Assessment of sea water intrusion into the coastal aquifers

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Introduction:

- The coast is where land, water and air interact.
- The coastal areas comprise of low lands with small gradients bordering sea and /or lower reaches of rivers of coastal marshes
- The economic significance of coastal regions requires no elaboration.
- Largest cities of the world are near to see and about 1/3rd of the human habitant is within a 100 km strip along the coast line and coastal deltas are major areas of grain productions.

- The issues relevant to coastal zones are
  - Storm, flood control,
  - Protection from coastal erosion and reclusive of land,
  - coastal inundation, depletion of forest resources,
  - increased salinity intrusion in coastal land and aquifers,
  - marines and industrial pollution,
  - effects due to change in agricultural practices,
  - land use pattern,
  - impact of aquaculture and fisheries.

Groundwater

- An important component of water resource systems.
- Extracted from aquifers through pumping wells and supplied for domestic use, industry and agriculture.
- With increased withdrawal of groundwater, the quality of groundwater has been continuously deteriorating.
- Growing concern about the water resources especially Water Crisis
- To meet the increasing demand of water – need to tap ground water resources

Hydrological Issues of Coastal Regions:

- Hydrology of coastal areas is distinct
- In a delta the water levels and flows are influenced by the water levels of sea
- The impact assessment of development activities on coastal area is normally complicated due to the involvement of so many factors
- As a result, it is not feasible to draw guidelines to address the various interactive processes
- It would be realistic to confine to impacts that expressed in terms of changes in the quantity and quality of water for subsequent use as inputs

- The coastal aquifers constituent an important source of water in the world.
- The fresh water aquifers are in contact with the sea due to that the planning and management of such aquifers requires special attention associated with the danger of seawater intrusion.
- As seawater intrusion progresses, the part of the aquifer close to the sea become saline and pumping wells that operate close to the coast have to be dissolute.
- Also, the area above the intruding seawater wedge, which remains fresh by natural replenishment, is lost as source of freshwater

Problems with groundwater

- Groundwater overdraft / mining / subsidence
- Water logging
- Seawater intrusion
- Groundwater pollution

- Coastal aquifers prove to be an important source of ground water resource.
- Seawater is the most common pollutant of fresh water in coastal aquifers
- Seawater intrusion in fresh water aquifers- Results from the activities of Man.
- Excessive ground water pumping
  - Deterioration of water quality
  - Dictating expensive remedies

Objectives:

- The main objective of present work is to assess the seawater intrusion in coastal areas of Nellore district, Andhra Pradesh . Nellore district is situated in the south-eastern part of the Andhra Pradesh.

- To study shallow groundwater hydrochemistry and its variations from sea coast.
  a) Hydro chemical variations [Ca/Mg ratio, TA/TH ratio, Cl/(Co3 + HCo3) ratio, base exchange Index, Mg/Ca Vs Cl ratio, I/Cl ratio]
  b) SAR & % NA variations
- To assess ground water quality parameters with WHO & ISI drinking water standards and its suitability for drinking and agricultural purposes.
- To suggest possible mitigation measures for saltwater intruded areas in the study area.

Location:

- The study area comprises, nine coastal mandals, viz Kavali, Allur, Vidvalur, Indukurpet, T.P Gudur, Muthukur, Kota, Vakadu, Chittamur situated along eastern part of the Nellore district
- Nellore district is approximately between 13°30'- 15°05' of North Latitude, 79°05'- 80°15' of East Longitude.

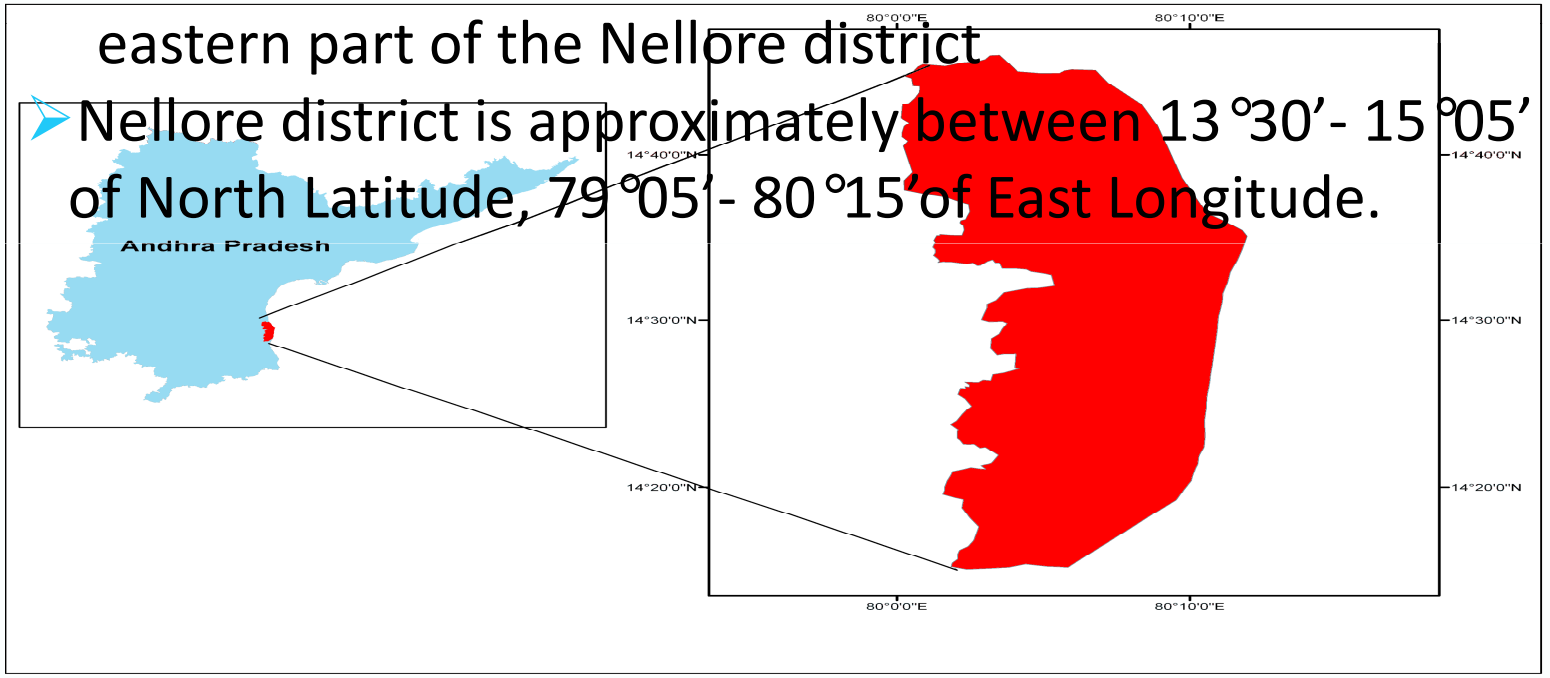
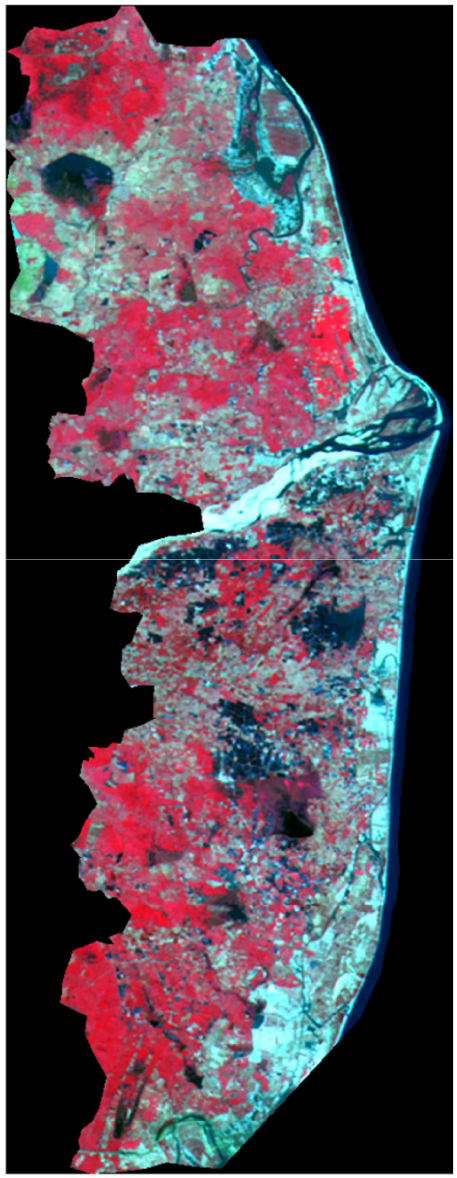


Fig. Location Map of the Study area

Study Area



SATELLITE IMAGE
OF THE STUDY AREA
DURING 2010

Rainfall:

- Due to SW and NE monsoons in Nellore district the rainfall ranges from **700-1000 mm**
- In the year 2009-10 the normal rainfall of the district is **1080mm**
- During the reference year 2009-10, the actual quantum of rainfall received was **996.1mm**
- From September to December the major portion of the rainfall is received during the northeast monsoon period to an extent of **610.8 mm**
- The total rainfall received during 2011 is **1309.71 mm**
- But most of the rainfall received during two months only, i.e., in October and November with a rainfall of **813.51mm**

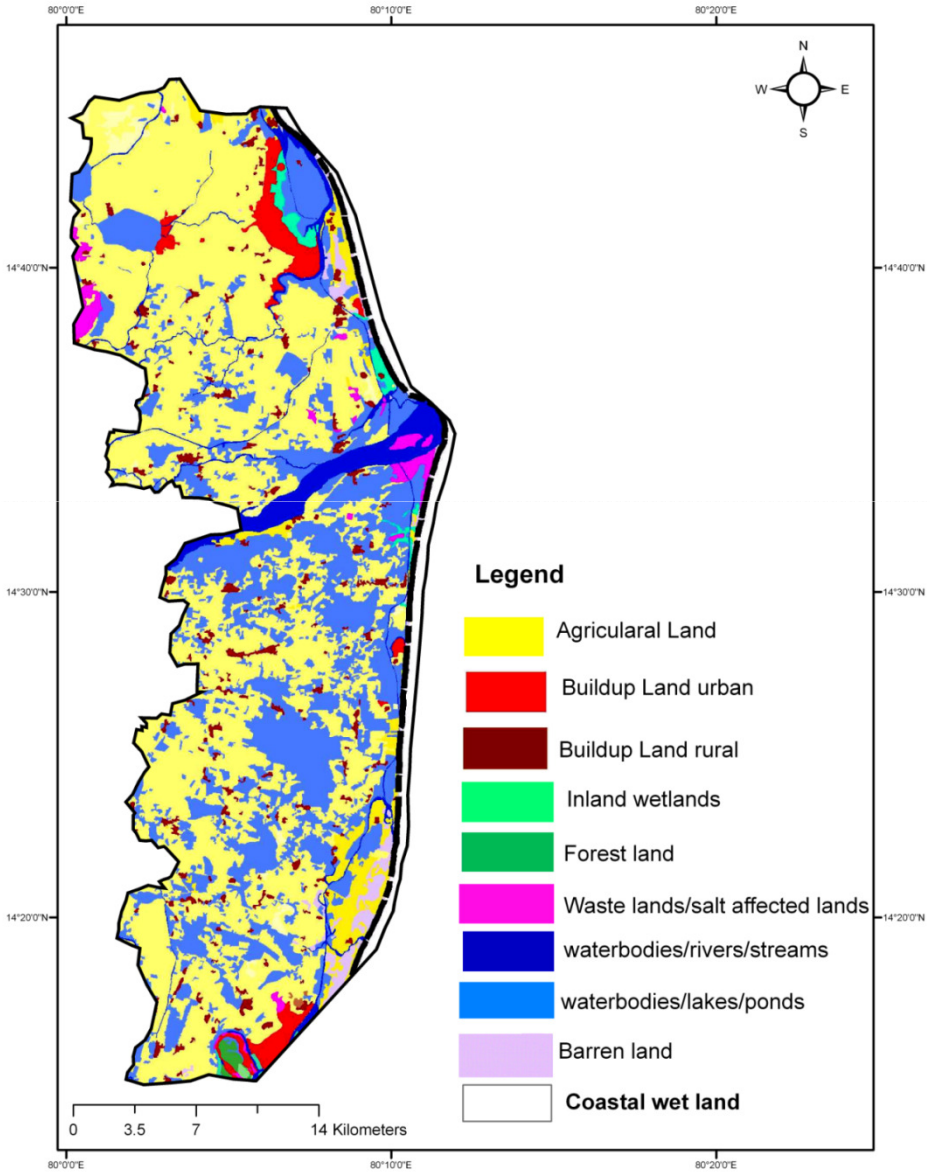
Soils:

- The soils of the district are classified as red, black and sandy.
- The red soils are predominant with 40% of the area whereas black cotton soil and sandy loams occupy 23% and 34% of the area respectively.
- A major portion of the area is covered by red soils

Land utilization and Crop Particulars:

- The principle crops being grown are paddy, bajra, sugarcane, groundnut, fruits & vegetables, chilies, cotton and tobacco

Land Use


80°0'0"E
80°10'0"E
80°20'0"E
N
W
E
S
14°40'0"N
14°30'0"N
14°20'0"N
Legend
Agricularal Land
Buildup Land urban
Buildup Land rural
Inland wetlands
Forest land
Waste lands/salt affected lands
waterbodies/rivers/streams
waterbodies/lakes/ponds
Barren land
Coastal wet land
0
3.5
7
14 Kilometers

Methodology

The following methodology has been adopted in the present study

- Collection of monthly rainfall data from District Statistical Department
- Collection of periodic groundwater levels from State Groundwater Department
- Correlation of groundwater levels with rainfall data
- Preparation of contour maps and drainage maps of the study area
- Model conceptualization and data preparation
- Model Simulations and calibration

Methodology

- Analysis of water samples
- Comparison of hydro chemical data with various parameters to identify seawater intrusion
- Suitability of groundwater for drinking and agricultural purposes
- Identification of saline water intrusion with the help of MODFLOW

Collection of Rainfall Data:

- Monthly rainfall data collected from District Statistical Department, Nellore for the period 2011 for the Coastal mandals viz Kavali, Allur, Vidvalur, Indukurpet, T.P Gudur, Muthukur, Kota, Vakadu, and Chittamur

Table 1 Amount of rainfall in the year 2011

MONTH	RAINFALL(2011) (mm)	G.W.LEVEL(2011) (mm)
January	18.81	3.42
February	38.88	-
March	0	4.11
April	74.74	-
May	1.16	5.89
June	57.62	-
July	63.06	6.57
August	142.95	-
September	51.56	5.89
October	371.52	-
November	441.88	3.15
December	47.53	-

Chemical Analysis:

- Groundwater analysis data of 33 samples (May, 2011) from 9 coastal mandals was collected from the State Groundwater Department, Nellore for the following parameters/ ions, viz., Hydrogen ion concentration (pH), Electrical Conductivity (EC), Total Dissolved Solids (TDS), Calcium (Ca), Magnesium (Mg), Chlorides (Cl), Sulphates (SO_4), Sodium (Na), Potassium (K), and Total hardness (as $CaCO_3$)

Chemical Parameters

- Various chemical ratios, viz. Ca /Mg, Cl / CO3 +HCO3), Na /Cl were calculated based on equivalent parts per million (epm) of respective cations and ions present in the groundwater to recognise the salt water intrusion in coastal aquifers of Nellore district.

Results and Discussions

- The groundwater analysis data of 33samples (May, 2011) from 9 coastal mandals was collected from the State Groundwater Department, Nellore. These parameters /ions are expressed in mg/l.

The details of groundwater quality particulars are shown in Table

General Quality of Ground Water:

Hydrogen ion Activity (pH):

- The pH of groundwater in the study area ranges from 7.59 to 8.94.
- The pH generally ranges from 7.0 to 8.5 with the higher range 7.5 to 8.0 confined to the eastern, central and north western parts.
- Higher pH is observed in area where the soil profile contains higher concentrations as at Alluru, Kudithipalem, and Mypadu.

Total Dissolved Solids:

- In the study area the TDS values are ranging from 428 to 4463 mg/lit.
- The TDS with less than 500 mg/l is observed in Kesavaram belonging to Kota Mandal.
- Maximum ranges TDS with more than 1500 mg/l occurs in the Ramudupalem belonging to Indukurpet Mandal with the range of 4463 mg/l.
- According to the classification given by Robinove et al. groundwater in the study area are, in general nonsaline (less than 1000 mg/l) and in a few parts of study area are slightly saline (1000 to 3000 mg/l).

Toatal Hardness:

- Hardness of ground waters in the study area ranges from 36 to 1238 mg/l. But the general range is 300 to 600 mg/l.

Water is classified with respect to TH as shown below.

Description	TH (mg/l)
Soft	< 75
Moderately hard	75-150
Hard	150-300
Very hard	>300

- In the study area, TH with less than 75 mg/l is not observed, shows that no sample falls under soft category.
- Moderately hard water (75-150 mg/l) occurs in Pallipadu and Mothali.
- Hard water with 150-300 mg/l range covers most of the area.
- Maximum range of more than 300 mg/l, i.e., very hard waters are observed in most of the places in Kudithipalem belonging to Indukurpet Mandal.

Chemical constituents:

Calcium (Ca):

- Calcium concentration in the study area varies from 16-320mg/l.
- Low concentration of 16 mg/l is observed mostly in the Kesavaram belonging to Kota Mandal.
- Higher concentrations with 50-100 mg/l are found the Indukurpet and Vidavlur Mandals.
- Maximum range of more than 100 mg/l occurs in the Alluru Mandal.
- Groundwater body modifies its chemical composition by the process of cation exchange in the study area, and inverse relation is observed between Ca & Na ions.
- The Ca rich show low Na concentration and vice-versa.

Magnesium (Mg):

- In the groundwater study area Mg content is less than Ca.
- It varies from 19 to 340 mg/lit. Most of the area shows 30 to 50 mg/lit.
- Higher range of 50-150 mg/lit is observed in the Mandals Vakadu & Kavali.
- Maximum content above 150mg/lit observed in Mandal Alluru
- Generally Mg content is also controlled by the presence of CO_2 like Ca. About 190mg/lit of Mg will remain in the solution under the influence of atmospheric CO_2.
- Therefore it is possible that all the Mg in the groundwater of the study area remains in solution.

Sodium (Na):

- It is found that Na is the dominant cation in the study area and its concentration in the groundwater's of the study area varies between 106 and 680mg/lit.
- Most of the study area falls in the range of 100-250mg/lit.
- The minimum range of Na is about 106mg/lit situated in Indukurpeta Mandal and the maximum range of 680mg/lit situated in Mypadu present in Indukurpeta Mandal.

Chloride (Cl):

- Among anions, Chloride is the dominant anion in the groundwater of the study area. Its concentration ranges from 30- 1300 mg/lit.
- Low concentration of 30 mg/lit is observed in Kesavaram situated in Kota Mandal.
- The lowest concentration of Cl is almost coincides with the lowest of TDS.
- The maximum concentration of Cl is 1300mg/lit observed in the Kudithipalem situated in Indukurpeta Mandal.
- High Chloride contains in certain zones in the study area may be due to its accumulation in the permeable zones as in the finites sediments and in topography lows as there is no source of pollution in the area.

Sulphates (SO_4):

- Sulphate is generally less abundant than chloride in most of the natural water; the same is observed in the ground waters of the study area also.
- In the study area the sulphates are ranges from 3-372 mg/lit.
- The lower concentrations are observed in Mypadu situated in Indukurpeta Mandal.
- The higher concentrations are observed in Kudithipalem situated in Indukurpeta Mandal.

Table: Maximum, Minimum Values and General Range in the Study Area.

S.No.	Parameter	Min.Value (mg/l)	Max.Value (mg/l)	General range (mg/l)
1.	Ph	7.59	8.94	8-8.6
2.	TDS	428	4463	400-1000
3.	Total hardness	36	1238	100-300
4.	Calcium	16	320	25 – 50
5.	Magnesium	19	340	< 50
6.	Sulphates	3	372	50-250

Criteria for reorganisation of saltwater intrusion

Hydrogeochemical parameters:

- In order to identify saline waters hydro geochemical parameters are normally used.
- A few hydro chemical parameters that are suggested as criteria for Ca/Mg, Cl/(CO_3+HCO3), Mg/Ca, and Na/Cl ratios.
- In the study area the ratios are ranging by following values.

Ca/Mg Ratio:

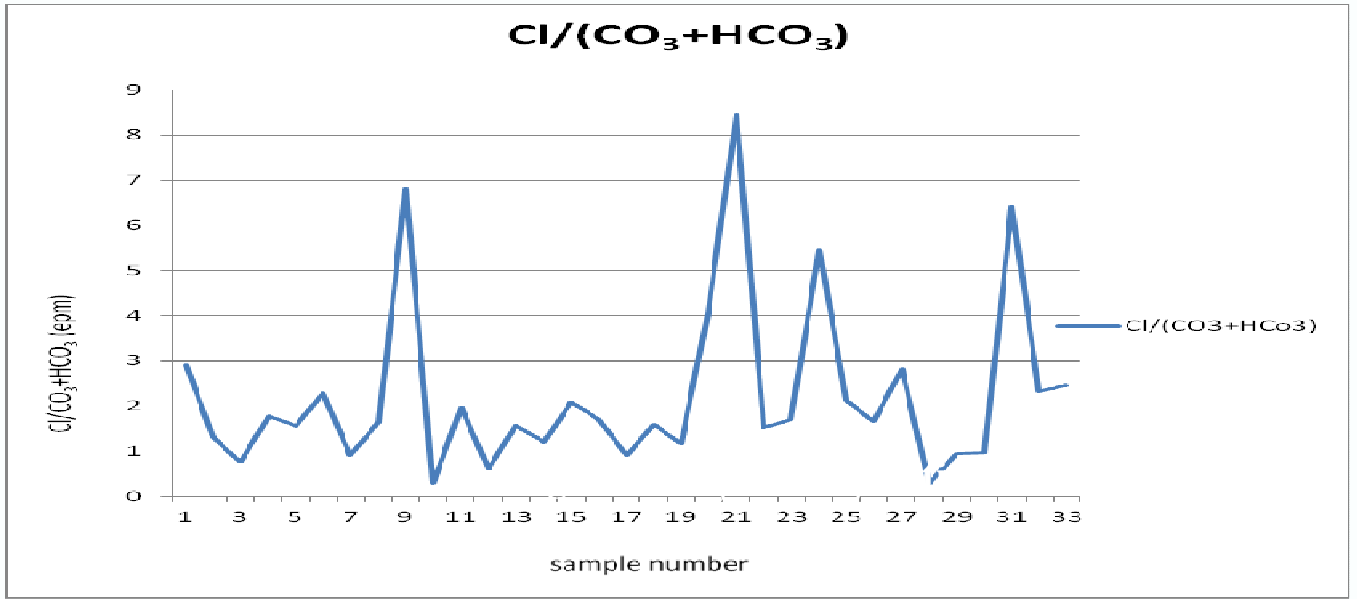
- A low Ca/Mg ratio may be indicative of salt water contamination because magnesium is present in sea water in much greater concentration than calcium.
- Therefore, Ca/Mg ratio is considered as a parameter for determining sea water contamination.
- According to Ca/Mg ratio, in the above 33 samples only one sample that is Muthukur is contaminated with seawater and 32 samples free from seawater intrusion.

$Cl / (CO_3+HCO_3)$ Ratio:

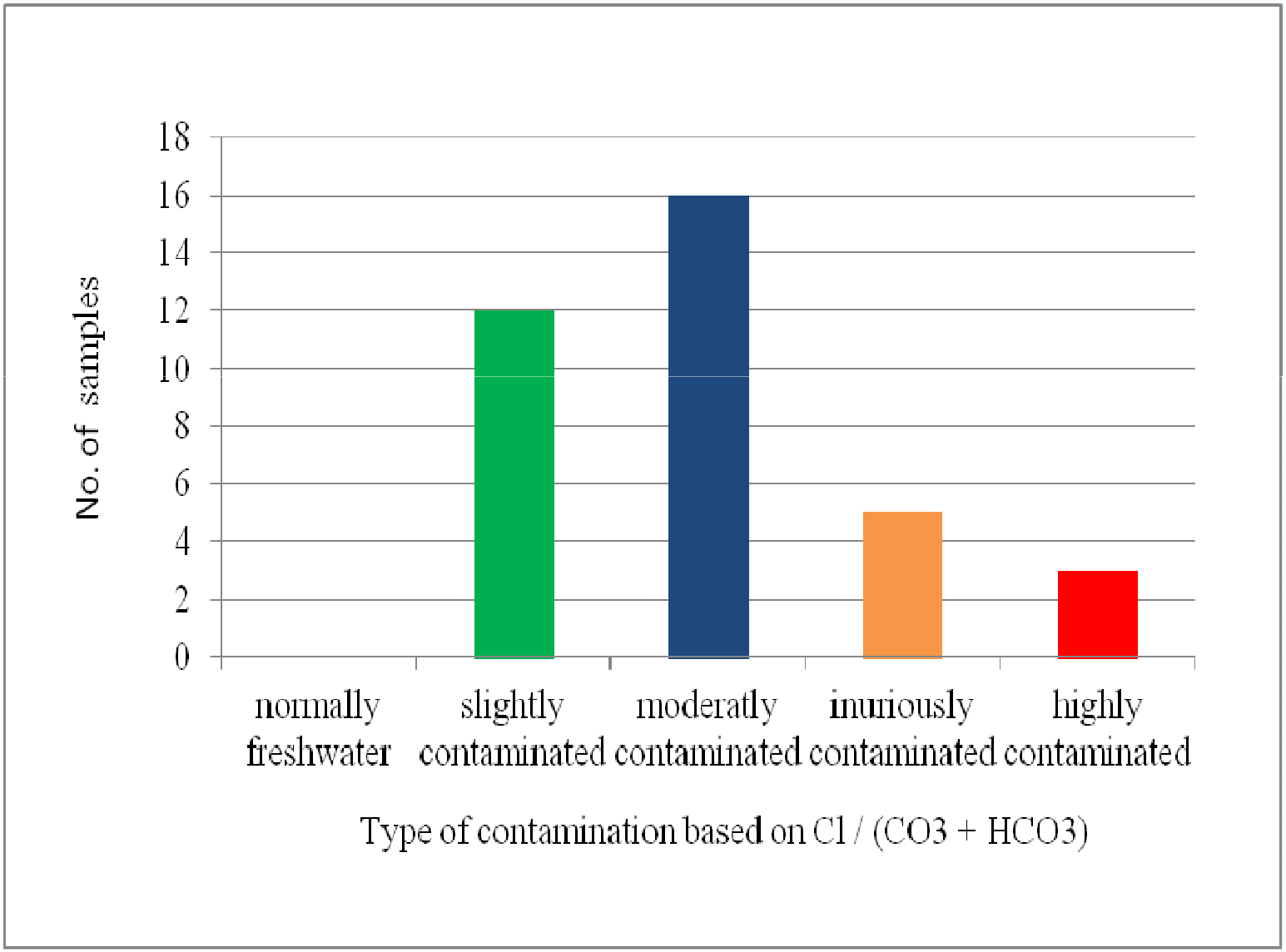
- Revelle (1941) recommended the $Cl / (CO_3+HCO_3)$ ratio as a criterion to evaluate the salt water intrusion.
- Chloride is the domination ion of ocean water and normally occurs in only small amount in groundwater while HCO_3 is usually the most abundant negative ion in ground waters, but it occurs in only minor amounts in sea water. The degree of concentration is assessed by Simpson (1946) as follows:

Range of Cl / (CO_3+HCO_3) Ratio:	**Description**
<0.05	Normally fresh ground water
0.05-1.30	Slightly contaminated ground water
1.30-2.80	Moderately contaminated ground water
2.80-6.60	Injuriously contaminated ground water
6.60-15.50	Highly contaminated ground water (near sea water)
>200	Sea water

- From the above limit values out of 33 samples only one sample which is Kesavaram situated in Kota mandal is free from contamination, 8 samples are slightly contaminated ground water, 15 samples are moderately contaminated groundwater, 9 samples are injuriously contaminated groundwater and only 3 samples are highly contaminated but no one is fully seawater intrusion.



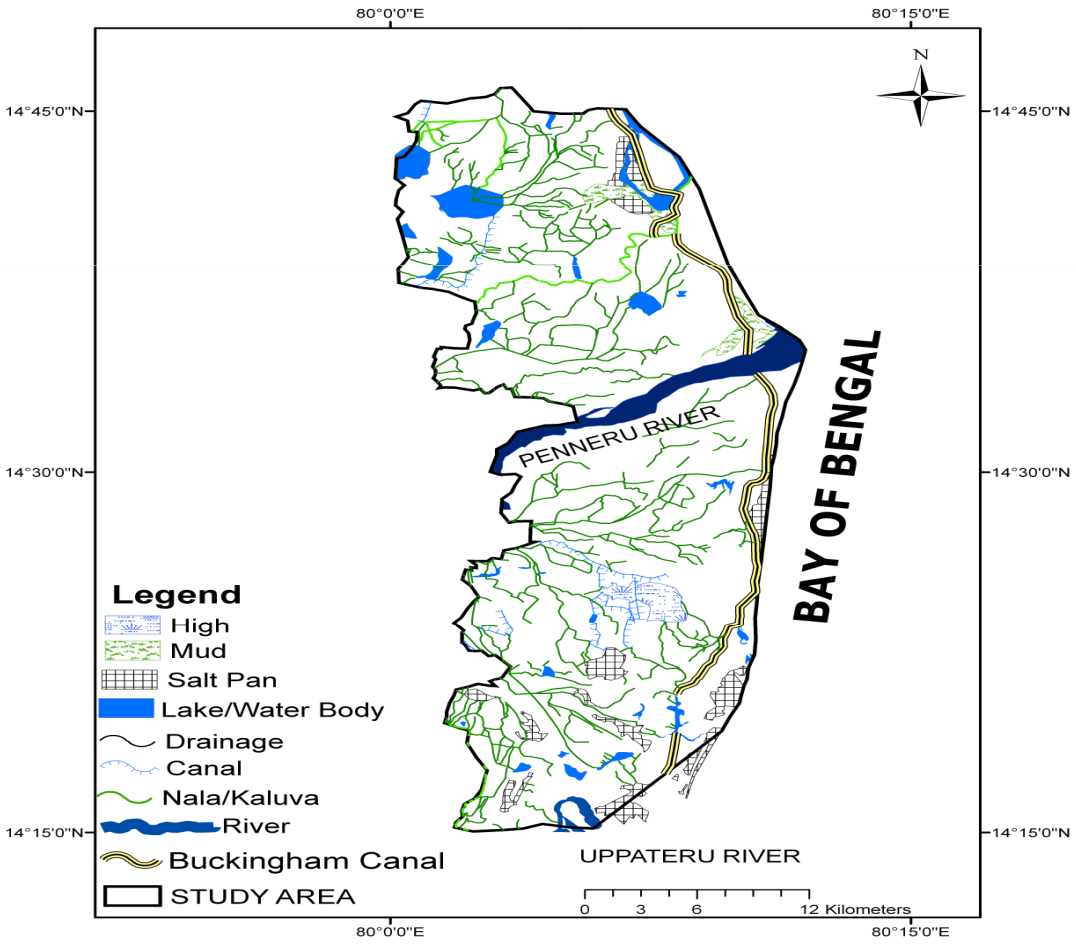
contamination based on Cl / (CO_3 + HCO_3) in the study areas



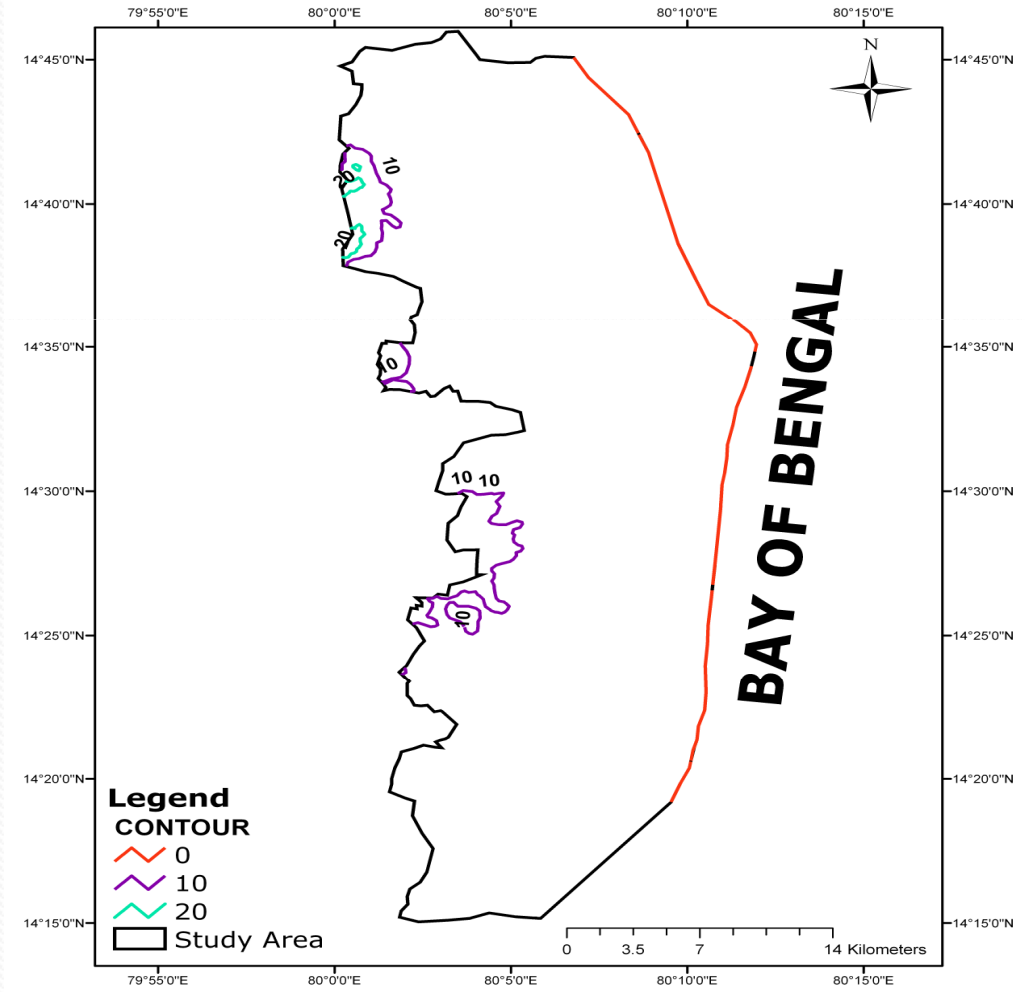
Na/Cl Ratio:

- Na / Cl ratios of saltwater intrusion are usually lower than the marine values.
- On the other hand, high Na/Cl ratios, typically characterize anthropogenic sources like domestic waters.
- Thus low Na/Cl ratios combined with other geological parameters, can foretell the arrival of saltwater intrusion.
- According to Na/Cl ratio, with less than 0.86 value in 23 samples indicates marine source of contamination.
- Remaining 10 samples may be due to anthropogenic sources like salt water pans and aquaculture farms.

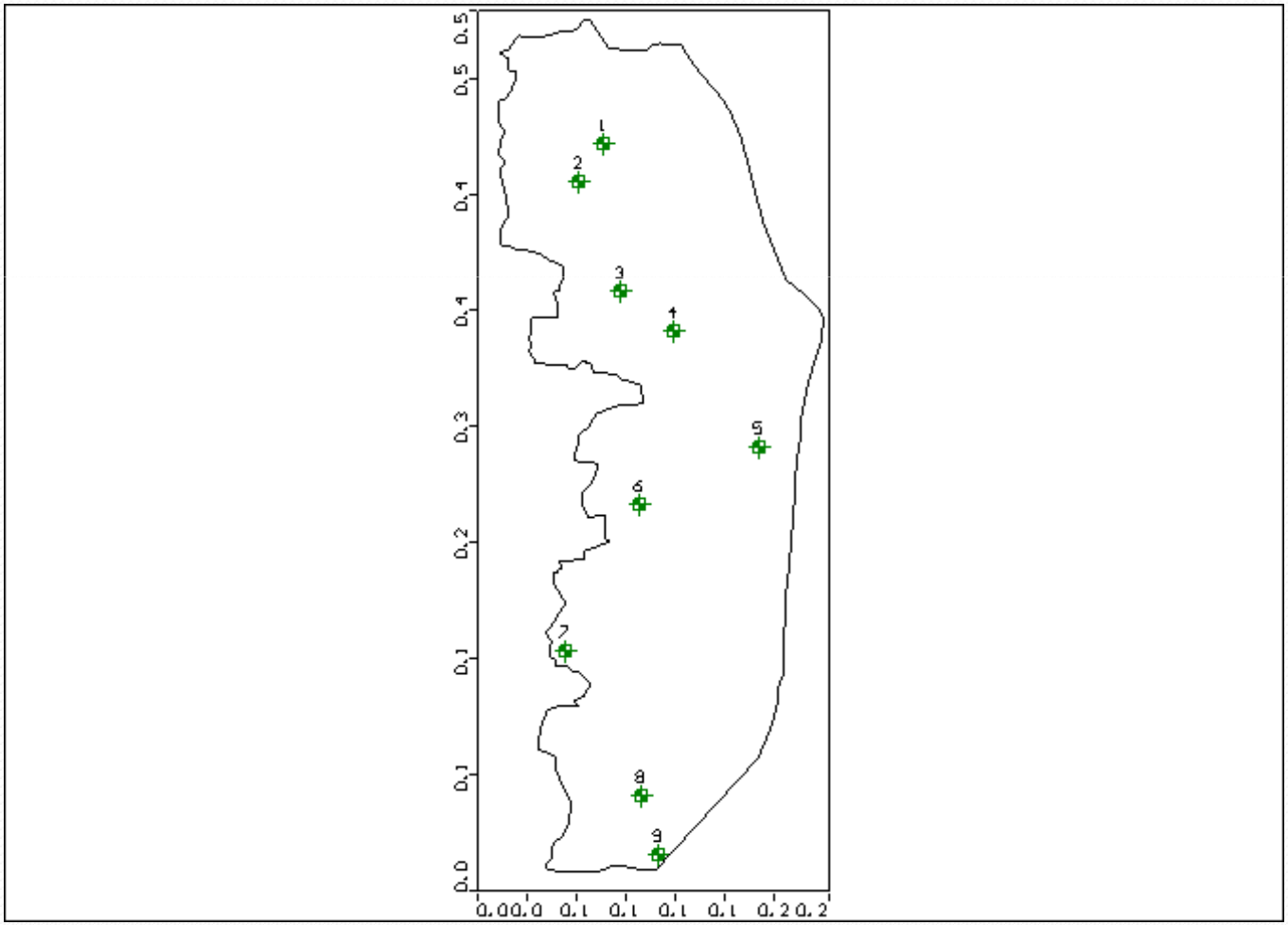
Drainage Map



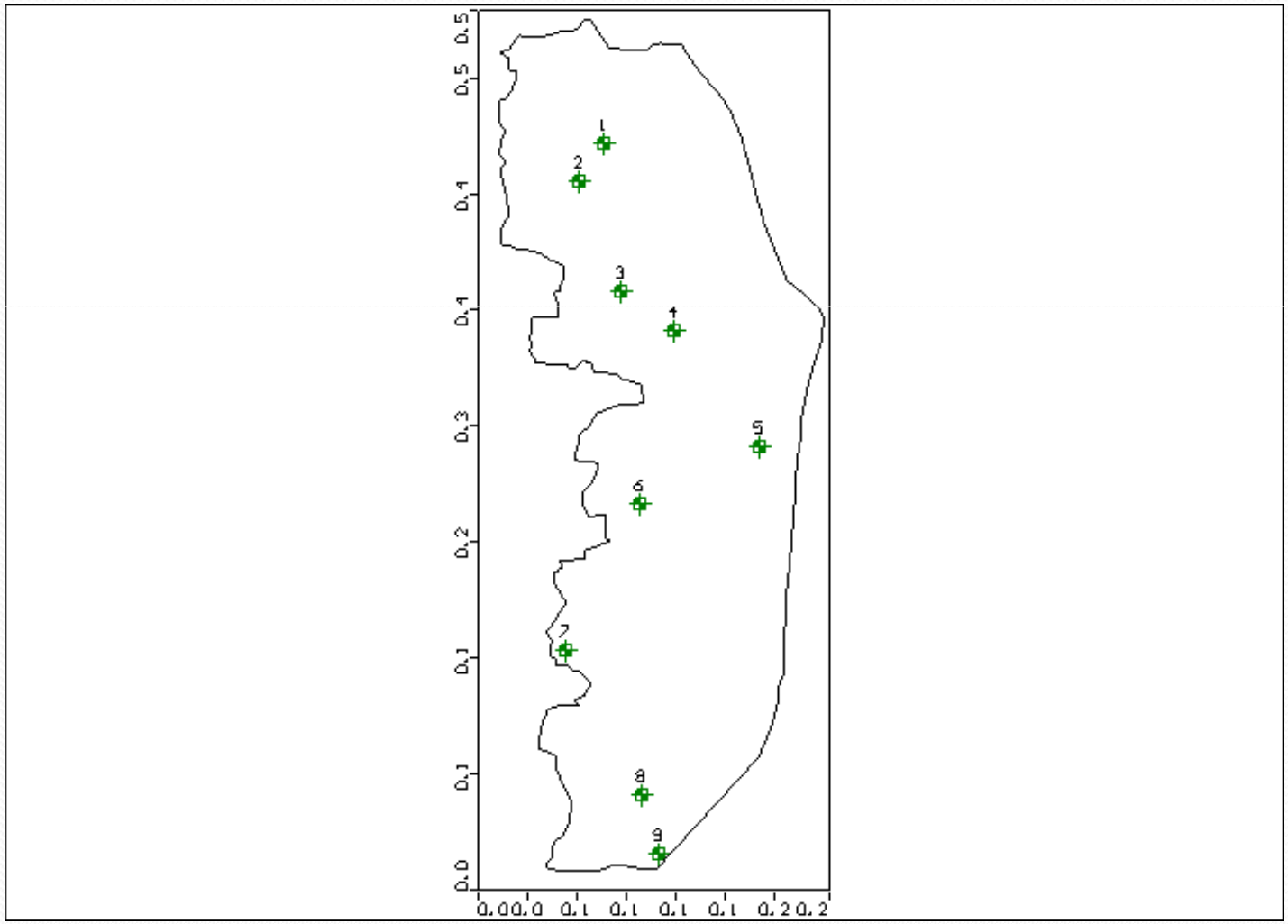
Slope Map


79°55'0"E
80°0'0"E
80°5'0"E
80°10'0"E
80°15'0"E
14°45'0"N
14°40'0"N
14°35'0"N
14°30'0"N
14°25'0"N
14°20'0"N
14°15'0"N
N
BAY OF BENGAL
10
20
10
10
10
Legend
CONTOUR
0
10
20
Study Area
0
3.5
7
14 Kilometers

Observation Wells



Pumping Wells



Model Calibration and Sensitivity

- In this study, groundwater flow model calibration has been achieved through a trail and error method by adjusting the two key parameters i.e., hydraulic conductivity and recharge rates until head values as calculated by SEAWAT match the observed hydraulic head values to a satisfactory degree.
- No attempt was made just several transport parameters including effective porosity set at 0.3. Their values remain the same as initially assigned. The aquifer hydraulic conductivity was decreased with depth due to increased overburden of the aquifer material.

Model Calibration and Sensitivity

- The conductivity of the clay was reduced to 8.2m/day, 7.1m/day and 6.5m/day from top to bottom from the initial value of 10.1m/day, where as conductivity of sand was increased to 10.1m/day to 9.9m/day and 9.7m/day from 10m/day top to bottom.
- Calibration result show an overall correlation coefficient of 0.91, root mean square of 1.389 and standard error of 0.258 were obtained when model calibration was finished and indicates a reasonable matching between observation and calculated heads.

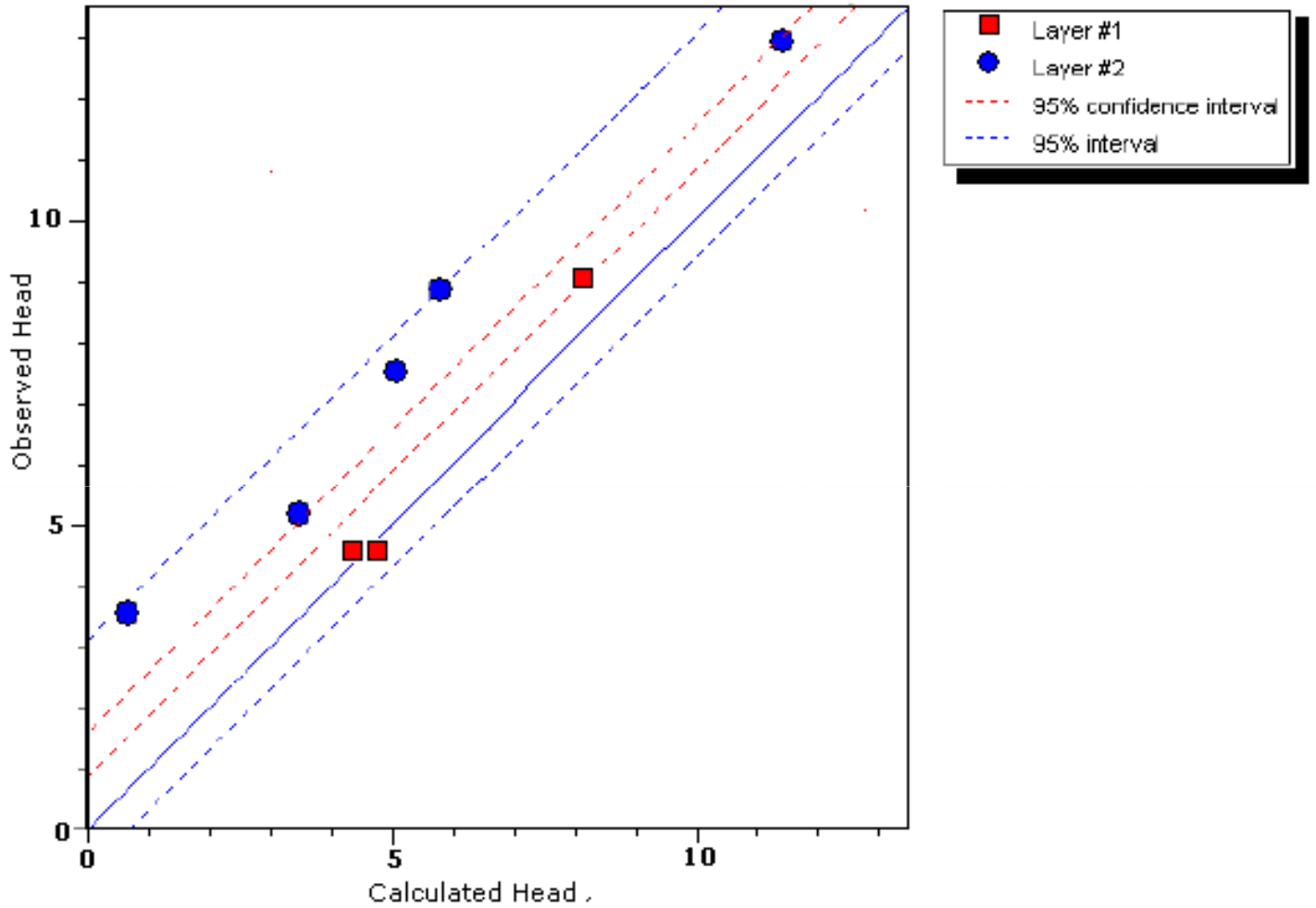
Transient Modeling

- The transient modeling was performed to simulate density dependent solute transport modeling using SEAWAT with period May 2012 and January 2013 hydrological parameters including TDS Values in which have been obtained from the analytical results and identified that there is a mismatch at the initial stage.
- Therefore greater effort was made to obtain a better match by modifying the magnitude and distribution of the background salt concentration closer to the analysed values.
- By changing the transport parameters, dispersivity, effective porosity values.

Transient Modeling

- The dispersivity changed to 95m (from 100m) and effective porosity changed to 0.3 (from 0.25) then it was found that there is a good match between observed and computed TDS concentrations with correlation coefficient 0.971 and normalized RMS error of 12.95. All the concentration values are based on the concentrations at the bottom of the top sand layer.

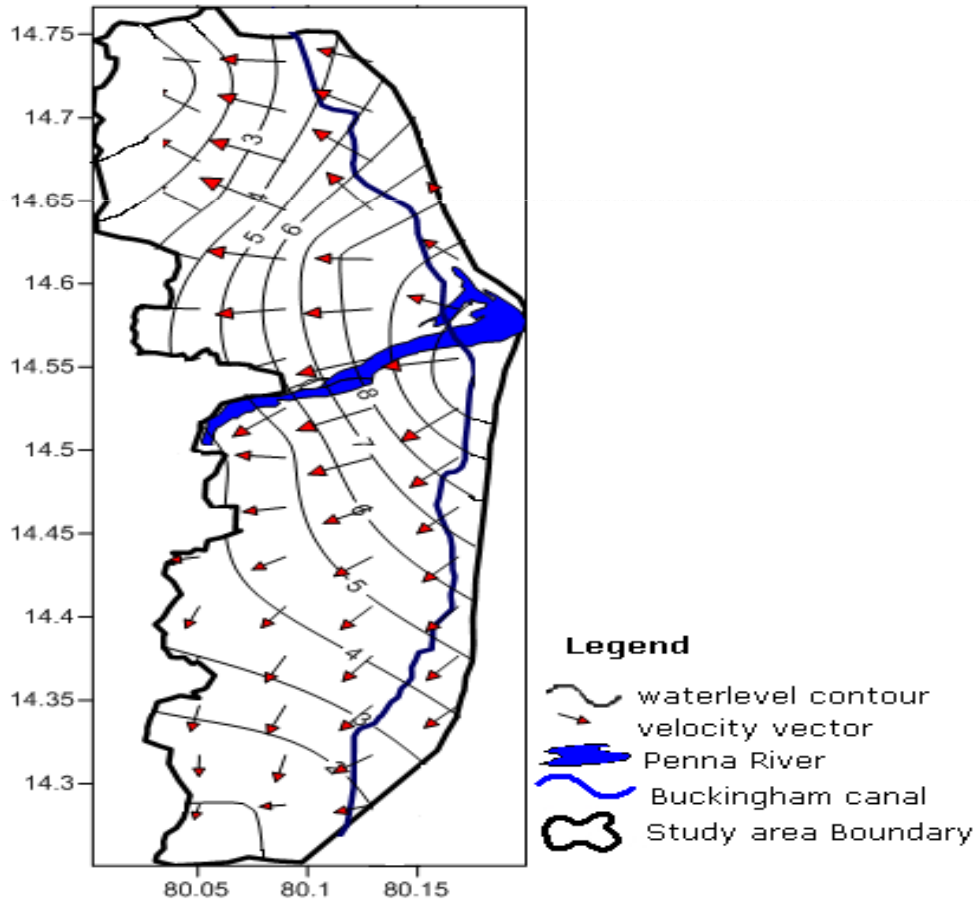
Transient State Calibration



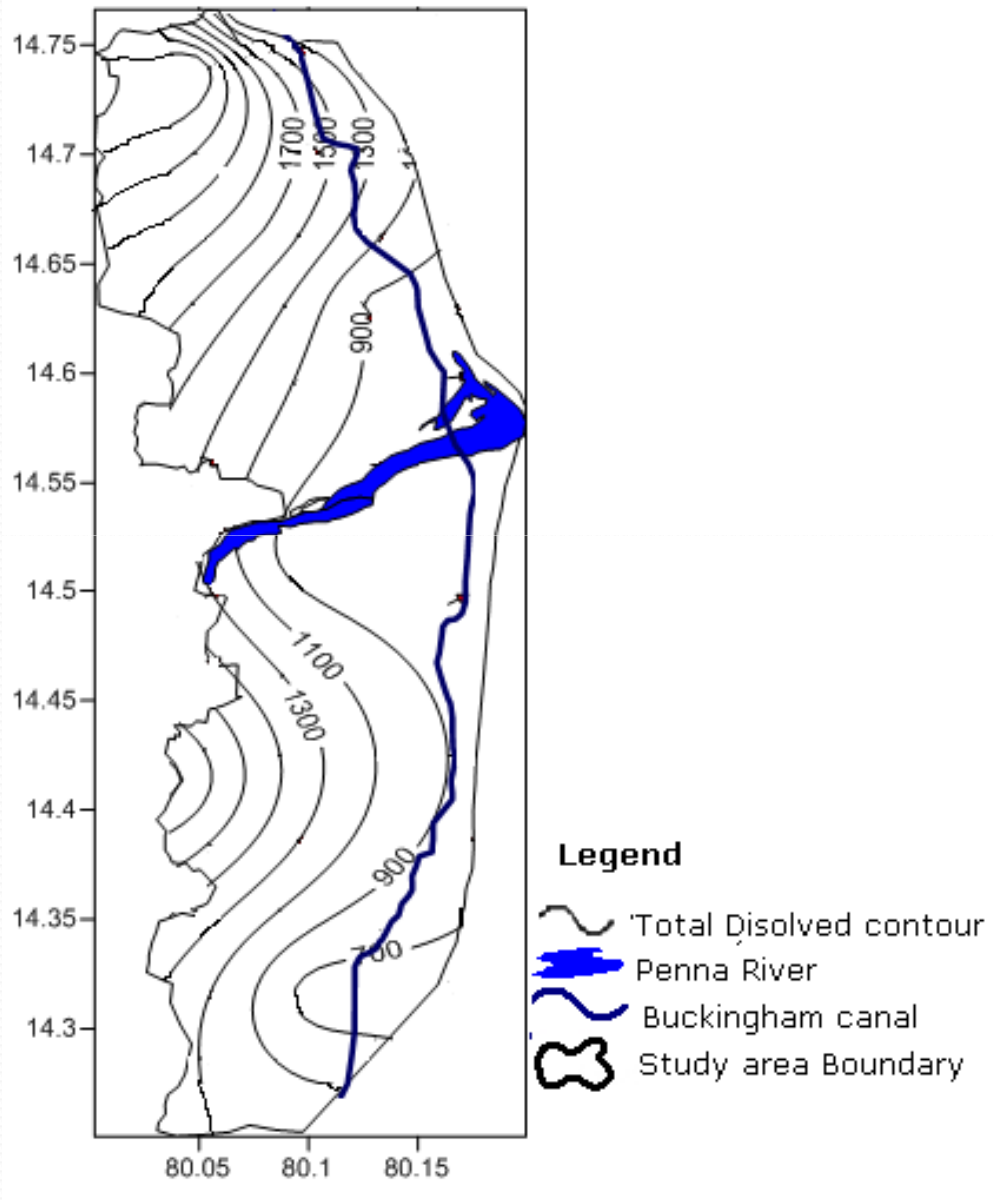
Num. of Data Points : 9
Max. Residual: 30.475 (m) at 22/A
Min. Residual 1.249 (m) at 11/A
Residual Mean : 12.176 (m)
Abs. Residual Mean : 12.29 (m)

Standard Error of the Estimate : 1.806 (m)
Root Mean Squared : 15.158 (m)
Normalized RMS : 12.958 (%)
Correlation Coefficient : 0.971

Groundwater Contours In m (amsl) in January 2013



Observed TDS Contours In The Study Area During May 2012



Conclusions

- The study area covering 9 coastal of Nellore district Groundwater development is mainly for drinking purpose and certain areas are for agricultural purposes.
- A total number of 33 villages of the study area were observed and groundwater quality data taken from the State Groundwater Department, Nellore.
- Groundwater quality was assessed by estimating major cations and anions.
- The dominant cation is magnesium and dominant anion is chloride in the study area.
- According to drinking water standards, the ground water in the study area is potable

- Regarding salt water intrusion, the low Ca / Mg ratio may be indicative of salt water contamination.
- According to Cl / (CO_3+HCO_3) ratio, the study area is found to be contaminated with slightly to moderately contaminated groundwater and there are no fresh ground water is encountered.
- According to Na / Cl ratio, the contamination may be due to marine source of origin.
- Based on the hydrogeochemcial parameters the seawater intrusion is noticed in Indukurpet mandal followed by Muttukur.


THANK YOU!!!