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Research paper

Geological and Geomorphological Evaluation of Kolleru-Upputeru catchment using Geospatial Technologies

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Abstract

Kolleru Lake is a unique world famous wetland ecosystem. It is one of the prime coastal ecosystems in India and regarded as Ramsar site. It is located in the coastal tracts of Krishna and West Godavari districts of Andhra Pradesh. Overexploitation and mismanagement of land and water resources are exerting detrimental impact on the lake environment. The striking manifestation of this phenomenon is seen various kinds of problems such as shrinkage in Lake area, floods in foreshore area, pollution and siltation of lake, sea water intrusion, land degradation etc. The challenge therefore is, to arrest the degradational processes and restore the lake eco-system. The generation and evaluation spatial information on the terrain conditions that include Tectonic frame work, Lithology, Structure and Geomorphology of the area using geospatial technologies carried out in the present study forms an important component to address various issues in respect of land and water resources. Thus, the spatial database facilitates to formulate a scientific plan for the conservation, restoration and management of Kolleru lake ecosystem.

Keywords: *Tectonics; Lithology; Structure; Geomorphology; Lake Ecosystem; Geospatial Technology*

1. Introduction

Kolleru Lake is the largest natural fresh water lake in the coastal region in India and occupies an area of nearly 900 sq.km., when the water level rises to 10 ft above m.s.l. during monsoon period. This fresh water lake and its catchment environs have been subjected to rapid degradation due to anthropogenic activities of mismanagement of land and water resources in the catchment as well as lake environs particularly in the last two and half decades (Raju P.A.R.K et al., 2002, Nageswara Rao, K. et al., 2004). Keeping in view of restoring the lake to its original state and addressing various related issues, an integrated project "Geospatial Technologies – Restoration of Kolleru Lake Ecosystem" has been contemplated. The present study on Spatial database generation and evaluation on lithology, structure and geomorphology pertains to the Kolleru and northern portion of Upputeru sub-catchment and covers northern parts of West Godavari and Krishna and small isolated southern parts of Khammam district and amounts to an extent of 8708.04 sq.km. The area lies between 80°28'07" and 81°40'45" east longitudes and 16°29'15" and 17°24'34" north latitudes. The location map of the study area is shown in **Figure 1**. Eluru canal originating from Sir Arthur Cotton Barrage on Godavari and Prakasam Barrage on Krishna and joining at Eluru almost forms the boundary between the northern upland catchment and the southern inter-deltaic plain. The database generated in GIS domain is amenable for the integrated and task oriented analysis of all the associated land, hydrological and biological parameters that have been studied by various institutions involved in the integrated project. The analysis of all the related parameters that have a direct bearing on the Kolleru Lake provides enormous scope for drawing meaningful conclusions and suggests appropriate solutions for the restoration of Kolleru Lake.

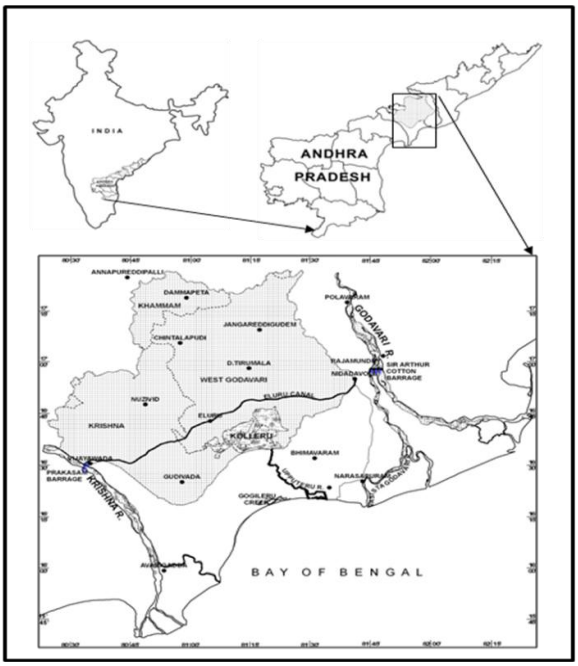

Fig. 1: Location map

2. Methodology

Geospatial technologies that include Remote Sensing, GIS and

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GPS have been employed for the generating information on lithology, structure and geomorphology. The required input data combines high resolution satellite images and other ancillary data in the form of toposheets, reports, small scale maps, ground truth / field data etc. The IRS-P6 LISS IV MX digital satellite image has been used to carry out the information. Besides, maps published by Geological Survey of India, published reports and literature on geology, geomorphology, climate, rainfall, hydrology, land use, soils, ground water resources, etc. from various state and central departments and institutions have been consulted in the mapping and analysis of resource parameters. The spatial database on lithology, structure and geomorphology has been generated by visual interpretation of high resolution remote sensing data sets, which facilitate to produce the final out puts on 1:10,000 scale. In addition to the image elements, the terrain elements such as drainage pattern, drainage density, topography / landform and erosion status have been effectively used in the image interpretation. Generally, the morphology indicates the textural and structural variations and the tone on the image indicates the compositional variations (Rao D.P and Reddy P.R 1995). By combining both morphological and spectral characteristics, different lithological units have been mapped. Different types of primary and secondary geological structures, such as foliation, faults, fractures/ lineaments, folds, strike and dip etc. have been derived from the satellite image by studying the landform, slope asymmetry, outcrop pattern, drainage pattern, individual stream/river courses etc. The Satellite images in combination with elevation and drainage data helped in geomorphic analysis and mapping of landforms / geomorphic units. The Data model prepared based on the NRSC/APSRAC guidelines/standards (NRSC 1995 and 1999) and consulting other collateral data has been followed while preparing these maps. The large scale resource maps finalized after incorporation of field data form a part of scientific database for Kolleru and northern part of Upputeru sub-catchment and help in addressing various land, water and environmental issues of Kolleru Lake.

3. Hydrology

The area is drained by five major hydrological systems that include Budameru, Ramileru, Tammileru, Gunderu and Errakalava of which the first four directly flow and let water into Kolleru whereas, Errakalava linked near to the mouth of Upputeru by construction of Enamadurru drain and thus falls into Upputeru Sub-catchment. Jalleru, Jalavagu, Thurpukalava, Padamatikalava and Paletivagu of Errakalava, Palavagu of Gunderu, Kompini, Chimalavagu etc of Budameru are the important tributaries draining the area and feeding the irrigation systems. These rivers are ephemeral in nature and flow in response to rainfall and are influent to effluent in nature. The hydrological system depicting the Kolleru-Upputeru catchment and their watersheds is shown in figure 2. The Kolleru sub-catchment includes Upper and Lower Budimeru, Upper and Lower Tammileru, Gunderu and Kolleru watersheds whereas the Upputeru covers Upper and Lower Errakalava, West and East Upputeru and Gonteru watersheds. The present study includes entire Kolleru sub-catchment and northern part of Upputeru sub-catchment i.e. Upper and Lower Errakalava watersheds. The drainage represents mostly dendritic to sub-dendritic patterns in nature with pinnate and parallel patterns at places. In general, the density of drainage is high in eastern and western hilly terrain occupied by highly resistant metamorphic rocks. Whereas, the northern central parts covered by Chinthalpudi sub-basin exhibit moderate drainage density. The southeastern portion is characterized by sparse and discontinuous drainage indicating highly porous and permeable sandstones of different formations and alluvium.

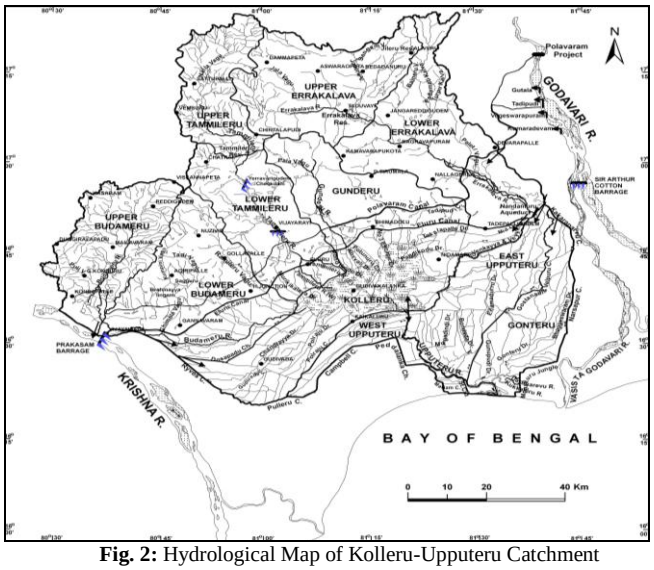

Fig. 2: Hydrological Map of Kolleru-Upputeru Catchment

4. Physiography

The Kolleru and the northern part of Upputeru sub-catchment can be broadly divided into three natural physiographic units namely the northern hilly terrain, the southern low-lying Upland area and the southernmost alluvial plain. The lacustrine Kolleru is situated almost at the southernmost central part of the area. The Eastern Ghats hilly terrain comprises of Papikondalu hills, which traverse Polavaram, Buttaigudem, Jeelugumilli and Koyyalagudem mandals in the east, Kondapalli hills extending in Nandigama and Vijayawada mandals, Kondur and Duggiralapadu hills near Sunnampadu, Jammalapuram hills near Tiruvuru in the west. The highest peak in the area is 707 m. above msl in the Papikondalu reserve forest area near Daravada. The general elevation of this region varies between 200 and 350 m. above msl. Most of these hills are covered by forests that range from scrub to deciduous forest. The low ridges, which are the outlying spurs of Eastern Ghats, occur in both the eastern and western parts of the catchment. Major portion of the catchment is occupied by low-lying Upland area which is characterized by rolling topography and broad valleys. In general, the elevation of this unit ranges between 20 to 200 m. above msl. The elevation of alluvial plain generally ranges between 5 to 20 m. above msl.

5. Lithology

The study area is characterized by a variety of lithological formations ranging from the Archaeans to the recent alluvium. The lithological map of the area is shown in figure 3. A total of 17 litho-units cover the study area. The oldest rock types are of Archaean age, belonging to the Eastern Ghats Super group, represented by Khondalite with Sillimanite quartzite; Charnakite of Hypersthene-biotite Granulite and Pyroxene Granulite and Peninsular gneissic complex comprising banded biotite – hornblende gneiss, banded migmatite gneiss and grey and pink granite gneiss. The Sillimanite quartzite and Pyroxene granulite occur as inliers in Khondalite and Hyperthene-biotite granulite respectively. The Khondalite group exhibit foliation trending dominantly in NE-SW with dips due SE. The gneissic complex is mostly represented by Migmatites with enclaves of older Metamorphics. The dominant grey granite gneissic rocks, which are mostly confined to the western part is well banded with alternate light and dark colour. The contact between the crystallines and the Gondwana sediments is marked by a pronounced Eparchaean unconformity (Raman P.K and Murthy V.N 1997). The Talchir - sandstone with shale and siltstone, Barakar – sandstone with carbonaceous shale and coal and Kamthi- ferruginous pebbly / conglomeratic sandstone and shale formations of lower Gondwana; Kota- sandstone and lime-

stone and Gangapur – white sandstone with horizontal bedding formations associated with equal proportions of shale and clay intercalations of Upper Gondwana represent Gondwana sediments of Upper Corboniferous to Lower Cretaceous age. All the above formations exhibit tabular cross stratification. Gollapalli and Raghavapuram shale with intercalated sandstone and siltstone and Tirupathi – pebbly / conglomeritic sandstone representing East Coast Gondwanas are equivalents to Upper Gondwanas in the area. The Sedimentaries in the area strike mostly in NE-SW direction with gentle dips towards SE. The Deccan Traps overlie Tirupathi sandstones in the area. The deposition of Rajahmundry sandstones-ferruginous sandstone, clay and pebble bed along the southern part in the area indicates marine transgression during Mio-Pliocene. Laterite, the oldest quaternary formation flanked by depositional environment occurs as 0.5 to 1.3 m. thick capping on Rajahmundry sandstone as isolated patches at 20 m. amsl. The Quaternary fluvial sediments occur in the southern margin. The Kolleru and the upper deltaic plain overlie the laterites. The Archaeans and Chinthalapudi formations cover major part of the area.

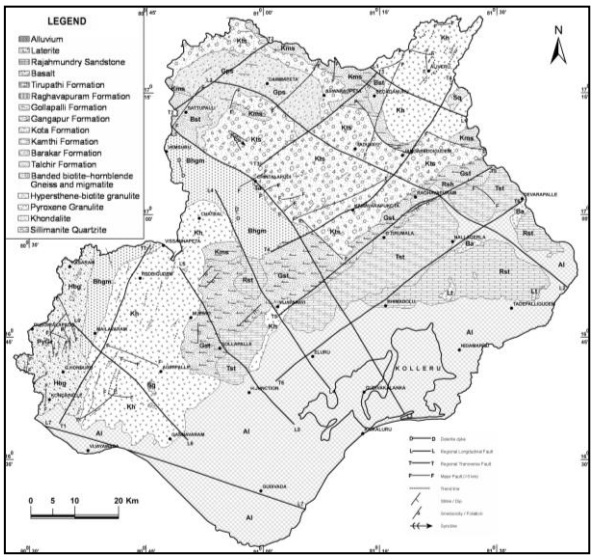

Fig. 3: Lithological Map

6. Structure

The study area is traversed by two dominant parallel sets of lineaments and faults. They exhibit Pre-Gondwana NW-SE longitudinal and Post-Gondwana NE-SW transverse trends. These two prominent trends coinciding with two distinct phases of basin development are discernible. The structural map derived from high resolution satellite data is shown in figure 4. The lineaments in the area have been categorized into two types such as major fractures/lineaments and minor fractures/lineaments. Lineaments having more than 3km. length are considered as major lineaments. Most of these lineaments are associated with topographic low areas and control most of the drainage in the area.

The most dominant directions of these lineaments are NW-SE and NE-SW. The less prominent directions include WNW-ESE, ENE-WSW, E-W and N-S. The fractures/lineaments are more conspicuous in the northern part covered by Archaean metamorphic rocks and Gondwanas of Chinthalapudi sub-basin. Whereas, the fracture/lineament pattern is not clearly manifested in the southern part occupied by Gollapalli, Raghavapuram Tirupathi and Rajahmundry formations. The structures in the area control the occurrence and movement of ground water. The depth of weathering is relatively more in the areas associated with fractures. The fracture zones are associated with good weathering, shallow water table conditions and good recharge contributed by the drainage system.

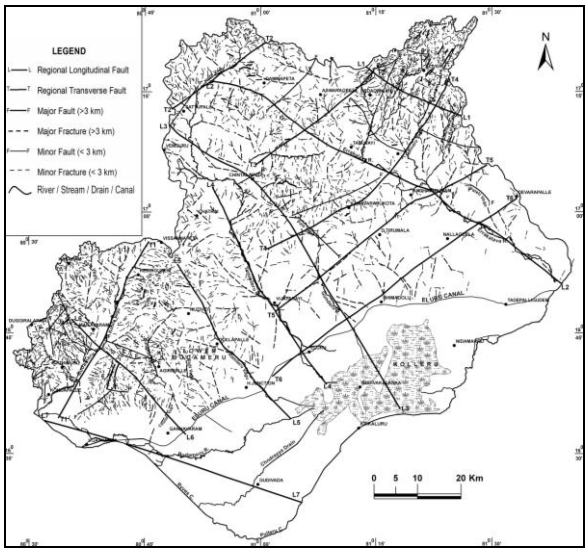

Fig. 4: Structure Map

7. Geomorphology

The interaction between different elements like lithology, structure, climate etc, played a vital role in the geomorphic evolution of the Kolleru-Upputeru catchment. Though the extent of the catchment is very small, it experiences a wide range of geomorphological processes that include (i) structural, (ii) denudational, (iii) fluvial and (iv) marine (v) lacustrine processes and resulting in the formation of varied geomorphic units / landforms. The location and spatial distribution of these features have been derived using high resolution satellite remote sensing data. The geomorphological map of the Kolleru sub-catchment and Errakalava of Upputeru sub-catchment is shown in **Figure 5**.

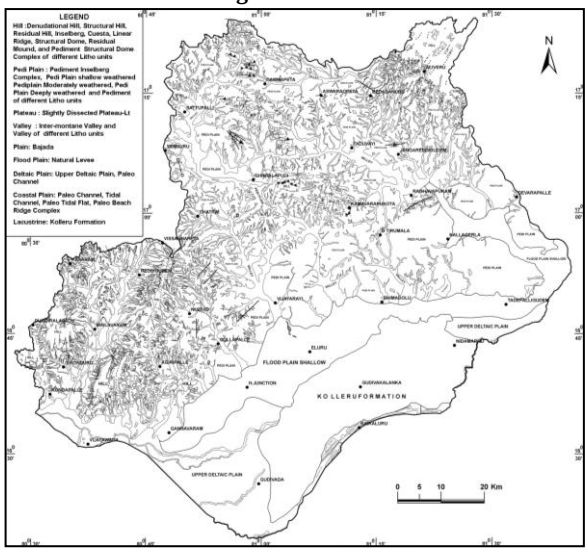

Figure 5:. Geomorphological Map

Based on the origin, lithology, structure and depth of weathering, a total of 114 geomorphic units / landforms have been identified in the area. However, the units in the northern part are grouped as hills, pediplains, valleys etc. in the above mentioned figure for better legibility. Area estimates different grouped landforms/geomorphic is shown in the table 1. In general, the northern part of the area experiences the denudational and structural processes and the southern part displays landforms of fluvial and marine origin.

Table 1:. Area Estimates of Geomorphic units in the Study Area

S.No	Geomorphic Unit / Landform	Kolleru Sub-catchment		Errakalava Water-shed	
		Area in sq.km	(%)	Area in sq.km	(%)
1	Hills / Plateau	272.66	4.37	253.37	10.28
2	Valleys	904.12	14.48	409.79	16.62
3	Pediplain	2593.91	41.55	1598.91	64.86
4	Plain	2472.22	39.60	203.06	8.24
	Total	6242.91	100.00	2465.13	100.00

.

The positive landforms of denudational and structural origin include denudational, structural and residual hills, Inselbergs, linear ridges, structural domes, pediment-inselberg complex, pediment-structural dome complex and residual mound of different rock types. The denudational hills with high relief are confined to the metamorphic country where as the structural hills are mostly limited to the sedimentary terrain and occur in the northern part of the area. The low relief positive landforms of both structural and denudational origin are interspersed in the northern and central part of the area. The hills and plateaus in Kolleru sub-catchment cover only 5 % of the total area. The valley portions in the area have been demarcated as valley fills and inter-montane valleys.

They comprise alluvium / colluvium of varying thicknesses. They occupy 15% of total area of Kolleru sub-catchment. The inter-montane valleys occur as isolated patches amidst denudational hills in the northeastern and western parts. The valley fills traversing across the pediplain is associated with structure controlled drainage network. They occur conspicuously in the entire area indicating the intensity of erosion in the region. They exhibit different shapes and sizes occupied by valley fill material of partly detrital and partly weathered material. They are narrow in the elevated sloppy areas and become broader as they approach the plain country. The drainage / valleys are modified / narrowed down with intensive agricultural activities. At places, the drainage follows the field boundaries deviating from the natural course. Bajada is mostly confined to the piedmont zones of denudational hills. The pediplain acts as backdrop for both positive landforms and valleys and display a gently to highly undulating terrain. The pediplains cover nearly 40% of the total area of Kolleru sub-catchment. The pediplain units were abruptly terminating because of varied lithological and structural parameters. Depending upon the depth of weathering, the pediplains have been classified as pediplain with shallow (0-10m.), moderate (10-20m.) and deep (>20m.) weathering. The pediplain with deep weathering is noticed in almost all the sedimentary formations. Higher elevated areas usually display shallow weathering conditions in almost all the lithological formations, where as deeper weathering is associated with fracture controlled drainage. The slightly dissected plateau associated with laterite occurs as isolated patches in the elevated pediplain areas of Rajahmundry sandstones. The depositional landforms in the southern part comprises of flood plain, deltaic plain, paleo-channel of fluvial origin; paleo-tidal flat, and paleo-beach ridge due to marine processes and lacustrine Kolleru formation. They occupy nearly 40% of the total area of Kolleru sub-catchment. The evolution of these landforms of upper inter-deltaic plain corresponds to the progradation of Krishna and Godavari deltas. The progradation has been initiated due to global marine transgression and subsequent stabilization of sea level in the Early-Holocene period (Rao, C.V.N.K, 2001). This has resulted in the formation of inter-deltaic bay between the two deltas. This was possible only because of the geographical set-up of the two basins and the close proximity of the mouths of the two mighty rivers Krishna and Godavari. The marine transgression occurred again during Mid-Holocene and caused the termination of the delta fronts. The development and growth of beach ridges anchored to the active distributaries of the two rivers has taken place during the still-stand stabilization of sea level. The formation of beach ridges is favored when the beach front is steeper with coarse material and lower waves at the time of formation. The inter-deltaic bay was gradually separated from the sea by coalescence and continuation of beach ridges which are anchored to the distributaries of Godavari and Krishna.

Thus, the Inter-deltaic bay has been transformed into a lagoon with limited access to the sea through an estuary called Upputeru. The lagoon thus formed has been slowly degenerated into tidal delta, subsequently to mangrove swamp and finally to fresh water lake. Hence, but for this Kaikalur beach ridge swale complex, there would not have been Kolleru and only a perfect estuary should have been formed. Further, this has resulted in the evolution of Kolleru sub-catchment with outlet Upputeru, which is a unique phenomenon that does not usually exist near the coastal region. Prior to the evolution of the inter-deltaic plain, all the rivers draining the study area were directly letting water into Bay of Bengal. The Kolleru Lake is subjecting to sedimentation right from its evolution due to stream and river contributed sediment from the catchment and subsequently the sediment carried through irrigation network of Godavari and Krishna. The sedimentation of lake has its influence on the present geometry and flooding of foreshore areas. The flood plain is mostly confined to the lower parts of Errakalava and Tammileru. The paleo-tidal flat in the area confines to the southern part of the area in the coastal plain. This indicates the existence of strandline of Bay of Bengal above Kolleru Lake in the Early-Holocene period.

8. Conclusions

The regional tectonics pertaining to the Pranahita-Godavari, Krishna-Godavari and Eastern Ghats Upheaval and Marine transgression / regression have played a major role in the evolution of the unique Kolleru-Upputeru catchment in the coastal region. The area exhibits diverse / heterogeneous landforms caused due to complex geological / tectonic set-up, marine transgression / regression and volcanic activities. In spite of being tectonically active in the geological past, at present the northern Upland part of the catchment represents a relatively stable terrain as the faulting movements came to a stop during Miocene period in the northern part of the area. However, the southern part signifies the neo-tectonic activity particularly in the younger deltaic plain. Though the extent is very limited, the Kolleru-Upputeru catchment experiences a wide range of geological, geomorphological and hydrological processes which are having a direct bearing on the geometry and configuration of the catchment. In general, the NW-SE longitudinal faults and NE-SW transverse strike slip faults delimit the drainage and topography respectively in the area. This also resulted in the formation of mostly Fern / Pinnate patterned geohydrological systems in the northern part and major rivers exhibiting steep bed slopes. The fractures / lineaments are associated with lithological boundaries, topographic lows and control the drainage as well as occurrence and movement of ground water in the area. The southern part of the catchment representing almost a flat terrain of depositional origin is marked by manmade delta irrigation network.

The Kolleru-Upputeru catchment represents a unique and complex geohydrological system subjecting to varied geomorphological processes such as structural, denudational, fluvial, marine and lacustrine processes resulting in the formation of wide range of geomorphic units / landforms. While the structural and denudational processes are delimiting the northern upland part, the southern part displays landforms of fluvial, marine and lacustrine origin. The geospatial database generated on large scale in the present study along with the information on other land, water and biomass resource parameters developed by various institutions in-

volved in the integrated project helps in the preparation of plans for watershed treatment in the catchment, modification of hydrological systems to maintain sustained inflows into the lake and prevention of back water deep into inland portions in the coastal region. The scientific document thus prepared will address all the issues and measures to be taken for restoration of Kolleru lake ecosystem.

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