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Evaluating the Land Use Land Cover Dynamics of Loktak Lake, A Ramsar Wetland of International Importance in North East India

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ABSTRACT

In fragile transitional freshwater ecosystems, such as wetlands, the increasing anthropogenic and natural pressures, including climate change and industrialisation, have impacted the land use/land cover (LULC). The present study aims to identify the LULC changes occurring in Loktak Lake, a Ramsar Wetland of International Importance, included in the Montreux Record between 2009 and 2020 using LANDSAT imageries. In order to quantify the LULC, a Maximum Likelihood Classifier was carried out in Arc GIS 10.8.1. A total of six land use classes were classified viz., open water body, athaphum, phumdi, built up, agriculture and barren area. It also attempts to undertake landscape modelling to look at the fragmentation of phumdi class through FRAGSTATS utilising the Number of Patches (NP), Patch Density (PD), Largest Patch Index (LPI) and Cohesion metrics. An overall decline in phumdi, athaphum, agriculture and open water body land uses at the rate of 5.9, 14.54, 110.1 and 1%, respectively, was observed. Meanwhile, built-up and barren land uses showed an overall increase at the rate of 18.31 and 31.25%, respecively. These LULC changes observed have been primarily because of anthropogenic factors, which threaten an already fragile ecosystem. The landscape modelling exercise showed that phumdi is aggregated at the innermost portions of the lake. It also showed that the patches of phumdi were higher in years 2011 and 2020, which may be due to the use of phumdi strips in athaphum (fish farms on the lake). The study indirectly revealed the effectiveness of past management actions by relevant organisations, as remotely sensed information requires ground validation. It also highlighted the absence of baseline data information and emphasised integrating present, past and future LULC modelling for management purposes.

Key words: Fragstats, Montreux record, Land use land cover change, Maximum Likelihood Classifier, Loktak Lake management

INTRODUCTION

The inherently complex nature of wetlands makes them one of the richest ecosystems, with a net worth of natural wetlands estimated to be at 47.4 $ trillion/year, accounting for almost 43.5% of other natural ecosystems (Davidson 2019). However, wetlands are also a deteriorating system shown by the steady decline of an average of 35% globally from 1970 to 2015 (Darrah et al. 2019). The deterioration is marked by factors such as agriculture, urbanization, aquaculture, and industrial development, all of which are significant land use land cover changes (LULC) (Anonymous 2021a, Baluut Dajud et al. 2022). Although the LULC terms are used interchangeably, land cover denotes the physical characteristics that cover the earth's surfaces, while land use is the activities carried out by humankind to fulfil a particular objective by using the resources of the land (Jamal and Ahmed 2020). Further, essential policy processes, including RSP 2016-2024 and Sustainable Development Goals (SDGs), have overarching goals that embrace addressing the drivers of wetland loss and degradation and enhancing implementation (RSP 2016-2024). More specifically, SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), SDG 14 (Life below water), and SDG 15 (Life below Land) are directly related to wetlands and are also areas where LULC changes are discernible.

Remote sensing and GIS have been extensively used in global wetland studies, such as LULC changes in wetlands and mapping hydrological processes (Jensen et al. 1995, Rebelo et al. 2009, Nagabhatla et al. 2010). Multiple multispectral datasets viz., LANDSAT Multispectral Scanner (MSS), Thematic Mapper (TM) and the Operational Land Imager (OLI), IKONOS-2 and SPOT 1-5 datasets have also been used widely (Mahdavi et al. 2018). Additionally, changes in the landscape can also be detected using landscape metrics through spatial programmes like FRAGSTATS. Various studies have also reported the using FRAGSTATS in a highly threatened system like a wetland. The combination of RIS, GIS, and FRAGSTAT provides insight into landscape dynamics, decision-making processes and implementation in specific sites. In the Indian context, remote sensing and GIS was used for the first recorded scientific inventory of wetlands in 1992/93 that was updated in 2004/2005, 2007/2008 and 2017/2018, respectively (Garg 2015, Anonymous 2021c). It was followed by the formation of the Wetland Information System (WIS) in West Bengal and Loktak Lake, Manipur, by ISRO using GIS. Numerous studies have been carried out such as the use of spatio-temporal LULC changes, water pollution, water spread area, wetland shrinkage, fragmentation analysis and modelling future changes (Joshi et al. 2002, Mabwoga et al. 2010, Singh et al. 2020, Jamal and Ahmed 2020, Basu et al. 2021).

Loktak lake, an Indo-Burma biodiversity hotspot is also a Ramsar Wetland of International Importance harbouring endemic species such as Sangai (*Cervus eldii eldii* – Endangered) and extensive bird diversity (Myers et al. 2000, Rahmani et al. 2016). Additionally, the lake has a unique ecosystem known to play an essential role in nutrient cycling (Meitei and Prasad 2014, Anonymous 2002). However, its inclusion in the Montreux record in 1993 is evidence of the deteriorating state of the lake. Consequently, interventions such as Sustainable Development and Water Resources Management of Loktak Lake (SDWRMLL) and the Short-Term Action Plan (STAP) encompassing management actions have been carried out post the inclusion (Trisal and Manihar 2002). Still, an increase in the agricultural area and settlement by 25.33 and 5.75 km^2, respectively, between 1977-2015 have partly contributed to the increase in pollution load as evidenced by the Water Quality Index (WQI) ranging between 64-77 for July 2013-May 2014 (Kangabam et al. 2017, 2019)

Various studies on water quality, fishery assessment, biodiversity, and carbon sequestration have been conducted in the Loktak wetland area (Roy and Majumdar 2019, Khwairakpam et al. 2019, Roy et al. 2022). However, studies tracking the LULC changes are few and do not factor in crucial management intervention timelines. The present study used GIS, RS, and FRAGSTAT to analyse the LULC changes in Loktak Lake, specifically concerning the timeline of management interventions. It would indirectly discern the effectiveness of the management and provide reference information that would help policy formulation.

METHODOLOGY

Description of the study area

Loktak lake lies between 93°46'-95°55'E and 24°25'-24°42'N (Trisal and Manihar 2000). The lake has a unique ecosystem in the form of *phumdis,* which floats on the lake with about one-fifth on the surface and the fourth-fifth under the water (Meitei and Prasad 2014). The indigenous athaphum technique of fishing also characterizes the lake by using enclosures made of strips of *phumdi* (Anonymous 2002). As per the Loktak atlas, the lake is categorized into a northern, southern and western portion for management. The southern part comprises the Keibul Lamjao National Park. It is an Important Bird and Biodiversity Area (IBA) falling under A1 (globally threatened species) and A4 (Congregation of $\geq$ 1% of the global population of one or more species) (Anonymous 2021b, Rahmani et al. 2016).

Dataset and classification

Landsat 5 TM (February 2009, 2011) and Landsat 8 OLI (February 2017, 2020) cloud-free satellite imagery data of Loktak Lake covering important management timeline (Table 1) were obtained from the United States Geological Service (USGS) site (https://earthexplorer.usgs.gov/), avoiding the images with clouds, and undesired spotting which can significantly reduce the accuracy result of the classified map (Vivekananda et al. 2020). As the images were pre-processed, no processing procedures were carried out. The study area was delineated using a Loktak shapefile from Loktak Development Authority, Manipur, in Arc GIS version 10.8.1. A predetermined six LULC (Land Use Land Cover) classes based on Anderson et al. (1976) were identified. These are Water body comprising of lakes and stream; Athaphum; Phumdi; built up comprising of roads, residential area and fish farms on land;

Table 1. Milestone years in Loktak lake management

Timeline	Description
2009	Post completion of the Sustainable and Water Resource Development (SWRD) project (1996-2003)
2011	Start of Short Term Action Plan (STAP)
2017	Ongoing period of management intervention through Annual Plans and completion of STAP
2020	5 years post the STAP completion

Agricultural land comprising of crop fields and Barren composing of small hillocks and barren land. Athaphum and phumdi classes are unique to Loktak lake with the former referring to fish farms constructed artificially in the lake using phumdi and appearing as concentric rings, The latter are floating masses of organic material in varying levels of decomposition. The reflectance plot for these 6 LULC classes plotted using ERDAS 2015 is given in Supplementary Figure 1. Although different image classification methods exist, such as unsupervised and object-based classification, supervised

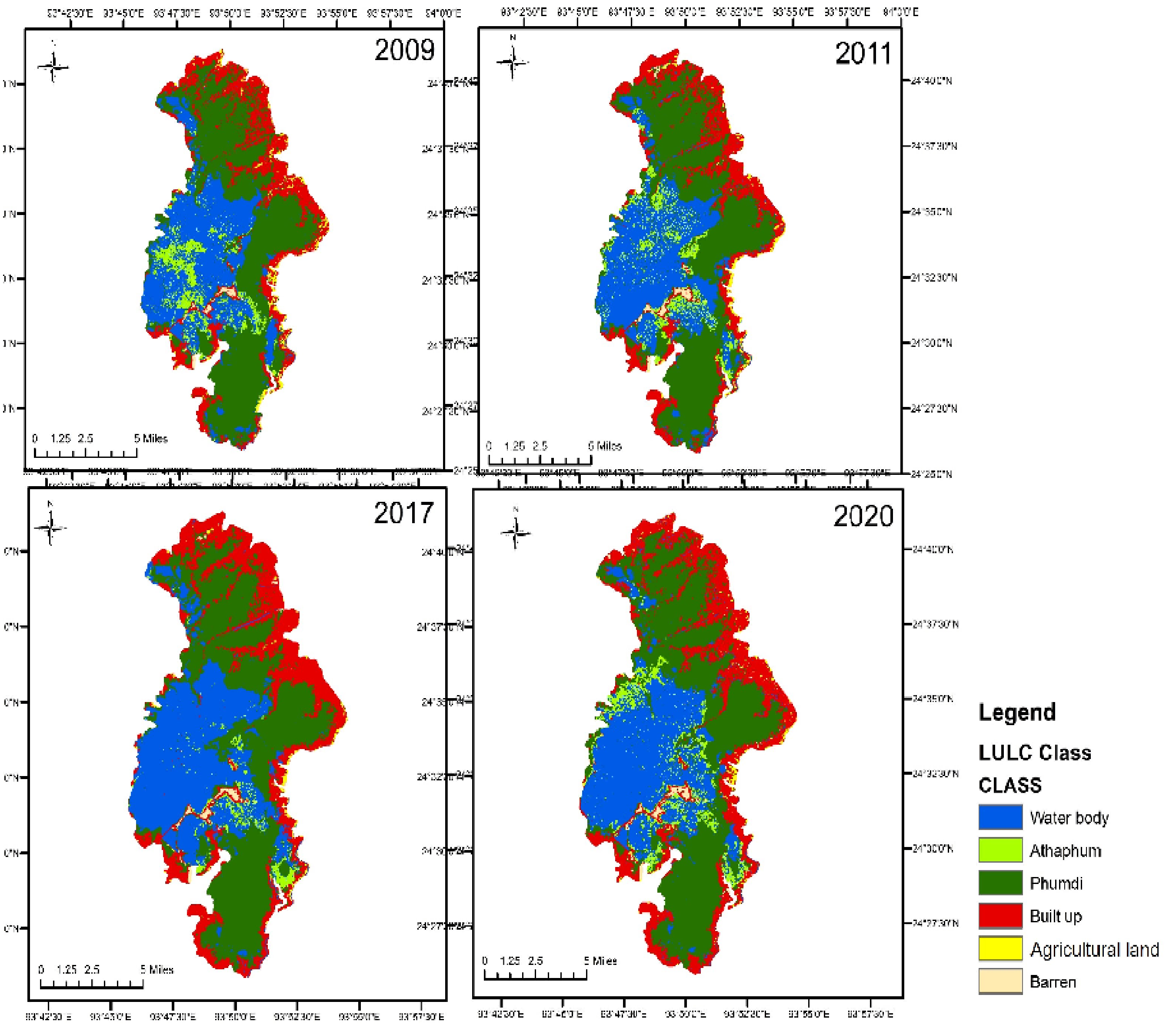

Figure.1. LULC of Loktak lake for timeline years

classification methods; specifically, rule-based Maximum Likelihood Classification (MLC), were carried out in Arc GIS 10.8.1. Considering the greater accuracy of supervised methods in a mixed pixels and heterogenous landscape like a wetland, it was so done. Training samples of 200-300 were collected for each category by drawing representative polygons around each class. It was enhanced with google earth and GPS collected from field visits. Before the analysis of multi-temporal imageries, a majority 3*3 filter was applied to reduce salt and pepper effects. Multi-temporal LULC maps (2009, 2011, 2017 and 2020) were generated following which change detection to analyze changes in land use was carried out.

Accuracy assessment

A total of 30-70 sampling points as reference points were collected through ground truthing for Landsat 8 OLI (2020), while for Landsat 8 OLI (2017), Landsat 5 TM (2011), Landsat 5 TM (2009), it was done through Google Earth Historical Imagery. Accuracy assessment was then carried out in Arc GIS 10.8.1 for each class in a stratified random manner for every classified map following which confusion matrix was obtained. It in turn generated Producer Accuracy, Users Accuracy and Kappa Index while Overall Accuracy and Kappa coefficient was calculated using the following formula:

$$\text{Overall Accuracy} = \sum_{i=1}^{r} x_{ii} \quad (1)$$

$$\text{Kappa coefficient } \hat{\kappa} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} x_{i+} . x_{+i}}{N^2 - \sum_{i=1}^{r} x_{i+} . x_{+i}} \quad (2)$$

Where, x_{ii} is the diagonal elements in the matrix; x is the total number of samples in the matrix; N is total number of observations in the matrix; x_{i+} and x_{+i} are total number of samples in row i and column i respectively; r is number of rows in the matrix

Change detection

Besides temporal LULC changes, understanding the amount of change that occurs in the classes between successive years is also essential for planning purposes. Although different change detection methods are available, the post classification technique which compares pixel by pixel is found to be accurate as per available studies. It involves comparing of corresponding classes for the classified images to determine changes that have occurred (Vivekananda et al 2020). The magnitude of change and percentage change (C%) is determined using the formula given in Equation 3 obtained from Vivekananda et al. 2020.

$$C_i = L_i - B_i \quad (3)$$

$$P_i = \frac{L_i - B_i}{B_i} * 100 \quad (4)$$

Where i = number of classes in a classified image P_i= Percentage of change in class "I" , L_i= Base image, B_i = Latest image,

Landscape modelling

Preliminary landscape analysis was carried put using FRAGSTATS 4.3 at the class level for the phumdi class. Considering the importance of phumdi class as it functions as a habitat refugee for endangered Sangai and host to endemic plants, landscape modelling was carried out on only on this particular class. A total of 4 different type of landscape metrics were selected that includes Number of Patches (NP), Patch Density (PD), Largest Patch Index (LPI) and Cohesion based on secondary literature (Pang et al. 2010, Lee et al. 2015).A brief description and rationale of selection of these metrics are placed in Table 2.

RESULTS AND DISCUSSION

Land use land cover (LULC) of Loktak lake

The LULC of Loktak lake for the years 2009, 2011, 2017 and 2020 is shown in Figure 1. The area coverage for the six LULC classes and the trends in the changes are given in Table 3. The LULC of 2009 showed that phumdi and water body accounted for most of the area, amounting to approximately 71.64%. It was followed by a built up area covering about 19.42%, while agriculture and barren land covered the least, which is 2.16 and 0.52%, respectively. The year 2011 shows that phumdi, water body and built up area cover the majority of the area, accounting for 91.44%. It was followed by athaphum covering about 6.4%, whereas agriculture and bare land occupy the least amounting to 1.35 and 0.8%, respectively.

The trend of phumdi and water body covering a majority of the area was followed in 2017 and 2020, accounting for about 72.1 and 68.96% of the total area, respectively. However, the total area's built-up area share increased in 2017 and 2020, accounting

Table 2. Landscape metrics selected for Loktak lake

Metrics	Scale	Description	Rationale forselection
Number of Patches (NP)	Class	It is the number of patches in a certain landscape	It is the basis for computing interpretable measures
Patch Density (PD)	Class	The number of patches per unit area in the landscape	Degree of habitat fragmentation
Largest Patch Index (LPI)	Class	It is the portion of landscape that is occupied by the largest patch of the landscape (measure of dominance)	Habitat provisioning and contiguity
Cohesion	Class	It characterizes the physical connectedness of the patches	Enables one to assess if patches are isolated or aggregated

Table 3. Land use land cover of Loktak lake for selected time periods

Class	**Area (km^2)**							
	2009	**(%)**	**2011**	**(%)**	**2017**	**(%)**	**2020**	**(%)**
Water body	67.2	28.42	69.9	29.59	73.6	31.2	66.5	28.16
Athaphum	14.8	6.27	15.1	6.4	5.3	6.1	13	5.48
Phumdi	102.1	43.22	100.7	42.6	96.7	40.9	96.4	40.8
Built up	45.8	19.42	45.5	19.25	57.1	24.2	56.2	23.78
Agriculture	5.1	2.16	3.4	1.35	1.9	0.8	2.4	1.03
Barren land	1.2	0.52	1.9	0.8	1.6	0.7	1.8	0.75
Total	**236.3**	**100**	**236.3**	**100**	**236.3**	**100**	**236.3**	**100**

Table 4. Accuracy assessment of Loktak lake for selected time periods

	2009		2011		2017		2020	
	Producer accuracy	User accuracy	Producer accuracy	User accuracy	Producer accuracy	User accuracy	Producer accuracy	User accuracy
Water body	0.85	0.88	83.33	83.33	0.96	0.91	95.12	85
Athaphum	0.85	0.77	78.87	90.32	0.81	1	81.25	93
Phumdi	0.79	0.91	86.42	79.55	0.98	0.86	90.57	84
Built up	0.87	0.87	90.67	85	0.94	0.77	92	88
Agriculture	0.93	0.85	84.21	96.97	0.82	0.98	88.37	100
Barren	1	1	93.10	87.1	0.94	1	93.62	94
Overall	87.47%		85.56%		90.7 %		90%	
Kappa Coefficiency	0.85%		0.82%		0.89 %		0.88%	

for about 24.2 and 23.78%, respectively, compared to 2009 and 2017. Meanwhile, agriculture covered 1.35 and 1% of the total area in 2017 and 2020, respectively, whereas barren occupied approximately 0.7% of the total area in the same timeframe.

The classification accuracy with overall accuracy and kappa co-efficiency was carried out for all four years with the details in Table 4. Considering the sensitivity of some of the LULC classes, the producer and user accuracy are also placed in the same.

Trend of LULC changes

At any level of management, especially in environmental planning, it is essential to understand

Table 5. Pattern of LULC change* of Loktak lake in selected time periods

Class	Magnitude of change	Change (%) between 2009-2011	Magnitude of change	Change (%) between 2011-2017	Magnitude of change	Change (%) between 2017-2020	Magnitude of change	Net change between 2009-2020
Water body	-2.7	-3.9	-3.7	-5	+7.1	+10.7	+0.6	+1
Athaphum	-0.3	-2	+9.9	+187.8	-7.7	-59.2	+1.9	+14.54
Phumdi	+1.5	+1.4	+3.9	+4.1	+0.3	+0.3	+5.7	+5.9
Built up	+0.3	+0.9	-11.6	-20.4	+0.9	+1.6	-10.4	-18.4
Agriculture	+1.9	+59.3	+1.3	+66.5	-0.5	-20.8	+2.7	+110.1
Barren	-0.7	-37	+0.3	+15.8	-0.2	-11.1	-0.55	-31.2

*(- indicates increase while + indicates decrease)

the change occurring within the landscape. In the case of Loktak lake, the LULC changes are analysed for 2009, 2011, 2017 and 2020, each of which coincides with significant management interventions. The per cent change in each LULC class for three different periods, 2009-2011, 2011-2017 and 2017-2020 and the net change for 2009-2020, are in gien in Table 5, Figure 2.

It has been observed that the change in LULC classes is more or less similar across the three-time period. Phumdi showed a steady decline across the three periods, with a peak in 2011-2017, where it decreased by 4.1%. Water body showed a steady increase with a steep decline in 2017-2020, amounting to approximately 10.7%. Athaphum, on the other hand, showed both an increase and decrease in the subsequent two time periods (2009-2011, 2017-2020), amounting to 9.9 and 187.8%, respectively. Meanwhile, agriculture showed an initial decline followed by an increasing trend, where in 2017-2020, it increased by 26.3%. Similarly, built up fluctuated between an increasing and decreasing trend, with the peak increase in 2011-2017, where it increased by 20.4%, while the subsequent decline in 2017-2020 is minimal. The same also applies to barren land, where a substantial decrease was seen in 2011-2017, possibly due to the fragmentation of small hillocks for roadway construction.

Landscape analysis at class level

The result of the landscape modelling exercise at the

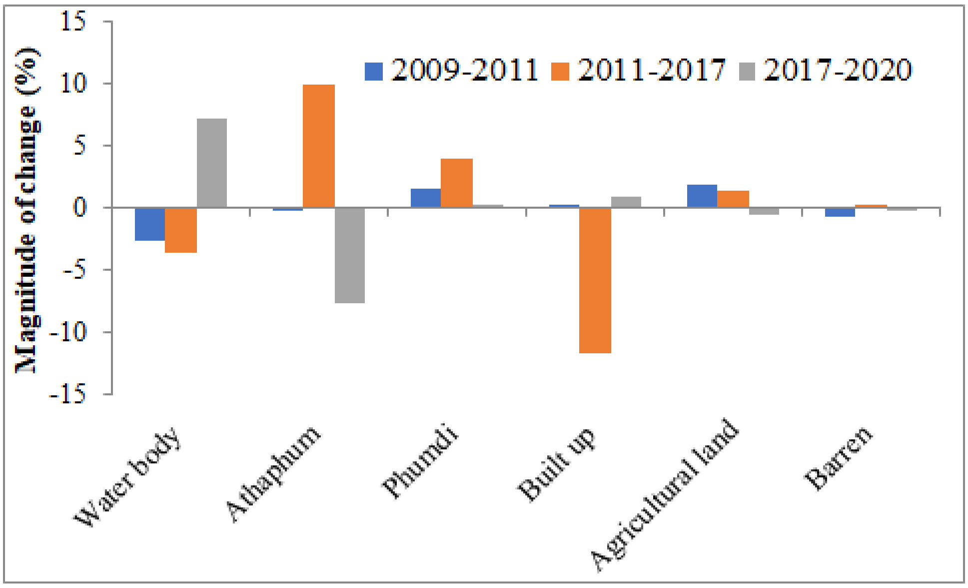

Figure 2. Change observed in the LULC classes for timeline years

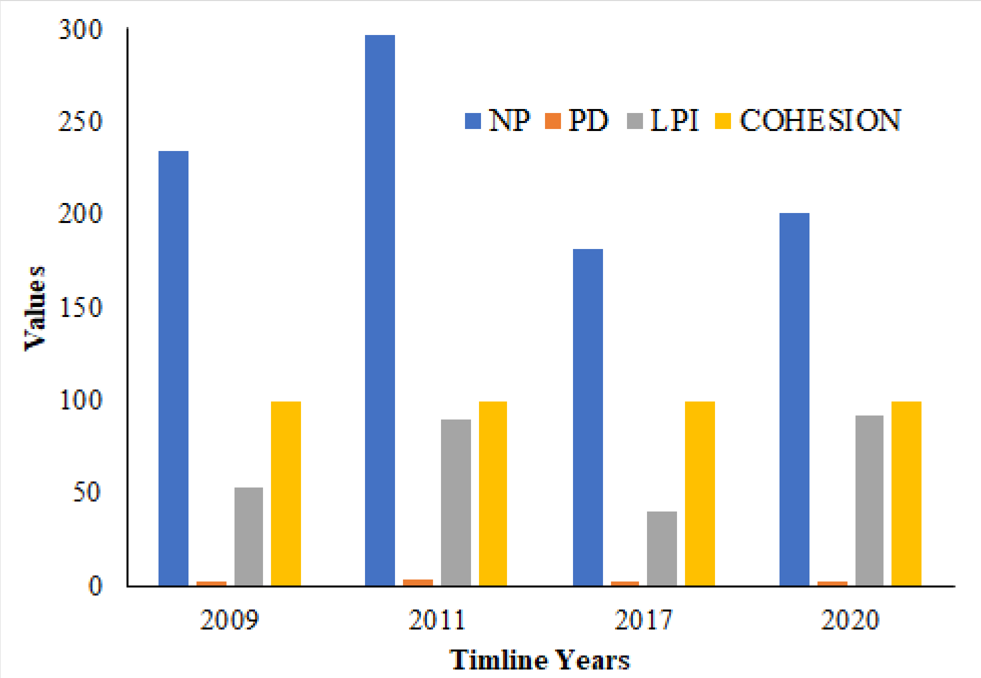

Figure.3. Fragmentation observed in phumdi for timeline years

phumdi (class) level is illustrated in Figure 3. As seen, the Cohesion and Patch Density (PD) index are relatively unchanged across the timeline years. Conversely, Number of Patch (NP) index shows the highest percentage in 2011 followed by a significant dip in 2017 and an increase in 2020. Meanwhile Largest Patch Index (LPI) is marked by a decline in 2017 and an increase in 2011 and 2020.

Assessment of changes observed in the LULC classes

As seen above, water body and phumdi cover the maximum coverage of the total area in the wetland that in turn indirectly impacts the ecosystem health. It is because phumdi besides providing a biological sink for key nutrients, it also governs the water and nutrient dynamics of the lake (Anonymous 2002). Given the LULC timeline covering crucial management milestones, studies done specifically in Loktak lake provided in Table 6 were mainly discussed in conjunction with the present study.

Changes in water body

The present study showed increasing coverage of open water body with a steep decline in 2017-2020 which follows a similar trend with other studies (Singh et al. 2000, Trisal and Manihar 2004, Singh and Khundrakpam 2009). The steep decline observed in our study, from 73.6 km^2 in 2017 to 66.5 km^2 in 2020 is similar to the decline observed in Table 5. This may be explained due to increase aquacultural practices, mainly athaphum fishing, proliferation of phumdi and increased population were also factors mentioned by other studies (Trisal and Manihar 2004, Singh and Khundrakpam 2009).

Kangabam et al. (2019) although observed an increase in the water body in 2015 which is similar to the increase observed in our study in 2017. It is mainly due to the phumdi management component of the STAP (2009-2013), and subsequent annual plans which focus on removing phumdi in the central zone of the lake (Anonymous 2005).

Changes in athaphum

The present study indicated a declining trend in athaphum class compared to previous studies (Table 5), where it was estimated to be at 38.41 km^2 in 2004 (Devi et al. 2004). However, a fluctuating trend with an increase in 2011 (15.1 km^2) and 2020 (13 km^2) and a decrease in 2017 (5.3 km^2) was noticed. The decrease is mainly due to management interventions during 2008-2011, largely comprising the removal of the phum huts and providing livelihood packages to athaphum fishers. Meanwhile, the increase is due to the higher income return fisherfolk obtained from athaphum fishing.

This fluctuating trend is a cause for concern as the athaphum class, besides providing subsistence to fishermen, can also contribute to source pollution if inorganic pesticides, feedstocks, and manures are used as they may flow into the lake. It could also indirectly lead to the proliferation of phumdi, which would be detrimental to the lake. Further, the subsequent increase post 2011 points indicated the futility of the management interventions carried out as a part of STAP. Moreover, the increase also points to the degree of effectiveness in implementing the MLLPA, 2006 as athaphum is not permissible within the core zone of the lake while there is no clarity on the number of athaphums in the buffer area.

Changes in phumdi

Past studies have highlighted both the proliferation of the phumdi and the subsequent decline in phumdi coverage that has been substantiated in Table 6. The present study also indicated the decline as the phumdi cover was estimated at 96.7 and 96.4 km^2 for 2017 and 2020, respectively. It indicated that the phumdi cover is declining, partly addressing the phumdi proliferation threat, as in 2002, it was 134.6 km^2 (Singh and Khundrakpam 2009).

Although it showed the effectiveness of the interventions under STAP towards this particular land class, the question remains of future practices. Further, coupled with the dynamic nature of phumdi and the need for baseline data, there is a gap in understanding the optimum level of phumdi coverage in the lake.

Changes in built up area

Previous wetland studies have shown an overall increase in built up area (Table 5). Our study also indicated an overall increase in built up area by 18.4% between 2009-2020, that may be due to conversion of other land class. It is higher than the 2.23% increase observed by Kangabam et al. (2019) between 1977-2015, that may be on account of differences in the composition of built up area. Further, conversion of other land classes (phumdi, agriculture) to fish farms, an increasing population observed at 28.56 lakh in 2011 compared to 2001, and Loktak lake as a major tourism hotspots may have contributed to the increase in built up area (Anonymous 2011).

However, mitigation strategies need to be explored since, with the increase in this particular land class, the pressure on the lake would be immense and indirectly contribute to deteriorating water quality. In this respect, the STAP is a short-term intervention mainly focused on the operationalisation of hatcheries and promotion of pen culture, with other interventions as a part of LTAP (Long Term Action Plan). Specifically, the LTAP had elements of sewage treatment and solid waste management, which would have remedied the spillover effluents and domestic waste that would accompany built-up areas such as housing complexes or fish farms (Anonymous 2009). For instance, fish feeds in fish farms may overflow into the lake due to flooding, leading to the proliferation of phumdi. However, the LTAP is currently not a part of any ongoing management plan as the preparation of an integrated management plan for the lake is under process.

Changes in agricultural land

Previous wetland studies have shown fluctuation when it comes to agriculture class (Table 5). The present study has shown an overall decrease in agriculture at 110.1% for 2009-2020 while Kangabam et al. (2019) have shown an overall increase at 10.27% for 1997-2015. The difference

Table 6. PAST LULC studies in Loktak lake

Timeline	**Area (km^2)**						**Reference**
	Water body	**Athaphum**	**Phumdi**	**Built up**	**Agriculture**	**Barren**	
1977	74.76	NA	156.57	5.6	10.33	NA	Kangabam et al. (2009)
1989	84.6	NA	116.4	84	*	2.0	Trisal and Manihar (2004)
1995	78.75	5	355.76	99.47	NA	NA	Singh et al. (2000)
2002	43.9	11.18	134.6	106.5	*	2.0	Trisal and Manihar (2004)
2004	26.34	38.41	119.78	69.91	8	3.54	Devi et al. (2004)
2015	101.65	NA	98.5	10. 91	35.66	NA	Kangabam et al. (2009)

*Provided as fish farm cum Agriculture; NA - not available observed is mainly due to conversion of inundated agricultural land into fish farms. It is also similar to the result observed by Devi et al (2004) that indicated increased fish yield observed from the converted fish farms.

In terms of specific interventions in STAP, LTAP and subsequent annual plans of the LDA, direct interventions were not marked out for this particular land class category (Anonymous 2005). Considering that the Bishnupur district under which Loktak lake falls has the highest cropping intensity, approximately 180%, among all the other districts, it is pertinent that management interventions make notes of the same. It is because although agriculture occupies the second least area among all the other land classes, the use of insecticides and pesticides, if not regulated or managed efficiently, can be harmful. It would not only lead to the eutrophication of the lake and, thereby, the proliferation of the phumdi. But also, bioaccumulation of the toxins, which adversely affect the health of the faunal component of the lake

Changes in barren land

Previous wetland studies have shown that this LULC class covers the least area and shows an increasing trend (Table 6). For instance, Devi et al. (2004) have shown it to occupy 3.54 km^2 while Trisal and Manihar (2002) have shown it at 2 km^2. The present study also indicated an increasing trend by 31.2% between 2009-2020 that may be due to conversion from other land classes (agriculture). However, a decrease between 2011-17 is also observed that may be explained due to fragmentation for building utilities such as houses.

The STAP and subsequent annual plans do not have direct management interventions for this land class. In view of the possibility of this particular land class being fragmented in the future owing to increasing population, safeguards may need to be put into practice

Fragmentation in phumdi

As seen from Figure 3, the phumdi cover across the timeline years shows a stable trajectory in terms of its cohesiveness that may be due to land cover changes in the peripheral regions, specifically conversion into fish farms. On the other hand, the fluctuation observed in the number of patches specifically in 2011 and 2020, is due to the use of phumdi while constructing athaphums by fisherman. It is corroborated by the increase in the athaphum land class in 2011 and 2020. The decrease in 2017, meanwhile, is due to the state drive to remove athaphum and phum huts as a part of the phumdi management activity under STAP.. Meanwhile, 2017 shows the least LPI that may be due to the phumdi management actions carried out as a part of the STAP interventions.

In light of the above, it is important that adaptive measures are put into place as the LULC mapping exercise has shown potential areas of management interventions. Considering the increase in built up area, concerned state departments, specifically Fishery Department can undertake census exercise to look into the extent of the fish farms in and around Loktak lake. Additionally, remote sensing can be utilised to geotagged these farms as well as athaphums for use as baseline indicators or data bank for driving future management actions. A study may also be carried out to determine the optimum coverage of phumdi as this is a significant resource providing multiple ecosystem services. Although the increase in the open water body and decreasing phumdi coverage in the central zone is a welcome improvement, it is vital to ensure that it is sustained.

CONCLUSIONS

The study showed the importance of considering the present and past land use of Loktak lake to help inform management planning. Our study also showed the gap in identifying baseline data, specifically phumdi cover, which would impact future management planning. Specifically, in landscape modelling, the absence of a reference point to base the result makes it difficult to compare. In this respect, future studies can develop a baseline on the optimum level or extent of phumdi that should be maintained. Moreover, scenario LULC analysis can also be conducted to ascertain possible outcomes, which can then be utilized in management planning.

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Authors' contributions: Both the authors contributed equally

Conflict of interest: Authors declare no conflict of interest

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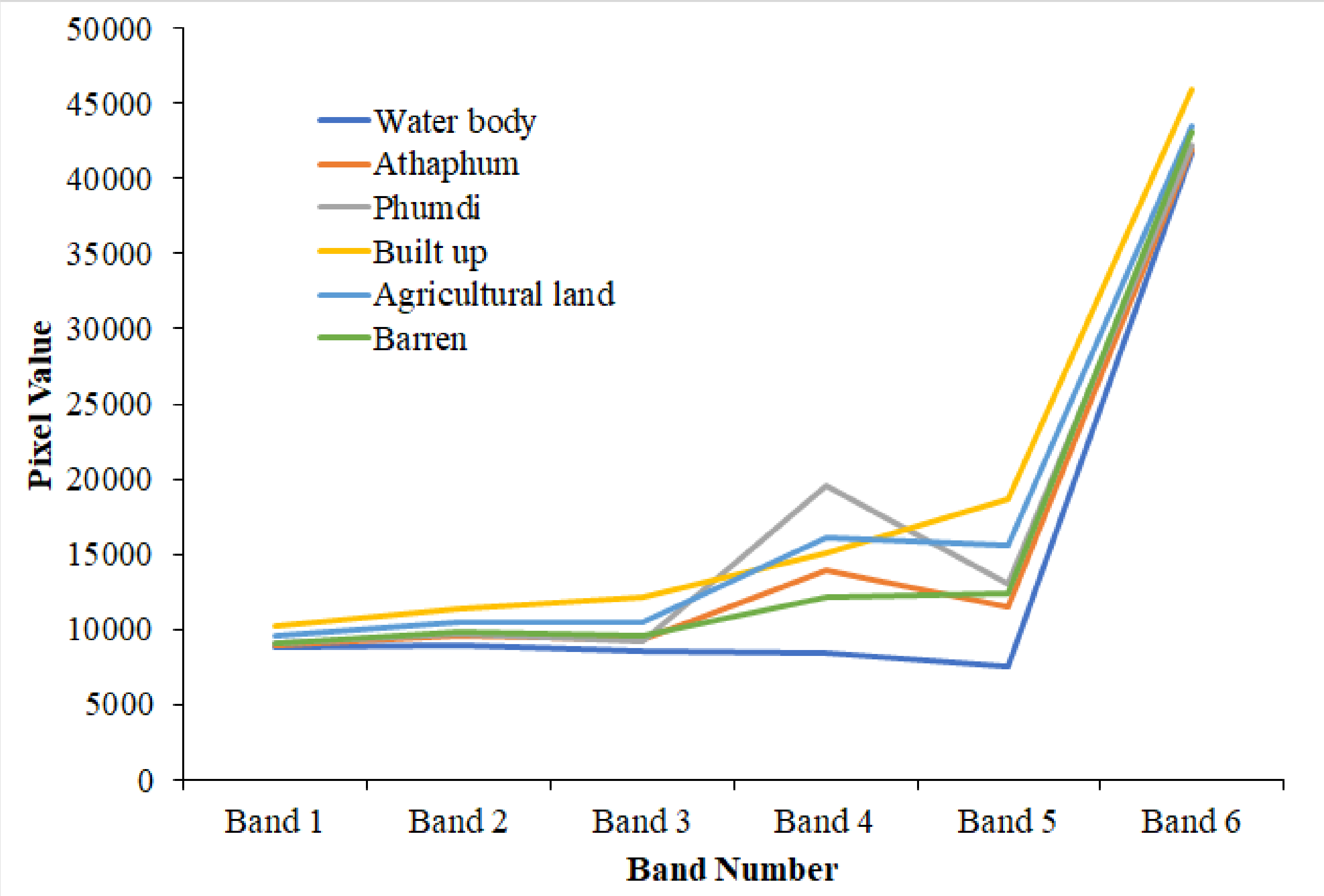

Suppementary figure 1. Spectral profile of LULC classes for Loktak lake