A Study on Saltwater Intrusion Around Kolleru Lake, Andhra Pradesh, India

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Abstract**-** Kolleru Lake, the largest natural fresh water lake in Andhra Pradesh in India, located between Krishna and Godavari deltas is acting as a natural flood balancing reservoir and is fed directly by water from the seasonal rivers Budameru, Ramileru and Tammileru, and is also connected to the Krishna and Godavari drainage system consists of over 68 inflowing drains and channels. Over-exploitation of groundwater and land use conversions to aqua-culture are becoming the sources for salt-water intrusion to this lake and coastal aquifers, in specific, are highly vulnerable to seawater intrusion. Hydrogeomorphological study indicates that the potential aquifers around the Kolleru lake are paleo beach ridges and buried river courses. All other geomorphic features either aquiclude or aquitards are may not be considered as prospective zones for groundwater. Though there are number of open wells present in the villages used for potable water earlier, people switched over to imported water as their drinking water source may be due to significant contamination of groundwater resources. Present land use activities like aqua-culture, agriculture, large-scale industries and allied industries in and around the Kolleru lake region has large contribution for the change of water quality. The paleo beach ridge areas, where the permeability of the sandy soil is very high, are also converted into aqua ponds.

Integrated study using remote sensing, hydrogeology, hydrochemistry and geophysical investigations revealed the extent of salt-water intrusion up to the northern part of the lake which is about 40 km from the coast line. The electrical resistivity of aquifers is less than 1.0 (ohm-m) having salinity of more than 1.2 ppt and the resistivity is around 20 (ohm-m) where the salinity is less than 0.5 ppt, has also served as an excellent criteria for delineating the fresh-water and salt-water interface. Lenses of fresh water/ brackish water are noticed only in the beach ridges limiting to 2-8m depth below the natural ground level.

I.INTRODUCTION

Saltwater intrusion can pose serious problems to freshwater aquifers along the coastal areas having marine-aquifer hydraulic interaction. Coastal aquifers are contaminated with saltwater intrusion particularly in and around the Kolleru lake region, mainly because of the growing demand for seafood, has lead many farmers to take up aquaculture as a more profitable source of income, where salt water is used from the nearby creaks. The water quality in these aquaculture tanks is usually saline, which slowly infiltrates and reaches the water table. The aquifers in this region were contaminated with salt water. The natural balance between freshwater and saltwater in coastal aquifers is disturbed by groundwater withdrawals and other human activities that lower groundwater levels, reduce fresh groundwater flow to coastal waters, and ultimately cause saltwater to intrude coastal aquifers [1]. Hence people living in the lake area are getting drinking water from far places, which indicate the available groundwater in the lake area is not potable. Understanding of saline intrusion into the coastal aquifers is essential for efficient planning and management of coastal aquifers. It is also essential to delineate and predict the extent of saline water intrusion into the aquifers in response to variations in the components of the freshwater mass-balance [2].

There are several geochemical, remote sensing and geophysical techniques are used to directly or indirectly monitor saltwater in coastal aquifers, because of the very high concentration of chloride in seawater (typically about 19,000 mg/L), the chloride concentration of groundwater samples has been the most commonly used indicator of saltwater occurrence and intrusion in coastal aquifers. However, other indicators of groundwater salinity, such as the total dissolved-solids concentration or specific conductance of groundwater samples, also are used frequently [3] [4]. A systematic integration of these data with follow up of hydrogeological investigation provides rapid and cost-effective delineation of fresh and salt water zones.

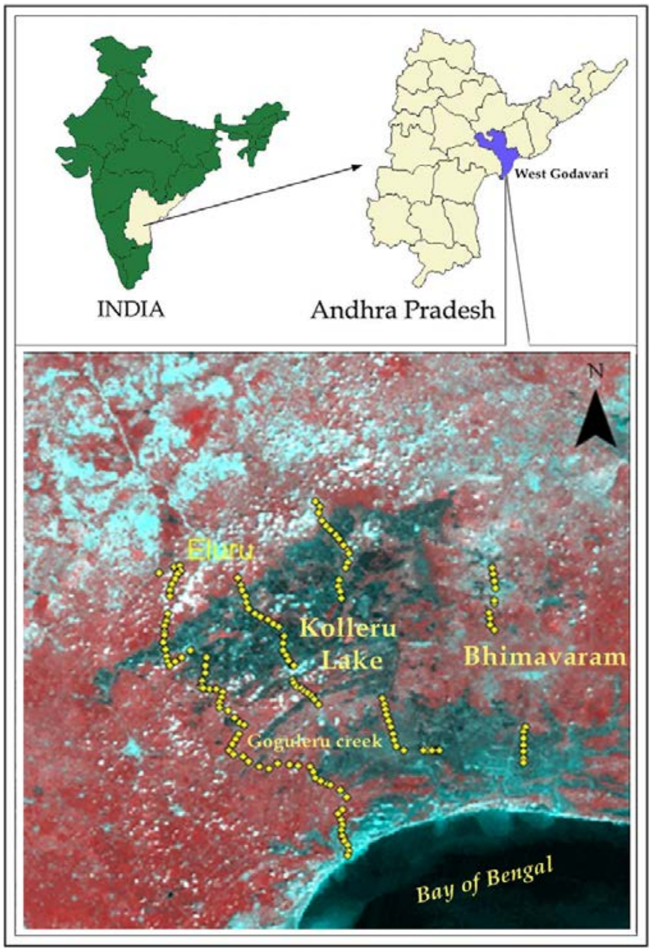
Resistivity survey is one of the surface geophysical methods to delineate the sub-surface layers, which includes aquifers and to certain extent the quality of groundwater [5]. Resistivity survey has been carried out to delineate sea water-fresh water interface and the extent of aquifer zones. Surface electrical resistivity surveys provide valuable information on the hydrogeological system of the aquifer, and delineate the salinity of groundwater and its subsurface configuration. However, Electrical resistivity methods have been widely applied in coastal and island environments because of their ability to detect increases in the conductivity of an aquifer that result from

increases in pore-water conductivity [6]. The electrical conductivity of an aquifer is controlled primarily by the amount of pore space of the aquifer (that is, the aquifer porosity) and by the salinity of the water in the pore space; increases in either the porosity or the concentration of dissolved ions result in increases in the conductivity of the groundwater. Because seawater has a high concentration of dissolved ions, its presence in a coastal aquifer can be inferred from measurements of the spatial distribution of electrical conductivity [7][8].
In the present paper, geophysical resistivity studies and chemical analyses of groundwater for TDS, conductivity and salinity of different open wells are compared. Finally, an attempt has been made to compare the analysis of Vertical Electrical Soundings (VES) data and chemical data of observation wells near the resistivity location along with the hydrogeomorphic units.

II. STUDY AREA

The study area is located in between 16°17'00" and 16°59'00" N latitudes and 80°50'00" and 81°39'00" E longitudes, covering in and around Kolleru lake region (Fig. 1). Water source to this lake is from its tributaries – Budameru, Tammileru and Ramileru, originating from the Eastern Ghats. Excess water from the applied irrigation around the lake area also joins the lake through number of drains. The outlet of the lake is a lead channel joins with Bay of Bengal and is about 38 km, which also allow salt-water during high tide and summer because of back-waters.

Fig.1. Location Map of the study area



III . HYDROGEOMORPHOLOGY

Hydrogeomorphological maps depicting the occurrence of aquifers containing potable water and groundwater vulnerability maps are both important means by which to present the outcomes of such complex investigations of groundwater resources [9].

Geomorphology provides knowledge of the geological environment and tectonic structure is the key element in groundwater resources investigation and development [10]. Landforms are delineated using the image characteristics (IRS-P6, LISS IV) along with the available geological and geomorphology details (Fig. 2). Ground truth verification was done in needy and problematic areas. The geomorphic units thus delineated are paleo beach ridges, marine-built up area, flood plain deposit, paleo lagoon plain, paleo tidal channel, tidal channel and tidal mud flats.

Beach Ridge: Linear ridge of unconsolidated sand / silt parallel to shore line. The beach ridges are present in three curvilinear rows parallel to coast between the southern boundary of the lake and the coast line. The ridge near the lake is continuous on which settlements and roads are developed. It

is relatively elevated ground than the surroundings, offer protection from frequent floods in this low-lying coastal region. A group of beach ridges and swales occurring together

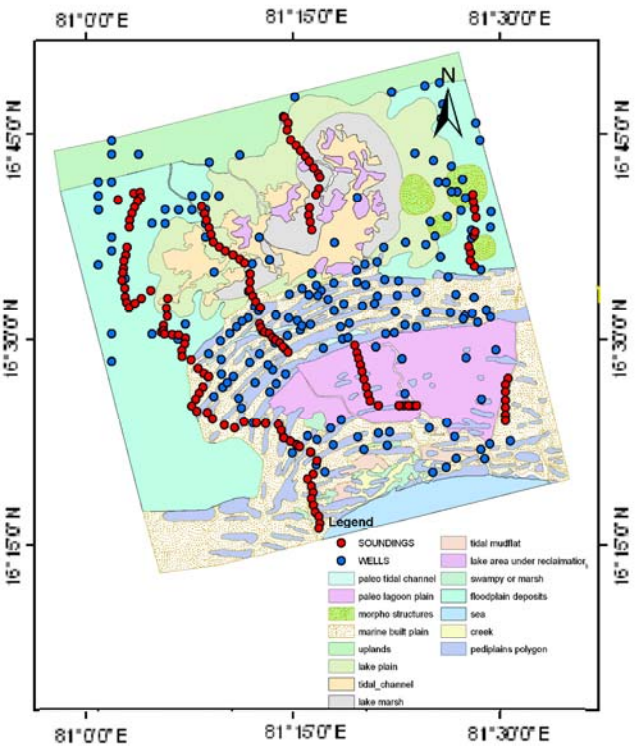


Fig.2. Hydrogeomorphology Map with VES and well locations.

are present in the downstream of Kolleru lake. Beach ridges consist of fine to medium sand and allow more rainwater to percolate and forms high yielding aquifer.

Paleo Lagoon plain: It is an elongated body of water lying almost parallel to the coastline and separated from the sea by a paleo beach ridge. It is observed in the coastal region of central Godavari delta. The paleo-lagoon is no more connected with the sea.

Paleo tidal channel: An earlier river course filled with channel-lag or channel-fill sediments due to tidal action, which is cutoff from the main river. Several paleo tidal channels are observed throughout the Godavari delta.

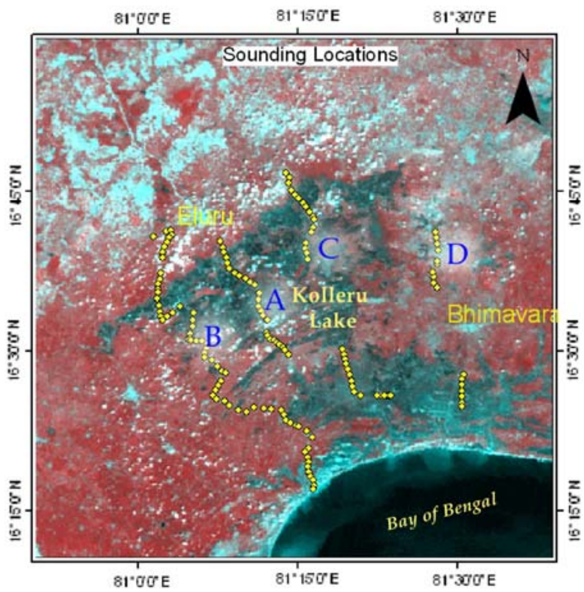
Tidal channels: These are formed by tides comprising of mostly mud and fine sand. These are curvilinear water bodies connected to the sea.

Tidal Mud Flat: Mud deposited in the back swamps and along tidal creeks. Among all the geomorphological features identified, beach ridges are the possible fresh water zones in the study area. These may have limited aerial and depth extension and act as isolated or perched aquifers. Aquifer recharge for these ridges may be from the direct rainfall percolation and sometimes from applied irrigation.

IV. GEOPHYSICAL STUDY

Resistivity survey has been carried to delineate sea water-fresh water interface and the extent of aquifer zones. In the present study Vertical Electrical Soundings (VES) have been carried out at 1.0 km interval along 4 traverses across the lake, in north-south orientation, perpendicular to the coastline namely A,B,C and D respectively, a total of 165 VES data are collected using Schlumberger electrode configuration with an electrode spacing varying between 150 and 200 m. All the VES apparent

Fig:3 VES locations Map of the study area



resistivity data are plotted traverse wise. Resistivity contours are drawn for 1ohm-m, 2ohm-m, 5ohm-m and 10ohm-m for all the traverses. All the VES locations are referred with respect to geographic coordinates with GPS and the locations are shown on the satellite image (Fig.3).

Analysis of Vertical Electrical Soundings data:

Each VES data is interpreted with the standard techniques and the subsurface layers are arrived. The cross sections shown in Fig. 4 shows the apparent resistivity contours drawn for i) less than 1.0 ohm-m, ii) 1-2 ohm-m, iii) 2-5 ohm-m, iv) 5-10 ohm-m and v) >10 ohm-m.

Resistivity is variable with the aquifer material, percentage of fluids filled in it and the quality of fluid. It is comparable with the quality of groundwater in which the parameters - salinity, TDS, electrical conductivity are closely related. Resistivity is low with increase of these parameters in the groundwater which is filled in the pore spaces of the subsurface lithological layers. Resistivity variations along the geophysical traverses are shown below.

Results of Resistivity Surveys

Traverse-A: This traverse runs in the middle portion of the lake for a length of 51km starting at the northern boundary of the lake and ending up at coast. Apparent resistivity more than 10 ohm-m area is matching with the geomorphology unit 'beach ridge' and groundwater in the wells present in this zone are used for domestic needs other than drinking. Less than 1.0 and 1-2 ohm-m zones are present for the entire traverse length starting at A5 (near the northern boundary of the lake) and their extent increased vertically towards the coast area and this zone is treated as salt water intrusion zone. Dark red colour indicates the salt water intrusion zone and its thickness increased towards coast between VES A35 and A51.

Traverse-B: The traverse is along the western boarder of the lake and runs for a length of 71 km starting near Eluru and ending up at coast. More than 10 ohm.m zone is noticed on the main beach ridge around Akivedu village and the fresh-water

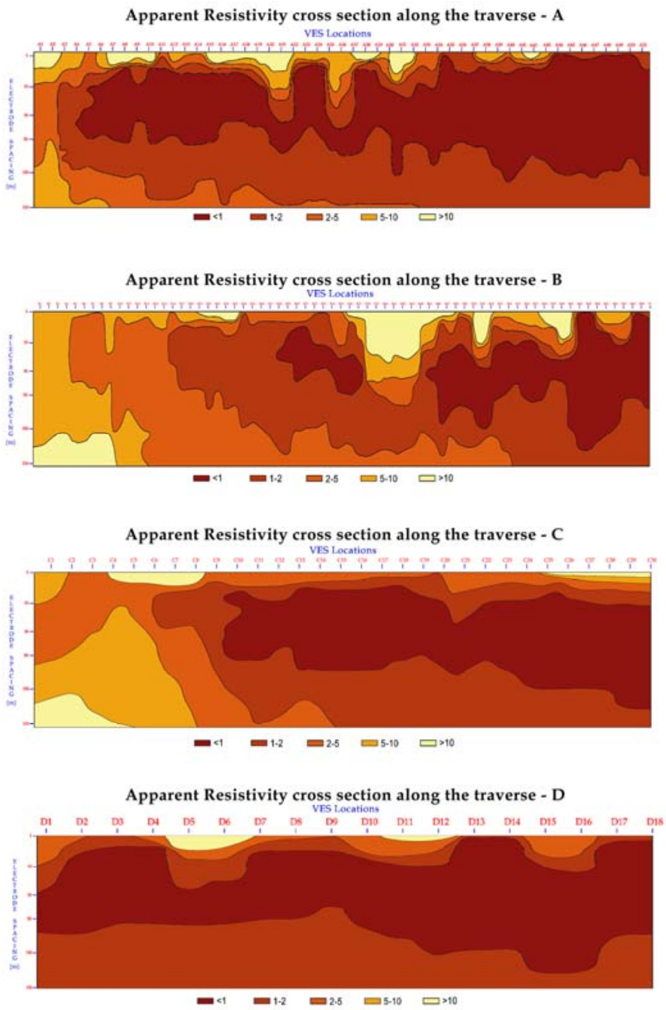


Fig.4. Apparent resistivity contours Map of the Traverses in the Study Area.

zone is extended up to 10 to 15m depth. Salt water zone is indicated beyond 5m electrode separation along the traverse-B, between VES-B16 and the coast .

Traverse-C: This runs for length of 29 km along the eastern edge of the lake boundary. More than 10 ohm-m zone is limited between C4 and C8 and is limited to 3 to 4m electrode separation. Resistivity of less than 1.0 ohm-m indicates saltwater intrusion i.e. between C9 and C29 .

Traverse-D: The traverse runs for a length of 18 km between the main beach ridge and the coast. Beach ridge is indicated between D5 and D7 and again D11 and D12. Salt-water zone (<1 ohm.m and 2 ohm.m) exists beyond 2 to 4m electrode separation and extend up to coast line.

V.COMPARISON OF RESISTIVITY - CHEMICAL QUALITY- HYDROGEOMORPHOLOGY

Resistivity of subsurface layers obtained from the interpretation of the field resistivity data contains i) thickness of layers and ii) resistivity of the formations. Each sounding is interpreted in which 3 to 4 layers are identified within the depth of investigation. VES data near to the existing open wells are considered and Resistivity of aquifer zone is compared with the

Table:1- Comparison of certain chemical parameters with field Resistivity of the aquifer

VES –Traverse-B	**B1**	**B11**	**B12**	**B15,B16**	**B27,B28**	**B37**	**B40**
Latitude	16.68335	16.6336	16.61672	16.58355	16.5167	16.49263	16.4524
Longitude	81.00022	81.01673	81.01683	81.03334	81.0669	81.13755	81.155
E.C(µmhos)	2.51	0.77	2.46	1.27	7.38	4.13	0.95
TDS (ppt)	1.38	0.41	1.31	0.7	3.97	2.28	0.52
Salinity (ppt)	1.14	0.34	1.1	0.59	3.34	2.63	0.6
Depth to watertable(m)	9.3	20.8	1.8	1.9	0.6	2.14	2.15
Total Depth(m)	10.2	24.3	3.4	5.6	5	4.26	3.96
Resistivity(ohm-m)	5.2	11.6	0.9	26	0.4	1.0	30.0
VES-Traverse-D	**D1**	**D4**	**D5**	**D6**	**D8**	**D14**	**D17**
Latitude	16.594233	16.620533	16.632	16.6421	16.668483	16.438167	16.564267
Longitude	81.476017	81.456883	81.464767	81.4685	81.468617	81.4769	81.444883
E.C(µmhos)	7.4	0.765	2.12	15.3	5.17	1.35	1.45
TDS (ppt)	3.9	0.411	1.14	8.2	2.79	0.71	0.79
Salinity (ppt)	4.58	0.47	1.36	9.47	3.22	0.82	0.91
Depth to watertable(m)	2.75	1.54	2.06	1.12	2.08	2.25	2.2
Total Depth(m)	4.12	4.4	5.25	4.70	3.6	3.15	4.12
Aquifer Resistivity(ohm-m)	0.5	5.0	0.82	0.25	0.56	0.62	0.86

groundwater quality parameters – Total Dissolved Salts(TDS),Electrical conductivity(EC) and salinity data which are more related. Table-1 shows the nearest VES location, observation well coordinates and dimensions, aquifer level and true resistivity of the aquifer. Resistivity data and the chemical parameters along the traverses ‘B’ and ‘D’ are compared and in total 14 observation wells data compared with the nearby VES data. The distance between the compared VES and the observation well may vary between 10m to 400m.

All the observation wells are located predominantly in the hydrogeomorphic unit- paleo-beach ridges and regularly used for domestic needs. With the introduction of aqua farms even in the beach ridges, quality of water deteriorated to non potable at some places. However, thickness of sand in the paleo beach ridges may vary from the centre of the ridge to the fringes across the longitudinal direction of the ridge alignment. All these wells shallow and mostly less than 5m depth.

Resistivity of the aquifer zone is less than 1.0 ohm-m where salinity is >1.2 ppt, EC is >2 µmhos and TDS is >1.5ppt. Resistivity varies between 10 and 30 ohm-m when the salinity is <0.5 ppt. EC is <1 µmhos and TDS is <0.5ppt. There may not be exactly a multiple or divide factor to demarcate the resistivity and compared water quality parameters may be due to the aquifer material and the influence of other quality parameters. Broadly, the resistivity and groundwater quality are comparable. Out of the 14 observation well locations, only 4 are within the potable quality standard which is an indicative of ground water quality deterioration.

VI.CONCLUSION

Remote sensing study indicates the various hydrogeomorphic units that contain fresh-water and saline aquifers. Paleo beach ridges are the potable groundwater potential zones in and around the kolleru lake. Geophysical data are compared qualitatively to delineate the saltwater intrusion zones vertically as well as lateral direction. Chemical analysis of groundwater samples collected from the open wells clearly indicates the level of salinity. Comparison of resistivity and chemical quality is helpful in demarcating the seawater intrusion vertically as well in the lateral direction.

Extensive field verification of sample wells and integration with geomorphological and socio-economic factors will aid GIS based demarcation of seawater intrusion which is to be carried further. Through extensive ground surveys, examination points will be established as part of the study and results will superimposed on remote sensing data sets. Measured parameters will be integrated in a GIS platform. Socio-economic data will also be integrated to render the study more profound and to enable policy makers to take more informed decisions for mitigation initiatives. Points of intense exploitation for aqua ponds farming using groundwater and associated sea-water intrusion status will be exhaustively studied to serve as Bench mark points for monitoring future changes in terms of increased or decreased risk status.

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