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Determination of Areal Shrinkage of Sasthamkotta Freshwater Wetland a Ramsar Site in South India

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ABSTRACT

Wetlands perform valuable functions such as recycling nutrients, purifying water, attenuating floods, maintaining stream flow, recharging ground water and also serve the water needs of the human populace. In this study, the shrinkage in aerial extent of Sasthamkotta lake, a freshwater wetland and a Ramsar site in the Southern part of India between 1973 and 2021 is determined using Remote Sensing data and Geographical Information System technology. The water spread area was delineated from the available cloud free satellite images and the same was computed using Normalised Difference Water Index. It was found that the water spread area of the lake has shrunk from 3.02 km^2 in the year 1973 to 2.55 km^2 in the year 2021 respectively. The percentage aerial reduction of the lake for the said period was found to be 15.56%. Decrease in rainfall, increased rate of water withdrawal from the lake and land use land cover changes in the adjoining areas of the lake could be attributed to the reduction in the aerial spread.

***Key words**: Aerial shrinkage, Sasthamkotta lake, Freshwater wetland, Ramsar site, Remote sensing, Geographical Information System.*

Introduction

Wetlands provide significant economic, social and cultural benefits as they recharge groundwater; cater to the human needs and support recreational and tourist activities. Wetlands also help reduce the impacts from storm damage and flooding, maintain good water quality in rivers and supports rich biodiversity as well.

More than 70 percentage of earth's surface is covered by water, out of which fresh water ecosystems constitute only less than 1 percentage. By 2025, it is estimated that around 1.8 billion people will live in areas plagued by water scarcity, with two-thirds of the world's population living in water-stressed regions as a result of unsustainable water consumption, population explosion, industrialisation and climate change (Salin and Sreedevi, 2013). Moreover, the quality of the available water resources is also questionable due to overwhelming pollution. This calls for the adoption of sustainable conservation measures for protecting the existing fresh water bodies. Thus the need of the hour is constant quantitative as well as qualitative monitoring of water bodies thereby restoring the existing fresh water resources.

To carry out studies on water bodies of large extent, conventional land based techniques must be complemented by using remote sensing and geographical information system (Che *et al*., 2009).

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Nowadays surface water bodies can be mapped using high resolution multispectral and radar sensors; water content in the soil can be remotely sensed with microwave and underground water sprouts can be detected using thermal infrared radiometres (Zhang *et al.,* 2015). Satellite sensors and satellite gravitational surveys can be used in combination with ancillary data to infer groundwater behaviour from surface expressions and to estimate groundwater aquifer storage (Metev and Veiko, 1998). Remote sensing can also be implied in computing water quality parameters namely pH, chlorophyll concentration, turbidity, salinity etc (Ballatore *et al*., 2014).

Geographical Information System (GIS) is an excellent tool in mapping water quality parameters as well as delineating freshwater bodies. Remote Sensing (RS) carried out with the use of satellite imagery can be considered as an inexpensive alternative to the conventional water quality monitoring method (Breckling, 1989). With recent advances in remote sensing, faster updates are possible in a short time interval with high resolution sensors and repeated area coverage (Chan and Bing, 2013). Decrease in areal extent of water bodies can be determined using time series remote sensing images as well (Mohsen *et al.,* 2016).

The integration of RS and GIS technologies proves to be an efficient method for mapping and analysis of urban land use changes as well (Chen *et al*., 2006). The great development of the spatial, temporal and spectral resolution of the Earth Observation systems (EO-systems), such as Landsat, GeoEye-1, Moderate Resolution Imaging Spectroradiometer (MODIS), Indian Remote Sensing spot (IRS spot) and Environmental Satellite (ENVISAT) has led to monitoring the water quality changes on our planet more easily and accurately. Remote sensing approach can be used where in situ monitoring of water bodies is financially, institutionally and spatially constrained (Lu, 2013).

Normalised Difference Water Index (NDWI) is the approach used in this study to delineate water features from satellite images. NDWI makes use of reflected near infrared and visible green light to enhance the presence of water features. NDWI can be expressed as follows (given as Equation 1). (Mcfeeters, 1996)

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR} \quad .. (1)$$

Where GREEN is a band that encompasses the Green band information and NIR is the Near Infra-Red band information. The selection of these wavelengths can maximise the typical features of water, minimise the low reflectance of NIR by water features and take advantage of the high reflectance of NIR by terrestrial vegetation and soil features (Hanqiu, 2006).

This study focuses on determining the aerial shrinkage of Sasthamkotta freshwater wetland, a Ramsar site in Kollam district (in Kerala State) in South India. Remotely sensed images of the lake obtained from Landsat were processed using ArcGIS 10.3 and the aerial change of the water spread area over a period of 48 years (from 1973 to 2021) was determined. Since the water spread area of any lake varies with season, the comparison of lake area holds good only for that particular season. In this study, the areal extent of Sasthamkotta lake is determined for the pre-monsoon period (i.e from the month of January to the month of May). Cloud free satellite images taken during the pre-monsoon season during the said period was used for the study.

Study Area

Sasthamkotta lake lies between latitude $9^0$11′N to $9^0$41′N and longitude $76^0$36′30" E to $76^0$40′E and it spreads out in three Panchayats namely, Sasthamkotta, Mynagapally and Western Kallada. The map of the study area is shown in Figure 1. The lake is surrounded by small residual hills on three sides and the lake has an irregular shape. An artificial bund was constructed in the south eastern part of the lake in the year 1956 which separates the lake from the surrounding lowland (Salin and Sreedevi, 2013). A river named Kallada flows about 2.5 kilometres south east of the lake.

Water has been extracted from Sasthamkotta lake since 1956 for drinking purpose. This freshwater lake caters to the drinking needs of more than 10 lakh people in Kollam district. The initial capacity of the water treatment plant constructed in the year 1956 was 22 MLD, which was enhanced later in the year 1991 to 37.5 MLD. In addition to the said water withdrawal, another water treatment plant with a capacity of 11.5 MLD was set up in the year 2008. Thereafter in 2015 an additional water treatment plant with a capacity of 9 MLD started functioning. As on today water is pumped from Sasthamkotta lake at a withdrawal rate of about 58 million litres per day (MLD) for the said purpose.

The south western tip of the lake corresponding to the Anjalimoodu region, south eastern portion of the lake corresponding to the bund that separates the lake from the surrounding paddy fields, Ambalakkadavu region and Bharanikkavu-Ookkanmukku region of Sasthamkotta lake has turned lush grassland over the years and the same is utilised by local farmers for grazing their livestock.

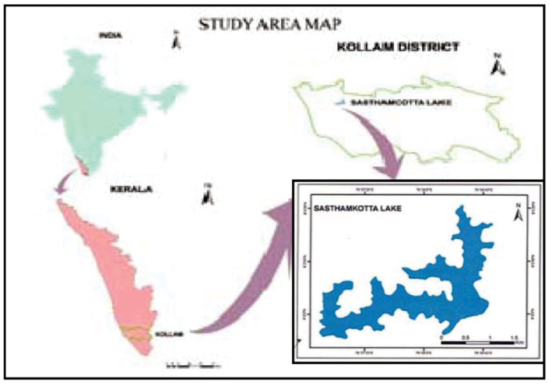

Fig. 1. Map of the study area

Data Sources

The data required for this study include cloud free satellite images during the period 1973 to 2021 and Landsat images were used for the same. These images were downloaded from the USGS official website. Satellite images namely Landsat Multispectral Scanner (Landsat MSS), Landsat Thematic Mapper (Landsat TM), Landsat Thematic Mapper (Landsat ETM) and Landsat 8 Operational Land Imager (Landsat 8 OLI) were used in this study. The details of the said satellite images which were downloaded for the study are given in Table 1.

Methodology

The methodology of the work carried out in this study could be generalised as digitising the lake boundary from each of the downloaded satellite images and computing the area of the corresponding polygons. This was carried out using the software ArcGIS 10.3. The water spread area was delineated, from the downloaded satellite images and the same was computed using Normalised Difference Water Index (NDWI). Equation (1) was applied to the said satellite images using the raster calculator in ArcMAP 10.3. This resulted in an image with pixel values ranging from -1 to +1. A threshold was applied to the said image to mask out features other than water. Thereafter, the image is converted from raster form to vector form using the 'raster to vector' conversion tool. Thus, the lake boundary is obtained as a polygon feature, and thereafter the threshold value with respect to the NDWI result was adjusted and the same was applied to extract the water spread area.

Results and Discussion

The areal spread of the lake was calculated from 1973 to 2021 during the pre-monsoon season from the available cloud free satellite images. In the month of February 1973 using Landsat MSS image, the water spread area of the lake was delineated and the same was found to be 3.02 km^2. Figure 2 shows the water spread area of the lake for the month of February 1973.

On processing the Landsat TM image of February 1990, the water spread area of the lake was delineated and the same was found to be 3.13 km^2. Figure 3 shows the water spread area of the lake for the month of February 1990.

Landsat ETM image of February 2005 was used

Table 1. List of satellite imagery used in the study

Satellite and Sensor	Date of Acquisition	Path and Row	Spatial Resolution (m)
Landsat MSS	February, 1973	154/54	60
Landsat TM	February, 1990	144/54	30
Landsat ETM	February, 2005	144/54	30
Landsat 8 OLI	April, 2013	144/54	30
Landsat OLI	January, 2014	144/54	30
Landsat OLI	January, 2015	144/54	30
Landsat OLI	May, 2016	144/54	30
Landsat OLI	February, 2017	144/54	30
Landsat OLI	February,2018	154/54	30
Landsat OLI	February, 2019	154/54	30
Landsat OLI	February,2020	154/54	30
Landsat OLI	March,2021	154/54	30

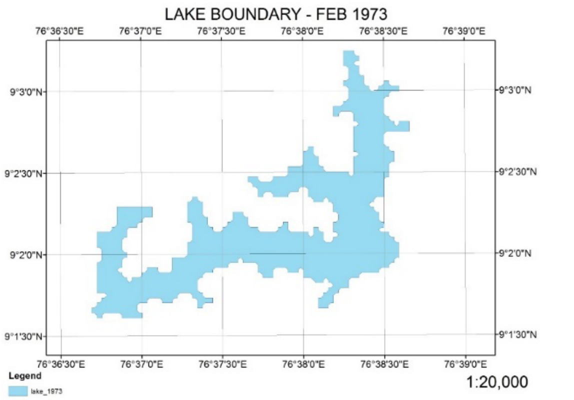

Fig. 2. Water spread area of the lake in the month of February 1973

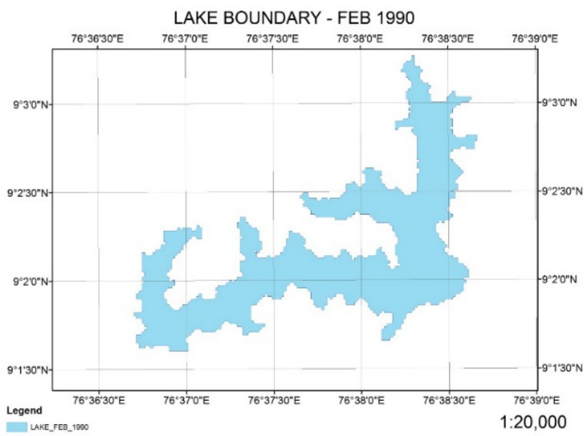

Fig. 3. Water spread area of the lake in the month of February 1990

to delineate the water spread area and the same was found to be 3.11 km^2. Figure 4 shows the water spread area of the lake for the month of February 2005.

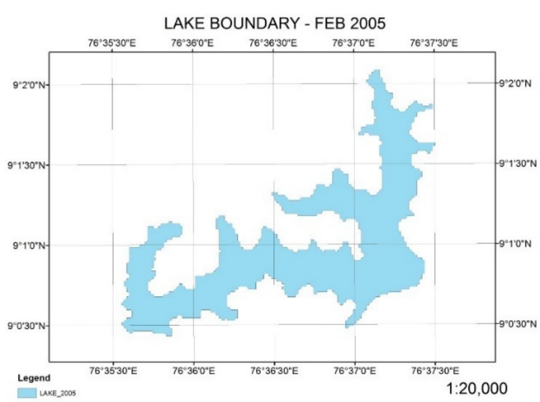

Fig. 4. Water spread area of the lake in the month of February 2005

Water level of Sathamkotta lake began to show a depleting trend since 2008, since the inception of the 11.50 MLD water supply scheme started functioning with lake as its source. On processing the Landsat 8 OLI image of April 2013, the water spread area of the lake was delineated and the same was found to be 2.12 km^2. It was found that there was a significant reduction in the water spread area in the month of April 2013. The water level in the lake has gone below Mean Sea Level (MSL) in the year 2013 for the first time in its recorded history. The collected rainfall data from the Indian Meteorological Department (IMD) was analysed and it was found that, there was a significant decrease in the monthly rainfall in the month of April 2013. The average rainfall in the month of April 2013 was only 7.86 mm/day. Thus it can be inferred that the decrease in rainfall coupled with excessive water withdrawal had a significant impact on the lake area reduction in the month of April 2013. Figure 5 shows the water spread area of the lake for the month of April 2013.

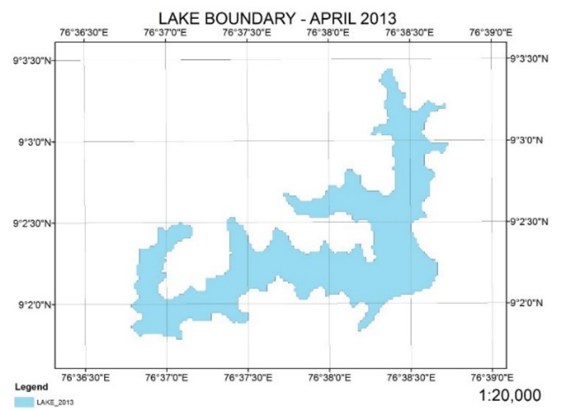

Fig. 5. Water spread area of the lake in the month of April 2013

In the month of January 2014 the water spread area of the lake was found to be 2.96 km^2. This increase in water spread area (in the month of January 2014) could be attributed to the increase in precipitation of 9.24 mm/day (average value) as compared to that of 7.86 mm/day (average value) in the month of April 2013. Figure 6 shows the water spread area of the lake for the month of January 2014.

Landsat OLI image of January 2015 was used to delineate the water spread area of the lake and the same was found to be 3.23 km^2. As per the data from IMD the average precipitation in the month of January 2015 was only 8.60 mm/day. Figure 7 shows the water spread area of the lake for the month of January 2015.

In May 2016 the water spread area of the lake was found to be 2.54 km^2. An additional water treatment plant of capacity 9 MLD started functioning from the year 2015 with Sasthamkotta lake as its source. As per the data from IMD the average precipitation in the month of May 2016 was only 5.09 mm/day. Decrease in rainfall and excessive water withdrawal could be the major cause for the reduction in the water spread area of the lake in the month of May 2016. Figure 8 shows the water spread area of the lake for the month of May 2016.

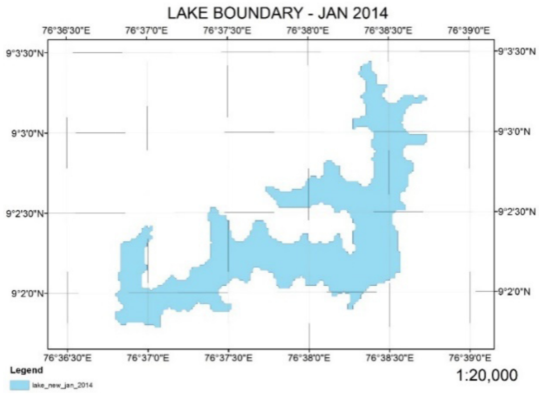

Fig. 6. Water spread area of the lake in the month of January 2014

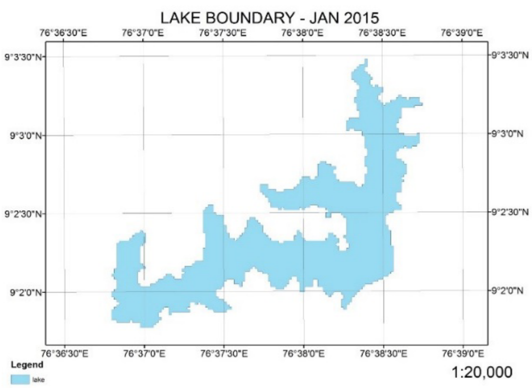

Fig. 7. Water spread area of the lake in the month of January 2015

Landsat OLI image of February 2017 was used to delineate the water spread area and the same was found to be 2.20 km^2. The decrease in water spread area (in the month of February 2017) could be attributed to the excessive water withdrawal from the lake. Figure 9 shows the water spread area of the lake for the month of February 2017.

Landsat OLI image of February 2018 was used to delineate the water spread area and the same was found to be 2.36 km^2. This could be attributed to less precipitation of 10.6 mm/day (average value) during the month of February 2018. Figure 10 shows the water spread area of the lake for the month of February 2018.

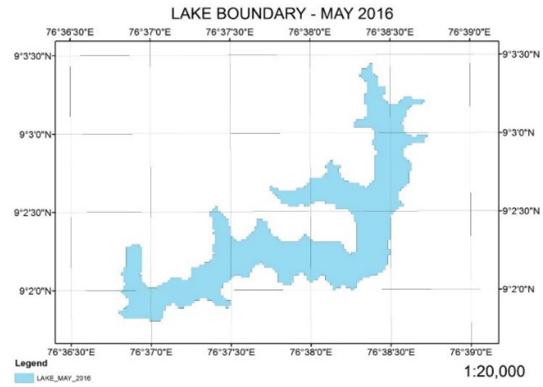

Fig. 8. Water spread area of the lake in the month of May 2016

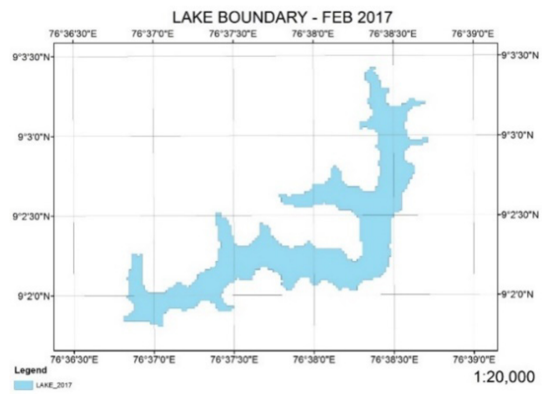

Fig 9. Water spread area of the lake in the month of February 2017

Landsat OLI image of February 2019 was used to delineate the water spread area and the same was found to be 2.88 km^2. This could be attributed to less precipitation of 10.71 mm/day (average value) during the month of February 2019. Figure 11 shows the water spread area of the lake for the month of February 2019.

Landsat OLI image of February 2020 was used to delineate the water spread area and the area was found to be 2.66 km^2. The aerial extent of the lake slightly decreased compared to that of the previous year. This could be attributed to less precipitation of

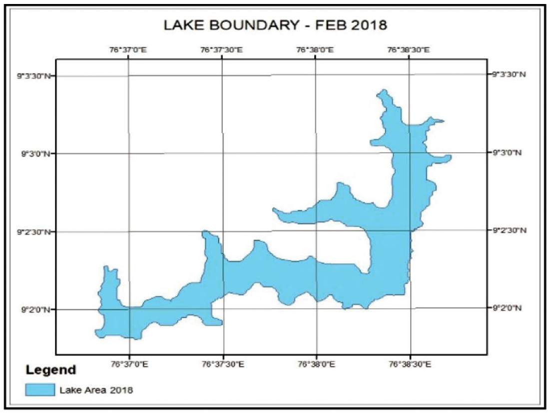

Fig. 10. Water spread area of the lake in the month of February 2018

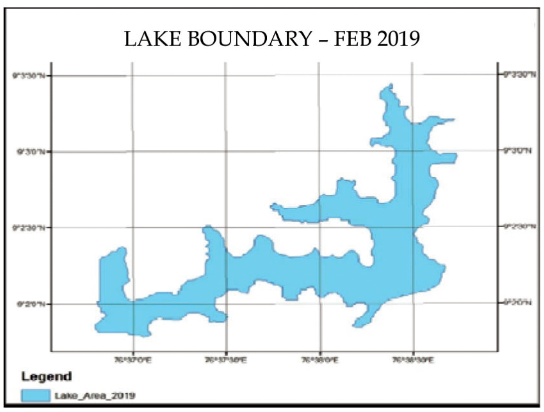

Fig. 11. Water spread area of the lake in the month of February 2019

9.6 mm/day (average value) during the month of February 2020 whereas in the month of February 2019 the same was 10.71 mm/day. Figure 12 shows the water spread area of the lake for the month of February 2020.

In February 2021 there was a decrease in the water spread area of the lake by 0.11 km^2 compared to that of February 2020. This could be due to the decrease in the amount of average precipitation in the month of March 2021 which was only 5.5 mm/day. It was also observed that the water level of Sasthamkotta lake could not rise above the MSL since 2016. Figure 13 shows the water spread area of the lake for the month of February 2021.

From Table 2, it can be seen that the water spread area of the lake has been reduced considerably during the past 48 years. Less rainfall coupled with excessive water withdrawal could be attributed for the same.

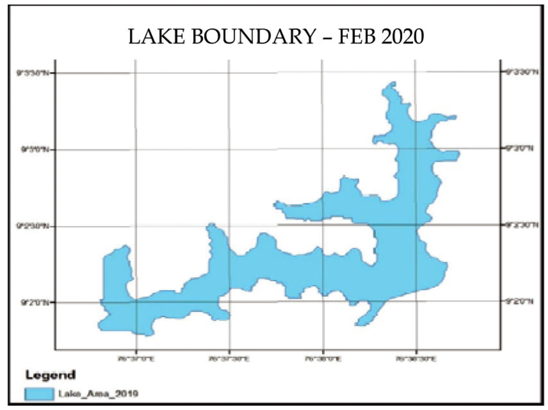

Fig. 12. Water spread area of the lake in the month of February 2020

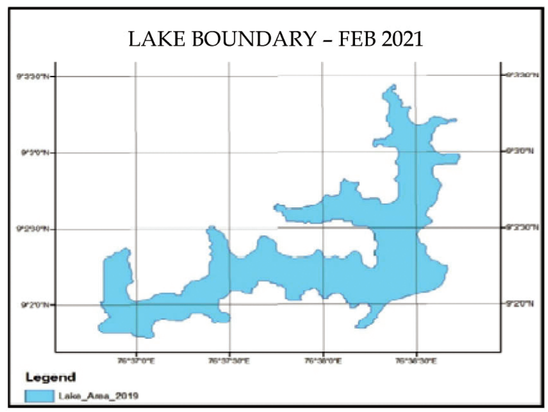

Fig. 13. Water spread area of the lake in the month of February 2021

Figure 14 shows the shrinkage in the water spread area of the lake during 1973 and 2021. It could be seen that the shrinkage of Sasthamkotta lake has mostly occurred in the south western part of Anjalimoodu, Ambalakadavu and south eastern part of the bund region.

Conclusion

With increasing demand for the lake's freshwater in the years to come, the stress on the lake will definitely increase. Less rainfall and increased rate of water withdrawal from lake are the major causes for the reduction in the water spread area. The aerial water spread of Sathamkotta lake, a fresh water Ramsar site has reduced from 3.02 km^2 in the year 1973 to 2.55 km^2 in the year 2021 respectively. Moreover it could be observed that the lake is drying up at a rapid pace since 2016. A study on the aerial

Table 2. Water spread area of the lake from 1973 to 2021

Year	Month	Water spread area of the lake (km^2)	Percentage change compared to that of 1973
1973	February	3.02	-
1990	February	3.13	3.64
2005	February	3.11	2.98
2013	April	2.12	29.80
2014	January	2.96	19.87
2015	January	3.23	6.95
2016	May	2.54	15.89
2017	February	2.20	27.15
2018	February	2.36	21.85
2019	February	2.88	4.64
2020	February	2.66	11.92
2021	February	2.55	15.56

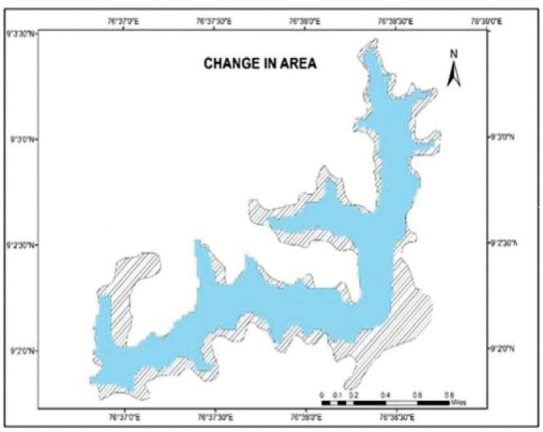

Fig. 14. Shrinkage in the water spread area of the lake during 1973 and 2021

change alone will not be enough to understand the actual plight of the lake. The shrinkage in the water spread area of the lake may also be attributed to the change in land use land cover in the adjoining areas of the lake and sediment deposition as well. The change in lake volume is to be determined as well. Sediment deposition studies coupled with change in land use land cover in the adjoining areas of the lake should also be carried out, after which a sustainable management plan is to be implemented for the conservation of the lake.

Conflict of Interest

The authors declare that there is no conflict of interest.

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