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Impacts of urbanization on land use /cover changes and its probable implications on local climate and groundwater level

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ABSTRACT

Given that urbanization is considered as one of the most significant anthropogenic alterations of the environmental framework, the present study attempts to understand spatiotemporal characteristics of urban growth and its implications for the hydro-meteorological parameters in the Howrah Municipal Corporation (HMC) of the Indian state of West Bengal. The empirical approach of the paper is based on land use/land cover (LULC) changes and normalized difference built-up index (NDBI) computed using remote sensing and GIS techniques. Spatiotemporal satellite images and conventional data are used to characterize the urban growth process, whereas K-Means based unsupervised classification technique is used for LULC changes. Inverse distance weighting (IDW) interpolation method is applied for the spatial distribution of rainfall, temperature and groundwater level analysis. In order to examine whether hydro-meteorological (e.g., rainfall, temperature) parameters have any relationship with hydrological components (e.g., groundwater level) the Kendalls Tau test was performed. It is found that the maximum urban built-up area has increased during the last two decades with fluctuations in depth to groundwater level in northern, north-western and south-western side of the city. Notably, built-up expansions have taken place from the north-eastern to the south-eastern part. There are evidences of urban sprawl or shrinkage indicating expansion of built-up area and thus causing environmental degradation in the city area. While the methodology used in the paper has the potential for understanding the urbanization process, the findings have important implications for designing necessary policies and regulations.

1. Introduction

While the process of urbanization has important implications for changes in demographic characteristics and transformation of the physical landscape, unplanned, unsystematic and rapid urbanization can cause profound impacts on various environmental components, especially on land and water. A detailed understanding of the dynamics of urbanization induced land-cover change is, therefore, necessary for coping with environmental changes and facilitating sustainability. This is so particularly because most of the urban areas in the world has experienced considerable land-cover changes over the years. Further, these urban areas consume most of the global energy and cause serious environmental problems and degradation of ecosystems through pollution of air, water and land (Battista & Vollaro, 2017; Yan, Wang, Xia, & Feng, 2016).

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The problem is more critical in India that contributes nearly 16 percent of world's total human population with only 2.5 percent of the total geographical area (UNEP, 2001).[1] The degree of urbanization in the country has also increased significantly over the years (Elmqvist et al. 2013; Nagendra, Sudhira, Katti, & Schewenius, 2013).[2] It has increased from 27.7 percent to 31.1 percent with a growth of 3.3 percent points during 2001–2011 as compared to an increase of 2.1 percent during 1991–2001(Bhagat, 2011). It is projected that urban population of India will nearly double reaching 600 million by 2031 (Heilig 2012). Such rapid urbanization in the country seems to have transformed the urban landscape leading to changes in land-use and land-cover considerably and causing severe pressure on various natural resources. It is expected that with degree of urbanization, Indian cities will suffer from local environmental problems and unhealthy living conditions (Kantakumar, Kumar, & Schneider, 2016; Mohan, Pathan, Narendrareddy, Kandya, & Pandey, 2011).

Rapid urbanization and changing environment in the developing countries like India raise three important research questions:

(1) How does urbanization cause spatiotemporal changes in LULC?
(2) How does urbanization affect temperature, rainfall, and groundwater level?
(3) What are the interrelationships amongst temperature, rainfall, and groundwater level under rapid urbanizations?

There are a large number of studies that have attempted to examine land use and land cover changes using remote sensing and GIS techniques. It is found that anthropogenic activities influence urban environment considerably (Alberti et al., 2003; Andersson, 2006; Lundholm et al., 2010), and hence greater attention is required towards monitoring the changes in land use and land cover in urban areas (Stow & Chen, 2002). Further, a number of climatic parameters also change following replacement of vegetation by urban settlement (Cui & Shi, 2012; Kometa & Akoh 2012; Voogt & Oke, 2003; Zhao et al., 2006). According to Kalnay and Cai (2003), both the minimum and the maximum temperature increased due to changes in land cover in the USA. Urbanization also impacts groundwater status (both quality and quantity) and its recharge adversely (Graniel, Morris, & Carrillo-Rivera, 1999; Karamouz, Ahmadi, & Akhbari, 2011). It is observed that conversion of natural, agricultural and other low-population density lands into urban settlements has changed the hydrology of the area (Blanco, McCarney, Parnell, Schmidt, & Seto, 2011). Evidences suggest that, with extreme urbanization, more than one-half of rainwater runs off and only a fraction of it goes for deep infiltration (Arnold & Gibbons 1996).

From the above review of literature, it is clear that urbanization and subsequent changes in land use and land cover has severe adverse implications for the local ecology (Fig. 1). However, the existing studies have, in general, focused on examining bivariate relationships between urbanization and LULC changes (Alqurashi & Kumar, 2017; Sajjad & Iqbal, 2012), urbanization and changes in temperature (Chapman, Watson, Salazar, Thatcher, & McAlpine, 2017; Wang, Yan, Li, Liu, & Wang, 2013), urbanization and changes in rainfall (Chen, Li, Du, Mao, & Zhang, 2015; Kug & Ahn, 2013), or urbanization and changes in groundwater level (Khazaei, Mackay, & Warner, 2004; Wakode, Baier, Jha, & Azzam, 2018). Hence, multivariate relationships amongst urbanization, LULC changes, changes in temperature, rainfall, groundwater level have remained largely unexplored in the literature. The present paper is an attempt to fill in this gap. In other words, the present paper is to examine urbanization and temperature, rainfall and groundwater controlling for their interdependence.

Thus, the rationale of the present paper lies in understanding spatiotemporal urban dynamics through LULC analysis, changes in local climate, and their probable impacts on groundwater level. This is very important in the context of rapid urban growth with serious social and environmental challenges, such as urban poverty, various forms of pollution, vulnerabilities to natural events and climate change impacts. It is expected that findings of the paper would help in designing sustainable urban development policies and comprehensive framework for its planning and management. In addition, the findings are also likely to pave the way for further research on sustainable utilization of urban land and its necessary eco-friendly modifications and distribution given the local ecology and socio-economic dimensions.

2. Study area

The present study has been carried out in Howrah Municipal Corporation (HMC) area. It is one of the oldest urban settlements in the eastern part of the country. The Howrah municipality was first established in 1862 and it became a municipal corporation in 1984. Earlier, Howrah used to be known as the "Manchester of India" for its industrial activities. Location of a number of jute mills and dockyards were other important sources of economic activities in the area. The HMC, located between 22° 33′ 00″ North to 22° 37′ 4.8″ North Latitude and 88° 14′ 38.40″ East to 88° 21′ 39.60″ East Longitude is a riparian city stretching over 14 km along the west bank of the river Hooghly (Ganges) with an average width of about 6 km. Howrah is the second largest town within the Kolkata Metropolitan Area (KMA) and also in the state of West Bengal. Since long, it has been conceived as a twin city of Kolkata, with the river Hooghly acting as a physical barrier between these two cities. Today, the HMC has an area of 51.74 square km and is subdivided into 50 wards. As Bally Municipality very recently merged with HMC since 1st August 2015 now the total Wards no. is increased from 50 to 66 as well. Fig. 2 depicts administrative boundary of the HMC. Climate of Howrah is hot moist and sub-humid. The population of the study area (Fig. 3) grew 17.36 percent from 1991 to 2001 and only 1.96 percent from 2001 to 2011 (Census of India, 2011).

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[1] Currently, urban population in India is around 377 million comprising 30 percent of the country's total population (JNNURM Directorate, Ministry of Urban Development, Government of India, and National Institute of Urban Affairs, 2011).

[2] The Indian cities are expanding fast in respect of both the size and density of population.

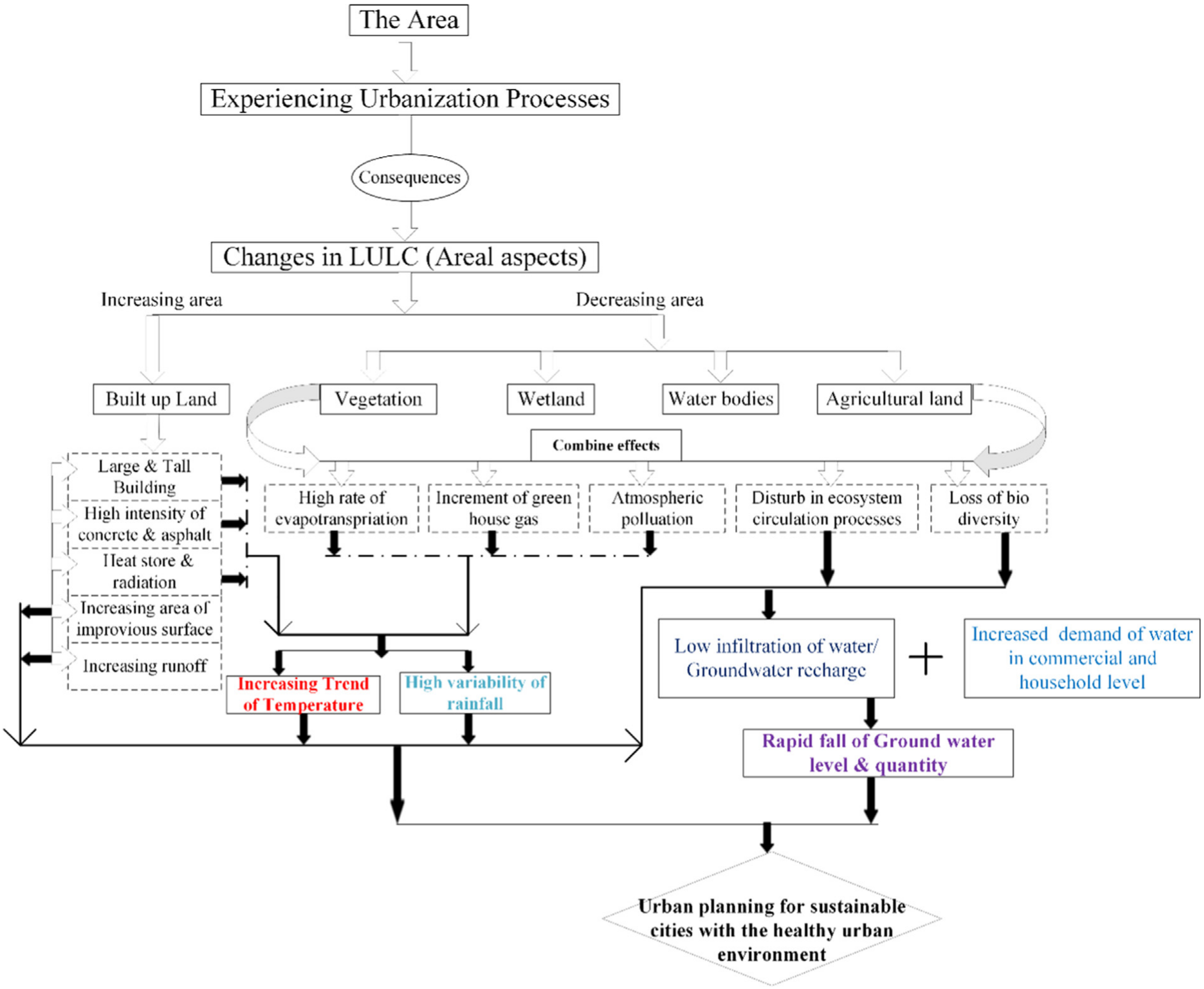

Fig. 1. Showing effect of the related environmental consequences of urbanization processes.

3. Material and methods

3.1. Data used

In an address, its research objectives, the present paper uses data on remote sensing for the HMC for different time span collected from the Landsat database of the Global Land Cover Facility (URL:http://www.glcf.umd.edu) and the United States Geological Survey Earth Explorer (URL:http://edcsns17.cr.usgs.gov) and the National Remote Sensing Centre (URL: http://bhuvan.nrsc.gov.in). LANDSAT data are useful, particularly due to the availability of a long-term digital archive with a medium spatial resolution and quite consistent spectral and radiometric resolutions. The vector map of the HMC was used for clipping and subsetting the satellite images. The following remote sensing imageries were used for the detection of the changes in LULC: Landsat Multispectral Scanner (MSS) image (Path 149, Row 044) with 79 m resolution

- Landsat Thematic Mapper (TM) image (Path 138, Row 044) with 30 m resolution
- Landsat Enhanced Thematic Mapper Plus (ETM+) image (path 138, row 44) with 30 m resolution
- Indian Remote Sensing (IRS) Resourcesat 1 Linear Imaging Self-scanning Sensor (LISS) III image (Path 108, Row 056) with 30 m resolution.

Spectral details of the aforementioned imageries are given in Table 1.

Similarly, in order to analyze climatic implications of LULC, data on rainfall and temperature [grid data (1°, daily)] are collected from the NASA (National Aeronautics and Space Administration) Prediction of Worldwide Energy Resources (URL: https://power.larc.nasa.gov). In addition, for assessing the combined effects of changes in LULC and climatic conditions on groundwater resource (especially, depth of groundwater), data on Spatio-temporal fluctuations of groundwater (in respect of its pre and post monsoon

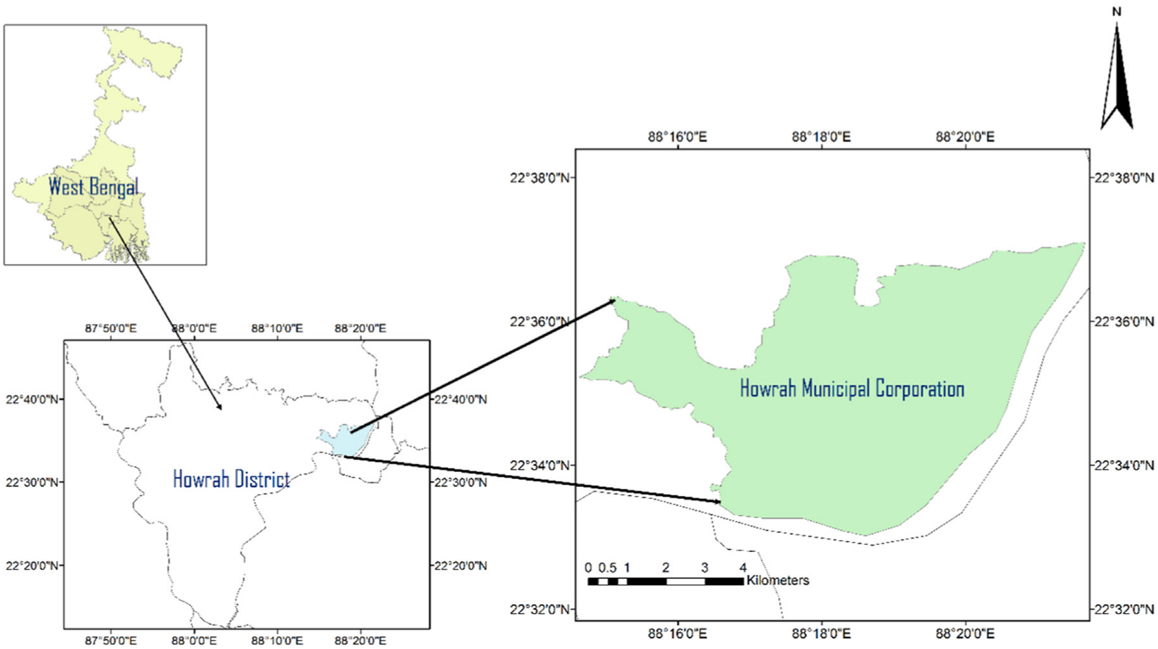

Fig. 2. Location map of the study area.

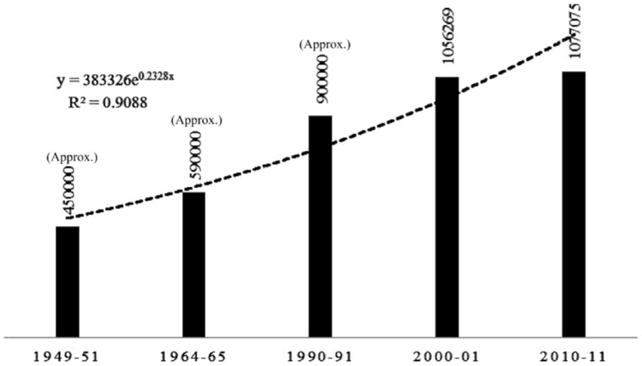

Fig. 3. Growth of population of HMC from 1949-51 to 2010-11.

Table 1
Spectral details of the satellite imageries.

Landsat MSS		**Landsat TM and Landsat ETM+**		**Resourcesat-1 LISS-III**	
Bands	Spectral resolution (μm)	Bands	Spectral resolution (μm)	Bands	Spectral resolution (μm)
4	0.5–0.6	1	0.45–0.52		
5	0.6–0.7	2	0.52–0.60	2	0.52–0.59
6	0.7–0.8	3	0.63–0.69	3	0.62–0.68
7	0.8–1.1	4	0.76–0.90	4	0.77–0.86
		5	1.55–1.75	5	1.55–1.70
		7	2.08–2.35		

depth) in the study area and its adjoining parts are collected from India-Water Resource Information System (WRIS) (URL:http://www.india-wris.nrsc.gov.in/). The data on population and other aspects were collected from the Census of India and the reports of the Municipal Corporation.

Table 2
Land use/cover classification statistics from 1975 to 2015 (area in km^2).

Land use type	1975		1989		2000		2009		2015	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Agricultural lands	13.12	25.37	11.15	21.56	6.47	12.51	3.13	6.04	1.16	2.23
Built up area	9.86	19.05	19.22	37.14	28.02	54.15	35.55	68.70	39.95	77.21
Vegetation cover	11.20	21.65	8.24	15.93	7.46	14.41	5.67	10.96	4.15	8.02
Water bodies	9.49	18.34	7.03	11.80	5.65	10.90	4.51	8.72	3.50	6.77
Wet land	8.07	15.60	6.10	13.59	4.15	8.02	2.90	5.59	2.99	5.77

3.2. Methodology

3.2.1. Land Use /Land Cover (LULC) analysis

Analysis of changes in LULC is carried out using unsupervised pattern classifier i.e., K-means clustering algorithm that includes all the LULC types in detail as given in Table 2. The K-means classifier algorithm is an indirect clustering method based on similarity of the samples. Class centres were moved successively through iterations until the best clustering results were obtained. The following formula is used for the purpose:

$$j_{j=}\sum_{x\varepsilon s_j(l)} \|x - z_j(l+1)\|^2 \tag{1}$$

and

$$z_j(l+1) = \frac{1}{N_j}\sum_{x\varepsilon s(l)} x \tag{2}$$

Here, j_j is the clustering criteria of error sum of squares and N_j is the sample number contained in S_j which is the clustering class j, and $j = 1,2,3.....k$

3.2.2. Normalized Difference Built-up Index (NDBI)

In order to examine the growth of area covered by impervious surfaces such as asphalt and concrete, the built up index has been computed. The built-up land (Fig. 4) has been generated using the NDBI of Zha, Gao, and Ni (2003) with the following equation:

$$NDBI = \frac{MIR - NIR}{MIR + NIR} \tag{3}$$

Here, NIR is a near infrared band such as ETM+ and TM and LISS III is a band no. 4, MIR is a middle infrared band such as ETM+ and TM and LISS III is a band no. 5. The index is based on the unique spectral response of built-up lands that have a higher reflectance in MIR wavelength range as compared to that in NIR wavelength range. The NDBI values range from -1 to +1. Very low values of the NDBI (0.1 and below) correspond to non-urban features (like i.e., canopy of vegetation), while high values indicate covering of areas by impervious surfaces such as asphalt and concrete.

3.2.3. Climatic condition analysis

The impact of changes in LULC on local climatic parameters, especially on a spatial distribution of temperature and rainfall during 1996–2014 is examined using the method of Inverse Distance Weighting (IDW) as discussed below.

3.2.3.1. Inverse Distance Weighting (IDW) Method. The method of IDW is based on the concept of Tobler's first law (Tobler, 1970). The

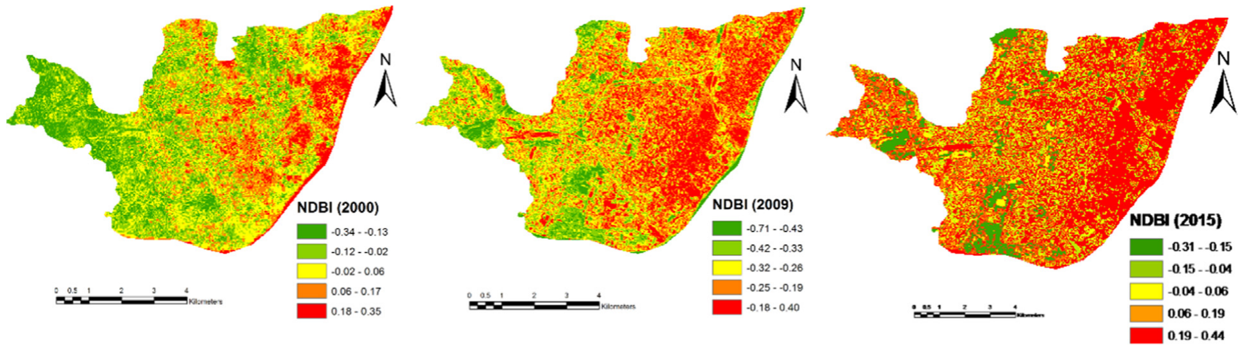

Fig. 4. Spatio-temporal dynamics of Normalised Different Built-up Index (NDBI) image of HMC during 2000, 2009 and 2015.

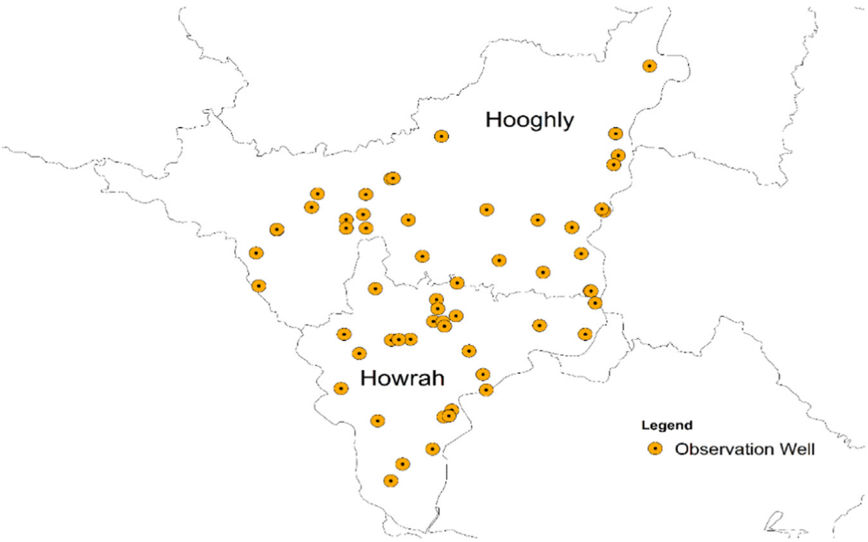

Fig. 5. Ground water Observation well point over the study area and its adjoining part.

IDW is a mapping technique of convex interpolation that fits for the continuous models of spatial variations. It is used to interpolate spatial rainfall and temperature data. The IDW derives the values of a variable at some new location using data obtained from other locations (Childs, 2004). The IDW formulas are given below.

$$\hat{X}_p = \sum_{i=1}^{N} w_i X_i \tag{4}$$

$$w_i = \frac{d_i^{-\alpha}}{\sum_{i=1}^{N} d_i^{-\alpha}} \tag{5}$$

Here, $\hat{X}_p$ stands for the unknown data on rainfall or temperature, X_i for the data from known stations, N for the number of data stations, w_i for the weight of each concerned data station, d_i for the distance from each concerned data station to the unknown site, and α for the power. It is also used as a control parameter generally with a value 2 as assumed by Huiyi and Shaofeng (2010) and Lin and Yu (2008).

3.2.4. Analysis of groundwater level

In order to examine the probable combine effects of changes in LULC and climatic conditions on spatial and temporal variability of groundwater level during 1996–2015, four time points, viz., 1996, 2002, 2008 and 2015 are selected. Due to lack of sufficient number of wells in the study area, 43 monitoring wells have been selected randomly in combination with its adjoining part for better outcomes (Fig. 5). The normal QQ plot of pre and post monsoon groundwater level at different time points are shown in Fig. 6.

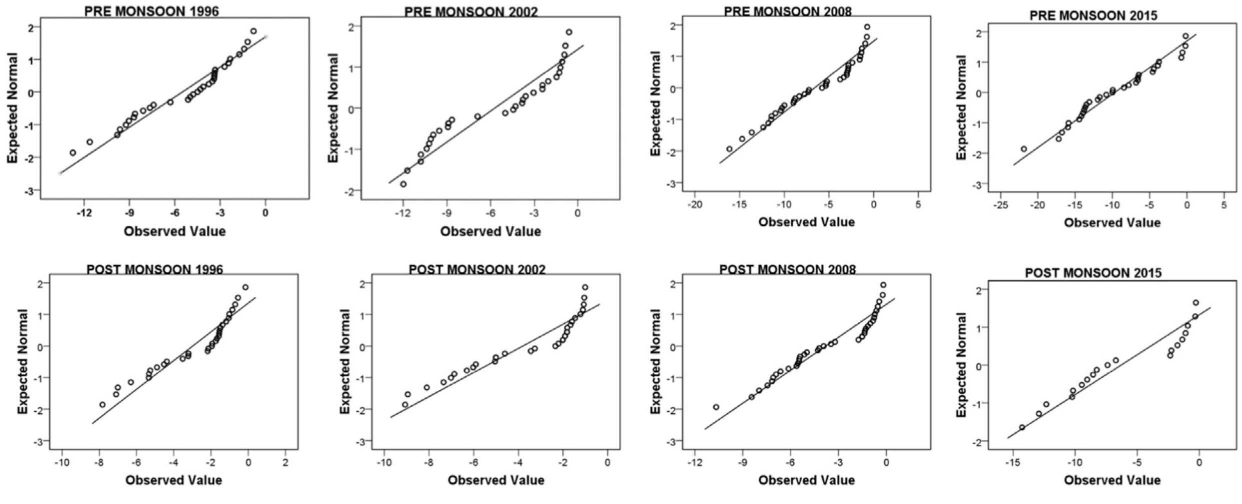

Fig. 6. Normal QQ plot of groundwater level data for different years.

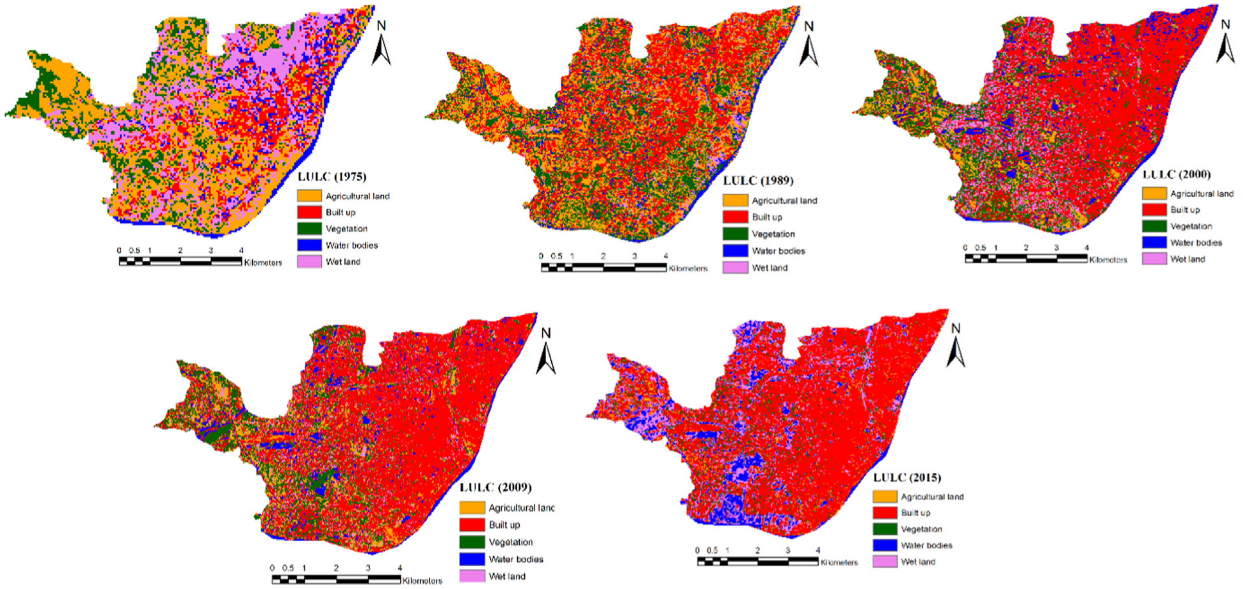

Fig. 7. Land-use and land-cover maps of HMC during 1975, 1989, 2000, 2009 and 2015.

3.2.5. *Kendalls Tau Test*

In order to examine whether hydro-meteorological (e.g., rainfall, temperature) parameters have any relationship with hydrological components (e.g., groundwater level) the Kendalls Tau test (non-parametric rank correlations test) was performed (Dhar, Sahoo, Dey, & Sahoo, 2014). Kendall's tau will take values between -1 and +1, with a positive correlation indicating that the ranks of both variables increase together whilst a negative correlation indicates that as the rank of one variable increases the other one decreases The Kendall tau value zero or close to zero means that the number of larger subsequent values should approximately equal the number of smaller subsequent values. Thus, no trends exist in the data.

4. Results and discussions

4.1. *Assessment of Land Use / Land Cover changes*

Spatial patterns of LULC changes in the HMC for the year 1975, 1989, 2000, 2009 and 2015 are shown in Fig. 7. The total area of every LULC category and its share during 1975–2015 are presented in Table 2. It is observed that the area under different LULC classes changed over the years. The data on changes in LULC show considerable expansion (nearly four times) at the cost of vegetation, wetland, and agricultural land. As regards the land use classes, over the past 40 years, an urban built-up area has increased by approximately 30 km^2 at an average rate of 0.75 km^2.

The present paper also attempts to detect the post-classification changes (in terms of the nature, rate and location of changes) over the years in two phases, i.e., during 1975–2000 and 2000–2015. In 1975, vegetation, agricultural land, water bodies and wetland were the dominant types of LULC, and most of the urban settlements (considered as the built-up category) were concentrated in the north-east part of the city along the course of the river Ganga. On the contrary, in 2000, the built-up category increased their footprint all over the area with the significant decrease in water bodies, wetland as well as cultivable land. The built-up area covered more than the half (54.15%) of the total area. Furthermore, the built-up area came out as a giant class with coverage of 77.21% of the total area followed by only 8.02 percent under vegetation, 6.77% under water bodies, 5.77% as the wetland, and 2.23% as agricultural land. Table 3 gives a detailed understanding of the changes in LULC classes over the years.

Table 3
Area and amount of change in different land use/cover categories in the HMC during 1975 to 2015.

Land use type	**Change 1975–2000**		**Change 2000–2015**		**Overall Change 1975–2015**	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Agricultural lands	-6.65	-12.68	-5.31	-10.28	-11.96	-23.14
Built up area	+18.13	+35.10	+11.93	+23.06	+30.09	+58.16
Vegetation cover	-3.74	-7.24	-3.31	-6.39	-7.05	-13.63
Water bodies	-3.84	-7.44	-2.15	-4.13	-5.99	-11.57
Wet land	-3.92	-7.85	-1.16	-2.25	-5.08	-9.83

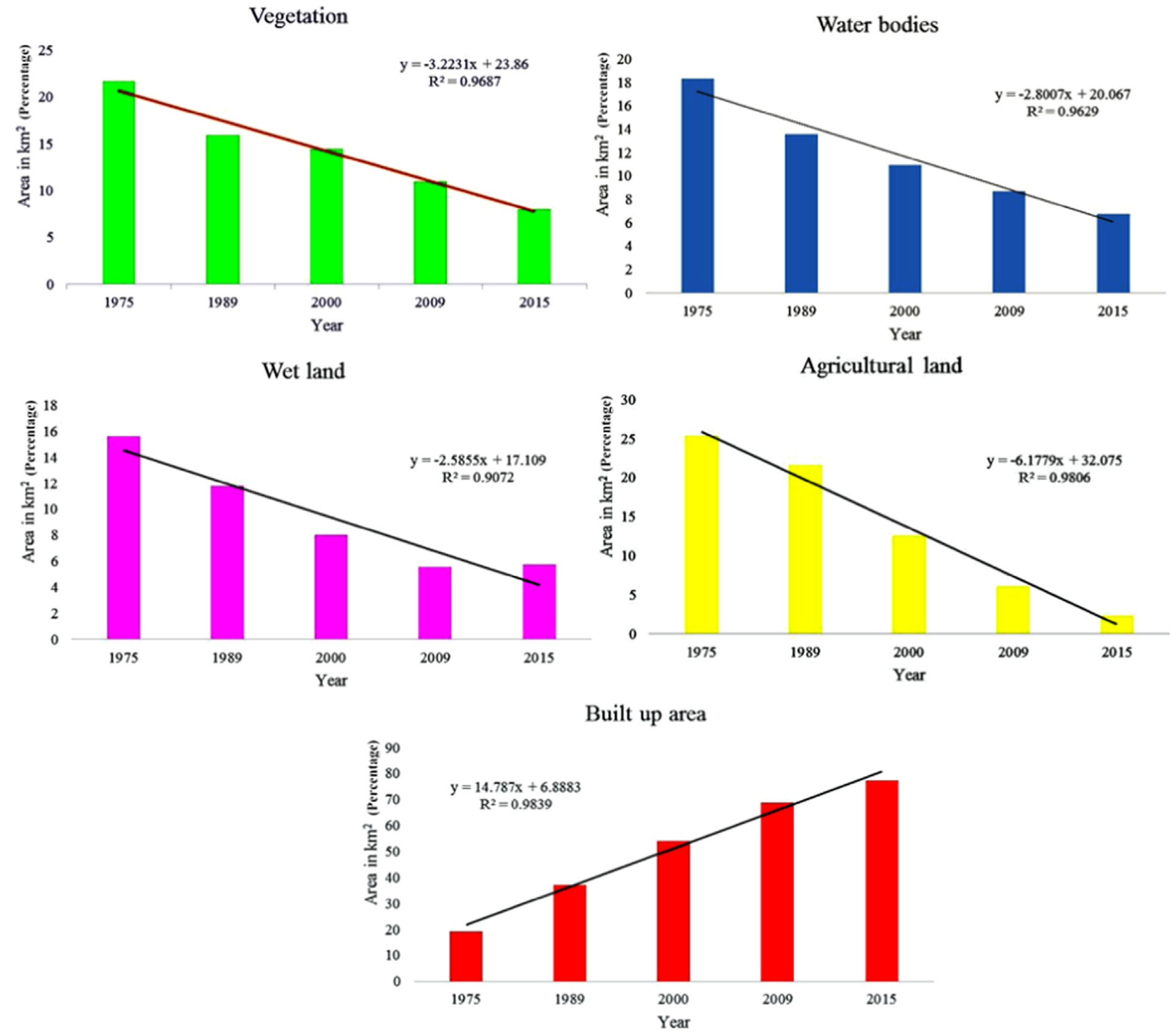

Fig. 8. Changes in area of various land-use and land-cover classes of HMC during 1975, 1989, 2000, 2009 and 2015.

An analysis of changes in LULC in the HMC shows a considerable increase in the built-up area (by 18.13 square km, i.e., 1813 ha) during 1975–2000 with an average increase of 0.73 square km/ year (i.e., 73 ha). Similarly, the built-up area increased in size by 11.93 square km (i.e., 1193 ha) during 2000–2015 and the net increase in urban area was nearly 3000 ha (Table 3). The results also show that in recent years the city (new urban region) has grown largely towards the north, northeast, and southeast direction. Regression analysis has been carried out to the track the trends of the changes in each individuals LULC class (Fig. 8). It is found that all the four LULC classes (i.e., agricultural, vegetation, water bodies and wet land) have recorded decreasing trend with very high R^2 values of the trend equations.

From the above discussions, it is, therefore, clear that rapid urbanization with the considerable increase in built-up area has caused severe losses of land under agriculture, vegetation and water bodies. While such expansion is attributed to increasing urban population with greater non-farm activities, significant changes in climatic conditions from land surface to atmosphere is very likely (Sun, Tan, & Xu, 2010).

4.2. Patterns of spatial and temporal distribution of temperature

Fig. 9a shows the spatial and temporal variations in an average of the maximum temperature at different time points. Expansion of high-temperature zone was significant in 2008 as compared to that in 2000. It appears that these high-temperature zones have gradually expanded towards the western and south-western direction. These observations are also supported by the LULC and NDBI maps which indicate that the built-up area and its index. In the same way, the average maximum temperature variation map of 2014 indicates an increase in area under high-temperature vis-a-vis that in 2008. A clear temperature gradient in between the northern and

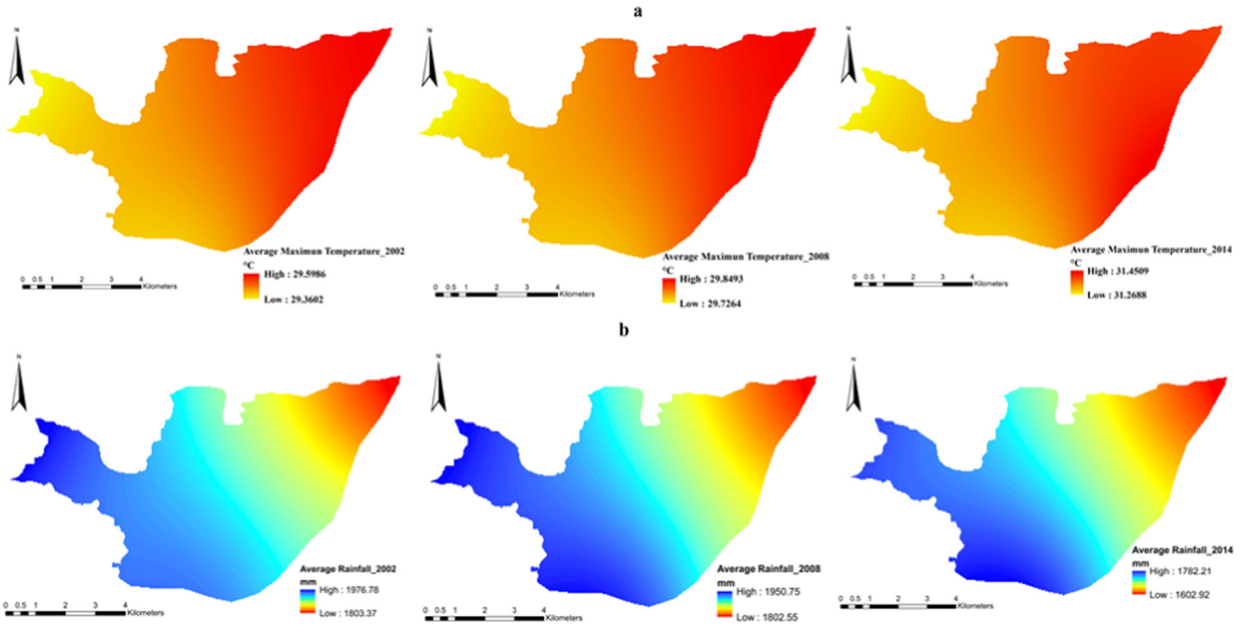

Fig. 9. Spatio-temporal variation of (a) The average maximum temperature (b) The average rainfall distribution map for the year of 2000, 2008, and 2014(Based on IDW method).

north-eastern parts to the southern and south-western parts of the city is observed. This is so because the northern and north-eastern parts are more urbanized (covered with materials such as asphalt and concrete that have a high radiant temperature) as compared to the southern and south-western parts.

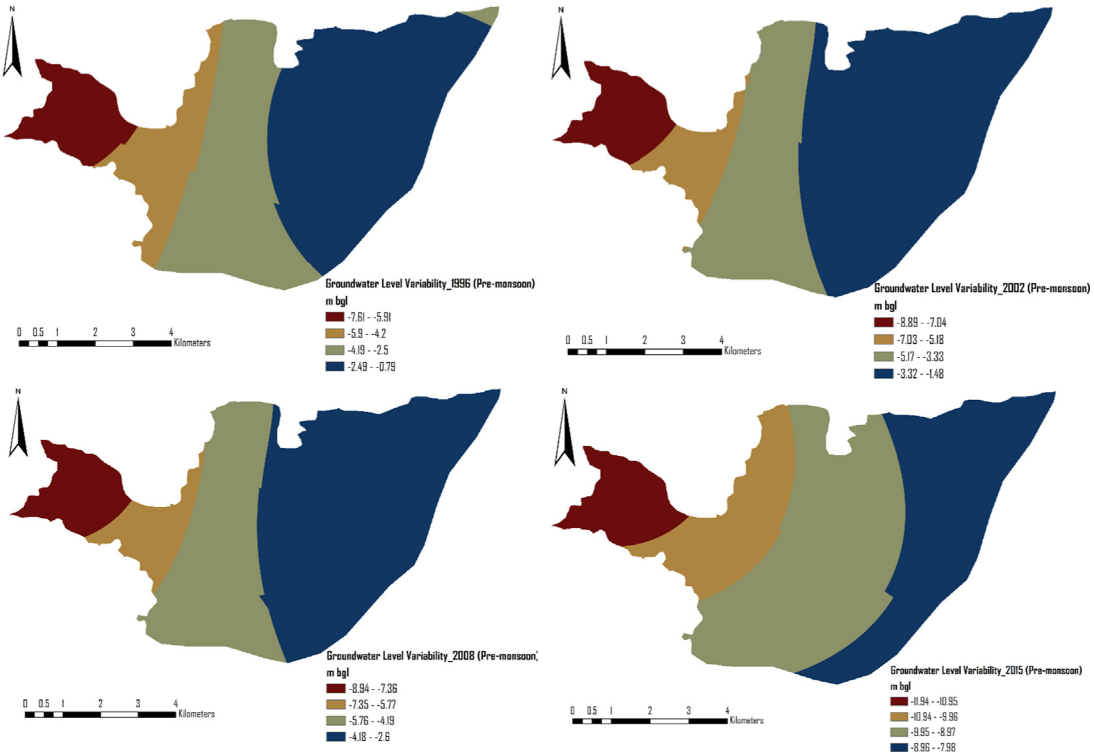

Fig. 10. Spatio-temporal variation of groundwater level (mbgl) in pre monsoon condition for the year of 1996, 2002, 2008, and 2015 (Based on IDW method).

4.3. Patterns of spatial and temporal distribution of rainfall

Fig. 9b shows the average rainfall distribution map for the year 2000, 2008, and 2014 respectively. It is observed that there was a sharply declining gradient of spatial rainfall pattern from the western and south-western parts to the north and north-eastern parts of the city. This is opposite to the temperature distribution patterns. However, the amount of rainfall shows a declining trend during the same period. When compared with the spatially distributed rainfall map of 2002 and 2008, it appears that the distribution has decreased in 2008. Accordingly, the spatial distribution of low rainfall zones has expanded during 2008–2014. The changing LULC pattern coupled with increasing trend of average temperature seem to have resulted in declining rainfall temporally as well as spatially. Notably, the direction of declining rainfall has exactly followed the path of growing urbanization.

Several studies (Cao, Yu, Georgescu, Han, & Wu, 2015; Fu & Weng, 2016; Kharol, Kaskaoutis, Badarinath, Sharma, & Singh, 2013) have revealed that micro-level changes in climatic conditions, especially in terms of variations in rainfall and temperature are related to changes in LULC. Urban surface covered with materials such as concrete and asphalt has large thermal inertia and hence stores great amounts of heat (Porson, Clark, Harman, Best, & Belcher, 2010). Further, lower evapotranspiration in urban areas due to lack of vegetation and rapid surface water runoff reduces the moisture available as locally generated precipitation (Adler et al., 2013). Particulates and aerosol from urban industry and transportation can act as nuclei that seed urban rainstorm (Changnon, 1992). However sufficient anthropogenic aerosol can have the opposite effect. With too many nuclei, cloud water vapour can be distributed among the droplets that remain too small to fall as rain (Rosenfeld, 2000). Such principle appears to hold in the case of HMC. It is evident that there was more than four times increase (from 9.86 square km to 39.95 square km, where the total area of HMC was 51.74 km^2) in the built up area, whereas area under wetland, water bodies, and vegetation cover decreased by 5.08 square km, 5.99 square km, and 7.05 square km during 1975–2015 (Table 2). Such spatial decrease in the vegetation cover, water bodies, and wetland seems to have changed climatic conditions of the area considerably. Hence, changes in LULC in the HMC can be considered as a major factor for the increase in temperature and decrease in rainfall in the study area.

4.4. Spatial and temporal analysis of groundwater level

4.4.1. Pre-monsoon analysis

Fig. 10 indicates that the pre-monsoon depth of groundwater level has changed rapidly over the years. Further, both the minimum and maximum depths of groundwater level have become deeper during 1996–2015. As regards areal coverage of a particular groundwater class, Table 4 exhibits that about 88.72 percent of the area cover had a depth of groundwater 0.79 to -5.9 mbgl in 1996, but it declined to -7.98 to -11.94 mbgl for the entire study area in 2015. According to Fig. 10, the depth of groundwater level has decreased towards the northern, north-western and south-western parts of the city that has experienced significant growth of urban built-up of non-impervious nature.

4.4.2. Post-monsoon analysis

The post-monsoon depth of groundwater level has also followed a declining trend with the passage of time (Fig. 11). This is an indicator of the state of groundwater recharge through infiltration processes due to monsoonal rainfall. The differences in minimum and a maximum depth of groundwater have gone down by about -2.82 and -3.89 mbgl during 1996–2015. Further, the spatial distribution of the range of groundwater level stood in between -1.97 to -4.36 mbgl in 1996, whereas the corresponding figures increased to -4.79 mbgl and -8.25 mbgl respectively in 2015 (Table 5). This may be largely due to a high concentration of urban population, greater built up area of impervious nature and lesser infiltration capacity (Fig. 12).

As mentioned earlier, existing studies reveal that changing patterns of LULC coupled with rapid urbanization cause direct impacts on quantity as well as a quality of groundwater resources by changing patterns and rate of recharge and initiating new abstraction regimes (Foster et al., 1988). As it is found in the present study, the upper mentation principle gives the causes of decreasing level (mbgl) and increasing the variability of groundwater level during both pre and post-monsoon periods. It is also seen that LULC in the HMC is largely responsible for the increase in temperature as well as a decrease in an amount of rainfall in the area. Such low rainfall coupled with impermeabilization of land surface due to growing urbanization seem to have resulted in low recharge, whereas an increase in the commercial and domestic use of water has raised demand for water. As a result, groundwater level has decreased during pre as well as post monsoon period posting serious threats to the sustainability of urbanization process in the HMC.

Table 4
Area occupied by different groundwater class (mbgl) in pre monsoon condition.

1996		2002		2008		2015	
Class (mbgl)	Area (%)	Class (mbgl)	Area (%)	Class (mbgl)	Area (%)	Class (mbgl)	Area (%)
-7.61 - -5.91	11.27684	-8.89 - -7.04	10.74903	-8.94 - -7.36	10.6603	-11.94 - 10.95	10.49368
-5.9 - -4.2	23.5335	-7.03 - -5.18	19.8294	-7.35 - -5.77	19.318	-10.94 - -9.96	20.46829
-4.19 - -2.5	29.75335	-5.17 - -3.33	25.93816	-5.76 - -4.19	24.78613	-9.95 - -8.97	32.89646
-2.49 - -0.79	35.43631	-3.32 - -1.48	43.48341	-4.18 - -2.6	45.23556	-8.96 - -7.98	36.14157

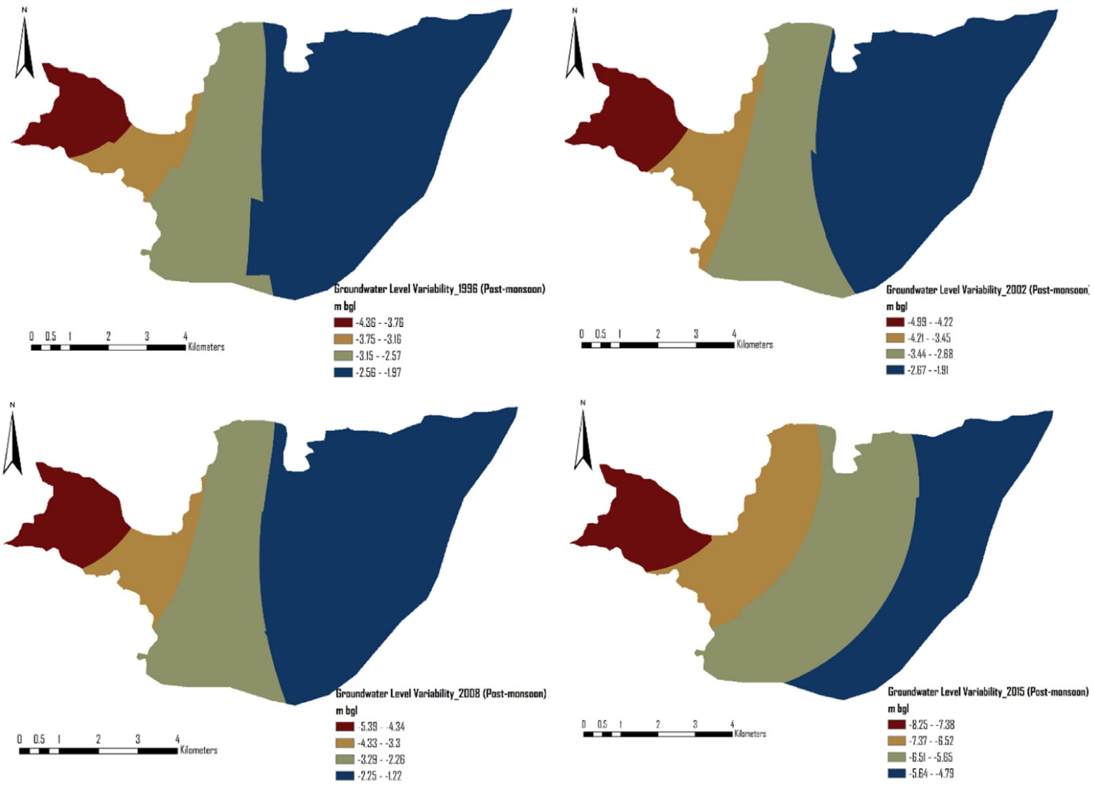

Fig. 11. Spatio-temporal variation of groundwater level (mbgl) in post monsoon condition for the year of 1996, 2002, 2008, and 2015 (Based on IDW method).

Table 5
Area occupied by different groundwater class (m bgl) in post monsoon condition.

1996		**2002**		**2008**		**2015**	
Class (mbgl)	**Area (%)**	**Class (mbgl)**	**Area (%)**	**Class (mbgl)**	**Area (%)**	**Class (mbgl)**	**Area (%)**
-4.36 - -3.76	10.26384	-4.99 - -4.22	10.91076	-5.39 - -4.34	10.8147	-8.25 - -7.38	10.82762
-3.75 - -3.16	14.93833	-4.21 - -3.45	20.38864	-4.33 - -3.3	19.06231	-7.37 - -6.52	21.68145
-3.15 - -2.57	27.38152	-3.44 - -2.68	25.26888	-3.29 - -2.26	25.11064	-6.51 - -5.65	30.16554
-2.56 - -1.97	47.41631	-2.67 - -1.91	43.43171	-2.25 - -1.22	45.01235	-5.64 - -4.79	37.32469

4.5. Correlation between urbanization and explanatory variables

Rapid increase in built up area seems to be the central cause behind various social, economic and environmental changes over the years. Faster urbanization has caused deterioration in social, economic and environmental aspects in terms of both quality and quantity. Fig. 13 illustrates that there is a strong statistical correlation between the growth of built up area and the variables like, population (r = 0.987), temperature (r = 0.899), rainfall (r = -0.860), pre-monsoon (r = 0.847) & post-monsoon (r =0.765) groundwater depth. It is possible that unsystematic/unplanned growth of built up area has affected important socio-economic and environmental components adversely. However, confirmation in this regard requires further scrutiny.

On the other hand, in order to examine the relationships between the explanatory variable and dependent variable (within a single modelling framework) over the space, the paper carries out geographically weighted regression (GWR) analysis. It is a local version of spatial regression that generates disaggregated parameters through spatial units of analysis. The ward wise population and average groundwater level are taken as the explanatory variables and the percentage of built up area (ward wise) as the dependent variable. Fig. 14 shows, the results of the GWR model reveal how the local R^2 vary across the 50 Wards in HMC. The findings also indicate interesting spatial patterns. In this particular model, the whole area is divided into four classes, i.e., (i) 0.45 - 0.52, (ii) 0.52 - 0.59, (iii) 0.59 - 0.66, and (iv) 0.66 - 0.83 respectively. Fig. 14 shows that the changes of built up area in ward no 41 and 44 to 50 are highly correlated with the variations of population and groundwater level. On the other hand, in case of the north, north-east and south eastern part of the HMC (mainly parallel to Ganga river side), local R^2 value falls under 0.45 to .59. The value of global R^2 is 0.74 which reflects the significance of the model. The results suggest that ensuring sustainability of urbanization requires restricting

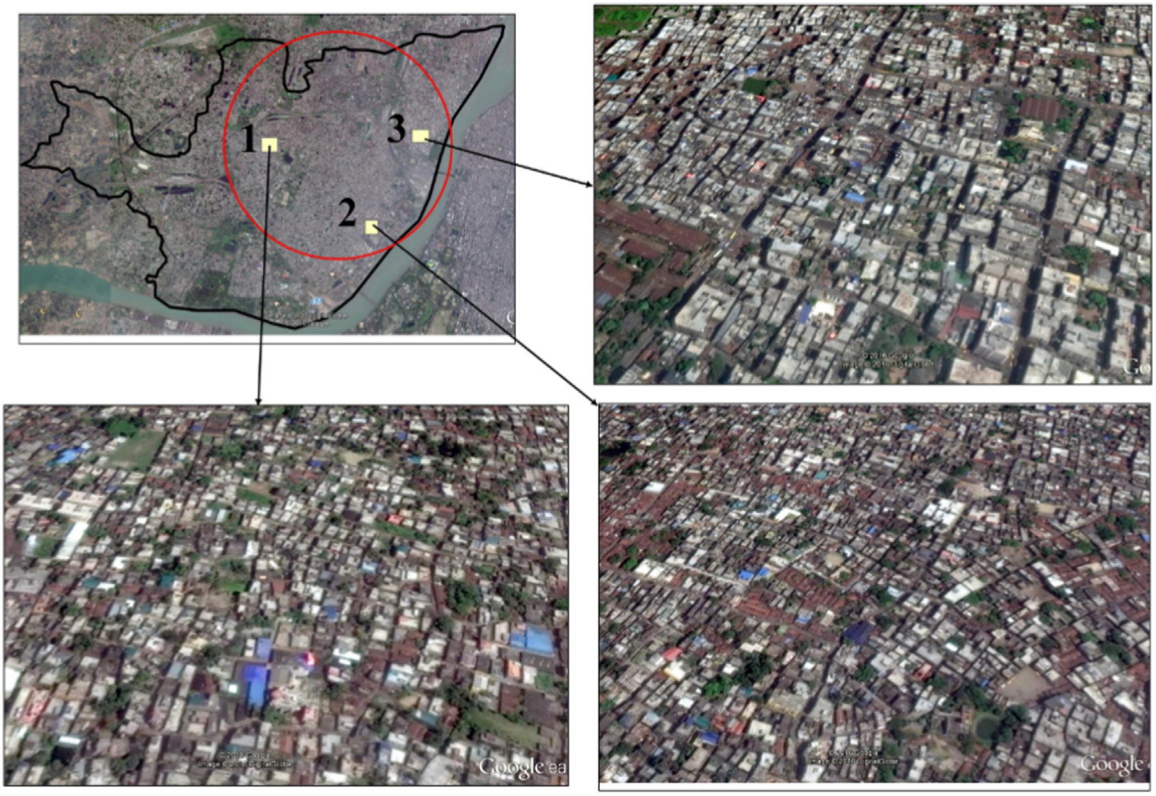

Fig. 12. Showing the example of concentration of urban landscape over the different parts of the HMC.

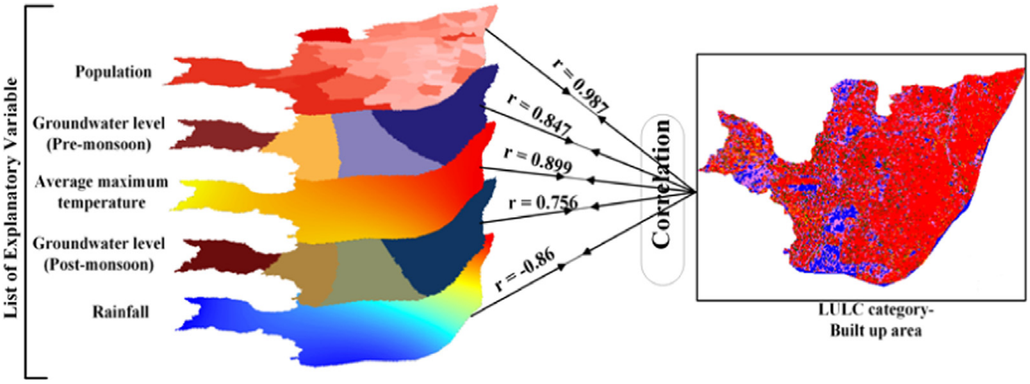

Fig. 13. Corelation analysis between built up area and various explanatory variable.

the growth of population.

4.6. Results of Kendalls Tau Test (τ)

Results for the Kendalls Tau tests are presented in Table 6. The data on temperature, rainfall and groundwater show better correlation among the variables. The results indicate that average annual temperature of the entire study area is significantly correlated (negative) with the annual average rainfall (-0.7711) and annual groundwater level (-0.7536). This suggests that with the increase of temperature in the HMC, the amount of rainfall has gradually decreased. Further, there is high temperature where the level of groundwater is noticeably low. On the other hand, Kendalls Tau tests show that the annual groundwater level has positive (0.6976) relationship with annual average rainfall. It reveals that the increment of groundwater level has direct relationship with the amount and intensity of rainfall. Finally, the results suggest that the variations of one variable have largely affected the nature of other environmental components affecting natural as well as socio economic characteristics of the area considerably.

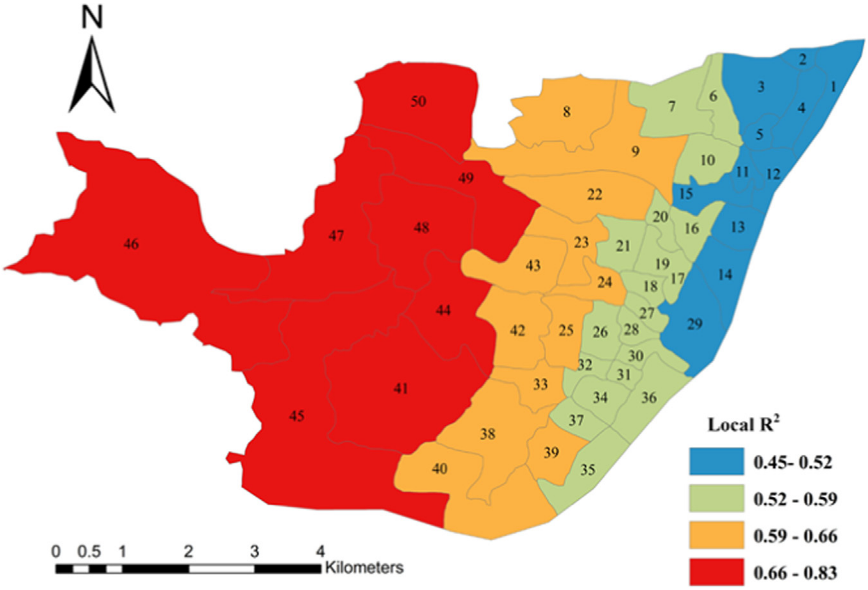

Fig. 14. Results of the GWR model for spatial heterogeneity of built up area in HMC.

Table 6
Kendall's τ rank correlation among temperature, rainfall and groundwater levels.

τ	T	R	GW
T	1.0000	-0.7711	-0.7536
R	-0.7711	1.0000	0.6976
GW	-0.7536	0.6976	1.0000

τ Kendall's Tau, T= temperature, R = Rainfall, GW = groundwater level

5. Recommendations for sustainable urban planning

- *Promoting integrated spatial planning to maintain urban growth*: The key instrument to achieve systematic urbanization in the HMC is spatial planning. The primary role of spatial planning is the integration of various LULC, strategic and urban infrastructure development and improvement in local governance. Such an effort is necessary to facilitate rational use of land and water resources on sustained basis in the long-run.

- *Increase urban greenery*: Vegetation is a natural cooling mechanism as it encourages evapotranspiration, and energy is dissipated more through latent heating rather than sensible heating. It can also be a sink for CO_2. This is expected to help in ground water recharge and conservation of soil. However, the type of vegetation is very important in this regard. The households of the area should be guided by the respective government department and agencies in respect of appropriate mix of vegetables to be cultivated and various inputs to be used.
- *Conservation of wetlands and water bodies*: Retaining water in the urban landscape enhances evaporation. Similarly, as the vegetation and wetlands tend to absorb heat, the ambient air temperatures are likely to decrease. This is especially true in the case of day time (maximum) temperatures. Hence, water sensitive urban design is necessary to sustain urban climate. There should be appropriate regulatory structure for conservation and restoration of wetland and water bodies.
- *Promoting sustainable groundwater management plan*: The ward wise sustainable planning should be designed to mitigate an "alarming" stage of groundwater condition. The sustainable groundwater planning should be made with careful consideration of physical and socioeconomic characteristics of each ward. The ward wise sustainable groundwater planning should emphasise on judicious use of ground water, promoting surface water conservation, progressive water tariff structure, enhancing awareness of the people, scientific planning on water distribution, and promoting domestic and industrial water saving practices.
- *Training and awareness program*: Finally, people should be made aware of the fact that social, economic and environmental changes over the years in the area have largely been caused by rapid, unplanned and unsystematic urbanization leading to inefficient use of critical natural resources like land and water. Proper capacity building and awareness programmes should be initiated by the state government, local body, and NGOs to disseminate information about the adverse effects of rapid urbanization on various socio-economic and environmental aspects.

6. Conclusions

The present paper is an attempt to examine changes in LULC and the dynamics of urban expansion in the HMC area during a period of four decades using the RS data. It is found that the HMC has experienced rapid changes in LULC, particularly in respect of built-up areas. The analysis reveals that urban area has expanded by 1813 ha during 1975–2000 and 1193 ha during 2000–2015 leading to substantial reduction in the area under water bodies, vegetation, cultivation and wetlands/lowland. The massive expansion of urban features, like concrete, asphalt, etc. that absorb and storing incoming solar radiation has led to increasing in the average maximum and minimum temperature and decrease in rainfall in the area during this period. The study also reveals that the changing rate of precipitation and temperature coupled with the growth of urban built-up area has affected the groundwater table adversely during both pre and post monsoon period.

Thus, unsystematic, rapid, unplanned urbanization threatens the sustainability of the development process by affecting the critical environmental components, like rainfall, temperature, and groundwater level adversely. In order to overcome this problem, there is a need for systematic and comprehensive planning for sustainable development of the cities with the healthy urban environment and conservation of natural resources. This necessitates an integrated approach to urban planning to ensure the conservation of water, moderation of climatic conditions at the micro level, etc. Conservative urban planning may facilitate sustenance of natural resources and people's livelihoods. A holistic approach to urban development is necessary with a significant proactive role of the local body. There should also be effective integration of various line departments/agencies of the state as well as the central government.

More importantly, in addition to appropriate policies for sustainable urban development, there is also a need for regulation of unsystematic urban growth, particularly in respect of use and management of the critical natural resources like land and water. This requires enactment of laws and formation of enforcement agencies with necessary incentive/disincentive structures. While the incentives are expected to encourage systematic growth of urban areas, the disincentives (penalties) will restrict illegal expansions and wastage of resources.

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Conflict of interest

No potential conflict of interest was reported by the authors

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