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REVIEW ARTICLE

Possible Socio-scientific Issues of Land-use and Land-cover Change Impact and Associated Tools of Study with a Special Reference to Delhi-Mumbai Industrial Corridor Region

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Abstract

The prevailing land-use and land-cover (LULC) and associated land-surface characteristics play a significant role in governing the near-surface atmospheric features and regulating the local or regional environment. Any alteration in the existing LULC would bring the change in near-surface boundary layer characteristics in the immediate neighborhoods of Earth. Therefore, urban expansions bringing the LULC change influence the local environment in general and mesoscale weather and climate of that region in particular. Consequently, the associated social factors including population, quality of life, water quality and also the biodiversity are affected. In order to study the socio-scientific issues related to LULC change impact, one needs certain tools including remote sensing techniques, statistical analysis and numerical modeling. Such things need to be studied while urban expansion is done like that of Delhi-Mumbai industrial corridor (DMIC). This manuscript reviews all the possible socio-scientific issues related to LULC change impact and the possible tools required for studying these aspects by taking into account DMIC region as a special reference.

Key words: Land-use and land-cover change, Urbanization, Aerosols, Ozone, Rainfall, Remote sensing and GIS.

1. Introduction

Impacts of land-use and land-cover change are one of the core scientific issues to understand while analyzing the influence of human activities on weather and climate. Anthropogenic activities relating to the increasing urbanization, population growth and economic advancement etc. are causing adverse impacts on the natural environment. Since, land-use and land-cover (LULC) change is an important component in current scenario while monitoring environmental changes, the researchers are trying to analyze the scientific issues relating to the impacts of LULC on weather and climate (e. g. Deng *et al.*, 2013). For instance, the recent studies by Singh and Shi (2014) review the possible impact of land-use on changing climate, in which LULC change over Indian region is discussed. It is noticed that the western Dedicated Fright Corridor (DFC) along DMIC (Delhi Mumbai Industrial Corridor, shown in fig. 1) would change the land cover pattern due to building of bridges, software parks, hospitals, logistic hubs, airports and power plants etc. Therefore, LULC change would have possible significant consequences in general and the impact would particularly be on the environment. Hence, there is a need of scientific investigation of the possible causes and consequences of LULC change and it requires an interdisciplinary approach integrating both natural and socio-scientific methods. In view of this, an effort is made in this paper in order to review the possible impact of LULC change due to urban expansion with a special reference to DMIC (Fig 1).

Land use is the manner in which human beings employ land and its resources for various purposes including agriculture, urban development, and mining etc. (Jaisawal *et al.*, 1999). The intended employment of land management strategy placed on the land cover by human agents or land managers is to exploit the land cover and therefore, reflects human activities in industrial zones, residential zones, agricultural fields-

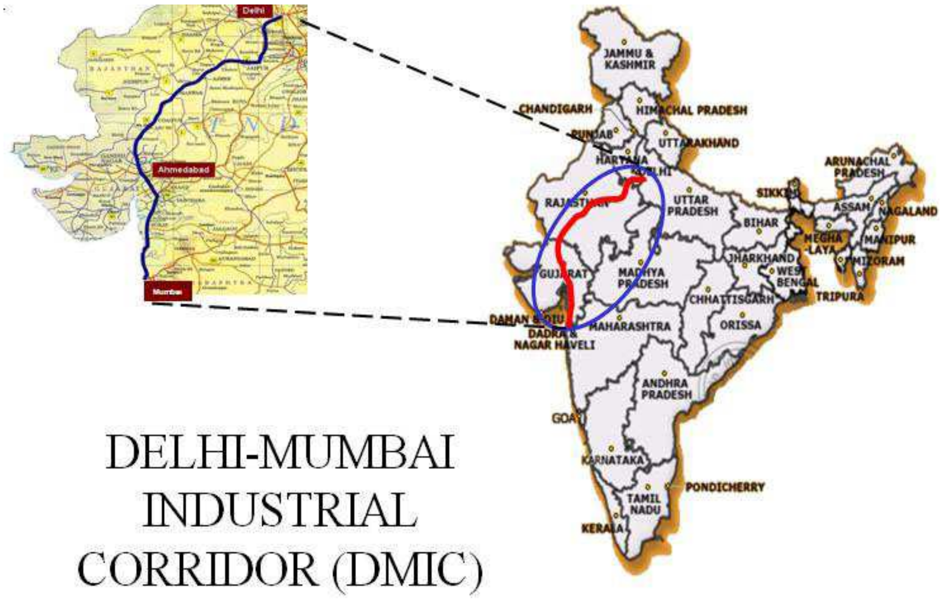

Fig 1: Delhi-Mumbai industrial corridor (DMIC) region planned by Government of India (indicated within the elliptical shape in India's map). This figure is obtained from http://dholerasir.com/visionfordmic.aspx

and mining etc. (Zubair, 2006). Land cover is defined by the attributes of the earth's land surface captured in the distribution of vegetation, water, desert and ice and the immediate sub-surface that includes biota, soil, topography and groundwater besides the structures created by mine exposures and settlement (Lambin *et al.*, 2003).

Local LULC changes, ranging from loses of wetlands, productive lands and biodiversity to the expansion of croplands at the expense of forests across the world are most important human induced disturbances that contribute to global environmental and climate change (Kalnay *et al.*, 2003). Currently, LULC changes due to human disturbance are a net source of carbon emissions to the atmosphere as well. In addition, change in LULC affects exchange of energy, water, and momentum between biosphere and atmosphere. Further, change in LULC also enhances soil erosion, creates strong environmental impacts and high economic costs by affecting agricultural production, infrastructure and water quality (e.g. Pimentel *et al.*, 1995).

With increase in urbanization, problems in the changing climate are becoming worse, since pervious areas are becoming impervious leading to decrease in vegetation cover and increase in temperature. On the other hand, there is no doubt that changes in natural factors like sea surface temperature, the earth's rotation and solar cycles can cause changes in the climate. However, there is not any existing mechanism to control these factors. Anthropogenic activities like urbanization and land use change can still be regulated in view of the consequent effects on local or regional climate. The effects of these factors (anthropogenic activities) could be minimized by taking appropriate adaptation and mitigation measures. In order to improve the economic condition of an area without further deteriorating the bio-environment, every bit of the available land has to be used in the most rational way (Babykalpana, 2012).

2. Delhi Mumbai Industrial Corridor and prevailing land-use

In order to address existing systemic challenges and encourage a broad-based, multi-stakeholder development model for infrastructure creation, the Government of India has envisaged the DMIC (Fig 1) project, spanning over 1,483 km between the political (Delhi) and the financial (Mumbai) capitals of the country. The Western DFC would connect Dadri in Uttar Pradesh to the Jawaharlal Nehru Port Trust (JNPT) near Mumbai, with a route length of 1483 km. The Delhi–Mumbai DFC, will hereafter be referred as the western DFC as four more DFCs will be developed in future including East-West Corridor (2000 km), North-South Corridor (2173 km), East Coast Corridor (1100 km) and Southern Corridor (890 km).

DMIC (Fig 1), with the DFC as its strong backbone, offers a huge chance to bring up both good fortune and a secure future to lot of people due to strong business opportunity and industrial development along with modern infrastructure. The new green-field cities, being planned under DMIC, are expected to address the pressures of urbanization and are primarily driven by extensive growth in the manufacturing and the services sectors. The DMIC project contains priority industries like motor vehicles, auto components, pharmaceuticals, clinical research, contract, Manufacturing, information technology based industries, agro and food products, textiles and apparels, machinery and equipment (including electrical machinery), and refined petroleum products etc. These cities are being planned as sustainable and smart cities, with interconnected roads, and rail and communication systems providing speed, access and global connectivity. However, creation of the urbanized corridor will undoubtedly pose threat to the environment in general and weather and climate in particular. On the other hand, developing the cities in a sustainable manner would indeed be a challenging job. In view of this, this paper is mainly focused on the possible impact of the LULC change along the DMIC region.

The LULC map (e.g. Fig 2) for this region usually confirms to be following the normal standard categories defined by the United States Geological Survey in addition to the considered local factors like topography, land use etc. Accordingly, ten separate LULC classes are defined namely: dense built-up (few open space, narrow lanes, higher up to 5 storey buildings), medium dense (3-4 storey building with some multistory buildings, commercial area, shopping malls) built-up, less dense built-up (residential area with plenty of green areas and open spaces), crop land, fallow land, forest cover, scrub land, sandy areas, deep water bodies and shallow water bodies.

3. Causes and Consequences

Most of the area in DMIC region comes under arid and semi-arid category (Fig 2) where communities are particularly vulnerable to climate change not only because of their dependence on sensitive sectors such as agriculture and forestry etc. but also due to limited capabilities in order to anticipate and effectively respond to the change in climate. It is needless to say that climate change projections showing erratic rainfall and extreme weather, increase in natural hazards, rising temperature etc. would have an adverse impact on food security, energy security, livelihood security and environmental sustainability that would affect the socio-economic condition of the nation.

The prevailing environment in arid and semi-arid regions supports mainly the growth of tropical grasses and small plants, which need lower atmospheric CO_2 levels, higher temperature and lower soil moisture. With the change in CO_2 levels, increase in temperature and variation in soil moisture, the changes in type of vegetation are bound to occur. The outcome of climate change would be region-specific and involve a complex interaction of several factors. For instance, arid and semi-arid region of moist Savanna (32.5%) and dry Savanna (33%) is projected to change, such that tropical dry forest (37.2%) and tropical seasonal forest (28.4%) become dominant (Garg *et al.,* 2012). It may be noted that both of the semiarid and arid regions have comparatively low adaptive capacity making them more vulnerable to climate change impacts.

Previously, there was reduction in the area under open forest and increase in the area of agricultural land in the DMIC region. However, industries, buildings, bridges etc. are replacing the agricultural land in the DMIC region these days. Such LULC changes are expected to have short and long term effects on weather and climate. In view of this, several possible effects are discussed in this section.

3.1 Temperature

Earlier findings suggest that the western part of India is getting warmer by 0.13 degree per decade (Nayak and Mandal, 2012). This warming is due to the combined effect of increase in concentration of greenhouse gases and LULC changes. The LULC changes have contributed to warming over the region by 0.06 degree per decade (Nayak and Mandal, 2012). The change in temperature and its trend mainly occurs due to natural and anthropogenic activities. Change in LULC primarily modifies the underlying land surface characteristics, which in turn change the land-air interaction i. e. the exchange of energy and moisture between land surface and atmosphere is affected. The LULC change is mainly due to urbanization, deforestation and changes in agricultural pattern. The overall analysis over western India indicates that warming during 1975-2005 is because of the conversion of water body/ agricultural/scrub type of land-use to dry land, shrub/other vegetation/open forest to agricultural land, open forest/dense forest to shrub/other vegetation and dense forest to open forest (Nayak and Mandal, 2012).

Due to urban development along DMIC, the resulting change in LULC will possibly have a –

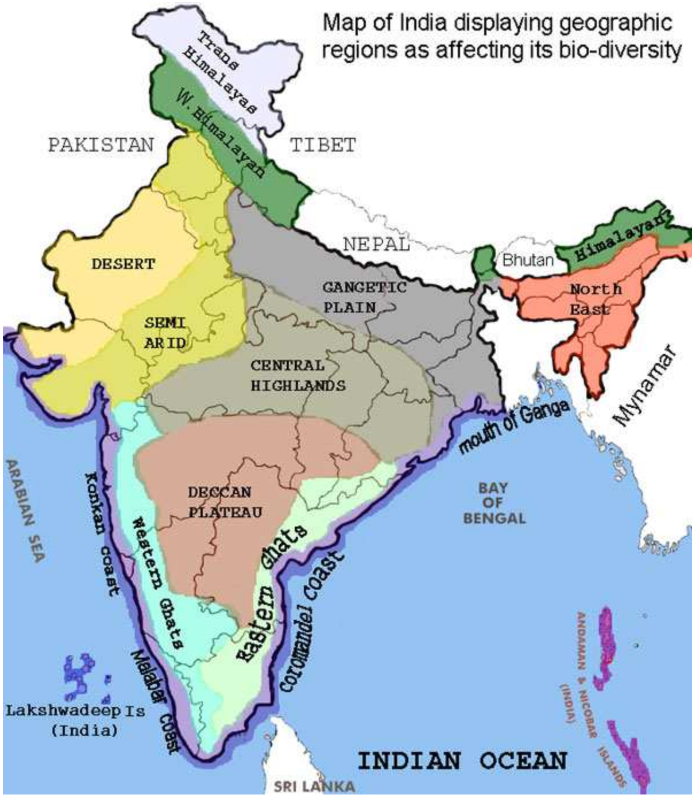

Fig 2: Different Geographical regions of India (http://www.birding.in/biological_regions_of_india.htm)

significant effect on surface heat fluxes due to change in land-surface characteristics. Over urban areas, the interactions of land surface with the atmosphere are primarily governed by surface heat fluxes (Chen *et al.*, 2011; Lemone *et al.*, 2010; Li *et al.*, 2013; Miao *et al.*, 2009; Panda *et al.*, 2014). The main factors having impact on heat fluxes from urban areas are changes in the physical properties of the surface albedo, thermal capacity and heat conductivity in addition to anthropogenic heating (Li *et al.*, 2013; Quah and Roth, 2012). The conversion of vegetation/ natural surfaces by asphalt and concrete (pervious to impervious surfaces), decrease in surface moisture available for evapotranspiration and the near surface flow, due to the complicated geometry of streets and tall buildings. This results in a difference of temperature between urban and rural areas and consequently, urban heat island (UHI) effect (Stathopoulou and Cartalis, 2007; Sobrino *et al.*, 2013) is observed. UHI intensity is related to patterns of LULC changes. For example, the composition of vegetation extent, water and built-up and changes in them (Weng, 2001; 2003; Streutker, 2002; Cai *et al.*, 2011) in urban expansion results in formation of UHI (e. g. Miao *et al.*, 2009).

Delhi experiences an UHI effect due to urbanization (Mallick *et al.*, 2013; Mohan *et al.*, 2011a, 2011b and 2012) and possibly Mumbai as well due to dense built up of infrastructure, industries and commercial centers. The UHI intensity is observed to be higher in magnitude both during afternoon hours and night hours (maximum up to 8.3°C). There is a warming trend experienced in general over Delhi region in past few decades. Increasing warming trends in the night-time temperatures reflect the contribution of changing land-use patterns and additional anthropogenic heat that may enhance the UHI intensities in a city. A research done on 33 urban areas in the western parts of India also shows significant increasing warming trend in annual and seasonal scale in most of the cities (Pingale *et al.*, 2014) and consequently, indicating an impact of LULC change.

3.2 Population

Urban population in India is continuously increasing (Fig 3). Therefore, the pressure of building enough infrastructures for the rising population is increasing and consequently, LULC is changing. As discussed in the previous sub-section, LULC plays an important role in the development of UHI and the associated consequences of urbanization (Kishtawal *et al.*, 2010; Li *et al.*, 2013; Miao *et al.*, 2009; Mohan *et al.*, 2011a; 2011b and 2012). For instance, a sharp rise in population recorded in the last decade in Delhi when it reached from 9.42 million in 1991 to 13.78 million in 2001 (Table 1) is an example of high pressure on the existing urban infrastructure in a mega city. Rapidly increasing population in megacities (e.g. Fig 3) is associated with somewhat similar growth rates in vehicular traffic, residential and commercial complexes, industries and other infrastructure resulting into significant changes in LULC and increase in anthropogenic heat emissions (e.g. Fig 4). The cities are found to be expanding beyond its planned urban extension areas due to increase in population. Due to rise in population (Fig 3) and requirement of residential areas, there would be a high demand of land since most of the land would be occupied by industries, shopping malls and commercial complexes (Fig 3). In order to fulfill the demand of this increased population every bit of land should be used effectively without harming the environment.

3.3 Pollutant Emission and Ozone

The land surface characteristics associated with LULC change play a significant role in governing the greenhouse gas emission and pollutant dispersion. The complexity and dynamic interplay of land surface processes favoring net accumulation versus net release of carbon dioxide (CO_2) and other greenhouse gases makes it a poorly constrained component of global budgets for these gases. Consequently, the global temperature has increased about 0.8 ^oC in the 21st century due to the CO_2 emission from fossil fuel combustion, cement production and land use changes such as deforestation (Battisti and Naylor, 2009). A source of uncertainty in estimating the change in climate caused by alteration of LULC is the release of sulfur dioxide and particulates by biomass combustion associated with agriculture, land clearing and human settlements as well. These emissions are believed to be the possible cause for regional and global warming and/or cooling by the reflection of sunlight from particulates and aerosols and by their direct and/or indirect effects on cloud cover. Global cooling results from the scattering of incoming solar radiations back into space and an increase in cloud reflectivity. The increased reflectivity is because of a higher number concentration of cloud droplets due to an increased concentration of tropospheric condensation nuclei. Both mechanisms modify the earth radiation balance so as to cool the earth's surface. This is called "white house" effect, as an analogue to the greenhouse effect (Londahl *et al.*, 2010).

Changes in land use and land cover are important drivers of water, soil and air pollution. Perhaps the oldest of these is land clearing for agriculture and the harvest of trees and other biomass. Vegetation removal leaves soils vulnerable to massive increase in soil erosion by wind and water, especially on steep terrain and when accompanied by fire. This not only degrades soil fertility over time, reducing the suitability of land for future agricultural use but also releases huge quantities of phosphorus, nitrogen and sediments to aquatic ecosystems, causing a variety of negative impacts (e.g. increased sedimentation, turbidity, eutrophication and coastal hypoxia).

The urban areas created through urbanization and LULC change usually contains several oil refineries and power plants etc., which produce SO_2. This air pollutant combines with water to form aqueous sulfuric acid (H_2SO_4). This acidic liquid solution is in the form of a vapor and condenses on to particles of solid matter like dusts and consequently transported from the surface to the stratosphere (Charlson *et al.*, 1991) due to highly convective activities. Mining can also produce even greater impacts including pollution by toxic metals exposed in the process.

Modern agricultural practices, which include intensive inputs of nitrogen and phosphorus fertilizers and the concentration of livestock and their manures within small areas, have substantially increased the pollution of surface water by runoff and erosion and the pollution of groundwater by leaching of excess nitrogen (as nitrate). Other agricultural chemicals, including herbicides and pesticides are also released to ground and surface waters and in some cases remain as contaminants in the soil. The burning of biomass to clear agricultural fields (crop residues, weeds) remains a potent contributor to regional air pollution. The biomass burning produces organic aerosols, which have the characteristics of absorbing the solar radiation and consequently, slow down the convective activities at a place (Rivera-Carpio *et al.*, 1996).

Urban expansion under DMIC (fig. 1) project would increase the emission of long-lived greenhouse gases including CO_2, CH_4 and N_2O as well as climate-active pollutants such as NOx, VOC and particulate matter (PM) due to growth in industries. The emissions of NOx, CO and VOC are likely to result in an increase in the tropospheric ozone concentration. Due to the urbanization, tropospheric ozone air quality is also affected.

Nitrous oxide emissions from megacities have a very small effect on climate, partly because a much larger proportion of the anthropogenic N_2O emissions come from agricultural and other sources not associated with cities. Anthropogenic activities produce nitrogen-bearing gases. The major nitrogen compound in the atmosphere is nitrous oxide (N_2O), which decomposes into nitrogen and nitric oxide (NO). Nitric oxide quickly oxidized to nitrogen dioxide (NO_2) by reacting with ozone. NO_2 reacts with OH and forms HNO_3 (Logan *et al.,* 1983). Therefore, it may be inferred that the impact of megacities on climate is primarily dominated by emission of long-lived greenhouse gases.

Environmental impacts of LULC change also include the destruction of stratospheric ozone by nitrous oxide release from agricultural land and altered regional and local hydrology (dam construction, wetland drainage, irrigation projects, increased impervious surfaces in urban areas).

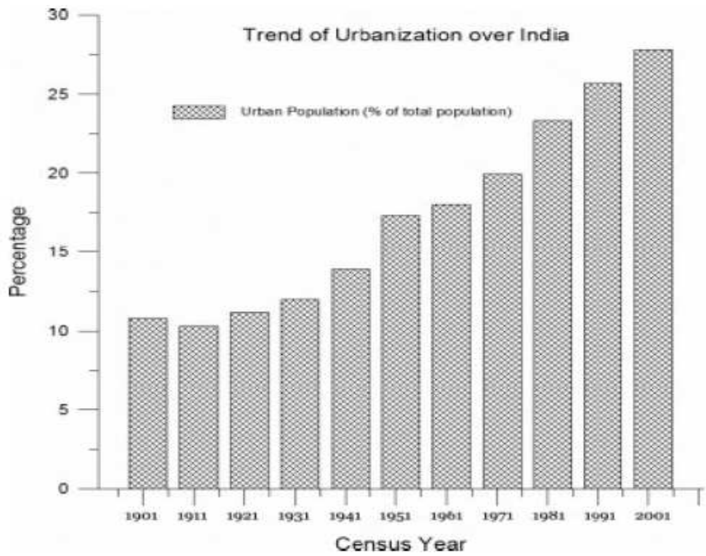

Fig 3: Growth of fraction of urban population (indicated as percentage along y-axis) for India during past century (Kishtawal *et al*., 2012).

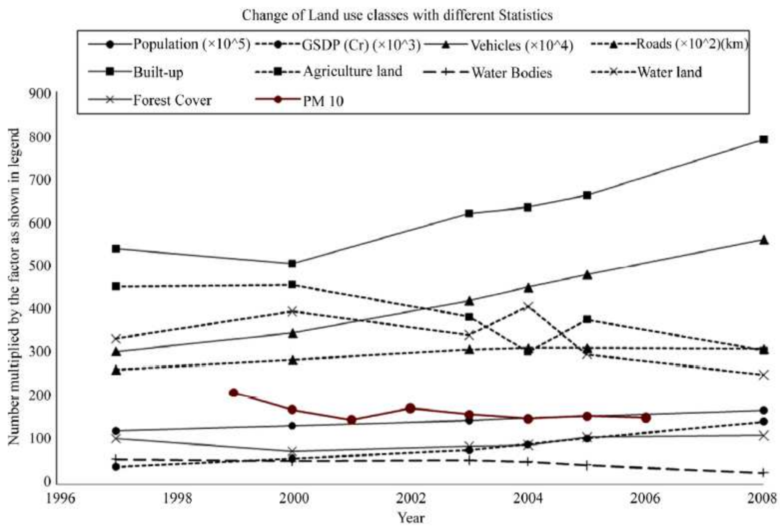

Fig 4: Change of land use classes with different statistics (shown in the box) from 1997 to 2008 (Mohan *et al.,* 2011b).

Table 1: Population changes (in lakhs) in National Capital Territory of Delhi (Mohan *et al.,* 2011b)

		Increase in Population				
			Addition by Natu Growth		Increase due to Migration	
Year	Total Populati	Net Increa	Population	%	Population	%
1901	4.06					
1911	4.14	0.08				
1921	4.89	0.75				
1931	6.36	1.47				
1941	9.18	2.82				
1951	17.44	8.26				
1961	26.59	9.15				
1971	40.66	14.07				
1981	62.2	21.54	12	55.71	9.54	44.29
1991	94.21	32.01	18.9	59.04	13.11	40.96
2001	138.2	43.99	26.66	60.6	17.33	39.4
2011	182.39	44.19	24.2	54.76	19.99	45.24
2021	230	47.61	24	50.41	23.61	49.59

3.4 Rainfall and Lighting activity

Urban environment can influence the local convections, consequent occurrence of rainfall and the lightning activities over big cities (e.g. Lal and Pawar, 2011) like Delhi (e.g. Fig 5), Mumbai and Singapore (e. g. Panda *et al.,* 2014). The effect of urbanization on local weather (Chen *et al.,* 2011; Li *et al.,* 2013; Panda *et al.,* 2014) is mainly due to changes in thermo-dynamical properties as well as increase in aerosol concentration. Bell *et al.* (2008) suggest that in favorable conditions like high instability, high humidity, aerosol can enhance convection and increase precipitation in localized manner over a city. The increased aerosol concentration can reduce mean droplet size, suppress warm rain coalescence and enhance the cloud water reaching the mixed phase region, which can increase the lightning activity (Bell *et al.,* 2008; Williams *et al.,* 2002). The increase in aerosol concentration can increase the ice content in thunderclouds, if the aerosols contain ice nuclei. Several earlier studies including that of Orville *et al.* (2001) and Steiger *et al.* (2002) illustrate the enhancement in cloud-to-ground lightning flash density, which is attributed to increased aerosol concentration. The studies by Williams *et al*. (2002) proposed that the observed contrast between lightning activity over land and sea can be due to differences in pollution levels between land and ocean.

The increase in industrialization over land can increase the aerosol concentration and increased aerosol concentration can influence the cloud microphysical properties (Rosenfeld *et al.,* 2008; Koren *et al.,* 2008). The responses of lightning and rainfall (e.g. Fig 5) to the enhancement in aerosols are different. Lightning increases with increase in aerosol concentration (Williams *et al.,* 2002), whereas decrease or increase of rainfall with increase in aerosol concentration depends upon the concentration and size distribution of aerosols (Rosenfeld *et al.,* 2008; Koren *et al.,* 2008).

Over an inland city, where aerosol concentration is not increased appreciably in last few years, the enhancement in convective activity and lightning is controlled by thermodynamic effect. On the other hand, it also is noticed that over a city where aerosol concentration shows increasing trend (e.g. Delhi as shown in Fig 6), lightning activity increases (Fig 5) possibly due to combined effect of thermodynamics and aerosols (Lal and Pawar, 2011). In an inland city like Delhi, AOD (Aerosol Optical Depth) increases during pre-monsoon and winter season primarily due to transport of dust from Thar desert (Panda *et al.,* 2009) and biomass burning (Gautam *et al.,* 2007) respectively (Fig 6). The decrease in AOD during January to March could be due to western disturbance which brings sudden winter rain (Mohan *et al.,* 2014). Drastic decrease of AOD during the monsoon season could be due to wet removal or rainfall. Due to the persistent cloudiness and heavy rainfall during monsoon season, the surface cools drastically as compared to pre-monsoon period resulting in low convective activity and consequently, brings down the aerosol loading through wet removal process (Dey *et al.,* 2004).

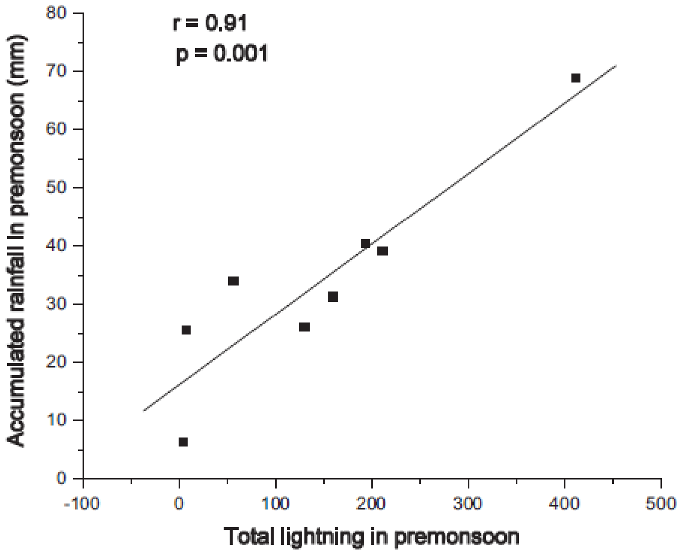

Fig 5: Scattered diagram of accumulated rain and lightning over Delhi (India) with line of best fit (Lal and Pawar, 2011).

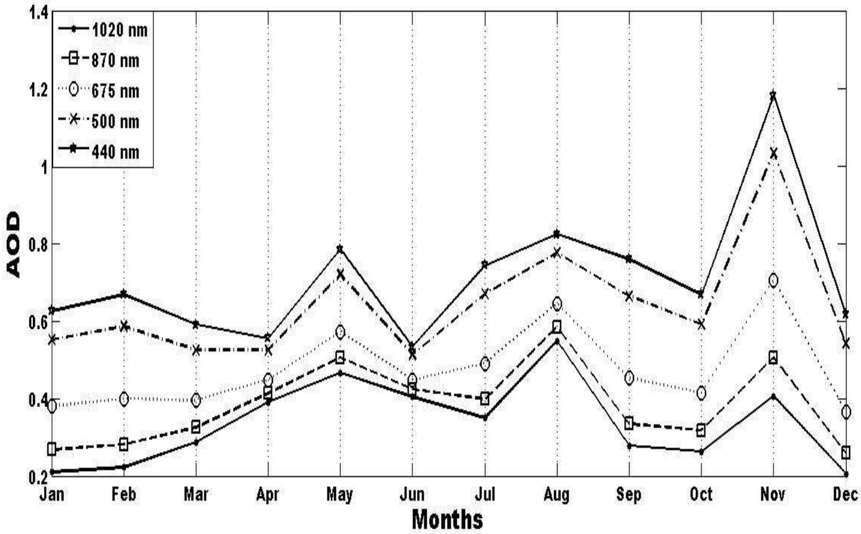

Fig 6: Variation of aerosol optical depth (AOD) over New Delhi during 2006 measured at various wavelengths. Monthly mean values of AOD are computed using AERONET observations (http://aeronet.gsfc.nasa.gov).

The analysis of lightning, aerosols and rainfall over the coastal city Mumbai (19.11 N, 72.85 E) do not show any increasing trend in rainfall (annual average rainfall over Mumbai is 180 cm) and lightning activity, which suggest that during pre-monsoon period all these parameters are controlled mostly by large scale processes (Singh *et al.,* 2008). Surface winds during pre-monsoon season are from ocean to land for the case of a coastal city like Mumbai and consequently, there is no possibility for a systematic increase in aerosol concentration observed over the coastal cities. Since the coastal cities are surrounded by ocean at least from one side the heat island effect should be a prominent feature (e.g. Li *et al.,* 2013), which support localized convective activities. Some cities, where aerosol concentration is not increased appreciably in last few years, the enhancement in localized convective activity and resulting thunderstorm and lightning should in-principle be controlled by UHI effect though it is not mandatory for every urban area.

Urban regions usually experience less occurrences of light rainfall and significantly higher occurrences of intense precipitation compared to nonurban regions. Very heavy and extreme rainfall events showed increasing trends over both urban and rural areas, but the trends over urban areas were larger and statistically more significant. In a polluted (i.e. urban) region having large amount of aerosols, there is a possibility of heavy rainfall due to more cloud condensation nuclei as compared to a less polluted (i.e. rural) region (Andreae, 2009). There is adequate statistical basis to conclude that the observed increasing trend in the frequency of heavy rainfall events over Indian monsoon region is more likely to be over regions where the pace of urbanization is faster (Kishtawal *et al*., 2010). In such areas, How exactly the urbanization alters the rainfall patterns through UHIs, mesoscale convergences (e.g. Li *et al.,* 2013; Panda *et al.,* 2014), and urban aerosol interactions in a humid and convectively unstable environment is still an active area of research.

There are two phases in monsoon season: weak phase and active phase. Weak phase is associated with deficient rainfall and active phase means widespread and substantial rainfall. A study by Rao *et al*. (1995) suggests that Jodhpur (a city in Rajasthan, India) has as high as 450 W/m^2 heat flux during weak monsoon days; while during active days, the heat flux never exceeds 200 W/m^2. Due to urbanization, the land-surface temperature is supposed to increase and consequently it would have an influence on surface fluxes (e.g. Li *et al.,* 2013; Panda *et al.,* 2014). Every city has a different urban pattern and land-surface features. Therefore, DMIC (Fig 1) should take optimum care in order to make the urban planning in a better manner so as to harm the environment as less as possible.

3.5 Biodiversity loss

Biodiversity is often reduced dramatically by LULC change. When land is transformed from a primary forest to a farm, the loss of forest species within deforested areas is immediate and complete. Even when unaccompanied by apparent changes in land cover, similar effects are observed whenever relatively undisturbed lands are transformed to more intensive uses, including livestock grazing, selective tree harvest and fire prevention. The habitat suitability of forests and other ecosystems surrounding those under intensive use are also impacted by the fragmenting of existing habitat into smaller pieces (habitat fragmentation), which exposes forest edges to external influences and decreases core habitat area. Smaller habitat areas generally support fewer species (island biogeography), and for species requiring undisturbed core habitat, fragmentation can cause local and even general extinction. Research also demonstrates that species invasions by non-native plants, animals and diseases may occur more readily in areas exposed by LULC change, especially in proximity to human settlements like the case of DMIC region.

3.6 Change in Albedo

Land cover changes that alter the reflection of sunlight from land surfaces (albedo) are another major driver of climate change. The precise contribution of this effect to global climate change remains a controversial but growing concern. The impact of albedo changes on regional and local climates is also an active area of research, especially changes in climate in response to changes in land cover by dense vegetation and built structures. These changes alter surface heat balance not only by changing surface albedo, but also by altering evaporative heat transfer caused by evapotranspiration from vegetation (highest in closed canopy forest), and by changes in surface roughness, which alter heat transfer between the relatively stagnant layer of air at Earth’s surface (the boundary layer) and the troposphere (Ellis, 2013). An example of this is the UHI effect, where warmer temperatures are observed within urban areas as compared to the surrounding rural areas.

4. Available tools for studies relating to LULC change

In order to study the LULC change and the associated impact, several methods are adopted including remote sensing techniques, geospatial analysis and modeling, together with the interdisciplinary assortment of natural and social scientific methods. These methods are needed to investigate the causes and consequences across a range of spatial and temporal scales. Some of them are described in this section.

4.1 Remote sensing techniques and geospatial analysis

Remote sensing and GIS (Geographical Information System) techniques are useful tools for land use/cover mapping and also to improve the detailed selection of areas designed for agricultural, urban and/or industrial land-use types. Some recent studies (Jaiswal *et al.,* 1999; Samant and Subramanyan, 1998) have shown the utility of remote sensing and GIS techniques in land use change detection and their implication. Application of remotely sensed data made possible to study the changes in land cover (Mallick *et al.,* 2013) in less time, at low cost and with better accuracy (Kachhwala, 1985) in association with GIS that provides suitable platform for data analysis and retrieval (Star *et al.,* 1997; Chilar, 2000). Digital change detection techniques based on multi-temporal and multi-spectral remotely sensed data have demonstrated a great potential in order to understand landscape dynamics and monitor differences in land use/cover patterns irrespective of the causal factors. Remote sensing techniques also help researchers in obtaining LULC data over large areas of interest and facilitate optimal assessment and monitoring as well. These features make remote sensing an optimal tool for such type of studies besides helping in the understanding of environmental changes (Mallick *et al.,* 2013; Mukherjee 2009).

Remote sensing techniques facilitate observations across larger extents of Earth's surface than is possible by ground-based observations. This is accomplished by use of cameras, multi-spectral scanners, RADAR (Radio Detection and Ranging) and LiDAR (Light Detection and Ranging) sensors mounted on air- and space-borne platforms yielding aerial photographs, satellite imagery and several types of datasets.

Maps of land use and land cover (LULC) are produced from remotely sensed data by inferring land use from land cover (e.g., urban = barren, agriculture = herbaceous vegetation). Conventional LULC maps are categorical in nature since they classify the land into several categories of land use and land cover types (thematic mapping; land classification), while recent techniques allow the mapping of LULC or other properties of land as continuous variables or as fractional cover of the land such as tree canopy, herbaceous vegetation, and barren (continuous fields mapping). Both types of LULC datasets may be compared between time periods using GIS to map and measure the changes and land-use and/or land-cover at local, regional, and global scales.

4.2 Numerical modeling and statistical analysis

Maps and measurements of land cover can be derived directly from remotely sensed data by a variety of analytical procedures, including statistical methods and human interpretation. The effect of LULC change due to urban expansion can be studied using remotely sensed data and meteorological observations using well known statistical methods and tools (Feng *et al.,* 2013; Mallick *et al.,* 2013) as well as numerical models (Li *et al.,* 2013; Niyogi *et al.,* 2006; Panda *et al.,* 2014). While the statistical tools and methods only help in comparing the two data remotely sensed sets or meteorological observations, the numerical modeling uses highly resolved land-use and topography data sets in order to study the impact of such changes on near-surface characteristics (Li *et al.,* 2013), mesoscale weather (Panda *et al.,* 2014) and seasonal or climatological variations (Kar *et al.,* 2014).

Further, spatially-explicit models of the social and environmental causes and consequences of LULC change are made possible by GIS and other computer-based techniques, which can define and test relationships between environmental and social variables using a combination of existing data (census data, soil maps, LULC maps) and ground (ecological measurements, household surveys and interviews with land managers) and remotely sensed observations. These spatial models are quite useful to establish the cause and effect of LULC changes observed in past and also for future alterations to occur. Therefore, these tools may be used for policy making purpose, land management and forecasting future impact of land use changes.

5. Concluding remarks

The LULC and associated land-surface characteristics has a significant role to play in governing the near surface characteristics, atmospheric boundary layer processes, mesoscale weather and also the climatology of a region. In view of this, reviewing the possible socio-scientific impact of LULC change provides enough bullet points to understand the current scenario and assessing the existing policies. Therefore, this review is quite helpful and important for future urban expansions especially in developing countries since it is a challenging task for them to develop through industrial advancement and taking care of the environment at the same time.

Driving forces on LULC change can include almost any factor that influences human activity, including local culture (food preference, etc.), economics (demand for specific products, financial incentives), environmental conditions (soil quality, terrain, moisture availability), land policy and development programs (agricultural programs, road building, zoning), and feedbacks between these factors, including past human activity on the land (land degradation, irrigation and roads). Investigation of these drivers of LULC change requires a full range of methods from the natural and social sciences including climatology, soil science, ecology, environmental science, hydrology, geography, information systems, computer science, anthropology, sociology, and science of policy making. Thus, a sustainable management of land and environment is essential which can take care of drinking water quality, ground water recharge, growing supply of food, sanitation, green belts for plantation, soil erosion, air pollution and industrialization or urban expansion. Despite of various implications and initiative measures (like CNG implementation, utilizing solar energy or less polluting sources of energy etc for public transport and other requirements) taken from past years, the pollution levels have not shown a satisfying decreasing trend rather it has increased with time at several metropolitan cities including Delhi and Mumbai. Therefore, the future policies must be made in such a way that they incorporate holistic approaches to urban development in order to appropriately preserve the areas of various land-use classes and follow visions for sustainable management of environment.

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