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Assessment of Groundwater Quality by Using the Ionic Ratios in the Coastal Region of Guntur District, Andhra Pradesh, India

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Abstract

Seawater intrusion into the coastal region has occurred all around the world as a result of extensive groundwater depletion brought on by population development, agricultural practices, and rapid urbanization. As a result, the natural balance has been altered, and the salinization process has accelerated due to its continued stress on the world's water and land resources. One such area currently susceptible to salinization is the coastal region of the Guntur district, particularly when seawater intrusion occurs. Demand for freshwater is rising in coastal areas, which makes this issue worse. The current study makes an effort to examine the water quality parameters and to discover the contamination groundwater with saline water intrusion into the coastal mandals of Guntur district. Sampling and analysis of the samples of the study region for physcio-chemical properties of the major ions used to identify saltwater intrusion in groundwater. Ionic ratios of different kinds, including Na^+/Cl^-, Mg^{2+}/Ca^{2+}, Mg/Cl^-, SO_4^{2-}/Cl^-, K^+/Cl^-, $Ca^{2+}/(HCO_3+SO_4^{2-})$, $Cl^-/(HCO_3^- + CO_3^-)$, Cl^-/HCO_3^- *and the Base Exchange Index (BEX) was used to determine whether or not saltwater had an impact on groundwater quality. The results of the analysis indicating that intrusion of seawater has caused salinization in the majority of the studied region and also showing higher levels of chloride, bicarbonate and sodium concentrations. By the overall observation of results it is known that contamination of the area caused by intrusion of seawater.*

Keywords: *Groundwater, Seawater intrusion, Ionic ratios, Coastal region*

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Introduction

In coastal places all over the world, saltwater intrusion is a serious issue since it endangers the health and even lives of many residents. Water may become unsuitable for human utilities because of increased groundwater salinity. Because a small amount of saltwater is mixed with groundwater, it renders freshwater unusable and may force the abandonment of freshwater supplies, salinization of groundwater is considered a distinct kind of pollution that affects groundwater resources. Aquifers are being over-extracted as a result of the high rate of population expansion. Roughly two-thirds of the world's population residing at coastal regions of different parts of the world. As a result, saltwater is migrating into the aquifers (Gimenez and Morell1997; Todd and Mays 2005; Ragunath, 2006; Kantamaneni *et al.*, 2017). Freshwater aquifers normally moving towards the sea when they are in hydraulic contact with seas (van Camp *et al.*, 2014). However, excessive pumping could cause saltwater intrusion by inverting the groundwater flow from the coast into the interior. The exploitation of coastal aquifers as water supplies might increase the naturally occurring phenomenon of salty water intrusion in coastal zones (Martinez and Bocanegra 2002; Ozler 2003).

Population of the coastal areas heavily depends on the fresh water aquifers for domestic purposes (Neumannet al., 2015). High salinity has deteriorated quality of ground water aquifers of the castal areas (Lee 2007; Nair 2016; Alfarrah and Walraevens, 2018). Groundwater present in these areas is becoming unfit for domestic, industrial and agricultural settings. (Ganyaglo 2015; Hamed *et al*., 2018). Some of the coastal aquifers may contain significant levels of salinity caused by intrusion of seawater. Soil erosion and other anthropogenic factors including agriculture return flows also responsible for contaminated water in the coastal region (Martinez *et al*. 2002).

Todd and Mays 2005) used the major ions concentration to evaluate the ground water quality. During the transportation process ground water has diluted different ions and changes their initial concentrations at discharge points which will help to identify the contamination of saline water with ground water (Sudaryanto Naily., 2018). Various techniques, including geochemical monitoring and mapping have been used to study and monitor the intrusion of seawater development (Bear et al., 1999; Carol and Kruse 2012). There is a significant effect on ratios of the ground water quality when sea water enters into fresh water aquifers

The interactions between freshwater and saltwater (oxidation-reduction and ion exchange) during the seawater intrusion process have a significant impact on the major ionic ratios of the ground water (Stoessell 1997; Sudaryanto and Naily 2018). various ionic ratios are projected and used to know the salinization of coastal aquifers by the intrusion of coastal aquifers. Na^+/Cl^-, K^+/Cl^+, Mg^{+2}/Cl^-, Mg^{+2}/Ca^{+2}, K^+/Cl^-, SO_4^{-2}/Cl^-, $Ca^{+2}/(HCO_3^- + SO_4^{-2})$, $(Ca^{+2} + Mg^{+2})/Cl^-$, $Cl^-/(SO_4^{-2} + HCO_3^-)$ and Cl^-/HCO_3^- are some of the ionic ratios proposed by Revelle 1941; Todd 1959; Stuyfzand1989, 1993; Vengosh and Rosenthal, 1994; Vengosh and Ben-Zvi, 1994; Jones *et al*. 1999, Sanchez-Martos *et al*., 1999; Vengosh *et al*., 1999; Metcalf & Eddy, 2000, Kim *et al*., 2003; and Lagudu *et al*., 2013 have been recognized all over the world. Klassen *et al*. (2014) have stated that it can be challenging to only utilize one chemical criterion to determine whether seawater has contaminated fresh coastal groundwater. As a result, more chemical characteristics must be taken into account during the analysis stage to ensure that a variety of distinct ionic ratios are available for the assessment in order to evaluate seawater intrusion properly. Simply put, these ionic ratios are utilized because "groundwater composition also partially indicating the dissolved ions in the groundwater independent of the substance it encountered" (Stuyfzand, 1993). Numerous studies have been conducted in coastal areas all over the world to comprehend the problem of seawater intrusion.

According to CGWB (2014) Indian subcontinent has also facing saline water intrusion problem because India has vast coastline which is about 7,500 km length, enclosed by Bay of Bengal, Arabian Sea and Indian Ocean. The Indian coastline is made up of about 53 coastal districts spread over nine coastal states (Chachadi, 2005). The geological formations of the Indian coastal area ages are ranging from older crystalline basement rocks to more recent alluvial deposits (Manivannan and Elango, 2019).

Greater dependence on groundwater resources in India is as result of factors like rainfall variability, surface water scarcity in some areas and local access to fresh groundwater. Groundwater levels have dramatically decreased as a result of increased urbanization and different unethical land use practices reduced significantly recharge patterns of ground water (Patra *et al*., 2018). The groundwater table significantly drops in the summer due to virtually little recharge, making the situation serious (Dams *et al*., 2012). According to Mukherjee *et al*. (2015), widespread irrigation in India is the main factor contributing to the depletion of groundwater resources. Based on the current rate of population growth, India would likely encounter severe water scarcity by 2050 (Gupta and Deshpande 2004).

The second-largest length of coastline in India is present in Andhra Pradesh. The salinity of the groundwater in an estimated 1760 square kilometres of the state (Farooqui *et al*., 2009). Groundwater quality decline and deterioration of agricultural lands are both significantly impacted by sea level rise (Kantamaneni *et al*., 2019). According to hydrochemical study, Groundwater salinity in some areas has been linked to up-coning of seawater and paleo-seawater, according to Surinaidu *et al*. (2015). However, through lake water, it has been found up to 40 kilometres inland (Karanam *et al*., 2019). These studies demonstrate how the state's deltaic regions are susceptible to seawater intrusion because of rising sea levels and considerable amount of water withdrawal.

Study area:

The current research area encompasses a total of eight mandals namely Bapatla, Karlapalem, Nizampatnam, Pittalavanipalem, Cherukupalle, Bhattiprolu, Nagaram and Repalle which are very close to coast line with a length of 57.68 km out of the total coastal length of 72.56 km in Guntur district. The study area location map and its satellite view are shown in Figures 1 and 2

The geographic size of the study area is about 1201.20 km². It is bounded north by Guntur city, South by Bay of Bengal, East by Krishna river and Krishna district and West by Prakasam district. Geographically, the study area lies between 15° 47' 49.2" - 16° 48' 58.7" North latitudes and 79° 13' 22.0" - 80° 25' 02.5" East longitudes

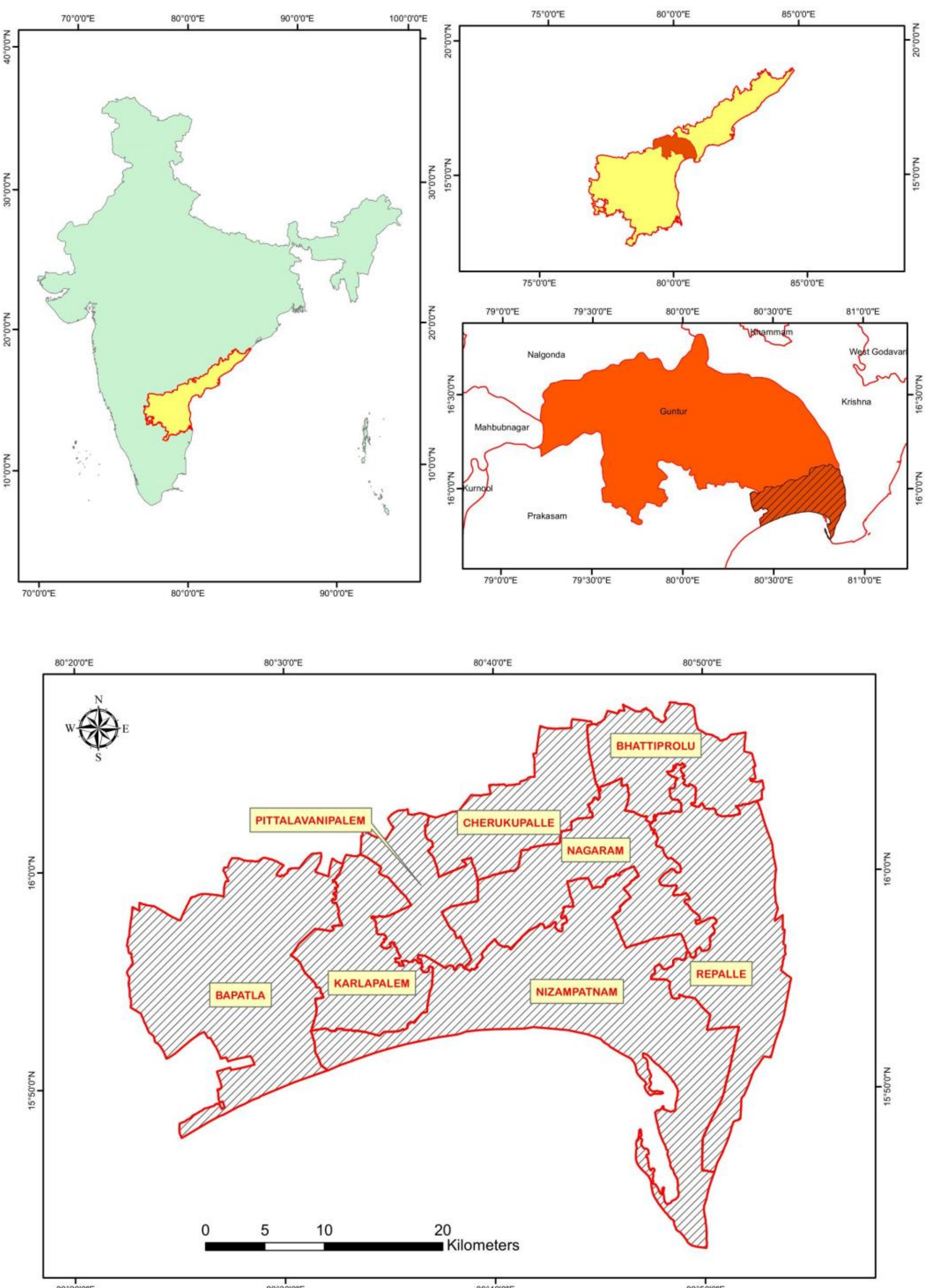

Figure - 1: Location map of the study area

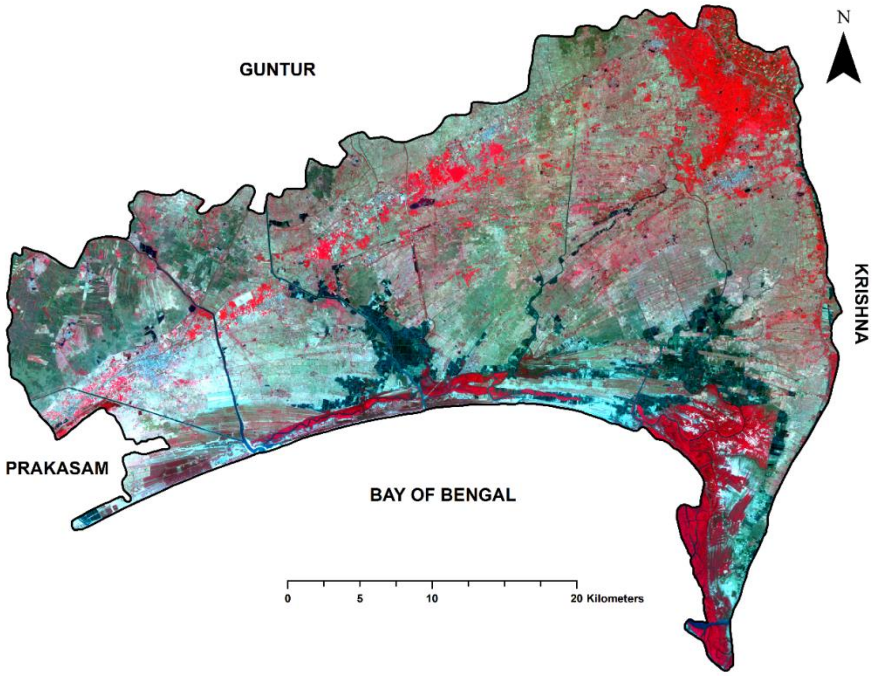

Figure - 2: Satellite image (LISS-IV) of the study area

Sampling and analytical procedures

In the study region 71 ground water samples collected during pre- and post-monsoons periods (May 2017 and January 2022) (Figure – 3). Clean polyethylene bottles of two litres capacity are used to collect the groundwater samples. The bottles are rinsed with distilled water before sampling to avoid the contamination.

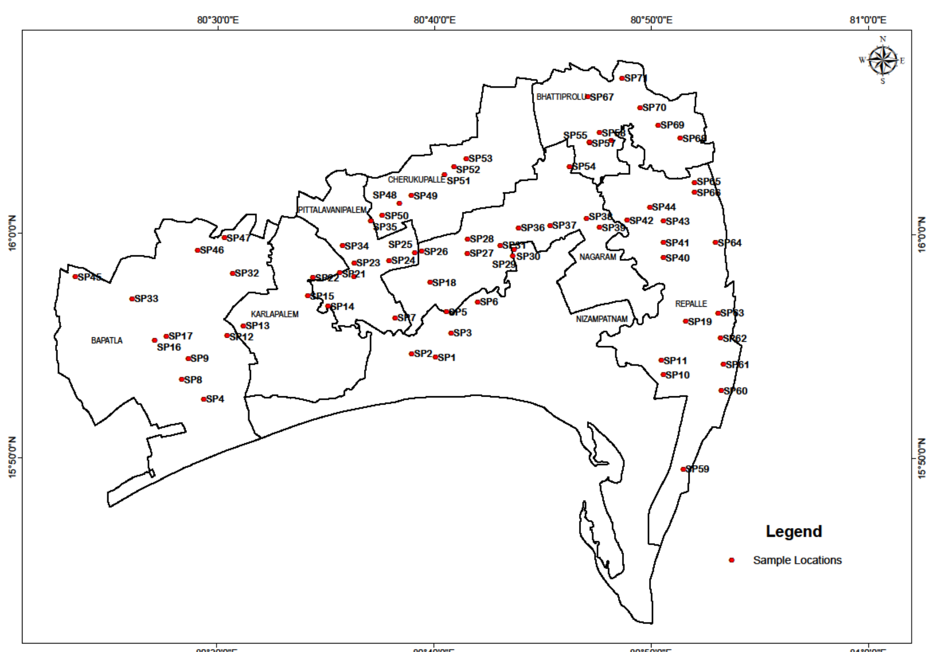

Figure 3: Sample location map of groundwater for major ions

The samples collected are examined for a mixture of physical and chemical parameter such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), Total Alkalinity (TA), Iron (Fe), Sodium(Na^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Nitrate (NO_3^-),Carbonate (CO_3^{2-}), Phosphate (PO_4^{2-}), Bicarbonate (HCO_3^-), Sulphate (SO_4^{2-}), Chloride (Cl^-) and Fluoride (F^-) as suggested by the APHA (2005). Analytical concentration are compared with BIS (2012) and WHO (2011) standards to identify their suitability for drinking purpose.

Data analyses to identify Saline water intrusion

To eliminate the impact of changes of ions, the major ion concentrations are changed into mg/L to meq/L before the analysis. Coastal groundwater contamination with salinity is identified using ten (9) distinct ionic ratios. The ionic ratios Na^+/Cl^-, Mg^{+2}/Cl^-, Ca^{+2}/Mg^{+2}, K^+/Cl^-, SO_4^{-2}/Cl^-, $Ca^{+2}/(HCO_3^- + SO_4^{-2})$, $(Ca^{+2} + Mg^{+2})/Cl^-$, $Cl^-/(SO_4^{-2} + HCO_3^-)$, Cl^-/HCO_3^- and (BEX) are used in the present study.

Table. 1: Signature of seawater intrusion by different ionic ratios

Parameter (Ionic Ratio)	**Signature of Seawater intrusioin**	**Authors**
Na^+/Cl^-	0.86 –1	Vengosh and Rosenthal, 1994; Vengosh and Ben-Zvi, 1994
SO_4^{2-}/Cl^-	0.05	Vengosh and Rosenthal, 1994; Vengosh *et al.*, 1999; Lagudu *et al.*, 2013
K^+/Cl^-	K^+/Cl^- = 0.019 seawater intrusion K^+/Cl^- < 0.019 deep seawater intrusion K^+/Cl^- > 0.019 waste water infiltration	Jones*et al.* 1999
Mg^{2+}/Ca^{2+}	> 5 (Saline water intrusion) > 1 (Deep saline upcoming)	Vengosh and Rosenthal, 1994; Vengosh and Ben-Zvi, 1994; Metcalf & Eddy, 2000
$Ca^{2+}/(HCO_3^- + SO_4^{2-})$	0.35 – <1 (seawater intrusion) > 1 (Deep Saline upcoming)	Vengosh and Rosenthal, 1994
$Cl^-/(HCO_3^- + CO_3^-)$	< 0.5 meq/L (no contamination) 0.5 to 2.8 (Slightly contaminated) > 2.8 (Contaminated with Seawater)	Simpson, 1946; Todd,1959
Mg^{2+}/Cl^-	< 1	Domenico and Schwartz 1997
Cl^-/HCO_3^-	<0.5 (unaffected) 0.6–6.6 (moderately affected) > 6.6 (strongly affected)	Revelle 1941; Todd 1959; Sanchez-Martos *et al.*, 1999; Kim *et al.*, 2003
Base Exchange Index **(BEX) =** **(**Na + K + Mg) – (1.0716 X Cl)	**"-"** value represents salinization. **"+"** value represents freshening	Stuyfzand1989, 1993, 2008

Table. 2: Minimum, Maximum and Average ratios values of the study area

Parameter	Minimum		Maximum		Average	
	pre- monsoon (May – 2017)	post-monsoon (January-2018)	pre- monsoon (May – 2017)	post-monsoon (January-2018)	pre- monsoon (May – 2017)	Post-monsoon (January-2018)
Mg^{+2}/Ca^{+2}	0.150	0.264	1.429	1.557	0.874	0.921
Na^+/Cl^-	0.403	0.326	1.439	1.579	0.828	0.784
$Cl^-/(HCO_3^- + CO_3^-)$	0.714	0.702	1.605	1.986	1.210	1.235
SO_4^{-2}/Cl^-	0.037	0.040	0.576	0.565	0.154	0.162
$Na^+/(Ca^{+2}+Mg^{+2})$	0.807	0.788	4.440	4.392	1.510	1.446
K^+/Cl^-	0.018	0.014	0.171	0.164	0.070	0.071
Mg^{+2}/Cl^-	0.064	0.044	0.553	0.549	0.257	0.264
$Ca^{+2}/(HCO_3^- + SO_4^{-2})$	0.050	0.038	0.652	0.568	0.327	0.308
Cl^-/HCO_3^-	0.714	0.702	1.605	1.986	1.286	1.265
BEX	-14.359	-12.906	8.644	8.122	-0.633	-1.064

Results and Discussion

The minimum, maximum and average values of the ionic ratios of all the samples for both pre- and post-monsoon seasons (May 2017 and January 2018) are furnished in above Table .2

In the present study area the Mg^{+2}/Ca^{+2} ratio values of the groundwater are falling in the range of 0.150 meq/L to 1.429 meq/L with an average of 0.874 meq/L during pre-monsoon period. The Mg^{+2}/Ca^{+2} ratio values fall in the range of 0.264 meq/L to 1.557 meq/L with an average of 0.921 meq/L during post-monsoon period. The Mg^{+2}/Ca^{+2} ratio values of the study area in the pre- and post-monsoon seasons all samples are falling in between < 5 and > 1 meq/L which suggests deep brine upconing in the study area are shown in Table. 1.

The Na^{+}/Cl^{-} ratio values of the groundwater are falling in the range of 0.403 meq/L to 1.439 meq/L with an average of 0.828 meq/L during pre-monsoon period. The Na^{+}/Cl^{-} ratio values fall in the range of 0.326 meq/L to 1.579 meq/L with an average of 0.784 meq/L during post monsoon period. The Na^{+}/Cl^{-} ratio values of the study area in the pre- and post-monsoon seasons indicating that 45.07% and 59.15% of the groundwater samples fall in < 0.86 meq/L, which shows groundwater is not contaminated. Remaining 54.93% and 40.85% of the samples exceeded the Na^{+}/Cl^{-} ratio of > 0.86 meq/L, which shows groundwater contaminated with seawater (Table 1).

The $Cl^{-}/(HCO_3^{-} + CO_3^{-})$ ratio values of the groundwater are falling in the range of 0.714 meq/L to 1.605 meq/L with an average of 1.210 meq/L during pre-monsoon period. The $Cl^{-}/(HCO_3^{-} + CO_3^{-})$ ratio values fall in the range of 0.702 meq/L to 1.986 meq/L with an average of 1.235 meq/L during post monsoon period. The $Cl^{-}/(HCO_3^{-} + CO_3^{-})$ ratio values of the study area in the pre- and post-monsoon seasons are indicating that all samples fall in between 0.5 meq/L and 2.8 meq/L, which shows that all the water samples in the study area is slightly contaminated (Table. 1).

The SO_4^{-2}/Cl^{-} ratio values of the groundwater are falling in the range of 0.037 meq/L to 0.576 meq/L with an average of 0.154 meq/L during pre-monsoon period. The SO_4^{-2}/Cl^{-} ratio values fall in the range of 0.040 meq/L to 0.565 meq/L with an average of 0.162 meq/L during post monsoon period. The SO_4^{-2}/Cl^{-} ratio values of the study area both in the pre and post-monsoon seasons are indicating that 2.82 % of the groundwater samples fall in < 0.05 meq/L which shows no water contamination. Remaining 97.18 % of the samples exceeded the SO_4^{-2}/Cl^{-} ratio of > 0.05 meq/L which shows samples are contaminated with seawater (Table. 1).

The $Ca^{2+}/(HCO_3^{-}+SO_4^{2-})$ ratio values of the groundwater are falling in the range of 0.050 meq/L to 0.652 meq/L with an average of 0.327 meq/L during pre-monsoon period. The $Ca^{2+}/(HCO_3^{-}+SO_4^{2-})$ ratio values fall in the range of 0.038 meq/L to 0.568 meq/L with an average of 0.308 meq/L during post monsoon period. The $Ca^{2+}/(HCO_3^{-}+SO_4^{2-})$ ratio values of the study area in the pre- and post-monsoon seasons are indicating that 64.79 % and 71.83 % of the groundwater samples fall in < 0.35 meq/L, which shows groundwater is not contaminated. Remaining 35.21 % and 28.17 % of the samples are falling in the 0.35 meq/L to < 1 meq/L, which shows groundwater contaminated with seawater (Table 1).

The K^{+}/Cl^{-} ratio values of the groundwater are falling in the range of 0.018 meq/L to 0.171 meq/L with an average of 0.070 meq/L during pre-monsoon period. The K^{+}/Cl^{-} ratio values fall in the range of 0.014 meq/L to 0.164 meq/L with an average of 0.071 meq/L during post monsoon period. The K^{+}/Cl^{-} ratio values of the study area in the pre- and post-monsoon seasons indicate that very few samples are falling in < 0.019 meq/L, which shows groundwater is contaminated deep upcoming of saline water. Maximum number of samples fall in K^{+}/Cl^{-} ratio >> 0.2 which indicating wastewater infiltration (Table 1).

The Mg^{2+}/Cl^{-} ratio ratio values of the groundwater are falling in the range of 0.064 meq/L to 0.553 meq/L with an average of 0.257 meq/L during pre-monsoon period. The Mg^{2+}/Cl^{-} ratio values fall in the range of 0.044 meq/L to 0.549 meq/L with an average of 0.264 meq/L during post monsoon period. The Mg^{2+}/Cl^{-} ratio values of the study area in the pre- and post-monsoon seasons, all samples are falling in < 1 meq/L which means all samples in the study area contaminated with seawater (Table 1).

The Cl^-/HCO_3^- ratio values of the groundwater are falling in the range of 0.714 meq/L to 1.605 meq/L with an average of 1.286 meq/L during pre-monsoon period. The Cl^-/HCO_3^- ratio values fall in the range of 0.702 meq/L to 1.986 meq/L with an average of 1.265 meq/L during post monsoon period. The Cl^-/HCO_3^- ratio values of the study area in the pre- and post-monsoon seasons all the groundwater samples are falling in between 0.6 meq/L and 6.6 meq/L which mean all samples in the study area moderately contaminated with seawater (Table 1).

The Base Exchange Indices (BEX) values of the groundwater are falling in the range of -14.359 meq/L to 8.644 meq/L with an average of -0.633 meq/L during pre-monsoon period. The BEX values fall in the range of -12.906 meq/L to 8.122 meq/L with an average of -1.064 meq/L during post monsoon period. The BEX values of the study area in the pre- and post-monsoon seasons indicate that 42.25% and 50.70% of the groundwater samples are having negative "-" values, which shows groundwater is contaminated with seawater. Remaining 57.75 % and 49.30% of the samples having positive "+" values, which shows groundwater is not contaminated with seawater (Table 1).

Conclusion

The study aimed at evaluating whether seawater intrusion would be accountable for the high salinity of study area's coastal zone. This study used a variety of important ionic variables, including ionic ratios and BEX. Seawater intrusion, brine upconing, irrigation water return flow, and wastewater leakage are some of the mechanisms that may contribute the salinization of coastal region of Guntur. different ionic ratios such as Na^+/Cl^-, Mg^{2+}/Ca^{2+}, Mg/Cl^-, SO_4^{2-}/Cl^-, K^+/Cl^-, $Ca^{2+}/(HCO_3+SO_4^{2-})$, $Cl^-/(HCO_3^- + CO_3^-)$, Cl^-/HCO_3^- and BEX are used to find out whether saltwater has an impact on the quality of groundwater. The ratios and BEX classification indicated that intrusion of seawater is the primary cause of the majority of the high salinity groundwater. The magnitude of the incursion is mostly visible in the pre-monsoon due to excessive groundwater pumping. Significantly, seawater intrusion has caused the low quality of ground water in the study area. Future freshwater supplies must be conserved through integrated water resources management.

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