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SEAWATER INTRUSION USING CHEMICAL INDICATORS IN THE COASTAL AQUIFERS EAST GODAVARI & VISAKHAPATNAM DISTRICTS

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Abstract: Ground water is an essential and vital component of any life-supporting system. It is not only a basic need for human existence but also a vital input for all development activities. Increasing usage of ground water tends to cause sea water intrusion. Sea water intrusion often happens in coastal areas. An attempt has been made in the present study to analyses the water quality parameters and to find the sea water intrusion in the coastal regions of East Godavari and Visakhapatnam districts. For this study, 16 well samples are considered within a 20km radius of the coast, and the seawater intrusion is determined from 2000–2018. Chemical indicators such as Ca/Mg, Cl/[HCO3+CO3], Na/Cl, Cl/[HCO3+SO4], and base exchange indices (BEX) were used to identify sea water intrusion areas. The determination of the distribution of sea water intrusion was done by mapping analysis using the Arc GIS application program. The piper plot diagram also shown (from 2000 to 2018) it is an effective graphic procedure to segregate relevant analytical data to understand the sources of the dissolved constituents in water. To create a graph with the major water constituents, Piper has two triangles corresponding with the cations and anions, respectively, and one diamond that summarize both triangles. Based on the results, all the locations are intruded, but 8 locations show more contamination than others.

Index Terms – Sea Water intrusion, Arc GIS, Piper Plot.

I. INTRODUCTION

Water is one of the most important natural resources, serving as a major source of irrigation and drinking water. Water is required by all living things on Earth, including plants, animals, and humans. Ground water is one alternative source of water. Ground water can be easily and inexpensively accessed by drilling or digging. Groundwater use has recently increased in parallel with population growth. Approximately 70% of the world's population lives along the coast. The induced flow of saltwater into the inland groundwater table, known as saline water intrusion or seawater intrusion, is one of the major factors commonly encountered in coastal aquifers. When fresh groundwater is withdrawn from wells faster than it can be replenished in the land hydraulic system, a drawdown of the water table occurs, resulting in a decrease in overall hydrostatic pressure. When this occurs near an ocean coast, saltwater from the ocean intruded into the freshwater aquifer. The migration of seawater into an inland groundwater table as a result of both natural and man-made phenomena is known as seawater intrusion. The differing densities of saltwater and freshwater allow the ocean water to intrude into the freshwater aquifer in coastal freshwater aquifers. The boundary between seawater and freshwater is typically a zone of mixing. A slight increase in sodium chloride (salt) in groundwater near the coast may indicate a landward movement of the mixing zone, also known as seawater intrusion.. Some scientists consider 100mg of chloride per litre of water to be an indicator of intrusion. Freshwater typically contains less than 30 mg/l of chloride, whereas seawater contains 19,000 mg/l. The majority of people experience a salty taste when chloride concentrations in drinking water exceed 250 mg/l. The encroaching seawater will come into contact with the zone of dispersion, where freshwater and saltwater mix and form an interface. A drop in groundwater level below the mean sea level causes a reversal of the hydraulic gradient and inland movement of seawater in the coastal aquifer. Seawater intrusion refers to the inland movement of seawater into the coastal aquifer, which has been the primary cause of the deterioration of coastal ground water resources. Seawater intrusion not only has an impact on industrial and agricultural growth in the area, but it also has an impact on people's living standards. A well-established mathematical relationship known as the "Ghyben-Herzberg" relationship governs the upward or downward movement of seawater into the coastal aquifer. According to the relationship, for every one-meter increase in the water table, the thickness of seawater decreases by 40 metres.

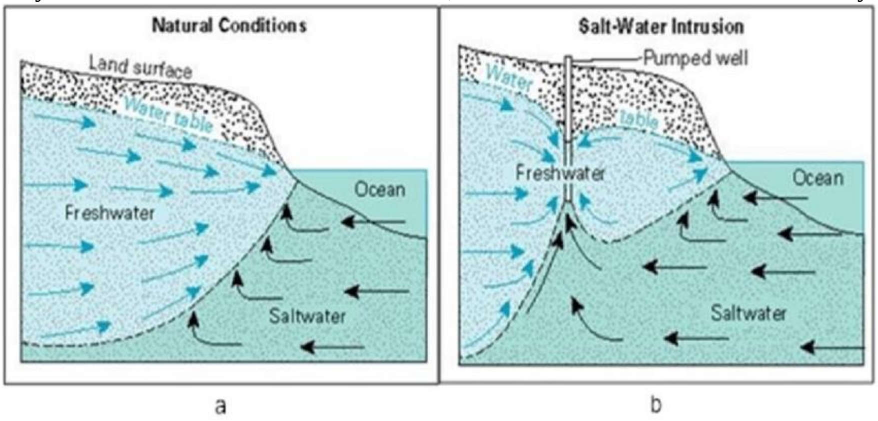

Figure 1: Natural conditions and salt water intrusion.

II. FACTORS AFFECTING THE COASTAL AQUIFER

Coastal aquifers are extremely vulnerable to regional and global phenomena such as sea-level rise, storm surges, climatic changes, shoreline erosion, and coastal flooding, among others. Human activities are also hastening the process of salinization in coastal areas. Surface water sources, in addition to coastal aquifers, are influenced by their interactions with seawater

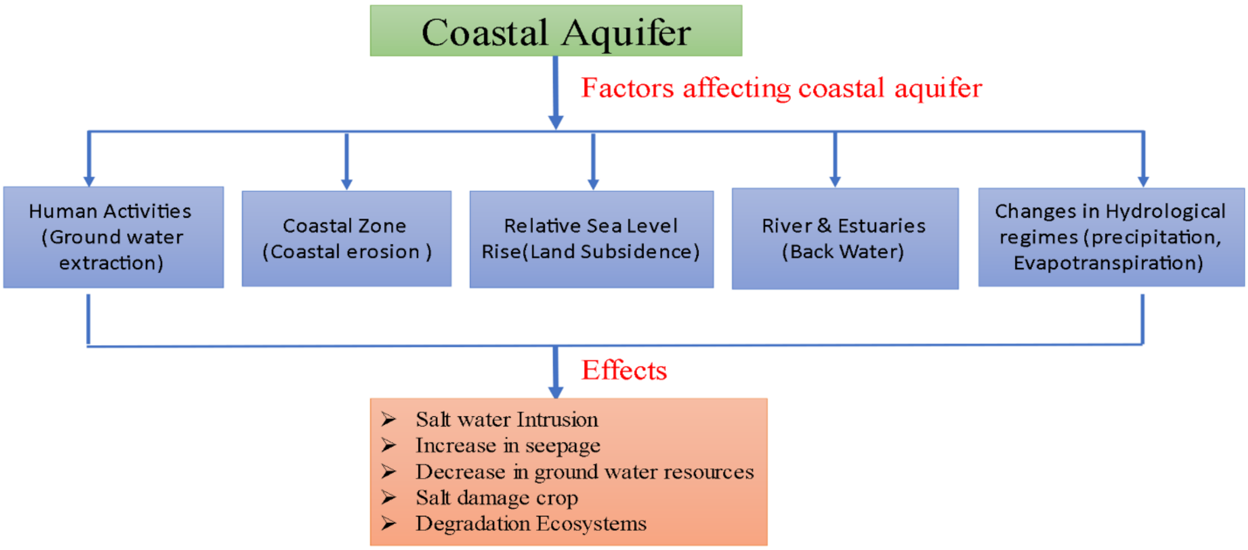

Figure 2: factors influencing the coastal aquifer and their consequences

III. STUDY AREA

Visakhapatnam and East Godavari are the districts of the Coastal Andhra region of Andhra Pradesh, India. **Visakhapatnam**, also known as Vizag, is Andhra Pradesh largest and most populous city, located between the Eastern Ghats and the Bay of Bengal coast. It is the second largest city on the east coast of India after Chennai, and the fourth-largest in South India. It is an ancient port city which had trade relations with the Middle East and Rome. Visakhapatnam has a total coastal length of 135km. It lies between the latitude and longitude of 17.7041N and 83.2977E. The area of the city is 682 km$^{2.}$ The altitude of Visakhapatnam is 45 m**. East Godavari** district is situated in the North East of Andhra Pradesh in the geographical coordinates of 16^0-30^0 and 18^0-20^0 of the Northern Latitude and 81^0-30^0 and 82^0-36^0 of the Eastern Longitude. The district is bounded on the north by Visakhapatnam district and the state of Orissa; on the east by the Bay of Bengal; and on the south and west by West Godavari and Khammam districts. Kakinada is the district headquarters with a population of 5,151,549 (Census of 2011). The area of East Godavari district is 10,807 km^2. It has a coastal line of 144 km. In this study, a total of 16 stations in both Visakhapatnam and East Godavari districts were considered at distances of below 15 km from the coast line. These stations are: Mindivanipalem, Bhimunipatnam, Gurrajupeta, Rambilli, S. Rayavaram, Revupolavaram, Yelamanchili, Amalapuram, Gollaprolu, I. Polavaram, Vakalpudi, Kakinada(U), Gurajanpalle, Uppada, Pithapuram, Samarlakota.

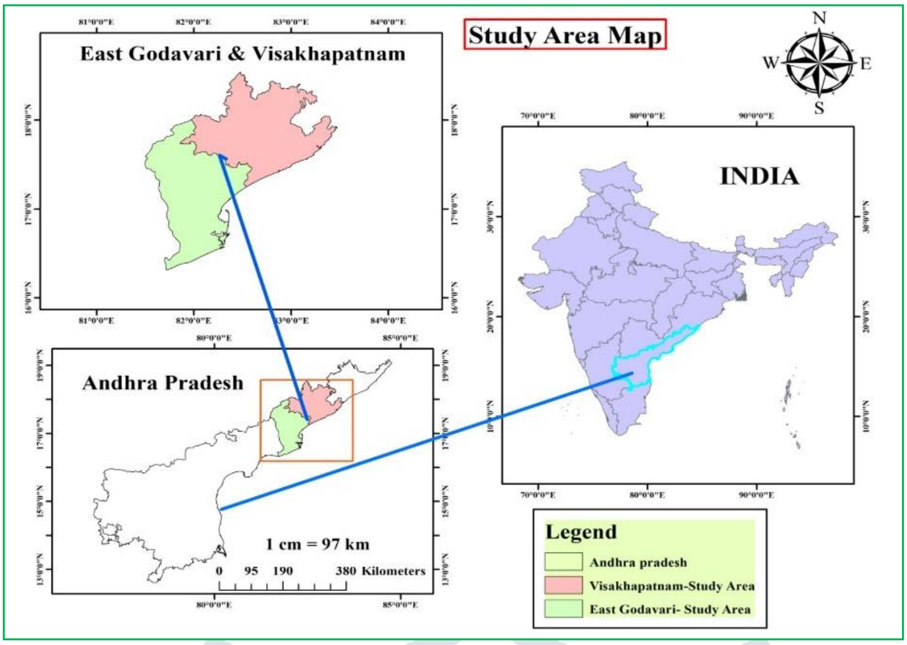

Figure 3: Study area map of Visakhapatnam and East Godavari District

Table 1: Sampling Locations with Coordinates and Distances

Locations	Coordinates		Distance from coast	Sample Location	District
	Y(Latitude)	X(Longitude)			
L1	17°52'50" N	83°18'45" E	11.17 km	Mindivanipalem	Visakhapatnam
L2	17°53'0" N	83°26'0" E	1.45 km	Bhimunipatnam	Visakhapatnam
L3	17°22'55" N	82°46'15" E	756 m	Gurrajupeta	Visakhapatnam
L4	17°29'0" N	83°0'15" E	50 m	Rambilli	Visakhapatnam
L5	17°27'30" N	82°51'0" E	3.86 km	S.Rayavaram	Visakhapatnam
L6	17°23'50" N	82°49'0" E	252.578 m	Revupolavaram	Visakhapatnam
L7	17°33'0" N	82°51'15" E	13.84 km	Yelamanchili	Visakhapatnam
L8	16°34'59" N	82°1'42" E	13.9 km	Amalapuram	East Godavari
L9	17°10'0" N	82°17'0" E	10.9 km	Gollaprolu	East Godavari
L10	16°44'0" N	82°13'34" E	12 km	I.Polavaram	East Godavari
L11	17°1'30" N	82°17'30" E	333.22 m	Vakalpudi	East Godavari
L12	16°57'0" N	82°14'15" E	2.5 km	Kakinada(U)	East Godavari
L13	16°53'30" N	82°14'0" E	2.31 km	Gurajanpalle	East Godavari
L14	17°4'50" N	82°20'15" E	174.0 m	Uppada	East Godavari
L15	17°6'40" N	82°15'45" E	8.28 km	Pithapuram	East Godavari
L16	17°3'0" N	82°15'0" E	5.51 km	Samarlakota	East Godavari

IV. METHODOLOGY

In this case study, the input data of sample locations and chemical parameters were considered from CGWB (Central Ground Water Board) with latitudes and longitudes. The distance of the sample location from the coastline is measured by using Field Area Measurement and a distance of less than 20 km from the coastline is taken into consideration for determining the SWI. For determining the SWI, the main chemical parameters were considered. After determining SWI, it is located in Arc GIS. The piper plot diagram is also used for determining the TDS in the study area. The flow chart of methodology is shown below.

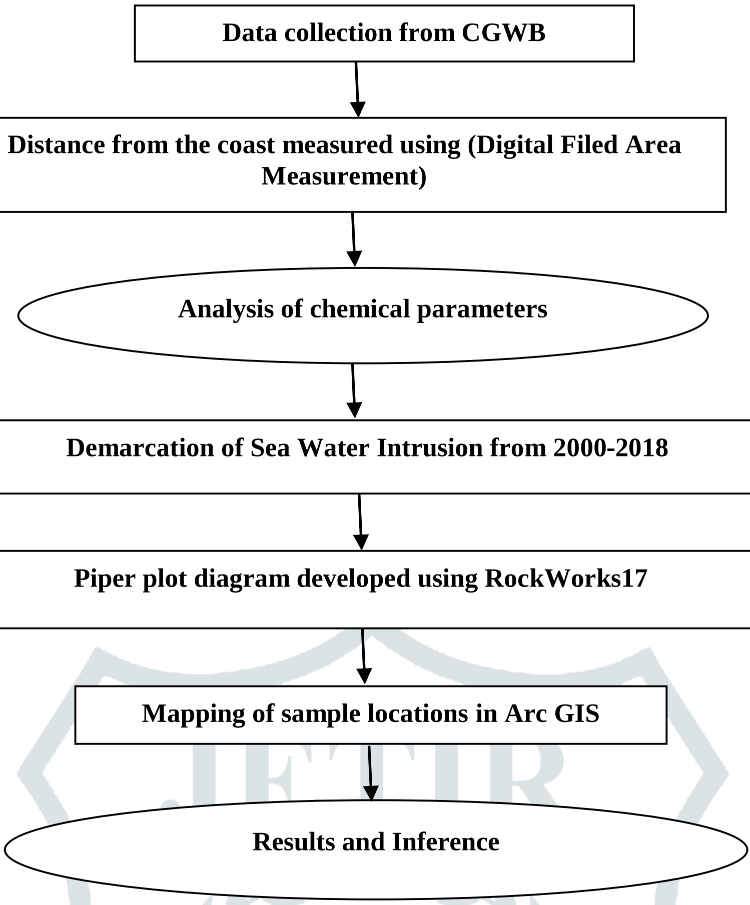

Figure 4: Flow chart of Methodology

4.1 ANALYSIS OF CHEMICAL PARAMETERS

In this study, the major chemical parameters are considered which influence for sea water intrusion and the parameters are Na, Cl, Mg, Ca, Hco3, Co3, So4, K. If the ratio of Ca and Mg is greater than 1, it indicates seawater intrusion. If the ratio of Na and Cl is less than 0.86, it indicates seawater intrusion. If Cl/[Hco3+So4] exceeds one, it indicates seawater intrusion. If the BEX (Base Exchange Indices) value is negative, it indicates seawater intrusion. BEX = Na+K+Mg-1.0716Cl. If Cl/[Hco3+Co3] is < 0.5 - Good Quality, 0.5 to 1.3-Slightly contaminated, 1.3 to 2.8-Moderately contaminated, 2.86 to 6.6-Highly contaminate, 6.6 to 15.5-Extremely contaminate. A variety of common indicators used in previous studies were applied to the Coastal regions of Andhra Pradesh (Visakhapatnam & East Godavari) data in order to determine which wells may be affected by SWI. Plotting Histogram charts of Chemical parameters vs Years for Individual Locations.

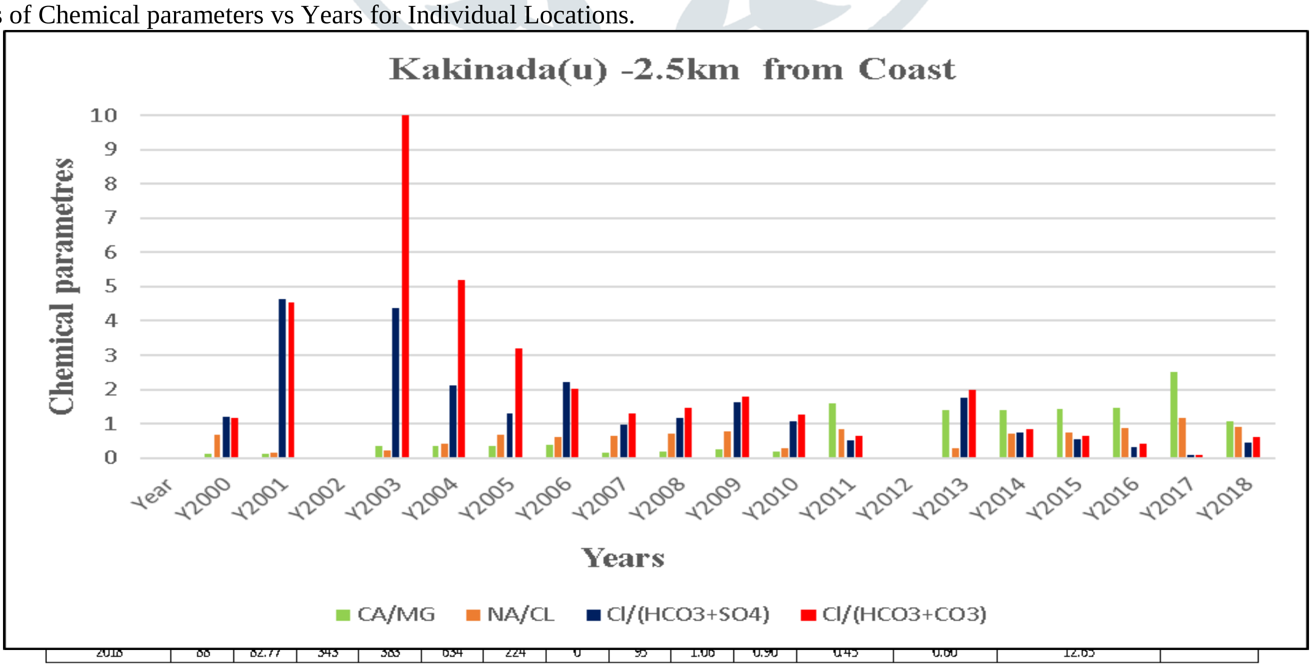

Figure 5: Histogram chart for Kakinada(U)

4.2 PIPER PLOTTING

Groundwater chemical data were processed on a Piper diagram to govern groundwater compositional trends, as shown in Fig. This diagram shows that samples plot in a variety of hydro chemical facies, with Ca-Mg-SO4-Cl, Ca-HCO3, and Na-Cl types being the most common. Groundwater in the study area shows a pattern of hydrogeochemical trends that progresses from a Ca-Mg-SO4-Cl type to a Na-Cl type via a Na-HCO3 type, or from a Ca-HCO3 type to a Na-Cl type directly. The piper plot can be used to determine the path of mixing or migration of groundwater composition with seawater (Varma et al. 1996). TDS (Total Dissolved Solids) circles are plotted as rings around each point in the diamond portion of the Piper diagram, and represent the combined total of all of the cations and anions in parts per million (or mg/l) for that sample (standard and any additional ions). A piper plot is developed for all the sample locations from 2000-2018 for the coastal distance within 20km.

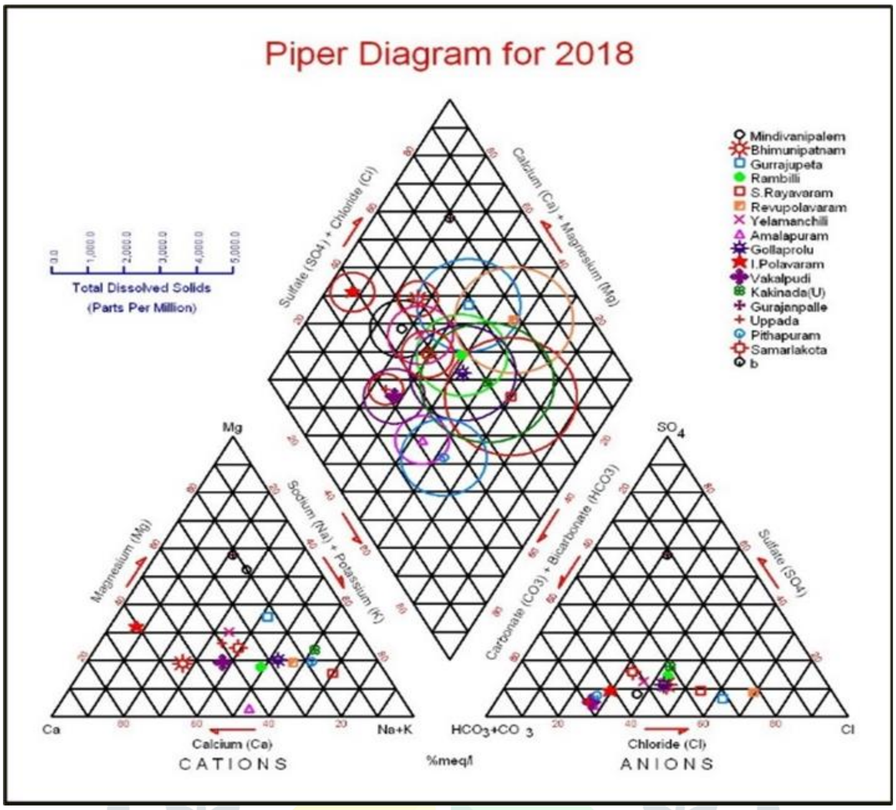

Figure 6: Piper Plotting for 2018

4.3 ARC GIS

ArcGIS is a Geographic Information System (GIS) that is used to display geographic data, or to create maps in simpler terms. It is a part of software that allows you to handle and analyses geographic information by visualizing geographical statistics such as climate data or trade flows through layer building mapsArcGIS stores the data in ArcMap, ArcCatalog, Arc Toolbox, and ArcGIS Extensions- spatial analyst, geostatistical analyst, and 3D analyst. ArcGIS, like many GIS software, creates maps with layers that organize categories. Each layer is spatially registered, so that when they are overlaid on top of one another, the programme correctly aligns them to create a complex data map. The base layer is almost always a geographical map, which can come from a variety of sources depending on the type of visualization required (satellite, road map, etc.). This programme provides users with access to a large number of them, as well as live feed layers with traffic information. The first three layers are known as feature or vector layers, and they each contain unique functions that the platform distinguishes. The Study Area map of sample locations is generated by using Arc GIS, and the intruded areas are mapped in Arc GIS.

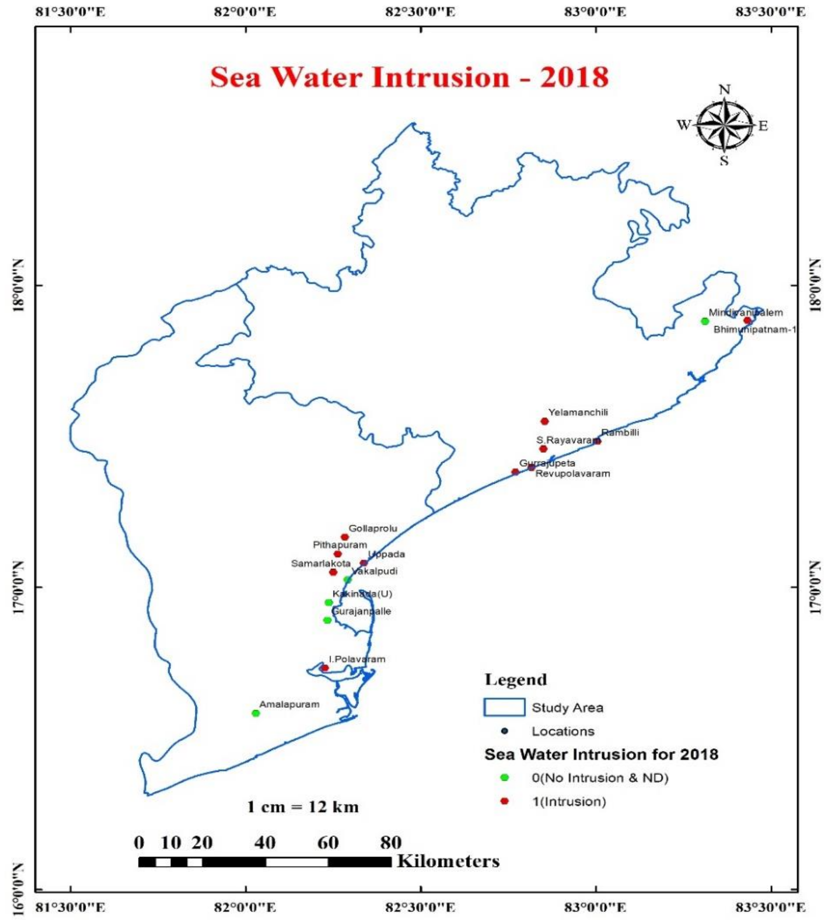

Figure 7: Sea water intrusion in 2018

V. RESULTS

Enrichment of Ca is an indicator of sea water intrusion. The enrichment of Ca as the principal ion can also be used as an indicator of sea water Intrusion into ground. If the ratio of Ca/mg is greater than 1, it indicates sea water intrusion. If Cl/[Hco3+So4] is greater than 1, it indicates Sea Water Intrusion. If the ratio of Na/Cl is less than 1, it indicates Sea Water Intrusion. If the BEX (Base Exchange Indices) value is negative, it indicates seawater intrusion. According to Simpson's ratio, If Cl/[Hco3+Co3] is < 0.5 - Good Quality, 0.5 to 1.3-Slightly contaminated, 1.3 to 2.8-Moderately contaminated, 2.86 to 6.6-Highly contaminate, 6.6 to 15.5-Extremely contaminate. This contamination is mainly occurring due to lowering of water table, No rainfall and Excess pumping. If any two conditions exceeds or subceed the permissible limit, it indicates Sea Water Intrusion. ***For Kakinada(u) Location*** in the present study, the ratio of Ca/mg in the years 2011,2013,2014,2015,2016,2017,2018 were exceeded permissible limits. Na/Cl in this location all the years having values less than 0.86 which shows that the well is getting to intruded except 2017 and 2018.Cl/[Hco3+So4] Except for 2007, 2011,2014,2015,2016,2017 and 2018 all are exceeded to permissible limits. BEX value here in 2001,2002,2003,2004,2012 and 2013 is negative, indicating sea water intrusion. Cl/[Hco3+Co3] in this location, the years 2016 and 2017 are of Good Quality and 2000, 2007,2010,2011,2014,2015,2016,2017 and 2018 are of slightly contaminated and 2006,2008,2009 and 2013 are of moderately contaminated and 2001,2004are of highly contaminated and 2003 is of extremely contaminated.

VI. CONCLUSIONS

For many people around the world, ground water is an important source of drinking water. The purpose of the study was to test different indicators for the cause of Sea Water Intrusion. To assess the intrusion, piper diagram & chemical Indicators were analyzed. On the basis of my results, the temporal distribution of 2000 - 41.67% of well samples ,2001-83.3% of well samples,2002-93.33% of well samples,2003-86.67% of well samples,2004-73.33% of well samples,2005-75% of well samples,2006-75% of well samples,2007-68.7% of well samples,2008-75% of well samples,2009-68.7% of well samples,2010-56.25% of well samples,2011-68.7% of well samples,2013-66.67% of well samples,2014-60% of well samples,2015-66.67% of well samples,2016-46.67% of well samples,2017-73.33% of well samples,2018-73.33% of well samples are undergoing intrusion and spatial distribution of Amalapuram – 42.1%,Gollaprolu – 89.47, I. Polavaram – 57.89, Vakalpudi – 68.42, Kakinada(U) – 78.94,Gurajanpalle – 61.53, Uppada – 68.42, pithapuram – 73.68, Samarlakota – 36.84,Mindivanipalem – 50,Bhimunipatnam1 – 70.58, Gurrajupeta – 100, Rambili – 78.94, S.Rayavaram – 73.68, Revupolaram – 94.11, Yelamanchili – 89.17. The histograms are developed based on the chemical indicators vs years for individual locations. Piper plot is developed for all the locations and it is plotted using the intersection line between anions and cations. The study Area map of sample locations is generated by using Arc GIS, the determination of the distribution of seawater intrusion was done by mapping analysis using the Arc GIS application program, and the intruded and non-intruded areas are indicated with red and green color. Decrease in groundwater recharge rate and increase in usage would make the area more chance to get seawater intrusion. To control saltwater intrusion, the proper balance between water is being pumped from an aquifer and the amount of water recharging it is be maintained.

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