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Exploring geospatial techniques for spatiotemporal change detection in land cover dynamics along Soan River, Pakistan

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Abstract Classification of land cover dynamics via satellite imagery has played indispensible services in developing effective management strategies for evaluation and management of water resources. The present study employed geospatial techniques, i.e., integrated GIS and remote sensing for effectual land change study. Hybrid classification approach was applied using ERDAS Imagine 11 to detect changes in land cover dynamics using satellite imagery of Landsat 4, 5 TM, Landsat 7 ETM, and Landsat 8 OLI for the years of 1992, 2002, and 2015, respectively. The study area was classified into four categories, i.e., vegetation, water body, barren, and urban area. Resultant maps, overlay maps, and post classification comparison maps were produced using ArcGIS 10.2 indicated remarkable shrinkage of water body up to 58.81%, reduction in vegetation area 53.24%, and increase in urban and barren area to 49.04 and 137.32%, respectively. The significant changes in land cover dynamics of Soan River are posing threats to its survival. Therefore, proper management, policies, and development of land use inventory are needs of the hour for saving Soan River.

Keywords Geospatial techniques · Hybrid classification · Land cover dynamics · Land change detection

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Introduction

Environmental issues have obsessed almost all the countries across the globe. Therefore, environmental fortification and fresh water natural resources (rivers, lakes, water bodies, etc.) management have become key concerns for scientists and policy-makers for protecting them for future generations. Changes in watershed's ecology and hydrology can be assessed by accurate assessment of changes in land cover dynamics over decades (Butt et al. 2015). Changes in land use dynamics could be symbolized by complex interactions between the structural and behavioral aspects of environment of point of interest depending upon demand, nature, and technological capability that had an effect over both the environmental capacity and demand (Verburg et al. 2004). Ecological scientists highlighted land use/land cover dynamics as important factor affecting the aquatic biodiversity. Changes in land use/land cover dynamics of rivers reduce water eminence, groundwater replenishment, and pollutants relocation and intensify erosion, sedimentation, and runoff over surface (Turner et al. 2001). Therefore, for better planning, management, and conservation of water resource, changes in land cover dynamics are decisive component in evaluating change detection.

Analysis of changes detected in dynamic patterns of land cover enables in discerning substantial knowledge about underlying causes of thematic change information by providing data frame work and temporal changes over decades (Ahmad 2012). This analysis of change about earth's surface features is crucial for delineating complex relation between anthropogenic activities and natural process for better management of resources and decision-making (Lu et al. 2004; Seif and Mokarram 2012). This phenomenon utilizes multitemporal remotely sensed knowledge, compares the knowledge with the past information datasets, and thus determines the changes occurred quantitatively in land use dynamics (Lu et al. 2004; Seif and Mokarram 2012; Zoran 2006).

Various researches have been conducted throughout the world for detecting changes in watersheds/rivers using variety of approaches for proposing better management policies across the world (Ashraf 2013; Bazgeera et al. 2008; Caruso et al. 2005; Dietzel et al. 2005; Fortin et al. 2003; Gajbhiye and Sharma 2012, Hu et al. 2012; Kearns et al. 2005; Parker and Meretsky 2004; Stewart et al. 2004; Wang et al. 2004). Management of watersheds is crucial because of its hydrological properties (Singh et al. 2014) and socioeconomic services for local residents and for nation (Wani et al. 2008). Changes in land use/land cover dynamics of watersheds include commercialization and deforestation affecting water availability and aquatic ecosystem which could be overcome by spatiotemporal analysis of changes occurred in watershed over decades (Ashraf 2013).

Geospatial techniques proved best for mapping changes in land cover dynamics. Geospatial techniques integrated remote sensing and GIS (Rawat et al. 2013) thus provided new dimensions to land cover mapping by incorporating remotely sensed data as cost-effective, accurate, and less time-consuming (Kachhwala 1985) in combination with GIS for effective data analysis, update, and repossession (Star et al. 1997; Chilar 2000). This combination of geospatial techniques involving multispectral and multitemporal data sets of remote sensing gives detailed insight for land cover dynamics and helps in detecting and monitoring variations in LULC pattern over decades (Rawat et al. 2013).

The study area was selected for LULC mapping because of being subjected to extensive commercialization, housing schemes developments, deforestation, soil erosion, reduction in water availability, industrial discharge to river without prior treatment, threats to biodiversity, and continuous shrinkage of river area (Ahmad et al. 2012; Hussain et al. 2014; Jehanzeb 2004; Iqbal et al. 2004).

The present study discerns the application of geospatial techniques for extent of change over 2 decades along Soan River, Pakistan. However, the specific objectives of the study were (a) to identify and delineate different categories of land use/land cover dynamics from 1992 to 2015, (b) to inspect potential of geospatial techniques for detecting changes in land cover dynamics over spatial and temporal scales, and (c) to determine the categories shifted over selected time scale by comparison of spatial LULC produced maps.

Materials and methods

Study area

Soan River, significant seasonal river of Punjab, Pakistan, lies between geographical coordinates of 71° 45′ to 73° 35′ longitude and 32° 45′ to 33° 55′ latitude. The river lies on the left bank of Indus tributary, starts from Murree hills, passes through Rawalpindi, and ends at Indus tributary. The area experiences extreme summers at the point of Rawalpindi and extreme winters in Murree with December and January as the coldest months. The area receives average rainfall ranging between 750 and 1400 mm area (Ahmad et al. 2012; Hussain et al. 2014; Jehanzeb 2004; Iqbal et al. 2004). The map of study area is shown in Fig. 1.

Data sets

For geospatial analysis of land cover dynamics of Soan River, two types of data sets were obtained: (a) satellite imagery for the years of 1992, 2002, and 2015 was downloaded from USGS glovis and (b) ancillary data including ground truth data, topographic maps, and aerial images of study area. The ground truth data was used as reference data gathered through GPS for image classification and overall accuracy assessment. Specifications of satellite imagery are given in Table 1.

Image preprocessing and classification

Preprocessing of satellite imagery has immense importance as it links data acquired and biophysical process (Coppin et al. 2004). Data was preprocessed in ERDAS Imagine 11 for geoprocessing (geometric corrections) followed by subsetting on the basis of area of interest (AOI). Hybrid classification approach was adopted which combined supervised and unsupervised classification approach. Firstly, unsupervised classification

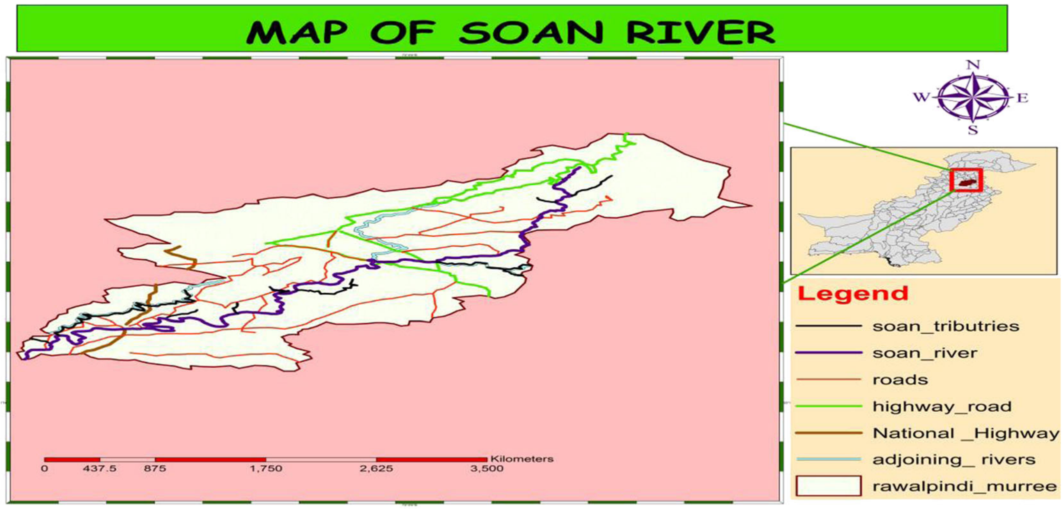

Fig. 1 Study area map of Soan River

approach was adopted and four classes, i.e., vegetation, water body, barren, and urban area were delineated on the basis of reflective spectral band (Yuan et al. 2005; Appiah et al. 2015). The outputs of unsupervised classification were refined by using maximum likelihood algorithm of supervised classification approach.

Unsupervised classification

Unsupervised classification approach needs no previous information about study area and based on self association of spectral clusters and helps in highlighting spectral clusters which are difficult to differentiate in supervised classification (Liu and Mason 2009). In the present study, different land use classes were differentiated using ISODATA algorithm that calculated evenly distributed class in data space then clustered the remaining pixels on the basis of minimum distance (Melesse and Jordan 2002). A total of 100 iterations were run for each class and every iteration recalculated mean and pixels were reclassified on the basis of newly calculated mean. The process was continued till the iteration number was reached to the selected number for particular class, and class was changed to other to delineate four classes on the basis of spectral curves, i.e., water body, vegetation, barren, and urban area.

Supervised classification

Supervised classification approach needs number of training sample to be selected by analyst for representing subject that is under consideration for classification (Jensen 1996). These training samples are identified on the basis of ground truth data for identifying particular land use class (Purkis and klemas 2011). After that, digital number statistics is used to classify pixels of particular land cover. Digital number value was assigned on one pixel and differentiated by other on basis of value of raw digital number (Tardie and Congalton 2007). Per pixel signatures were taken and stored in signature file, and raw digital number value of each pixel was

Table 1 Data acquisition of remotely sensed satellite data

Data	Year	Source	Path/row	Resolution	Band	Acquisition date
Landsat 4, 5 TM	1992 (June)	USGS Glovis	150/37	240 m	Multispectral	14 April 2016
Landsat 7 ETM	2002 (April)	USGS Glovis	150/37	240 m	Multispectral	14 April 2016
Landsat 8 OLI	2015 (April)	USGS Glovis	150/37	240 m	Multispectral	14 April 2016

http://landsat.gsfc.nasa.gov/?page_id=2(USGS, 2016) therefore transformed to radiance value (Butt et al. 2015). In order to add any absent signature cluster of particular class, supervised classification was performed. From several algorithms of supervised classification, maximum likelihood algorithm was applied in the present study because of its advantage of consider variable pixels in feature space, vector mean of pixels and calculates probability of specific pixel for particular land use class (Jensen 1996). The signature files from unsupervised classification were further used to form one signature file and were processed through maximum likelihood algorithm to classify subsetted image. Four classes were delineated, i.e., water body, vegetation, barren, and urban area.

By combining both the unsupervised and supervised approach, hybrid approach was adopted. In this approach, level 1 classes were clustered on the basis of reflective band width. Similar classes were merged. Class histograms were checked for normality and unwanted smaller classes were deleted. Further, maximum likelihood algorithm was to reduce classification anomalies raised by similarity in spectral responses of some classes (Yaun et al. 2005).

Accuracy assessment

Accuracy of classified images for the years of 1992, 2002, and 2015 was assessed to check quality of classification for effective change detection analysis. This process compared categorized data with reference data for same training site (Jensen 2007; Lachowski 1996). Error matrix is deemed as standard method for presenting outcomes of accuracy assessment (Story and Congalton 1986) and characterizes classification performance (Rees 1999). Overall accuracy assessment is ratio between sums of diagonal entries and total number of inspected pixels and results into percentage of accurately classified pixels (Campbell and Wynne, 2011). Stratified random technique was utilized to present different land cover classes and to assess accuracy. One hundred twenty random points for each class on the basis of ground truth data and visual estimation were generated. Then, the statistical comparison between reference data and classification results was performed using error matrix. Kappa coefficient test (K) was further performed to assess accuracy of particular classes generated from remotely sensed image was either better from randomly assigned class from area. It was calculated from the following formula (Eq. 1).

$$K = P(A) - P(E) \div 1 - P(E) \quad (1)$$

In equation, $P(A)$ is the total number of times K which is accurate, while $P(E)$ is expected rate of accuracy of K (Gwet 2002; Vierra and Garrett 2005). If values of kappa statistics exceed 0.8, then accuracy of image is good, but if it is between 0.8 and 0.4, then image is poorly classified. (Vierra and Garrett 2005).

Post classification comparison and change detection

For improving classification accuracy, post classification comparison was performed for increasing effectiveness of technique in (Harris and Ventura 1995) and removing mixed pixels (Lu and Weng 2005); particularly for urban class, i.e., consisting mixed features of buildings, roads, and soil (Jensen and Im 2007). As hybrid classification was adopted, the problem of mixed pixels was trounced. Post classification comparison and change detection were performed in ArcGIS 10.2. Overlay change detection was adopted to detect change in particular class between selected time periods. Percentage of change was calculated from the following formula (Eq. 2)

$$\text{Percentage change} = [(b - a)/a] \times 100 \quad (2)$$

In Eq. 2,
a = area of class in old year
b = area of class in new year

For determining quantity of one particular class shifted to other class, cross tabulation was conducted using pixel by pixel matrix. Therefore, new thematic map was generated for representing land use class changed "from" or "to" other land use.

Results

Classification accuracy assessment

Error matrix and kappa coefficient were used for assessing accuracy of classified images and are summa-

Table 2 Overall classification accuracy and kappa coefficient

	1992	2002	2015
Overall classification accuracy (%)	95.32	96	95.03
Overall kappa coefficient	0.9237	0.9392	0.9071

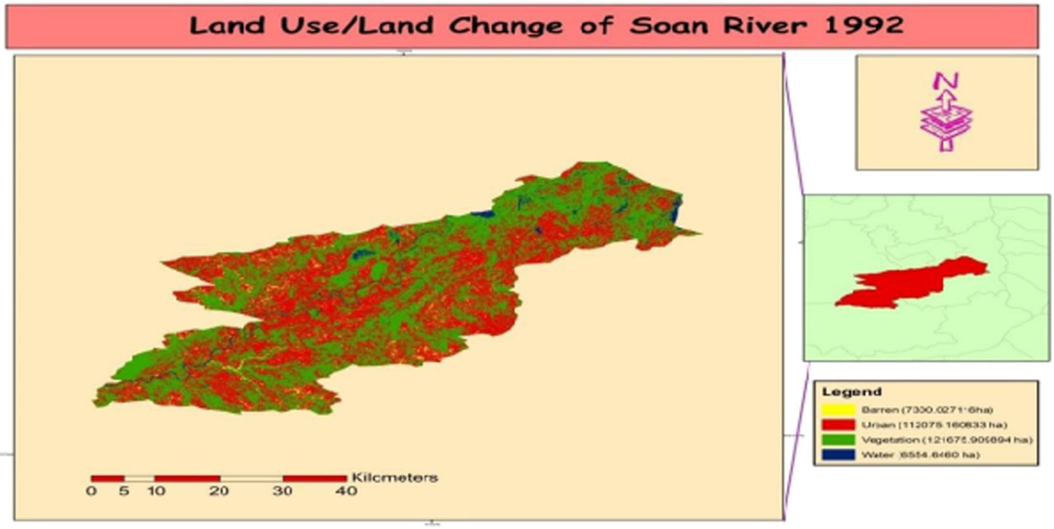

Fig. 2 Land use land change map of Soan River 1992

rized in Table 2. Overall accuracies for 1992, 2002, and 2015 were 95.32, 96, and 95.03% with kappa coefficients 0.9237, 0.9392, and 0.9071, respectively. Lea and Curtis (2010) reported accuracy report above 90%, and kappa coefficient above 0.9 reflects good classification and this criterion is successfully achieved in this study.

Classification and change map statistics

Maps were generated for classified images of the years 1992, 2002, and 2015 (Figs. 2, 3, 4), while area and percentage of individual classes of land use is summarized in Table 3.

The results revealed major decline in area coverage for vegetation and water body class, while area for barren and urban increased significantly. Vegetation area coverage was reduced from 2.02% (1992–2002) to 53.24% (2002–2015), while area for water body which was already least than other classes was shrank to 58.81% (2002–2015). Urban class and barren increased their share up to 49.04 (2002–2015) and 137.32% (2002–2015) from 1.07 (1992–2002) and 17.49% (1992–2002), respectively (Fig. 5).

Area shift

The cross tabulation results for 1992–2002 and 2002–2015 showed 68.89% of the area remained unchanged for the years of 1992–2002, while 36.03% of area was changed into other land use classes (Figs. 6, 7). The unchanged area for years of 2002–2015 was estimated as 44.1%, while 55.9% was changed as summarized in Tables 4, 5. Vegetation class was predominantly changed to urban area in 2002, while barren area also

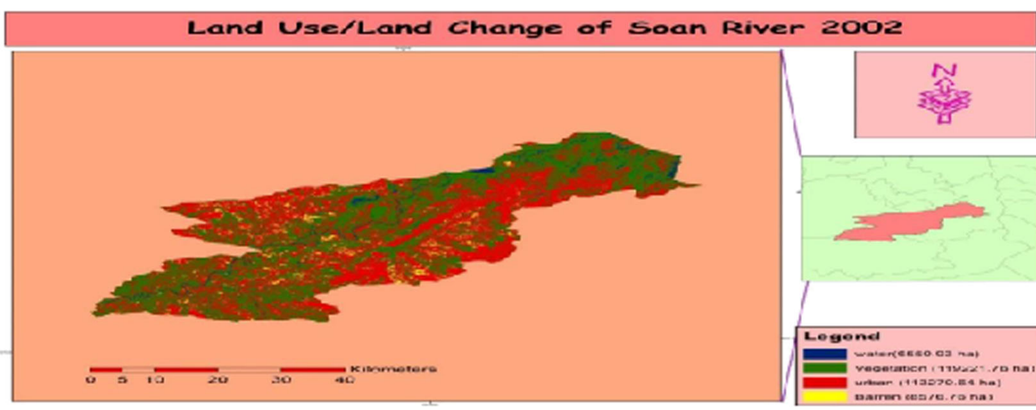

Fig. 3 Land use land change map of Soan River 2002

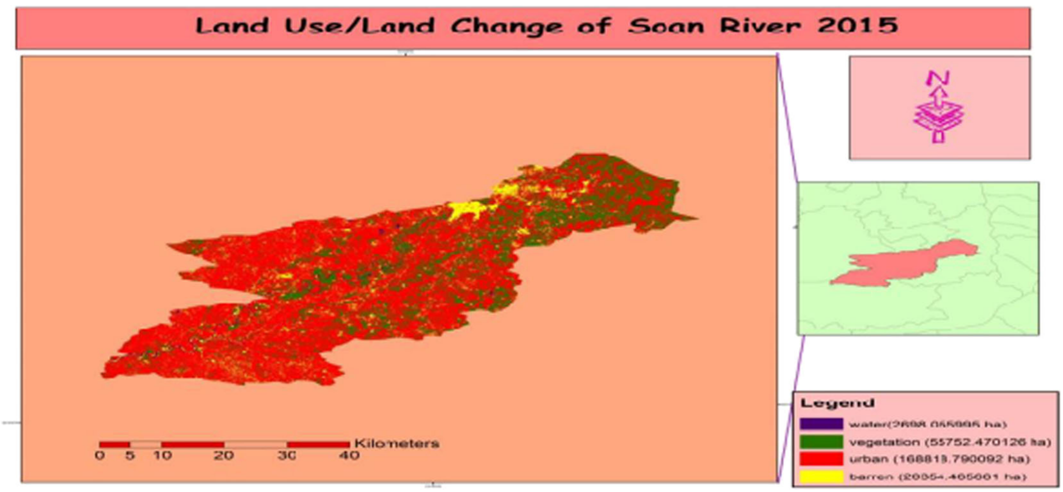

Fig. 4 Land use land change map of Soan River 2015

showed significant share in reducing vegetation. Water body showed shrinkage due to conversion of more land to urban and barren in 2015.

Discussions

Change detection analysis in land cover dynamics is off significant importance in monitoring and management of environmental earth resources. It helps in understanding impact of human laid activities over environmental resources (Prakasam 2010) as these activities directly or indirectly related to land cover dynamics (FAO 1995). Since the last 2 decades, change in land cover dynamics was identified as stimulating factor posing threat to biodiversity (MEA 2005).

Results of classification comparison showed remarkable change between 2 decades (1992–2015). Figure 5 illustrates the trends in change in land cover dynamics from 1992 to 2002. From the figure, obvious increase in barren area class and urban area class could be noted, while vegetation class and water body class showed remarkable reduction.

According to results, vegetation was decreased to 53.24% (2002–2015). The valley was reported to full of pastures, herbs, shrubs, and rangelands. The major causes for major decline include deforestation, extensive population growth, urbanization, low rainfall, and selling of precious plants in markets for earning livelihood by poor people (Ahmad et al. 2012). Forest fires were also resulted in decrease in vegetation class (WWF 1994). Extensive usage of herbs with replacement is another facilitating reduction in area coverage of vegetation class (Ahmad et al. 2012). Ali et al. (2008) reported if the urban area would continued to increase around Rawalpindi and Islamabad, surface runoff would be increased which would result in reduction in vegetation. IUCN (2005) and Tanvir et al. (2006)

Table 3 Area statistics and percentage change from 1992 to 2002 and 2002 to 2015

Land use/land cover classes	1992		2002		2015		Percentage change	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	1992–2000 (%)	2000–2011 (%)
Vegetation	121,675	49.14	119,221.76	48.15	55,752.470126	22.51	−2.02	−53.24
Water	6554.6	2.65	6550.93	2.64	2698.05595	1.09	−0.06	−58.81
Barren	7300	2.95	8576.76	3.46	20,354.465661	8.22	17.49	137.32
Urban area	112,075	45.26	113,270.64	45.75	168,818.790092	68.18	1.07	49.04
Total	247,604.6	100	247,604.09	100	247,623.78	100		

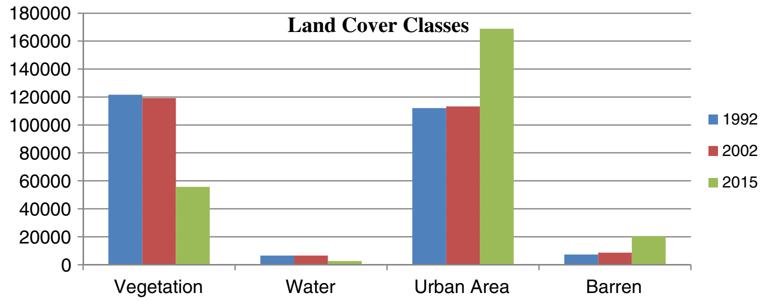

Fig. 5 Nature of relative land cover changes from 1992 to 2015

reported anthropogenic activities such as utilization of forest wood for household purposes, timber production, illegal cutting, forest fires, over grazing, ineffective vegetation management are key components that play role in vegetation decline. Mather and Needle (2000) indicated increased population and poverty as the root cause in declining vegetation cover and it is shifting to barren land or agricultural area.

Butt et al. (2015) studied the land use classes along Simly Water shed, Islamabad, by using supervised classification. Out of total classes that were formed, vegetation class showed decrease in 69 to 43% from 1992 to 2012. The major reasons identified in decreasing land use class were its change to settlement and agriculture. Other reasons were forest fires, illegal cutting, and unsustainable utilization of forest.

The second class faced shrinkage was water body reduced to 58.81% (2002–2015). The major shrinkage might be due to extensive urbanization, decreased rainfall, evaporation, seepage, and percolation (Ashraf et al. 2007; Bailly 2007; Keller et al. 2000). The other reasons affecting water body included industrial discharges, and agricultural waste of herbicides and pesticides is affecting water quality and depleting nutrients (IUCN 2005).

Abdeji and Ajibade (2008) studied changes in area of major dams in Osun State, Nigeria, using ILWIS 3.3 software. The results indicated sharp reduction in water area from 37.49 to 45.42% from 1989 to 2002.

Barren class witnessed increment up to 137.32. The increase in barren area could be accredited by anthropogenic activities such as overgrazing of rangelands, forest fires, unsystematic bush burning, stone crushing, and fuel wood extraction. With the increasing population, unoccupied land is becoming rare due to its conversion to housing schemes, and rich people are buying these lands at any cost to enjoy lavish lifestyle. This had

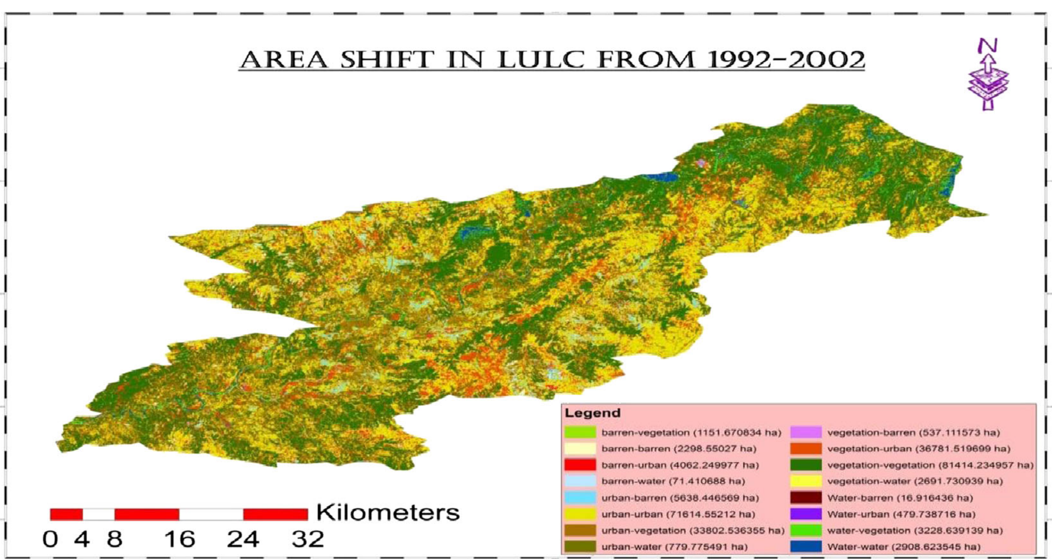

Fig. 6 Area shift map of Soan River from 1992 to 2002

Table 4 Land cover shift summary from 1992 to 2002

Changed class in 2002 in hectares (ha)

Class (1992)	% unchanged	% changed	Vegetation	Water	Barren	Urban area	Total (1992)
Vegetation	32.88	16.16	81,414.234957	2691.730939	537.111573	36,781.519699	121,424.597168
Water	1.17	1.5	3228.639139	2908.623545	16.916436	479.738716	6633.917836
Barren	0.92	2.13	1151.670834	71.410688	2298.55027	4062.249977	7583.881799
Urban area	28.92	16.24	33,802.536355	5638.446569	779.775491	71,614.55212	111,835.310535
Total (2002)	63.89	36.03	119,597.081285	11,310.211741	3632.35377	75,753.471997598	247,604.09

resulted in increase in residential colonies along study area. The increase in barren soil might be due to increased deforestation. The removal of vegetative cover increased barren area. As a result of it, soil is losing accelerating erosion and making productive land unavailable for cultivation posing threats to nation's economy (Butt et al. 2015). Butt et al. (2015) applied maximum likelihood algorithm to study change in water area of Simly Dam, Islamabad. Six percent area was decreased from 1992 to 2002.

According to the results of study area, urban class showed considerable increase up to 49.04%. Urbanization is reported to increase due to establishment of many housing schemes such as Bahria town, airport society, and construction of metro bus project (Fareed et al. 2016). The increase in such developments had resulted in declining vegetation area and water body. The increase in urbanization had increased in impervious area which increased surface runoff thus accelerated soil erosion (Hussain et al. 2014). Urban area was reported to be increased by clearing of natural vegetation (Martellozzo et al. 2014). Torahi and Rai (2011) studied LULC pattern of forest cover in Dehdez area of Zagros Mountains in Iran. Supervised classification was performed to assess Landsat TM and Aster imagery. Urban area was showed increase of 7.2% from 1990 to 2006.

Soan River which starts from Murree made its way to Rawalpindi. The tributaries and adjoining rivers responsible for flooding in Soan were also included. Soan River is facing problem due to urban development and deforestation which is changing the land use pattern. The growth in population and development of housing schemes is adversely affecting the Soan River (Hussain et al. 2014). Deforestation is becoming common because of high market value and for house hold purposes. It is posing negative affect over aquatic habitat and water quality. Removal of vegetative cover from steep slopes is making water reservoir more vulnerable to soil erosion and increased surface runoff. Herbicides and pesticide usage for improving crop yield is threatening water quality by increasing toxicity (Butt et al. 2015), while discharge of effluents in Soan's water is affecting aquatic life of Soan. Ahmad et al. (2012) and Hussain et al. (2014) concluded that rapid urbanization,

Table 5 Land cover shift summary from 2002 to 2015

Changed class in 2015 in hectares (ha)

Class (2002)	% unchanged	% changed	Vegetation	Water	Barren	Urban area	Total (2002)
Vegetation	11	37	27,406.765511	1171.755367	8209.240396	82,328.322294	119,116.083568
Water	0.5	2.2	2937.24689	1141.366558	440.787216	2088.397874	6607.798538
Barren	0.8	2.6	1319.006528	45.593395	2074.648669	5191.81108	8631.059672
Urban area	31.8	14	24,293.531144	346.532058	9865.433198	78,760.611952	113,266.108352
Total (2015)	44.1	55.9	55,956.550073	2705.247378	20,590.109479	168,369.1432	247,623.78

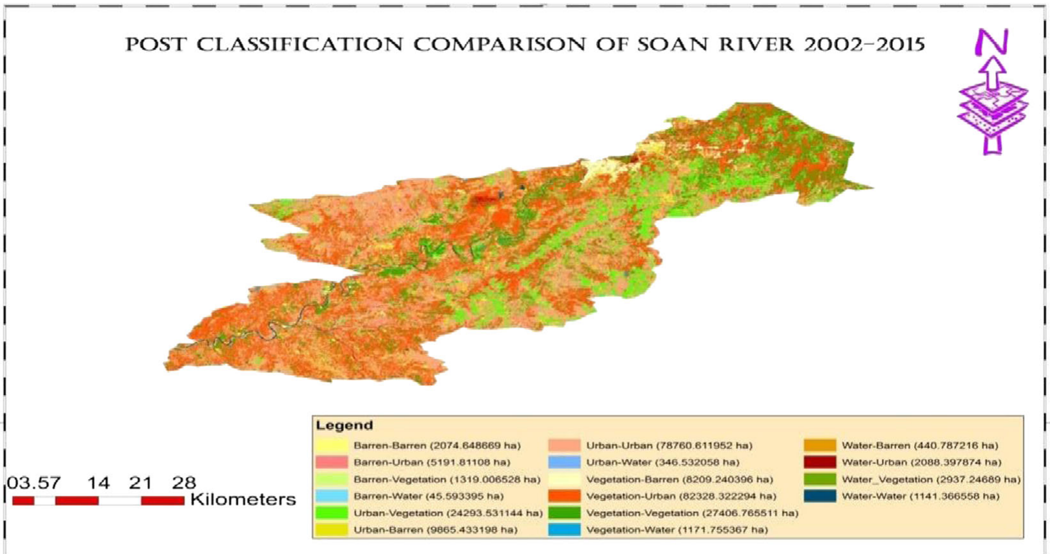

Fig. 7 Area shift map of Soan River from 2002 to 2015

deforestation, and changing land use patterns along Soan River were prime factors affecting water quality and increasing sedimentation and soil erosion.

Present study elucidated the implication of geospatial approach in detecting changes in land cover dynamics as it helped in detecting spatial and temporal changes between two decades (1992–2015), while application of hybrid approach helped in achieving better accuracy and proved effective method for change documentation in land cover dynamics.

Conclusion

The conclusion is based on the classification results, obtained by application of geospatial techniques, for obtaining specific research objectives, and highlighted significant alterations in land cover dynamics of study area in the last 2 decades. Geospatial techniques provided an effective way in understanding the spatiotemporal changes which excluded the anomalies usually faced during single classification approach. Further, accuracy assessment results were very encouraging and hopeful for the adopted approach. The adopted approach showed clear reduction in water body up to 58.8%. Although careful investigation was done but still a 100% accuracy rate was not achieved due to absence of previous data set records for the years of 1992–2002 and uncertainties in reference data (Foody 2010), rapid urbanization and reduction in vegetation is affecting water quality and ended up in increase flood frequencies. All the alterations in land cover dynamics are due to lack of proper management, poor EIA conductance, and negligence of environmental laws. For increasing lifetime of Soan River, the government should take strong initiatives for restoring degraded lands and should impose penalties on the projects started with poor EIA.

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