chronology of Himalayan cedar spanning from AD 1168 to 1988 (821 years) prepared using living tree samples from Harshil, Uttarkashi, Uttaranchal[3]. To fulfill the need of millennium long chronology we describe here a 1198-year long ring-width chronology of Himalayan cedar from a site featured by rocky slopes with thin soil cover in Bhaironghati, Uttarkashi, Uttaranchal. The chronology provides valuable input to the global data network required to infer the hemispheric-scale changes in climate.

The tree-ring samples in the form of increment cores (usually two from each tree) were collected from 30 living trees during two field trips undertaken in September 2000 and June 2003 from a site near Bhaironghati (Figure 1). The krummholz nature and crown dieback with umbrella-shaped canopy of the trees indicate old age and climatic stress. Several trees at this site were found to be 700–800 years old, except one tree where the number of rings in the extracted core was around 1200. Complete age of this tree could not be determined, as the core length retrieved was limited due to heart rot. However, in order to obtain longer series, we attempted to take six cores from different directions of the main stem at variable heights. Due to the presence of narrow rings towards the inner end of the cores, we expect that the age of the tree could extend beyond 1500 years.

The increment cores collected were air-dried and glued on grooved wooden supports for safe handling in the laboratory. The growth ring sequences were cross-dated using skeleton plotting[4]. In this procedure, the relative narrowness of rings in comparison with the adjacent ones was plotted on graph-paper strips and then ring-width sequences among the samples crossmatched. About 2.3% rings were recorded missing in samples, indicating climatic stress experienced by the trees. The nature and location of the site also indicate that the trees might be subjected to frequent stone-fall injuries. The falling stones damage the trees coming in their way. The damages due to stone fall are healed in few years, leaving no visible scar on the outer surface. If the increment corer passes through such old injuries, the core extracted has several missing rings depending on the magnitude of the damage. Cores with a number of missing rings were noted in many samples in our collection. When dating in such cases was not possible, the sample in question was rejected for further study. We have been able to successfully cross-date 43 core samples derived from 24 trees. The ring-widths of dated growth-ring sequences were measured to 0.01 mm accuracy using linear encoder coupled with a personal computer. The accuracy of cross-dating among the samples was cross-checked using a dating quality control program, COFECHA[5]. This helps in identifying segments of a core or group of cores where dating or measurement errors may have occurred. Samples that showed ambiguity were rechecked, and where problems could not be corrected, the material in question was excluded from further analysis. The tree-ring-width patterns within the samples showed good cross-dating. COFECHA showed a mean correlation of all 43 radii from 24 trees with the master series of 0.83. Such a high correlation and good

*For correspondence. (e-mail: rryadav2000@yahoo.co.in)