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Spatial and temporal dynamics of Pai forest vegetation in Pakistan assessed by RS and GIS

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Abstract Pai, an arid forest in Sindh Province of Pakistan, is important for the environmental, social, economic development and conservation of ecosystems of the province. Considering the significance of the forest for Sindh and the calls from the local population for its deforestation, we quantified the spatial and temporal variation in the vegetation of the forest and land surface temperature (LST) using optical and thermal Landsat satellite data. Our analysis of temporal (1987–2014) images with ArcGIS 10.1 revealed that the dense forest area was greatest at 725 ha (37 % of the total forest area) during 2013 while it was smallest at 217 ha (11 %) in 1992. The sparse forest area peaked during 1987 at 1115 ha (58 %) under shrubs whereas it was smallest at 840 ha (43 %) in 1992, and the maximum deforestation of Pai forest occurred during 1992. Spatial change in vegetation over a period of about 27 years (1987–2014) revealed that vegetation increased on an area of 735 ha (37 %), decreased on 427 ha (22 %), and there was no change on 808 ha (41 %) of the forest. Variation in temperature between shaded (dense forest) and unshaded areas (bare land) of the forest was from 6 to 10 °C. While the temperature difference between areas with sparse forest and bare land ranged from 4 to 6 °C. An inverse relationship between LST and NDVI of Pai forest with coefficients of determination of 0.944 and 0.917 was observed when NDVI was plotted against minimum and maximum LST, respectively. The vegetation in the forest increased with time and the areas of more dense Pai forest supported lower surface temperature and thus air temperature.

Keywords Landsat · Arid forest · NDVI · Deforestation · Ecosystem · Land surface temperature (LST)

Introduction

Forests not only provide livelihood to about one billion people (UNEP 2011; Sunderland et al. 2013) but also provide employment directly or indirectly to more than one hundred million people around the globe (UNEP 2011). Forests protect environment through soil conservation, watershed management, and provide protection against floods and landslides. Forests have an important impact on local as well as global environment and climate change (Xiao et al. 2004). Temporal changes in forest land cover can result in a wide variety of ecological impacts, including changes in productivity, composition, nutrient dynamics, species diversity, and increased atmospheric carbon dioxide (Braswell et al. 2003).

Measuring, mapping and classifying forests is important for monitoring spatial and temporal variation in vegetation and for planning and implementation of forest restoration programs (Rikimaru 1999). Traditional methods of mapping and categorizing forests through field surveys, literature reviews, map interpretation and secondary data analysis are time consuming, laborious, and uneconomical. Therefore, Remote Sensing and GIS tools are often used

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for mapping, monitoring and analyzing forest vegetation as these tools are economical and rapid (Kumar 2010). Acquiring high spatial resolution satellite imagery is often expensive and cost-prohibitive. In contrast, Google Earth® (GE) is a free source of high resolution satellite imagery (Madin et al. 2011; Hughes et al. 2011; Pringle 2010) but its applications are limited by inadequate temporal availability of imagery and low spectral resolution and number of spectral bands (Potere 2008; McInnes et al. 2011). Hence, Landsat imagery is widely used for monitoring global surface change as it is a free multispectral and medium spatial resolution resource of imagery (Goward et al. 2006; Masek et al. 2008; Wulder et al. 2008; Xie et al. 2008; Bhandari et al. 2012). The diurnal land surface temperature (LST) derived from thermal infrared (TIR) bands is reported to be closely related to the density of the forest canopy (Nemani and Running 1997). Pongratz et al. (2006) confirmed that increase in LST occurs in areas with lower forest cover compared with dense forest. Yang et al. (2007) observed a good agreement with coefficient of determination of $R^2 = 0.80$ and RMSE = 0.7 °C between predicted and observed air-surface temperature profile in mixed forest. Wickham et al. (2012) reported that forest surface temperatures were cooler than cropland surface temperatures. Thus, day LST can be used to detect changes in the forest cover (van Leeuwen et al. 2011).

Pai forest, one of the major forests of Sindh, Pakistan is reported to be endangered due to natural factors such as chronic water shortage, soil salinization, threats from land grabbers and lumber mafia, and deforestation due to cutting of trees by nearby villagers (WWF 2008). It is claimed by local people that trees are cut from an area of about 200 ha and the land is then brought under cultivation for crops. These threats are countered by calls from civil society to prevent deforestation and conserve the forest. There is a need to study the temporal and spatial change in the vegetation of the forest in order to analyze threats to the forest as claimed by people. Our study was thus conducted using temporal Landsat optical data to quantify the spatial and temporal variation in the vegetation of the forest. Spatial variation in LST during winter (January), spring (March), summer (June) and autumn (October) was determined from Landsat TIR data for the year 2013–2014 only.

Materials and methods

Study area

Pakistan has about 4.57 million hectares of forests, which is equivalent to 5.2 % of the total geographical area (GoP 2003). This is low compared to the global average of 30 % (FAO 2001) but the climate of Pakistan is predominantly arid and largely unsuited to forest development. The total riverine area in Sindh, Pakistan is 0.855 million ha which is confined between flood protective embankments on both sides of the main stream of the river Indus (Panhwar 2002). The riverine forests in Sindh are mostly on rich alluvial soils that support trees such as *Prosopis juliflora* (Babol), *Acacia nilotica* (Kikar), *Populus euphratica* (Bahan), *Tamarix aphylla* and *Tamarix dioica* (Lai), *Dalbergia sissoo* (Shesham), *Prosopis cineraria* (Kandi), and *Azadirachta indica* (Neem). These forests are the major sources of timber, firewood and fodder for livestock (Mughal 2010).

Pai forest is considered to be one of the important forest of Sindh province and covers an area of 1977 ha. It is surrounded by vast fertile cultivated lands (Qureshi and Bhatti 2010; Faruqi 2011). WWF (2008) reported that during 2008, about 1502 ha (76 %) were under tree cover while the remaining 468 ha (23.7 %) were either cultivated or were bare land with salty patches. The forest is located in arid area with mean annual rainfall of about 150 mm and maximum surface evaporation rates of about 9–10 mm day^{-1} during May and June.

The forest is situated in Shaheed Benazirabad, a central district of Sindh, near Sakrand town on the left bank of the river Indus between longitudes 68°12′20″ and 68°17′04″E and latitudes 26°04′50″ and 26°07′40″N at 30 m above mean sea level (Fig. 1). The Pai forest in true color, pseudo natural color, and false color is shown in Fig. 2. The study area is mainly covered by vegetation (Fig. 2c). Areas covered by isolated bushes are shown in purple color in Fig. 2b, agricultural land is shown in magenta color in Fig. 2b, and bare land is shown in white color in Fig. 2a.

Pai forest was a riverine forest until its source of irrigation was cut off from the river Indus due to construction of flood protection bunds along the Indus river banks during the era of British rule. It is now a canal irrigated forest, being irrigated by the Rahib Shah distributary, a branch of the Rohri Canal and by groundwater through tube-wells installed for this purpose. The forest provides habitat for flora and fauna including the indigenous Mesquite (*P. juliflora*), Arabic gumtree (*A. nilotica*), Spunge tree (*P. cineraria*), Indian rosewood or Bombay Blackwood (*D. sissoo*) and Hog deer, Partridges, Asiatic jackals, Jungle cat, Porcupine, reptiles. Qureshi and Bhatti (2010) reported total of 93 plant species in the forest. The forest also provides livelihood to 21 villages located on the periphery of the forest. They are dependent upon the natural products of the forest to meet their daily requirement of food, fuel wood and earnings.

Satellite imagery

Temporal and spatial variation in vegetative cover of Pai forest was quantified using Landsat imagery. Landsat

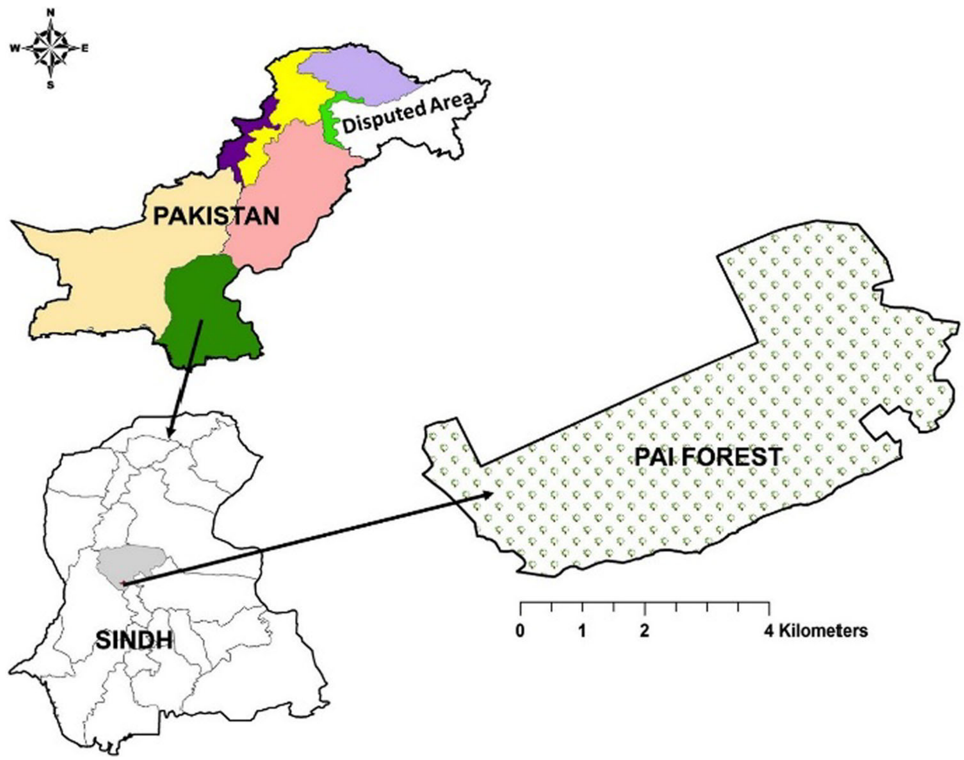

Fig. 1 Location of Pai forest in Sind, Pakistan

imagery of WRS-2 path 152, row 42, datum WGS84, processing L1T from November, 1987 to November, 2014 was downloaded from the United States Geological Survey portal (GloVis) website. Details of the downloaded imagery are listed in Table 1. Only two images of the site were available from the GloVis archive for the year 1992, hence, for that year we used the image made in April.

Image processing

Extraction of Pai forest and image classification

The acquired Landsat imagery was processed in ArcGIS 10.1. The image of only Pai forest was extracted from the entire scene using 'Extract by Mask' tool, by adding the shapefile of the forest as a mask. The extracted images of Pai forest of all acquired imagery were classified using a maximum likelihood algorithm. For this, the training samples were produced on the raster image of the entire area of Pai forest using Training Sample Manager. Training samples were created by drawing polygons at different locations in the forest area and then all samples were merged to a single class. The area was thus trained for three classes viz. dense forest (dense trees), sparse forest (scrub and stunted bushes) and bare land. From the training area and classes, a signature file was prepared which was then used as an input file during running of the maximum likelihood algorithm. The area under each class was computed by converting the raster data into polygons and then summing the area of all polygons of the same class.

Temporal and spatial variations in crop cover and NDVI

The temporal and spatial vegetation change in forest between November 1987 and November 2014 was determined by comparing the near infrared (NIR) bands (band 4 of Landsat 5 and band 5 of Landsat 8) of both years and running the image difference algorithm in the Image Analysis Window of ArcGIS 10.1.

Normalized difference vegetation index (NDVI) is usually used to estimate vegetation biomass, greenness and production of the vegetative cover (Kawamura et al. 2005; Telesca et al. 2006). It is generally calculated from the visible red and near-infrared light reflected by vegetation. The NDVI of a given pixel always results in a number that ranges from -1 to $+1$. A value between -1 and 0 shows a water body in the area, while NDVI between 0 and 0.2 represents bare land and 0.2 and 1.0 indicates the vegetative cover. The NDVI of all the extracted images of Pai forest was calculated using following relation (Rouse et al. 1974):

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}} \quad (1)$$

where, ρ_{nir} is the near infrared band, and ρ_{red} is the red band.

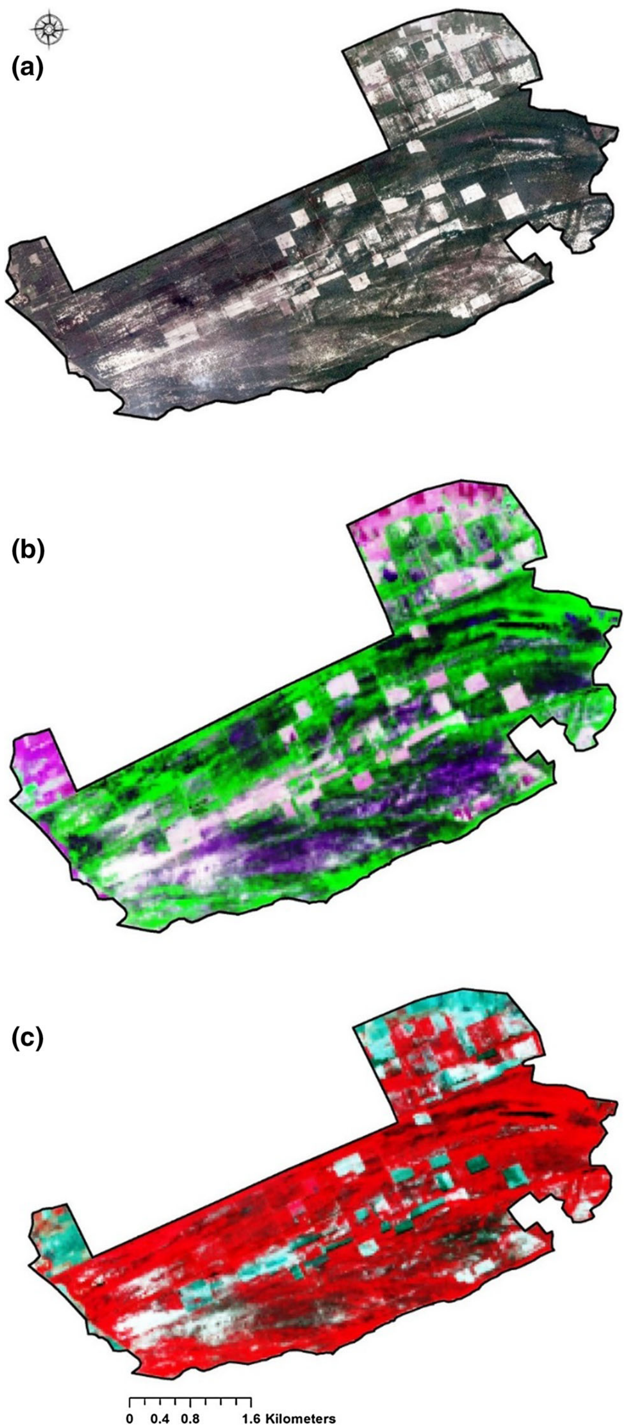

Fig. 2 Pai forest in true (**a**), pseudo natural (**b**) and false *colors* (**c**). The band combinations in RGB were **a** B4, B3, B2 **b** B6, B5, B4 and **c** B5, B4, B3

Land surface temperature (LST)

Satellite thermal infrared sensor (TIR) is usually used to quantify the top of the atmosphere (TOA) radiances, from which brightness temperatures (blackbody temperatures) can be derived using Plank's law (Dash et al. 2002). Temporal and spatial variation in temperature of Pai forest was also monitored throughout the year i.e. winter, spring, summer and autumn. Landsat 8 imagery (Table 2) was also processed for this purpose. A newly launched Landsat 8 satellite is equipped with TIRS, a new instrument for capturing surface temperature information. Two electromagnetic spectral bands are delivered by this sensor with 100 m resolution to estimate the temperature at the Earth's surface. To calculate the actual surface temperature of the area under study, digital numbers (DNs) of thermal bands (band 10 or band 11) were first converted into top-of-the-atmosphere (ToA) radiance values and then ToA radiance values to ToA brightness temperature in Kelvin and then to centigrade using Eqs. 2 and 3.

Table 1 Landsat optical images used in the study with years of acquisition of the data, row, path, the sensors, and day of the year (DOY)

Year	Acquisition date	Satellite	Sensor ID	DOY
1987	November 08	Landsat 5	TM	312
1992	April 27	Landsat 5	TM	118
2000	November 19	Landsat 7	ETM	324
2010	November 07	Landsat 5	TM	311
2013	November 15	Landsat 8	OLI and TIRS	319
2014	November 18	Landsat 8	OLI and TIRS	322

$$L = (M_L \times Q_{cal}) + A_L \quad (2)$$

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L} + 1\right)} - 273.0 \quad (3)$$

where, L_λ TOA spectral radiance, M_L Band-specific multiplicative rescaling factor, A_L Band-specific additive rescaling factor, Q_{cal} Quantized and calibrated standard product pixel values (DN), T ToA brightness temperature (°C), K_1 Band-specific thermal conversion constant, and K_2 Band-specific thermal conversion constant.

The input parameters of Eqs. 2 and 3 (M_L, A_L, K_1 and K_2) for band 10 and band 11 of Landsat 8 obtained from metafile of images are given in Table 3.

Table 2 Landsat OLI and TIRS images used for determination of temporal and spatial variation in temperature

Year	Acquisition date	Sensor	DOY
2013	October 13	OLI and TIRS	287
2014	January 18	OLI and TIRS	18
2014	March 07	OLI and TIRS	66
2014	June 11	OLI and TIRS	162

Table 3 Landsat 8-TIRS constants for bands 10 and 11

Band	M_L	A_L	K_1	K_2
Band 10	0.0003342	0.1	774.89	1321.08
Band 11	0.0003342	0.1	480.89	1201.14

By extracting the LST values from randomly selected points of ToA brightness temperature raster image, the spatial variation of LST under different land use classes (bare land, sparse forest and dense forest) was determined.

A study conducted by Li et al. (2008) to investigate the relationship between LST and air temperature revealed that

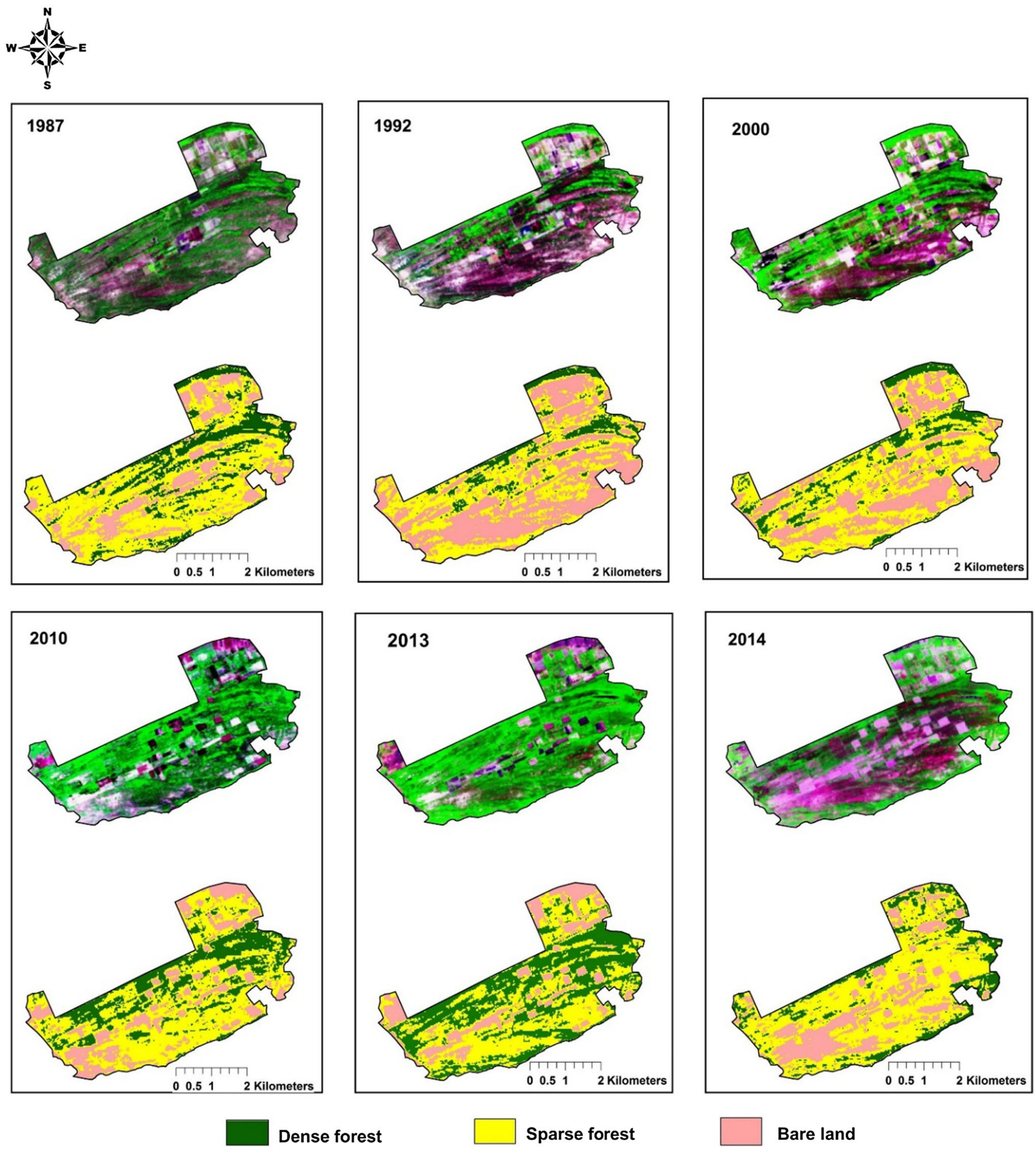

Fig. 3 Landsat images (pseudo natural *color*) and classified images of Pai forest for the years of 1987, 1992, 2000, 2010, 2013 and 2014

Table 4 Temporal variation in vegetative cover of Pai forest from 1987 to 2014

Year	Dense forest (ha)	Sparse forest (ha)	Forest total (ha)	Bare land (ha)	Total (ha)	Vegetative cover ratio (%)
1987	437	1115	1525	425	1977	78.5
1992	217	840	1057	920	1977	53.46
2000	280	1010	1290	687	1977	65.25
2010	482	1042	1524	453	1977	77.08
2013	725	894	1619	358	1977	81.89
2014	689	948	1637	340	1977	82.8

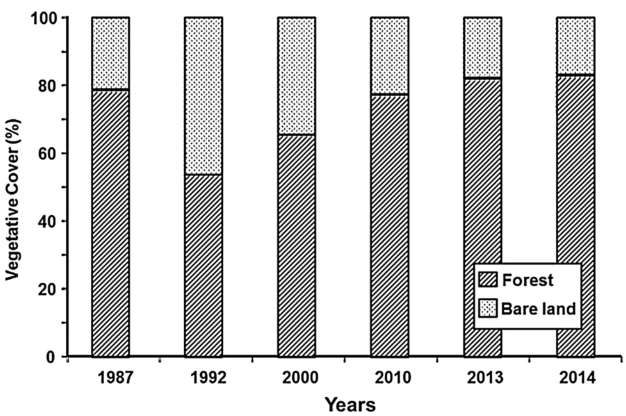

Fig. 4 Temporal variation (%) in vegetative cover of Pai forest

differences are relatively small in areas of high temperature but are larger in low temperature areas. They also reported moderate to high correlations ranging from 0.73 to 0.79 between air temperature and LST. For the present study difference between air temperature and LST was assumed very small as Pai forest is located in hot and dry climate region.

Results and discussion

Temporal and spatial variations in vegetative cover

Figure 3 shows the Landsat images in pseudo natural color and classified images of Pai forest for the years 1987, 1992, 2000, 2010, 2013 and 2014. All the Landsat images of Pai forest were classified for dense forest (pixels represent only trees), sparse forest (mixed pixels representing both sparse shrubs and bare land) and bare land (pixels represent only bare land). Variation in vegetative cover of Pai forest from 1987 to 2014 showed that about 1552 ha (79 %) of forest were covered with vegetation (trees and shrubs) in 1987. This declined to 1057 ha (53 %) in 1992, a 26 % reduction in vegetative cover in 5 years (Table 4). This might have been due to illegal harvest of trees or drying of trees due to shortage of irrigation water during that period as reported

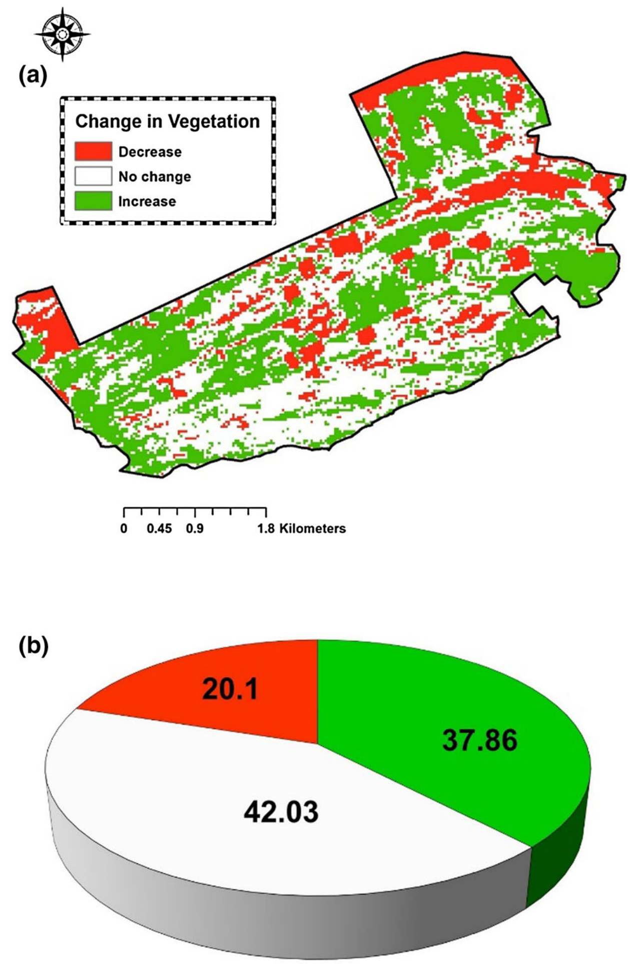

Fig. 5 Spatial change in vegetation of Pai forest occurred in 27 years (**a**) and pie graph of variation in vegetation (% area) of forest in 27 years (**b**)

by Siddiqui (2009). We were unable to confirm the cause of the decrease in vegetative area in 1992 through consultation with the Forest Department Sindh. Another reason for reduction in vegetation in 1992 might have been bias of the satellite image as it was captured during April while the rest of images were captured during winter. Our analysis of an image captured during June 1992 revealed that there

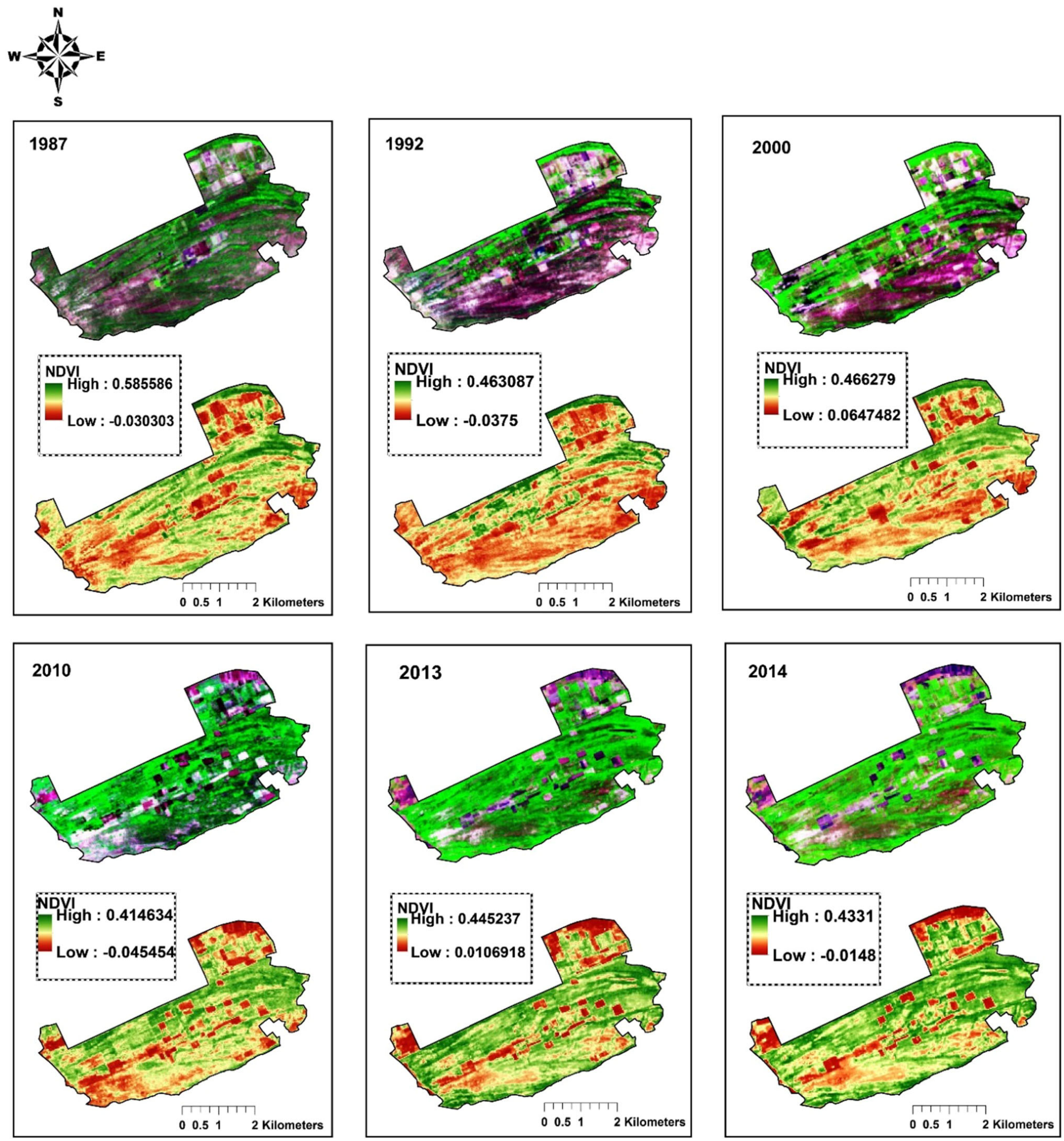

Fig. 6 Temporal variation in NDVI of Pai forest from 1987 to 2014

was a non-significant difference in vegetative area represented by both images (April and June). Thus, we conclude that the decrease in vegetation from 1987 to 1992 was not due to the influence of the difference in season.

After 1992, the vegetated area increased to 1290 ha in 2000 (65 %), 1524 ha in 2010 (77 %), 1619 ha in 2013 (82 %), and 1637 ha in 2014 (83 %). Vegetation gradually increased on about 467 ha (24 %) over a period of 18 years (1992–2010) with an average annual increase in area of 26 ha (Table 4). While from 2010 to 2014, vegetation increased on an area of about 113 ha (6 %) with an average annual increase of 28 ha. Rapid increase in vegetation from 2010 to 2014 might be due to favorable soil moisture conditions in forest due to above average rainfall and heavy

Table 5 Spatio-temporal distribution of vegetation cover of Pai forest, Sindh, Pakistan

Date	Parameters	Vegetative cover			Total
		Dense forest	Sparse forest	Bare land and water body	
Nov. 08, 1987	NDVI	0.35–0.58	0.20–0.35	−0.03–0.20	−0.03–0.58
	Area (ha)	437	1115	425	1977
	Area (%)	22.2	56.3	21.5	100
Apr. 27, 1992	NDVI	0.35–0.46	0.20–0.35	−0.03–0.20	−0.03–0.46
	Area (ha)	217	840	920	1977
	Area (%)	11.0	42.5	46.5	100
Nov. 19, 2000	NDVI	0.35–0.46	0.20–0.35	0.06–0.20	0.06–0.46
	Area (ha)	280	1010	687	1977
	Area (%)	14.1	51.1	34.8	100
Nov. 07, 2010	NDVI	0.35–0.41	0.20–0.35	−0.04–0.2	−0.04–0.41
	Area (ha)	482	1042	453	1977
	Area (%)	24.3	52.7	23.0	100
Nov. 15, 2013	NDVI	0.35–0.44	0.2–0.35	0.01–0.2	0.01–0.44
	Area (ha)	725	894	358	1977
	Area (%)	36.6	45.2	18.2	100
Nov. 18, 2014	NDVI	0.35–0.43	0.2–0.35	−0.01–0.2	−0.01–0.43
	Area (ha)	698	948	340	1977
	Area (%)	34.8	48.0	17.2	100

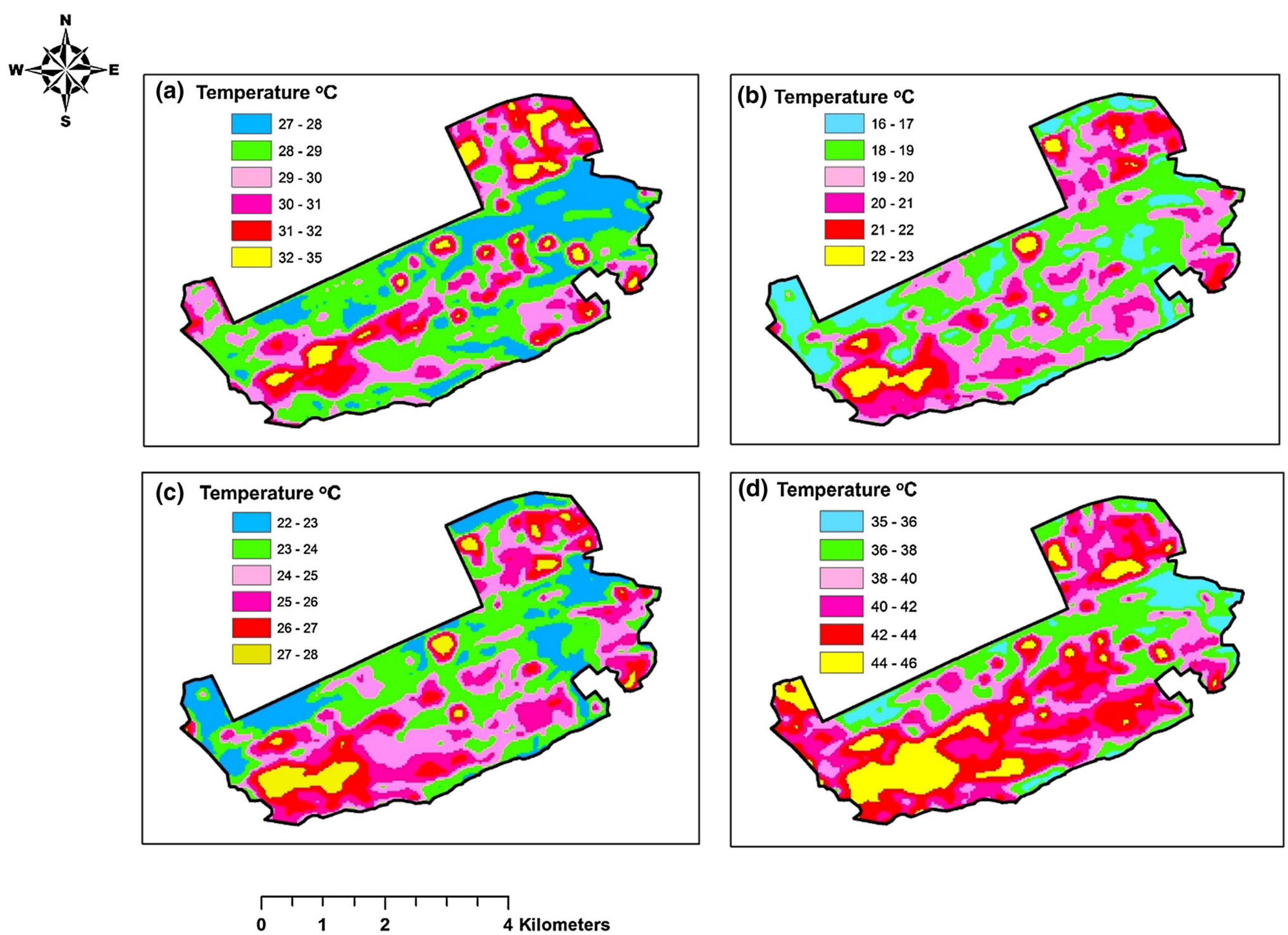

Fig. 7 Spatial and temporal variation in temperature of Pai forest (**a**) October, 2013 (**b**) January, 2014 (**c**) March, 2014, and (**d**) June, 2014

Table 6 Forest area under different temperature ranges during winter, spring, summer and winter

Temperature (°C)	Area under different temperatures			
	Oct. 14, 2013	Jan. 18, 2014	March 07, 2014	June 11, 2014
16–20	–	1821.4	–	–
20–24	–	155.6	1305.2	–
24–28	–	–	671.8	–
28–32	1788	–	–	–
32–36	189	–	–	–
36–40	–	–	–	975
40–46	–	–	–	1002
Total area (ha)	1977	1977	1977	1977

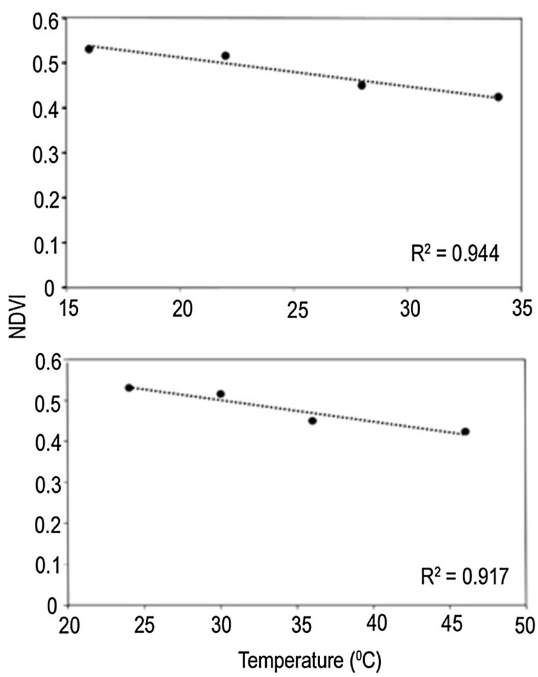

Fig. 8 Relationship between NDVI and **a** minimum LST and **b** maximum LST

floods during 2010 and 2011 in Sindh. The temporal variation in vegetative cover of the forest is graphically presented in Fig. 4. Spatial variation in vegetation cover of the forest shows that reduction in vegetation before 2010 mainly occurred at the central and southern parts along the boundary of Pai forest but after 2010, the northeast part of the forest was affected (Fig. 3).

The spatial change in vegetation of Pai forest occurred over nearly 27 years from 1987 to 2014 and shows that there was more forestation than deforestation (Fig. 5a). This change was reflected by an increase in vegetation on an area of 735 ha (37 %), a decline on 427 ha (22 %), and no change on 808 ha (41 %) of the forest (Fig. 5b). The same qualitative and quantitative conclusions can be derived from Fig. 4 and Table 4.

Temporal and spatial variations in NDVI

The temporal and spatial variation in NDVI of Pai forest from November, 1987 to November, 2014 showed values between −0.045 and 0.58 (Fig. 6). The NDVI value above 0 is categorized into three groups viz. bare land (0–0.2), sparse forest with scrub and stunted bushes (0.2–0.35) and dense forest (>0.35). Thus, for all evaluated years NDVI was higher at those places where dense forest was located, whereas it was minimum for bare land. It varied from year to year such that maximum NDVI of vegetation was recorded in 1987 and minimum NDVI in 2010.

Based on NDVI, the area classification of Pai forest from 1987 to 2014 is given in Table 5. The area under dense forest was greatest at 725 ha (37 %) during 2013 and least at 217 ha (11 %) in 1992. While sparse forest covered the greatest area during 1987 (56 %) and the smallest area in 1992 (43 %). Thus, the smallest areas of both dense and sparse vegetative cover in Pai forest occurred in 1992.

Temporal and spatial variation in Land Surface Temperature (LST)

Temporal and spatial variation in LST of forest for the years 2013–2014 shows that the LST of the forest during autumn, winter, spring and summer varied between 27 and 35 °C, 16 and 23 °C, 22 and 28 °C, and 35 and 45 °C, respectively (Fig. 7). The bare land area had high temperature whereas area under vegetation had low temperature. A variation in LST from 6 to 10 °C between shaded (dense forest) and unshaded areas (bare land) of the forest was observed. Similarly, the temperature difference between areas with sparse forest and bare land ranged between 4 and 6 °C. LST was higher for the bare land and lower for areas with vegetative cover. The forest areas and their temperature ranges during winter, spring, summer and winter are listed in Table 6. Forest, thus decrease surface and air temperatures by providing shade and through evapotranspiration. Akbari and Kurn (1997) reported that temperature under tree canopy can be 11–25 °C cooler than on bare lands. A study conducted in Spain showed that temperature differences between barren and forested lands ranged up to 13 °C (Gomez et al. 2004). Regression analysis of both minimum and maximum LST and NDVI was carried out to assess the impact of extreme temperatures on NDVI of the forest. An inverse relationship was documented between LST and NDVI of Pai forest with coefficients of determination of 0.944 and 0.917 when NDVI was plotted against minimum and maximum LST, respectively (Fig. 8). This might have been due to latent heat transfer through evapotranspiration, lower heat capacity, or thermal inertia of vegetation compared to soil (Goward and Hope 1989). Similar results were reported by Wilson et al. (2003), Small (2006), Yue and Tan (2007), and Singh (2015).

Because increasing vegetative cover brings down the LST, hence a healthy Pai forest will lower the surface and air temperature, increase the humidity and thus decrease the intensity of scorching heat in the area. Because increasing vegetative cover reduces LST hence greater tree density and canopy closure in Pai forest would be expected to lower LST and thus air temperature as there is generally a close correlation between LST and surface air temperature (Farina 2012).

Conclusion

Maximum reduction in the vegetation of Pai forest was observed during 1992. Spatial change in vegetation of Pai forest over about 27 years (1987–2014) revealed that there was more increase in vegetation than reduction of vegetation. Thus, over 27 years, vegetation increased on 37.31 % of the forest, decreased on 21.68 %, and there was no change on 41.02 % of the forest. Variation of LST between shaded (dense forest) and unshaded areas (bare land) of the forest ranged from 6 to 10 °C. While the LST difference between areas with sparse forest and bare land ranged between 4 and 6 °C. Regression analysis of both minimum and maximum LST and NDVI showed an inverse relationship between LST and NDVI of Pai forest with coefficients of determination of 0.94 and 0.92, when NVI was plotted against minimum and maximum LST, respectively.

Our results how that overall vegetation in forest increased from 1552 ha (78.5 %) in 1987 to 1637 ha (83 %) in 2014 though there was a significant decrease in vegetation 1992. GIS and remote sensing tools can be used for monitoring of spatial and temporal change in vegetation as well as spatial change in LST of forests in arid regions. These results can also be helpful for decision and policy makers for developing an effective forest management system and viable policies for the Pai and other arid forests.

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