METROPOLITAN GROWTH MONITORING AND LANDUSE CLASSIFICATION USING GEOSPATIAL TECHNIQUES

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ABSTRACT:

The present research relates to the exploitation of Remote Sensing and GIS techniques for studying the metropolitan expansion and landuse/ landcover classification of Lahore, the second largest city of Pakistan where urbanization is taking place at a striking rate with inadequate development of the requisite infrastructure. Such sprawl gives rise to the congestion, pollution and commuting time issues. The metropolitan expansion, based on growth direction and distance from the city centre, was observed for a period of about thirty years. The classification of the complex spatial assemblage of urban environment and its expanding precincts was done using the temporally spaced satellite images geo-referenced to a common coordinate system and census data. Spatial categorization of urban landscape involving densely populated residential areas, sparsely inhibited regions, bare soil patches, water bodies, vegetation, Parks, and mixed features was done with the help of satellite images. Resultantly, remote sensing and GIS techniques were found very efficient and effective for studying the metropolitan growth patterns along with the classification of urban features in to prominent categories. In addition, census data augments the usefulness of spatial techniques for carrying out such studies.

1. INTRODUCTION

Located at 31^034'north latitude and 74^022"east longitude, the geographic expanse of Lahore district has witnessed random growth in population from 0.67million to 6.3188million during 1941 to 1998 (FBS-1998). This alarming growth rate has heaved the population density from 379 to 3,566 persons per square kilometre giving rise to congestion, commuting problems, improper provision of civic amenities to the citizens, and environmental pollution etc. Eighty two percent of the total population of Lahore district is urban and the rest is rural. Out of the total urban population, 88% are provided with clean water supply and 80% have the drainage facility. On the other hand, only about 20% of the rural population enjoys afore-said basic facilities (FBS-2002). Urbanization can be viewed as a characteristic of the population, as a characteristic of particular kinds of land uses and land covers, as well as a characteristic of social and economic processes and interactions affecting both population and land (McIntyre *et al.* 2000). In particular, urban places are routinely defined as concentrations of people who are engaged in non-agricultural activities (Weeks, 2002). Definitions based on size, density, and economic activity all imply a dichotomy between urban and rural, and that notion is almost certainly accurate from an historical perspective.

The management of fast growing population in Lahore is beset with a complex set of problems borne out of the inter-netting of both service and administrative infrastructures. Information sharing and management in such environment is of critical importance to city planners and also to the public at large. Unlike developed countries where computerized databases provide interactive map information to the general public on transportation routing, location of service centres, tourist sites and emergency response centres, no such context-sensitive information has yet in practice. Development could only be availed until the information is rightly and precisely available.

Until a few years ago, provision of context-sensitive geographic information was difficult to imagine without computer automation. Now, not only the digital manipulation techniques have improved but the fundamental need for high degree of geographic details has also been satisfied. As such, it has become possible to link the nature (service and administrative facets) of information to its respective geographic location. The geographic information systems (GIS) are the preferred tools to administer such a linkage for developing a Metropolitan Information System (MIS). GIS provides a way in which the statistical results can be represented spatially on the map and spatial patterns can be recognized. The quality of geographic information is of real interest and importance for all the people concerned with its use and exploitation. In the absence of conventional maps showing details on infrastructure, high-resolution satellite images can be used to effectively monitor and implement changes in land use through detailed street level mapping. The integration of remote sensing and geographic information systems (GIS) has been widely applied and been recognized as a powerful and effective tool in detecting urban land use and land cover change (Ehlers *et al.* 1990, Treitz *et al.* 1992, Harris and Ventura 1995). The Satellite Image interpretation and understanding always involve object recognition and scene analysis tasks. All municipalities have internal data flows between departments that may or may not be explicitly documented. These data flows often require a re-evaluation when department responsibilities or new technologies are introduced into the organization.

The foregoing strengthened the anticipated need for technological assails in managing the civic infrastructure within the metropolitan environment. For the geographical expanse of Lahore, it is imperative to not only improve the current capability to monitor and channelise existing resource-base but also to facilitate planned interventions. For all this to happen,

the approach to information handling takes cognizance of the geographical proximity of civic amenities and infrastructure with respect to residential, commercial, industrial and administrative zoning. In present effort, census data has also been attributed to the respective point locations of villages and union councils to make various analyses of social significance. Based on the aggregate census data, scholars have used population density functions, either mono-centric or polycentric models, to analyze urban population distribution (Baumont et al., 2004).

The growing trend towards decentralization of national development planning activities to regional, local government bodies means that decision-making must be taken closer to the grassroots level. Planners therefore, need to use more advanced than the present techniques for spatial analysis. The availability of spatial datasets those might be routine applications of GIS in developed countries often become pioneering ventures when used in developing countries.

2. OBJECTIVES

- Digital image classification of multi-spectral imagery for prominent surface features, particularly with reference to population growth, within the precincts of Lahore district.
- Development of thematic layers of administrative divides comprising both rural and urban settlements (villages & union councils) and linkage of population census data with the respective geographic features.
- Monitoring and analyses of the population sprawl and study of subsequent environmental implications.
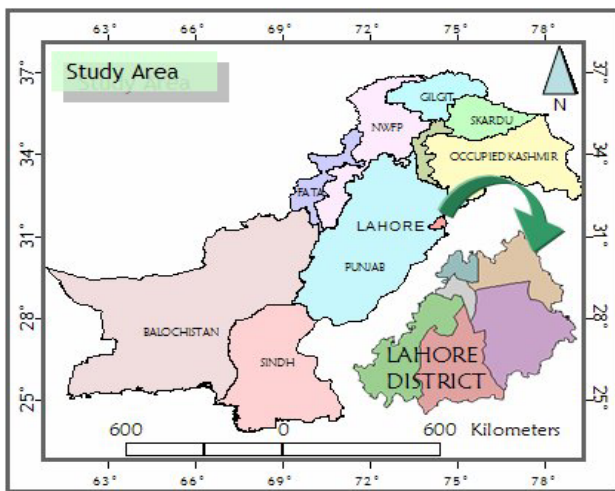

Figure 1. Location of Study Area, Lahore District, Pakistan.

3. STUDY AREA

Lahore is the Capital of Punjab province and is the second largest city of Pakistan with a history of more than 10 centuries old. It is located at the left bank of river Ravi, one of the five rivers of the Punjab province. Situated within the geographic extents of (74^0east to $74^0$39'23"east) longitude and ($31^0$13'18"north to $31^0$43'north) latitude, the expanse of Lahore district encompasses an area of 1772sqkm. With a population of over 6million people, Lahore is famous for its rich culture,

historical sites and gardens. An interesting saying about Lahore is "haven't seen Lahore, haven't been born".

4. METHODOLOGY

To achieve the first objective of the study, image datasets of the Landsat system in MSS, TM and ETM modes were acquired for March 23, 1973, October 25, 1992 and September 30, 2001 respectively. The images were first geo-referenced on a common coordinate system (UTM43 Projection & WGS84 datum) and then each image was truncated on the precinct of Lahore district. Training areas for supervised classification were defined with the help of field-acquired data. Image classification is a process whereby all pixels in the image are categorized into a landcover class or theme (Lillesand & Kiefer, 2000). The surface features classified from the image datasets comprised Thick Population (TP), Sparse Population (SP), Mixed Residential (MR), Vegetation (VG), Recreation Parks (RP), Water Bodies (WB), Turbid Water (TW), Sand (SD), and Bare Soil (BS). Monitoring of extension in residential areas with population growth in past 30 years was the main focus of image classification. The logic behind image classification in to more number of categories was to distinctively segregate the focused classes more accurately. Abundant information has been published demonstrating the ability to extract population information either directly from remotely-sensed data, or indirectly by analyzing information derived from the imagery (Elvidge et al., 1997; Mesev, 1998; Rashed et al., 2001). Elvidge et al. (1997) and Doll et al. (2000) have exploited satellite images to see the relation between population, gross domestic product and electric power consumption in 21 countries.

The resulting classified image datasets show a very prominent expansion in populated regimes. The expansion of population can be seen in the directions of south-east, south and south-west.

North and north-east sides are blocked by the river Ravi, while precinct of Lahore district in east is bounded by the Pak-India border. The later features impose limitation on spreading out of population in those directions due to natural barriers.
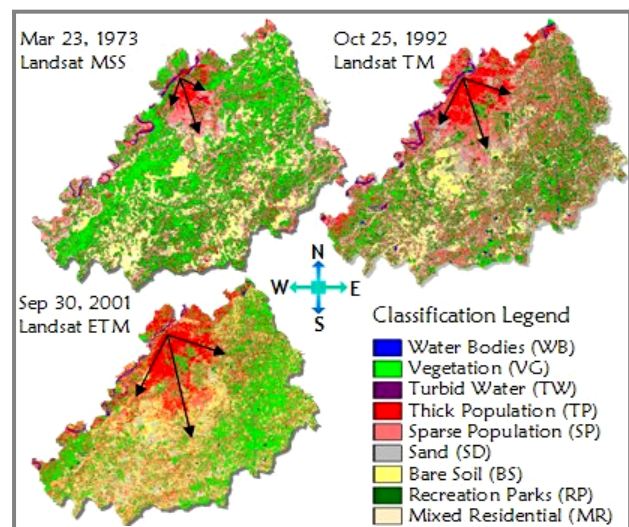

Figure 2. Supervised image Classification showing Extent and Direction of Population Growth in the Study Area.

Supervised image classification accuracy assessment was carried out for each of three datasets. Confusion matrices were developed to highlight the classification accuracy. Confusion Matrix for each image is given below showing the relation between reference data and the classified product.

Landsat MSS – March 23, 1973 (Classification Accuracy: 86%)

	WB	VG	TW	TP	SP	SD	MR	RP	BS
WB	87	0	0	1	0	0	0	0	0
VG	0	90	0	0	0	0	0	23	0
TW	0	0	100	0	0	0	0	0	0
TP	13	0	0	99	1	0	0	0	0
SP	0	0	0	0	80	10	0	23	0
SD	0	0	0	0	19	90	3	0	0
MR	0	0	0	0	0	0	94	0	1
RP	0	10	0	0	0	0	0	54	0
BS	0	0	0	0	0	0	3	0	99

Landsat TM – October 25, 1992 (Classification Accuracy: 75%)

	TW	SD	WB	VG	TP	SP	MR	RP	BS
TW	84	0	76	0	5	2	0	0	0
SD	0	94	0	0	0	0	4	0	0
WB	2	0	73	1	17	5	0	0	0
VG	0	0	0	74	0	2	0	21	0
TP	0	0	20	0	70	8	0	0	0
SP	8	0	18	2	17	75	1	21	0
MR	0	4	0	0	0	0	82	0	14
RP	6	0	7	16	0	8	0	65	0
BS	0	1	0	0	0	0	1	0	98

Landsat ETM – September 30, 2001(Classification Accuracy: 74%)

	WB	VG	TW	TP	SP	SD	MR	RP	BS
WB	82	5	5	0	4	0	0	2	0
VG	17	44	7	0	2	0	0	27	0
TW	10	0	85	0	0	0	0	3	0
TP	0	0	0	86	5	0	8	0	0
SP	12	14	0	5	66	0	0	0	0
SD	0	0	0	0	0	56	11	0	32
MR	0	0	0	8	11	2	78	0	0
RP	1	5	7	0	0	0	0	85	0
BS	0	0	0	0	0	0	0	0	99

Table 1. Confusion Matrices indicating the Accuracies of Classification (percentage) for each Classified Image.

The afore-mentioned classification accuracies were achieved after refining the reference data (Training areas) 8-11 times. The higher levels of accuracies were achieved in case of Landsat MSS Image Dataset because that image contained more spectrally separable features than those were in the image datasets of the later dates. Difference in Spectral, spatial and radiometric resolutions of each datasets could also be one of the reasons for varying classification success rates. Diminishing vegetation can be observed in the direction of population expansion, the agricultural land is successively being converted into commercial/ residential areas for potential construction of houses, apartments and plazas. Moreover, as obvious from the classified image datasets, areas of sparse population convert into those of thick population over a period of 5-10 years. Hence transformation occurs from spacious to congested city environs and from rural agriculture land to urban residential/ commercial land within the district.

Since images used in the current study did not belong to the same date for varying years, DN values of the thermal image (band-6) of year 2001 and 1992 were re-computed to their equivalent radiant temperature values (Celsius) using the following formula, originally developed by (Malaret et al. 1985), with a little modification:

$$T(^0C) = (209.831+0.834DN - 0.00133 \, DN^2) - 273 \qquad (1)$$

The histogram of the brightness values that was formerly covering the range 161DN to 215DN resulted in 36^0C to 56^0C radiant temperature range for the thermal image of year-2001 and 133DN to 172DN came out to be in the range 24^0C to 40^0C for the thermal image of year 1992. The meteorological temperatures ranges on image acquisition dates were 24 to 36 and 18 to 32 (PMD). The difference between image-derived and meteorological temperatures for each date was found to be less deviating. The higher values of the radiant temperatures computed from the thermal image may correspond to heat island in the congested city areas where concrete construction, asphalt roads and heavy traffic cause the temperature to rise more than the surrounding areas.

To accomplish the second objective, settlements (villages) and urban administrative units (Union Councils) falling within the precincts of Lahore District were digitized as point locations using reference data from paper layouts developed by Water and Sanitation Agency and City District Government. Later on alpha-numeric data of the most recent population census were appended as attributes to each demarcated entity or village location (DCR-1998). There are 262 villages in the rural part of Lahore district, while there exist a total of 150 Union Councils, out of which 25 are rural and the remaining fall in the metropolis boundary of Lahore city. The following figure shows the afore-said locations in Lahore district.
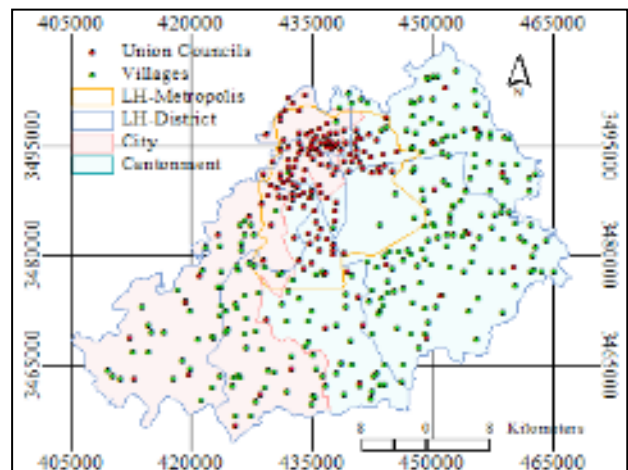

Figure 3. Geospatial Layers of Thematic Information.

The contents of census data comprised, census code, denomination of administrative divides (Tehsil, Qanoongo Halqa, Patwar Circle, Village or Mauza), population (by number and gender), literacy ratio, number of houses, household size, percentage of male and female matriculates, married women and area in acres. On the other hand, available textual data was attributed to the respective union council locations that was challenging because of the difficulty to integrate aggregate census data with disaggregate land-use data.

Since Lahore is undergoing drastic growth and suburbanization, population distribution is an important factor to consider for better planning and management of the urban infrastructure and

provision of essential civic utilities. This could only be made possible in the presence of demographic data at finer details. 82.4 percent population of Lahore district is living in the city metropolis area that constitutes 20.31 percent (360sqkm) of the total district area (1772sqkm). The population density in the urban precincts amounts to 14,450 persons/ sqkm, which is quite a huge value. The complexity of commuting problems can be well-imagined keeping in view the humongous population density. Similar is the case with environmental contamination, noise pollution and traffic control. The congested area can be observed in Figure 3, where overlays of the geospatial layers of thematic information are very elaborately depicting the agglomeration of population near the city center, where the original walled city still exists. The same feature of the existence of crammed population and its expansion is apparent on the classified satellite image datasets in Figure 2. The remote sensing has stimulated the interests of researchers to use ancillary data such as land use data extracted from satellite imagery to interpolate original areal population counts to surface cells (Eicher and Brewer, 2001; Langford et al., 1991). The combination of satellite imagery in multi-spectral mode, GIS layers and census data can be effectively exploited for studying the urban features in detail. Various analyses among a range of census data elements were made to study various census elements with reference to one another.

Literacy Ratio (%)	No. of Villages (Total: 262)	Total Population	% of Matriculates (Male)	% of Matriculates (Female)
41 & less	188	618100	3	0.8
42-44	16	74659	5	2
45-49	28	180786	6	2
50-54	11	85701	7	4
55-59	06	25451	6	3
60-64	07	115451	12	7
65-69	01	784	13	8
70 & above	05	12869	19	14

Table 2. Demographic Values Computed from the Census Data with Reference to Literacy Ratio.

The distribution of villages with reference to the Literacy Ratio (%) can be observed in the following.
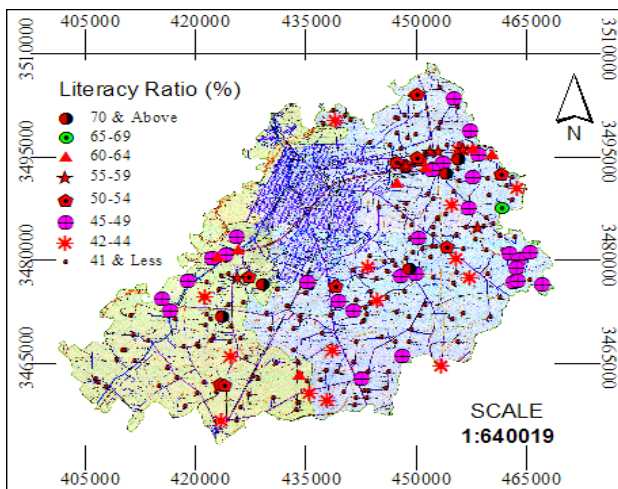

Figure 4. Map of the Spatial Distribution of Villages with

Reference to the Literacy Ratio (%) and other Aspects.

Another analysis was made by again considering the literacy ratio as a reference for studying the percentage of slum houses and that of married women corresponding to the percentage of rural population. Table 3 shows the derived census elements relate to the literacy ratio.

Literacy Ratio Range (%)	Rural Population (%)	Slum Houses (%)	Married Women (%) (15-49)
3.4-19.9	2	19	69.7
20.3-29.8	12	16	69.2
30.1-41.4	41	11.5	68.7
42-50	23	6.7	67.2
51-59.8	19	4.1	66
60.5-90.9	2	9	66.4

Table 3. Relationship of Literacy Ratio with Rural Population, Slum Houses and the Percentage of the Married Women.

The graphical representation of the Table 3 is given below to analyse the relationship among the tabulated values with reference to the brackets of respective literacy ratios.
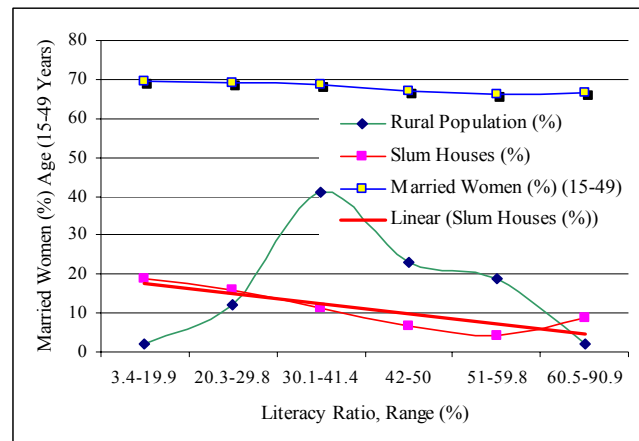

Figure 5. Graph Showing Relationship among Literacy Ratio, Slum Houses and Percentage of Married Women.

5. RESULTS AND DISCUSSION

Digital classification of the temporally separated image datasets reveals the results that support the stimulus behind conceiving the studies like the current one. The imagery datasets selected for the present research were of three different sensors acquired on three different dates with a periodic gap of nearly ten years and spanning an interval of about 30-years. The dynamics of population expansion and its effects on the land cover features is obvious on the classified image datasets. Urbanization, the conversion of other types of land to uses associated with growth of populations and economy, is a main type of land use and land cover change in human history (Q. Weng, 2004).

The graphical representation of the supervised image classification results, Figure 6, indicates the inter-transformation of land cover categories.
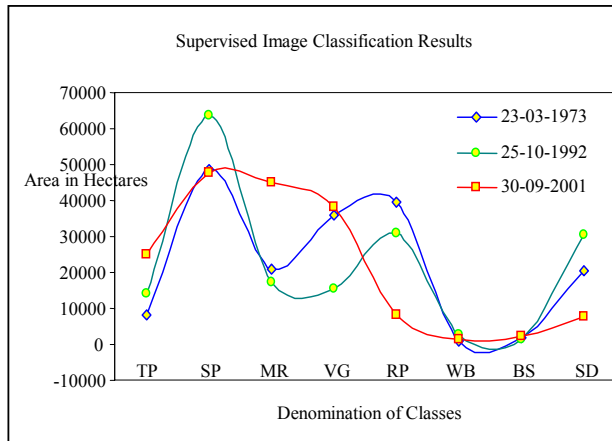

Figure 6. Curves Indicating the Results of Supervised Classification using Three Different Image Datasets.

As regards the Thick Population (TP), the increase for the subsequent years is quite conspicuous. As concerns the Sparse Population (SP), area coverage is more in 1992 image than that of 2001, the reason being the residential land acquisition away from the congested city in southward direction but with construction at a low rate. Non-residential land use has significant impact on urban population distribution (Ingram, 1998), and an analysis of land use and population density can improve the understanding of urban spatial structure. Mennis (2003) used a spatial framework to develop population surface model for southeast Pennsylvania with special reference to relative difference of population distribution among census blocks and among different urbanization-based land-uses. As we go further in the graph, the preceding argument takes the strength and area under Mixed Residential (MR) Class shows a remarkable increase. The combined effect of Vegetation (VG) and Recreation Parks (RP) reveals the net decrease in the green areas due to the expanding city in to the rural regions. Area covered by Water Bodies (WB) does not show much difference graphically, but variation in the location of this feature can be found on each of three images. Bare Soil (BS) can also be justified with more or less the same argument. As the population has grown substantially near the banks of River Ravi, the area classified as Sand (SD) has remarkably decreased as we observe it from 1973 to 2001. This way a dynamic picture of the population expansion can be well conceived over a period of about 30 years.
Linkage of alpha-numeric census data with the geographic locations of Urban and Rural administrative divides of the Lahore district resulted in a context-sensitive geospatial information. The exercise made it possible to carry out various demographic-cum-spatial analyses based on geospatial information. The District Census Report (DCR-2000) reveals that the total life time in-migrants in Lahore District were 16.4 per cent of the total population. This happened to be one of the major factors of population expansion within the district. The Lahore City is growing with only limited town planning and management, resulting in inadequate infrastructure and facilities. This is particularly so for transportation and food marketing facilities (MCL, 1999).

The results of various analyses carried out using the combination of census and thematic data indicated that the villages hav-

ing higher percentage of literacy ratio were either having very easy access to the major roads or were located along those roads. Moreover, such villages can be found in the suburban areas as the distance from the city increases the literacy ratio decreases. This phenomenon relates directly to the essential facilities and degree of awareness that are the characteristics of an urban environment.

The percentage of 41.4 is the average literacy in the rural part of the Lahore district (Census-1998). The decreasing percentage of married women with increasing literacy ratio is an indication of awareness, certainly being an outcome of education, that people discourage under-aged marriages. The higher literacy ratio may therefore, be an indicator of population control. Same way the percentage of slum houses reveal the decreasing trend with increasing literacy ratio that again shows a healthy trend of living in properly constructed safe houses. The findings can be observed in Figure 5.

The urban centres in Pakistan are characterized by haphazard growth, congestion, pollution and unplanned expansion, including settlements along major national highways adjacent to metropolitan areas. This has put increasing burden on an already inadequate infrastructure and contributed to environmental problems including traffic congestion and pollution problems associated with inadequate provision of water supply, sanitation, drainage, solid waste management, and urban flood protection. The situation has been further compounded by the inadequate technical and financial capacities of the local governments and other involved agencies, and the lack of an integrated urban development approach without integrated urban planning and zoning resulting in disintegrated development of services like electricity, natural-gas, and telephone. (Planning Commission, 2005-2010).

GIS and other information technologies can be seen 'as "things" that materialize for people as diverse social practices and that may vary as much as the contexts in which they are used' (Valentine & Holloway, 2001). GIS improves our ability to produce maps at disparate scales, including detail-rich fine-scale maps. Such maps would be very lingering (or impossible) to produce and evaluate manually. Remotely sensed image data, on the other hand, is not only used to update existing maps but it also facilitates in categorization of land cover features with reliable accuracies.

6. CONCLUSIONS

The present research focused on using geospatial techniques for combining multi-concept image datasets, geospatial themes and population census data to study various surface features in the environs of Lahore district, the dynamics of urban expansion with reference to population growth, and analyse different population aspects with reference to the spatial distribution of urban and rural administrative units within the district. Landsat image datasets have been found appropriate and effective for classification of land use/ land cover features. The resultant classes demonstrated logical synergy among various land cover categories. The potential direction of population expansion in the district can be predicted by carefully examining the existing growth patterns in the historical and current classified satellite image datasets. Further to this, attributing population census data to respective features, digitized as thematic layers of geospatial information, developed into useful information for carrying out various demographic analyses corresponding to spatial

distribution of urban and rural localities. It is recommended that such studies may be repeated after a regular agreed-upon time-intervals, so that not only the activity of keeping the statistical/ census data updated continues but also the maps, both cadastre and physical, could be improved for new features using satellite images at high spatial detail.

REFERENCES

Baumont C, Ertur C, and Le Gallo J, 2004, "Spatial Analysis of Employment and Population Density: The Case of the Agglomeration Of Dijon 1999" *Geographical Analysis* 36(2) 146-176.

Census 1998, *District Census Report, Lahore (DCR-2000)*, Population Census Organization, Statistics Division, Govt. of Pakistan.

Doll, C. N. H., Muller, J. P., & Elvidge, C. D., 2000, Night-Time Imagery as a Tool For Global Mapping Of Socioeconomic Parameters And Greenhouse Gas Emissions. *AMBIO*, 29, 157-162.

Ehlers, M., Jadkowski, M. A., Howard, R. R., and Brostuen, D. E., 1990, Application of SPOT Data for Regional Growth Analysis and Local Planning. *Photogrammetric Engineering and Remote Sensing*, 56, 175–180.

Eicher C L, and Brewer C A, 2001, "Dasymetric Mapping and Areal Interpolation: Implementation and Evaluation" *Cartography and Geographic Information Science* 28(2) 125-138.

Elvigde, C. D., et. al. (1997): Mapping City Light With Night-time Data From the DMSP Operational Linescan System, *Photogrammetric Engineering & Remote Sensing*, 63, 727-734.

Federal Bureau of Statistics (FBS), Government of Pakistan.

Harris, P. M., and Ventura, S. J., 1995, The Integration of Geographic Data with Remotely Sensed Imagery to Improve Classification in an Urban Area. *Photogrammetric Engineering and Remote Sensing*, 61, 993–998.

Ingram G K, 1998, "Patterns of Metropolitan Development: What have we learned?" *Urban Studies* 35(7) 1019-1035.

John R. Weeks, 2002. *New Forms of Urbanization: Beyond the Urban-Rural Dichotomy*. Aldershot, UK: Ashgate Publishing Co., 2003, pp. 324-343.

Langford M, Maguire D J, and Unwin D J, 1991, *Estimating Population using RS in a GIS framework", in Handling Geographical Information*. Edition-I, (Wiley: London) pp. 55-77.

Lillesand, T. M. and R. W. Kiefer. 2000. *Remote Sensing and Image Interpretation*. 4th ed. John Wiley and Sons, New York, NY, pp. 724.

Lo, C. P., Quattrochi, D. A., and Luvall, J. C., 1997, Application of High-Res. TIR RS and GIS to Assess the Urban Heat Island Effect. *International Journal of Remote Sensing*, 18, 287–304.

Malaret, E., Bartolucci, L.A., Lozano, D.F., Anuta, P.E., McGillem, C.D., 1985. Landsat-4 and Landsat-5 Thematic Mapper Data Quality Analysis. *Photogrammetric Engineering and Remote Sensing* 51, 1407–1416

McIntyre, N.E., K. Knowles-Yanez, and D. Hope, 2000, "Urban Ecology as an Interdisciplinary Field: Differences in the Use of 'Urban' Between the Social and Natural Sciences," *Urban Ecosystems*, 4: 5-24.

Mennis J, 2003, "Generating Surface Models of Population Using Dasymetric Mapping" *The Professional Geographer* 55(1) 31-42.

Mesev, V. 1998. The Use Of Census Data In Urban Image Classification, *Photogrammetric Engineering and Remote Sensing*, 64, 5, pp. 431 – 438.

Metropolitan Corporation Lahore (MCL), Report-1999.

Pakistan Meteorological Department, Islamabad, Pakistan.

Planning Commission of Pakistan, Report (2005-2010).

Rashed, T., Weeks, J., Gadalla, M. and Hill, A., 2001. Revealing the Anatomy of Cities through Spectral Mixture Analysis of Multispectral Satellite Imagery: A Case Study Greater Cairo, Egypt. *Geocarto International*, 16(4): 5-16.

Ryzner, R. M., 1998. *Urban Vegetation and Social Change: An Analysis Using Remote Sensing and Census Data*. Ph.D. Dissertation, University of Michigan, 124 pp.

Treitz, P.M.,Howard, P. J.,and Gong, P., 1992, Application of Satellite and GIS technologies for Land-cover and Land-use Mapping at the Rural-Urban Fringe: A Case Study. *Photogrammetric Engineering and Remote Sensing*, 58, 439–448.

Valentine, Gill & Holloway, Sarah. 2001. On-line Dangers? Geographies of Parents' Fear for Children's Safety in Cyberspace, *Professional Geographer*, 53, pp. 71–83.

Weng Q., D. Lu, and J. Schubring, 2004. Estimation of Land Surface Temperature–Vegetation Abundance Relationship for Urban Heat Island Studies, *Remote Sensing of Environment* 89: 467–483.