Impact of land-use and land-cover changes on temperature trends over Western India

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We study the regional variation of temperature trends (warming or cooling) over Western India and the contribution of land-use and land-cover (LULC) changes towards this warming or cooling based on temperature datasets of 37 years (1973–2009). The contribution of LULC to the warming or cooling is estimated based on deviation in temperature in the observation and reanalysis datasets. The observed temperature dataset indicates that Western India is getting warmer by 0.13°C per decade. This warming is the combined effect of increase in concentration of greenhouse gases and LULC changes. The impact of LULC changes on temperature trends over Western India is estimated using 'observation minus reanalysis' method. The results indicate that the LULC changes have contributed to warming over this region by 0.06°C per decade. Comparison of the change in temperature trend with the change in LULC indicates warming due to LULC changes because of the reduction of area under open forest and subsequent increase of the area under agricultural land. The study highlights the impact of land-use change to be more significant and the utility of satellite data for periodic LULC studies in climate change research.

Keywords: Land-use and land-cover changes, regional warming, temperature trends.

Introduction

THE recent climate change and changes in temperature trends are due to natural and anthropogenic forcing[1–5]. Recent studies have shown that the anthropogenic forcing due to land-use and land-cover changes (LULCC) may also significantly modify the temperature trends[6–12]. The changes in LULC modify the underlying land surface conditions which in turn change the interaction, i.e. the exchange of energy and moisture between land surface and the atmosphere[13–15]. LULCC can influence climate variables such as maximum, minimum and diurnal temperature range[10,16,17]. The LULCC is mainly due to urbanization, deforestation and changes in agricultural pattern. A number of studies have been conducted on the effect of urbanization on temperature trends by classifying meteorological stations as urban or rural based on population data[18,19] or satellite measurements of night lights[7,20]. In recent years, the impact/contribution of LULCC on regional climate has been studied[10,16,17,21–26]. Gallo *et al.*[16] observed that LULCC even within 10 km radius, can significantly influence the diurnal temperature range. Balling *et al.*[17] reported that in the Sonoran desert (North America), the areas undergoing land degradation reveal a significant increase in the diurnal temperature range. Christy *et al.*[10] simulated significant rise in minimum temperature (~3°C in June–July–August [JJA] and September–October–November [SON]) in San Joaquin valley, central California. These studies clearly demonstrate the influence of LULCC on regional climate. Kalnay and Cai[21] obtained 0.27°C mean surface warming per century due to LULCC in the continental United States over past 50 years. Studies have also estimated reasonable values for surface warming trends caused by Chinese urbanization[22], Tibetan plateau land-use changes[23] and the northern hemispheric land vegetation changes[24]. Fall *et al.*[26] studied the sensitivity of surface temperature trends to LULC over the conterminous United States (CONUS) for the 1979–2003 period from the US Historical Climate Network (USHCN) and NCEP–NCAR North American Regional Reanalysis (NARR). However, no such study has been conducted over Indian region and hence it is important to document the impact/contribution of LULCC on temperature trends over this region. Here, we have studied the impact of LULCC on temperature trends over Western India.

Methodology

The impact of LULCC on temperature trends is estimated by computing the difference in the surface temperature trends in the observation and reanalysis datasets. This is known as 'observation minus reanalysis' (OMR) method. Some recent workers have used this method to study the impact of LULCC over other parts of the world[21–26]. This method can be used if the land surface parameters are not assimilated in the process of preparing the reanalysis and hence the temperature obtained from reanalysis dataset does not include the effect of LULCC, but the effect of greenhouse gases (GHGs) only. The observed temperature dataset includes the effect of change in concentration of GHGs and LULCC[21]. Here, the

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Table 1. Representative mean temperatures (°C) for 1975, 1990, 2000 and 2005 as obtained from observation, reanalysis and observation minus reanalysis (OMR)

	1973–1977 (representing 1975)	1985–1994 (representing 1990)	1995–2004 (representing 2000)	2000–2009 (representing 2005)
Observation	26.19	26.81	26.95	27.02
Reanalysis	25.79	26.38	26.33	26.38
OMR	0.40	0.43	0.62	0.64

NCEP/NCAR reanalysis (NNRP1) dataset is used, which does not include the effect of LULCC. It is the global (daily) mean surface temperature gridded on 2.5° Gaussian boxes (~277 km × 277 km). The observed temperature at 17 stations over Western India for the period 1973–2009 is obtained from 'Cooperative Summary of the Day' dataset at the National Climatic Data Center (NCDC). The reanalysis temperature at any of the above 17 stations is obtained from the temperatures at the four corners of the box in which the station falls using the equation

$$T_s = \frac{\sum_{i=1}^{4} d_t \times T_{g_i}}{\sum_{i=1}^{4} d_i} \quad \{i = 1, ..., 4\}, \tag{1}$$

where T_s is the reanalysis temperature at the station, d_i^{-1} is the Euclidean distance from the station to the corner point g_i and T_{g_i} is the reanalysis temperature at the point g_i. The mean temperature for four different time periods, viz. 1975, 1990, 2000 and 2005, and 10-year moving averages of temperatures for the period 1973–2009 are estimated from both observation and reanalysis dataset (Table 1, Figure 1). The moving average is calculated using the equation

$$S_i = \frac{1}{n} \sum_{j=i-\left(\frac{n}{2}-1\right)}^{i+\frac{n}{2}} T_j \quad \left\{\begin{matrix} i = 1977, ..., 2004 \\ n = 10 \\ j = 1973, ..., 2009 \end{matrix}\right\}, \tag{2}$$

where S_i is the moving average for the *i*th year and *n* is the number of years on which the moving average is taken. In the present study decadal moving average has been taken, i.e. $n = 10$. T_j is the average temperature for the *j*th year. The impact of LULCC on temperature trends is estimated over Western India and also over its three sub-regions (as shown in Figure 1), mainly based on state boundaries.

The satellite imageries for four different time periods were obtained from the Global Land Cover Facility (GLCF). The geometrically rectified NIR and RED bands of NASA Landsat Multi Spectral Scanner (MSS), Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper plus (ETM^+) obtained from Earthsat and United States Geological Survey (USGS) are utilized. The LULC scenario over the region for a particular year was generated using 54 Landsat scenes (185 km × 185 km). Due to non-availability of the scenes over the whole region in the same year, as a methodological reason, the scenes of the adjacent years have been used to obtain the LULC scenario. To reduce the inconsistencies in reflectance due to calibration errors and atmospheric noise, the NIR and RED bands of each image are subjected to generation of radiance images using the equation[27,28]

$$L = \left[\frac{(L_{\max} - L_{\min})}{255} \times DN\right] + L_{\min}, \tag{3}$$

where *L* is the radiance expressed in $Wm^{-2}\ sr^{-1}$. The obtained radiance images from NIR and RED band separately are subjected to the process of mosaicking to generate radiance image with two bands (NIR and RED) for the whole study area, i.e. over Western India for the representative years 1975, 1990, 2000 and 2005 (Figure 2 *a*–*d*). The resolution of the obtained radiance image for each time period is downscaled to 1 km. Normalized Difference Vegetation Index (NDVI) is calculated from the radiance images using the equation[29]

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})}. \tag{4}$$

Controlled cluster technique is used to categorize the six broad different LULC types from NDVI of the study region for each time period, viz. 1975, 1990, 2000 and 2005 (Figure 2 *a*–*d*). The generated LULC map is subjected to a statistical filtering using median as function in 5 × 5 window size. The accuracy of the LULC maps is checked using random sample points generated from Landsat ETM MSS + PAN with 15 m spatial resolution. The user's accuracy, producer's accuracy and overall accuracy are calculated using 120 randomly selected sample points (Figure 2 *e*, Table 2).

Results and discussion

Figure 1 shows the decadal moving average of temperatures during the period 1973–2009 from observation,

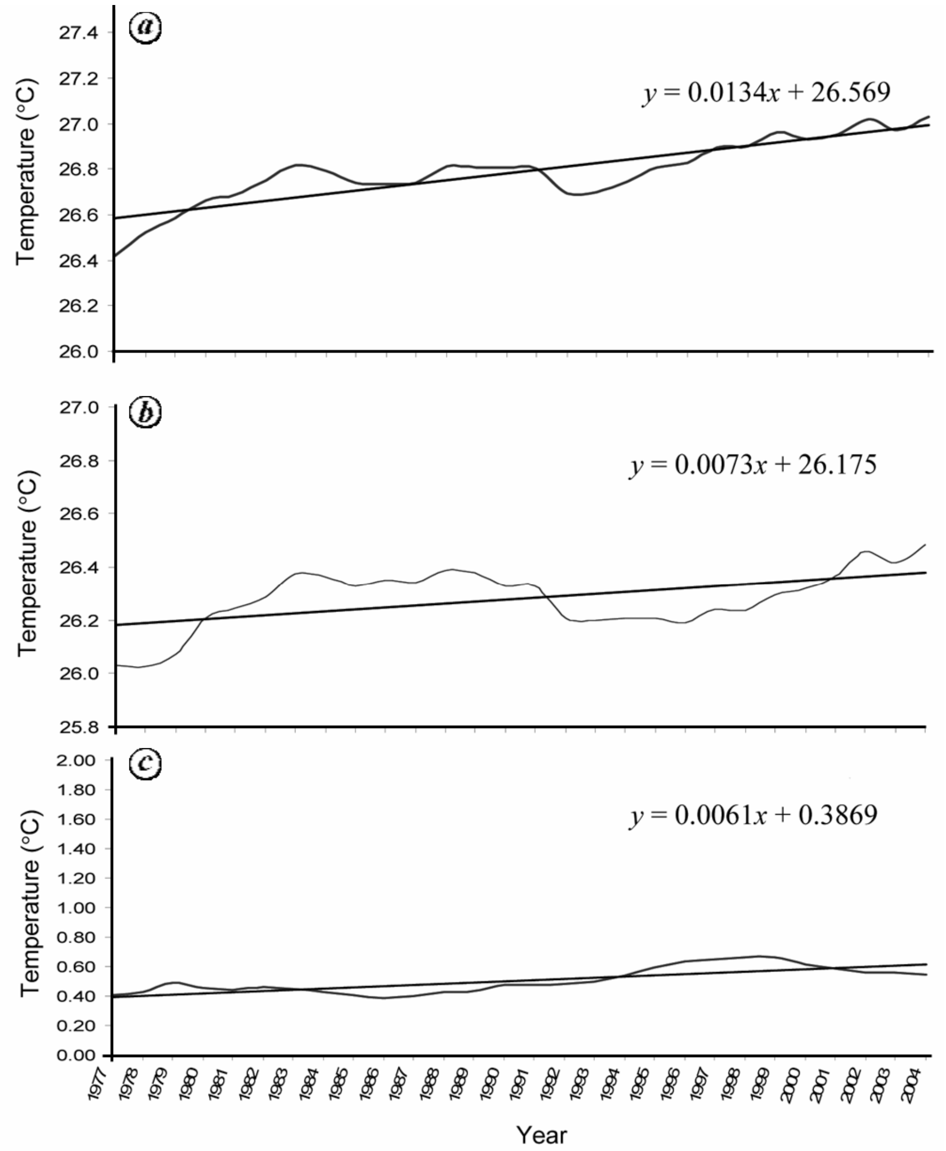

Figure 1. Decadal moving average of temperatures from (***a***) observation; (***b***) reanalysis and (***c***) observation minus reanalysis.

reanalysis and OMR. The straight line in Figure 1 *a–c* represents the linear trend of the decadal moving average of temperature during the said period. The analysis of observed temperature trends shows a warming trend with a rate of 0.13°C per decade (Figure 1 *a*) and reanalysis trends show a warming trend of 0.07°C per decade (Figure 1 *b*). The OMR trend indicates that LULCC during this period has contributed to warming over Western India at a rate of 0.06°C per decade (Figure 1 *c*). Table 1 shows OMR for the representative years 1975, 1990, 2000 and 2005 are 0.40°C, 0.43°C, 0.62°C and 0.64°C respectively.

The LULC classification over Western India represents different LULC types, viz. water body (WB), dry land (DL), agricultural/fallow land (AF), shrubs/other vegetation (SO), open forest (OF) and dense forest (DF; Figure 2 *a–d*). Comparison of the 120 random sample points derived from merged image with the LULC maps showed overall classification accuracy of 91.47%, 90.70%, 86.05% and 89.92% for the LULC map of 1975, 1990, 2000 and 2005 respectively (Table 2). During 1975–2005, the water body increased by 2.02%, dry land decreased by 2.24%, agricultural/fallow land increased by 1.09%, shrubs/other vegetation increased by 0.23%, open forest decreased by 0.98% and dense forest decreased by 0.12% (Table 2). Comparison with the actual forest cover from the FSI report[30] indicates that the area under forest cover (open and dense) is over estimated up to 3–4%. The change area matrix for different periods of LULCC during 1975–1990, 1990–2000, 2000–2005 and 1975–2005 and the impact of LULCC from temperature dataset during the above periods are given in Table 3.

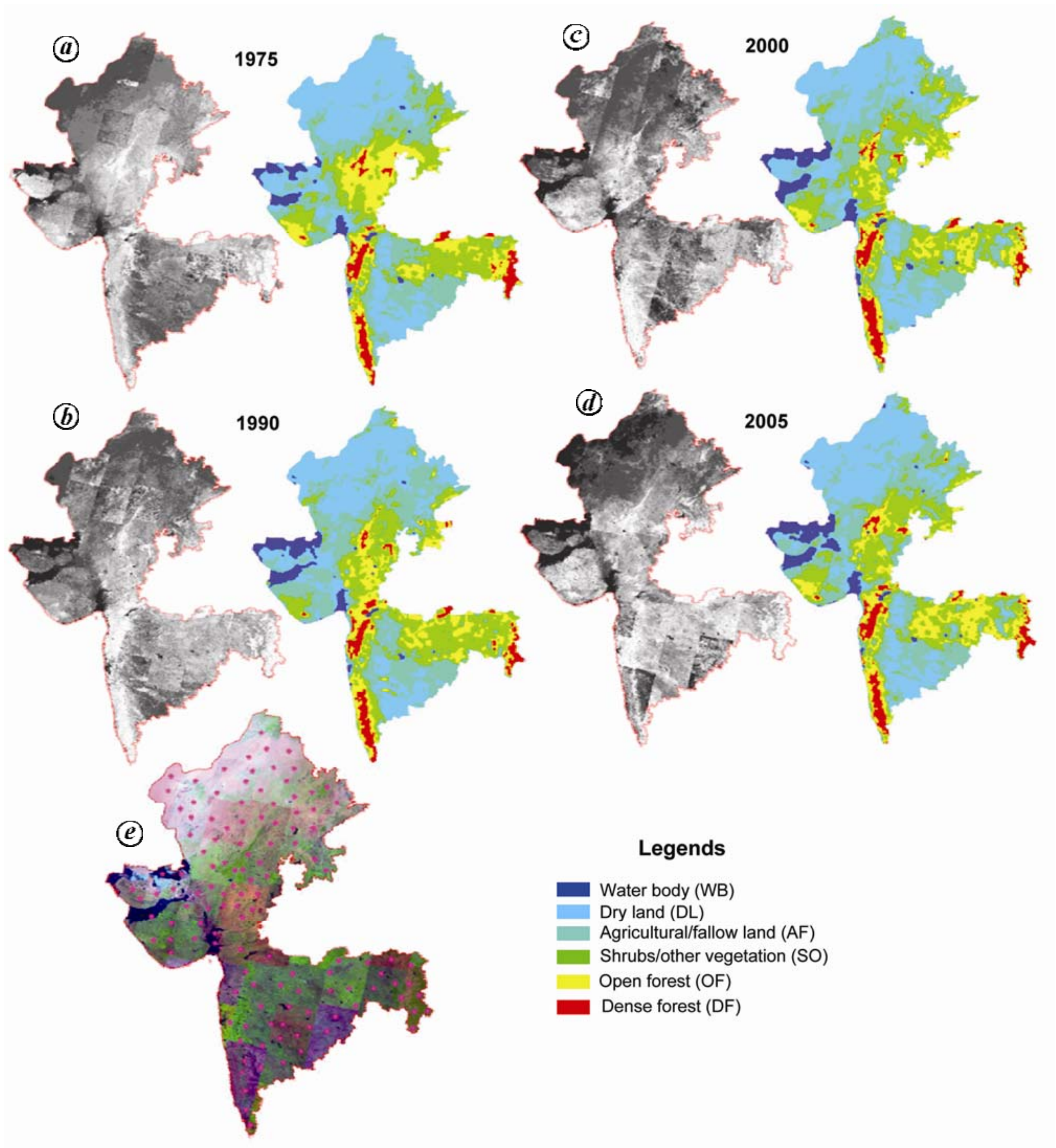

Figure 2. NDVI and corresponding land-use and land-cover (LULC) map of Western India for (***a***) 1975; (***b***) 1990; (***c***) 2000; (***d***) 2005 and ***e***, Landsat-ETM MSS + PAN merged image with random sample points overlaid for classification accuracy assessment.

Table 3(i) shows a comparison between the changes in different LULC types from the LULC map during 1975–1990 with an accuracy of 91.08% and the impacts of LULCC from temperature dataset during the same period. It clearly indicates that 1.27% dry land changed to water body during 1975–1990. It also indicates that 0.27% water body, 3.93% agricultural/fallow land and 0.76% shrub/other vegetation changed to dry land during the period. It is also observed that 6.25% dry land, 4.85% shrubs/other vegetation and 1.31% open forest changed to agricultural/fallow land during the period. Similarly, 0.64% dry land, 3.95% agricultural/fallow land, 5.87% open forest and 0.11% dense forest changed to shrubs/other vegetation during the same period. Also, 1.24% agricultural land, 3.16% shrubs/other vegetation and 0.97% dense forest changed to open forest during this period. And

Table 2. Accuracy assessment of land-use and land-cover (LULC) classes using unsupervised classification during 1975–2005

LULC type	1975 Producers accuracy (%)	1975 Users accuracy (%)	1990 Producers accuracy (%)	1990 Users accuracy (%)	2000 Producers accuracy (%)	2000 Users accuracy (%)	2005 Producers accuracy (%)	2005 Users accuracy (%)
Water body (WB)	50.00	100.00	71.43	100.00	80.00	66.67	66.67	85.71
Dry land (DL)	93.33	90.32	87.10	96.43	85.19	85.19	92.59	96.15
Agriculture/fallow land (AF)	100.00	87.50	92.86	92.86	93.10	81.82	94.29	89.19
Shrubs/other vegetation (SO)	92.86	92.86	94.29	89.19	83.78	96.88	88.89	88.89
Open forest (OF)	92.86	96.30	95.24	90.91	86.96	83.33	96.43	87.10
Dense forest (DF)	92.86	86.67	85.71	66.67	75.00	85.71	75.00	90.00
Overall classification accuracy (%)	91.47		90.70		86.05		89.92	

0.65% open forest changed to dense forest during the same period. All these above changes and conversions in different LULC types led to the warming over the region by 0.03°C during 1975–1990.

Table 3(ii) shows the comparison of LULCC during 1990–2000 from the LULC map (accuracy of 88.37%) with the impact of LULC from OMR during the same period. It shows that 0.53% dry land and 0.20% of agricultural/fallow lands changed to water body during this period. It also indicates that 0.40% water body, 4.89% agricultural/fallow land, 0.88% shrubs/other vegetation and 0.13% open forest changed to dry land during the same period. Similarly, 5.29% dry land, 4.04% shrubs/other vegetation and 0.87% open forest changed to agricultural/fallow land during the period. It is also observed that 0.51% dry land, 5.61% agricultural/fallow land, 3.31% open forest and 0.11% dense forest changed to shrubs/other vegetation during this period. Similarly, 0.41% agricultural/fallow land, 3.46% shrubs/other vegetation and 0.75% dense forest changed to open forest during the period. It also shows that 0.11% shrubs/other vegetation and 0.89% open forest changed to dense forest. All these above changes in LULC led to warming over the region by 0.19°C during this period.

Table 3(iii) presents the comparison of LULCC from the LULC map (accuracy of 87.98%) during 2000–2005 with the corresponding impact of LULC from OMR. It indicates that 0.86% dry land changed to water body during this period. It also indicates that 0.23% water body, 5.22% agricultural/fallow land and 0.54% shrubs/other vegetation changed to dry land during the same period. It also shows that 0.17% water body, 4.12% dry land, 3.33% shrubs/other vegetation and 0.24% open forest changed to agricultural/fallow land during this period. It is also observed that 0.40% dry land, 3.36% agricultural/fallow land and 2.35% open forest changed to shrubs/other vegetation during the same period. Similarly, 0.59% agricultural/fallow land, 3.90% shrubs/other vegetation and 0.70% dry land changed to open forest during this period. And 0.71% open forest changed to dense forest during the period. All these above changes in different LULC types during this period resulted in increase in temperature by 0.02°C.

The comparison of LULCC during 1975–2005 from the LULC map (accuracy of 87.98%) with the impact of LULC from OMR trend during the same period is shown in Table 3(iv). It indicates that 1.93% dry land changed to water body during this period. It also indicates that 0.14% water body, 2.66% agricultural/fallow land, 0.70% shrubs/other vegetation and 0.14% open forest changed to dry land during the period. It also shows that 3.91% dry land, 3.64% shrubs/other vegetation and 1.70% open forest changed to agricultural/fallow land during this period. It is also observed that 0.44% dry land, 3.46% agricultural/fallow land and 4.48% open forest changed to shrubs/other vegetation during the period. Similarly, 1.04% agricultural/fallow land, 3.99% shrubs/other vegetation and 0.85% dense forest changed to open forest during this period. And 0.66% open forest changed to dense forest during the period. All these above changes in LULC during 1975–2005 produced warming over the region by 0.06°C per decade. The observed temperature shows warming trend at a rate of 0.23°C per decade in the northern part (Rajasthan) and 0.09°C per decade in the other two parts (Gujarat and Maharashtra) of the region. It is found that LULCC is contributing to warming at a rate of 0.16°C, 0.012°C and 0.011°C respectively, over Rajasthan, Gujarat and Maharashtra. The comparison of LULC types with the OMR trends shows prominent increase (0.16°C per decade) over the dry lands of Rajasthan during 1975–2005. This warming is because of the conversion of shrubs/other vegetation/open forest into dry land and shrubs/open forest to agricultural lands (Figure 3). On the other hand, Gujarat and Maharashtra covered mostly by water body, dense, open and other vegetation, demonstrate an increase of 0.012°C and 0.011°C per decade respectively.

The analysis of OMR trend with respect to LULCC indicates that the warming during the period 1973–1989 is due to the subsequent increase of agricultural/fallow land, shrubs/other vegetation and reduction of open forest. The LULCC is due to the conversion of shrubs/other vegetation into agricultural/fallow land and open forest into shrubs/other vegetation. The same analysis of OMR trend with respect to LULCC indicates that warming during the period 1990–1999 is due to reduction of the area under open

Table 3. Matrix representation of classified areas of Western India in (i) 1975 with respect to 1990, (ii) 1990 with respect to 2000, (iii) 2000 with respect to 2005 and (iv) 1975 with respect to 2005 (LULC abbreviations are as mentioned in Table 2)

(i) Matrix analysis (in %) during 1975–1990 with accuracy of 91.08%

LULC class	WB	DL	AF	SO	OF	DF	1990
WB	2.71	1.27	0.04	0.00	0.04	0.00	4.06
DL	0.27	23.11	3.93	0.76	0.06	0.00	28.14
AF	0.07	6.25	16.07	4.85	1.31	0.01	28.55
SO	0.03	0.64	3.95	11.44	5.87	0.11	22.05
OF	0.01	0.09	1.24	3.16	6.37	0.97	11.84
DF	0.01	0.01	0.00	0.06	0.65	3.44	4.18
1975	3.09	31.37	25.25	20.27	14.30	4.53	98.82

Contribution from LULC (in °C)

1975	1990
0.40	0.43

Impact of LULC changes results in 0.03°C warming

Areas not considered in matrix analysis = 1.18%.

(ii) Matrix analysis (in %) during 1990–2000 with accuracy of 88.37%

LULC class	WB	DL	AF	SO	OF	DF	2000
WB	3.62	0.53	0.20	0.09	0.02	0.00	4.47
DL	0.40	22.33	4.89	0.88	0.13	0.00	28.64
AF	0.04	5.29	17.73	4.04	0.87	0.02	27.98
SO	0.00	0.51	5.61	12.66	3.31	0.11	22.20
OF	0.00	0.00	0.41	3.46	6.73	0.75	11.35
DF	0.00	0.00	0.00	0.11	0.89	3.31	4.31
1990	4.06	28.67	28.84	21.25	11.94	4.19	98.95

Contribution from LULC (in °C)

1990	2000
0.43	0.62

Impact of LULC changes results in 0.19°C warming

Areas not considered in matrix analysis = 1.05%.

(iii) Matrix analysis (in %) during 2000–2005 with accuracy of 87.98%

LULC type	WB	DL	AF	SO	OF	DF	2005
WB	3.99	0.86	0.04	0.01	0.00	0.00	4.90
DL	0.23	22.84	5.22	0.54	0.05	0.00	28.88
AF	0.17	4.12	19.55	3.33	0.24	0.00	27.41
SO	0.06	0.40	3.36	14.21	2.35	0.02	20.40
OF	0.02	0.05	0.59	3.90	7.98	0.70	13.23
DF	0.00	0.01	0.00	0.05	0.71	3.58	4.36
2000	4.46	28.28	28.77	22.04	11.33	4.30	99.18

Contribution from LULC (in °C)

2000	2005
0.62	0.64

Impact of LULC changes results in 0.02°C warming

Areas not considered in matrix analysis = 0.82%.

(iv) Matrix analysis (in %) during 1975–2005 with accuracy of 87.98%

LULC type	WB	DL	AF	SO	OF	DF	2005
WB	2.90	1.93	0.04	0.00	0.03	0.00	4.90
DL	0.14	25.05	2.66	0.70	0.14	0.00	28.68
AF	0.02	3.91	18.05	3.64	1.70	0.01	27.34
SO	0.02	0.44	3.46	11.85	4.48	0.08	20.33
OF	0.01	0.03	1.04	3.99	7.30	0.85	13.21
DF	0.00	0.01	0.01	0.09	0.66	3.59	4.36
1975	3.09	31.37	25.25	20.27	14.31	4.53	98.82

Impact of LULC changes from OMR trend results in 0.06°C average warming per decade

Areas not considered in matrix analysis = 1.18%.

forest and subsequent increase in shrubs/other vegetation. The same analysis of OMR trend with respect to LULCC also indicates that warming during the period 2000–2009 is due to the reduction of area under agricultural/fallow land and subsequent increase of the area under dry land. The changes in LULC are due to conversion of dense forest into open forest/shrubs/other vegetation and open forest/shrubs/other vegetations into agricultural/fallow land/dry land. However, the overall analysis of OMR trend with respect to LULCC indicates that warming during the period 1973–2009 is due to the decrease of area under open forest, subsequent increase of the area under agriculture land and because of conversion of water body/agricultural/shrub to dry land, shrubs/other vegetation/open forest to agricultural land, open forest/dense forest to shrubs/other vegetation and dense forest to open forest.

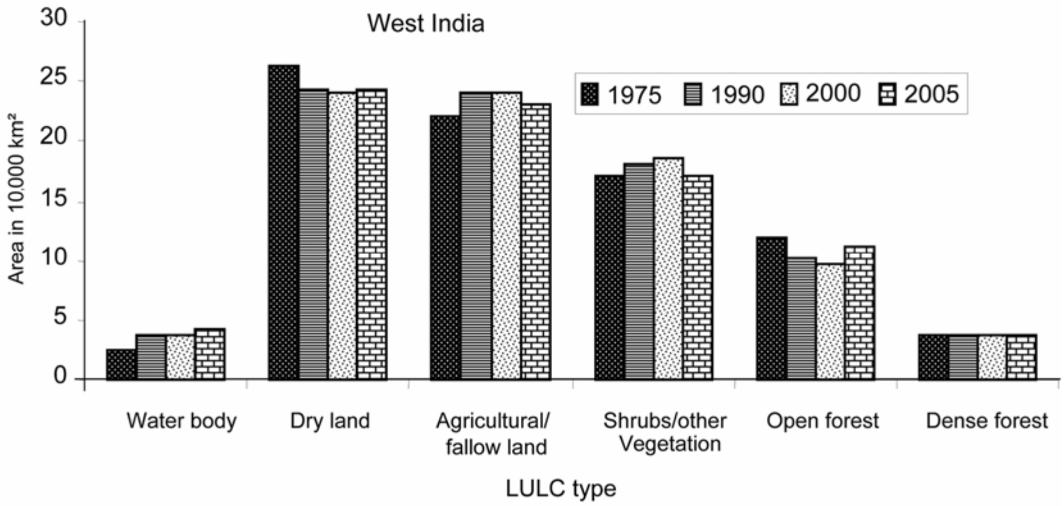

Figure 3. Histogram showing area estimates of various LULC classes during 1975 and 2005.

Conclusions

Western India is getting warmer by 0.13°C per decade and LULCC is contributing towards overall warming by 0.06°C per decade over the region. The classified LULC map is used to identify the changes in LULC during four different periods to understand the influence of LULCC on changing temperature trends. This indicates that the warming during the period 1973–1989 is due to conversion of agricultural/fallow land/water body into dry land and open forest/shrub to agricultural land and dense forest to open forest. Similarly, the warming during 1990–1999 is due to the increase of the area under shrubs/other vegetation and decrease of the area under open forest. The overall analysis concludes that warming during 1975–2005 is because of conversion of water body/agricultural/shrub to dry land, shrubs/other vegetation/open forest to agricultural land, open forest/dense forest to shrubs/other vegetation and dense forest to open forest. Land-use change and transformations are key drivers of changes in biodiversity at the global, national and local scales. Land change science has now emerged as a central component of global, environmental and sustainability research. By 2100, the impact of land-use change on biodiversity is likely to be more significant than climate change and changing atmospheric concentrations of CO_2 at global scales. Land change science needs to develop new and better technologies such as satellite remote sensing for characterizing the land.

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