Research Article

Impact of 2014 Kashmir flood on land use/land cover transformation in Dal lake and its surroundings, Kashmir valley

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Abstract
Kashmir Valley has witnessed a catastrophic flood in 2014, which led thousands of people homeless and devastated the agricultural lands. In the present study, the impact of 2014 flood occurred during the month of September was analysed in the vicinity of Dal lake using the pre- and post-flood periods satellite observations. The study exhibited an inundation of 42.50 km^2 area (52.47% of total area) during September 2014 flood period, which is primarily topographical low-lying area (i.e. below 1530 m). The land use/land cover (LULC) analysis during pre- and post-flood periods exhibited significant impact over the built-up land with 20.4% decrease in the built-up (from 25.44 to 20.25 km^2), which was mostly evident in the western, southern and eastern parts of Dal lake. It has also severely affected the road network with inundation of 220.84 kms (55.62% of total road network). The road network in the lower elevation (< 1530 m) not only disrupted but also acted as a carrier for the flood water dispersal in the region. The long-term impact and recovery of flood inundation were assessed using spatio-temporal built-up growth during 2014, 2015 and 2018 within the flooded zone through geospatial overlay analysis. The flood (September 2014) affected a total 10.42 km^2 of built-up, wherein the built-up was reduced to 7.50 km^2, due to the low-lying topography and nearest proximity to flow path of Jhelum river. Later, the built-up was increased to 9.60 km^2 within the flooded zone during 2018 primarily in the southern parts, representing the long-term recovery after the flood aftermath. Although the impact of flood (2014) was evident in both the flooded and non-flooded zones, the built-up growth was reduced significantly in the flooded zone (– 25.18% change) as compared to non-flooded zones (– 17.32% change). Also, the long-term recovery was comparatively higher in the non-flooded zone (31.84% growth) as compared to the flooded zone (28.03% growth). The study necessitates towards implication of effective urban planning method primarily along the major lakes in order to reduce the increasing impact of catastrophic flood.

Keywords Dal lake · Flood inundation · LULC · Built-up growth · Recovery

1 Introduction

The lakes in the world are facing the tremendous environmental problems due to combination of rapid urbanization and natural hazards [25, 55, 77]. The lakes contribute an important role in ecological balance as well as serve as a primary source for local economy, cultural heritage and socio-economic values. The major lakes of the world are affected by eutrophication affecting the lake ecosystem [60]. There are several lakes (Dal, Anchar, Khanpur, Manasbal, Naranbagh, Pashkuri, Tilwan, Trigam, Waskur and Wular) located in Kashmir valley (Western Himalayas) at high altitude (1510–1600 m) [84]. The structural and functional process of these aquatic ecosystem has been the major attraction for the researchers [32, 33, 35, 75, 85]. Dal lake is multi-basined-shaped lake located in Srinagar city, Kashmir valley. It is one of the major sources of irrigation and economy including floating gardens for fresh

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vegetables and flowers and referred as urban type lake [29]. Rapid urban growth intensified agricultural practices, disposal of municipal drainage and sewage has altered the aquatic ecosystem in the Dal lake, which results rapid increase in eutrophication and pollution in the lake [34, 35, 82].

Nevertheless, flood has emerged as important threat, affecting large area and population around the world [53]. More than 75% of natural hazard occur worldwide due to flooding with often immeasurable impact, affecting 170 million. people annually [36]. Floods are the natural disasters causing enormous damage to the mankind and environment throughout the globe [76]. Being integral part of hydrological cycle, floods occur due to heavy precipitation and / or extreme flows of rivers inundating the neighbouring floodplains or terrains [5, 26, 41]. About 82% population of world and one-third of the total landscape of earth is prone to flood [19, 54]. Though flood over the aquatic vegetation was observed to be a natural process, which rejuvenates lake ecosystem with rich sediments [1, 2, 81]. The change in climate has evident as increase in global temperature coupled with anthropogenic influence and aggravated the impact of floods [8, 46, 64, 83]. It has been reported that the flood also occurs due to manmade rampant alteration on the natural landscape, loss of wetlands and deforestation [20, 43, 56, 57]. In recent decades, the short incidence of high flood intensity has increased due to changing climatic condition [11, 44]. As the climate shapes the earth being a major force, the frequent occurrence of extreme events has increased and will continue to create devastation with greater force in the coming decades [21, 24, 30, 73]. Climate change in the mountain areas is significant, which can be observed as increasing temperature, receding glaciers, and decreasing precipitation [15].

Resilience to potential environmental disasters can be increased through proper urban land use planning [78]. In this, geoinformatics has emerged extensively been used to monitor flood inundation and preparation of management plans [39, 59, 70, 76] urban studies [18, 28, 45, 74] monitoring of flood control, drainage improvement and bank protections, etc. [16, 27, 79]. Satellite-based flood inundation mapping provides accurate information about the inundation, which can be used to estimate the inundated area [3, 10, 49] monitoring flood inundation as well as supports in quick response in mitigation [7, 39, 51, 69]. Geoinformation science also contributes to flood hazard risk zonation as well as modelling to understand the dynamics of increasing flood episodes in various physiographical regions.

In India, about one-eighth of total area in Indo-Gangetic Plains (IGP) are prone to floods [23, 50, 66], which is increasing rapidly with 0.014 million. hectare/year [40, 71]. The incidence of cataclysmic flood in the mountainous regions has been increased throughout the globe in the last few decades [37, 68].

The location of Srinagar city in the flood plains of Jhelum basin makes it the most vulnerable to flood hazards [4, 48, 67]. Further, the region has fragile ecosystem and is extremely sensitive to global climatic variability [52]. The rapid urbanization and filling of wetlands in the city vicinity have significantly altered the natural setup which leads to urban flood situation [4, 63]. The analysis of historical meteorological data exhibited excessive precipitation is the main cause of floods in this region [38, 47]. Flash floods are often occurring in the mountain basin, which provides insufficient time to warning leading to high devastation and loss of life [12].

In 2014, catastrophic flood in Kashmir valley leads to colossal loss lives of more than 100 people along with economic loss of INR 1 trillion [80]. This was the worst flood witnessed in last 50 years in the region, which highlights the inability of the drainage system to handle the heavy discharge from Jhelum River as it was flowing 1.2 m above the danger mark [3, 10, 31]. Due to the absence of any diversion for the excess water at the floodgates near Rammunshi bagh, it leads to large increase in water in Dal lake [65]. The heavy rain leads to overspill of the Jhelum river beyond its course induced the pressure in the flood plain and neighbouring low-lying areas [9]. It has affected 2.2 million. people residing in 287 villages of Kashmir valley. The long duration (~ 2 weeks) inundation in the northern and central part of Kashmir valley made the conditions worst [10]. The built-up and agricultural land along Jhelum and lake environment was affected due to 2014 flood in Srinagar [1, 2]. Being in the central part of the Srinagar city, Dal lake was overloaded due to high precipitation and overflow of excess water inundated the surrounding built-up [22]. Therefore, in the present study, the impact of 2014 flood on the Dal lake environment was analysed using spatio-temporal satellite datasets. Also, the short and long-term recovery was evaluated using temporal satellite observations to deduce comprehensive implication of 2014 flood on Dal lake environs.

2 Study area

In the present study, Dal lake and its vicinity, Kashmir Valley, Western Himalayas was considered as study area (Fig. 1). The study area lies between 34° 06′ to 34° 16′ N latitude and 74° 79′ to 74° 90′ E longitudes at an average elevation of 1586 m above mean sea level comprising 81 km^2 of area. Dal lake covers ~ 20 km^2 area and is located at the foot of Zabarwan mountains and surrounded by Shankaracharya hill to the east and Kohi-Maran hills on

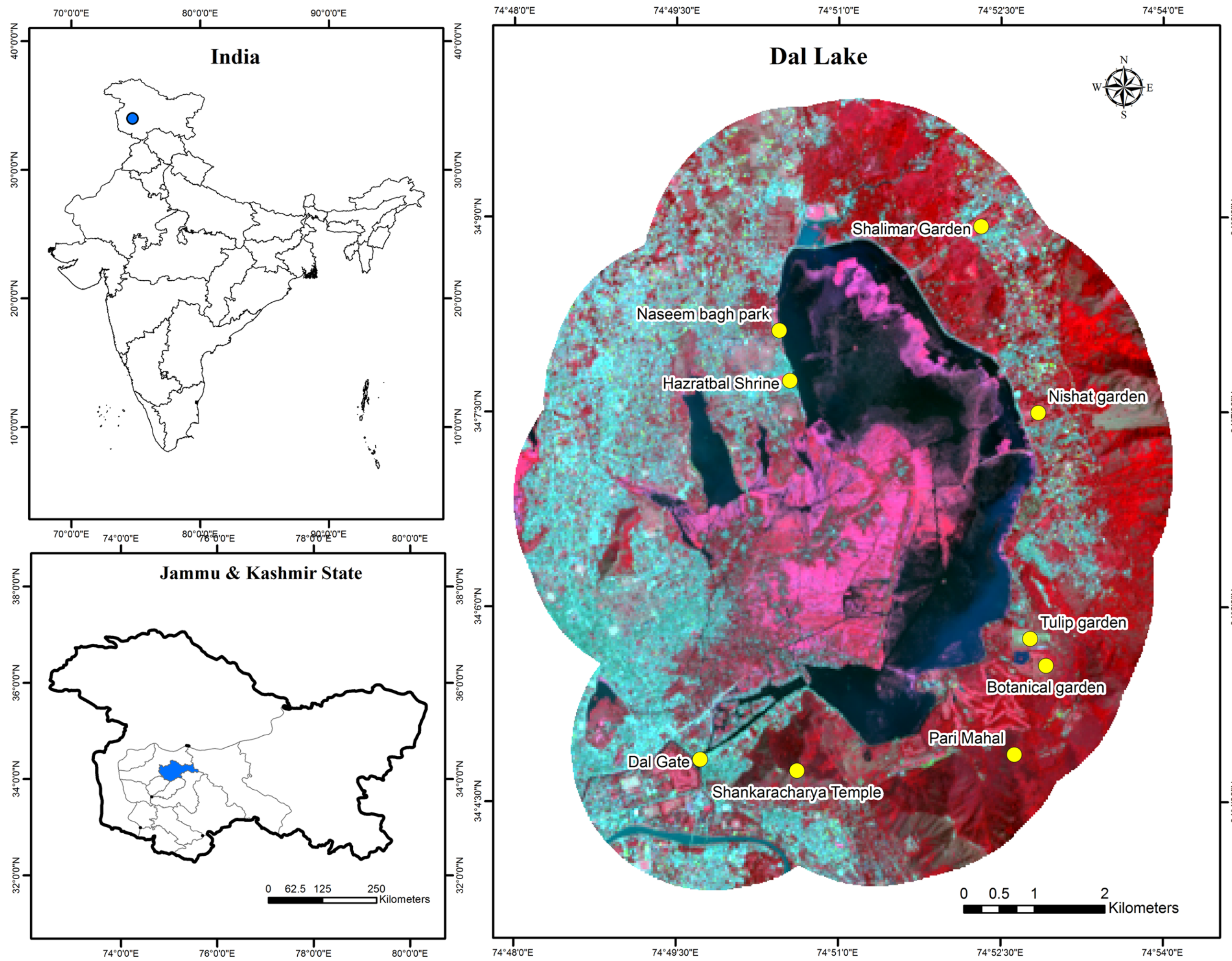

Fig. 1 Location map of Dal lake and its surroundings

the west [84]. It was formed as the ox-bow of the River Jhelum due to progressive shrinkage of a glacial lake [14, 18]. It is lake is surrounded by the road network from three sides. The major inflow in Dal lake receives from Telbal Nallah, whereas outflow through a weir and lock system located at Dal gate. Telbal Nallah is the main source of water in the Dachigam territory. The maximum depth of Dal lake is 6.5 m and average depth is under 3 m. The permanent source of water in the lake is due to the presence of multi-springs [42]. The precipitation in the Dal lake and surroundings receives in the form of snow in winter and rain in remaining seasons. The region receives an average annual rainfall of 655 mm and the temperatures range from 1 to 11 and 12 to 30 °C during winter and summer seasons, respectively [72]. The Dal lake is properly connected from all possible directions by roadways, whereas south-western part is directly linked to the major urban centre. A number of gardens like Nishat garden, Shalimar garden, Naseem bagh park, Tulip garden, Pari Mahal, Botanical garden and different religious places like Hazratbal shrine, Shankaracharya temple, etc., found on the periphery of Dal lake. Rapid urbanization has become challenge as excessive growth of water weeds and deterioration of water quality due to discharge of large quantities of waste from human built-up including house boats, agricultural land and the ecological stress. Dal lake is affected by the dense growth of macrophytes which leads to heavy mineral loading due to cultural eutrophication. The urban centre (Srinagar) accommodates 1,236,829 persons with 53% of male and 47% of female population [13]. During the last 42 years (1972–2014), the concomitant population growth in the Srinagar city was 224% [4]. The economy of the city is basically dependent on tourism and agriculture. The work force participation rate (WFPR) of gainfully occupied persons for the Srinagar city is 26% [13].

Table 1 Details of satellite data used in the study

Name of satellite	Sensor	Date of acquisition	Spatial resolution (m)
LANDSAT 7[a,b]	ETM +	25 Aug 2014	30
LANDSAT 8[a,b]	OLI	10 Sept 2014	30
LANDSAT 8[a,b]	OLI	13 Sept 2015	30
Sentinel 2A[a,b]	MSI	25 Oct 2018	10
Cartosat 1[a,c] DEM	Stereo data (fore & aft)	24 Sept 2006	10

[a]Path and row: 92/46

[b]*Source*: https://glovis.usgs.gov

[c]*Source*: NRSC (ISRO)

3 Data and methodology

In the present study, the impact of flood (10 September 2014) on land use/land cover (LULC) of Dal lake and its surrounding was analysed during the pre- and post-flood periods using temporal satellite datasets (Table 1). The LULC map was prepared using LANDSAT satellite images of pre- flood (25 August 2014), during flood (10 September 2014), and post-flood (13 September 2015 and 25 October 2018) periods, which were acquired from USGS website (https://glovis.usgs.gov). The outer buffer of 2 kms was created around the Dal lake for delineating the study area. The supervised classification technique was performed on the satellite images of 25 August 2014 and 13 September 2015 using maximum likelihood classifier, in which a pixel with the maximum likelihood is classified into corresponding class [62]. The supervised classification was performed by taking number of training sets for assigning the signature editor. The quality of a supervised classification technique basically depends on the validity of the training sets [58]. Therefore, in this study, 45 training sets were selected considering all LULC classification with minimum of 20 pixels for each training set. The region was classified into six LULC class, viz., terrestrial vegetation, aquatic vegetation, agriculture, built-up, water bodies and others. The terrestrial vegetation includes evergreen forest, semi-evergreen forest, and scrub forest. The agriculture class includes cultivated areas, plantation, and fallow land. All the vegetation grown within the water bodies (hydrophytes) considered under aquatic vegetation class. The built-up class incorporates built-up area including buildings, transport, etc. The surface water bodies including lakes, ponds, river, reservoirs, etc., were categorized under waterbodies. And the remaining areas including wasteland, barren land, sandy area, rock out crops, etc., were categorized under "others" class. To map the inundation, the two classes, *namely* land and water classes, were generated for the satellite image of 10 September 2014. The satellite image dated 25 October 2018 was used to delineate the built-up area of 2018. The satellite image dated 10 September 2014 was used to map flood water and correlated with LULC maps. The Kappa coefficient and overall accuracy were established method for assessing the accuracy of land use classifications [61], and therefore the Kappa coefficient and overall accuracy were determined using the following formulae:

$$\text{Kappa coefficient } (\hat{K}) = \frac{n\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+}x_{+i})}{n^2 - \sum_{i=1}^{r}(x_{i+}x_{+i})}$$

where r is the number of rows in the matrix, x_{ii} is the number of observations in row i and column i, x_{i+} and x_{+i} are marginal totals for row i and column i, respectively, and n is the total number of observations (pixels).

$$\text{Overall accuracy} = \frac{\sum_{i=1}^{r} x_{ii}}{x}$$

where x_{ii} is the diagonal elements in the error matrix, and x is the total number of samples in error matrix.

The overall accuracy was calculated for the LULC maps based on selective field checks during the month of March 2018 as well as using Google Earth images. The overall accuracy for each map (dated 25 August 2014, 10 September 2014, 13 September 2015 and 25 October 2018) was ranging between 92% to 95% with the Kappa Coefficient range of 0.6901 to 0.8814 (Table 2). The accuracy obtained for all the four raster layers is acceptable so the results obtained can be used for further calculations [6]. The wrong identified pixels were corrected and area calculation was performed. The stereo satellite image of Cartosat-1 during 24 September 2006 was acquired from NRSC (National Remote Sensing Centre) and was used to prepare digital elevation model of 10 m spatial resolution. The region was classified into various elevation zones, viz., very low (< 1530), low (1530–1550), medium (1550–1560) and high (> 1600). The flood inundation as well as DEM was spatially correlated with built-up of September 2015 and October 2018 to map the long and short-term recovery

Table 2 Accuracy assessment of LULC maps of 25 August 2014, 10 September 2014, 13 September 2015 and 25 October 2018

LULC classification	Overall accuracy (%)	Kappa coefficient
25 Aug 2014	92.00	0.8002
10 Sept 2014 (flood)	94.00	0.6901
13 Sept 2015	95.00	0.8814
25 Oct 2018	94.00	0.8604

after 2014 flood. The methodology adopted in the present study is given below in the flowchart (Fig. 2).

4 Results and discussion

In the present study, the Kashmir flood inundation (occurred during September 2014) in and around Dal lake and its impact on varied land use/land cover were analysed. Later, the built-up growth dynamics during 2015 and 2018 within the inundated zone was evaluated to deduce the recovery in the Dal lake environment.

4.1 Flood inundation mapping

The LANDSAT OLI satellite image of 10 September 2014-based assessment of flood inundation exhibited that the ~ 42.50 km^2 (52.47% of total area) area was affected due to flood inundation (Fig. 3). The inundation was primarily observed in the northern, southern, western, and south-western parts. In contrast, the area located in the eastern and south-eastern parts comprising of 38.50 km^2 (47.53%) was not affected by inundation due to its geographical location at higher elevation (Table 3). The level of inundation was correlated with DEM-based relief of the region. The result indicated that the majority of the area (41.14 km^2; 86% of total area) below the elevation 1530 m (47.62 km^2) was inundated during 2014 flood, which is equivalent to 96% (42.50 km^2) of total inundation in the Dal lake and its vicinity. This signifies that the 2014 flood was limited to the elevation of ~ 1530 m in the region.

4.2 Flood impacts on land use/land cover

The pre-flood LULC based on LANDSAT 7 ETM$^+$ (dated 25 August 2014) exhibits that built-up (25.44 km^2; 31.4%) was the dominant land use followed by agriculture (20.93 km^2; 25.8%), terrestrial vegetation (12.10 km^2; 14.9%) and water bodies (12.31 km^2; 15.2%) (Table 4 and Fig. 4 (a.1 and a.2)). The aquatic vegetation (6.73 km^2; 8.31%) and others (3.25 km^2; 4%) were comprised of very less area. The post-flood LULC based on LANDSAT 8 OLI (13 September 2015) exhibited that agriculture was the dominated land use (20.82 km^2) followed by built-up (20.25 km^2; 25%), terrestrial vegetation (15.44 km^2), aquatic vegetation (8.37 km^2) and others (3.88 km^2) LULC classes.

The pre- and post-flood LULC exhibited the significant decrease in built-up area (from 25.44 km^2 to 20.25 km^2) during the period, which was primarily evident in the western, southern and eastern parts of Dal lake, where

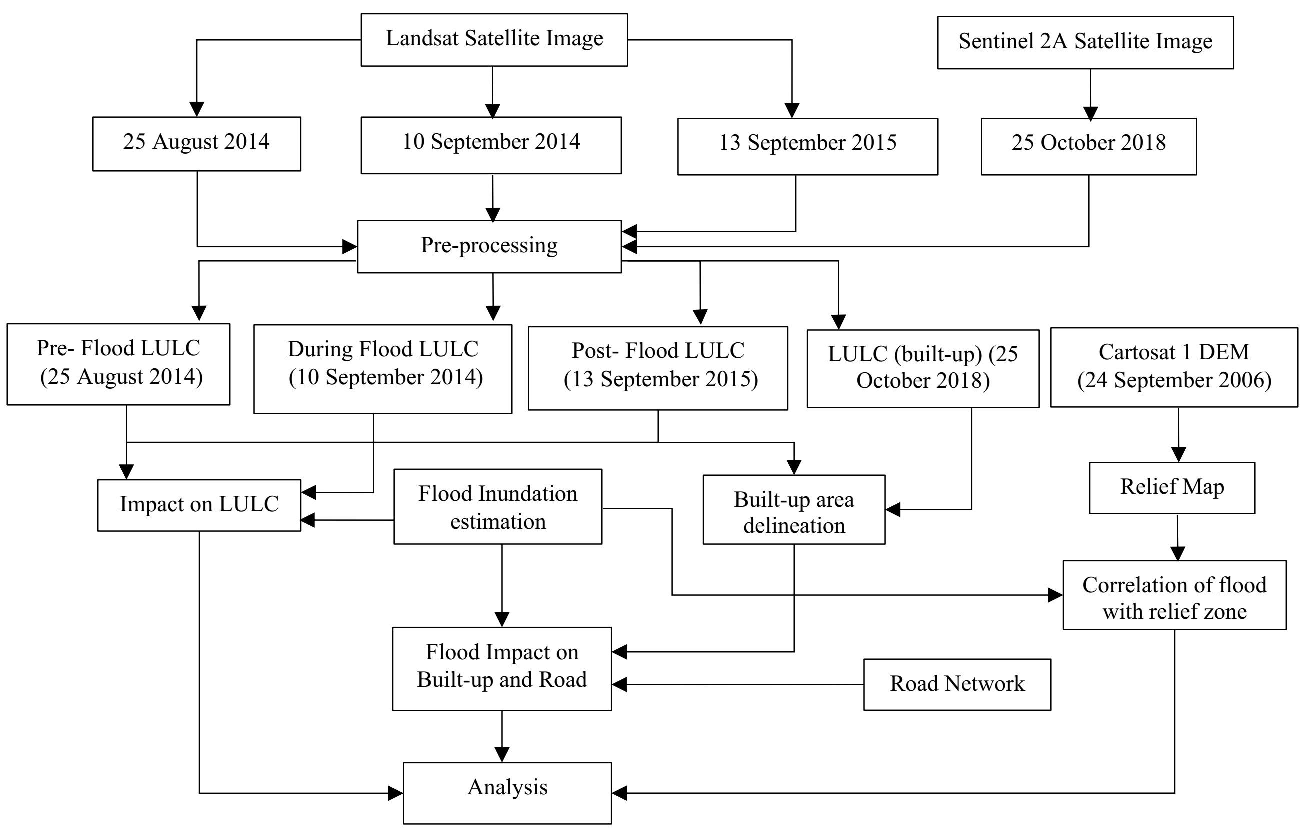

Fig. 2 Flow chart of the methodology

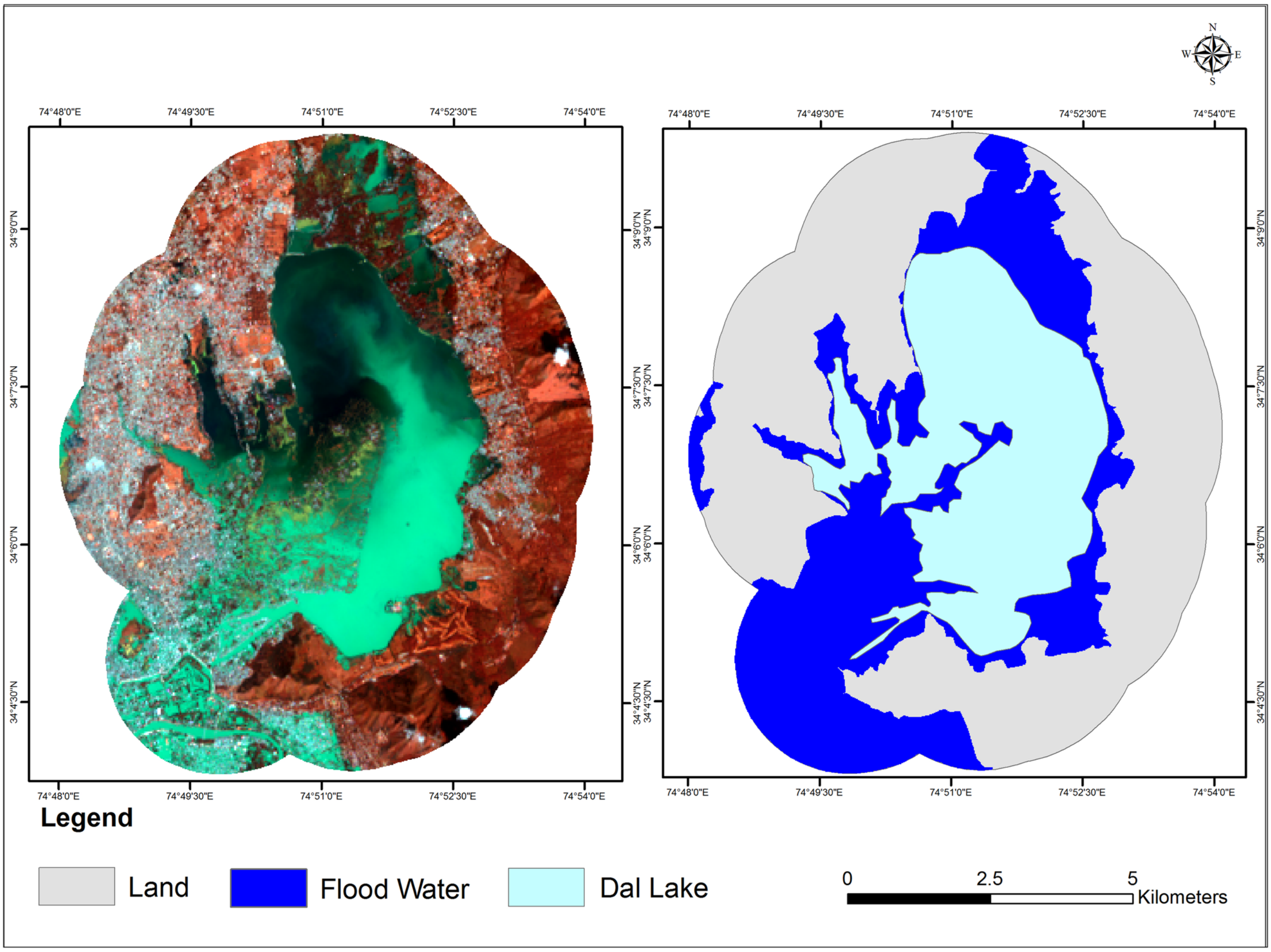

Fig. 3 Flood water inundation in the Dal lake and its surroundings along with the satellite image (Landsat 8 OLI) during 10 September 2014

Table 3 Flood water coverage area during flood period as on 10 September 2014

Class	Area in km^2	% of Total area
Inundated area	42.50	52.47
Non-inundated area	38.50	47.53
	81.00	100

the considerable proportion of built-up was reduced. In contrast, the floods impact was very less on agricultural land (0.11 km^2) and waterbodies (0.29 km^2). Also, the significant to minor increase in terrestrial vegetation (3.34 km^2; 27.6%), aquatic vegetation (1.64 km^2; 24.2%) and others (0.63 km^2; 19.4%) were evident. The impact of flood on built-up area was evident as the flood water impression on the buildings primarily observed in the southern part of the Dal lake observed during the field verification (Figs. 5f, 6).

The impact of flood (2014) was also observed on the transportation network in the Dal lake and its vicinity. The study exhibited a total road length of 220.84 kms (55.62% of total road network) including National Highway, and streets were inundation during September 2014, which was observed primarily in the southern part of the Dal lake (Fig. 5e**).** The inundation leads to catastrophic situation in the region by distrusting and damaging all the transportation communication primarily the roads located at the lower elevation (< 1530 m), which also acted as a carrier for the flood water dispersal in the built-up area [4].

4.3 Assessing long-term recovery after 2014 flood

The long-term impact and recovery of flood inundation were assessed using spatio-temporal built-up growth during 2014, 2015 and 2018 within the flooded zone through geospatial overlay analysis. The flood (September 2014) has affected total 10.42 km^2 of built-up, wherein the built-up was reduced to 7.50 km^2, which was primarily evident

Table 4 Land use/land cover statistics of Dal lake during pre-flood period (25 August 2014) and post-flood period (13 September 2015)

LULC classes	Pre-flood		Post-flood		Flood impact on LULC (Post 2015–Pre 2014)	% Change[a]
	LULC 2014 (km^2)	% of Total area	LULC 2015 (km^2)	% of Total area		
Terrestrial vegetation	12.10	14.94	15.44	19.06	3.34	27.58
Aquatic vegetation	6.73	8.31	8.37	10.33	1.64	24.28
Agricultural land	20.93	25.84	20.82	25.70	– 0.11	– 0.57
Built-up	25.44	31.40	20.25	25.00	– 5.19	– 20.40
Others	3.25	4.01	3.88	4.79	0.63	19.48
Water bodies	12.31	15.20	12.02	14.83	– 0.29	– 2.42
	81.00	100.00	81.00	100.00		

[a](% change = ((recent – previous)/previous) * 100)

in the southern and south-western parts of the Dal lake due to the low-lying topography and nearest proximity to flow path of Jhelum river (Fig. 5a). This may be attributed to the direct impact of inundation on built-up led the marooned population to shift to more safer places. Later, the built-up was increased to 9.60 km^2 within the flooded zone during 2018 primarily in the southern parts, representing the long-term recovery after the flood aftermath (Tables 5, 6).

It is to note that the built-up outside the flooded zone was 15.42 km^2 during the pre-flood period, which was reduced to 12.75 km^2 considering the probability of flood hazard in the region. Later, the built-up outside the flooded zone was increased to 16.81 during 2018, representing the natural built-up growth in the safer locations. Although the impact of flood (2014) was evident in both the flooded and non-flooded zones, the built-up growth was reduced significantly in the flooded zone (– 25.18% change) as compared to non-flooded zones (– 17.32% change). Also, the long-term recovery was comparatively higher in the non-flooded zone (31.84% growth) as compared to the flooded zone (28.03% growth) (Table 7).

Although the nature of flood was very devastating, the high influx of population led to built-up growth in the higher flood risk zone, which were considered relatively more suitable for the growth of built-up and having irregular occurrence of such as severe flood incidences. It is to note that the flood-affected areas were the active flood plain of Jhelum river, which were encroached by rapid built-up growth.

5 Conclusion

The Kashmir flood (September 2014) has severely affected primarily the low lying regions around Dal lake. A total of 52.47% (42.50 km^2) area in the Dal lake and its vicinity were inundated. The considerable and immediate impact of flood was evident on the built-up land, which was decreased by 20% (25.44–20.25 km^2) during observed during pre-flood (25 August 2014) and post-flood (13 September 2015) assessment. In contrast, the area coverage of terrestrial vegetation (28% growth) and aquatic vegetation was increased (19% growth) due to flood inundation in the region. It also disrupted the major length of road network (220 kms; 55.62%) including National Highway and streets in the region. The long-term impact and recovery of flood inundation using spatio-temporal built-up growth within the flooded zone exhibited comparatively higher built-up recovery in the non-flooded zone (31.84% growth) as compared to the flooded zone (28.03% growth). The relief-based analysis indicated that the region below the elevation of 1530 m was almost completely inundated (96%; 42.50 km^2) during the 2014 Kashmir flood. The population mostly residing in the higher flood-risk zone near the lake were considered relatively more suitable for built-up growth. The future built-up should be constructed away from the flood margin, preferably to the higher elevated (> 1530 m) region. As flooding is very frequent in Kashmir valley of varied intensity, therefore an adequate drainage system should be made to channelize the storm water

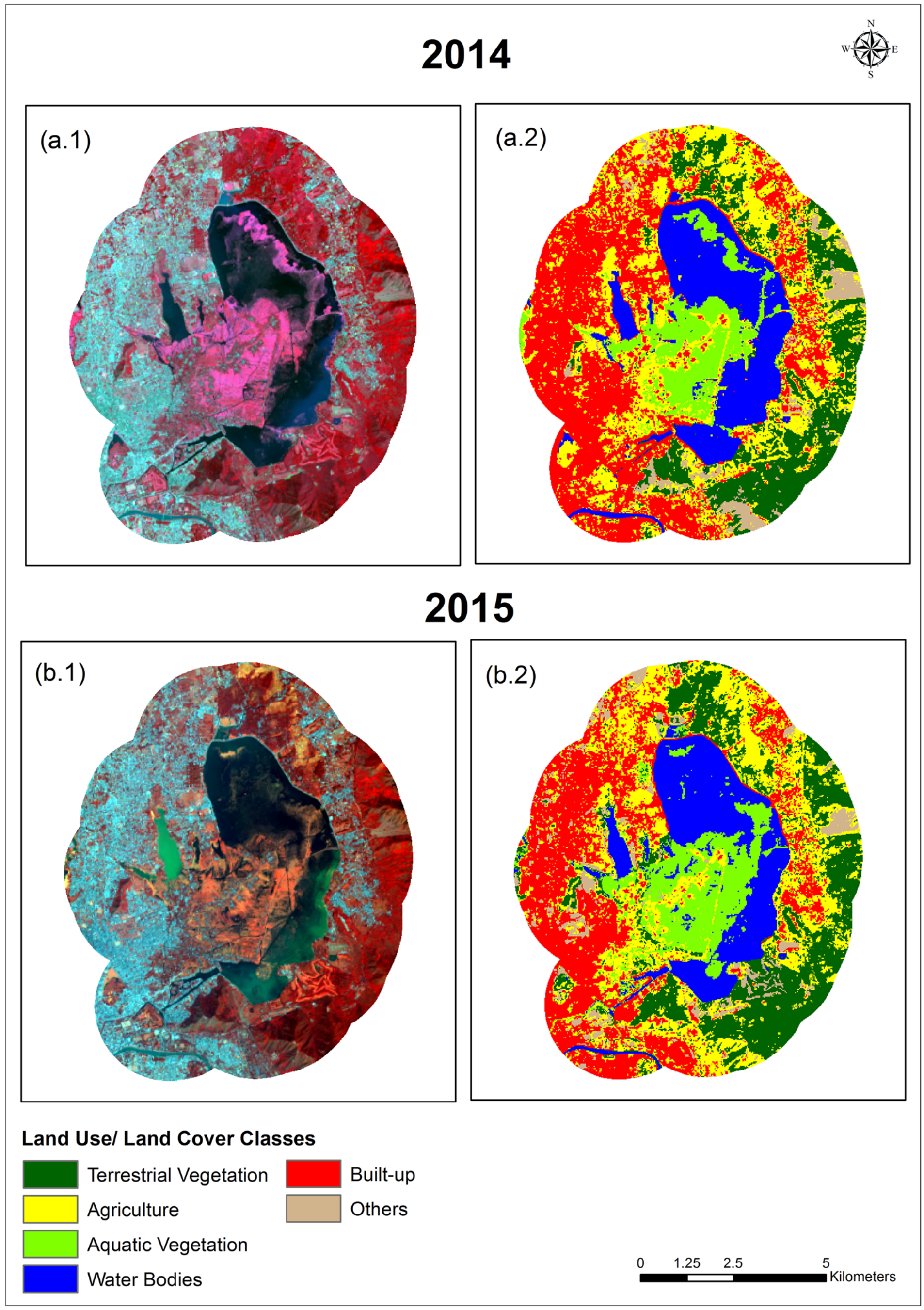

Fig. 4 Satellite image of 25 August 2014 (**a.1**) and 13 September 2015 (**b.1**) along with its corresponding land use/ land cover maps (**a.2**, **b.2**)

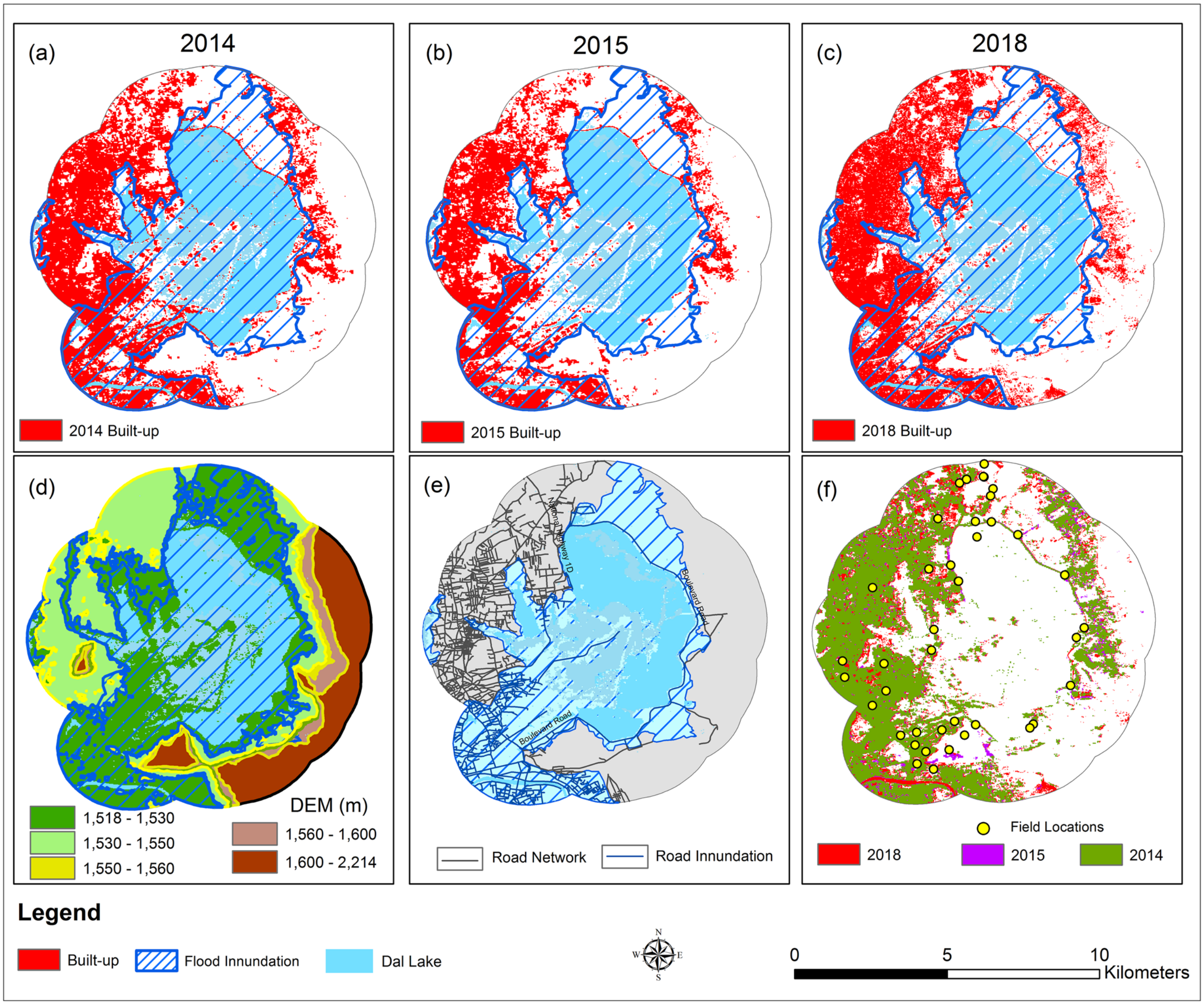

Fig. 5 Impact assessment of flood inundation (2014) on built-up area during 2014 (**a**), 2015 (**b**) and 2018 (**c**), digital elevation model (**d**), road network (**e**), and built-up dynamics during 2014–2018 (**f**)

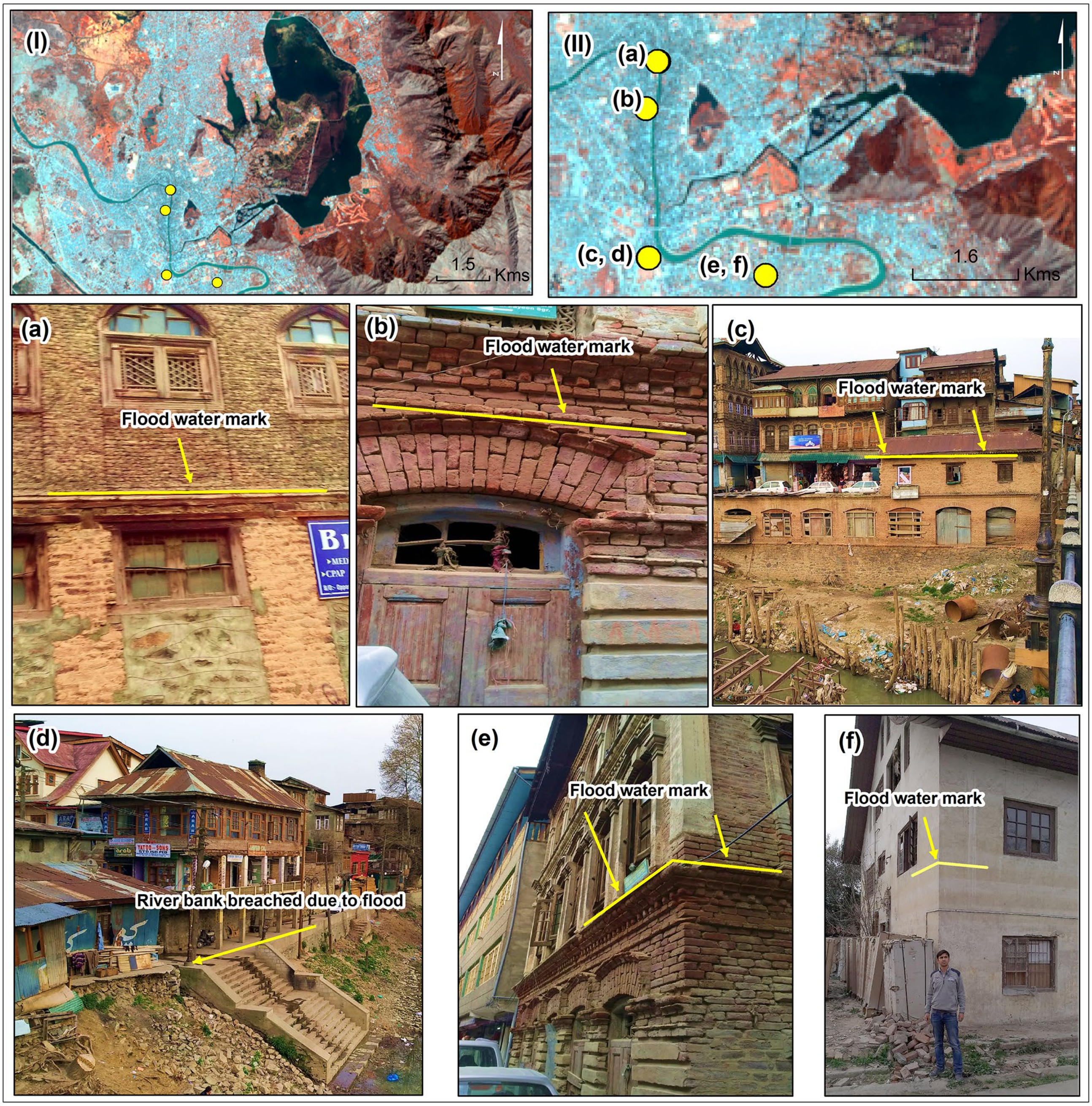

Fig. 6 Flood impression on the buildings within the Srinagar city (**a**, **b**, **c**, **e**, **f**) and breaching of river bank due to flood (**d**) and corresponding locations on the Satellite image (I and II)

Table 5 Built-up during 25 October 2018 with reference to 2014 flood inundated area (10 September 2014) in the Dal lake and its surroundings

Built-up area (km^2)	Area (km^2)	% area of total area
During 2018	26.41	32.60
Within inundation zone during 2014	9.60	42.50

during such flood to safeguard population from flood devastation. The temporal monitoring over the Dal lake should be performed, and measures should be taken to clean the lake environment to reduce eutrophication which will also increase the water holding capacity of lake. Numerous natural wetlands in the Kashmir valley may be rejuvenated and preserved to reduce the increasing impact of flood inundation.

Table 6 Built-up area in flooded and non-flooded zone

Year	Inundated		Non-Inundated		Total	
	Area in km^2	% change	Area in km^2	% change	Area in km^2	% change
2014	10.02		15.42		25.44	
2015	7.50	−25.18	12.75	−17.32	20.25	−42.49
2018	9.60	28.03	16.81	31.84	26.41	59.88

Table 7 Area statistics below the elevation of 1530 m and its relation with flood inundation (10 September 2014) and built-up (25 October 2018)

Class	Total area below 1530 m elevation	Inundation below 1530 m elevation		Total area in the Dal lake and its vicinity	
	Area in km^2	Area in km^2	% of total (*A*)	Area in km^2	% of total (*D*)
	A	*B*	$C = B/A * 100$	*D*	$E = B/D * 100$ (%)
Flooded area (10 Sept 2014)	47.62	41.14	86.39%	42.50	96.8
Built-up (25 Oct 2018)	12.78	3.78	29.58%	26.41	14.31

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Compliance with ethical standards

Conflict of interest There is no conflict of interest (financial or non-financial). The work done in this paper involves satellite images which are freely available or purchased from NRSC (ISRO) and authors informed or accepted the conditions from the different sources.

Human and animal rights There is no human or animal participation during this study.

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