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Geospatial Analysis for the Assessment of Urban Sprawl Impact on Water Table in Lahore, Punjab, Pakistan

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Abstract: Developing countries are facing a menace of disorganised urban growth. This is causing a stress on the available water resources. Lahore city having more than eleven million population is also facing similar problem. A study was conducted to analyse the impact of urban sprawl on the depth to water table in Lahore. Temporal images from 1990 to 2017 of Landsat satellite were used to measure the urban sprawl in Lahore. The groundwater level is consistently on the decline. The correlation between built-up area percentage and depth to water table was significant at (p>0.05). The land development authority of Lahore should take appropriate measures to control this unorganised urbanization.

Key words: Urban sprawl · Groundwater · Water table · NDBI · Remote sensing · GIS

INTRODUCTION

There is no concept of life without water. Every living organism requires water for survival. Average daily intake of water for a human being is about 2000 mL [1]. More than 97% of the water resources of this planet are in the form of seawater, whereas, the residual is regarded as freshwater that includes glaciers, icecaps, surface water and groundwater [2]. Usually the term groundwater is used to refer the water content available beneath the ground. It is found between rocks and soils below the surface of the earth in the upper part of the earth's crust.

Fast-tracked industrialization and high population growth are important factors in the depletion of groundwater which is the most cost-effective source of drinking water both for urban and rural populationof the world [3]. Around sixty percent of the population of Pakistan is living below poverty line and it does not have safe water to drink [4]. The changing climate, race for higher living standards and ever-growing population are severe challenges confronting the sustainable use of water in the agricultural and domestic sectors of Pakistan[5]. The arid and semi-arid regions of Pakistan are facing a menace of over-exploitation of groundwater due to limited precipitation, lack of surface water supplies and rapid urbanization [6, 7].

Since 1854, when John Snow drew a map for the patients of a waterborne disease, the use of maps to solve water related problems is getting common [8]. The scope of mapping also covers a wide range of issues associated with water resources and water availability both at a regional or local level. These days, remote sensing and the geographical information system (GIS) are used worldwide to solve the water related problems. Remote sensing enormously supports in determining the changes on the surface of the earth. The use of satellite imagery not only provides access to the past land use and land cover types but it is also cost effective. Nowadays, the transformation of rural areas into urban centres is experienced all over the world but the growth pattern and rate of urban expansion in developing countries is far ahead than the developed countries [9]. This unorganized expansion can become a hazard for the emerging economies. So the regular mapping the urban sprawl is imperative for sustainable development [10].

The most important and economic source of drinking water for the inhabitants of Lahore is groundwater [11]. Especially in the last decade, it has been noticed that the unprecedented growth in the use of water and rapid urbanization is jeopardising the Lahore aquifer [12]. Water and sanitation agency (WASA), Lahore is responsible for water supply to the industrial and domestic consumers in the city. The number of water connections provided by WASA has risen to 634, 000 out of which only 40, 000 water connections have functional meters. Resultingly, the gross groundwater extraction mainly by WASA tube wells and some private housing societies is going to touch 3 million cubic meters per day

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[13]. So a study was conducted to analyse the urban sprawl in Lahore district and the impact of urbanization on water table in WASA jurisdiction Lahore.

MATERIALS AND METHODS

Study Area: Lahore is said to be the heart of Pakistan having annual growth rate of over 3%.Its population has crossed eleven million in 2017. Ravi River flows in the north western part of Lahore and is an important source of groundwater recharge. Lahore district covers an area of 1, 772 km^2 whereas the area under the jurisdiction of WASA Lahore is about 250 km^2. The average annual rainfall is around 629mm. In case of a rainy event, the water infiltrates through unlined drains and substantially contributes to groundwater recharge. The study area map (Figure 1) and the location of WASA tubewells are provided below (Figure 2):

Satellite Imagery: In order to study urban expansion and change detection, remotely sensed satellite data is always been a great help. In the current research, we used Landsat legacy to determine the change in urban area that appeared during 1990 to 2017. So depending on the availability, the freely available satellite images of Landsat 4(TM), 5(TM), 7(ETM+) & 8(OLI) were downloaded for years 1990, 2000, 2011 and 2017 respectively. The satellite images were selected by considering certain factors like minimum cloud cover, maximum lush green vegetation and also suitable time span between dates of acquisition to detect an adequate amount of change. The dates of image acquisition and the description of images and bands used in the study are arranged in Table 1.

Image Pre-Processing: Downloaded images were extracted to different layers that actually correspond to the bands in which data was captured by the sensor. These layers of data were stacked to make a multi layered image. To subset this image according to our study area, we used administrative boundary layer of WASA Lahore. Subsetting of the image separates the irrelevant nearby areas from the area of interest and the process of data analysis speeds up. The image enhancement through histogram equalization helped in brightening up the features and for better visual interpretation.

Image Classification: Classification of a remotely sensed image is a process in which pixels of the whole image that contain different digital values are categorized as different land use classes to which they actually belong to, in relation to ground reality. In the current study, we performed supervised classification by using maximum likelihood algorithm that is highly dependent upon the analyst's skills and knowledge rather than just depending upon software. Selection of pixels for signature is of vital importance and should be done very keenly and wisely. Different signatures were created for each land use class and the maximum likelihood algorithm was run to get the classified image.

Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-up Index (NDBI): Normalized Difference Vegetation Index (NDVI) was used to enhance to vegetation in the study area. Normalized Difference Built-up Index (NDBI) a prevalent built-up area extraction technique was initially formulated to work with Landsat thematic mapper bands. It takes advantage of the unique spectral response of built-up areas over other land covers. Built-up areas were effectively mapped through arithmetic manipulation of re-coded Normalized Difference Vegetation Index (NDVI) and NDBI images derived from TM imagery. The results were also compared with the maximum likelihood classification method. The accuracy assessment of classified images was performed using the field knowledge and Google Earth [14]. The NDBI and NDVI were calculated using equations (1) and (2) respectively.

$$NDBI = \frac{(SWIR - NIR)}{(SWIR + NIR)} \quad (1)$$

where,
SWIR= Short wave infrared band
NIR= Near infrared band

$$NDVI = \frac{(IR - R)}{(IR + R)} \quad (2)$$

where,
IR= Infrared band
R= Red band

Water Table Data: In order to study thereduction of water level as an impact of urbanization, the temporal data about water table was required. Due to non-availability of water table data at regular intervals in the study area, we restricted urban impact assessment to only that portion of the study area that is under WASA Lahore's jurisdiction. So the water table data of WASA tubewells was aquired. The data was in the form of a database having global positioning system coordinates for each tubewell.

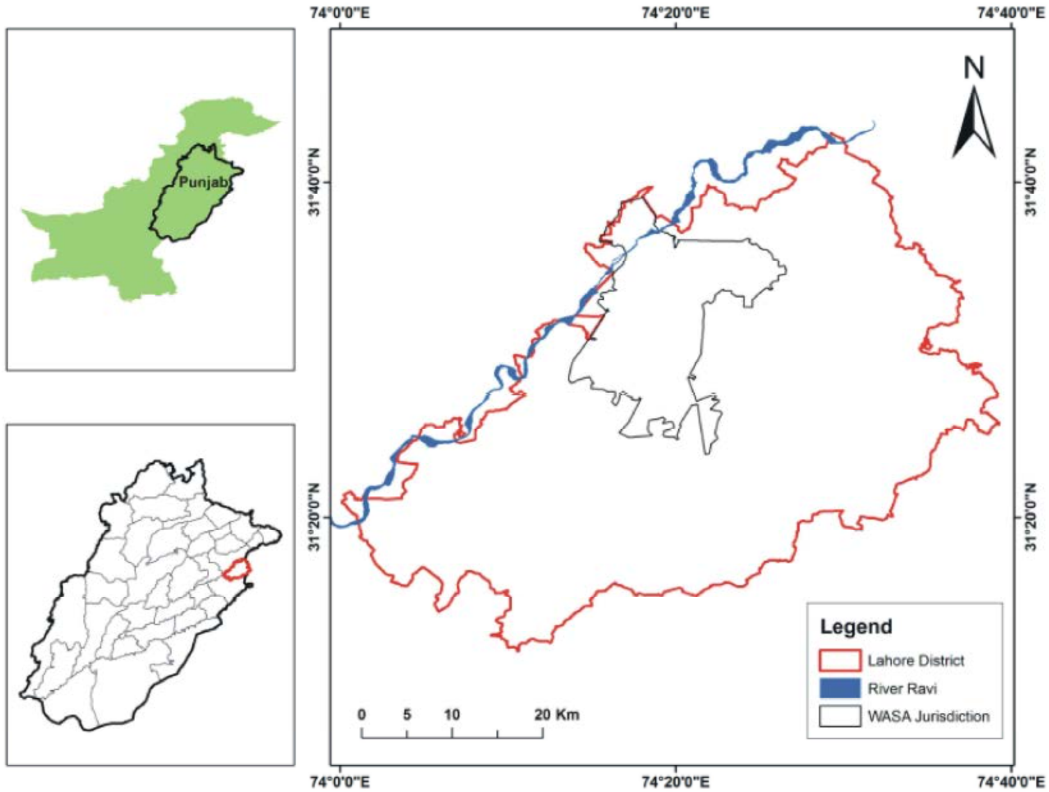

Fig. 1: Map showing study area

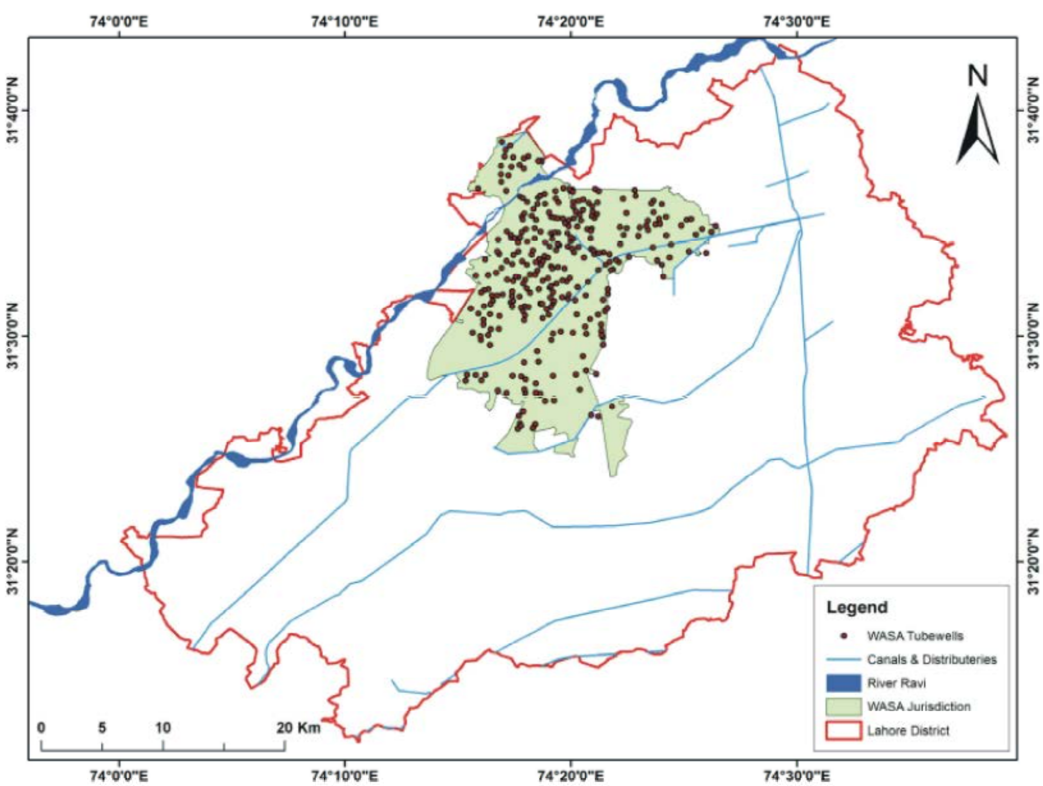

Fig. 2: Map showing locations of WASA tubewells in the study area

Table 1: Details of the Satellite images (Landsat) used for the study

Year	Sensor	Bands	Spatial Resolution	Thermal Resolution	Path/Row	Date of Acquisition
1990	TM	1-5 & 7	30m	--	149/38	26-3-1990
		Pan(8)	15m	--		
	TIR	6	--	60m		
2000	ETM+	1-5 & 7	30m	--	149/38	19-03-2000
		Pan(8)	15m	--		
	TIR	6	--	60m		
2011	TM	1-5 & 7	30m	--	149/38	10-3-2011
		Pan(8)	15m	--		
	TIR	6	--	60m		
2017	OLI	2-7 & 9	30m	--	149/38	26-3-2017
		Pan(8)	15m	--		
	TIR	10 & 11	--	100m		

Source: http://www.usgs.gov/.

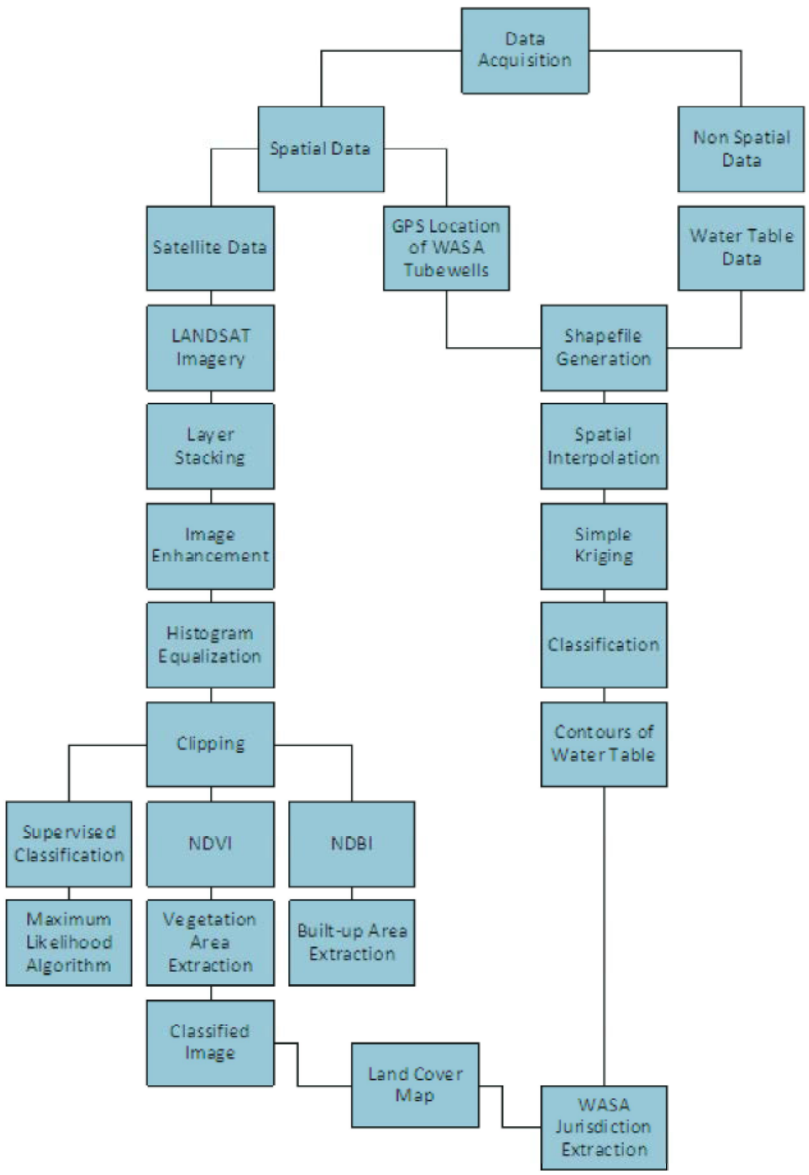

Fig. 3: Detailed methodological flow chart

The database was imported in Arc Map 10.3 to make a vector layer of tubewells location. The layer was exported as a shapefile containing points that were spatially distributed in the study area. Kriging method was performed to interpolate the water table values. Kriging method anlaysed the spatial structure and the empirical semi-variogram was fitted to the data. The advantage of kriging method is that it can predict the values beyond the range of data while keeping in view the spatial structure of the data [15]. The temporal water table maps for the WASA jurisdiction were generated and they were compared with the temporal built-up area percentage in WASA jurisdiction. The correlation coefficient was also calculated between the built-up area percentage and depth of water table. The assigned spatial reference to all the images was WGS84and UTM, zone 43N. Layer stacking, image subsetting, image enhancement, calculation of NDBI and NDVI and supervised Classification was done with the help of Erdas Imagine 2014 by Leica. Whereas ESRI's ArcGIS 10.3 was used for making shapefiles, contours, layers overlay and geostatistical analysis and drawing the final maps. Detailed methodology for the study is provided in Figure 3.

RESULTS AND DISCUSSION

The results of the study show (Figure 4) that most of the lahore district was covered with vegetation in 1990 and only 10.67% of the area was built-up. The built-up area expanded to around 16.26% in 2000 (Figure 5) and it reached 24% in 2011 (Figure 6). In 2017 around 30% of Lahore district is built-up (Figure 7). The enlargement of the built-up area on a regular interval of time clearly indicates that the infiltration from this area is certainly going down which will eventually lower the water table.

Table 2 shows that there is a drastic decrease in barren land class and vegetation class since 1990. The barren lands in the peripheries of the metropolitan are gradually transforming into urban fringes. The industrialiazation adjacent to some of the major roads like multan road in the south, grand trunk road in the north and ferozepure road in the east also play a key role in the increase of built-up area (Figure 7).The maps (Figures 4-7) show that there is an unorganized urban expansion in Lahore district. Although the built-up area is increasing along the borders of metropolitanyet the prominent direction of urbanization is in the north eastern and south western parts of Lahore. The reason for this uncontrolled

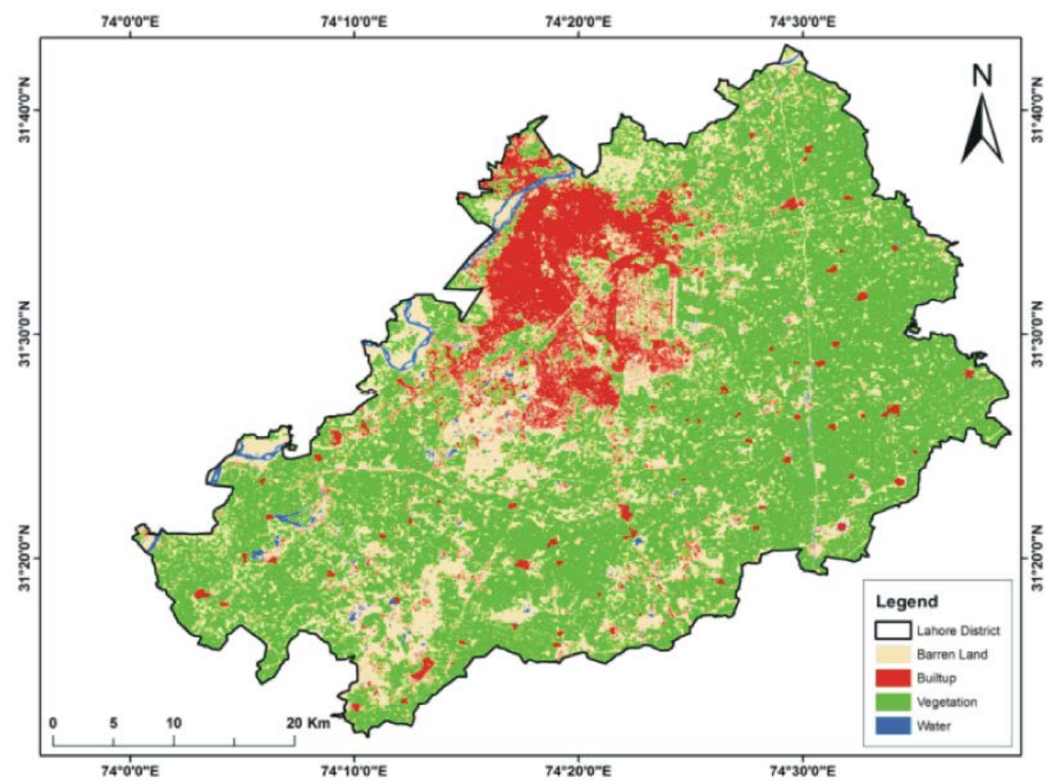

Fig. 4: Land cover map of Lahore district for 1990

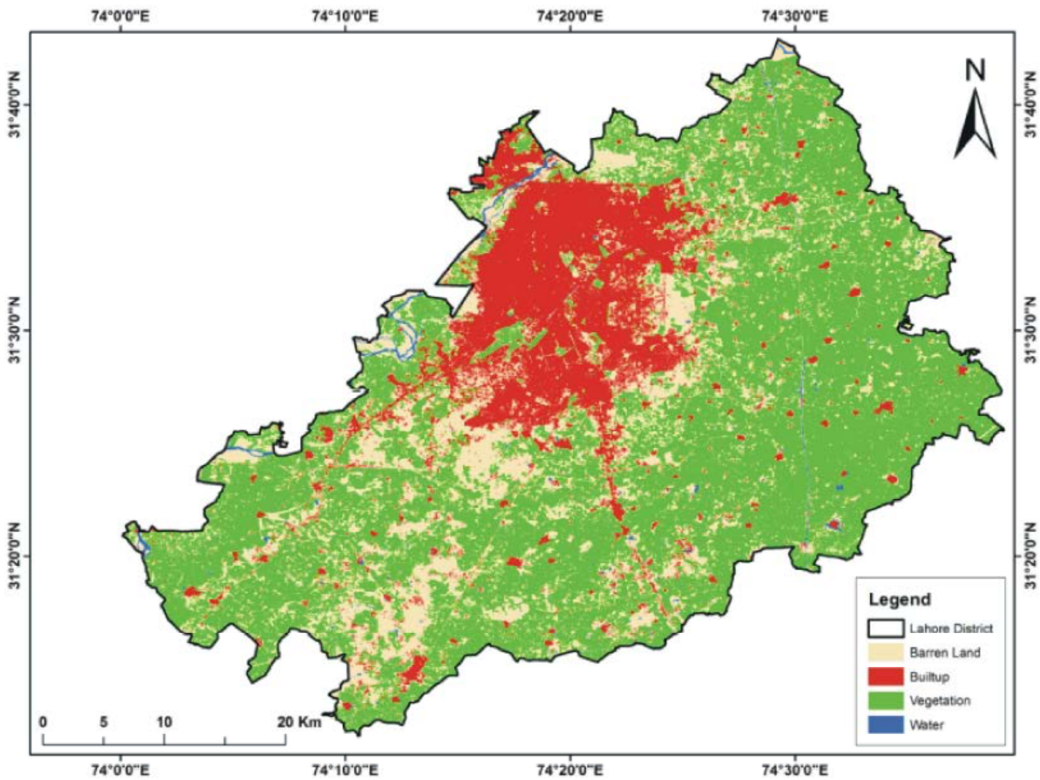

Fig. 5: Land cover map of Lahore district for 2000

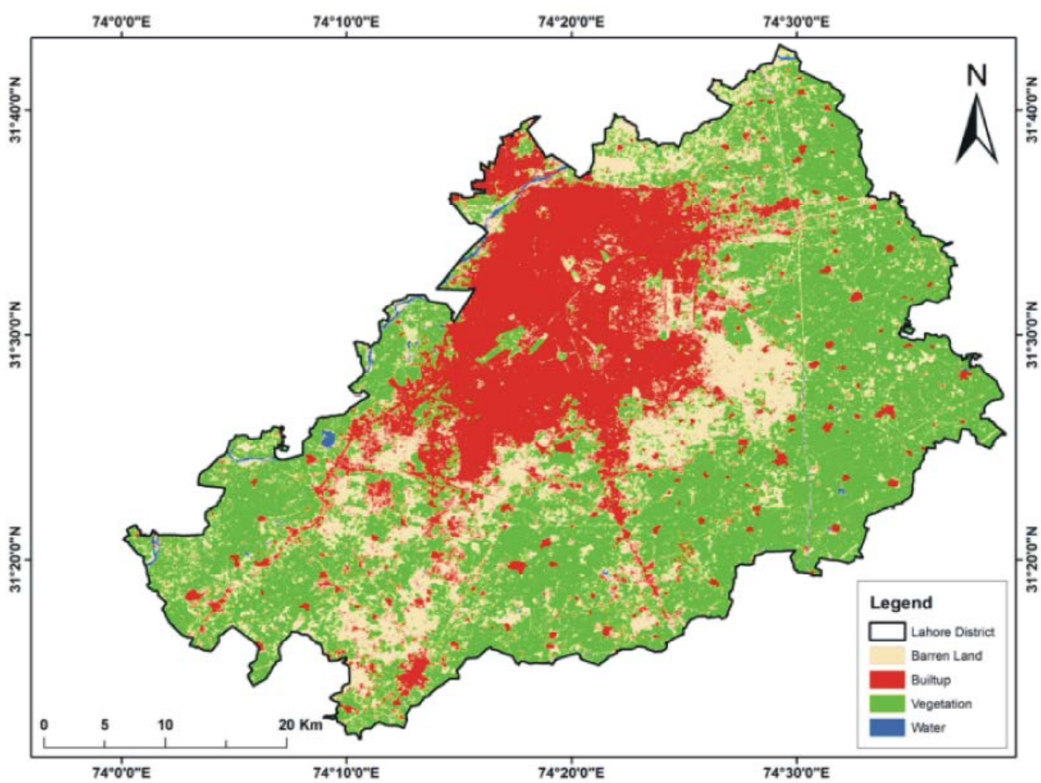

Fig. 6: Land cover map of Lahore district for 2011

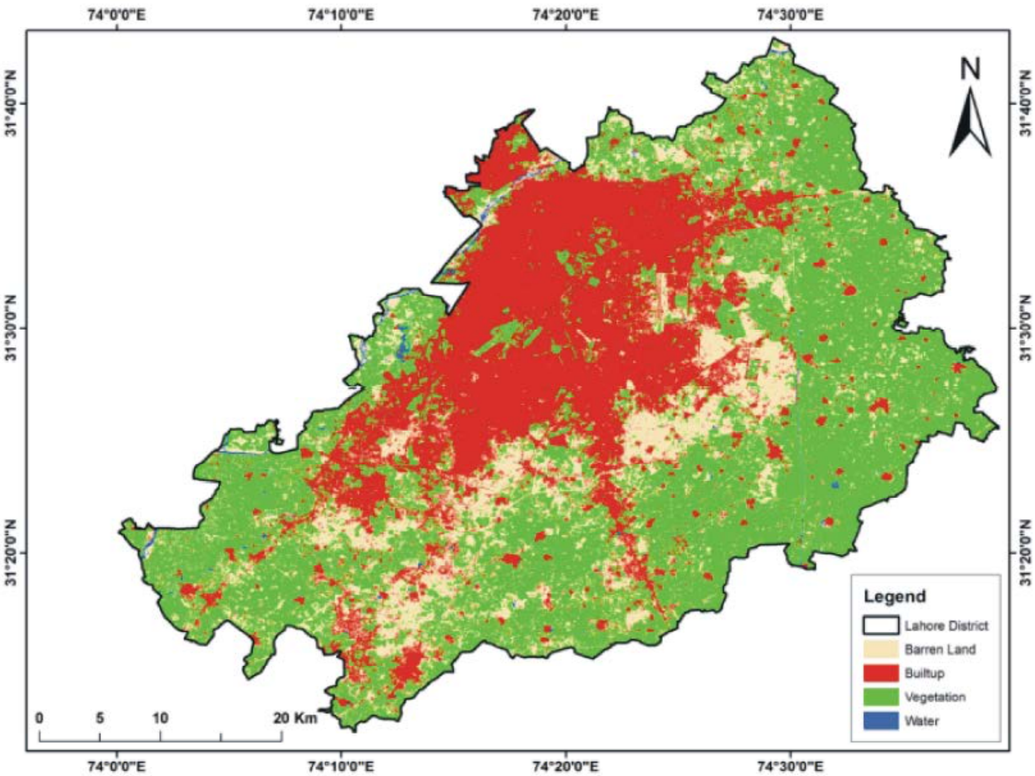

Fig. 7: Land cover map of Lahore district for 2017

Table 2: Table showing area in square kilometres of different land cover classes in Lahore district.

	YEAR			
Land Cover	1990	2000	2011	2017
Barren Land (km^2)	576.6	475.5	506.5	382.4
Built-up (km^2)	188.3	286.8	428.5	524.8
Vegetation (km^2)	981.7	985.3	820.2	841.4
Water (km^2)	17.2	16.3	8.7	15.4
Total	1763.9	1763.9	1763.9	1763.9

Table 3: Details of prediction errors using simple kriging

	Prediction Error			
Year	Mean Error	RMS Error	Mean Standardized Error	Average Standard Error
1990	0.2762299	2.600121	0.04230697	3.589588
2000	0.2322803	2.050334	0.04387747	3.034485
2011	-0.1236259	2.387342	-0.03802152	4.353332
2017	-0.1455051	2.715773	-0.03619386	4.490116

growth seems to be the River Ravi in the north western part (a natural barrier) and in the eastern part there is Indian border. Figure 8 shows the area in square kilometres covered by different land cover classes in Lahore district on temporal basis.

The area of Lahore district that is under WASA jurisdiction is converting into concrete rapidly (Figure 9, 10). The share of built-up area in WASA jurisdiction was around 50% in 1990 where as it is touching 80% in 2017. If this trend continues and the population in the downtown of Lahore city also increases at this rate then the city may face more challenges pertaining to increased temperature and water shortage.

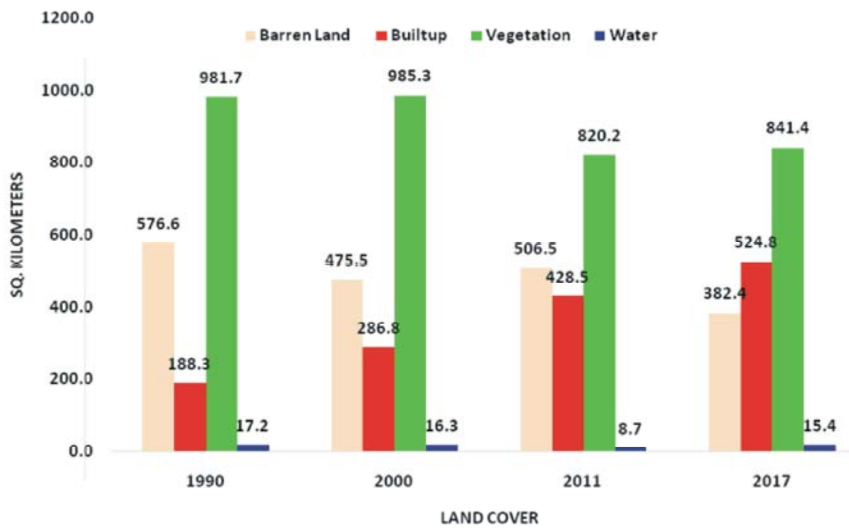

Fig. 8: Bar graph showing area in square kilometres of different land cover classes in Lahore district

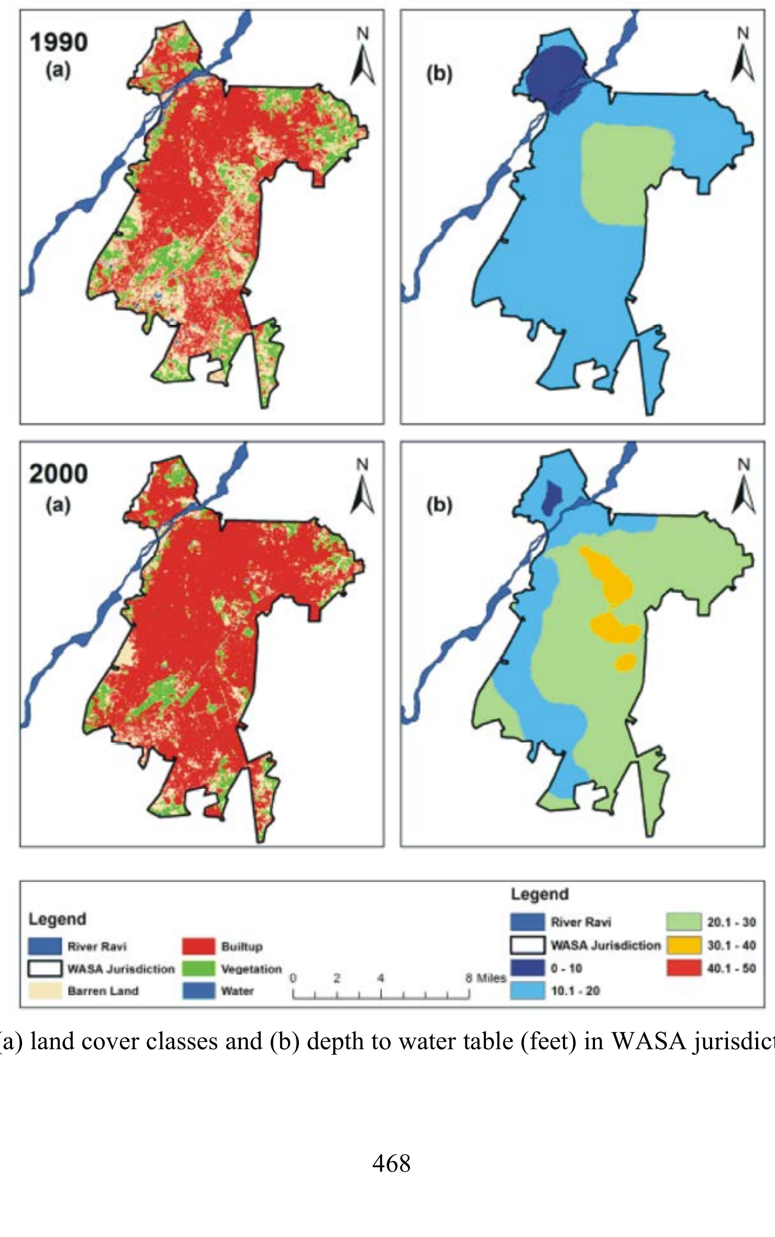

Fig. 9: Map showing (a) land cover classes and (b) depth to water table (feet) in WASA jurisdiction for years 1990 and 2000

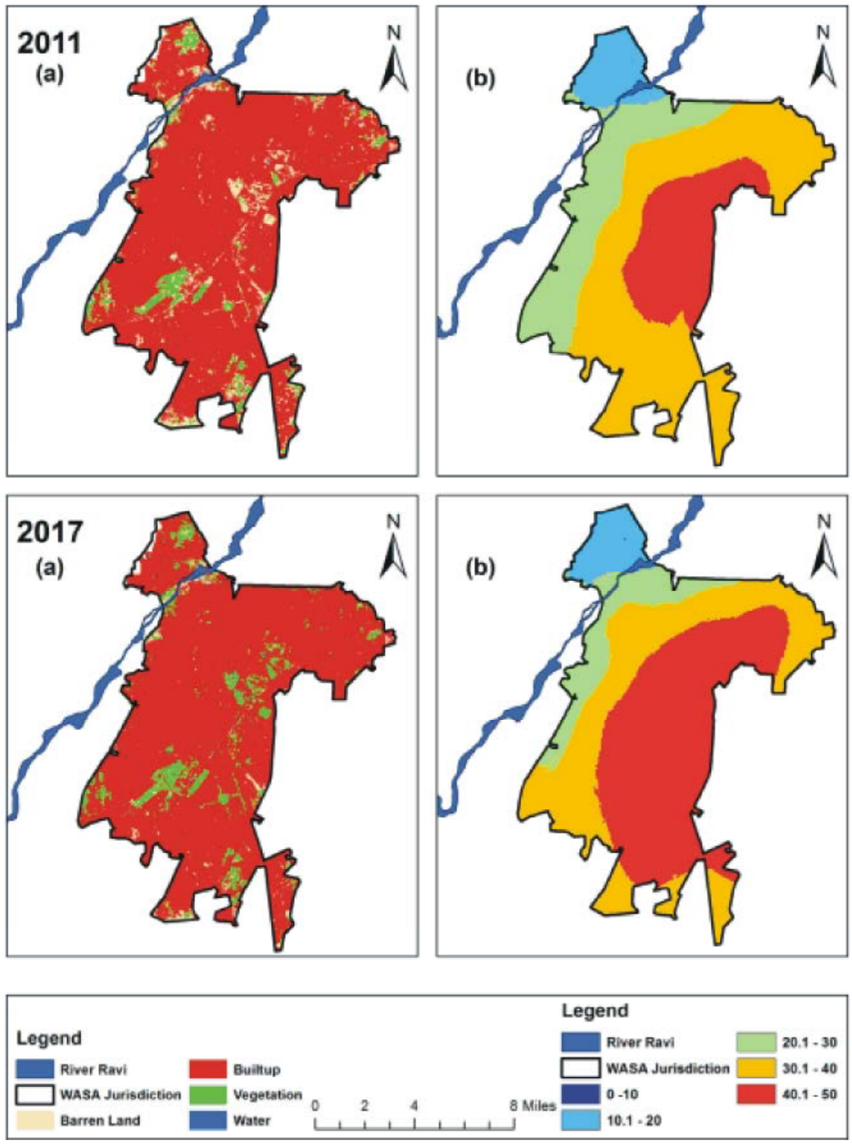

Fig. 10: Map showing (a) land cover classes and (b) depth to water table (feet) in WASA jurisdiction for years 2011 and 2017

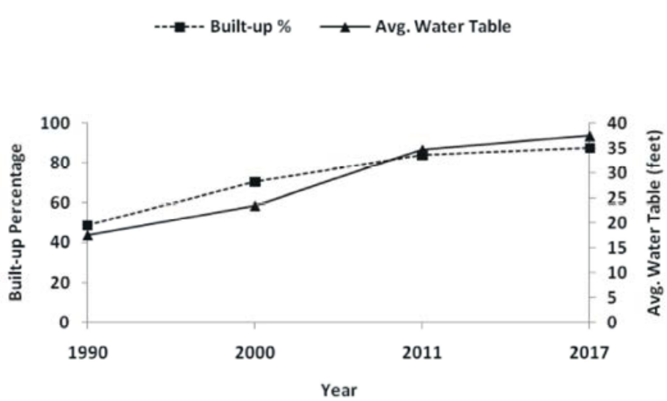

Fig. 11: Graph showing relationship between built-up area and average depth of water table (feet)

The results of geostatistical analysis (Table 3) show the prediction errors generated by kriging method. The mean standardized error and mean prediction error closer to 0 and the smaller root mean square error for all the four years validates the water table contours. The water table values for all the tubewells for a particular year were averaged to get a single value that was further used to find out the correlation between built-up area% and depth to water table in the WASA jurisdiction. The results showed a positive correlation ($p > 0.05$) between built-up area% and averaged depth to water table (Figure 11). This is alarming for Lahore city as the groundwater level is consistently depleting.

CONCLUSION

Accelerated urban sprawl is a menace to the sustainable development. Remote sensing technologies are very useful in the time series analysis of urban sprawl. The increasing rate of urbanization in Lahore city is severely affecting the water table of Lahore. There is a dire need to control this uncontrolled and unorganized urban expansion so as to save the population of Lahore from shortage of adequate water supply in future.

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