Original Research paper

Study on the Ground Water Quality with reference to Salt Water Intrusion in the Coastal Region of East Godavari District

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ABSTRACT:

The coastal aquifers of East Godavari district, Andhra Pradesh, are increasingly threatened by saltwater intrusion, primarily due to over-extraction of groundwater and inadequate recharge. This study aims to evaluate the groundwater quality in selected coastal villages, with particular focus on the extent and impact of saltwater intrusion. Physicochemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), calcium, magnesium, chloride, and total alkalinity were analyzed using APHA standard methods. The results indicate elevated EC and TDS levels in wells closer to the coastline, particularly in Koringa and P. Mallavaram, suggesting significant saltwater intrusion. The Sea Water Mixing Index (SMI) was employed to classify the vulnerability of each location, with higher values confirming intrusion in the coastal belt. Ratios such as Na^+/Cl^- and HCO_3^-/Cl^- were also used to identify the hydrogeochemical signatures of salinization. The study concludes that saltwater intrusion is adversely affecting groundwater quality, rendering it unsuitable for drinking and irrigation in certain areas. This necessitates the implementation of groundwater management strategies such as artificial recharge, regulated pumping, and real-time monitoring. These interventions are critical to sustaining freshwater resources in the face of growing demand and climate change impacts.

Keywords: Saltwater intrusion, Groundwater quality, East Godavari, Coastal aquifers, Sea Water Mixing Index (SMI)

INTRODUCTION:

Globally, groundwater serves as a primary source of freshwater. However, with rapid population growth and urban expansion, this resource is under immense stress. In coastal regions, a key concern is saltwater intrusion (SWI).The movement of saline water into freshwater aquifers, often induced by over-extraction of groundwater. When wells near the coast are pumped beyond sustainable limits, the freshwater-saltwater interface shifts landward, allowing saltwater to contaminate freshwater supplies. This phenomenon is particularly prevalent in areas where aquifers are hydraulically connected to the sea. Managing SWI requires maintaining a balance between groundwater extraction and natural or artificial recharge. Effective strategies include monitoring the position of the saltwater interface through hydrogeological and geophysical methods, forecasting water usage, computer modeling, and artificial

recharge. Climate change further complicates the situation, with sea level rise, changing rainfall patterns, and increased water demand likely to exacerbate saltwater intrusion.

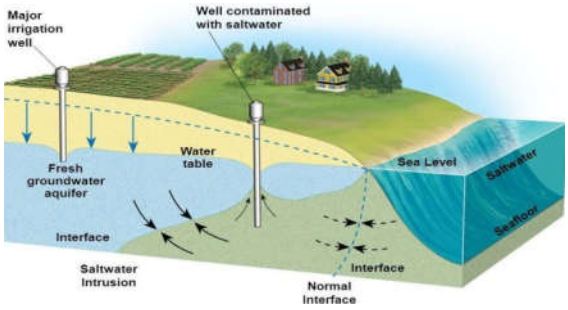


Fig 1:Saline water intrusion and pumping [(Holdredge C, 2008)]

Saltwater intrusion not only contaminates freshwater sources but also degrades soil quality. Elevated salinity reduces soil fertility and crop productivity, which is especially concerning in a country like India, where agriculture is a major economic activity. The intrusion alters soil chemistry, reducing its richness and affecting crop yields, ultimately impacting food security and rural livelihoods. Salinity in irrigation water can be especially detrimental to salt-sensitive crops like soybeans, wheat, rice, and many vegetables.

In addition to its agricultural and economic impacts, SWI also poses ecological threats. Coastal ecosystems such as mangroves, wetlands, and lagoons are highly sensitive to salinity changes. The encroachment of saline water can disrupt these fragile ecosystems, leading to loss of biodiversity and environmental degradation. In East Godavari, for instance, the coastal forests have shown signs of vegetation decline, including uprooting of tall trees, drying of certain species, and reduced biodiversity over the past decade.

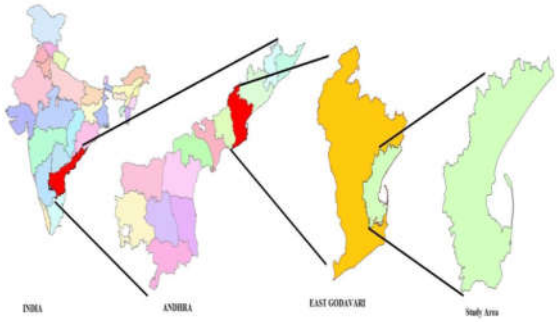
According to the Central Soil Salinity Research Institute, over 6.7 million hectares of land in India are affected by salinity and alkalinity. Andhra Pradesh alone has more than 274,000 hectares of salt-affected land, including over 77,000 hectares of coastal saline soils. This extensive degradation underscores the urgency of sustainable groundwater management.

Saltwater intrusion occurs naturally in several areas but can become problematic when groundwater is withdrawn (pumped) from the aquifer; this decreases the hydraulic head in the aquifer, consequently slowing or stopping the seaward flow of freshwater, which in turn allows saltwater to move further inland . Excessive pumping of groundwater can also induce saltwater intrusion through “up-coning,” when deeper saline waters from the underlying saltwater wedge are drawn in the direction of a pumping well. In either case, a portion of the aquifer becomes unhygienic with saltwater, thus compromising any nearby wells as feasible freshwater sources.The quality of drinking water is also compromised. Potable water should contain less than 500 mg/L of total dissolved solids (TDS), whereas seawater typically contains about 30,000 mg/L—60 times the acceptable limit. Even minor mixing of seawater can make groundwater unfit for human consumption. Saline water causes scaling and corrosion in pipes, increases treatment costs, and poses health risks.

MATERIALS AND METHODS:

Study Area: Geography of the East Godavari District , as the name suggests , is strongly associated with the river which occupies the major portion of the delta region. East Godavari District lies among 16º30” to 18º20” North Latitude and 81º30” to 82º36” East longitude .The entire East

Godavari District can be generally classified into three natural divisions, these are – the delta , upland and agency of hill tract. The general elevation of the East Godavari District area varies from a small number of meters near the sea to about 300 meters in the hills of the agency.



Study Area

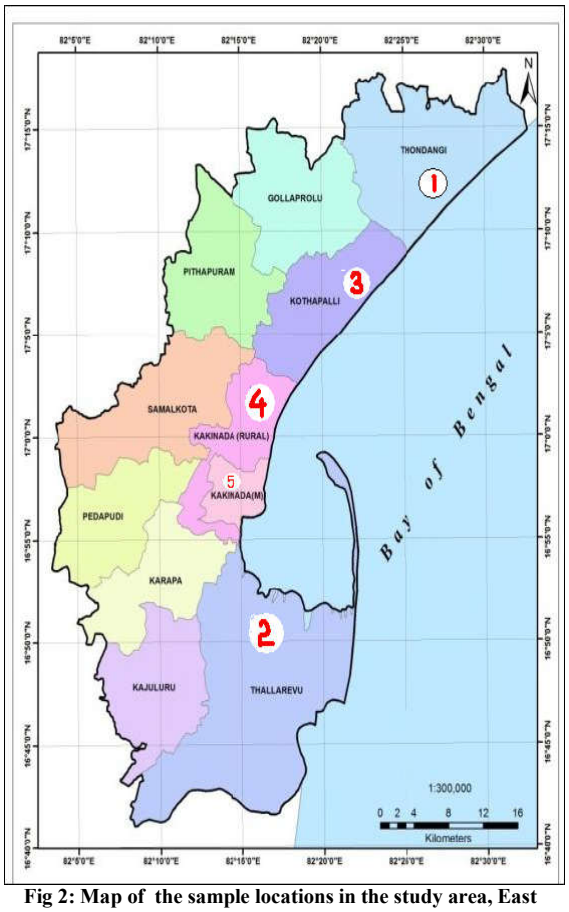
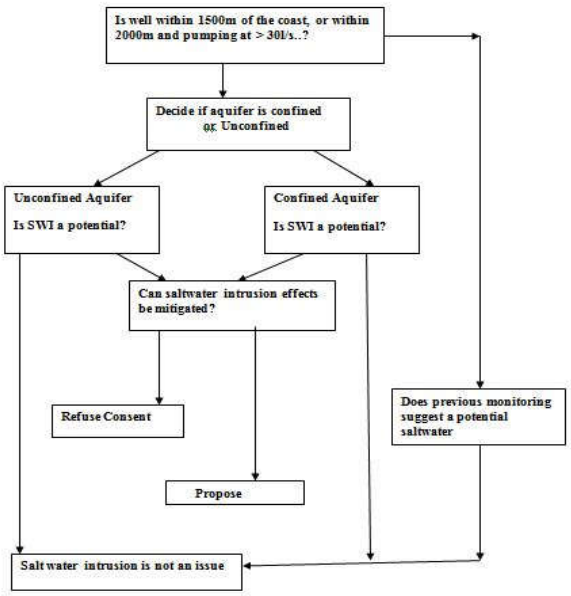


Fig 2: Map of the sample locations in the study area, East Godavari district, A.P

Table 1: Description of sampling locations

	Location number	Location Name	Description of Sampling Location
1	**1**	**Bendapudi (Thondangi Mandal)**	Soil Type: Loamy Rainfall :1869 mm Population (2015): 68,281 Well Depth (BGL): 8.24 m Distance from Sea: ~20 km
2	**2**	**Koringa (Thallarevu mandal)**	Soil Type: Alluvial Rainfall :1390 mm Population (2015): 63,145 Well Depth (BGL): 2.18 m Distance from Sea: 2-3 km
3	**3**	**P.Mallavaram (U Kothapalli mandal)**	Soil Type: Alluvial Rainfall :1533 mm Population (2015): 59,972 Well Depth (BGL): 8 m Distance from Sea: 5 km
4	**4**	**Nemam (Kakinada Rural)**	Soil Type: Alluvial Rainfall :1075 mm Population (2015): 1,74,348 Well Depth (BGL): 35 m Distance from Sea:4~ 5 km
5	**5**	**Kakinada (Kakinada Urban)**	Soil Type: Alluvial Rainfall :799 mm Population (2015): 4,12,255 Well Depth (BGL): 31 m Distance from Sea: 4 km

The analyzed parameters included HCO_3^-, Br^-, Ca^{2+}, Cl^-, EC, F^-, Mg^{2+}, NO_3^-, K^+, Na^+, SO_4^{2-}, and TDS. Frequently measured ions were Ca^{2+}, Cl^-, EC, F^-, Mg^{2+}, K^+, Na^+, and SO_4^{2-}; Br^-, NO_3^-, and HCO_3^- were less consistently available. TDS was recalculated as the sum of major ions for consistency.



Flowchart showing decision process for handling groundwater take consents with potential saltwater intrusion issues

Salt water mixing index:

Seawater mixing index (SMI) was estimated for water of all the sampling locations in order to understand the relative degree of seawater mixing. SMI was estimated using the relation

$$SMI = a \times \frac{CNa}{TNa} + b \times \frac{CMg}{TMg} + c \times \frac{CCl}{TCl} + d \times \frac{CSO_4}{TSO_4}$$

Where a, b, c and d are constants and represent the relative concentration proportion of Na, Mg, Cl and SO_4 respectively (a = 0.31, b = 0.04, c = 0.57, d = 0.08)

CNa, CMg, CCl and CSO_4 represent concentrations of Na, Mg, Cl and SO_4 respectively measured in groundwater samples expressed in mg/l

TNa, TMg, TCl and TSO_4 represent threshold values of Na, Mg, Cl and SO_4 which were estimated from interpretation of cumulative probability curves. When the calculated SMI is greater than one in magnitude the salt water intrusion is effecting the fresh water table in the sample area. when SWI is less than or equal to one in magnitude at the area where the sample of water is collected then that area is not effected by salt water intrusion.

RESULTS AND DISCUSSION:

The study of data generated from the periodic examination of depth of water level in the sample location (wells) generally indicate deep water levels during the pre-monsoon period (May) a progressive rise in water levels throughout the monsoon period, shallowest levels during the post monsoon period (November) followed by a progressive decline in water levels up to the beginning of next monsoon. As per the State Groundwater department, there is no over exploited basin in East Godavari district. Chemical analysis values of the ground water samples and the results of the present study are presented here under as for drinking purpose, irrigation purpose and industrial purpose.

Salt water intrusion is generally related to total dissolved solids (TDS) and electrical conductivity (EC) .High concentration of TDS and EC in irrigation water may increase soil salinity, which affects the salt intake of the plant. Soil is also affected due to Salt water intrusion. The soil loses its richness and the yield also reduces, as agriculture is the backbone of our country .It influences the financial sector. The population is mounting at an abnormal rate and the food production is diminishing due to Salt water intrusion. The health and physical condition of the people living in the coastal region are affected due to shrinkage in production of food. Environmentally fragile areas along coastlines may be adversely affected by saline water intrusion.

The condition are adverse which can be unrestrained by extensive groundwater extraction. The problem parameters, the risk of diminishing the quality of the vegetation capture zone needs to be taken care in a probabilistic framework. The existence of vegetation crops and complex ecosystems in such areas (i.e., lagoons, forest, and mangroves), also increases potential adverse impacts and strength, from an environmental point of view understanding the mechanisms whereby these sensitive environments or ecosystems can be affected by Saline water intrusion.

During the past ten years, the coastal forest of East Godavari District by the side of the coast, has been affected by a progressive declining in vegetation density, uprooting of tall plants, drying of pine plants, and changes in the enlargement of plant species. Agricultural crops vary in their sensitivity to elevated salt and high sodium levels.

Table 2: Ground water quality observation of the five sampling locations
Note: All parameters are given in mg/l except pH, Conductivity (µS/cm).

Ground water quality observation (Sample 1 - Bendapudi (Thondangi Mandal))			
S.No	**Chemical Parameter**	**Observed value**	
		Pre monsoon	**Post monsoon**
1	pH	8.5	8
2	Conductivity (EC) µS/cm	665	705
3	TDS(mg/l)	426	420
4	Total Alkalinity(mg/l)	470	486
5	Total hardness (mg/l)	652	695
6	Total suspended solids	310	325
7	Calcium(mg/l)	24	21
8	Magnesium (mg/l)	122	150
9	Chlorides (mg/l)	90	100
10	Nitrates(mg/l)	31	34
11	Sulphates (mg/l)	163	169
Ground water quality observation (Sample 2 - Koringa (Thallarevu Mandal))			
S.No	**Chemical Parameter**	**Observed value**	
		Pre monsoon	**Post monsoon**
1	pH	8.8	7.6
2	Conductivity (EC) µS/cm	4150	4751
3	TDS(mg/l)	2656	2695
4	Total Alkalinity(mg/l)	689	652
5	Total hardness (mg/l)	865	888
6	Total suspended solids	409	512
7	Calcium(mg/l)	28	28
8	Magnesium (mg/l)	142	162
9	Chlorides (mg/l)	1124	1248
10	Nitrates(mg/l)	40	43
11	Sulphates (mg/l)	115	102
Ground water quality observation (Sample 3 – P.Mallavaram (U kothapalli Mandal))			
S.No	**Chemical Parameter**	**Observed value**	
		Pre monsoon	**Post monsoon**
1	pH	8.2	6.8
2	Conductivity (EC) µS/cm	1356	1488
3	TDS(mg/l)	712	789
4	Total Alkalinity(mg/l)	470	450
5	Total hardness (mg/l)	655	688
6	Total suspended solids	234	260
7	Calcium(mg/l)	130	145
8	Magnesium (mg/l)	70	74
9	Chlorides (mg/l)	121	129
10	Nitrates(mg/l)	35	56
11	Sulphates (mg/l)	136	195

Ground water quality observation (Sample 4 - Nemam (Kakinada Rural))			
S.No	**Chemical Parameter**	**Observed value**	
		Pre monsoon	**Pre monsoon**
1	pH	8.3	7.5
2	Conductivity (EC) µS/cm	1850	1960
3	TDS(mg/l)	1184	1256
4	Total Alkalinity(mg/l)	405	396
5	Total hardness (mg/l)	756	786
6	Total suspended solids	345	358
7	Calcium(mg/l)	32	40
8	Magnesium (mg/l)	44	58
9	Chlorides (mg/l)	347	395
10	Nitrates(mg/l)	38	40
11	Sulphates (mg/l)	122	134
Ground water quality observation (Sample 5 - kakinada (KakinadaUrban))			
S.No	**Chemical Parameter**	**Observed value**	
		Pre monsoon	**Pre monsoon**
1	pH	8	8.2
2	Conductivity (EC) µS/cm	3510	3650
3	TDS(mg/l)	2247	2468
4	Total Alkalinity(mg/l)	305	304
5	Total hardness (mg/l)	561	605
6	Total suspended solids	310	389
7	Calcium(mg/l)	95	102
8	Magnesium (mg/l)	165	174
9	Chlorides (mg/l)	900	1100
10	Nitrates(mg/l)	37	52
11	Sulphates (mg/l)	141	170

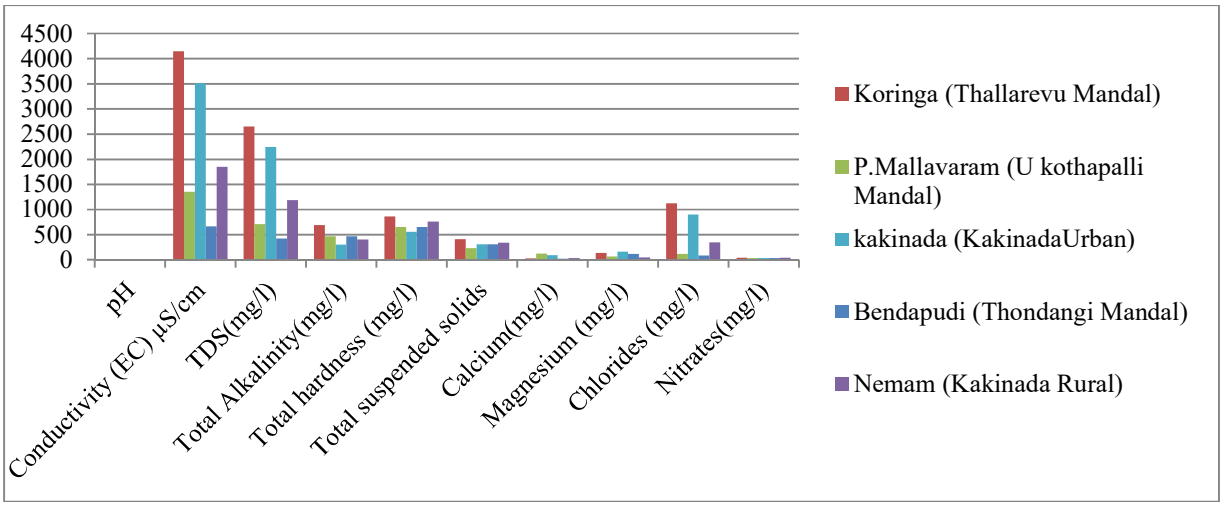


Figure 3: Ground water quality observation of the five sampling locations

Sea water mixing index:

The concentration of Na+, Mg+, Cl-, SO_4^{2-} are used to calculate the sea water mixing index. It had been calculated using the following equation. Where, Constants a, b, c and d denotes a relative proportion of Na+, Mg+, Cl^-, SO_4^{2-} respectively, there values are (a = 0.31, b = 0.04, c = 0.57, d = 0.08), T is the regional threshold values and C is the calculated Concentration of groundwater samples.

Table 3: The calculated values of SMI in the study area

S.No	Sample Location	SMI	Nature of Water
1	Bendapudi (Thondangi Mandal)	3.189	Saline
2	Koringa (Thallarevu Mandal)	7.144	Saline
3	P.Mallavaram (U kothapalli Mandal)	3.667	Saline
4	Nemam (Kakinada Rural)	2.604	Saline
5	kakinada (KakinadaUrban)	1.190	Saline

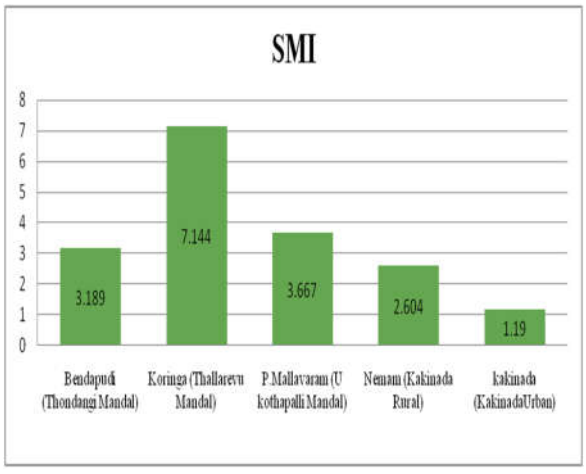


Figure 4: Graph showing SMI at various locations in Study area

From the values of salt water mixing index (SMI) it is understood that the samples collected from coastal areas near Kakinada, East Godavari (dist) of A.P state, chemical contamination of ground water in accumulation to salt water intrusion in the study areas is revealed. The main contributors for these results are higher values of EC, TDS, TH, Ca2+, Mg2+,TA, Na^+, K+, Cl^- and NO_3^- .Hence the water is not suitable either for drinking or for domestic purposes in the study areas.

CONCLUSION

The Sea Water Mixing Index (SMI) reveals that most parts of the coastal region in East Godavari District are significantly affected by seawater intrusion. Analysis of geographical and rainfall data indicates that all sampled locations are highly vulnerable to this phenomenon. Despite similar site characteristics across the study area, widespread intrusion is evident. It is crucial to educate local communities about saltwater intrusion and implement preventive measures to slow its progression. Groundwater in the region is predominantly alkaline, with pH values ranging from 7.40 to 9.10 and Total Alkalinity (TA) between 40 mg/L and 800 mg/L. In several locations, pH exceeds the acceptable drinking water limit (6.5–8.5). Additionally, chemical parameters such as TDS, TH, and TA surpass BIS permissible limits, making the water unsuitable for direct consumption without treatment.

Saline characteristics of groundwater, marked by high TDS, TH, and TA, also render it unfit for irrigation. Prolonged use could degrade soil quality and crop productivity. For industrial use, the water exhibits corrosive properties due to high chloride levels and suspended solids. Changes from Ca^{2+}-rich to Na^+-rich

composition, driven by mixing and cation exchange, further compromise its usability. Proper treatment is necessary before industrial application.

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