Journal of Urban and Environmental Engineering, v.11, n.1, p.79-87

ISSN 1982-3932
doi: 10.4090/juee.2017.v11n1.079087

Journal of Urban and Environmental Engineering

www.journal-uee.org

AN ASSESSMENT OF URBAN SPACE EXPANSION AND ITS IMPACT ON AIR QUALITY USING GEOSPATIAL APPROACH

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Received 17 September 2016; received in revised form 02 January 2017; accepted 18 March 2017

Abstract: The development oriented growth and accelerated industrialization had been rapidly worsening the environmental quality of urban centers. Jaipur, capital of Rajasthan India, the 10th largest metropolitan city of India, is also facing the increasing pressure on land due to urbanization and demographic factors. Therefore, in this study an integrated approach of remote sensing and GIS (Geographic Information System) was applied to examine the relationship among spatial variables such as impervious area, land consumption rate and air pollutants concentration within an urban context of Jaipur city. The urban sprawl over the period of five years (2008–2013) is determined by computing the impervious area or built up area using IRS (Indian Remote Sensing) Resourcesat 2 satellite data for Jaipur urban region. Thereafter, Land Consumption Rate (LCR) and Land Absorption Coefficient (LAC) were quantified to evaluate the impervious area growth in different wards of the Jaipur city. The temporal variations in gaseous and particulate pollutants were also investigated to ascertain the degree of association between air pollutants and impervious area. It has been observed that there is 74.89% increase in impervious area during 2008 to 2013.The zonal distribution of impervious area clearly indicates the increase in number of wards under Zone 5 (80-100%) category from 2008 to 2013. The spatial distribution of LCR reveals very high land consumption rate (>0.012) in outskirts of the city ie. Vidhyadhar Nagar, Jhotwara and Jagatpura area. The LAC is zero in wards of Kishanpole area and high (>0.06) for the wards of Civil lines, Jagatpura, and Jhotwara area of the city. The urban air quality pattern (2008-2013) results indicate that PM_{10} and SPM concentration have the greatest effects on the air environment in comparison to gaseous pollutants (SO_2 and NO_x). The association between particulate pollution and impervious area indicate strong correlation in zone 2 (R^2 = 0.72 for PM_{10} and R^2 = 0.63 for SPM) during 2013; however, correlation between PM_{10}/SPM ratio and LCR shows significant relation during 2011 and 2013.

Keywords: Urban Expansion; Impervious area; Land Consumption Rate; Air quality; Remote Sensing

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INTRODUCTION

Most of the world’s population growth is taking place in the urban areas (Satterthwaite, 2009) that leads to consequent strain on the existing urban system manifested in an environmental chaos. About 54 per cent of the world’s population lives in urban areas and it is expected to increase to 66 per cent by 2050 (UN DESA’s, 2014). The UN DESA’s Population Division also reported that urban population of the world has grown rapidly from 746 million in 1950 to 3.9 billion in 2014. According to New Climate Economy report (The economic times, 2014), India’s urban population has increased from 217 million to 377 million over the last two decades and this is expected to reach 600 million, or 40 per cent of the population by 2031. The accelerated urbanization has brought the problems of dense and unplanned residential areas, inadequate traffic corridors, poor infrastructure facilities, etc. and responsible to deteriorate the overall quality of the city environment (Rahman & Netzband, 2007; Breuste & Qureshi, 2013).

Population growth and in-migration of poor people influence the urban centers with unplanned and haphazard suburban sprawl. With the increasing pressure on land and other resources, urban sprawl is seen as one of the potential threats to sustainable development where urban planning with effective resource utilization and allocation of infrastructure initiatives are key concerns (Sudhira *et al.,* 2003; Dadhich & Hanaoka, 2012). Urban sprawl is also considered an important cause for cropland loss (Lin & Ho, 2003), hydrological alterations (Paul & Meyer, 2001), traffic congestion and air pollution; and irreversible damage to ecosystems caused by scattered and fragmented urban development in open lands (Frenkel *et al.,* 2005). The impervious surface or built-up is considered as the key parameter for quantifying the urban sprawl (Barnes *et al.,* 2001; Epstein *et al.,* 2002; Dadhich & Hanaoka, 2011). This impervious area is largely contributed by use of materials like concrete, bricks, tiles etc. for buildings and bitumen for roads and parking lots (Khandelwal & Goyal, 2010). The phenomenon of accelerated urbanization is the main factor responsible for increase in impervious area and deterioration of overall quality of the city environment.

An increasing concentration of human population and their activities in urban areas produces air pollutants with higher rate as compared to less-developed areas and natural environment (Ling *et al.*, 2014). Local pollution patterns in cities are mainly related to land use category, transportation network, and air flushing rates (Weng & Yang, 2006). The environmental quality of Jaipur city is also worsening due to rapid industrialization, land transformation, transportation and infrastructure development activities. Therefore, this paper aims to examine the urban change dynamics in terms of impervious area during 2008 to 2013 and its relationship with ambient air quality of Jaipur’s urban region. Satellite Remote Sensing, with its repetitive coverage together with multi-spectral (MSS) capabilities is a powerful tool (Rahman and Netzband, 2007, Dadhich & Nadaoka; 2012) to map and monitor the urban expansion over years (Dadhich & Hanaoka, 2010). The geospatial techniques not only provide a flexible environment for creating digital data from various primary and secondary sources, but also a potential means for analyzing their association (Herold *et al.*, 2005, Jun Yu & Nam Ng, 2007, Singhal & Goyal, 2012; Dadhich & Nadaoka; 2013). Therefore, in this research study an integrated approach of remote sensing and GIS was applied to ascertain the relationships among spatial variables such as impervious area, land consumption rate and temporal variations in gaseous and particulate pollutants within an urban context.

MATERIALS AND METHODS

Study area

Jaipur, popularly known as “Pink city” of India is the largest city and capital of Rajasthan state. Jaipur lies between north latitudes 26° 25’ and 27° 51’ and east longitudes 74° 55’ and 76° 15’ forms east-central part (as shown in **Fig. 1**) of the Rajasthan State. It is located in the Aravali hills at an altitude of 430 meters above mean sea level. It is the 10^{th} largest metropolitan city of India. The city’s economy is primarily based on trading, administration, tourism activities, & local handicrafts industries. Jaipur is a famous tourist destination, known for gems and jewellery and is also popular for Sanganer and Bagru prints. Jaipur has a semi-arid climate and annual rainfall is 650mm. Most of the rainfall is received in the monsoon months between July and September. Dust storms are very frequent in summer season (IMD, 2011).

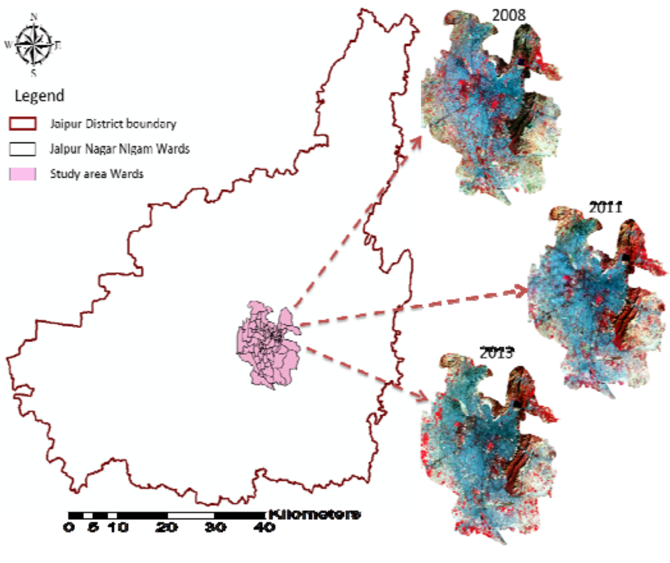

Fig. 1 Location map of the study area

Satellite data Acquisition

Understanding the dynamic phenomenon such as urban expansion requires urban sprawl change analysis over the years. The urban sprawl over the period of five years (2008–2013) is determined by computing the impervious area or built up area using IRS (Indian Remote Sensing) Resourcesat 2 satellite data for all the wards of the Jaipur urban region. The temporal satellite data of Resourcesat 2 LISS III (Linear Imaging Self-Scanner) of 2008, 2011 and 2013 were used for the study. The satellite datasets were downloaded from the National Remote Sensing Centre (NRSC) website. **Table 1** provides information about the satellite data used in the study. The satellite data analyses included bands extraction, enhancement and classification. The satellite image has been classified using Gaussian maximum likelihood classifier (MLC) followed by visual interpretation to improve the quality of output. The impervious area was extracted from the imagery and ward wise impervious area was calculated for the study periods.

Table 1. Data Used for the Study

Data Type	Acquisition date	Number of Bands	Spatial resolution	Source
Resourcesat 2 LISS III	13 October 2008	4	24	NRSC*
Resourcesat 2 LISS III	2 December 2011	4	24	NRSC*
Resourcesat 2 LISS III	13 January 2013	4	24	NRSC*

*National Remote Sensing Centre (NRSC), Hyderabad, India.

Land Consumption Rate (LCR) and Land Absorption Coefficient (LAC) estimation

Land consumption rate is a measure of compactness of urban structures and indicates the spatial expansion of a city. The high value of LCR indicates crowdedness while low value indicates free spaces. The land absorption coefficient is a measure of change in consumption of new urban land by each unit increase in urban population (Yeates & Garner, 1976; Opeyemi, 2008; Oladele & Oladimeji, 2011; Sharma *et al*., 2012). It indicates how new land is being used for built-up purposes and urban sprawl is taking place in the city. To estimate the LCR and LAC, ward wise population data of Jaipur city was collected from Census data (year 2001 and 2011). Population growth rate was estimated using population data of year 2001 and 2011. Thereafter, compounded exponential growth model was used to predict the population for the year 2008 and 2013 for each ward. The population projection equation is expressed as:

$$P_n = P_0\left(e^{rn}\right) \qquad (1)$$

where P_n = estimated population (2008, 2013), P_0 = initial population (i.e. year 2011), r= annual rate of growth, e = base of the natural logarithm, n= number of years. The projected total population for all the 77 wards (for year 2008 and 2013) is shown in **Table 2**.

Table 2. Population Figures for the selected study years

Year	Population figures
2008	2,815,903
2011	3,046,163
2013	3,233,939

The Land consumption rate (LCR) and land absorption coefficient (LAC) have been quantified by using the following equations (Yeates and Garner, 1976) :

$$LCR = \frac{Ai}{Pi} \qquad (2)$$

where, Ai = Impervious area of ith ward (in hectares), and Pi = Population of ith ward

$$LAC = \frac{(A2i - A1i)}{(P2i - P1i)} \qquad (3)$$

where, $A1_i$ and $A2_i$ = Impervious area of ith ward (in hectares) for the early and later years, and $P1_i$ and $P2_i$ = Population figure of ith ward for the early and later years, respectively.

Air quality Evaluation

The air quality data of gaseous air pollutants viz. sulfur dioxide (SO_2), nitrogen oxides (NO_X) and particulate air pollutants viz. suspended particulate matter (SPM) and respirable suspended particulate matter (RSPM) or PM_{10} was collected from Rajasthan Pollution Control Board (RPCB). This 24 hour average data of air pollutants concentration was collected from six fixed air quality monitoring stations of Jaipur city namely, Vishwakarma Industrial Area; Regional Office Building, RPCB, Sikar Road; Ajmeri Gate; Chandpole; Rajasthan Pollution Control Board, Jhalana and RIICO, Malaviya Industrial Area for the study periods. The location of all these six air quality monitoring stations was plotted in GIS and Inverse distance weighted (IDW) interpolation is used to generated the interpolated maps. On the basis of these ambient air quality data, the annual average interpolated maps were generated for SO_2, NO_x, SPM and PM_{10} for the year 2008, 2011 and 2013. The calculated annual mean values of each ward were used for ambient air quality evaluation of Jaipur city.

Relationship between air quality and urban expansion

The air quality of an urban area is mainly influenced by human activities. Therefore, the understanding of relationship between air pollutants and urban characteristics is quite important. Linear regression analysis was used to explore the association between air pollutants, impervious area and land consumption rate within the 77 wards of the Jaipur city.

RESULTS AND DISCUSSION

Impervious area dynamics and population growth

The result implies that the land development in Jaipur region is at excessive rates during 2008 to 2013 (**Fig. 2**). The land under impervious area in 2008 was 11,855.9 hectares, which grew to 17,565.7 hectare and 20,734.6 hectares in year 2011 and 2013 respectively.

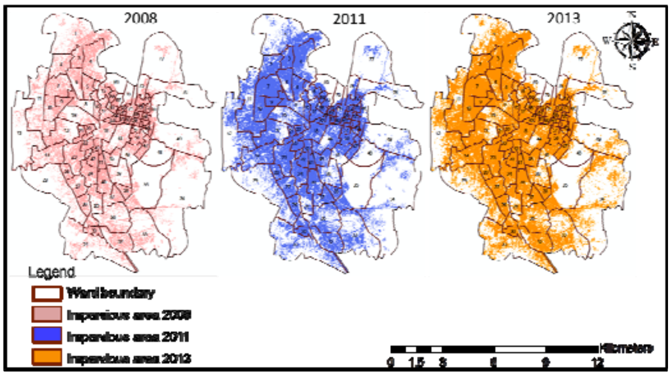

Fig. 2 Spatial and temporal changes in Impervious Area

Between 2008 and 2013, the population in the Jaipur city grew by about 14.85 % (Census of India, 2001 and 2011) while the amount of impervious area grew by about 74.89 %, or nearly five times the rate of population growth (**Fig. 3**).

This accelerated growth in impervious area clearly indicates that per capita consumption of land has increased exceptionally within five years period. The per capita land consumption refers to utilization of all lands for development initiatives like the commercial, industrial, educational, and recreational establishments along with the residential establishments per person (Sudhira *et al.*, 2004). The increase in impervious area over the years (2008-2013) has been calculated for all the 77 wards of the Jaipur city. The impervious area growth is categorized into five different zones for the ease of analysis. **Figure 4** depicts the zonal distribution of impervious area (in %) for Jaipur city region. Results clearly indicate that there is tremendous increase in number of wards under Zone 5 (impervious area 80-100 %) category from 2008 to 2013.

From **Fig. 4** it is elucidate that out of 77 wards, only 4 wards (ie. ward number 48, 70, 76 and 77) were remained under Zone 1 (impervious area 0-20 %). This lower impervious area development is due to the hilly area or higher slopes in these wards, however in other

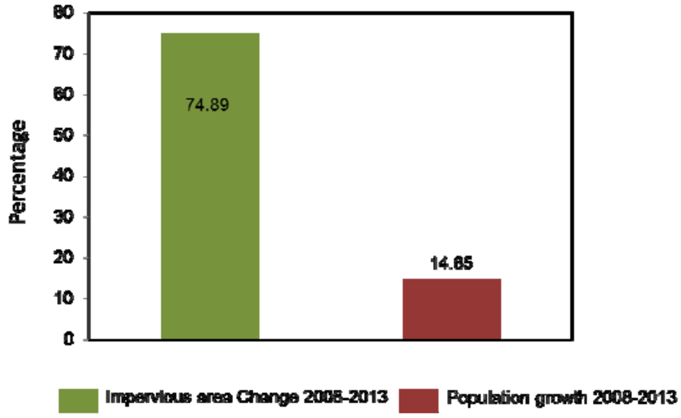

Fig. 3 Rates of growth in impervious area and population from 2008-2013

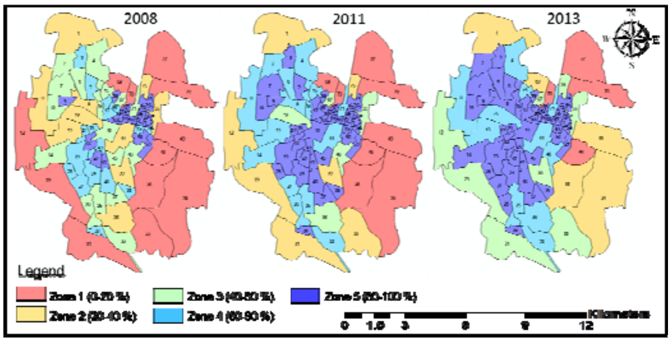

Fig. 4 Zonal distribution of Impervious Area (in %) in different wards of Jaipur

wards the urban space expansion is faster due to gentle slopes. Since landscape dynamics are influenced by every aspect of socio-economic development (Pares-Ramos et al, 2008), therefore, the increase in impervious area is seen as a direct consequence of a Jaipur region's economic development.

LCR and LAC analysis

The Land consumption rates were computed for all the 77 wards of the Jaipur city for the year 2008, 2011 and 2013. The LCR values then categorized into five categories namely very low (<0.003), low (0.003-0.006), moderate (0.006-0.009), high (0.009-0.012) and very high (>0.012) as shown in **Fig. 5**.

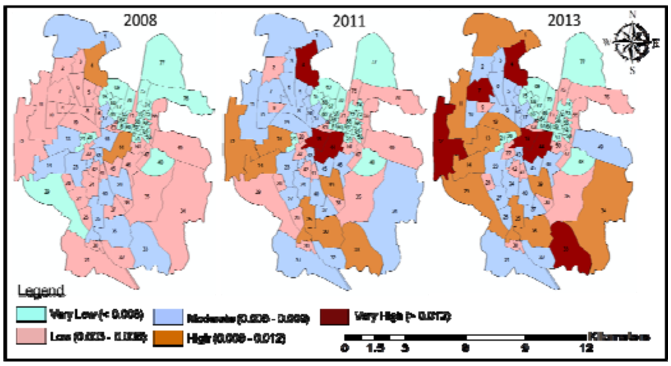

Fig. 5 Land Consumption Rate (LCR) in different wards of Jaipur city

Land consumption rate, which indicates progressive spatial expansion of the city, has shown an increasing trend between 2008 and 2013. Among the 77 wards of Jaipur city, the LCR values are very high for ward number 4(0.014), 7(0.013), 12(0.0125), 18(0.013), 33(0.014), 44(0.016), while very low LCR values were quantified for total 24 wards (<0.003) of the Jaipur city in year 2013.

LCR results indicate significant changes during 2008 and 2013 and infer that land-human ratio is very high in Vidhyadhar nagar, Jhotwara, Civil lines and Jagatpura area. The considerable increase in LCR values in these areas is due to the rapid industrialization and other socio-economic factors such as shifting of people from congested core city area towards the outskirts on open spaces. Another important aspect is that Jaipur is emerging as a property investment hub for the people from all over India and abroad, therefore, there is lot of residential colonies development in the western and southern parts of the city. On the other hand, the wards under very low LCR values category is mainly due to the non-availability of land for further urban expansion except ward number 48, 70 and 77. In these 3 wards the urban sprawl is taking place at slower rate due to hilly area or higher slopes.

The land absorption coefficient (LAC) results suggest that the rate at which new lands are acquired for development is high, with the exception of core city wards (53, 54, 57-62, 64; the Kishanpole area) where LAC is zero (**Fig. 6**), because of non-availability of land for further development.

The new land available for each unit increase in population is highest for ward number 11(0.067), 12(0.095), 18(0.084), 19(0.066), 33(0.061) and 44(0.10) during year 2008-2011. **Figure 6** indicates that the wards with higher LAC during the year 2011-2013 were 7(0.084), 29(0.063), 34(0.065) and during 2008-2013 were 12(0.073), 7(0.062), 44(0.069), 33(0.06) respectively. The LAC results have shown considerable areal growth in Jhotwara, Civil lines, and Jagatpura area of the Jaipur city during the study period (2008–2013). This urban space expansion is because of the fact that the main city area has become congested and due to the government strategies of developing important education centers, government and private offices, hospitals, industries in these areas of the city.

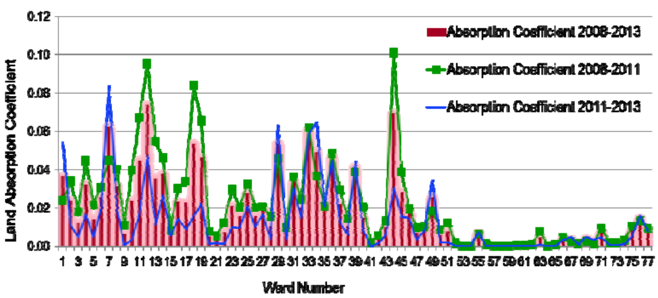

Fig. 6 Land Absorption Coefficient (LAC) in different wards of Jaipur city

Ambient air quality

From **Table 3** it is elucidate that annual average concentration of NO_X and SO_2 concentration did not cross the reference levels of 80/120 µg/m^3 during the study period, however, particulate matter (PM_{10} and SPM) concentration exceeds the standard value and shows increasing trend from 2008 to 2013. Many other studies (Maithani *et al.*, 2002; Chauhan and Joshi, 2010; Sahni & Gautam, 2012) also indicate the increase in concentration of particulate pollutants in ambient air. The high amount of SPM and PM_{10} may be due to the heavy transportation activities and industrial emission in ambient air (Rajasekhar *et al.*, 1999; Sandhu *et al.*, 2004; Kala *et al*., 2014).

Figure 7a–b reveals the spatial distribution of annual average NO_x concentration and annual average SO_2 concentration with respect to impervious area during the study period (2008-2013). NO_x and SO_2 contour lines clearly indicate the higher values in wards with more impervious area and lower concentration in wards with less impervious area or more open spaces. Marsh & Grossa (2002) also reported that the pollution level rise with land use density and tends to increase towards a city center. Results show the higher NO_x and SO_2 values at Vishwakarma Industrial Area and Kishanpole area. Yearly trend of NO_x and SO_2 indicates that rise in the concentration of these pollutants during 2011 and 2013 was lower in comparison to 2008 concentration. This decline may be due to the strict policies of Government as well as the strong action from the judiciary for proper implementation of environmental and transport laws (Rahman & Netzband, 2007).

Figure 7c–d indicates the spatial distribution of annual average SPM concentration and annual average PM_{10} concentration with respect to impervious area during the study period (2008-2013). The contour lines for particulate matter (SPM and PM_{10}) infer the increasing trend with rise in impervious area during 2008-2013.

Table 3 Concentration of gaseous and particulate pollutants during 2008 to 2013

Year	Concentration of gaseous pollutants in ambient air (µg/m^3)					
	NO_x			SO_2		
	Min	Max	Avg	Min	Max	Avg
2008	30.69	47.54	39.06	5.81	9.23	7.38
2011	34.83	39.11	37.59	5.90	6.67	6.24
2013	35.81	42.25	39.95	6.62	8.06	7.26
Year	**Concentration of particulate pollutants in ambient air (µg/m^3)**					
	SPM			PM_{10}		
	Min	Max	Avg	Min	Max	Avg
2008	202.02	355.68	278.43	74.19	181.55	111.09
2011	212.82	429.31	330.02	94.44	199.63	143.75
2013	190.43	442.21	286.61	107.30	225.89	140.16

Remarks: Min= minimum, Max = Maximum, Avg= Average

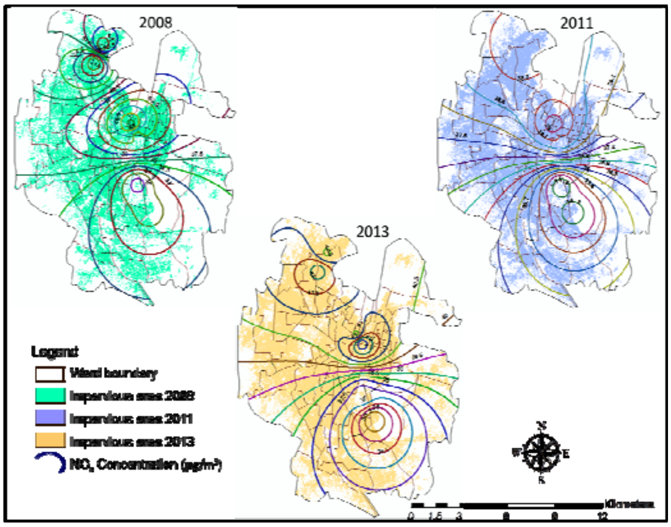

Fig. 7(a) Spatial distribution of Annual Average NO_X

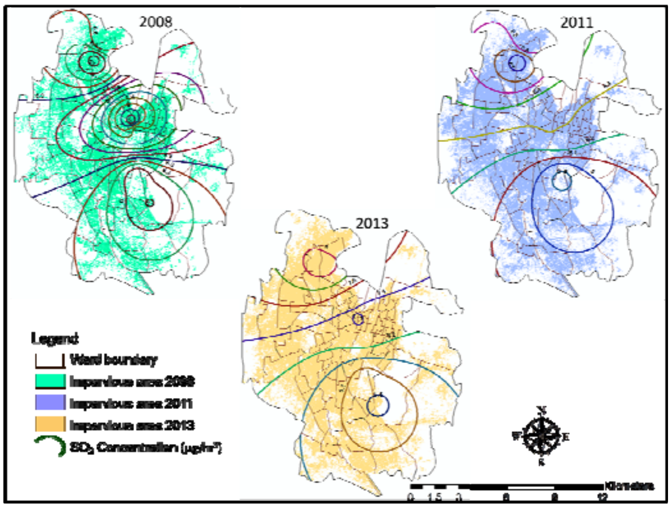

Fig.7(b) Spatial distribution of Annual Average SO_2

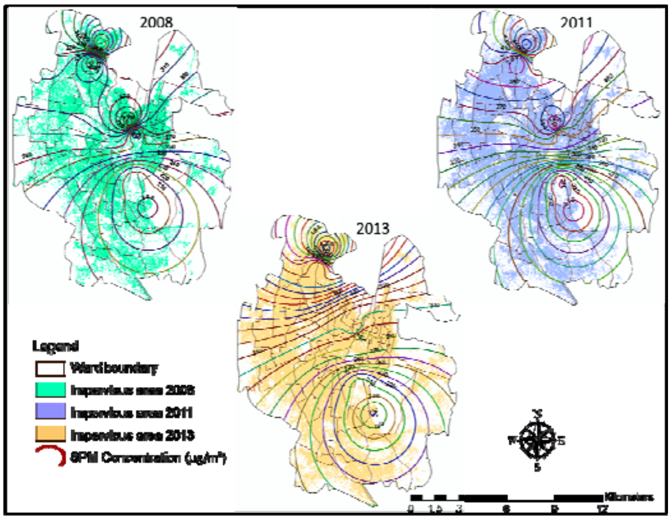

Fig 7(c) Spatial distribution of Annual Average SPM

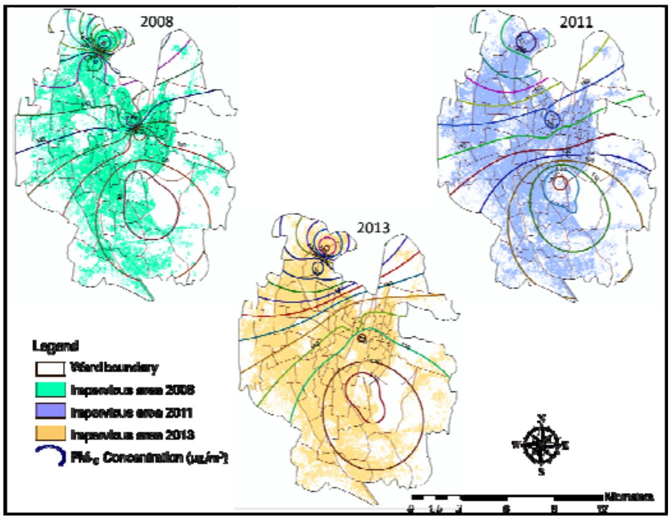

Fig. 7(d) Spatial distribution of Annual Average PM_{10}

Although particulate pollutants concentration is high in most of the wards of the Jaipur city but highest concentration was observed in Vishwakarma Industrial Area and Kishanpole area. While lowest concentration was in areas with more open spaces (Malaviya Nagar and Bagru area). This implies that air dispersion rate is more in low land use density areas in comparison to congested city areas.

Figure 8a–c indicates the pattern of different gaseous (NO_x and SO_2) and particulate pollutants (SPM and PM_{10}) with changes in impervious area in year 2008, 2011 and 2013. Similar pattern was observed for NO_x, SPM and PM_{10} with rise and dip in impervious area, however, no significant changes were found in SO_2 with respect to impervious area. These figures (8a, 8b and 8c) infer that the wards with higher coverage of impervious area are potentially unhealthier in term of the air quality than the area with less coverage of impervious area. Ling et al. (2014) also reported that area with large industrial, transportation and infrastructure land uses is potentially more polluted in terms of air quality.

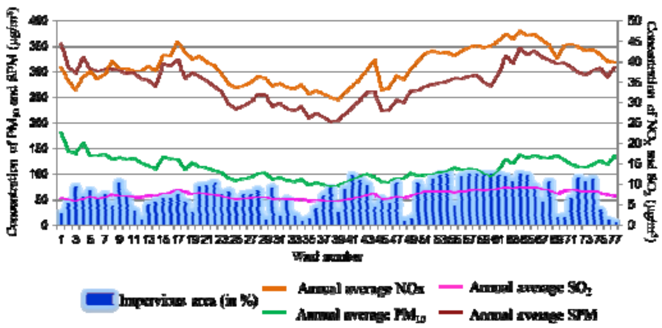

Fig. 8(a) Air pollutants (in µg/m^3) pattern with impervious area in 2008

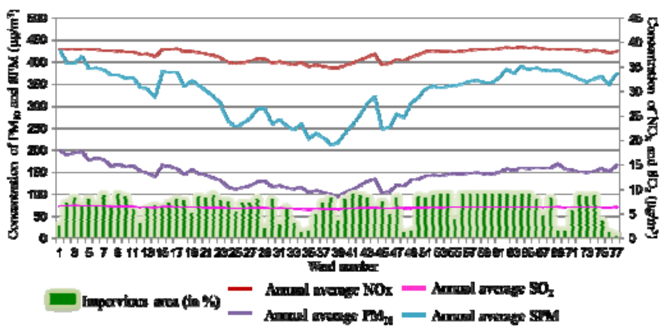

Fig. 8(b) Air pollutants (in µg/m^3) pattern with impervious area in 2011

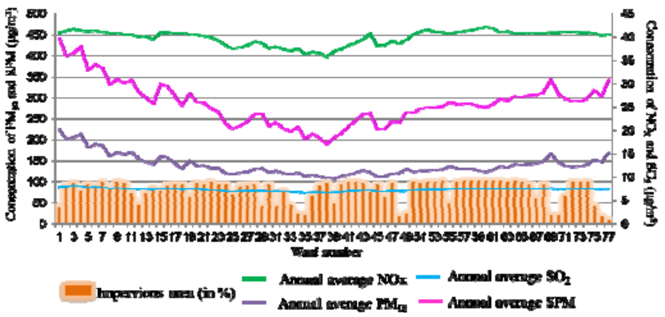

Fig. 8(c) Air pollutants (in µg/m^3) pattern with impervious area in 2013

Assessment of relationship between ambient air quality and urban space expansion

The urban areas are now facing the air pollution issue due to the excessive gases that produced by the vehicles (Ling et al., 2014) and by industries in the urban area. Therefore, the relationship between the impervious area and air quality level is an important aspect to understand for policy makers and urban planners. To assess the association between air pollutants, impervious area and land consumption rate within the 77 wards of the Jaipur city linear regression analysis was performed. Since the concentration of gaseous pollutants was under the prescribed limits of Central pollution Control Board (CPCB), therefore regression diagnostic was generated to estimate the correlation between particulate matter (dependent variable) and zone wise impervious area (independent variable) distribution of wards.

From graphical representation of R-sqaured values (**Fig. 9**) it is evident that there is significant correlation between respirable suspended particulate matter or PM_{10} and impervious area coverage in all five zones. Almost same trend is observed between SPM and impervious area coverage. It is evident from **Fig. 9** that there is a strong correlation in zone 2 (R^2 = 0.14, 0.18, 0.72 for PM_{10} and R^2 = 0.047, 0.058, 0.63 for SPM in year 2008, 2011 and 2013 respectively) in comparison to other zones. This significant correlation may be due to the presence of stone crushing units and other industries in Bagru and Vidhyadhar Nagar area. However, less

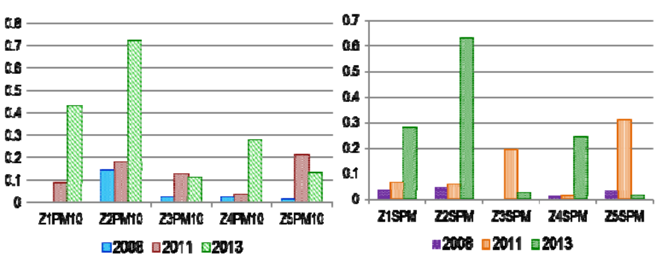

Fig. 9 Zone wise R^2 pattern between particulate air pollutants (PM_{10} & SPM) and impervious area

Remarks: Z1= Zone 1 (wards with Impervious area coverage 0-20 %), Z2= Zone 2 (wards with Impervious area coverage 20-40 %), Z3= Zone 3 (wards with Impervious area coverage 40-60 %), Z4= Zone 4 (wards with Impervious area coverage 60-80 %), Z5= Zone 5 (wards with Impervious area coverage 80-100 %)

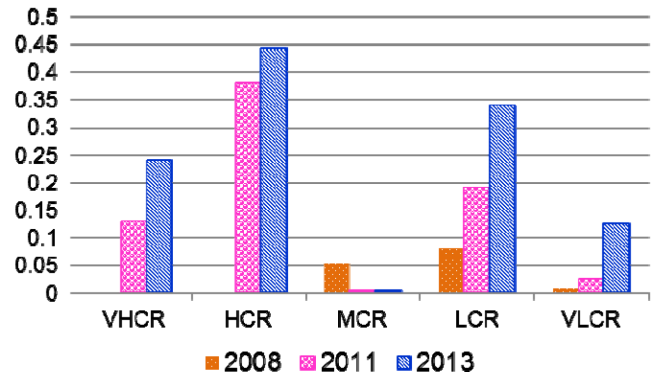

Fig. 10 R^2 pattern between ratio of particulate air pollutants (PM_{10}/SPM) and Land Consumption Rate (LCR) in different categories

Remarks: VHCR = Very High Consumption Rate (>0.012), HCR= High Consumption Rate (0.009-0.012), MCR= Moderate Consumption Rate (0.006-0.009), LCR= Low Consumption Rate (0.003-0.006), VLCR= Very Low Consumption Rate (<0.003)

significant correlation was observed in zone 5 (R^2 = 0.13 for PM_{10} and R^2 = 0.015 for SPM) in year 2013. This decline in R^2 values from 2011 to 2013 may be due to the government strict policies regarding environment and transportation laws.

Figure 10 illustrate the correlation between ratio of respirable particulate matter (RSPM or PM_{10}) and suspended particulate matter (SPM) with land consumption rate (LCR) in different categories for all the wards of the Jaipur city. The R- squared values clearly indicates that there is an increasing trend in all the categories except MCR (moderate consumption rate) category during 2008-2013.

CONCLUSIONS

Jaipur's high-speed socio-economic development has been characterized by rapid urbanization and its impact on urban air quality. Therefore, this paper investigated the coupling relationship between urbanization and the air environment from the perspective of urban space expansion in Jaipur region. Since co-ordinated development of urbanization and the air environment is a dynamic process, so this research shows that geospatial tools are very effective in analyzing the spatial and temporal pattern of air pollutants and their association with urbanization. The rapid impervious area growth was observed during the study period (2008-2013). The LCR and LAC results reveal that city is expanding mostly in north-west and south-east direction and restricted to the north-east, due to the natural barrier i.e. Aravali hills. Air quality results infer that two indicators of ambient air quality, PM_{10} and SPM concentration have the greatest effects on the air environment. The association between particulate pollution and impervious area indicate strong correlation in zone 2 during 2013; however, correlation between PM_{10}/SPM ratio and LCR shows significant relation during 2011 and 2013. This ward level information would be useful for policy makers and urban planners for future planning, proper management of land resources and to reduce the risks of further environmental degradation.

Conflict of interest

There is no conflict of interest.

Acknowledgement Authors acknowledge Department of Science & Technology, Government of India for financial support vide reference number SR/WOS-A/ET-1047/2014 (G) under Women Scientist Scheme (WOA-A) to carry out this research work.

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