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Assessment of Hydrochemical Characteristics of Groundwater for Drinking and Agricultural Purposes Along the Coastal Areas of Chennai City, India

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Groundwater samples from 18 locations were collected between December 2008 and March 2009 in the coastal areas of Chennai city along the Buckingham canal in Tamil Nadu, India. The quality of groundwater in this area has been analysed for drinking purposes by comparing the physical and chemical parameters with WHO standards. Further, the suitability of groundwater in this region for agriculture was evaluated based on sodium adsorption ratio and percent sodium. The present study reveals that quality of groundwater is found to be unsuitable for consumption at various sampling locations. For irrigational purpose, the groundwater quality was found suitable only at few places.

Key words: *Groundwater quality, coastal area, Buckingham canal, Chennai, India*

Introduction

Water is one of the most important natural resources for the development of agriculture, industries, navigation etc. Groundwater is the safest and most reliable source of available fresh water. For majority of people living in the urban areas where surface water sources are inadequate or nil, groundwater is the only source of drinking water. Thus, groundwater next to surface water is the most important water resource in meeting the domestic water requirement. Initially surface water was tapped and used continuously under the assumption that its availability is unlimited. In many basins of the world, inadequacy and unreliable supply of surface water has forced many to go for groundwater use, the rate of its use therefore has increased at an exponential rate. Rapid and unplanned urbanization in many parts of the world has brought in a number of environmental problems, such as over exploitation of groundwater, groundwater pollution due to sewage disposal, solid waste dumping in the water bodies, encroachment of public lands and flooding of low lying city areas. The indiscriminate use of the groundwater has also resulted in rapid decline in water table in many parts of the world. The coastal aquifers are more vulnerable due to this water decline which results in seawater intrusion which has been studied in many parts of the world[1-5]. Uncontrolled pumping in south of Chennai city also has caused seawater intrusion in the fragile coastal aquifers in a number of places. This had been studied by Gnanasundar and Elango[6] using VES (Vertical Electrical Sounding). Nearly ten years after the previous study, the present work has been carried out to appraise the status of the suitability of groundwater in these regions for drinking and irrigation purpose in the coastal regions of Chennai city along the Buckingham canal by groundwater quality assessment.

Study area

Chennai is the fourth largest city in India, covering an aerial extent of 172 sq.km. It is situated on the east coast of south India and is the capital of Tamil Nadu. The city lies in a relatively flat topographic gradient. Buckingham canal is a man-made canal constructed during the year 1806, and it runs parallel to the coast of Bay of Bengal, south-east India from Vijayawada in Andhra Pradesh to Cuddalore in Tamil Nadu. The total length of the Buckingham canal is 420 km, with 163 km lying in Tamil Nadu and 257 km in Andhra Pradesh. A length of 24 km in south Buckingham canal has been chosen for this study. The south Buckingham canal is located at a latitude of 13°04′04″N and longitude of 80°16′56″E (**Fig. 1**). The climate of the study area is characterized by typical coastal climate with high humidity and annual average temperature in the range of 32 °C. The study area experiences rainfall in the Southwest (June to September) and Northeast (October to December) monsoons. The annual rainfall is in the range of about 1230 mm. Rainfall in this area is characterized by heavy downpour resulting in water logging in low-lying areas. Gales and cyclones are experienced during the northeast monsoon.

Geological features

The sedimentary rocks and alluvial formation occur all along the coast. The sedimentary formation mainly consists of recent alluvial deposits, tertiary and cretaceous deposits. There are also sporadic occurrences of upper Gondwana beds in between the Archaeans and the younger sedimentary

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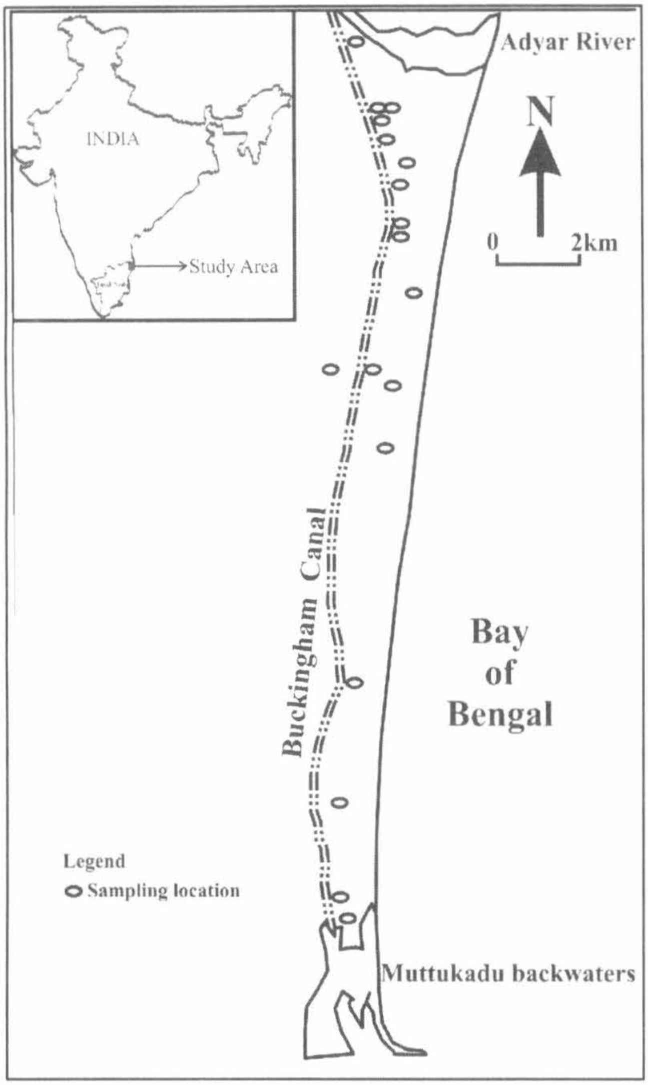

Fig. 1 : The study area

formations. The sedimentary rocks consisting of cuddalore sandstone, shales and sandstones of upper Gondwana and charnockites of Archaean era characterize the geology of the east coast. The study area under consideration has very shallow alluvial aquifer interposed with marine and bluish clay and bordered on the east by Bay of Bengal, on the west by gneissic mass overtopped by clay loam, on the south by Muttukadu backwaters and on the north by Adyar River.

Methodology

The groundwater samples were collected from 18 wells (**Fig. 1**) lying in and around the area of study during the month of December 2008, January 2009, February 2009 and March 2009. A total of 72 groundwater samples were collected during this study. The samples collected were analyzed for various physical and chemical parameters. 500 mL of water samples were collected in clean polythene bottles from the study area. The sampling bottles were cleaned with detergent and soaked with ten percentage of nitric acid followed by washing with distilled water. After the collection of samples, they were properly labeled indicating the source, date, time of collection and other records. The samples were kept in a cool place away from the sunlight. Samples were analyzed as per standard methods[7] within two days so as to get more reliable and accurate results. The instrumental and chemical techniques used for the analysis of the groundwater samples are given in **Table 1**.

Results and discussion

The samples were analysed for both physical and chemical parameters which are briefly discussed below. The statistical measures, such as minimum, maximum, mean and standard deviation of the physical and chemical parameters assessed are given in **Table 2**. In order to assess the suitability of the collected groundwater samples for drinking purposes, the analytical results obtained were compared with the standard guideline values of World Health Organisation (WHO)[8] (**Table 3**).

Table 1 : Methodology adopted for analysis of groundwater samples

Parameters	Method	Instrument
pH	-	Digital portable meter
Temperature	-	Digital portable meter
Total Dissolved Solids (TDS)	-	TDS meter with selective electrode
Calcium	Volumetric	Titration
Magnesium	Volumetric	Titration
Sodium	Flame photometry	Flame photometer
Potassium	Flame photometry	Flame photometer
Carbonate andBicarbonate	Volumetric	Titration
Chloride	Volumetric	Titration
Sulphate	Turbidity	Spectrophotometer

Table 2 : Minimum, maximum, mean and standard deviation of physical and chemical parameters

Parameter	Unit	Number of samples	Minimum	Maximum	Mean	Standard deviation
pH	-	72	6.5	8.1	7	0.30
Temperature	°C	72	27.8	30.9	29.4	0.78
TDS	mg/L	72	296	26000	2169	650.63
Sodium	mg/L	72	43	3589	402	59.01
Potassium	mg/L	72	2	348	45	75.80
Calcium	mg/L	72	5	500	45	32.99
Magnesium	mg/L	72	1	189	29	837.50
Chloride	mg/L	72	10	5890	393	332.42
Sulphate	mg/L	72	20	1910	160	0.00
Carbonate	mg/L	72	0	0	0	228.16
Bicarbonate	mg/L	72	156	1100	515	333.98
TH	mg/L	72	21	2026	289	4498.50

Physical parameters

Temperature and pH, the physical parameters, were measured in the field. The temperature of the groundwater samples collected from the study area for the period of four months ranged from 27.8°C to 30.9°C with an average of 29.4°C. The pH values showed both spatial and temporal variation. The pH values varied from 6.5 to 8.1 with a mean of 7. Most of the samples were alkaline in nature. It was observed that all the samples were within the permissible limits. A lower pH may cause tuberculation and corrosion of pipelines whereas high values may produce incrustation, sediment deposits, difficulty in chlorination and other bad effects on the humans who consume the water.

Chemical parameters

Cations, which include sodium, potassium, calcium and magnesium varied from place to place and their abundance was observed at some places which were located very near to the sea. Sodium was the major ion dominant in the cation category. A high concentration of sodium is an indication of seawater or brackish water contamination. 47.22% of the groundwater samples had sodium ion concentration above the WHO standards (200 mg/L). Calcium was the second dominant cation. The maximum allowable limit of calcium is 200 mg/L and the most desirable limit is 75 mg/L as per the WHO international standards and only 4.17% of the groundwater samples did not fall within the maximum permissible limit. Magnesium which is an essential element in chlorophyll of plants and in red blood cells of humans varied from 1 to 189 mg/L, and was within the desirable limit except in one sample (1.39%). This may be due to the disposal of domestic wastewater on the surface which percolates and mixes with groundwater.

Potassium was in the range of 2 to 348 mg/L. The concentration of potassium ion is not within the permissible level except in eleven groundwater samples. The carbonate and bicarbonate analysis indicated that the content of carbonate was totally absent in the study area. The minimum and maximum concentration of the bicarbonate varied from 156 mg/L to 1100 mg/L. The excessive concentration of this ion would cause objectionable taste. Chloride was the dominant ion present in the anion category. The maximum allowable limit of chloride is 600 mg/L and the most desirable limit is 200 mg/L as per the WHO standards. The minimum and maximum value of chloride content ranged from 72 mg/L to 855 mg/L. The excess of chloride are dangerous to the health and it imparts a salty taste to water. A positive correlation was found between chloride and sodium (**Fig. 2**) which shows that there is an intrusion of seawater in the study area which has resulted in the simultaneous increase in sodium and chloride ions concentration in the groundwater. The sulphate concentration was high in three groundwater samples. The reason for high concentration of sulphate upto 1910 mg/L may be due to domestic waste being dumped along the canal.

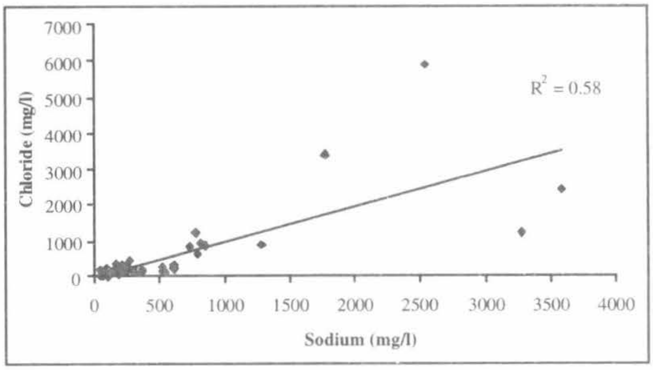

Fig. 2 Plot of sodium (mg/L) vs chloride (mg/L)

Table 3 : Comparison of groundwater samples with WHO standards

Parameter	WHO standard		Number of samples above maximum allowable limit	Percentage of samples above maximum limit allowable
	Desirable limit	Maximum allowable limit		
pH	6.5 – 8.5	9.2	Nil	Nil
TDS (mg/L)	500	1500	13	18.06
Calcium (mg/L)	75	200	3	4.17
Magnesium (mg/L)	50	150	1	1.39
Sodium (mg/L)	-	200	34	47.22
Potassium (mg/L)	-	12	61	84.72
Chloride (mg/L)	200	600	10	13.89
Sulphate (mg/L)	200	400	3	4.17

Total Hardness(TH)

The TH of the water samples has been calculated by using the formula[9] mentioned below:

$$TH = 2.497Ca + 4.115Mg \text{ in mg/L} \quad (1)$$

The maximum and minimum values of TH in the water samples were 21 mg/L to 2026 mg/L with an average of 289 mg/L. As per the WHO standards, the desirable limit of TH is 100 mg/L whereas the maximum permissible level is 500 mg/L. TH was above the maximum permissible limit of 500 mg/L in 9 groundwater samples (**Table 4**). 34.72% of the groundwater samples found under moderately high type with TH between 75 and 150 mg/L. Twenty samples were of soft water category contributing to 8.33%. Of the overall samples collected, 29.17% were very hard and 27.78% were hard natured with TH ranging between 150 to 300 mg/L.

Table 4 : Classification of groundwater based on TH (mg/L)

TH (mg/L)	Type of water	Number of samples	Percentage
<75	Soft	6	8.33
75 - 150	Moderately high	25	34.72
150 - 300	Hard	20	27.78
>300	Very Hard	21	29.17

Table 5 : Classification of groundwater based on TDS (mg/L) (Freeze and Cherry, 1979)

TDS (mg/L)	Classification	Number of samples	Percentage
<1,000	Fresh water	39	54.17
1,000 - 10,000	Brackish water	29	40.28
10,000 - 1,00,000	Saline water	4	5.55
>1,00,000	Brine	Nil	Nil

Total Dissolved Solids (TDS)

To find out the suitability of groundwater for various purposes, such as irrigation and domestic activities, it would be required to classify them based on the TDS values. Classification of the groundwater on the basis of TDS values is given in **Table 5** and **Table 6**. As per Freeze and Cherry[10] classification, most of the groundwater samples (54.16%) are of fresh water type. Brackish water type was found in 29 (40.28%) and saline water type in 4 (5.55%) of the groundwater samples. According to Davis and DeWiest[11] type of classification of groundwater based on TDS, only 39 samples were found to be permissible for drinking purpose. Of these 39 samples, 5 samples i.e. 6.95% were desirable for drinking and 34 samples (47.22%) were permissible for drinking. For irrigational purposes, 36.11% of the samples were suitable. Of the total 72 samples analysed, 9.72% of the groundwater samples were unfit for both irrigation and drinking purpose. Gnanasundar and Elango[6] also found that the groundwater quality was poor near the Buckingham canal. However, the same situation still prevails which is understood from this study.

Hydrochemical facies

The Piper trilinear diagram[12] was remarkably used to understand the geochemical evolution of groundwater. The groundwater chemical composition of the chosen study site when plotted on the Piper trilinear diagram showed mainly two types of water- Mixed Ca-Na-HCO_3 type and Na-Cl type (**Fig.3**). Mixed Ca-Na-HCO_3 groundwater type may be due to the mixing of domestic wastes and sewage which is not disposed properly. The Na-Cl groundwater type may be due to seawater intrusion.

Irrigation water quality

The suitability of water for irrigation purpose can be ascertained by using the following criteria- (i) SAR (Sodium

Table 6 : Classification of groundwater based on TDS (mg/L) (Davis and DeWiest, 1966)

TDS (mg/L)	Classification	Number of samples	Percentage
<500	Desirable for drinking		5 6.95
500 - 1,000	Permissible for drinking	34	47.22
1,000 - 3,000	Useful for irrigation		26 36.11
>3,000	Unfit for drinking and irrigation	7	9.72

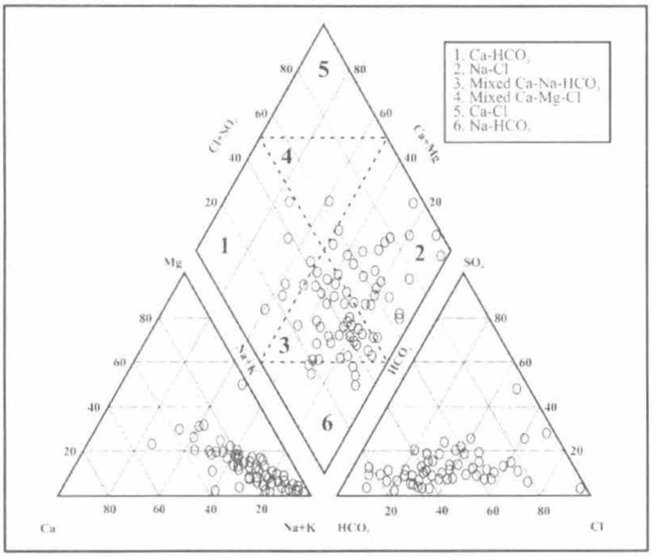

Fig. 3 : Piper diagram showing hydrochemical facies of groundwater

Adsorption Ratio) and (ii) %Na (percent sodium). The groundwater samples collected were classified based on the above mentioned criteria which are presented in **Table 7** and **Table 8**.

SAR is the measure of sodium hazard to the crops and it was calculated using the following formula[13].

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \qquad (2)$$

where the concentration of all the ions are represented in meq/l.

As per the SAR values, 58.33% of the samples were excellent for irrigation while 12.50% of the samples were unfit for this purpose. The percent sodium was calculated by the following formula where all the concentration is in meq/l[14]:

$$\%Na = \frac{(Na^{+} + K^{+})}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})} X100 \qquad (3)$$

Table 7 : Classification of groundwater based on SAR

Water class	SAR	Number of samples	Percentage
Excellent	Upto 10	42	58.33
Good	10 to 18	15	20.83
Medium	18 to 26	6	8.33
Bad	>26	9	12.50

Table 8 : Classification of groundwater based on sodium percentage

Water class	Percent sodium	Number of samples	Percentage
Excellent	<20	Nil	Nil
Good	20 to 40	1	1.39
Permissible	40 to 60	2	2.78
Doubtful	60 to 80	19	26.39
Unsuitable	>80	50	69.44

The % Na values indicate that most of the samples (69.44%) are unsuitable for irrigation purpose and only 21 samples can be used for agricultural activities. The values of SAR indicate that more number of samples can be used for irrigation purpose while the %Na shows that only a small number of samples are fit for irrigation.

Conclusion

The hydrochemical analysis of the groundwater samples collected along the coast of Chennai city, south-east India reveals that the groundwater in this area is mainly of two types namely, Mixed Ca-Na-HCO_3 type and Na-Cl type. Further, high concentration of sodium and chloride and a positive relationship between them indicate that the area under study is being influenced by seawater intrusion. More than half the number of samples (39 samples) is fresh water type based on TDS. TH was high pertaining to hard water in 41 samples. The samples were assessed for their quality for irrigation purpose based on SAR and %Na values which indicate that 50 samples (69.44%) are unfit for irrigation with respect to %Na. But, SAR values indicate that 12.50% of the samples alone are unsuitable for irrigation purpose. A number of samples exceeded the permissible concentration of various ions in drinking water as per WHO standards. Thus, overall groundwater quality in this area is not suitable for drinking purpose and to a certain extent for irrigation purpose. This is mainly due to the improper disposal of domestic sewage on land surface and seawater intrusion. It is essential to improve the quality of groundwater in this area by controlled pumping and modifying the pattern of pumping groundwater, by artificial recharge methods and by the construction of subsurface barriers to prevent the inflow of seawater.

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