An Experimental Investigation on Saltwater Intrusion in Kona Seema, Mapping, And Modeling Using GIS

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Abstract - The experimental study focused on investigating saltwater intrusion in the coastal areas of Konaseema. Coastal regions face significant challenges due to saltwater intrusion into freshwater sources, impacting ecosystems and local communities. Field investigations involve monitoring groundwater salinity levels at various locations in Konaseema by using a TDS meter (Total Dissolved Solids). We visited 29 different villages and evaluated 206 wells and pumps manually from different areas covering an area of around 800kmsq. Then the test data were arranged, and maps were collected from various sources like Google Maps, and the Administrative Map of India. The data obtained from water testing were used to develop the spatial distribution map. Then the data collected was analyzed by developing an interpolation map showing the distinct colors and lines of intrusion in the study area. The water quality analysis work's findings were displayed as Spatial Distribution maps that may be utilized to comprehend better the study area's current salinity and the intrusion level situation. The variation in the TDS level and its intrusion was discussed according to the outcomes of the data analysis.

Key Words: Saltwater intrusion, Salinity, TDS meter, Spatial Distribution, GIS

1.INTRODUCTION

The coast is where land, sea, and air interact. Coastal areas are vital ecosystems that support diverse vegetation and wildlife, providing resources, leisure activities, and economic opportunities. They also serve as hubs for trade, business, and cross-cultural interactions, promoting the growth of thriving communities. However, coastal areas face several challenges, such as climate change, increasing sea levels, and human activity. Extreme weather and rising sea levels significantly affect the resilience and stability of coastal ecosystems. Coastal water management requires a rational and comprehensive approach, involving the management of coastal water, coastal land, and the coastal ecosystem. The hydrological equilibrium of coastal aquifers is highly vulnerable to saltwater intrusion, which can lead to contamination of freshwater supplies, reduced crop yields, and even crop failure due to increased salinity in the soil. This can cause havoc with coastal ecosystems, resulting in reduced species diversity, loss of biodiversity, and the demise of significant habitats like marshes and wetlands. Infiltration of saltwater can erode foundations, pipes, and wells, raising maintenance costs and infrastructure failure. Coastal areas may experience a shortage of clean drinking water if freshwater sources get contaminated by saltwater, presenting significant health risks and requiring expensive investments in treatment facilities and alternate water sources. Freshwater-dependent industries may suffer large financial losses due to saltwater intrusion, jeopardizing their sustainability.

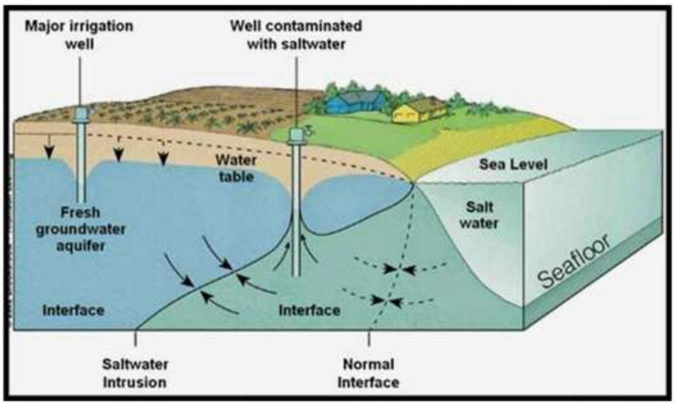

Fig.1: Saltwater Intrusion

Saltwater intrusion can weaken coastal ecosystems and make them more vulnerable to extreme weather events such as hurricanes, storm surges, and flooding. A wide variety of animals find vital habitat in coastal areas like salt marshes, estuaries, and mangroves, and many species may lose major areas for breeding and feeding due to saltwater intrusion. The main reasons for saltwater intrusion in coastal areas include over-extraction of groundwater, sea level rise, land subsidence, natural processes like tidal variations, storm surges, and coastal erosion, land-use changes and deforestation, drought conditions, geological factors, and ineffective irrigation techniques. To maintain the ecological integrity of coastal areas and the welfare of communities that depend on them, it is critical to find practical solutions for their conservation and sustainable management. By striking a balance between natural processes and human interventions, coastal communities can ensure the long-term sustainability of their ecosystems and the well-being of the community. Mumbai and Chennai are major cities affected by coastal intrusion, with groundwater quality monitored by the Maharashtra Pollution Control Board (MPCB) for 66 stations twice a year.

In 2015-16, TDS values ranged from 2500mg/l to 3000mg/l, with the highest hardness and calcium levels recorded in Turbhe, Navi Mumbai. The highest TDS levels were 43650 mg/liter in April, indicating peak summer. A study from Anna University and Freie University of Berlin found that seawater ingress was higher in the lower aquifer than in the upper aquifer in Chennai from 1969 to 2019. Groundwater salinity has increased four times over the past decade, with areas like Kattur, Mouthampedu, and Senganimedu having total dissolved solids exceeding the maximum permissible limit.
According to The Bureau of Indian Standards (BIS), the admissible limit for TDS in drinking water is 500 mg/L. Still, The World Health Organization recommends a TDS lower than 300 mg/ L for drinking water. The minimal TDS of drinking water shouldn't go below 50 ppm.

Table. 1: TDS value table for drinking water according to the BIS

TDS Level (mg/L)	Water Quality
50-500	Excellent
600-900	Fair
900-1200	Poor
1200-2000	Very Poor
>2000	Unacceptable

The Bureau of Indian Standards (BIS) in India sets up standards for the quality of water used in concrete buildings. The maximum allowable level of total dissolved solids (TDS) in water used to mix concrete is 2000 ppm (parts per million), as per the BIS IS 456:2000 code. By following this recommendation, concrete characteristics are protected, and proper quality water is used during the construction process. The American Concrete Institute (ACI) sets up the total dissolved solids (TDS) in water used to make concrete should not be more than 3,000 parts per million (ppm). The strength, durability, and setting time of concrete may all be affected by excessive dissolved particles in water. For agricultural purposes, the water should not have a TDS level of more than 2000 ppm. In many areas of India, underground water is pumped for irrigation and other farming purposes. If the quality of water is not good, then farmers have to face agricultural losses.

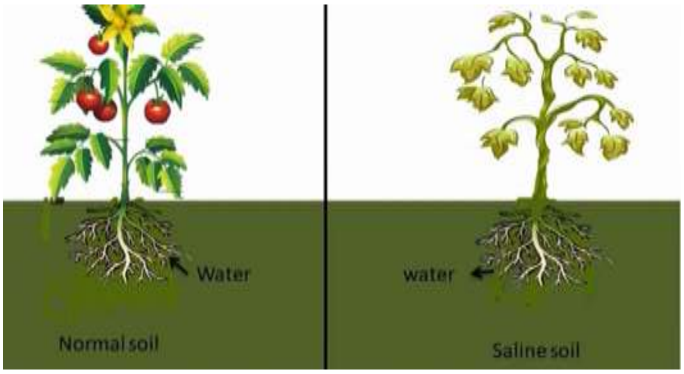

Fig. 2: Effect of higher saline soil in plant

Dr. Md. Mizanur Rahman et.al (2014) Salinity intrusion in Bangladesh's coastal aquifers is a significant issue due to climate change and reduced flood plains. This can impact groundwater aquifers and agriculture, necessitating effective management strategies to change land use and water management. M. Mohan Babu et.al (2013) The study assesses saltwater intrusion in five coastal mandals in Nellore District, focusing on drinking and agricultural purposes. It finds low Ca/Mg ratios suggest saltwater contamination, while Cl/(CO3+HCO3) ratios suggest slightly to moderately contaminated groundwater, possibly from marine sources. M.P Papadopoulou et.al (2005) The study investigates saltwater intrusion in coastal aquifers in the industrial zone of Heraklei in Creta, using in-situ geophysical measurements to identify the geology and fault impact on groundwater flow. The study found that saltwater intrusion occurs along the coastline and east fault, with a closed conduit. K. Harikrishna et.al (2012) A remote sensing study in Andhra Pradesh, India, identifies saltwater intrusion zones in paleo beach ridges around Kolleru Lake. Geophysical data and chemical analysis help identify intrusion zones, while field verification and integration with socio-economic factors help demarcate seawater intrusion.

Dr. K. Sundara Kumar et.al (2010) study uses geographical information systems to assess and measure groundwater quality in certain villages, revealing high fluoride and chloride concentrations, affecting water supply. Total hardness is high in all villages, suggesting groundwater treatment before consumption and developing suitable management practices to protect resources. S. Gopinath et.al (2015) The study investigates saline water intrusion in Nagapattinam coastal aquifers, Tamil Nadu, India. Results show higher EC and TDS, saline water traces, and higher nitrate and sulphate, suggesting fertilizer influences.

The SEAWAT model suggests saline water is upcoming, leading to increased chloride ions. Biplab Sarkar et.al (2021) study explores the impact of seawater intrusion into groundwater in West Bengal, India, revealing that the coastal aquifer is susceptible to salinization, with 51% of groundwater samples not suitable for irrigation due to high salinity levels. The overall irrigation water quality indicates that 58% of groundwater samples are low to moderately suitable for agriculture. Jeevan Panthi et.al (2022) This study reviews saltwater intrusion investigations in the contiguous United States, focusing on Florida and California, to protect drinking water supply, sustain ecosystems, agriculture, and infrastructure, and assess existing investigation approaches and data collection techniques.

Dr. Sajeena S et.al (2020) The coastal river basin's development, construction, and agriculture activities have increased groundwater pumping, leading to saltwater entering freshwater aquifers. Climate change and rising sea levels threaten these issues. Groundwater replenishment and sustainable development are key countermeasures. Konstantin J. Stylus et.al (2012) The study found that two Puducherry regions, Periyakalapet and Chinnakalapet, exceeded permissible limits for saltwater intrusion, while others were within permissible limits. To reduce seawater intrusion, a suitable recharge method and reduced over-water withdrawal are recommended. A.R. Costall et.al (2020) Groundwater throughflow and seawater intrusion influence coastal aquifer systems. Decoupling influences require hydraulics and groundwater chemistry information. Surface-based imaging and solute transport modeling help locate interfaces. Adanora G. Atuchukwu et.al (2022)

The study reveals a saltwater/freshwater stretch in the southern part of the study area, primarily around the Bonny and Opobo communities. Recommendations include preventing further use of boreholes in these communities, developing a government water exploitation plan, providing alternative water supplies, and using deep industrial boreholes for access to confined aquifers. Aman Timaniya et.al (2022) Results suggest increasing seawater intrusion, requiring restricted withdrawal and increased annual recharge to prevent saltwater intrusion and protect the aquifer system.

2.STUDY AREA

KONASEEMA DISTRICT: The newly formed Dr. B. R. Ambedkar Konaseema district shares borders with the Godavari regions to the north and south. East Godavari and Kakinada Districts in the north and the Bay of Bengal in the south both surround it. The district has a total geographic area of 2.081 lakh hectares. During 2019–20, 0.015 lakh hectares, or 0.75 percent of the total geographical area, is covered by forests. The district covers the 170 km of AP's coastline. The remaining portion is split roughly equally between land used for non-agricultural purposes (19.07%) and barren and uncultivable terrain (3.79%). 1.34 lakh hectares, or 64.32% of the total geographical area.

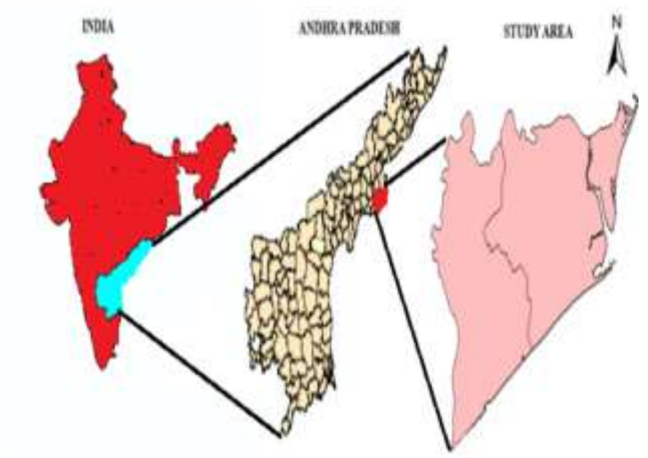

Fig.3: Study Area

The Godavari Delta region has predominantly alluvial soil, which is the predominant soil type in the district (Clay loamy). Sandy Clay in the Godavari's southernmost regions. The district's minor minerals include road metal, gravel, and collared granite, while the district's principal minerals are crude oil and natural gas. With fishponds included, the net area under cultivation in 2019–20 is 144994 hectares or 696.67% of the district's total geographic area. The district receives its irrigation from the Godavari Canal. In addition to aquaculture, which involves shrimp, black tiger prawns, crabs, and fish, poultry farms, and the export of aqua products, the economy of Konaseema District is dependent on agriculture, primarily on paddy, bananas, and coconuts.

3. MATERIALS & METHODS

Device used for investigation

A Total Dissolved Solids (TDS) meter is a tool used to measure the salinity of water, focusing on the concentration of dissolved solids in water, including salts, minerals, and other organic and inorganic compounds. These meters are widely used in various fields, including hydroponics, aquaculture, agriculture, water quality monitoring, and beverage manufacturing. The KONVIO NEER Total Dissolved Solid and EC meter was used in this study, which can measure both TDS and temperature simultaneously. The TDS meter operates based on the concept of electrical conductivity, which quantifies a solution's capacity to conduct electricity. It operates by splitting dissolved solids into ions, which are charged with electricity. A sensor probe with two or more electrodes, typically made of platinum or graphite, is used to measure the electrical conductivity of the liquid. The ions' mobility produces an electrical signal proportionate to the solution's conductivity. The TDS meter then measures the liquid's electrical conductivity using a calibration factor, which varies based on the dissolved solids in the liquid. The TDS value is displayed, usually expressed as milligrams per Liter or parts per million (ppm). To maintain accuracy, TDS meters need to be periodically calibrated using standard solutions with established TDS values. These solutions are designed with known dissolved solids concentrations and are used to match the meter's readings.

Fig.4: TDS and EC meter

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Sample collection

The eastern middle part of Konaseema district was selected for testing purposes. An area about 20km perpendicular to the coast was selected. The study covers around 800sqkm. Open as well as closed bore wells are selected for sample collection. The sample was collected from 206 wells. The list of places where testing was done along with the number of samples are listed below:

Table.2: Villages along with No. of sample collected.

S. No	NAME OF THE VILLAGES	NO. OF SAMPLE COLLECTED
1	Odalarevu	13
2	Komaragiripatnam	13
3	Naka Ramaseram	9
4	Surasaniyanam	5
5	T.Challapalli	6
6	Samanthakuru	5
7	Bendamurlanka	6
8	Mogallamuru	6
9	Godilanka	6
10	Allavaram	10
11	Rellugadda	6
12	Devaguptam	7
13	Kunavaram	8
14	Uppalaguptam	10
15	N. Kothapalli	10
16	Katrenikona	10
17	Dontikurru	6
18	Pallamkuru	6
19	Ainapuram	6
20	Mummidivaram	6
21	Cheyyeru	10
22	Mahipala Cherevu	5
23	Anaatavaram	4
24	Singarayapalam	6
25	Bhatnavilli	2
26	Amalapram Rural	10
27	Rollapalam	4
28	Gudala	6
29	Bodasakurru	5
Total		**206**

The average and highest TDS value of the different villages in the study area is given below:

Table. 3 Avg. & highest TDS of the villages.

Village name	Highest TDS (ppm)	AVG TDS (ppm)
Odalarevu	1970	956
Komaragiripatnam	1866	1143
Naka ramaseram	1874	1314
Surasaniyanam	2199	1913
Challapalli	1127	979
Samanthakuru	1528	1102
Bendamurlanka	2718	1519
Mogallamuru	4743	2364
Godilanka	1668	1258
Allavaram	1423	1856
Rellugada	2666	1450
Devaguptam	3666	1805
Kunavaram	1827	864
Uppalaguptam	788	460
N.kothapalli	2098	1380
Katrenikona	1357	947
Dontikurru	1858	1241
Pallamkuru	1093	906
Ainapuram	876	629
Mummidivaram	974	616
Cheyyeru	826	577
Mahipala cheruvu	1152	480
Anaatavaram	1406	586
Singharayapalam	2592	994
Bhatnavilli	3008	1039
Amalapuram rural	1089	651
Rollapalam	865	743
Gudala	869	622
Bodasakurru	1236	726

Creation of spatial distribution maps

First, we collected the maps from different sources like Google Earth and the Administrative Map of India. Then ArcGIS software was used to create the desired maps. After importing the maps into the software, the geo-referencing was done. Then the TDS data was imported into the map in the form of Excel sheets and interpolation was done, and the colour was selected as desired.

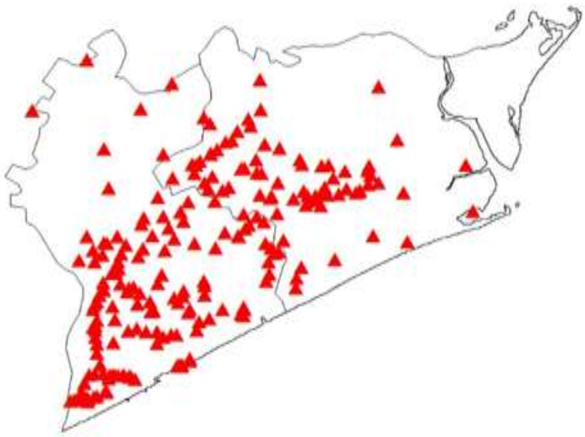

Fig.5: Map having all the TDS data

5. RESULT AND DISCUSSION

For this project, we visited 29 villages and checked more than 206 wells and underground pumps. The highest and average value of TDS was listed, and tabulation of data was made along with bar charts and graph, to compare the values of the different villages and to find out about the intrusion of saltwater into pure water. Many coastal villages of Konaseema use wells and pumps for domestic and agricultural purposes so many litters of water are extracted every day.

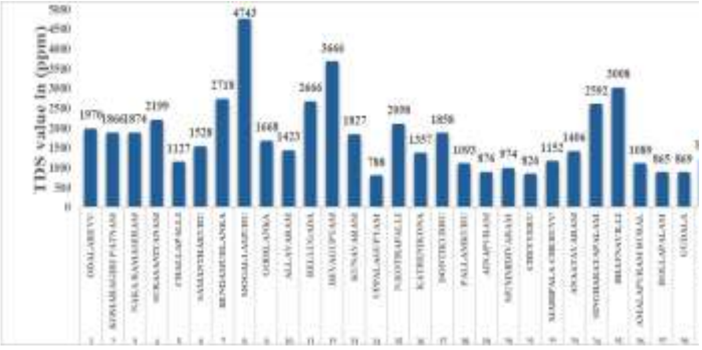

Fig. 6: Bar chart showing average TDS values found in the villages

Fig.7: Bar chart showing highest TDS values found in the villages

As seen by the bar chart above, some coastal areas have water that is unfit for agriculture, drinking, or concreting. Eight villages have a TDS value of greater than 2000 ppm, according to the bar graph above. At 4743ppm, Mogallamuru was the hamlet with the highest TDS value. Seawater intrusion may harm the settlements of Konaseema if the TDS level is not managed and regulations for sustainable groundwater are not created.

The average TDS levels in the villages are extremely high, as the bar graph above illustrates, and the water from any nearby wells is unfit for human consumption. It may be observed that the TDS of the groundwater was higher in the villages that use it for agriculture and fish farming. Unmanaged sewage dumping from several small channels is a significant contributing factor to the elevated TDS in the wells. Due to poorly managed sewage and the proximity of wells to the sewer line, the TDS values of the communities surrounding Amalapuram were higher. According to the above bar chart, the average TDS in the villages of Surasaniyanam, Bendamurlanka, Mogallamuru, Allavaram, and Devaguptam was more than 1500 ppm, while the average TDS in the villages of Uppalaguptam and Mahaipala Cheruvu was less than 500 ppm.

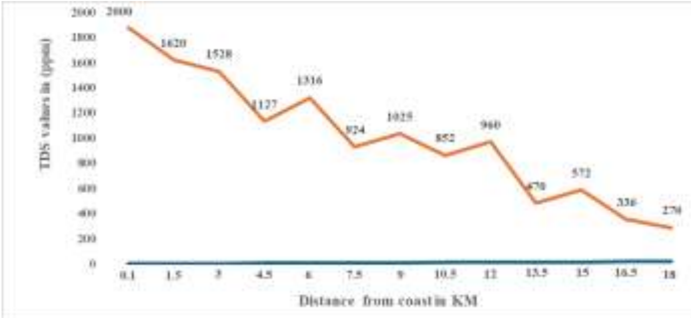

Fig.8: Graph showing TDS vs distance away from the coast.

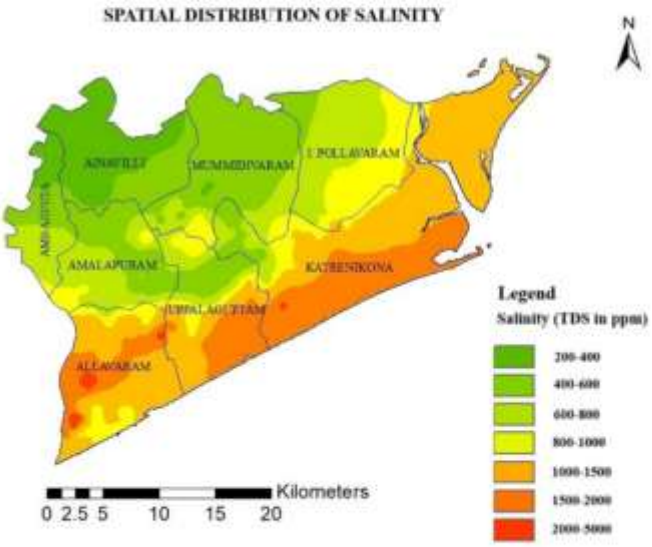

Fig.9: Spatial distribution of salinity

The map seen above was created using ArcGIS's interpolation function, which used our project's TDS values from the various locations we visited. We have gathered information from over 206 wells located in 29 coastal areas that are within 20 km from the ocean. After gathering the data, it was loaded onto the map, and values were assigned.

Table. 4: Table showing the area covered by salinity level.

S. No	TDS Value range(ppm)	Area (sq.km)	Colours
1	2000-5000	4	
2	1500-2000	128	
3	1000-1500	150	
4	800-1000	102	
5	600-800	163	
6	400-600	210	
7	200-400	77	

The map shows seawater intrusion in coastal areas, with areas closer to the sea having higher Total Dissolved Solids (TDS) values. Mandal, like Allavaram, Uppalaguptam and Katrenikona, has the highest value of TDS, which ranges between 5000ppm-1500ppm. Mandals like Amalapuram, Ambajapeta, Mummidavaram and I. Polavarem have a TDS range between 1500ppm to 600ppm. Only Ainavilli Mandal have which is drinkable TDS value of the place was found to be less than 500ppm.

• Mandal, like Allavaram, Uppalaguptam, and Katrenikona, have the highest value of TDS because of its nearness to the sea, and many fish farmers use groundwater, because of which a lot of water needs to be extracted from the ground, and, in the case of Katrenikona many wetlands and lakes are there which are connected to sea. For the above-mentioned reasons, groundwater in these areas a TDS range between 5000ppm-1500ppm.

• The mandal like Amalapuram and Mummidivaram are the most populated Mandals, among others. Some parts of the area have fishponds where extraction is high. The main reason for higher TDS value is because of unmanaged sewage. Sewage is directly thrown in canals and many of the wells in these areas are very near to those canals. The range of the TDS in those areas ranges from 1500ppm-600ppm.

• I. Pollavaram Mandal has a decent population and most of the people in this area are involved in fish and shrimp farming and this mandal is also on the bank of the west Godavari River, because of which the groundwater here has the TDS range between 1500ppm to 800ppm.

• The water's TDS level is less than 500 parts per million after 16 km from the coast. The majority of Anivavilli and Ambajipeta Mandal have TDS

values of less than 500 ppm, which is regarded as safe for drinking. The main reason for the less salinity/TDS is because of less extraction and these areas don't have many fish farming ponds.

• The water at Ainavilli Mandal, the furthest from the coastline at around 18 km, is the safest of all the mandals previously mentioned. The explanation for this might be that it is the farthest region in our research area and has fewer fishponds than other mandals in the vicinity.

6. CONCLUSIONS

The TDS level of the different villages which are within the 18 km range of the coastal line of the Konaseema district has been made, and the following conclusions were obtained from experimental observations.

a) The study area within the 20km range from the coastal line covering the total area of around 800 square kilometers was covered during the project.

b) Most of the people in the study area have wells and pumps for domestic and for fish farming.

c) The samples from the different wells and pumps from the villages in the study area and TDS and EC were measured for each water sample.

d) The TDS value collected from the different villages of the study area was tabulated according to the village name along with the longitude and latitude of the wells and pumps.

e) In total, we have checked the TDS and EC data from more than 206 wells during the project duration.

f) Data was analysed by using different bar charts and graphs along with the spatial distribution map obtained from ArcGIS.

g) The graph showing TDS in relation to the distance away from the coast and the spatial distribution map clearly show that the intrusion is happening in the study area.

h) From the coast up to the

- 2.5 km the TDS value was above 2000ppm, middle part of the Allavaram, and end part of the Uppalaguptam and Katrenikona are in this range.
- 2.5 km-5 km the TDS range was between 2000ppm-1000ppm.
- 5 km-7 km the TDS range was between 1000ppm-800ppm.
- 7 km-18km the range of the TDS was between 800ppm-400ppm.
- Only after 18km the range of the TDS was less than 500ppm.

In future, if not controlled in time, the intrusion will further increase and may cause adverse effects in the agriculture and ecosystem of the study area.

The sustainable plan and the regulation on the use of groundwater should be made to stop further intrusion of saltwater into the groundwater.

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