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ORIGINAL PAPER

High-resolution earth observation data for assessing the impact of land system changes on wetland health in Kashmir Himalaya, India

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Abstract
Wetlands in Kashmir are showing myriad signs of deterioration. In the present study, we assessed the spatio-temporal variations in the land use land cover of a semi-urban Narkara wetland, Kashmir, using high-resolution satellite data of 1965, 1980, and 2016. We also analyzed the impact of land system changes on the health Narkara wetland by estimating soil loss in the catchment of Narkara wetland using Revised Universal Soil Loss Equation (RUSLE) in GIS during the observation period. The land system changes indicated a massive increase of ~2663% in built-up area, while the area under agriculture showed ~78% decrease between 1965 and 2016. Small insignificant changes were manifest in other land cover types as well. The soil erosion estimates for the wetland catchment for 1965, 1980, and 2016 indicate 106.33 t ha^{-1} soil detachment for 1965, 120.21 t ha^{-1} for 1980, and 62.16 t ha^{-1} for 2016. This significant reduction in the soil erosion is attributed to the barren lands and agriculture being taken over by built-up area between 1980 and 2016. The reckless urbanization both within Narkara and its catchment not only affects the hydrology and ecology of this important semi-urban wetland but also increases vulnerability of people to flooding in this part of Himalaya.

Keywords Land system changes · Wetland health · RUSLE · Remote sensing · GIS · Narkara · Kashmir Himalaya

Introduction

Wetlands are among the most threatened habitats of the world (Vörösmarty et al. 2010). Wetlands in India, as elsewhere, are increasingly facing several anthropogenic pressures (Ozesmi and Bauer 2002; Dhillon and Mishra 2014). The rapidly expanding human population (Keddy 2010), large-scale changes in land use and land cover (Jenerette and Wu 2001), unplanned infrastructure development and encroachment (Romshoo and Rashid, 2014), landscape degradation (Joshi et al. 2002), and water pollution (Najar and Khan 2012) affect the health of wetlands. These anthropogenic pressures have accelerated the wetland degradation by impairing their ecohydrological and socioeconomic functionalities (Bourgeau-Chavez et al. 2001).

Different wetland types, due to their location, are affected by multiple drivers of change and therefore require tailored approaches to address human impacts (Zedler and Kercher 2005). Any alteration in the hydrological and sedimentation regimes results in wetland degradation. Urbanization increases run-off peak flows and total flow volumes, and deteriorates the otherwise pristine water besides affecting the esthetic setting through conversion of wetland area into impervious surfaces (Azous and Horner 2000; Romshoo et al. 2012). The intensities of these anthropogenic disturbances vary along different spatial and temporal scales (Chopra et al. 2001; Lindegarth and Hoskin 2001; Rashid and Romshoo 2013). These anthropogenic impacts lead to increased sediment loads (Badar et al. 2013a; Jain et al. 2001; Prachansri 2007; Romshoo and Muslim 2011; Zhou et al. 2008), water quality deterioration (Rashid et al. 2017b), and changes in aquatic biodiversity (Khan et al. 2004) thereby affecting wetland health. In addition, the rising temperatures in Kashmir have adversely affected the snow cover distribution and associated hydrological regimes that have a direct bearing on wetland hydrology (Fowler and Archer 2006; Rashid et al. 2017c; Rashid and Majeed 2018). There is no change in the annual precipitation (Rashid et al. 2015);

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however, owing to the rising temperatures, the form of winter precipitation is speculated to have changed (Romshoo et al. 2015). Due to human-induced modification, the natural wetland landscapes also are under acute pressures (Rashid et al. 2013). Wetland areas across Kashmir have been gradually squeezing affecting the buffering capacity of these ecosystems to withhold flood waters and storm water runoff (Rashid and Naseem 2007). This was clearly manifested during the 2014 devastating flood when residential area of the outskirts of capital city Srinagar, which used to be traditional floodplain, was inundated for more than 3 weeks in flood waters (Romshoo et al. 2017). The problem of wetland degradation in the region is further exacerbated by ill-conceived policy mechanism and lenient legal framework.

Keeping this in context, our study assessed the land system changes in and around Narkara wetland over 52 years between 1965 and 2016 by using high-resolution earth observation data. To our knowledge, it is for the first time that high-resolution satellite data has been used for assessing historical changes in land use land cover of a wetland in Kashmir region. The present study covers important aspects of monitoring the wetland health by assessing the catchment-scale land system changes and impact of such changes on soil erosion. The present is significant keeping in view the brunt of reckless unplanned urbanization (goo.gl/t4oScU) that Narkara wetland is facing and also that no major scientific work has reported historical changes in the land system of this semi-urban wetland.

Material and methods

Study area

Narkara wetland is located in the south western outskirts of Srinagar, the capital of north most state of India, Jammu and Kashmir (Fig. 1). The wetland catchment, spread over an area of 40.19 km^2, is located between geographical coordinates 34°03′03″–33°02′30″ N latitude and 74°46′10″–74°45′54″ E longitude with altitude range from 1558 to 1678 m amsl. It receives the waters from Sukhnag nallah, a left bank tributary of Jhelum River. The catchment of Narkara is predominantly a semi-urban setting with a lot of area under settlements, agricultural fields and table lands locally called *karewas* which are barren denuded landscapes. The wetland is a breeding ground for water fowl species that migrate from Russia and Central Asia especially during winters. Over the last few decades, the massive unplanned urbanization and encroachments have resulted into a substantial area under marshland getting converted into concrete built-up areas.

Data sets

A repository of high-resolution earth observation data, meteorological data, soil data, ground truth, and field photographs have been analyzed in GIS to accomplish this study. The details of these datasets are provided in Table 1.

Image geometric correction

The high-resolution IKONOS data (0.5 m) of 2016 comes up as georeferenced basemap freely accessible from ESRI ArcMap 10.1, while the declassified Corona data (KH-4A and KH-9/16) comes up as raw non-georeferenced product freely available from https://earthexplorer.usgs.gov/. Owing to the geometrical distortion (Schmidt and Nüsser 2012), Corona images were co-registered using projective transformation in ERDAS Imagine 9.0 (Jensen 2009; Rashid et al. 2017a). The images were coregistered based on 23 control points (Fig. 2) whose coordinates were taken from IKONOS imagery available as ESRI Basemap in Arc Map 10.1. Prominent road-stream junctions, airport runway, old building, and bridges were used for GCPs assuming that no changes occurred for these points on the ground during the observation period. Additionally, 20 other common features were carefully identified in each of the Corona images and IKONOS data. The horizontal shift (rot mean square error) in the two Corona images was ± 4.6 m and ± 3.8 m with respect to the IKONOS image that served as reference data.

Quantifying the land system changes

High-resolution earth observation data of 1965, 1980, and 2016 were used to produce multi-date land use land cover (LULC) maps of Narkara catchment. The study area was extracted using *extract by mask* tool in Arc Map 10.1, whereas 2016 satellite data was used by accessing high-resolution images from Arc Map 10.1. Owing to high resolution of earth observation data, LULC types were delineated using onscreen digitization at the scale of 1:5000 in Arc Map 10.1. Visual image interpretation was preferred over digital classification approach as it is advantageous for delineating LULC in mountainous areas primarily as it incorporates cognitive inputs from image analyst (Rashid et al. 2010, 2013, 2016). Total area under each land cover category was calculated for 1965, 1980, and 2016 which was followed up by change detection analysis. Survey of India topographical sheets, surveyed in 1962, were used for accuracy assessment of 1965 Corona generated land cover data. Since no reference data was available for 1980s, we could not carry out the accuracy assessment for 1980 land cover data. Accuracy assessment of land cover types delineated from 2016 satellite data is based on 117 well distributed field samples collected using Trimble Juno SB GPS with a positional accuracy of 5 m (Fig. 3). Kappa coefficient (Eq. 1)

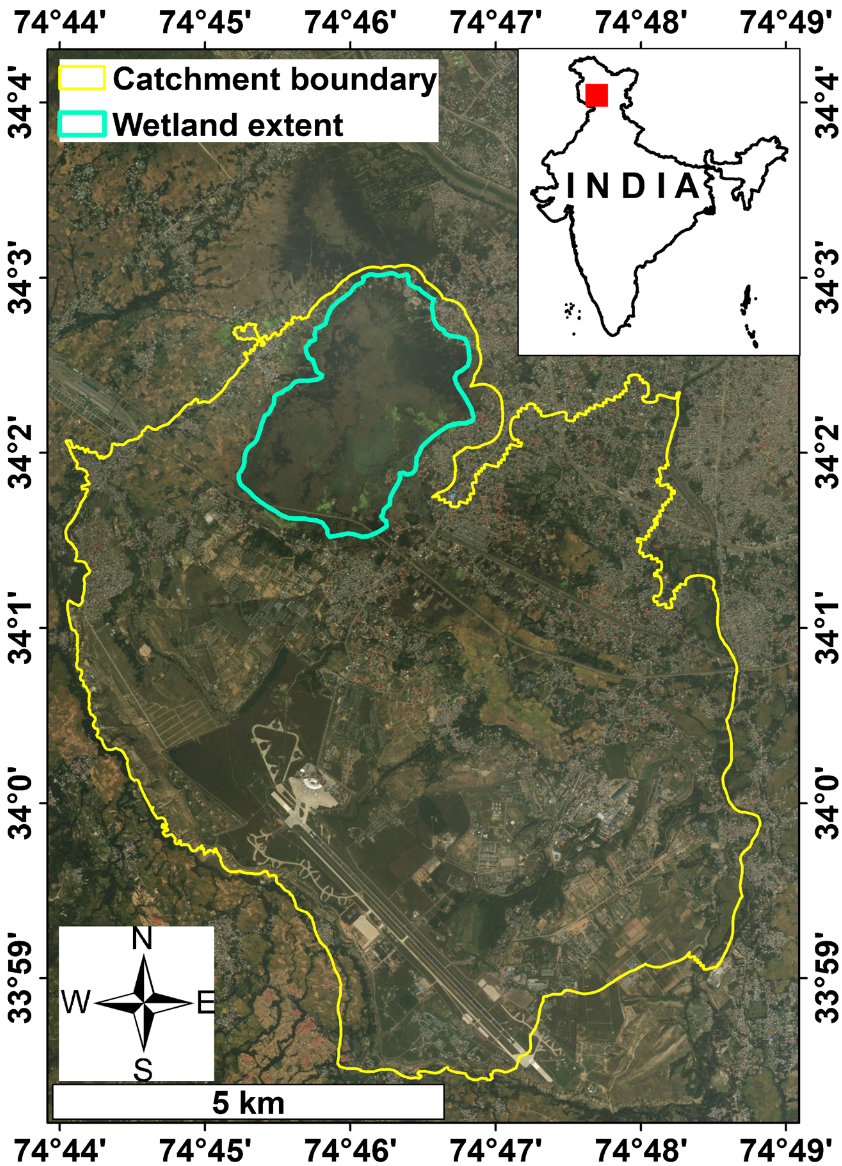

Fig. 1 Location of study area

was used for assessing the accuracy of delineated land cover types of 1965 and 2016 based on 117 samples each from topographical map and ground survey as:

$$k = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} (X_{1+}.X_{+i})}{N^2 - \sum_{i=1}^{r} (X_{i+}.X_{+i})} \quad (1)$$

where r is the number of rows in error matrix, X_{ii} is the number of observations in row i column i (on the major diagonal), X_{i+} is the total of observations in row i (shown as marginal total to right of the matrix), X_{+i} is the total of observations in column i (shown as marginal total at bottom of the matrix), and N is the total number of observations included in the matrix.

Additionally, user's accuracy, producer's accuracy, errors of omission, and commission were also computed to assess the accuracy of the land use and land cover data of 1965 and 2016. Kappa is lower than overall accuracy. The difference between kappa and overall accuracy results due to the fact that each index uses different information from the error matrix. While overall accuracy only includes the data along the major diagonal, kappa incorporates the non-diagonal elements of error matrix as a product of row and column marginal (Romshoo and Rashid 2014).

Erosion assessment

Among soil loss estimation models, universal soil loss equation (USLE) is considered one of the robust models and is being used worldwide for estimation of soil erosion (Wischmeier and Smith 1978). A revised version of this model, Revised USLE (RUSLE), has enhanced soil loss

Table 1 Datasets used for accomplishing the study

Datasets	Acquisition date	Spatial resolution/scale	Source
Satellite data			
Corona	3 November, 1965	2.8 m (9 ft)	https://earthexplorer.usgs.gov/
	7 October, 1980	1.87 m (6 ft)	
IKONOS	27 September, 2016	0.5 m	ESRI Basemap/Digital Globe
Topographical data			
SRTM DEM	February 2000	30 m	https://earthexplorer.usgs.gov/
Soil texture	2010–2016	1:10,000	Sheri Kashmir University of Agricultural Science and Technology (SKUAST)
Meteorological data			
World Clim version 1.4	1960–1990	1 km	http://www.worldclim.org/
Field data			
GPS measurements	2016	Point data	Ground Survey

predication capabilities (Renard et al. 1997). RUSLE predicts the long-term average annual rate of soil erosion (DAIS 2008) in variety of environments such as agriculture, forest, rangeland, mining sites, construction sites, etc. (Stone and Hilborn 2000) which means that it could be very well used for estimating soil erosion at catchment scale (Millward and Mersey 1999; Teng et al. 2018; Fang et al. 2019). RUSLE computes soil erosion using the following equation:

$$A = R \times K \times LS \times C \times P \quad (2)$$

where A is the average annual predicted soil loss from sheet and rill erosion (tons/ha/year), R is the rainfall/runoff erosivity

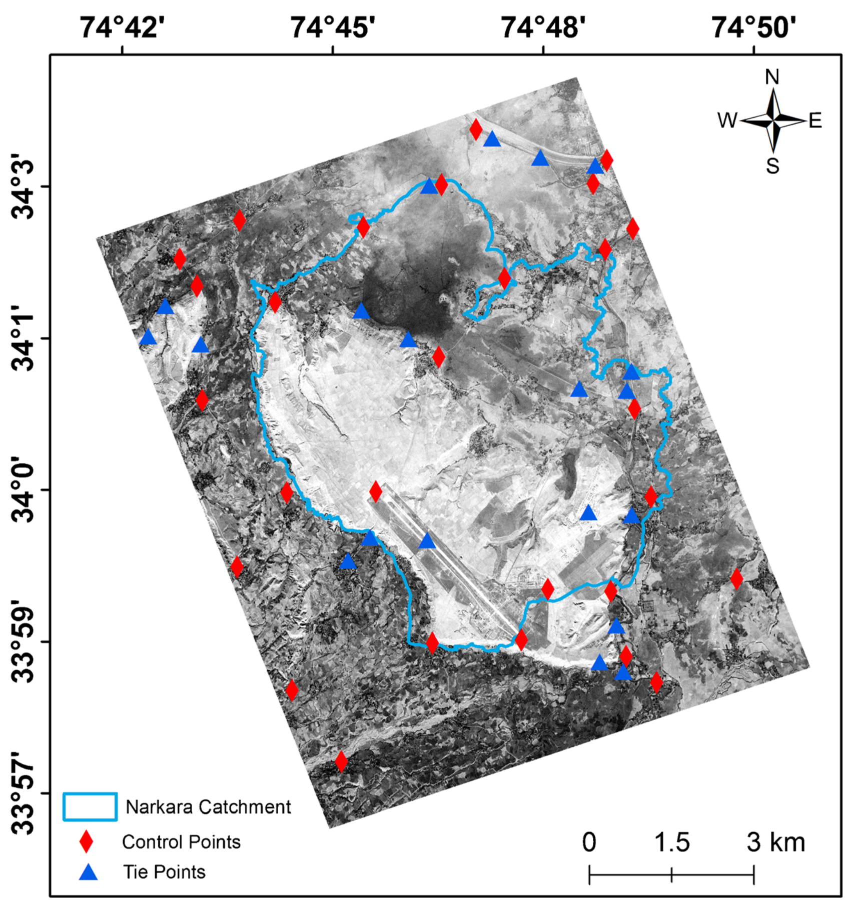

Fig. 2 Location of control points and tie points for georeferencing Corona satellite data

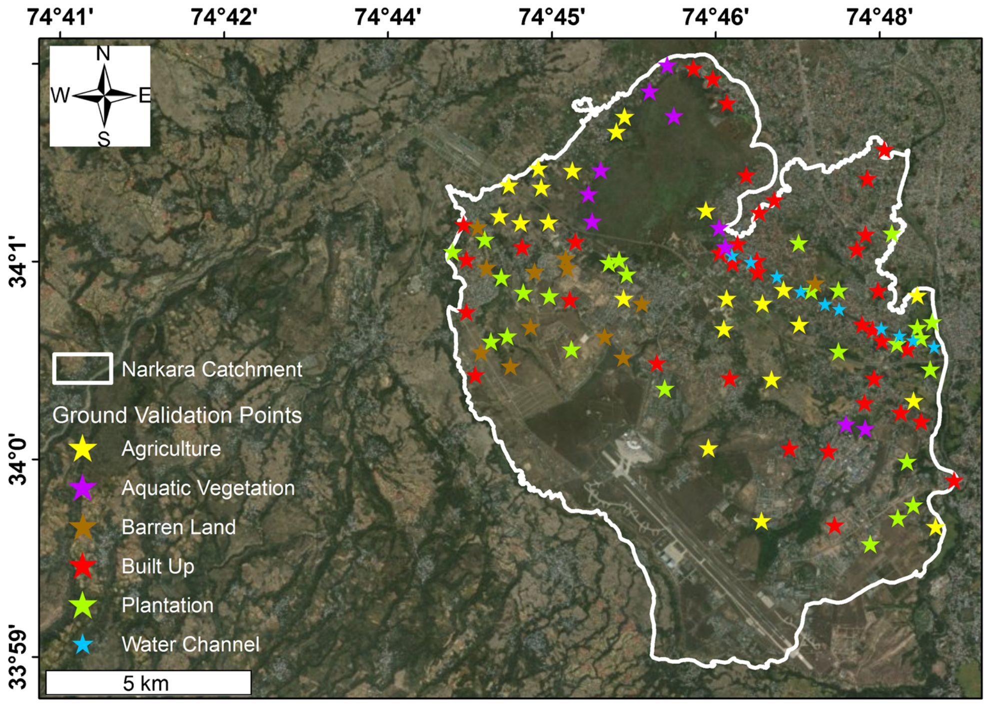

Fig. 3 Location of field points for validating land use land cover maps of Narkara catchment

(MJ mm/ha/h/year), K is the soil erodibility (Mg h/MJ/mm), LS is the slope length and steepness/topographic factor (dimensionless), C is the crop management factor (dimensionless), and P is the support practice (dimensionless).

Using Eq. 2 above, we assessed soil loss in the catchment of Narkara wetland for 1965, 1980, and 2016. The generation of input datasets for RUSLE was generated in Arc Map 10.1. The steps involved in preparation of input datasets for RUSLE have been described in the following sections:

Rainfall erosivity (R-factor) depends on the intensity and duration of rainfall. Precipitation data with a spatial resolution of 1 km^2 for the study area was extracted from WorldClim version1 (Accessible at http://worldclim.org/version1). Meteorological data from Worldclim has been extensively used for mapping and spatial modeling (Hijmans et al. 2005). Data of mean annual precipitation from 1960 to 1990 was used for the calculation of R factor keeping in view that no significant changes in precipitation have been reported in the region (Murtaza and Romshoo 2017). R factor was derived from Eq. 3 by Singh et al. (1981) as:

$$R_{fac} = 79 + 0.363R \quad (3)$$

where R_{fac} is the rainfall erosivity and R is the annual average rainfall in millimteter. Although it was prudent to use meteorological observations, however, owing to the scanty network of weather stations, we used gridded precipitation data from WorldClim which showed good agreement with rainfall observation station located at Rambagh, Srinagar. It must be noted that there is no weather station in the catchment of Narkara wetland. The entire mountainous Kashmir Valley spreading over ~ 15,500 km^2 has just 6 meteorological observatories, so the data are scanty in terms of spatial distribution, because of the terrain complexity of the region (Romshoo et al. 2018). In order to overcome this impediment, it was prudent to use gridded WordClim data that matched well (showing annual precipitation of 711 mm) with the nearest observatory located at Srinagar (with an annual precipitation of 723 mm). The annual precipitation at Srinagar station maintained by India Meteorological Department is 723 mm against 711 mm from the WorldClim data indicating an underestimation of 12 mm.

Soil erodibility (K-factor) is a measure of susceptibility of soil particles to detachment and transport by runoff. An important prerequisite for estimating soil erodibility is the soil texture. Soil texture information at a spatial resolution of 100 m was compiled from data provided by Sheri Kashmir University of Agricultural Science and Technology (SKUAST). The soil erodibility map was finally prepared by

Table 2 Soil types and their K-values as per Stone (2012)

Soil type	K-value (mg/h/MJ/mm)
Loam	0.67
Clay	0.49
Clay loam	0.67
Silty clay	0.58
Silt loam	0.85
Silty clay loam	0.72

Table 3 LULC-wise *C*- and *P* values after (Kumar et al. 2014; Patil et al. 2015)

LULC category	*C*-value	*P* value
Agriculture (3–8 slope)	0.28	0.5
Agriculture (9–12 slope)	0.28	0.6
Agriculture (13–16 slope)	0.28	0.7
Agriculture (17–20 slope)	0.28	0.8
Agriculture (20–25 slope)	0.28	0.9
Agriculture (< 3 and > 25 slope)	0.28	1
Aquatic vegetation	0.28	1
Barren land	0.18	1
Built-up	0.004	1
Plantation	0.28	1
Water	0.28	0

assigning *K*-value (Table 2) to the respective soil texture types from Stone (2012).

Topographic (LS) factor represents a combined effect of length and steepness of slope (Roose 1977). The gentler and shorter the slope, the lower is the risk of erosion and vice versa. Using SRTM DEM with a spatial resolution of 30 m, LS factor was computed using the method provided by Mitasova et al. (2001) as:

$$LS = (l/72.6)^m \left(65.41\sin^2\beta + 45.56\sin\beta + 0.065\right) \quad (4)$$

where l is the cumulative slope length in meters and β is the downhill slope angle, and m is the slope contingent variable (0.5 if the slope angle is greater than 2.86°, 0.4 on slopes of 1.72° to 2.86°; 0.3 on slopes of 0.57° to 1.72°; 0.2 on slopes less than 0.57°).

Support practice factor (*P*) reflects the effect of practices that reduce the runoff rate and check the soil loss (Stone and Hilborn 2000). The *P*-factor was computed from the slope and LULC as suggested in Kumar et al. (2014).

Crop management factor (*C*) represents the relative effectiveness of soil and crop management systems in terms of LULC practice with respect to preventing soil loss (Roose 1977). Among various RUSLE factors, the *C* factor has been considered as the most important as it is a conservation related factor that controls soil loss at a specific site (Teh 2011). To prepare the C-factor map, different LULC which were identified in 1965, 1980, and 2016 data were assigned *C*-value after Patil et al. (2015). LULC-wise C and *P* values are shown in Table 3.

All the above derived input parameters for RUSLE (R, K, LS, C, and P) were generated for the estimation of soil loss in the study area at different points in time.

Results and discussion

LULC dynamics

Six land use cover classes, which include Agriculture (AG), Aquatic vegetation (AV), Bare land (BL), Built-up (BU), Plantation (PL), and Water (WT), were delineated (Table 4) using on-screen digitization of high-resolution earth observation data of year 1965 (Fig. 4a), 1980 (Fig. 4b), and 2016 (Fig. 4c). From the analysis of 2016 land cover data, the catchment of Narkara wetland is predominantly an urban setting with built-up areas covering 37.12% of the total catchment area followed by Bare land (26.45%), Agriculture (12.47%), Plantation (12.22%), Aquatic vegetation (11.45%), and Water (0.30%). Built-up areas are mainly residential; however, Srinagar airport, associated military installations, and few government offices fall within the catchment of wetland. There are a lot of open spaces categorized as Bare land within the study area mostly under airport limits. Agriculture land is mainly composed of rice paddies and vegetable gardens. Plantation comprises of willows, poplars, and sporadic apple orchards. Aquatic vegetation restricted to Narkara catchment is mainly composed of watermoss, water lily, lotus, and invasive water fern, Azolla. However, the shallow waters on the periphery are dominated with cattail and common reed. Water is represented by a feeding Sukhnag tributary and a flood spill channel constructed after 1960s. Our analysis indicated

Table 4 LULC changes from 1965 to 2016 in the catchment of Narkara wetland

Class name	Area (km^2)			Change (km^2)	%change (1965–2016)
	1965	1980	2016		
Agriculture	22.63	17.01	5.01	− 17.62	− 77.86
Aquatic vegetation	4.62	4.30	4.60	− 0.02	− 0.43
Bare land	9.15	12.28	10.63	1.48	16.17
Built-up	0.54	1.99	14.92	14.38	2662.96
Plantation	3.15	4.48	4.91	1.76	55.87
Water	0.10	0.13	0.12	0.02	20.00
Total area	40.19	40.19	40.19		

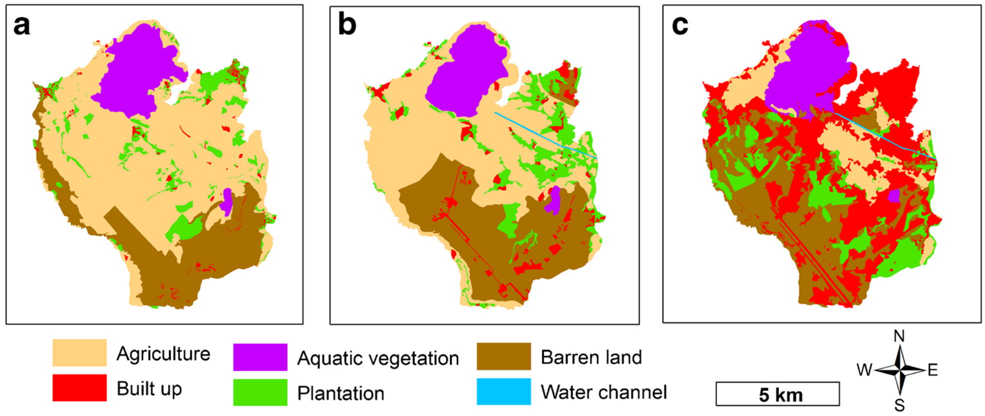

Fig. 4 High-resolution land use land cover maps of Narkara wetland catchment for **a** 1965, **b** 1980, and **c** 2016

substantial land system changes over the 52-year observation period between 1965 and 2016. Agriculture decreased from 22.63 km^2 (in 1965) to 5.01 km^2 (in 2016) indicating a 77.86% decrease; however, the decrease in agriculture area was more pronounced (53.02%) during 1980–2016 period. Massive increase (~2663%) in built-up areas were manifested between 1965 and 2016 owing to reckless urbanization in Narkara. The pace of urbanization exacerbated between 1980 and 2016 period as indicated by 2394% increase in built-up areas compared to 268% increase between 1965 and 1980 period. Similar urbanization patterns have been reported by Badar et al. (2013a) and Rashid et al. (2017a), (c) around wetlands and lakes in Kashmir. Area under plantation has increased by 55.87%, while bare lands, water, and aquatic vegetation are relatively stable between 1965 and 2016. A small increase in water area is attributed to construction of alternative flood spill channel after 1965 in the study area. Overall accuracy and class-wise accuracies for 1965 and 2016 data are provided in Tables 5 and 6. The accuracy of year 1965 land use classes was assessed using the Survey of India topographical map.

The overall accuracy of the 1965 land cover data was 87.18% (Table 5) with AV and WT having 100% accuracy followed by BU (86.49%), AG (85.71%), BL (85.71%), and PL (80%). The error of omission, i.e., probability of excluding a pixel that should have been included in the class was highest for AV (28.58%) followed by AG (25%), BL (20%), PL (4.76%), BU (3.03%), and WT (0%). Similarly, the error of commission which is the probability of including a pixel in a class when it should have been excluded was highest for PL (20%) followed by AG (14.29%), BL (14.29%), BU (13.51%), AV (0%), and WT (0%).

The accuracy of 2016 land cover data was assessed using field data of 117 ground sample points (Table 6). The overall accuracy of 2016 land cover data was 94.87% with AV and WT having 100% accuracy followed by BU (97.3%), PL (96.00%), AG (90.48%), and BL (85.71%). The higher accuracies of 2016 LULC data could be attributed to multispectral satellite data (Gao 1999; Khanna et al. 2018) and better spatial resolution (Hsieh et al. 2001) used for mapping in this study as compared to greyscale data of CORONA for 1965. The error

Table 5 Accuracy Assessment of 1965 LULC dataset

		Survey of India topographic data								
		AG	AV	BU	BL	PL	WT	Row total	User's accuracy (%)	Error of commission (%)
Classification data	AG	*18*	1	0	1	1	0	21	85.71	14.29
	AV	0	*10*	0	0	0	0	10	100.00	0
	BU	3	0	*32*	2	0	0	37	86.49	13.51
	BL	1	*0*	1	*12*	0	0	14	85.71	14.29
	PL	2	3	0	*0*	*20*	0	25	80.00	20
	WT	0	0	0	0	0	*10*	10	100.00	0
	Column total	24	14	33	15	21	10	117		
	Producer's accuracy (%)	75.00	71.42	96.97	80.00	95.24	100.00			
	Error of omission (%)	25	28.58	3.03	20	4.76	0			

Overall accuracy = [(18 + 10 + 32 + 12 + 20 + 10)/117] × 100 = 87.18%. k = 0.84

Italicized numbers indicate number of validation samples taken

Table 6 Accuracy Assessment of 2016 LULC dataset

		Field survey data								
		AG	AV	BU	BL	PL	WT	Row total	User's accuracy (%)	Error of commission (%)
Classification data	AG	*19*	1	0	0	1	0	21	90.48	9.52
	AV	0	*10*	0	0	0	0	10	100.00	0
	BU	0	0	*36*	1	0	0	37	97.30	2.7
	BL	1	0	1	*12*	0	0	14	85.71	12.49
	PL	1	0	0	*0*	*24*	0	25	96.00	4
	WT	0	0	0	0	0	*10*	10	100.00	0
	Column total	21	11	37	13	25	10	117		
	Producer's accuracy (%)	90.48	90.91	97.30	92.31	96.00	100.00			
	Error of omission (%)	9.52	9.09	2.7	7.69	4	0			

Overall accuracy = [(19 + 9 + 35 + 24 + 10)/117] × 100 = 94.87%. $k = 0.93$

Italicized numbers indicate number of ground samples taken

of omission was highest for AG (9.52%) followed by AV (9.09%), BL (7.69%), PL (4%), BU (2.7%), and WT (0%). Similarly, the error of commission was highest for BL (12.49%) followed by AG (9.52%), PL (4%), BU (2.7%), AV (0%), and WT (0%). The kappa statistics for 1965 and 2016 generated land cover data are 0.84 and 0.93, respectively.

By analyzing the multi-date LULC maps, it is clear that the expansion of built-up areas has resulted into shrinkage of agriculture fields. Similar observations have been reported by Romshoo et al. (2011) around a neighboring Hokersar wetland. Lack of a comprehensive wetland conservation scheme has turned the former wetland areas into concrete residential jungle mainly due to encroachments by the land grabbers (Parihar et al. 2013). It is pertinent to mention that built-up areas increased 28 times in the catchment of this semi-urban wetland during the 52-year observation period which could have a direct impact on the nutrient flux, eutrophication, sedimentation, and plant invasions (Khuroo et al. 2007; Badar et al. 2013b; Amin et al. 2014). Increase in Orchard land could be attributed to the fact that farmers have shifted from traditional rice paddy culture to orchard cultivation in view of depleting stream flows and economic considerations (Showqi et al. 2014; Rather et al. 2016). Further, the symptoms of the wetland deterioration are attributed to nutrient enrichment resulting due to the reckless use of fertilizers and pesticides from agriculture and orchard lands that pave way for proliferation of invasive aquatic species in wetlands across Kashmir (Pandit and Kumar 2006; Mushtaq et al. 2015); however, it needs to be researched.

Erosion estimates

The input datasets, *R*, *K*, LS, *C*, and *P* factors (Figs. 5, 6, and 7), were generated using rainfall, soil, SRTM DEM, and land cover data. LS (Fig. 5a) and *K* (Fig. 5c) factors are also assumed to remain constant throughout the analysis period. The R factor (Fig. 5b) has been kept constant for all the three time periods assuming that there are no changes in annual precipitation (Romshoo et al. 2015). However, owing to the land system changes, *C* (Fig. 6) and *P* factors (Fig. 7) are dynamic as they

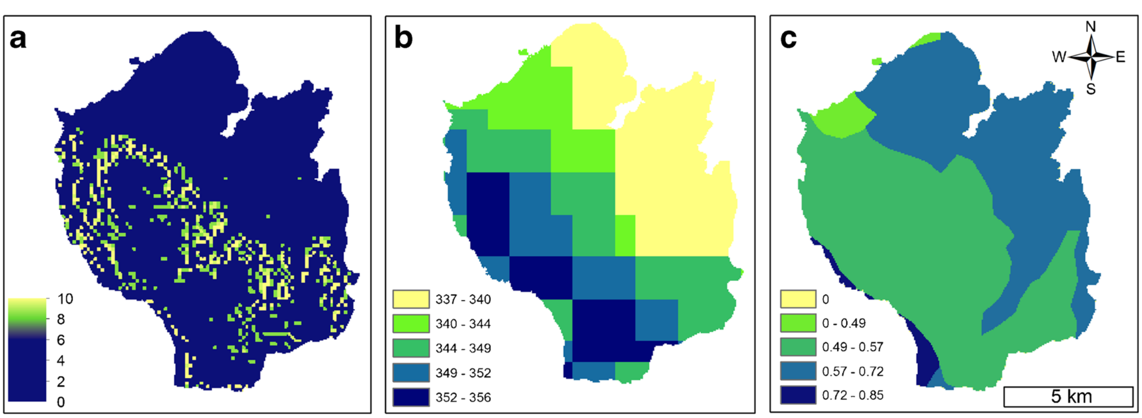

Fig. 5 RUSLE model input parameters. **a** LS factor. **b** R factor. **c** K factor

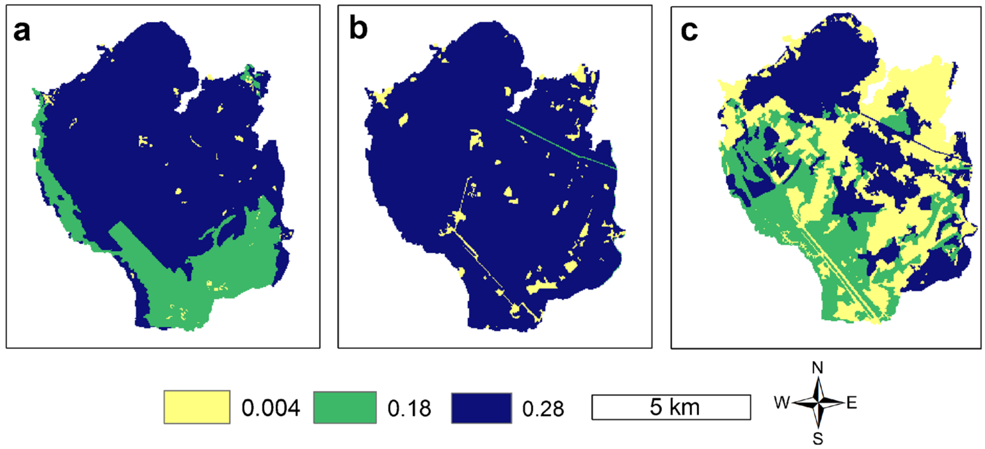

Fig. 6 Crop management (C factor) for **a** 1965, **b** 1980, and **c** 2016

depend on crop and support practices which are primarily determined by land use and land cover patterns in an area.

Six risk levels of soil detachment—very low (up to 1 kg ha^{-1}), low (1–2 kg ha^{-1}), medium (2–3 kg ha^{-1}), medium-high (3–400 kg ha^{-1}), high (400–800 kg ha^{-1}), and very high (800–1142.49 kg ha^{-1})—were identified (Fig. 8). The majority of the study area falls under very low and low risk levels. Very few areas fall in medium-high and high risk levels. Our analysis indicated that the soil erosion in the Narkara catchment decreased substantially from 106.33 × 10^3 kg in 1965 to 119.84 × 10^3 kg in 1980 to 61.90 × 10^3 kg in 2016 indicating a decrease of 41.78% during the assessment period at an annual average rate of − 0.87 × 10^3 kg. During the period from 1965 to 1980, soil erosion rates increased at an average annual rate of 0.9 × 10^3 kg per year. Such increase in soil erosion could be attributed to the increase in bare land area from 1965 to 1980. On contrary, soil erosion decreased by 44.83 × 10^3 kg with an annual average rate of 0.87 × 10^3 kg from 1980 to 2016. This could be attributed to the fact that area under barren land and agriculture was taken over by built-up areas owing to reckless urbanization from 1980 to 2016. Similar increase in the built-up has been reported by Rather et al. (2016) and Rashid et al. (2017b) in Kashmir Himalaya. Land system changes in the catchment over the 52-year observation period indicate massive increase (2622.96%) in the impervious surfaces (built-up areas) from 0.54 km^2 in 1965 to 1.99 km^2 in 1980 and 14.92 km^2 in 2016, in the Narkara catchment that prevent the rainfall from destabilizing upper soil leading to reduction in sediment yield over the course of time. However, massive increase in the built-up areas has reduced the buffering capacity of Narkara wetland to hold flood waters during extreme precipitation events. This was experienced during the mega flood event of September 2014 when almost 20.4% of the Narkara catchment got completely inundated including 10.2% of actual Narkara wetland area (Fig. 9).

Of the total soil erosion from the catchment, the highest contribution was from bare lands and agriculture land cover types which could be attributed to the loose soil particles having a capability to easily get detached as compared to other land cover types. High erosion rates from agriculture and bare lands together with sewage influx into Narkara wetland have a potential to cause sedimentation of the wetland bed and accelerate the process of eutrophication (Jain et al. 1999; Khan 2004; Vass et al. 2015); however, it needs to be further researched.

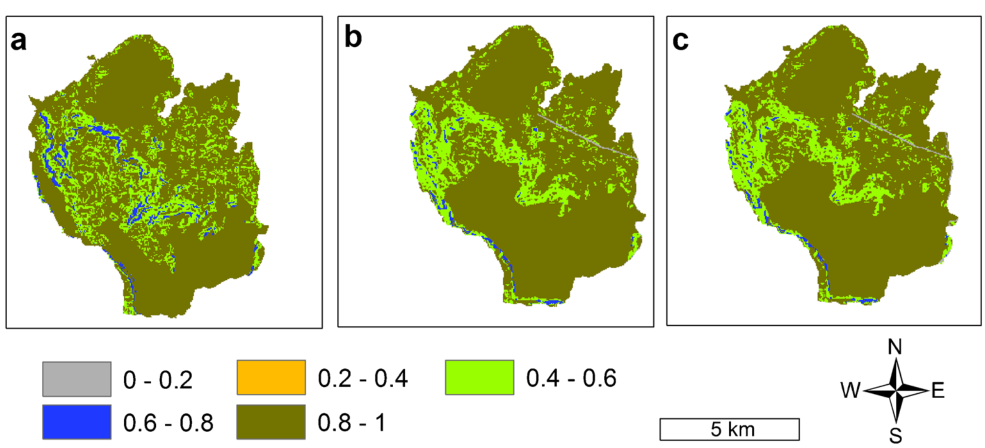

Fig. 7 Support practice (P factor) for **a** 1965, **b** 1980, and **c** 2016

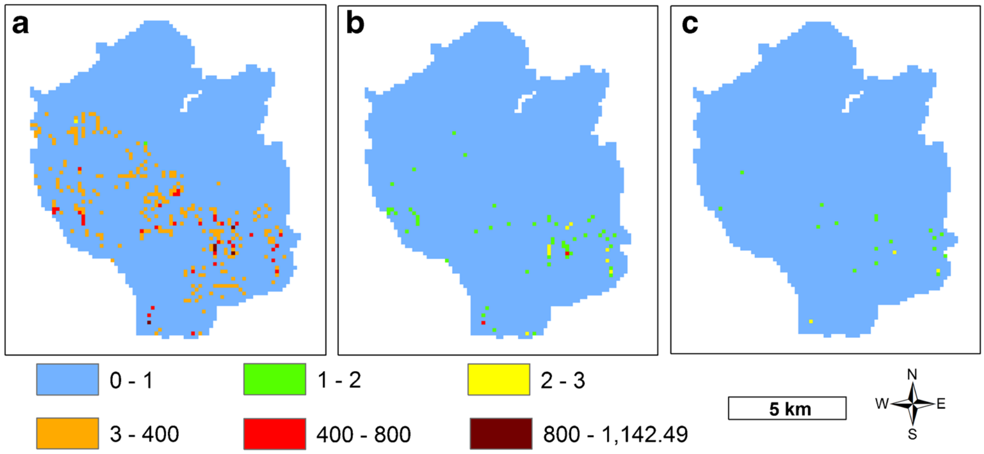

Fig. 8 Soil loss (kg ha^{-1}) over Narkara catchment for (**a**) 1965, (**b**) 1980, and (**c**) 2016

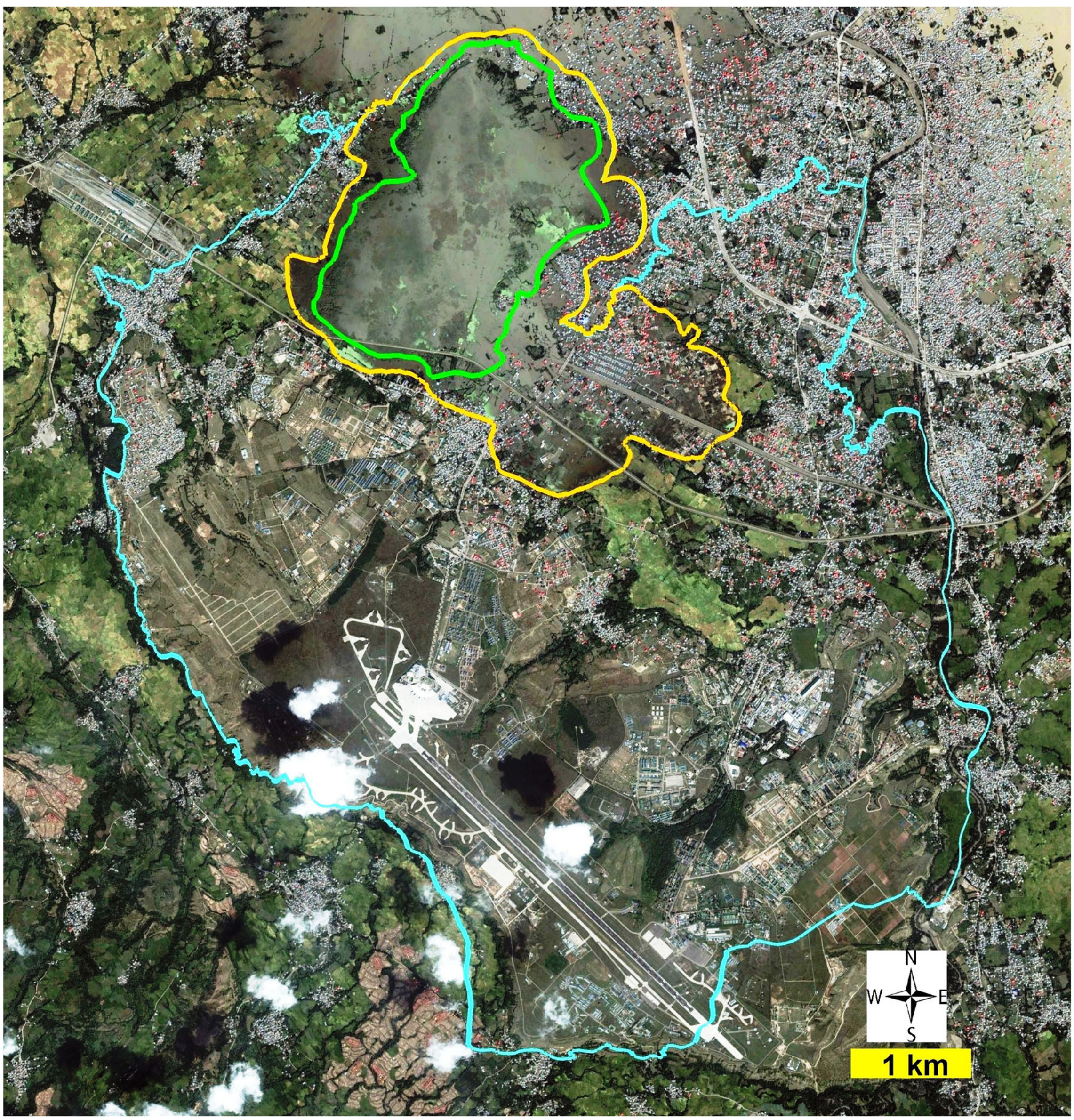

Fig. 9 Inundation of Narkara wetland catchment, as indicated by Yellow outline, during September 2014 flood. Cyan outline represents Narkara catchment, and green outline represents Narkara wetland

Conclusion

Keeping in view the reckless urbanization, land system changes in Narkara, a semi-urban wetland, were assessed using high-resolution satellite data between 1965 and 2016. The study assumes importance keeping in view the pace of urbanization that is deteriorating the health of this semi-urban wetland. Detailed ground truth was done to validate the land use land cover of Narkara catchment delineated from 2016 data. The land use land cover delineated from 1965 corona data was validated using Survey of India topographic map surveyed in 1962. Owing to the absence of any ancillary information, the land use land cover data of 1980 could not be validated; however, since corona data was also used for delineating land use land cover from 1965, it was presumed to have similar accuracy. Additionally, soil erosion was quantified for 1965, 1980, and 2016 to quantify the impact of land system changes on soil loss using RUSLE in a GIS environment. Massive land transformations were observed in the Narkara catchment. The area under built-up and plantation increased by 2663% and 55%, respectively, while agriculture area decreased by 78% between 1965 and 1980. However, the magnitude of these changes is more pronounced in 1980–2016 period owing to large-scale migration of people from rural Kashmir to urban Srinagar for better civic amenities. The soil erosion estimates from RUSLE suggest decrease in the soil detachment from 120.21 t ha^{-1} for 1980 to 62.16 t ha^{-1} for 2016 that could be attributed to the impervious urban surfaces taking over agricultural land especially during 1980–2016 period. The reckless urbanization in the Narkara affects the hydrological connectivity and ecology of this important semi-urban wetland which increases the vulnerability of people to flooding in the catchment of this Himalayan wetland. It is imperative that the development of infrastructure in the catchment could be allowed after carrying out a proper land suitability analysis of the wetland catchment. Additionally, robust scientific studies need to be taken up to assess the water quality, biota, and sediment characteristics for unraveling recent pattern of eutrophication of this semi-urban wetland. Owing to the fact that a large portion of Narkara wetland catchment falls under barren denuded landscapes, it becomes imperative for wetland managers to increase the green cover in the form of plantation to reduce the influx of sediment into the wetland. Since the wetland is very close to the Srinagar city center, it has a potential to be developed as an ecotourism site that may not only help build the economy but also inculcate a sense of environmentalism among the local population for safeguarding the pristine and ever shrinking wetlands of Kashmir Himalaya.

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References

Amin A, Fazal S, Mujtaba A, Singh SK (2014) Effects of land transformation on water quality of Dal Lake, Srinagar, India. J Indian Soc Remote Sens 42(1):119–128

Azous AL, Horner RR, (eds) (2000) Wetlands and urbanization: implications for the future. 356. CRC Press, Boca Raton

Badar B, Romshoo SA, Khan MA (2013a) Intergrating biophysical and socioeconomic information for prioritizing watersheds in a Kashmir Himalayan lake: a remote sensing and GIS approach. Environ Monit Assess 185:6419–6445

Badar B, Romshoo SA, Khan MA (2013b) Modelling catchment hydrological responses in a Himalayan Lake as a function of changing land use and land cover. J Earth Syst Sci 122(2):433–449

Bourgeau-Chavez LL, Kasischke ES, Brunzell SM, Mudd JP, Smith KB, Frick AL (2001) Analysis of space-borne SAR data for wetland mapping in Virginia riparian ecosystems. Int J Remote Sens 22(18):3665–3687

Chopra R, Verma VK, Sharma PK (2001) Mapping, monitoring and conservation of Harike wetland ecosystem, Punjab, India, through remote sensing. Int J Remote Sens 22(1):89–98

DAIS (2008) Directorate agricultural information services. Directorate Agricultural Land and Resources Management. Directorate Agricultural Information Services, Pretoria, pp 1–7

Dhillon JK, Mishra AK (2014) Estimation of trophic state index of Sukhna Lake using remote sensing and GIS. J Indian Soc Remote Sens 42(2):469–474

Fang G, Yuan T, Zhang Y, Wen X, Lin R (2019) Integrated study on soil erosion using RUSLE and GIS in Yangtze River Basin of Jiangsu Province (China). Arab J Geosci 12(5):173

Fowler HJ, Archer DR (2006) Conflicting signals of climatic change in the Upper Indus Basin. J Clim 19(17):4276–4293

Gao J (1999) A comparative study on spatial and spectral resolutions of satellite data in mapping mangrove forests. Int J Remote Sens 20(14):2823–2833

Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A (2005) Very high resolution interpolated climate surfaces for global land areas. Int J Climatol 25(15):1965–1978

Hsieh PF, Lee LC, Chen NY (2001) Effect of spatial resolution on classification errors of pure and mixed pixels in remote sensing. IEEE Trans Geosci Remote Sens 39(12):2657–2663

Jain A, Pal J, Sharma E (1999) Hydrology and nutrient dynamics of a sacred lake in Sikkim Himalaya. Hydrobiologia 416:13–22

Jain SK, Kumar S, Varghese J (2001) Estimation of soil erosion for a Himalayan watershed using GIS technique. Water Resour Manag 15(1):41–54

Jenerette GD, Wu J (2001) Analysis and simulation of land-use change in the Central Arizona–Phoenix region, USA. Landsc Ecol 16(7):611–626

Jensen JR (2009) Remote sensing of the environment: an earth resource perspective 2/e. Pearson Education India, New Delhi

Joshi PK, Rashid H, Roy PS (2002) Landscape dynamics in Hokersar Wetland, Jammu & Kashmir-an application of geospatial approach. J Indian Soc Remote Sens 30(1):1–5

Keddy PA (2010) Wetland ecology: principles and conservation. Cambridge University Press, New York

Khan MA (2004) Kashmir Himalayan waterfowl habitat, Hokersar: species composition and threat perceptions. In: Kumar A (ed) Environmental contamination and bioreclamation. APH Publishing Corporation, New Delhi, pp 188–193

Khan MA, Shah MA, Mir SS, Bashir S (2004) The environmental status of a Kashmir Himalayan wetland game reserve: aquatic plant communities and eco-restoration measures. Lakes Reserv Res Manag 9(2):125–132

Khanna S, Santos MJ, Ustin SL, Shapiro K, Haverkamp PJ, Lay M (2018) Comparing the potential of multispectral and hyperspectral data for monitoring oil spill impact. Sensors 18(2):558. https://doi.org/10.3390/s18020558

Khuroo AA, Rashid I, Reshi Z, Dar GH, Wafai BA (2007) The alien flora of Kashmir Himalaya. Biol Invasions 9:269–292

Kumar A, Devi M, Deshmukh B (2014) Integrated remote sensing and geographic information system based RUSLE modelling for estimation of soil loss in western Himalaya, India. Water Resour Manag 28(10):3307–3317

Lindegarth M, Hoskin M (2001) Patterns of distribution of macro-fauna in different types of estuarine, soft sediment habitats adjacent to urban and non-urban areas. Estuar Coast Shelf Sci 52(2):37–247

Millward AA, Mersey JE (1999) Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. Catena 38(2):109–129

Mitasova H, Brown WM, Hohmann M, Warren S (2001) Using soil erosion modeling for improved conservation planning: a GIS-based tutorial. Available at: http://www4.ncsu.edu/~hmitaso/gmslab/reports/CerlErosionTutorial/denix/Models%20and%20Processes/RUSLE3d/RUSLE3d.htm. Accessed on: 1st September, 2017

Murtaza KO, Romshoo SA (2017) Recent glacier changes in the Kashmir alpine Himalayas, India. Geocarto Int 32(2):188–205

Mushtaq F, Nee Lala MG, Pandey AC (2015) Assessment of pollution level in a Himalayan Lake, Kashmir, using geomatics approach. Int J Environ Anal Chem 95(11):1001–1013

Najar IA, Khan AB (2012) Assessment of water quality and identification of pollution sources of three lakes in Kashmir, India, using multivariate analysis. Environ Earth Sci 66(8):2367–2378

Ozesmi SL, Bauer ME (2002) Satellite remote sensing of wetlands. Wetl Ecol Manag 10(5):381–402

Pandit AK, Kumar R (2006) Comparative studies on ecology of Hokersar wetland, Kashmir: present and past. Journal of Himalayan Ecology and Sustainable Development 1:73–81

Parihar SM, Sarkar S, Dutta A, Sharma S, Dutta T (2013) Characterizing wetland dynamics: a post-classification change detection analysis of the East Kolkata Wetlands using open source satellite data. Geocarto Int 28:273–287

Patil RJ, Sharma SK, Tignath S (2015) Remote sensing and GIS based soil erosion assessment from an agricultural watershed. Arab J Geosci 8(9):6967–6984

Prachansri S (2007) Analysis of soil and land cover parameters for flood hazard assessment: a case study of the Nam Chun watershed, Phetchabun, Thailand. In: Earth systems analysis. International Institute for geo-information Science and Earth Observation (ITC) Enschede, The Netherlands

Rashid I, Majeed U (2018) Recent recession and potential future lake formation on Drang Drung glacier, Zanskar Himalaya, as assessed with earth observation data and glacier modelling. Environ Earth Sci 77(12):429. https://doi.org/10.1007/s12665-018-7601-5

Rashid H, Naseem G (2007) Quantification of loss in spatial extent of lakes and wetlands in the suburbs of Srinagar City during last century using Geospatial approach. In Proc. of Taal: The 12th World Lake Conference pp. 653–658

Rashid I, Romshoo SA (2013) Impact of anthropogenic activities on water quality of Lidder River in Kashmir Himalayas. Environ Monit Assess 185(6):4705–4719

Rashid I, Romshoo SA, Muslim M, Malik AH (2010) Landscape level vegetation characterization of Lidder valley using geoinformatics. Journal of Himalayan Ecology and Sustainable Development 6:11–24

Rashid I, Farooq M, Muslim M, Romshoo SA (2013) Assessing the impact of anthropogenic activities on Manasbal Lake in Kashmir Himalayas. Int J Environ Sci 3(6):2052–2063

Rashid I, Romshoo SA, Chaturvedi RK, Ravindranath NH, Sukumar R, Jayaraman M, Lakshmi TV, Sharma J (2015) Projected climate change impacts on vegetation distribution over Kashmir Himalayas. Clim Chang 132(4):601–613

Rashid I, Romshoo SA, Hajam JA, Abdullah T (2016) A semi-automated approach for mapping geomorphology in mountainous terrain, Ferozpora watershed (Kashmir Himalaya). J Geol Soc India 88(2): 206–212

Rashid I, Bhat MA, Romshoo SA (2017a) Assessing changes in the above ground biomass and carbon stocks of Lidder valley, Kashmir Himalaya, India. Geocarto Int 32(7):717–734

Rashid I, Romshoo SA, Amin M, Khanday SA, Chauhan P (2017b) Linking human-biophysical interactions with the trophic status of Dal Lake, Kashmir Himalaya, India. Limnologica-Ecology and Management of Inland Waters 62:84–96

Rashid I, Romshoo SA, Abdullah T (2017c) The recent deglaciation of Kolahoi valley in Kashmir Himalaya, India in response to the changing climate. J Asian Earth Sci 138:38–50

Rather MI, Rashid I, Shahi N, Murtaza KO, Hassan K, Yousuf AR, Romshoo SA, Shah IY (2016) Massive land system changes impact water quality of the Jhelum River in Kashmir Himalaya. Environ Monit Assess 188(3):1–20

Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC (1997) Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE), vol 703. US Government Printing Office, Washington, DC

Romshoo SA, Muslim M (2011) Geospatial modeling for assessing the nutrient load of a Himalayan lake. Environ Earth Sci 64(5):1269–1282

Romshoo SA, Rashid I (2014) Assessing the impacts of changing land cover and climate on Hokersar wetland in Indian Himalayas. Arab J Geosci 7(1):143–160

Romshoo SA, Ali N, Rashid I (2011) Geoinformatics for characterizing and understanding the spatio-temporal dynamics (1969 to 2008) of Hokersar wetland in Kashmir Himalayas. Int J Phys Sci 6(5):1026–1038

Romshoo SA, Bhat SA, Rashid I (2012) Geoinformatics for assessing the morphometric control on hydrological response at watershed scale in the Upper Indus Basin. J Earth Syst Sci 121(3):659–686

Romshoo SA, Dar RA, Rashid I, Marazi A, Ali N, Zaz SN (2015) Implications of shrinking cryosphere under changing climate on the streamflows in the Lidder catchment in the Upper Indus Basin, India. Arct Antarct Alp Res 47(4):627–644

Romshoo SA, Altaf S, Rashid I, Dar RA (2017) Climatic, geomorphic and anthropogenic drivers of the 2014 extreme flooding in Jhelum basin of Kashmir, India. Geomatics, Natural hazards and Risk 9(1): 224–248

Romshoo SA, Rafiq M, Rashid I (2018) Spatio-temporal variation of land surface temperature and temperature lapse rate over mountainous Kashmir Himalaya. J Mt Sci 15(3):563–576

Roose EJ (1977) Use of the universal soil loss equation to predict erosion in West Africa. In: soil erosion: prediction and control, vol 21. Soil conservation Society of America, Ankeny, pp 60–74

Schmidt S, Nüsser M (2012) Changes of high altitude glaciers from 1969 to 2010 in the Trans-Himalayan Kang Yatze Massif, Ladakh, Northwest India. Arct Antarct Alp Res 44(1):107–121

Showqi I, Rashid I, Romshoo SA (2014) Land use land cover dynamics as a function of changing demography and hydrology. GeoJournal 79(3):297–307

Singh G, Chandra S, Babu R (1981) Soil loss and prediction research in India. Central Soil and Water Conservation Research Training Institute, Bulletin No. T-12/D9

Stone RP (2012) Universal soil loss equation (USLE) factsheet. Ontario ministry of agriculture, food and rural affiars (OMAFRA). ISSN: 1198-712X. Available at: http://www.omafra.gov.on.ca/english/engineer/facts/12-051.htm accessed on: 21st august, 2017

Stone RP, Hilborn D (2000) Universal soil loss equation (USLE). Ontario Ministry of Agriculture, Food and Rural Affairs Factsheet

Teng H, Liang Z, Chen S, Liu Y, Rossel RAV, Chappell A, Yu W, Shi Z (2018) Current and future assessments of soil erosion by water on the Tibetan Plateau based on RUSLE and CMIP5 climate models. Sci Total Environ 635:673–686

Vass KK, Wangeneo A, Samanta S, Adhikari S, Muralidhar M (2015) Phosphorus dynamics, eutrophication and fisheries in the aquatic ecosystems in India. Curr Sci 108(7):1306–1314

Vörösmarty CJ, McIntyre PB, Gessner MO, Dudgeon D, Prusevich A, Green P, Glidden S, Bunn SE, Sullivan CA, Reidy Liermann C, Davies PM (2010) Global threats to human water security and river biodiversity. Nature 467(7315):555–561

Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses-a guide to conservation planning. Agric Handb 537:1–58

Zedler JB, Kercher S (2005) Wetland resources: status, trends, ecosystem services, and restorability. Annu Rev Environ Resour 30:39–74

Zhou P, Luukkanen O, Tokola T, Nieminen J (2008) Effect of vegetation cover on soil erosion in a mountainous watershed. Catena 75(3): 319–325