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Kolleru lake is vanishing – a revelation through digital processing of IRS-1D LISS-III sensor data

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Digital processing of the IRS-1D LISS-III image revealed a highly degraded state of the Kolleru lake. Among the several techniques tried, image enhancement through automatic log residuals method clearly indicated that about 42% of the 245 km^2 lake area was encroached for aquaculture and 8.5% more area was occupied for agriculture, while the rest of the lake is either being dried out by reclamation or is infested with weed. The study provides unambiguous visual information on the alarming levels of human-induced environmental degradation of Kolleru lake, which is one of the important coastal wetland ecosystems in the country.

THE Kolleru lake, situated between the Krishna and Godavari deltas along the east coast of India is the largest (245 km^2 as in topographic maps of 1930s) freshwater body in the country. Although the lake is about 35 km inland from the present coast, it was a coastal lagoon in the geological past, believed to have been formed around 6000 years BP, when the shoreline was far inland along the southern (seaward) margin of the lake, as evident from the presence of a series of relict sandy beach-dune ridges right up to the southern margin of the lake near Kaikalur and Akividu towns[1]. Kolleru still maintains its connection with the Bay of Bengal through a 60 km long, intricately meandering tidal channel called Upputeru – a typical characteristic of coastal lagoons (Figure 1). Apparently, this lagoon has progressively fallen inland with the advancement of the Krishna and Godavari deltas on both sides of it. As a number of rivulets such as Tammileru, Budimeru and several other smaller ones draining a total catchment of about 5400 km^2 are decanting their waters into it[2], the Kolleru has turned into a freshwater body, except in its southeastern part where brackish conditions prevail, especially during dry summer months due to incursion of tidal water through Upputeru. The lake continued to exist through thousands of years after its formation, in spite of sedimentation through inland streams and reduction in the flushing capacity of Upputeru due to the overextension of its course by progressive advancement of the coastline far away into the sea. Perhaps its topographical location over a deep-seated tectonic depression, which is geophysically known as Gudivada sub-basin or graben between the Bapatla and Tanuku subsurface ridges or highs[3,4], might be responsible for the persistence of the lake, although other lagoons much younger to Kolleru in the area toward the coast seem to have been emerged and dried out subsequently[5].

Kolleru has been designated as a Ramsar site[6], considering that the lake functions as a flood-balancing reservoir between the Krishna and Godavari deltas and that it supports vulnerable species like grey pelican as well as water fowl, including a variety of resident and migratory birds. However, the reality appears different. Due to lack

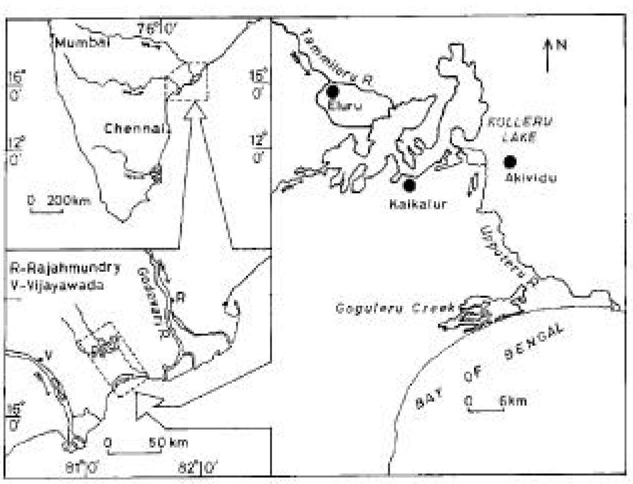

Figure 1. Map showing the location of Kolleru lake.

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of awareness among people and successive governments on the importance of this type of coastal wetland environments, the lake has been subjected to severe degradation during the recent decades. The average depth of the lake, which varies from 0.5 m to 2 m, is gradually being reduced due to siltation[7]. Moreover, the urban sewage, industrial effluents, and fertilizer and pesticide residues that reach the lake through a number of streams and drains are polluting the lake waters[7]. On the other hand, the lake area itself is being relentlessly encroached for agriculture and, of late, aquaculture. The maze of 2–3 m high embankments raised around hundreds of fishponds, besides extensive paddy fields makes it impossible to identify the lake extent and to gauge the level of its degradation through ground observations. Even the conventional colour composite images of the satellite sensor data do not provide a clear picture of the ground realities of Kolleru as the fishponds in the adjoining areas of the lake are encroached into the lake area as well. Similarly, the lake areas with dense weed are also difficult to be separated from the paddy fields in the adjoining areas. The only recourse to understand the nature of damage to this lake, once known as a haven for migratory birds, seems to be through modern methods of remote sensing and geographic information systems (GIS). The present study aims at understanding the status of Kolleru and also to find out the suitable image enhancement techniques that highlight the physical condition of the lake.

The multi-band digital image data of the IRS-1D LISS-III of Path 103–Row 61, dated 9 February 2001, pertaining to Kolleru lake region was processed through a computer software (ERDAS 8.5). The satellite sensor data for the month of February was found ideal for a proper assessment of the encroachments because paddy is grown in the lake-bed area only during rabi (winter) season and not as a monsoon crop, for fear of submergence in case of heavy rains and floods. Initially, the composite image generated through a combination of the spectral bands 2, 3 and 4 was geo-referenced by co-registering the selected ground control points that are prominently identifiable, both from the image as well as the topographic maps of the area on 1 : 50,000 scale. The resultant conventional False Colour Composite (FCC) image clearly shows the areas with vegetation/crops (red), the water bodies (blue), dry streams (light grey), villages and towns (bluish-green), etc. (Figure 2 *a*). However, it was rather difficult to trace the boundary of the lake from the image because of the continuity of fishponds and paddy fields from the adjoining areas into the lake proper, by encroachments during the recent decades. Therefore, the first task in this study was to demarcate the lake from the surrounding areas. This was achieved by tracing the lake boundary from the topographic maps of the area on 1 : 63,360 scale and superimposing the geo-referenced lake boundary onto the FCC using the overlay procedure in the software (Figure 2 *b*). Since these Survey of India topographic maps were from 1930s, the lake boundary extracted from these maps is considered to fairly represent the original extent of the lake, without any major land-use encroachments. The sub-image of the lake area, extracted from the FCC, was subjected to several image enhancement techniques such as principal component analysis (PCA), normalized difference water index (NDWI) and automatic log residuals (ALR) for clear visualization of the condition of the lake.

The images of various wavelength bands often appear to be similar and convey more or less the same information. The PCA reduces the redundancy or the overlapping spectral information between two bands[8]. Thus, it maximizes the separability of different classes and minimizes the variance within each class. A principal component of the subimage of the Kolleru lake was generated using Band 2 (the green band in the spectral range of 0.53–0.61 μm) and Band 4 (the near infrared, i.e. NIR-band in the spectral range of 0.72–0.81 μm). The green band has

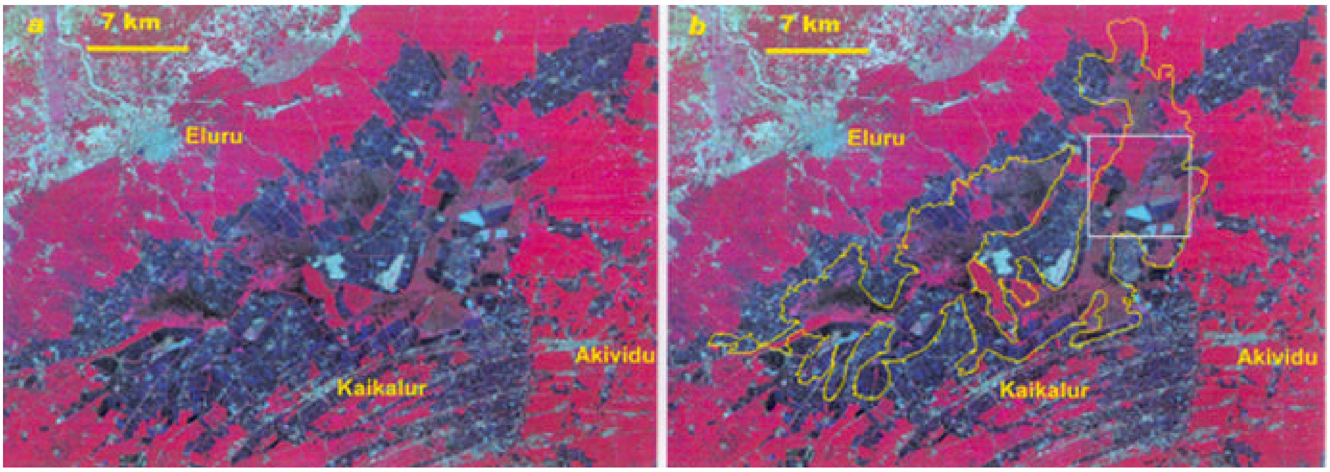

Figure 2. ***a***, FCC of IRS-1D LISS-III image dated 9 February 2001 covering Kolleru lake and its environs. ***b***, Boundary of the Kolleru lake (outlined from the topographic maps of 1930s) overlaid on the FCC. The area enclosed by the square is highlighted in Figure 3.

high reflectance values for barren soil (hence is likely to enhance the embankments of the fishponds), while the water bodies absorb the NIR radiance in Band 4. Therefore, a component of these two bands should help in a clear demarcation of the fishponds. Further, decorrelation stretch algorithm was applied to sharpen the boundaries. However, the output image of PCA could not show the dried-up fishponds separately from the lake areas with sparse weed. Furthermore, the lake area with dense weed, paddy fields and lake area under reclamation appeared similar and hence could not be separated (Figure 3 *b*).

The NDWI which is obtained using the function (Green – NIR)/(Green + NIR), is useful to demarcate the land–water boundary[9]. Application of this technique for a multi-spectral satellite image results in positive values for water features and zero or negative values for soil and vegetation[10]. When the NDWI is applied using Band 2 (green) and Band 4 (NIR) data of the LISS-III image of the Kolleru lake region, the fishpond boundaries were clear compared to the PCA output image. However, dry fishponds, lake areas with sparse weed and lake areas under reclamation appear similar, making the distinction between them difficult (Figure 3 *c*).

The ALR is an enhancement technique and, in fact, a combination of three digital processing algorithms, namely normalization, log residuals, and three-dimensional rescaling of an image[11]. This technique, mainly used in hyperspectral remote sensing, differentiates various land-cover

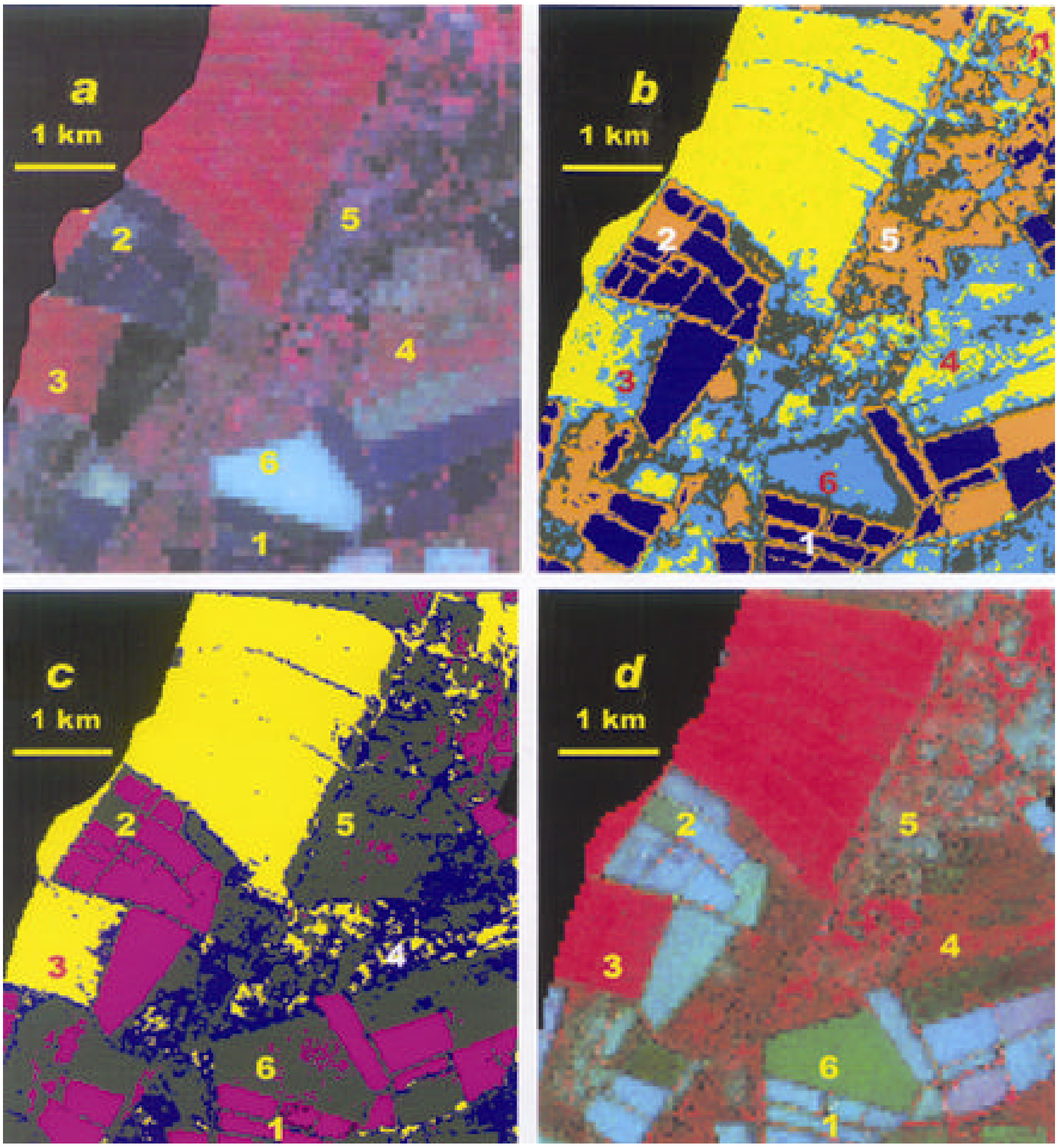

Figure 3. Part of Kolleru lake showing (***a***) conventional FCC, and output images of digital processing techniques of (***b***), PCA, (***c***), NDWI and (***d***), ALR. Note that in (***a***), fishponds (1) are not highlighted. In (***b***), distinction between dried-up fishponds (2) and lake area with sparse weed (5), and similarly, paddy fields (3), lake area with dense weed (4) and lake area under reclamation (6), is not clear. In (***c***), (2), (5) and (6) could not be separated, while in (***d***), there is a clear distinction among all these features. Location of this part of the lake is shown in Figure 2.

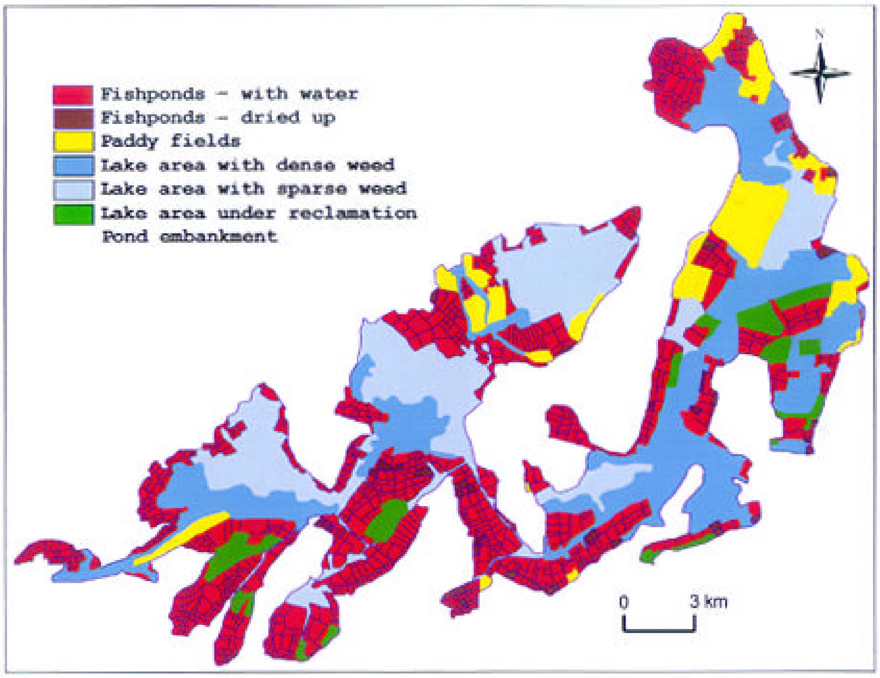

Figure 4. Land-use/land-cover features of Kolleru lake (as on 9 February 2001), generated from on-screen classification of the enhanced IRS-1D LISS-III sensor data through ALR technique.

classes by grouping and normalizing the like pixels of same DN (digital number) values from different spectral bands. The ALR would enhance the visual distinction between two different spatial features of similar character. As a 3D visualization impact is achieved by this technique, the output image highlights the visual discrimination between different feature classes for easy image interpretation. Since the commonly used PCA and also the NDWI techniques could not yield desirable results in this study, an attempt is made to process the FCC image (which is a combination of Bands 2, 3 and 4 of LISS III data) with ALR technique as its normalization and 3D rescaling effects might enhance the features in the lake. As expected, the image enhanced through ALR technique distinctly shows the fishponds with depth effect, while the lake areas with 2–3 m tall elephant grass are clearly separated from the paddy-crop zones. Furthermore, the lake areas with dense and sparse weed could also be separated. Similarly, the dry fishponds and the lake areas under reclamation could be identified separately (Figure 3 *d*). Thus the output image of the ALR enhancement technique was used to classify the various land-use/land-cover categories in the lake through on-screen digitization. The resultant polygon coverage map (Figure 4) was used to extract area statistics for all the feature classes through GIS software (ARC/INFO 8.2). The data revealed startling information on the status of Kolleru lake (Table 1). There were 1050 fishponds within the lake in addition to another 38 dried-up ponds, together covering an area of about 103 km^2, making up to about 42% of the total 245 km^2 area of the lake. The paddy fields encroach about 21 km^2 (8.5%), while the area already reclaimed (apparently for aquaculture), occupies another 4% of the lake area. The rest of the lake is covered by weed such as elephant grass, water hyacinth, etc. There was no stretch of clear water in the lake. This was the condition of the Kolleru as on 9 February 2001. The situation might have further worsened subsequently, as the lake reclamation for aquaculture and agriculture is going on unhindered (as revealed by field observations during September 2003). If this type of human-induced degradation of the Kolleru were left unchecked, this once-pristine natural water body would permanently disappear, sooner than later.

Table 1. Land-use/land-cover of Kolleru lake as interpreted from the IRS-1D LISS-III image of 9 February 2001

Land-use/land-cover category	Area in km^2	Percentage area
Fishponds with water (1050)*	98.98	40.40
Fishponds – dried up (38)*	4.00	1.63
Paddy fields	20.97	8.55
Lake area with dense weed	57.48	23.46
Lake area with sparse weed	53.27	21.74
Lake area under reclamation	10.30	4.20
Total	245.00	99.98

*Number of fishponds

The study highlights the significance of digital image processing and GIS analysis of the satellite sensor data in accurately assessing the physical environmental conditions and changes thereof in inaccessible terrains, such as in the case of the Kolleru lake, so that appropriate preventive and/or remedial measures can be taken up to protect such fragile but important coastal wetland ecosystems.

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Identification of conservation priority sites using remote sensing and GIS – A case study from Chitteri hills, Eastern Ghats, Tamil Nadu

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Conservation of the forest resources is being rightly considered as an urgent task to be pursued throughout the world. This communication deals with the delineation of conservation priority sites for effective management in the Chitteri hills, forming a part of the Eastern Ghats, Tamil Nadu using IRS 1C-LISS III satellite data and GIS overlay analysis. The various thematic layers such as vegetation type, species richness, endemic and red-listed plant species, biotic pressure zone and socio-economic value zone are overlaid using GIS in order to identify conservation-priority zones. This study reveals that about 8.2% (5367.85 ha) of the total hill area could be delineated as conservation-priority zone.

THERE is widespread agreement that global biodiversity is declining at an accelerated rate[1,2]. The main threat to tropical forest biodiversity is habitat loss, particularly loss of forest cover[3]. Even in protected areas, encroachment is widespread[4]. Protected areas in India have historically been established on an ad hoc basis, with little attention to the conservation value of an area[5]. For effective management of biodiversity, there is a need to prioritize areas, especially those which are considered most essential for conservation, i.e. biodiversity-priority areas[6]. Prioritization of strategies is again important to ensure that efforts at conservation yield best possible results avoiding the undesirable side effects, especially the alienation and impoverishment of local communities[7].

There is a need to prioritize such areas and in this case, the Eastern Ghats, a rugged hilly terrain running almost parallel to the eastern coast of India and covering three states, viz. Orissa, Andhra Pradesh and Tamil Nadu. The southeast portion of the eastern ghats in Tamil Nadu consists of several broken hill ranges, viz. Javadi, Elagiri, Melagiri, Shervarayan, Chitteri, Kalrayans, Kolli hills, Pacchaimalai hills and Bodamalai. They are dissected by rivers such as the Ponnaiyar, Cauvery and Vellar.

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