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Monitoring of current land use pattern of Ramsar designated Kolleru Wetland, India using geospatial technologies

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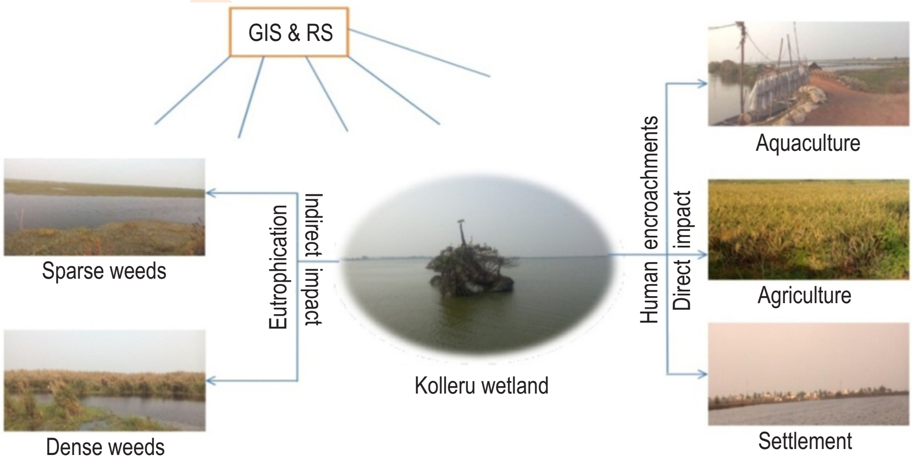
Abstract

Aim: The present study is an attempt to analyze the land use pattern of Kolleru Lake in and around by using the techniques of remote sensing and GIS to detect the temporal changes of the Kolleru Lake.

Methodology: The 1938 and 1967 years topographic sheets and Landsat-5 TM of 1997 and Resoucesat-2 LISS 4 of 2017 satellite images were used and analyzed by the latest version of Arc GIS 10.4 and ERDAS IMAGINE 2016 (Version 16.00). Unsupervised and supervised classification was done for 1997 and 2017 images, respectively.

Results: It was estimated from the topographic map of 1938 that the total lake boundary area was 230.15 km^2. Digital image processing of 2017 satellite data revealed that the lake area of 76.9 km^2 (32.45%) only remained degraded, extensively colonized by macrophytes. The land use/land cover maps of 1997 and 2017 revealed that lake area was significantly occupied by aquaculture which amounted to 84 km^2 (36.53%) and 56 km^2 (24.35%), respectively, and no aquaculture activity was reported from 1938 and 1967 toposheets.



Interpretation: The geospatial analysis data gives accurate and reliable information and associated factors. The spatio-temporal analysis data provide a significant foundation for monitoring activities in other lake systems, and are applicable to monitoring wetland use patterns in other sites of international importance.

Key words: Eutrophication, Geospatial technology, Kolleru wetland, Macrophytes, Remote sensing

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Introduction

Wetlands are the world's water filters, which provide many ecosystems and societal services, such as, water-quality improvement, flood mitigation, food security, habitat biodiversity and landscape aesthetics, however, they are under stress (Msusa, 2011; Kolka *et al.,* 2016). Wetlands are ecologically sensitive and adaptive systems and are the most productive ecosystems on the earth (Ghermandi *et al.,* 2011). Wetlands are still among the most vulnerable ecosystems, as they are often interfered by human activity, such as forestry, aquaculture, livestock farming, deforestation, use and urbanization of biological resources, vulnerability to invasive and climate change (Bassi *et al.,* 2014; Song and Liu, 2016). Change in land use causes an unprecedented change in habitats and environmental processes that has a direct and indirect effect on biotic and abiotic components, which lead to transformation from local, regional and national to global scale (Agarwal *et al.*, 2002; Chopra *et al*., 2001). Among the changes, the trend of human induced land use is regarded as one of the most significant factors for global changes in the environment (Chowdhury *et al.*, 2009). The present rate of change is higher than the past, which has become a major human concern due to rising population resulting in climate change, loss of biodiversity, and water, soil and air pollution (Davis *et al*., 1994; Erle, 2013). The last few decades have seen an emerging trend in wetland destruction causing a decrease in landscape diversity and increase in fragmentation rates, eventually altering to ecological function of wetlands (Constanza *et al.,* 1998; Chen and Lu, 2003; Bhattacharyya *et al*., 2013). The change in wetlands has affected the aquatic ecosystems hydrology through changes in precipitation and temperature, thus affecting human and other living organisms.

Further major shifts in land cover have been observed in the last few decades on spatial and temporal scale due to economic development and population growth (Mitsch and Gosselink, 1993; Davidson *et al*., 2018). Subsequently, the trend in wetland loss in India is similar to that in other developing countries, due to urbanization, land use changes, runoff from agriculture, growth of infrastructure and industrial pollution and variability in climate change (Nitin *et al.,* 2014). Consequently, wetland conservation advocates for the study of wetland landscape, structure and functions, which is essential for understanding the causes and consequences of degradation, and for providing protection and preservation alternatives. Current monitoring and assessment of wetlands is an important practice to preserve the wetland and its environment, and geospatial techniques provide powerful wetland protection, planning and management tools (Nath *et al*., 2000). Remote sensors on satellites aid in sustainable fisheries management efforts. Keeping in view the above, the present study was undertaken to track the trend in land use trends and their effects on the wetland environment.

Materials and Methods

Study area: Lake Kolleru is the biggest Indian freshwater lakes located 20 km from the city of Eluru in Andhra Pradesh. Kolleru located between the deltas of Krishna and Godavari covers approximately 245 km^2 area and serves as a natural flood-balancing reservoir for these two rivers. The lake is directly fed by water from the seasonal Budameru and Tammileru rivers, and the Krishna and Godavari systems connect it to over 68 in-flowing drains and channels. Lake Kolleru is connected to the Bay of Bengal by the Upputeru River at a distance of 60 km. The lake area is covered in the Survey of India (SOI) toposheets 65 H/2, 65H/5 and 65H/6. Lake Kolleru is a depression with a depth of 1 to 1.5 m with a maximum depth of 3 m during the south-west monsoon. The population within the lake area is close to two lakh. The main occupation of the people within the lake area is fishing, agriculture and cultivation.

Input data: In this study, different types of satellite images and topographic sheets were used. Topographic maps such as NE 44-15 (Published by Army Map Services in 1938) 65H/2, 65H/5 and 65H/6 (Published by Survey of India In 1967) were used. Satellite images of Landsat-5 TM and Resourcesat-2 LISS4 were used. Handheld Garmin GPS was used to collect GCP's (Ground Control Points) for ground truth verification. Complete ground truth verification was carried out using GS5+GPS with ARC PAD. The extent and latitude and longitude of different land and water use classes were verified. The boundary of aquaculture farm and agriculture field in the land use map was also checked and corrected through GPS readings, wherever necessary. For this study, the latest version of ArcGIS 10.4 software by ESRI and ERDAS IMAGINE® 2016 version of the software were used.

GIS analysis: Topographic map of 1938-NE 44-15 was geo-referenced, and lake boundary was extracted by using tools in ArcGIS 10.4. Topographic maps of 1967 - 65H/2, 65H/3, 65H/6 were geo-referenced and mosaicked using ArcGIS 10.4 and lake boundary was obtained by overlaying the 1938 toposheets lake boundary from mosaicked toposheets. All the topographic maps were projected under WGS1984 UTM Zone 44 N. The land use of Kolleru in 1938 and 1967 was developed based on the classes given in the SOI topographic maps.

Digital image processing: Digital image processing of Landsat-5 TM and Resourcesat-2 LISS4 images were done by using ERDAS imagine 2016. Due to the continuity of aquaculture farms and rice fields from adjacent areas to the lake, it was not possible to track the lake border from the image. Lake border derived from mosaic topographic maps was, therefore, considered to reflect the accurate original area of the lake.

The boundary of the lake, derived from the topographic map of 1938, was overlaid with satellite images to extract the lake area. The rectified and registered image was subjected to different image enhancement techniques such as PCA (principal component analysis), ALR (automatic log residuals), NDWI (normalized difference water index), contrast stretching (increase the brightness of the original image) for clear visualization of the condition of the lake, and image rectification was done so that the spatial coordinates correspond to its geographic coordinates. Based on the image characteristic keys produced by the Space Application Center (SAC), the land-use classes from satellite images were established. Satellite images were classified into six classes and images were assessed for accuracy test to check the accuracy of classified images.

Change detection analysis: To identify differences in the phenomenon by observing at different times, the classified land use map of 2017 was overlaid on the 1997 classified map. After integrating both maps, regrouping of added layers was carried out. Temporal changes under major land-use and land cover types were derived by the spatial intersection of 2017 and 1997 maps.

Results and Discussion

GIS analysis using a topographic map of 1938 revealed that the area of Kolleru lake was 230.15 km^2 in 1938. This extracted lake boundary map was used as a base/reference map. For further research, the lake boundary derived from a topography chart from 1938 was overlaid with geo-referenced toposheets and satellite images. The 1967 year topographic sheets were classified by overlaying the 1938 lake area boundary and lake area was classified into 4 classes. According to the 1967 year topographic sheets, lake area (which was extracted by overlaying the 1938 toposheet lake boundary) classification, in which the area covered by water body was 68.09 km^2 (29.59%), the area liable to flood during rainy season was 77.36 km^2 (33.61%) and the area under agriculture field was 84.64 km^2 (36.77%).

The area occupied by human settlement was 0.06 km^2 (0.02%). By 1967, aquaculture was not developed since the topographical maps had no fish ponds. According to the 1938 and 1967 topographic sheets, lake water body was drastically reduced from 194.95 km^2 (84.70%) in 1938 to 68.09 km^2 (29.58%) in 1967, while the flood area increased from 34.04 km^2 (14.79%) to 77.36 km^2 (33.77%) between 1938 and 1967. There was a drastic rise in agriculture from 1.1488 km^2 (0.499%) to 84.636 km^2 (36.77%) between 1938 and 1967 due to more demand for agriculture in 1940s. In 1967, 0.064 km^2 (0.027%) was occupied by human settlement, which was not recorded in 1938 toposheet. The scenario started changing with the rise in aquaculture around the lake. The Landsat-5 TM remotely sensed subset image underwent unsupervised classification and classified into six classes. The resulting polygon distribution map prepared from 1997 satellite data showed that the region under aquaculture was 84.08 km^2 (36.53%) and the lake water spread area was 28.42 km^2 (12.35%), respectively. The area covered with sparse weeds occupied 45.62 km^2 (19.82%) and dense weeds with 29.4741 km^2 (12.80%). Agriculture in 1997 occupied 41.7933 km^2 (18.15%) of the lake area. The area of human settlement was about 0.72 km^2 (12.34%). According to the Unsupervised classification of 1997 Landsat image, there was a significant change in the lake area from 1967 to 1997, out of the lake water body area of 68.09 km^2 (29.58%) in the previous year, only 28.42 km^2 (12.34%) remained as such, in the latter year.

The whole region was infested with aquatic weeds covering 77.30 km^2 (33.61%) area of the lake reported by the 1967 flood-prone area. The present study revealed beginning of tremendous growth of aquatic weeds covering most area of the lake. The area covered by dense weeds was 29.47 km^2 (12.80%), while sparse weeds occupied 45.62 km^2 (19.82%); as compared to dense weeds growth of sparse weeds was more. The remaining area of 84.08 km^2 (36.53%) was converted to aquaculture due to the enormous demand for aquaculture, agriculture area decreased from 84.63 km^2 (36.77%) to 41.79 km^2 (18.15%) between 1967 to 1997 with increase in human settlement from 0.0640 km^2 (0.027%) to 0.7281 km^2 (0.33%). Fig. 1(A) shows the land use/land cover map of the year 1997. The recent Resourcesat-2 subset image underwent supervised classification and classified into six classes. The lake classification from the 2017 satellite data revealed 56.04 km^2 (24.35%) area under aquaculture and the lake water spread area was 76.99 km^2 (32.45%). The area occupied with sparse weeds was 52.18 km^2 (22.67%) and dense weeds 27.59 km^2 (11.99%).

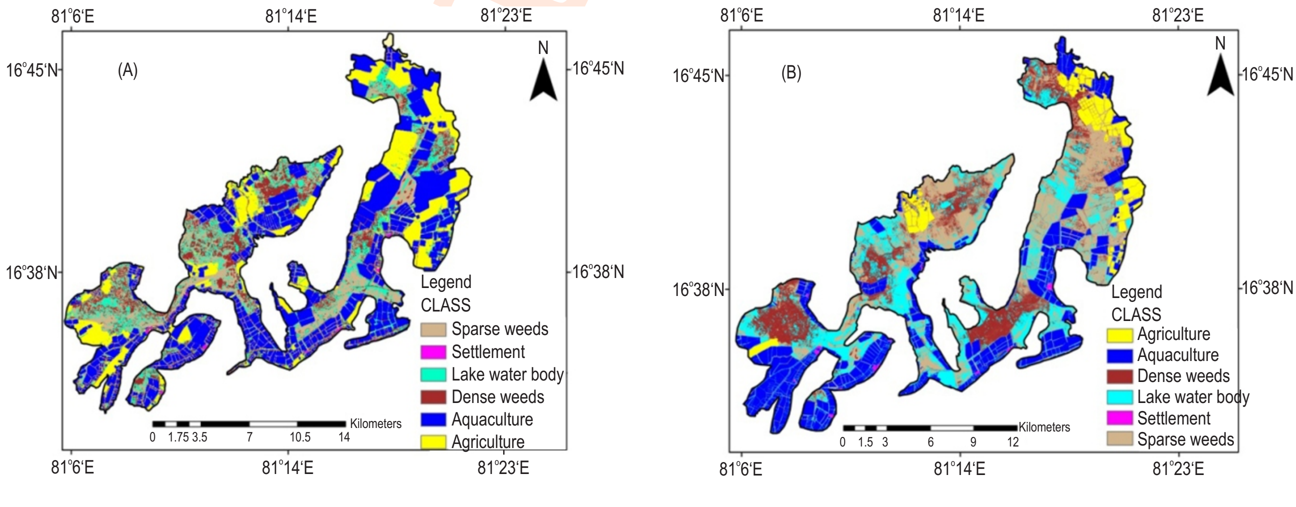

Fig. 1: Land use/land cover map of Kolleru lake in1997 (A) and 2017 (B), generated from on-screen classification of enhanced satellite images.

Table 1: Land use/land cover status of *Kolleru lake* area in the year 1938, 1967, 1997 and 2017 (in km^2), calculated from the classified topographic sheets and enhanced satellite images

	Area in km^2				Area in percentage			
Class name	1938	1967	1997	2017	1938	1967	1997	2017
Lake body	194.95	68.09	28.4229	76.9924	84.70	29.58	12.34	32.45
Agriculture	1.1488	84.63	41.7933	15.8216	0.49	36.77	18.15	6.87
Aquaculture	-	-	84.0816	56.0484	-	-	36.53	24.35
Dense weeds	-	-	29.4741	27.5988	-	-	12.80	11.99
Sparse weeds	-	-	45.6214	52.1813	-	-	19.82	22.67
Settlement	-	0.0640	0.7281	1.5128	-	0.027	0.33	0.65
Liable to flood/Mud	34.047	77.36	-	-	14.79	33.61	-	-
Total	230.15	230.15	230.15	230.15	100	100	100	100

Table 2: The area of lake Kolleru changed (in km^2) from class to class during 1997 to 2017, measured by using change detection analysis technique in Arc GIS

	2017							
	Class	**Aquaculture**	**Agriculture**	**Settlements**	**Sparse weeds**	**Dense weeds**	**Lake body**	**Total**
1997	Aquaculture	27.2412	4.9311	0.3471	17.6545	4.9699	27.7281	82.8719
	Agriculture	9.6570	8.1143	0.1474	11.3506	1.9821	11.1371	42.4227
	Settlements	0.1681	0.0052	0.2926	0.0241	0.0089	0.1041	0.6230
	Sparse weeds	9.9590	0.9278	0.1676	8.4111	9.1934	16.8568	45.2957
	Dense weeds	5.6209	0.4512	0.1545	6.8880	5.2904	11.3842	29.8892
	Lake body	5.5313	0.8820	0.1385	5.7433	6.7433	9.8301	28.8985
	Total	58.1775	15.3116	1.2477	50.0716	28.1880	77.0404	230.0368

Rice fields occupied 15.82 km^2 (6.88%) of the lake area. The area covered by human settlements amounted to 1.51 km^2 (0.65%). The present study showed a huge change from 1997 to 2017, out of the lake water area of 68.092 km^2 in 1997, there was an increase in the area to 76.99 km^2 in 2017 due to the operation Kolleru carried out during 2005 to 2006. Aquaculture and agriculture occupied areas decreased from 84.08 km^2 (36.53%) and 41.79 km^2 (18.15%) to 56.04 km^2 (24.35%) and 15.82 km^2 (6.87%), respectively, between 1997 to 2017. While the area covered by dense weeds in 1997 was 29.47 km^2 (12.80%), and it slightly decreased to 27.59 km^2 (11.99%) from 1997 to 2017 and the area of sparse weeds slightly increased from 45.62 km^2 (19.82%) to 52.18 km^2 (22.67%) from 1997 to 2017.

Table 1 shows temporal changes of Kolleru Lake from 1938 to 2017 and Table 2 shows the changes in land use patterns in Kolleru Lake between 1997 and 2017. Fig. 1(B) shows the land use/land cover map of the year 2017. Landsat-5 TM 1997 unsupervised classified image and Resourcesat-2 2017 supervised image was subjected to accuracy assessment test to check the level of accuracy and kappa statistics of each image. Each image was subjected to two accuracy assessment methods, such as random method and equalized random method. In the random method, supervised classifications showed 94.3 % accuracy with 0.9210 kappa value and unsupervised classification showed 86.4 % accuracy with 0.8723 kappa value. In the equalized random method, supervised classification showed 95.6 % accuracy with 0.9320 kappa value and unsupervised classification showed 88.4 % accuracy with 0.8912 kappa value, respectively. Lake area began to change in the 40's of the last century when the government started to parcel out the lake for agro production in order to increase the living standards in the lake area. For ages, native paddy variety was being grown at the bed of the Kolleru Lake and agriculture was carried out around the lake through irrigation system, with water being collected and transported from the lake to the croplands throughout the dry season (Narender, 1993).

Initially extensive crop cultivation methods were practiced, but gradually crop cultivation became more intensive (high yielding varieties replaced traditional varieties, usage of chemicals, and development of more and higher bunds to keep water out). In addition, the Government introduced cooperative farming in 1954 and set up 93 agricultural societies on 2.1 million acres. However, floods threatened the cultivated areas every year, as observed in the topographic maps. No aquaculture ponds were seen in during 1938 and 1967 topographic maps, although many areas of rice fields and settlements were present. In 1969, practically the entire lake was planted with large bands to keep the water out. By 1978, greater demand for fish from Calcutta resulted in enormous dike construction with the advancement of aquaculture and fish farming became more profitable by

1984 (Narender, 1993). The topographic maps of 1990s shows increased area of aquaculture the reason behind this was farmers started converted their agriculture farms to aquaculture farms and the agriculture area reduced at that time. During the year 2001, a total of 1050 aquaculture ponds were noticed in the lake bed area and 38 dried fish ponds were also recorded (Amaraneni *et al*., 2004). Human settlements covered a small area (0.65%) in 2017, which was 0.33% only in 1997. Human settlement near lake bed region had increased with rising aquaculture activities and main activity of people in lake area is fishing (Kumar *et al.,* 2016). The statistics showed that aquaculture practices in the study area decreased from 56% to 24% during the year 1997 to 2017, respectively. The agrarian statistics markedly reduced from 36.77% in 1967 to 18.15% in 1997 and then declined from 18.15% to 6.87% in 2017. The succession of *Operation Kolleru* increased the area of lake water body, sparse weeds and dense weeds by converting aquaculture and agriculture areas (Pattanaik *et al*., 2008 b).

Previous studies have shown that the lake area was 245 km^2, according to 1930 topographic sheet (Rao *et al.,* 2004). However, in the present study, it was observed there was a continuous decrease in the lake area from 1930 to 1967 toposheets like 230.15 km^2 lake area in 1938 toposheet but certainly, there was a decrease in the area of 14.85 km^2 from the year 1930 to 1938. The lake area further decreased to 180.15 km^2 in the 1967 topographic sheet, so there was a decrease in the lake area of 50 km^2 from 1938 to 1967. In 2001, the Government of Andhra Pradesh decided to remove encroachments from the lake area to normalize the lake bed (Rao *et al.,* 2006). In 2005-06, in compliance with the Supreme Court order, the Government of Andhra Pradesh conducted "*Operation Kolleru*". Even dynamites were used in the operation to blast the huge embankments and success of this operation resulted in the return of migratory birds to the lake (Pattanaik *et al.,* 2008). Nevertheless, the ground reality does not seem to be as delightful as what one would expect after government action (NageswaraRao *et al*.,2010; Rao *et al*., 2013).

According to Jayanthi *et al.* (2006), the overall lake loss between 1967 and 2004 was 109.02 km^2 and aquaculture, occupying 99.74 km^2 accounted for 55.3% of the lake area of 1967. Pattanaik *et al.* (2008) studied the aquaculture dynamics of *Kolleru* lake after *Operation Kolleru* and found that aquaculture ponds covering 158.5 km^2 in 2000 and after the implementation of demolition reduced to 15 km^2. NageswaraRao *et al.* (2010) noticed that the aquaculture ponds occupied 11.38 km^2 only area in lake bed 56.04 km^2 whereas in the present study, a notable increase in the aquaculture encroachment in the lake bed was observed. The ecosystem of the lake was significantly affected due to agriculture and aquaculture, increased industrial activity, growing numbers of human settlers and infrastructure building such as roads, etc .(Rao *et al*., 2000; Sellamuttu *et al*., 2012). Lake quality is deteriorating due to effluent inflow into the lake from surrounding industries (Amaraneni *et al*., 2004; Kumar *et al*., 2016). As the lake is shallow, nutrients reach higher levels in the lake and support numerous weeds, and floods are induced by siltation. Many seasonal migratory birds which are considered as endangered species hardly visit the place due to insufficient availability of fish, whose breeding capability declined due to eutrophication and abundant weed growth in lake (Venot *et al*., 2008). . Due to lack of regulation of seaward flow, monsoon season progressively increases high flood line, causing major flood problems in the surroundings. There is a need to widen and increase the depth of Upputeru River to increase its discharging capacity during flood times (Karanam *et al*., 2013). It is necessary to construct regulators on the Upputeru River which can obstruct seawater intrusion into the lake. There is a need to widen and increase the depth of Upputeru River to increase its discharging capacity during flood times.

Analysis of spatial data using satellite images revealed that the lake region was dramatically reduced and that its appearance was modified profoundly. In the last 70-80 years, people have messed with the natural state of the lake in an unprecedented way. The initiatives usually centered on the manipulation and extension of one or two of the facilities that the lake could provide. Generally, this was only feasible at the cost of other ecosystem services. Integrated analysis of the present study has generated extensive and updated datasets and tangible evidence on the degradation of Kolleru ecosystem. The intersected map produced by change detection analysis based on topographic maps and satellite data from 1938 to 2017 revealed the loss of a potential fisheries site of the Kolleru Lake. In the last four decades, numerous natural and human activities have significantly depleted the lake area. Kolleru is the best example of the impact of anthropogenic activities on the lakes. Hence, its conservation as biodiversity reserve requires minimal use of wetland by humans. To integrate, all the above land and water resources parameters suggested appropriate scientific management strategies, and more stringent restoration measures conserve this fragile green inter-deltaic environment in the coastal region. The result would be useful for planning and sustainable aquatic resource management strategies relying upon it.

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Add-on Information

Authors' contribution: A. Shivakrishna: Data collection, processing, analysis and writing; **K.K. Ramteke:** Guidance in data interpretation and validation; **S. Kesavan:** Formal analysis of data and data curation; **P. Prasad:** Methodology and conceptualization; **B.C. Naidu:**Ground truth verification and

formal analysis; **M. Dhanya:** Guidance in data pre and post processing; **Z.J. Abidi:** Validation and overall supervision.

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