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RESEARCH ARTICLE

Urban Sprawl Development Around Aligarh City: A Study Aided by Satellite Remote Sensing and GIS

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Abstract Rapid urbanization causes disorganized and unplanned growth of towns and cities. The pressure of an ever growing population becomes a burden on the limited civic amenities which are virtually collapsing. Asymmetrical growth of urban centres consumes agricultural land adjacent to these, resulting in lower agricultural productivity. Besides taxing the groundwater resources available for an urban centre, an increase in the paved area severely reduces the groundwater recharge potential, leading to situations which may truly be potential catastrophes. An understanding of the growth dynamics of urban agglomerations is essential for ecologically feasible developmental planning. With almost a third of India's population already having become urban, it is necessary to acquire information on growth patterns of cities and how they impact the living environment. The current trend of spatial urban growth in almost all Indian cities has a haphazard pattern, particularly along the urban-rural fringe. There is an obvious need for continuously monitoring the phenomena of growth, and mapping and analyzing its patterns, since this is of great concern to urban administrators and planners whose concern it is to provide basic amenities and infrastructure for the complex urban environment.

Mapping urban growth by conventional methods is too tedious and a slow process, and by the time information becomes available to planners, it is already outdated and redundant since the damage has already been done. Satellite remote sensing data and application of GIS technologies provide an al-ter-native means of rapidly assessing the dynamics and development of sprawl so that timely action may be taken. Besides being flexible and extensible, the

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datasets are easily rectified, updated and may be used for other applications.

The present study was carried out using Landsat, IRS and QuickBird data to delineate the extent, pace and pattern of growth of the city area of Aligarh. The study reveals that the urban area has increased almost three times since 1971. The rate of land consumption for urban purposes was substantially moderate till 1980s, but in the 1990s witnessed a sharp increase in land consumption as compared to population growth. The city still does not have a sewage treatment plant, and of the estimated 40 mld (million litres per day) of sewage produced by a population of 7,89,529, only 27 mld is pumped out or diverted for irrigation purposes, while the rest pollutes the urban environment or contaminates the ground water resources. Land consumption for urban purposes in the last fifteen years is estimated to be 1.428 km^2 per year. Besides, substantial land acquired by city dwellers for intended urban purposes along the urban-rural fringe has been rendered saline.

Introduction

The present structure of most Indian cities developed through growth of ancient urban cores encroaching into the rural fringe areas. With one third of the country's population already living in urban areas, it becomes imperative to have current information on urban growth patterns and its impact on the living environment. It is evident that the current trend of urban growth is haphazard along the urban-rural fringe areas in most Indian cities. In order to be able to provide basic amenities and infrastructure for the complex and dynamic urban environment there is an obvious need for planners and administrators to monitor the chaotic growth pattern and changing land use along the urban-rural fringe, as well as within the densely populated urban core. The outward spread of cities is accompanied by many environmental problems: changes in the land use patterns, fragmentation and destruction of wildlife habitat, discharge of polluted runoff water into streams and surface water bodies, and pollution of ground water resources.

The pattern and pace of land development in which the rate of land consumed for urban purposes exceeds the rate of population growth, and which results in an inefficient and consumptive use of land and its associated resources, is termed sprawl. Urban sprawl results in more paved surfaces and less area for water to drain into soils. An increase in the urban area with no corresponding increase in the capacity of the drainage/sewage systems brings more water into the systems at a faster rate, resulting in flooding of low lying areas. Increase in urban sprawl results in increases in land consumption, often agricultural, for housing construction.

By monitoring an area for changes in the urban sprawl over time, the progress of residential development can be monitored, and the impact this is likely to have on the land system can be assessed. Agencies entrusted with land use decision making can incorporate the data from maps into urban planning models, and thus have a more informed approach.

Depending upon their forms and patterns, sprawls have been categorized into three classes (Barnes *et al*., 2001):

a) *Low-density sprawl* This type of sprawl is one in which there is consumptive use of land for housing purposes along the margins of existing urban areas. This type of sprawl is supported by piecemeal extensions of basic urban infrastructures such as water, sewer, power, and roads.
b) *Ribbon sprawl* Development that follows major transportation corridors outward from urban centres is termed ribbon sprawl. Lands adjacent to major roads and highways are developed, while those distant from these retain a rural land use/land cover.
c) *Leapfrog sprawl* A discontinuous pattern of urbanization is termed leapfrog sprawl. This consists of patches of developed lands that are widely separated from each other and from the outer margins of well established urban centres. This form of development is the most

expensive in so far as providing civic services such as water and sewerage are concerned.

Recent advance in satellite-based land surface mapping provides a better opportunity for the creation of more accurate and detailed maps of our cities. These maps can provide urban planners with a better understanding of city growth, dynamics of the urban-rural interface, monitoring of stress on the existing civic amenities and urban infrastructure, and how rainfall runoff over paved surfaces impacts local groundwater balance and quality. They may also help in taking remedial measures and future developmental planning.

This paper is an effort to assess the growth of Aligarh city in the last 35 years. The study involves relating changes in land use/land cover to changes in population, using land use data from existing maps, satellite and census data.

Study area

The present study has been carried out in and around Aligarh city, located about 132 km southeast of Delhi in western Uttar Pradesh (Fig. 1a). The city was originally established as a fort in the 12th century and was taken by the British in 1803. The remains of the ancient fort still stand 3 km north of the town. Aligarh is an important railway junction of north India, connecting with most of the important destinations in the region.

The district is located in the plains between the Ganga and Yamuna Rivers. It is nearly a level plain, but with a slight elevation in the centre. The only other important river is the Kali Nadi which traverses the entire length of the district from north-west to south-east. The district, which has an area of about 3696 km^2, is traversed by the Upper Ganga Canal, which is navigable.

The study area is situated in Tahsil Koil of Aligarh District. The town is the administrative headquarters of the district, and an important agricultural trade center. The municipal limits of Aligarh, as notified in 1955, included an area measuring 31.57 km^2. This was extended in 1995 by an addition of 3.94 km^2 in the north, southeast and southwest (Fig. 1b). The city has a sizeable lock and hardware industry and a number of processing plants for agricultural goods. The population of Aligarh in 1901 is given as 70,127. It has since increased steadily to 6,69,087 in 2001, is estimated to be 7,89,529 in 2006 and is expected to be 9,12,000 by 2011.

Data and methodology

The data required for the present study comprised topographic maps, village maps, satellite image and demographic details. For mapping the extent of the urban area as it stood at the 1971 level, Survey of India Topographic map 54I/1 (Surveyed 1971, published 1975) was used. Apart from the extent of the urban area, this has details of drainage, water bodies and irrigation systems; rail and road network; built up area; and administrative boundaries. Landsat data made available under NASA sponsored Global Land Cover Facility (GLFC) and acquired from the Multi Resolution Seamless Image Database (MRSID) maintained by NASA at *https://zulu.ssc.nasa.gov/mrsid* were used to map the extent of sprawl for 1989 and 1999. For 1989, Landsat 5 TM data (Product ID: N-44-25: Path 146 Row 41, acquired 18.10.1989) was used whereas for 1999 Landsat ETM+ data (Product ID: N-44-25_2000: Path 146 Row 41, acquired 22.10.1999) was used. The available FCCs are a combination of bands 742 (band 7: 2.08–3.35 µm; band 4: 0.76–0.90 µm; band 2: 0.52–0.60 µm). Sample image data of QuickBird for the study area acquired February 05, 2006 available at *http://archivetool2.digitalglobe.com* was used to map the extent of sprawl as it stands today. For mapping wasteland, IRS 1B LISS II data (Path 28: Row 48, acquired 19.02.1999) was used. Demographic details for 1971 and 1981 were taken from Primary Census Abstracts (1971, 1981). For 1991 the population data was taken from the Uttar Pradesh District Census Handbook (1991), and for 2001 the population data was taken from the Final Population Totals of the Census of India (2001).

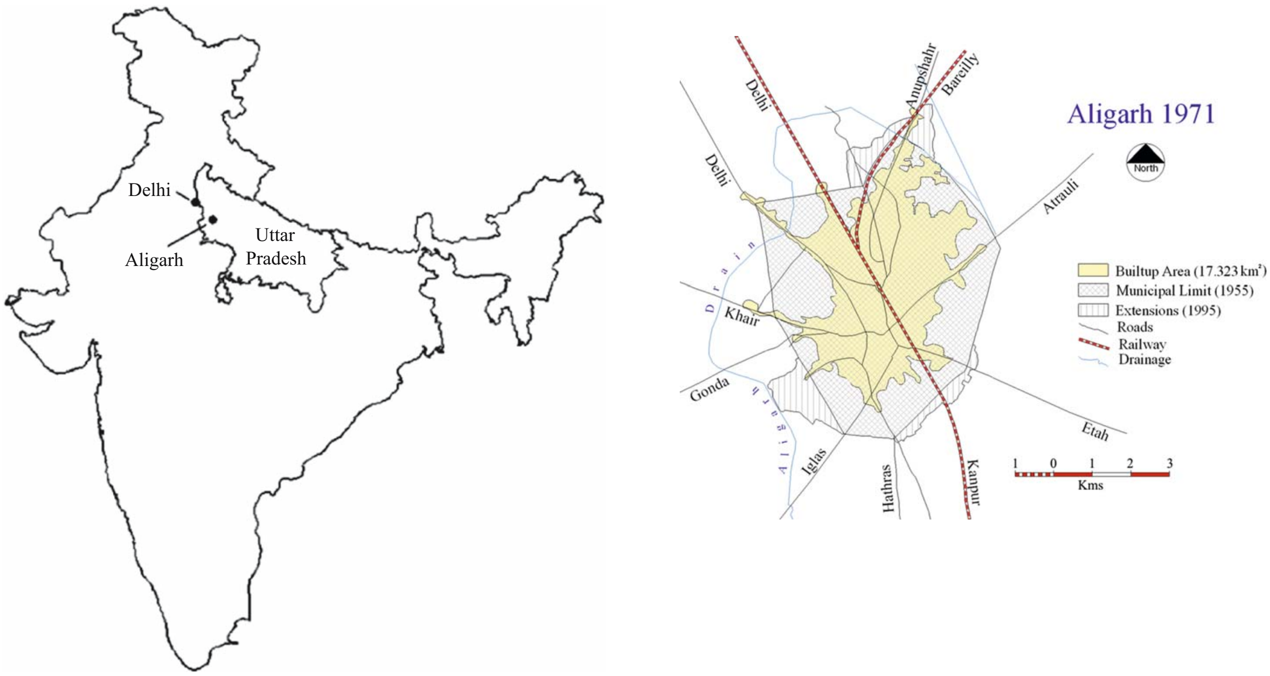

Fig. 1 **(a)** Location map of the study area **(b)** Map showing municipal limits and urban area of Aligarh city in 1971

The topographic map of Aligarh on 1:50,000 scale was georeferenced using MapMaker Pro©. The extent of the urban area of Aligarh as it stood in 1971 was vectorized from the Survey of India topographic map. Cultural features viz., roads, rail and drainage were also vectorized. Various classifications of the Landsat and IRS data for 1999, in conjunction with numerous field checks in the core and fringe areas, provided the basis for identification and delineation of urbanized areas.

For delineation of urban sprawl, Landsat data for 1989 and 1999 and QuickBird data of 2006 were enhanced in different ways using Geomatica V 9.1.0. The IRS data for 1999 was used for principal component analysis using image bands 4, 3 and 2 for the purpose of enhancing wasteland. All images were georferenced using coordinates of well established GCPs from the Survey of India toposheets on scales of 1:250,000 and 1:50,000.

The purpose of classification was aimed at identification of the urban structure and its evolution rather than mapping of typical land use/land cover classes. The approach was only to map the settlement patterns under densely built-up and sparsely built-up areas. Visual interpretation techniques of satellite data were used to interpret and delineate the land use classes. Due consideration was given to delineate the broader levels of land use zones within the old city areas.

For classification of land cover, ground data collection was considered an essential exercise, whereby relationships between different ground features and their corresponding spectral signatures were established. A 12-channel hand-held GPS receiver (Garmin GPS-12) was used for determining the location of different land cover classes in the field and relating these with pixel clusters in image to identify their spectral characteristics. In addition to relating spectral signatures with land use type, ground data collected through field surveys provided the basis for determination of accuracy of manual classification and identification of empirical relationships between surface properties and satellite observations. Hence, the collection of an unbiased data set for ground information was imperative for successful image classification and interpretation.

Results

In the present study, the extent of the urban area has been charted from 1971 onwards. The urban area of Aligarh consists of the old, thickly populated core constituting the ancient city which was in existence before the Master Plan for Aligarh was put in place in 1981. This is almost completely covered and there appears to be no patch available for any kind of development. The core area is subject to a mixed and complex land use and it is not possible to assign any one category of land use to this part.

The enhanced images and FCCs prepared from these were interpreted using standard image interpretation techniques based on shape, size, color, association etc. for delineating the urban extent. In the Landsat TM data for 1989, as also in the ETM+ data for 1999, both of which are a combination of bands 742, the built up area shows as clear purple and mottled brownish purple patches. In the FCC derived from the 1999 IRS data, the saline patches are associated with white to bluish grey color. The true color QuickBird image of February 2006 shows the urban area as mottled, light to dark brown patches.

The extent of identified urban areas was vectorized using MapMaker Pro©. Field checks at suitable spot locations were made as detailed above, for overall improvement in mapping accuracy. The extent of urban area for the years 1971, 1989, 1999 and 2006 are shown in Figs. 1b, 2a, 2b and 3a respectively. It may be mentioned that all satellite data are orthorectified, except the Quickbird data for February 2006. This data was acquired with an off nadir angle of 17^{o}, implying thereby that the built up area as measured from this image is somewhat less than what would be measured if the imagery were to be orthorectified.

It is apparent from Fig. 1b that up to 1971 the urban area of Aligarh was entirely confined within the municipal limits. By 1989, as evident from Fig. 2a, the development of Aligarh city was in the form of a low density sprawl whereby growth took place along the margin of the core area necessitating piecemeal extensions of basic urban infrastructures such as water, sewer, power and roads. In the 1990s the pattern of growth changed from a low density to a high density ribbon sprawl as is evident from the extensions of the city along the major transportation corridors (Fig. 2b), connecting Aligarh with Delhi, Mathura, Agra, Kanpur and Moradabad. The map for 2006 (Fig. 3a) suggests that not only have the ribbon sprawls, particularly along the Etah and Atrauli Highways, increased in length and width, but there has been substantial low density sprawl development along the eastern fringe of the city.

Salt affected land

A considerable amount of land, apparently acquired by the city dwellers along the urban-rural fringe with the intention of commercial/residential/recreational purposes, has gone out of agricultural use for long years. Left vacant without any 'development' (for whatever it is worth), such land has developed a high salinity as would be expected of any land that has not been tilled and irrigated for years. This is evident from Fig. 3b, which represents a supervised classification of the 1999 IRS imagery.

The saline patches were identified in the imagery in conjunction with ground verifications in about two dozen locations. As seen in the figure the saline patches are clustered along the urban-rural fringe. In an area of 280 km^2 centered around the urban core, such saline patches cover 20.36 km^2 in about 260 clusters. The largest of these are located on the eastern and south eastern side of the municipal area, and therefore, bear a spatial relationship with the most recent growth of the city area. These saline patches also lie closer to the Upper Ganga Canal flowing in a NW-SE direction in the northeast of Aligarh City (not shown in maps), the seepage from which

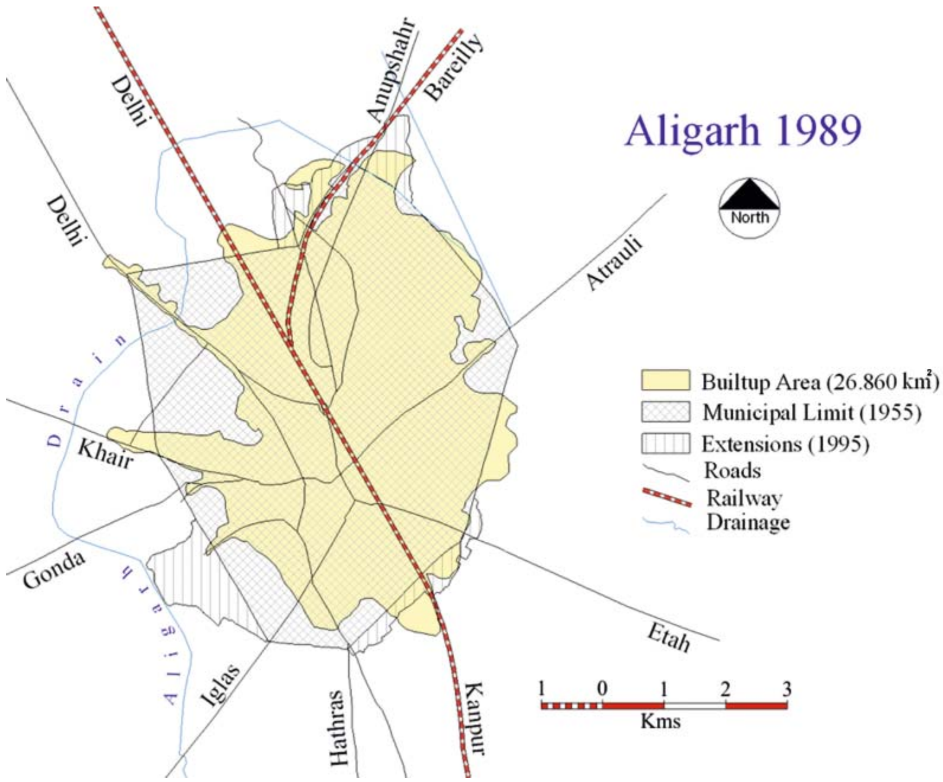

Fig. 2a Map showing municipal limits and urban area of Aligarh city in 1989

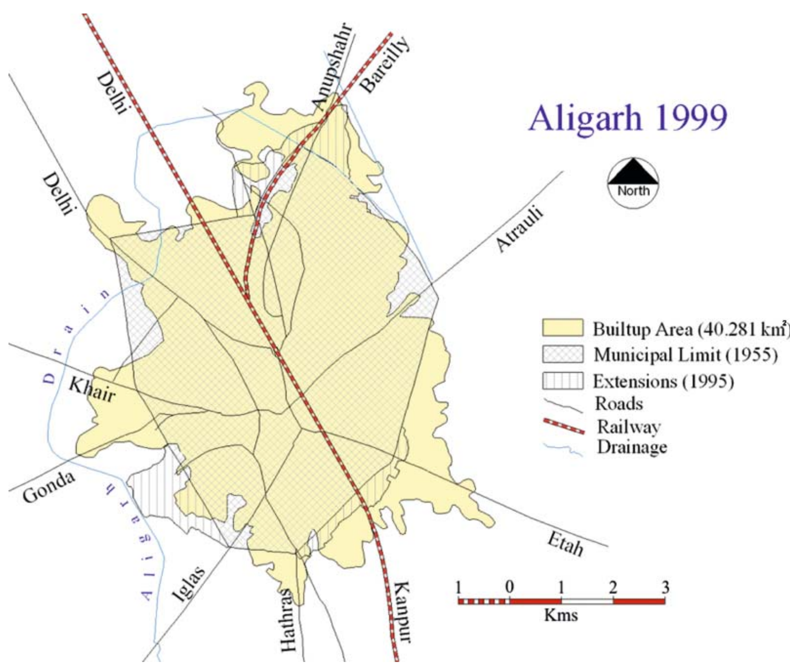

Fig. 2b Map showing municipal limits and urban area of Aligarh in 1999

appears to have contributed considerably to soil salinity. Steps may be initiated for reclamation and productive use of this wasteland, such as forestation, citing of industrial areas, infrastructure development and other developmental activities.

Sprawl metrics

Informed public policy to address sprawl development involves relating changes in land use/land cover to changes in population using satellite, census and other data. It also requires measurements that characterize the spatial patterns of development. Measuring sprawl provides an overview of where growth is occurring and where it is likely to develop in future, thus aiding the identification and assessment of threats that confront the environment and natural resources.

Appraisal of the maps of city limits juxtaposed with the municipal boundary and population data for the years 1971, 1989, 1999 and 2006 brings out the following facts:

1. The urban area of Aligarh in 1971 measured 17.323 km^2 and comprised mainly the ancient core lying almost entirely within the then municipal limits. This is borne out by an appraisal of the SOI topographic map of 1920–1921. The only additions over the 1921 limit are the small ribbon sprawls evident along the Delhi, Khair, Atrauli and Anupshahr roads. These are less than 2 km in length and constitute a total area of about 1km^2. Population density in 1971 was 14,500 persons per square kilometer.
2. By 1989, the urban area had increased by about 9.54 km^2. The growth was mainly on the northern, eastern and southeastern side. This represents an average growth rate of 0.53 km^2 per year. About 3.17 km^2 of the urban area extended beyond the municipal limits. Population density increased to about 16,500 persons per square kilometer.
3. The 10-year period between 1989 and 1999 witnessed a further expansion of the urban area by 13.42 km^2, mainly along the Delhi, Khair, Gonda and Etah roads, and the northern fringe. This represents a growth rate of 1.34 km^2 per year. The annual average population growth rate for the 1990s was 3.37% per annum. Population density by 1999 dropped to about 15,500 persons per square kilometer. This marks a sharp increase in land consumption for urban purposes.
4. Measurements made in the QuickBird imagery of February 05, 2006 reveal an increase in the urban extent by 10.26 km^2. The seven year period between 1999 and 2006 witnessed an increase of 1.47 km^2 per year. There has been a rapid development of ribbon sprawl along the Delhi, Etah and Atrauli highways, all of which are major transportation corridors linking Aligarh with Delhi, Kanpur and Bareilly (also Moradabad and Rampur) respectively. Table 1 shows the pattern of population growth and extension of the urban area from 1971 to 2006.
5. The population of Aligarh city for 2006 has been estimated on the basis of 1991 and 2001 census data, which works out to an annual average growth rate of 3.36 %. The estimated population for 2006 works out to 7,89,529.
6. It is noteworthy that whereas the national decadal growth rate of population for 1991–2001 is 21.43 % (Census of India, n.d.), the growth rate for Aligarh city during the same period is 39.24 % – almost twice the national growth rate. This is marginally less than that of the national capital, which stands at 46.31%.

Table 2 shows the development of sprawl in relation to the municipal limits. It is evident that in 1971, almost the entire urban area was confined to the municipal limit, more than half of which was undeveloped (Fig. 1b). In 2006, almost one third of the urban area (35.10 %) lies outside the municipal limits. There is still 2.67 km^2 (7.52 %) area within the municipal limits that is undeveloped.

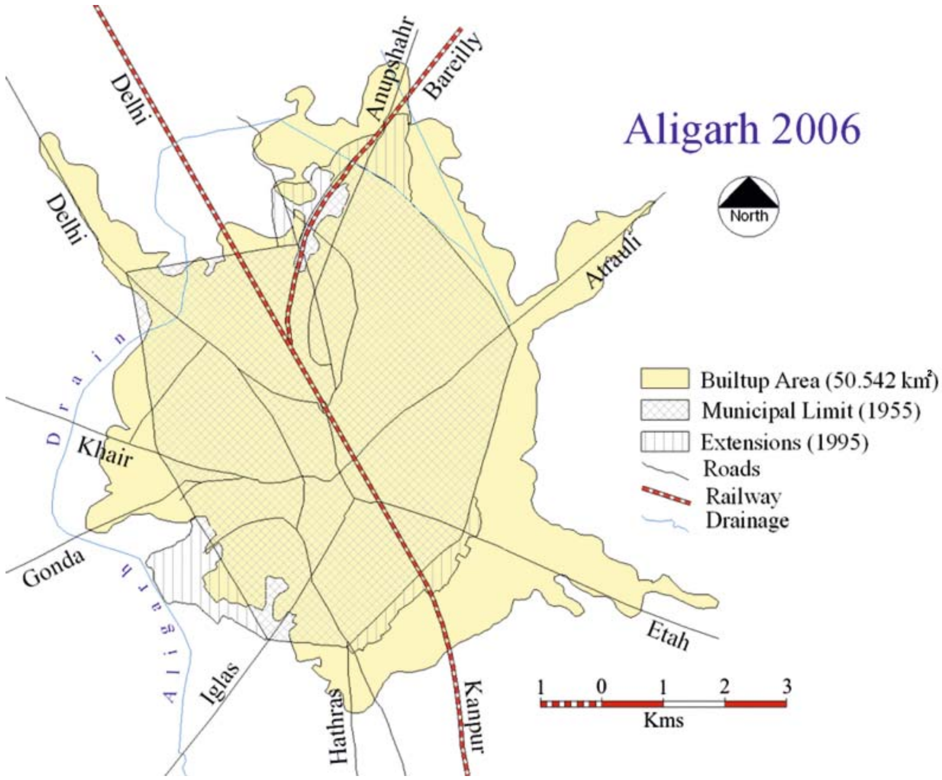

Fig. 3a Map showing municipal limits and urban area of Aligarh in 2006

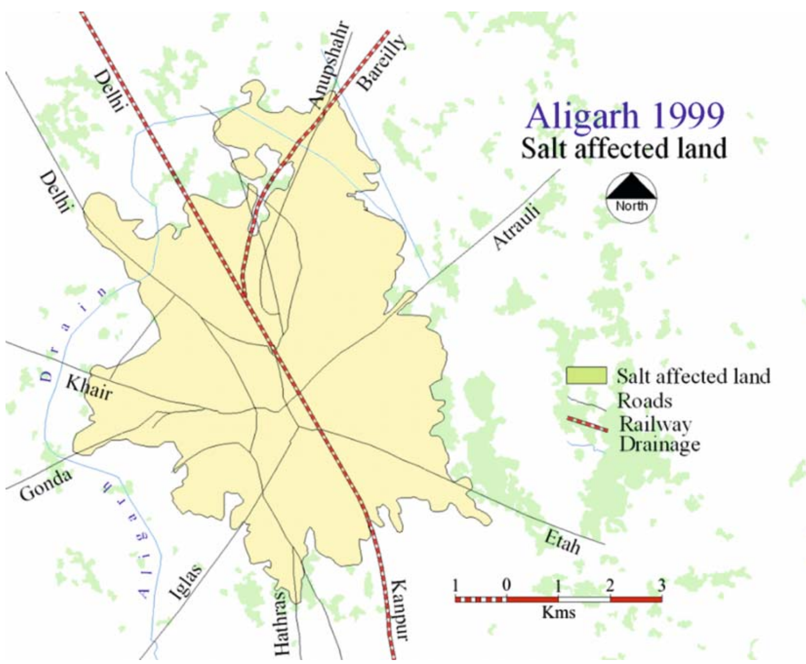

Fig. 3b Map showing the extent of urban area of Aligarh city and land affected by salt efflorescence in 1999

Sprawl development

In so far as land consumption for urban use is concerned, things seemed to be going well for the city till about the end of the decade of the 1980s. As can be seen from Table 1, the urban area of Aligarh city in 1971 stood at 17.323 sq km and the population was 2,52,314. The rate of growth during 1971–1981 in the built up area was 29.57 % while the population increased by 27.15 % (Table 3). During 1981–1991, the urban area expanded by 31.78 % while the population increased by 49.78 %. The most remarkable tendency towards sprawl development was witnessed in the 1990s decadal period when the city area grew by 47.55 % while the population increased by 39.24%. The 15-year period from 1991 to 2006 saw an increase of 73.52 % in the urban area as against a 64.31 % increase in population.

As can be appreciated from the foregoing, the rate of development of land in Aligarh is currently in excess of the population growth. This implies that land is being consumed at excessive and perhaps unnecessary amounts. This consumption obviously includes all development initiatives for commercial, industrial, residential, educational, and recreational establishments.

Hydrology, water requirement and availability

Aligarh city is located over the Quarternary sediments laid down by the Ganga and Yamuna rivers and their various tributaries. The bedrock comprises the Red Shales of the Bhander Group of Upper Vindhyans and can be located at a depth of 340 m (Pathak, 1978). Aligarh falls within the south-western semi-arid zone of Uttar Pradesh. The soils are alluvial in nature consisting of various grades of sand, silt and clay, variously affected by salts. Zones of kankar, a calcium carbonate of sedimentary origin, are associated with the fine grained strata. The average annual rainfall over Aligarh is 750 mm and the temperatures ranges between 4°C and 47°C. The average relative humidity ranges from 32 to 82%. The ground water of Aligarh district is brackish. Strata charts and hy-

Table 1 Sprawl metrics and population of Aligarh city

Year	Population	Urban area		
		Total (km^2)	Increase from previous decade	Percentage increase
1971	2,52,314	17.323	–	–
1981	3,20,816	22.103	4.780	27.59
1989	4,43,221	26.860	5.809	29.57
1991	4,80,520	29.128	7.025	31.78
1999	6,26,222	40.281	13.421	49.96
2006	7,89,529	50.542	14.872	41.69

Table 2 Relationship of urban area and municipal limits of Aligarh city (area in km^2)

Year	Municipal area	Urban area	Area outside municipal limits	Municipal area with no development
1971	31.57	17.32	0.43	15.43
1989	31.57	26.86	3.17	7.90
1999	35.51	40.28	9.05	4.51
2006	35.51	50.54	17.74	2.67

Table 3 Increase in urban area and population of Aligarh city

Period	Population		Urban area	
	Net increase	Percentage increase	Net increase (sq km)	Percentage increase
1971–1981	68,502	27.15	4.78	27.59
1981–1991	1,59,704	49.78	7.02	31.78
1991–2006	3,09,009	64.31	21.41	73.52

drological records maintained at the district office of the Uttar Pradesh Jal Nigam reveal the occurrence of alternate layers of clay and sand down to the depth of 140 m bgl (below ground level). The clay horizons, mixed with kankar, which invariably underlie the granular zone, are discontinuous, lenticular in form, and pinch out laterally. The alluvial deposits therefore form a highly transmissive interconnected aquifer system.

Dutt (1969), while investigating the groundwater conditions of the entire Aligarh district, reported the depth to water table ranging from 1.2 to 9.6 m bgl. The water table was reported to be shallowest in the vicinity of the Upper Ganga Canal passing 12.5 km northeast of the city area. The general groundwater flow direction in the city area is, however, from north to south with few local variations. Records maintained by the Uttar Pradesh Jal Nigam reveal that the water table beneath the municipal area which stood at 9.10 m in 1976 has receded steadily to 18.7 m in 2006.

The Uttar Pradesh Jal Nigam, which is entrusted with supplying water to the city population, has installed 58 tube wells which together yield 76.65 MLD. Apart from these, 2175 deep hand pumps, which yield less than 2.0 MLD, have been installed to supplement the supply. As against this supply, the current requirement of the town is 120 MLD. The projected requirement for the year 2030 is 204 MLD.

Sewage system

The sewage system of Aligarh municipality is far from adequate. Although the total length of sewer lines in the city is 40 km, only about 1/5 of the total area, catering to the needs of about 2,00,000 out of a population of 7,89,529 is covered by the sewage system. Whereas the total installed capacity of the system is 22.50 MLD, the total quantity of sewage produced by the city dwellers is 40.00 MLD. Recycling sewage water for agricultural purposes accounts for just 5.00 MLD while the remainder is discharged into the Kali Nadi untreated.

Discussion

The total urban population of India, an estimated 285 million, is more than the total population of several countries. It is also a little over 10 per cent of the total urban population of the world. There are 5161 urban centres in the country, a thousand more than in 1981 (Sivaramakrishna *et al*., 2005). The urban population of Aligarh city alone has soared from 2,52,314 in 1971 to more than 7,89,529 in 2006 – a more than three-fold increase over a three and a half decadal time span. This has been accompanied by an unprecedented wave of development. Every year, during the last fifteen years, an area of 1.428 km^2 is paved over or otherwise converted to urban human uses. Notwithstanding the poor pollution control facilities, every person added to the population consumes additional resources and creates additional waste.

Investigating the interrelationships between sprawl development and available civic amenities/infrastructure reveals the plight of administrators in maintaining and developing these. In the case of Aligarh, increase in tax revenues has obviously not been commensurate with urbanization as is evident from the fact that as of now, 17.74 km^2 (almost one third) of the urban area lies outside the demarcated municipal, and therefore taxable boundaries. This implies that whereas the existing public services and infrastructure such as roads, water supply, sewage, schools and hospitals are under severe stress, the demand for extension of these has increased manifold. It also means that the municipal authorities are not able to cope with this situation because of low revenue collection. All this has resulted in decline in the quality of life, especially for the growing urban underclass. In the context of sprawl development, one of the primary issues is the loss of prime agricultural land due to urbanization. On average, an estimated 95 ha of agricultural land has been converted to urban use per year in the last 35 years. It is alarming to note that the rate of land consumption for urban purposes in the last 7 years has been as high as 171 ha per year.

Implications for the quality of city life

As per figures published by the Aligarh Development Authority, the city population which stood at 6,69,087 in 2001, is expected to increase to 9,12,388 by 2011 and to 11,61,673 by 2021 (Aligarh Development Authority, n.d.). According to the Master Plan for Aligarh approved by the Government of Uttar Pradesh in 1980, it was proposed to develop an area of 4980 hectares (49.80 km^2) for a projected population of about 6,00,000 by the year 2001. This included 2200 ha of residential area. However, by 2001 only 3209 ha of land was said to be developed, which constituted only 64.44 per cent of planned development. Apart from this, an area of 619.85 ha is reported to have been developed outside of the proposed city area demarcated for development. According to the report of the Aligarh Development Authority, this makes for a total of 3828.85 ha developed by the year 2001.

Conclusion

Most land use activity in urban areas spells irreversible changes. There is a need to balance present requirements of land against future needs. Preserving agricultural land in the fringe areas of expanding cities is vital for preserving and maintaining open spaces and therefore, environmental quality. To regulate and control the development of sprawl, land use control and regulation through legislation may be warranted. To adopt an informed and scientific approach towards management of urban sprawl, the following suggestions merit attention:

i. Identifying areas along the urban-rural fringe where development is feasible.
ii. Restrictions on conversion of agricultural land lying outside identified zones.
iii. Developing a land information system featuring high resolution digital topographical and attribute datasets for use in planning and urban environment management.
iv. Generation of databases for cadastral applications.
v. Training municipal staff to adopt and use information from these systems for their day to day work.
vi. Promoting the use of these databases and information systems in urban planning and management.

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