

Preliminary Study on Seawater Intrusion in Coastal Aquifers of Visakhapatnam



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Abbreviations

APHA	American Public Health Association
BIS	Bureau of Indian Standards
Ca	Calcium
CaH	Calcium Hardness
Cl	Chlorides
EC	Electrical Conductivity
EEC	European Economic Community
MgH	Magnesium Hardness
Na	Sodium
TA	Total Alkalinity
TDS	Total Dissolved Solids
TH	Total Hardness
WHO	World Health Organisation

1 Introduction

Water is essential to people's lives and livelihoods. It causes the demand for clean water to rise in lockstep with global population growth. Without groundwater, the

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largest and most reliable of all freshwater resources, it would be impossible to maintain secure water supplies for drinking, industry, and agriculture. Groundwater, unlike other natural resources or raw materials, is found all over the world. Because of rainfall patterns and aquifer distribution, the possibilities for its extraction vary greatly from place to place (rocks, sand layers, and so on, in whose pore spaces the groundwater sits). Because of the hydraulic gradient of groundwater above mean sea level, freshwater is also widespread in the coastal aquifer [1, 2]. The mass transport of saline waters into previously occupied zones by fresher waters is known as saltwater intrusion. The movement of saltwater with high total dissolved solids (TDS) content into freshwaters is characterised as saltwater intrusion. Coastal aquifers are important sources of freshwater supply in many countries around the world, particularly in arid and semi-arid zones [3]. Many coastal areas in India are heavily urbanised, exacerbating the need for freshwater. Aquifers along the coast are vulnerable to disturbances. Inadequate management of a coastal aquifer may result in its demise as a source of freshwater much sooner than other aquifers not connected to the sea. The threat of seawater intrusion is the reason [4, 5].

The chemical composition of groundwater is determined primarily by three processes: atmospheric inputs, water interaction with soil and rock, and anthropogenic activities. Precipitation, climate change, and natural hazards all contribute to atmospheric inputs, while water interaction with soil and rock causes weathering and erosion of crustal materials. Over-exploitation of groundwater and the location of industries above sensitive zones have a significant impact on groundwater quality [6]. The presence of highly brackish waters in certain localised pockets of the coastal aquifer, such as Kaniti-Paravada near Visakhapatnam, is caused by hydrogeological processes in the area, not by sea influence [7]. The purpose of this paper is to investigate the controlling mechanism of seawater intrusion in Visakhapatnam's coastal aquifers.

- MeghadriGedda Reservoir
- Raiwada Link Canal
- Yeleru Left Bank Canal

2 Materials and Methods

2.1 Study Area

Greater Visakhapatnam, once a small fishing village, has grown into a major port city over the years. It also serves as the administrative centre for the Visakhapatnam district. Visakhapatnam is located on India's east coast, at 17°42' North latitude and 82°02' East range of hills. The city and its surroundings can be divided into four categories based on topographical conditions: Hilly region, Upland tracks, Rolling plains, and Plains.

The main surface sources of water for the city of Visakhapatnam are

Table 1 Details of sampling sites with codes in Visakhapatnam

Sample code	Sample site	Source	Use of water
S1	Bheemunipatnam	Hand pump	Drinking, domestic
S2	Chepaluppada	Open well	Domestic, laundry
S3	Mangamaripeta	Bore well	Drinking, domestic
S4	Timmapuram	Bore well	Drinking, domestic
S5	Rushikonda	Bore well	Drinking, domestic
S6	SagarNagar Colony	Hand pump	Drinking, domestic
S7	Jodugullapalem	Hand pump	Domestic, laundry
S8	Appugarh	Hand pump	Drinking, domestic
S9	MVP Colony	Hand pump	Drinking, public usage
S10	PeddaWaltair	Hand pump	Drinking, domestic
S111	EastPoint Colony	Hand pump	Drinking, domestic
S12	Babuji Nagar	Hand pump	Drinking, domestic
S13	Pandurangapuram	Hand pump	Drinking, domestic
S14	MaharaniPeta	Hand pump	Drinking, domestic
S15	Opp. KGH Hospital	Hand pump	Drinking, public usage
S16	Burujupeta	Hand pump	Drinking, domestic

- Mudasarlova Reservoir
- GambheeramGedda Reservoir
- Gosthani River
- Thatipudi Reservoir

Ground water samples (from open wells, bore wells, and hand pumps) were collected from sixteen locations along Visakhapatnam's coastline (from Burujupeta to Bheemunipatnam). The sampling sites are located 5–8 kms from the coast, and the details of the sampling sites are provided in Table 1. Water samples were collected in 2-L polythene bottles (soaked overnight in 2% nitric acid and washed thoroughly in distilled water) from each location and analysed for pH, Conductance, Total Dissolved Solids, Total Hardness, Calcium Hardness, Magnesium Hardness, Alkalinity, Chloride, Sulphate, Nitrate, Phosphate, Iron, Sodium, and Potassium as per standard methods [8].

3 Results and Discussion

Table 2 shows the results of the various quality parameters for all samples. A brief description of the essential physicochemical properties of groundwater is provided below.

Table 2 Physico-Chemical characteristics of ground water samples collected from different areas of Visakhapatnam city

Sample Code	pH	Electrical Conductivity (mmhos)	Total Dissolved Solids	Chlorides	Alkalinity	Total Hardness	Calcium Hardness	Magnesium hardness	Phosphates	Sulphates	Nitrates	Iron	Sodium	Potassium
S1	7.49	0.78	429	24.99	160	170	70	100	0.5	7.5	0.04	0.153	60.3	6.5
S2	7.85	2.08	1144	149.99	380	340	160	180	0.62	31.5	0.069	0.22	132.8	7.3
S3	7.1	0.31	170.5	24	110	120	90	30	0.64	3.5	0.027	0.04	32.2	1.8
S4	7.38	1.06	583	74	160	280	150	130	0.54	11	0.042	0.15	49.0	9.6
S5	8.12	1.41	775.5	99	290	320	180	140	0.96	11	0.034	0.2	71.9	7.7
S6	8.01	2.02	1111	124	300	360	200	160	0.3	16	0.049	BDL	170.6	25.8
S7	7.21	1.25	687.5	99	160	290	160	130	0.6	10	0.037	BDL	91.2	4.3
S8	8.2	2.36	1298	199	440	380	220	160	0.72	33	0.067	BDL	200.1	11.3
S9	7.91	1.81	995.5	149	370	320	170	150	0.89	10	0.04	0.01	127.6	2.5
S10	7.84	1.67	918.5	149	260	340	180	160	0.68	17.5	0.059	0.06	66.2	3.7
S11	7.72	1.96	1078	174	340	280	170	110	0.74	20	0.066	BDL	87.1	11.4
S12	7.02	2.18	1199	199	300	280	130	150	0.2	33.5	0.078	0.02	161.5	11.7
S13	7.5	1.49	819.5	174	250	240	140	100	0.2	18.5	0.064	BDL	92.6	4.3
S14	7.73	1.39	764.5	99.99	280	270	130	140	0.48	3.5	0.028	0.09	93.0	3.7
S15	7.69	1.4	770	99.99	280	240	130	110	0.62	3.5	0.022	0.15	93.0	2.8
S16	8.21	2.11	1160.5	149.99	360	340	160	180	0.8	23.5	0.072	0.08	150.7	68.4

* pH; No measurements, EC: mmhos; Cl, Alkalinity, CaH, MgH, TH, phosphates, Sulphates, Nitrates, Iron, Sodium, Potassium measures in mg/l
BDL = Below Detection Level

3.1 pH

The pH in the study areas ranged from 8.21 at (S-16) in Burujupeta to 7.02 at (S-12) PeddaWaltair. All of the pH values in the samples are well within the ranges for various water uses, including drinking and other domestic supplies [8, 9].

3.2 Conductance

The conductance ranged from a maximum of 2.36 mmhos/cm at (S-8) Appugarh to a minimum of 0.31 mmhos/cm at (S-3). Due to the high concentration of Ionic constituents present in the water bodies under study, almost all of the water samples under study exceeded the permissible limit (0.3 mmhos/cm), reflecting the contributions from salinity intrusion and pollution by domestic wastes. The dissolved ions such as bicarbonates, chlorides, sodium, potassium, magnesium, and sulphate are primarily responsible for electrical conductivity [11].

3.3 Total Dissolved Solids (TDS)

The values of Total Dissolved Solids (TDS) in groundwater in the current study range from 170.5 to 1298 mg/l, indicating high mineralization in the study area. Furthermore, organic substances commonly found in polluted water may contribute to the Dissolved Solids. Water with more than 500 mg/l TDS is not considered desirable for drinking water supplies, though more highly mineralized water is used in places where better water is unavailable. As a result, for drinking water, 500 mg/l has been proposed as the desirable limit and 2000 mg/l as the maximum permissible limit [8, 9]. TDS levels greater than 500 mg/l in water cause gastrointestinal irritation [8, 9].

3.4 Chlorides

Ranged from 24 to 199 mg/l in the study areas. Chloride limits have been established primarily based on taste considerations. A desirable limit of 250 mg/l chlorides has been recommended for drinking water [8, 9]. However, no adverse health effects on humans have been reported from drinking water with a higher chloride content [10, 11].

3.5 Alkalinity

Alkalinity in the natural system is primarily composed of carbonates, bicarbonates, and hydroxides. These constituents are formed as a result of mineral dissolution in the soil and atmosphere [12]. Carbonate and bicarbonates can also be produced by microbial decomposition of organic matter. The alkalinity ranged from 440 mg/l at S-8 in Appugarh to 110 mg/l at S-3 in Mangamaripeta. The alkalinity of almost all of the areas studied was found to be higher than the allowable limit (120 mg/l). This could be due to the percolation of the area's domestic sewage [13].

3.6 Total Hardness

The carbonates, sulphates, and chlorides of calcium and magnesium, as well as their carbonates, sulphates, and chlorides, harden the water. Total Hardness ranged from a maximum of 380.0 mg/l at S-8, Appugarh, to a minimum of 120.0 mg/l at S-3, Mangamaripeta. For drinking water, a desirable limit of 300 mg/l and a permissible limit of 600 mg/l have been recommended [8]. Hardness has no known negative effects on health; however, some evidence suggests that it may play a role in heart disease [14].

3.7 Calcium Hardness

Calcium concentrations in the study area ranged from 70 mg/l in Bheemili to a maximum of 220 mg/l in Appugarh. Calcium in drinking water has a maximum desirable limit of 75 mg/l and a maximum permissible limit of 200 mg/l. The calcium ions in the majority of the study samples exceeded the desirable limit, but remained within allowable limits. Calcium is a necessary component of the human body. Rickets and tooth decay can be caused by low calcium levels in drinking water. It is required for nervous system function, cardiac function, and blood coagulation [15].

3.8 Magnesium Hardness

Magnesium concentrations in the current study area ranged from 30 mg/l in Mangamaripeta to a maximum of 180 mg/l in Burujupeta. Magnesium in drinking water has a maximum desirable limit of 30 mg/l and a maximum permissible limit of 100 mg/l. Magnesium ions exceeded the allowable limit in 90 per cent of the study samples. Magnesium concentration in water is lower than calcium concentration, possibly due

to the lower occurrence of Magnesium Minerals. Magnesium is a moderately toxic element when present in high concentrations in drinking water [15].

3.9 Phosphates

Phosphate concentrations in the study area are low in all locations. Phosphorus is a necessary plant nutrient that is widely used in fertilisers. In acidic soils, phosphate is adsorbed or fixed as aluminium or iron phosphate, while in alkaline or neutral soils, it is fixed as calcium phosphate. As a result, phosphate concentrations in groundwater are typically low, but phosphate mobility in subsoil and groundwater may be induced by various chemical processes in soil strata.

3.10 Sulphates

The soluble salts of calcium, magnesium, and sodium make up the majority of the sulphate content in groundwater. The sulphate content of rainfall infiltration and groundwater recharge, primarily from stagnant water pools and surface runoff water collected in low-lying areas, changes significantly over time. Sulphate levels in the study area ranged from 3.5 mg/l in Maharani-peta to 33.5 mg/l in Babuji-nagar. Sulphate levels are within the prescribed standard (200 mg/l) at all sampling stations. Sulphate is poorly absorbed from the human intestine and slowly penetrates into the cellular membranes of mammals before being rapidly eliminated through the kidneys. In humans, sodium and magnesium sulphates have a cathartic effect. It has also been linked to respiratory diseases [16].

3.11 Nitrates

The presence of nitrates in drinking water is thought to be necessary for its negative health effects. The presence of high nitrate levels in groundwater is a major issue in many parts of the country. The Nitrate content in the study area is low in all sampling locations. Nitrate is a plant nutrient that is both effective and moderately toxic. [8, 9] have set a limit of 45 mg/l for drinking water supplies. Its concentrations above 45 mg/l may be hazardous to human health. At higher concentrations, nitrate can cause Methaemoglobinaemia (blue baby syndrome) [17], a disease that primarily affects bottle-fed infants. Ingestion of high doses of nitrates on a regular basis may also result in carcinogenic diseases.

3.12 Iron

The highest iron content was found in the current study areas at Chepaluppada, at 0.22 mg/l. Iron content was found to be low in the other regions, and in Sagarnagar colony, Jodugullapalem, Appugarh, MVP Colony, and EastPoint Colony, iron content was found to be below the detectable level of 0.3 mg/l, as prescribed by BIS [9] for drinking water supplies. Iron concentrations above 0.3 mg/l stain clothing and utensils. The water is also unsuitable for processing food, beverages, ice, dyeing, bleaching, and other similar processes. The limit for iron in water is determined by aesthetic and taste considerations rather than physiological effects [18].

3.13 Sodium and Potassium

In the study area, sodium concentrations range from 32 mg/l in Mangamaripeta to 200 mg/l in Appugarh. Sodium has not been included in drinking water standards set by the Bureau of Indian Standards. The high sodium levels could be due to base-exchange phenomena. The potassium concentration in groundwater in the study area ranged from 1.8 to 68.4 mg/l. Potassium is an essential element for humans, plants, and animals, and it is derived primarily from vegetation and soil in the food chain. Rainwater, potash silicate minerals, the use of potash fertilisers, and surface water for irrigation are the primary sources of potassium in groundwater. It is more common in sedimentary rocks and is found in feldspar, mica, and other clay minerals. Potassium has not been included in drinking water standards set by the Bureau of Indian Standards. However, the European Economic Community [19] has set a guideline level of potassium in drinking water at 10 mg/l. Potassium levels were found to be high in Sagarnagar Colony (25.8 mg/l) and Burujupeta (68.4 mg/l).

3.14 Correlation Analysis

The correlation analysis of 13 physicochemical parameters of groundwater from 16 different sites in Visakhapatnam city was performed, and the correlation coefficients (r) are shown in Table 3. Between EC and TDS ($r = 1$), Sulphates and Nitrates ($r = 0.94$), Total Hardness and Calcium Hardness ($r = 0.91$), Total Hardness and Magnesium Hardness ($r = 0.9$), TDS and Chlorides ($r = 0.90$), and TDS and Alkalinity ($r = 0.90$), there is a strong correlation ($r = 0.9$). A very high positive correlation also exist between TDS and Sodium ($r = 0.86$), EC and Total Hardness ($r = 0.84$), EC and Magnesium Hardness ($r = 0.80$), Chlorides and Nitrates ($r = 0.78$), Alkalinity and Sodium ($r = 0.78$), Chlorides and Sulphates ($r = 0.77$), TDS and Sulphates ($r = 0.77$), EC and Nitrates ($r = 0.73$), pH and Alkalinity ($r = 0.72$), EC and Calcium Hardness ($r = 0.72$), Chlorides and Sodium ($r = 0.71$), pH and Total Hardness ($r = 0.70$).

It can thus be assumed that the concurrent increase/decrease in ion composition in these waters is primarily due to dissolution/precipitation reactions and concentration effects.

3.15 Sea Water Contamination Using Chemical Ratio

The ratio of specific chemical parameters such as $\text{Ca}^{2+}/\text{Mg}^{2+}$, $\text{Cl}/(\text{CO}_3 + \text{HCO}_3)$, and TA/TH can be used to assess saltwater intrusion into coastal aquifers [20]. Because magnesium is much more abundant in seawater than calcium, the Ca/Mg ratio is recommended as a parameter for determining saltwater contamination. A low Ca/Mg ratio could also indicate saltwater contamination [21].

If the ratio is less than one, the area is thought to be heavily impacted by saltwater intrusion. Similarly, one of the criteria used to assess the presence of seawater intrusion is the $\text{Cl}/(\text{CO}_3 + \text{HCO}_3)$ ratio. Table 4 shows the $\text{Cl}/(\text{CO}_3 + \text{HCO}_3)$, TA/TH, and Ca/Mg ratios.

A low Ca/Mg ratio may also indicate saltwater contamination. If the ratio is less than one, the area is considered to be heavily impacted by saltwater intrusion. Similarly, the $\text{Cl}/(\text{CO}_3 + \text{HCO}_3)$ ratio is one of the criteria used to determine the

Table 4 Verification of seawater contamination in different location in Visakhapatnam

Sample site	Conductivity mmhos	Cl/CO ₃ + HCO ₃	TA/TH	Ca/Mg
Bheemunipatnam	0.78	0.119227	0.941	0.7
Chepaluppada	2.08	0.301306	1.117	0.88
Mangamaripeta	0.31	0.173421	0.916	3
Timmapuram	1.06	0.357777	0.571	1.15
Rushikonda	1.41	0.263201	0.906	1.28
SagarNagar Colony	2.02	0.318041	0.833	1.25
Jodugullapalem	1.25	0.477052	0.551	1.23
Appugarh	2.36	0.346964	1.157	1.37
MVP Colony	1.81	0.309449	1.156	1.13
PeddaWaltair	1.67	0.44037	0.764	1.125
EastPoint Colony	1.96	0.392883	1.214	1.545
Babuji Nagar	2.18	0.50888	1.071	0.866
Pandurangapuram	1.49	0.534321	1.041	1.4
MaharaniPeta	1.39	0.272601	1.037	0.928
Opp.KGH Hospital	1.4	0.272601	1.166	1.181
Burujupeta	2.11	0.318045	1.058	0.88

* measures in mg/l

presence of seawater intrusion. Table 4 shows the ratios of $Cl/(CO_3 + HCO_3)$, TA/TH , and Ca/Mg .

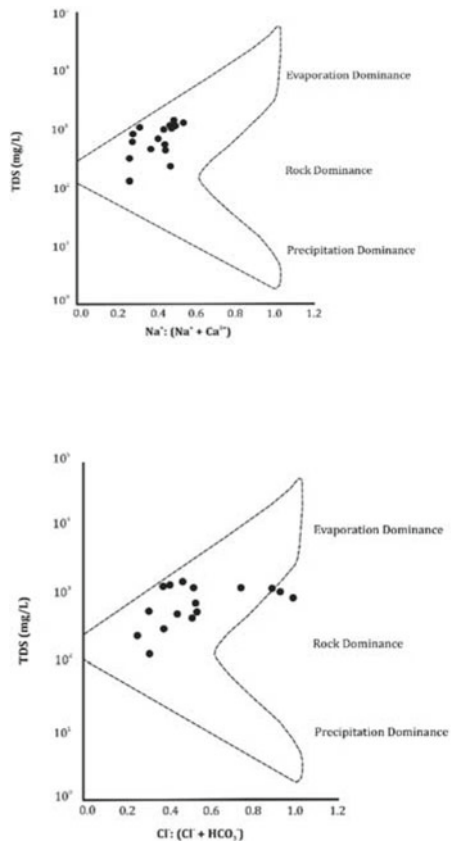
3.16 GIBB'S Diagram

The Gibb's ratio for the ions ($Na/(Na + Ca)$ and $Cl/(Cl + HCO_3)$) of groundwater samples was plotted against the TDS values. The plot shows that all of the groundwater samples belong to the rock dominant category. The interaction between aquifer rocks and groundwater causes rock dominance in the samples (Fig. 1).

TDS vs $Na/(Na + Ca)$

TDS vs $Cl/(Cl + HCO_3)$

Fig. 1 Gibb's Diagram showing the controlling mechanism of groundwater



4 Summary and Conclusion

Water samples were collected and analysed to assess the quality (in terms of physical and chemical content) of Visakhapatnam City's coastal aquifers. The study revealed the following findings. Groundwater in the study area is moderately complex and slightly alkaline. According to the current study, seawater intrusion is the cause of increased ion concentrations in the coastal aquifer. According to the findings of this study, the coastal aquifer is slightly contaminated by seawater intrusion, which is most likely due to increased over-exploitation of groundwater sources. More research on seawater intrusion into the coastal aquifer and geological weathering is needed to accurately quantify groundwater contamination.

5 Suggestions

- To protect coastal ground water, the sources of saline water intrusion and mobility mechanisms must be identified and investigated for sustainable groundwater resource development.
- Data collected during this study should be expanded to include all seasons of the year, as changes in water quality that occur as a result of normal seasonal variations are not reflected in this report due to the limited period of performance.
- The 2002 National Water Policy emphasises that “overexploitation of groundwater should be avoided, particularly near the coast, to prevent ingress of seawater into sweet water aquifers”. As a result, determining the extent of seawater intrusion is critical for planning and managing groundwater resource protection in coastal aquifers.

Acknowledgements The authors are thankful to GITAM Management to carry out the work. The authors also thanking Prof. Sabu Joseph, Department of Environmental Sciences, University of Kerala for GIBBS software assistance.

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