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Remote Sensing and GIS Applications for Assessment of Urban Sprawl in Karachi, Pakistan

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Abstract: Over the past 30 years, Land development and consumption have been out of control and expanding out of order, especially to marginal areas of some metropolises in Pakistan. In this research, the dynamic change of urban sprawl and its spatial and temporal characteristics was analyzed for Karachi division, Pakistan. To achieve the goal different image processing techniques were applied i.e., (i) Supervised, (ii) Unsupervised image classification and (iii) Normalized Difference Built-Up Index on Landsat imageries for the years 1991, 2000 and 2013. Unsupervised classification technique was proved to be more effective with an overall agreement of 81%. The study concluded that from 1991-2000, the urbanization in Karachi was increased from 486-729.2 km^2, whereas from 2000-2013 the urbanization was almost double i.e., 1582.5 km^2. Apart from the derived results, this study also proved the potentials of remote sensing data and effectiveness of demonstrated/proposed techniques in urban geographic studies.

Key words: Remote sensing, GIS, image processing, urban sprawl mega city Pakistan, change detection

INTRODUCTION

Urban sprawl is outward spreading of a city and its suburbs to exurbs, to low-density and often auto-dependent development on rural land (Gillham and MacLean, 2002). The rapid urbanization is usually caused by the increase in population in an area. The extent of urbanization or its growth drives the change in land use/cover pattern. Land use and landcover changes may have adverse impacts on ecology of the area, especially the greenness (Herold *et al*., 2003; Liu and Lathrop Jr., 2002; Grimm *et al*., 2000). Precise information on the extent of urban growth is of great interest for the municipalities of growing urban and suburban areas for diverse purposes such as urban planning, water and land resource management, marketing analysis, service allocation, etc. Development authorities are required to give more time, attention and effort to manage the use of land and other resources to accommodate the expanding population.

But unfortunately, the conventional surveying and mapping techniques are expensive and time consuming for the estimation of urban sprawl and such information is not available for most of the urban centers, especially in developing countries. As a result, increased research interest is being directed to the mapping and monitoring of urban sprawl/growth using GIS and remote sensing techniques (Goetz, 2013).

Remote sensing is cost effective and technologically sound, so is increasingly used for the analysis of urban sprawl (Carlson, 2003; Bhatta *et al*., 2010; Radhakrishnan *et al*., 2014; Mahboob *et al*., 2015). For nearly three decades, extensive research efforts have been made for urban change detection using remotely sensed images (e.g., Yang *et al*., 2001; Zhao *et al*., 2013; Ji *et al*., 2006; Yang and Lo, 2002; Ward *et al*., 2000; Lv *et al*., 2012; Hallum, 1993; Luo *et al*., 2008; Yuan *et al*., 2005; Weng, 2001; Chowdhury *et al*., 2009). These studies have been supported through either an image-to-image comparison or a post-classification comparison.

Statistical techniques along with remote sensing and GIS have been used in many urban sprawl studies (Malinverni, 2011; Lo and Choi, 2004; Weng, 2012; Cheng and Masser, 2003; Lu *et al*., 2008, Taubenbock *et al*., 2012; Sun *et al*., 2013). Urban growth studies have been attempted in several developed countries (Hu *et al*., 2003; Radhakrishnan *et al*., 2014; Sudhira *et al*., 2004; Triantakonstantis and Stathakis, 2015). These are some examples and similar applications also exist for other countries like China (Yu and Ng, 2007; Weng, 2001; Xiao *et al*., 2006) and India (Rahman *et al*., 2011; Taubenbock *et al*., 2009). The convergence of GIS and database management systems has helped in quantifying, monitoring, modelling and

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subsequently predicting the urban sprawl phenomenon. Characterizing urban sprawl pattern involves detection and quantification with appropriate scales and statistical summarization. Appropriate scale of urban sprawl characterization is the suitable spatial unit used in such analysis.

The study was conducted to analyze the dynamics of urban sprawl by using the remote sensing and GIS techniques. Largest division of Pakistan was selected, where urbanization would be hazard if not properly managed. Temporal window of 20 years ranging from 1991-2013 was considered to examine the spatial variation in urban sprawl of Karachi division and to establish the relationship between urban development and some its causative factors, like population, population density, density of built-up. Maximum Likelihood Classifier (MLC) approach was used for landsat image classification to inspect the spatial variability of urban sprawl as well as other land covers like water, vegetation, barren land.

MATERIALS AND METHODS

Study area: The study area for this research is Karachi division which is an administrative division of the Sindh Province of Pakistan as shown in Fig. 1. The Karachi division was abolished in 2000 and five districts of Karachi were merged in City District Karachi. The City District Karachi was divided in 18 Towns and 178 union councils. On 11 July, 2011 Sindh Government restored again 5 districts of Karachi division.

Total Area of Karachi is 3,527 km² and it is located at 24.8600°N, 67.0100°E.

Data used: The data was collected from primary data source include Survey Of Pakistan (SOP) topo-sheets of Karachi (scale, 1:50,000) and multi-spectral Landsat MSS, TM, ETM+sensors. The data collected from secondary sources include the administrative boundary map. The details are given in Table 1.

Methodology: Understanding the dynamic phenomenon, such as urban sprawl/growth, requires land use change analyses, urban sprawl pattern identification. The ERDAS (Leica) and ArcGIS software (ESRI) was used to generate various thematic layers, like, Karachi administrative boundary map, roads, railways network and administrative boundary map using the topo-sheets and other available maps. Complete methodology has been given in Fig. 2.

The standard image processing techniques, such as image extraction, rectification, restoration and classification was used for the analysis of three satellite images (1991, 2000 and 2002). The ERDAS imagine software was used for image analysis. First of

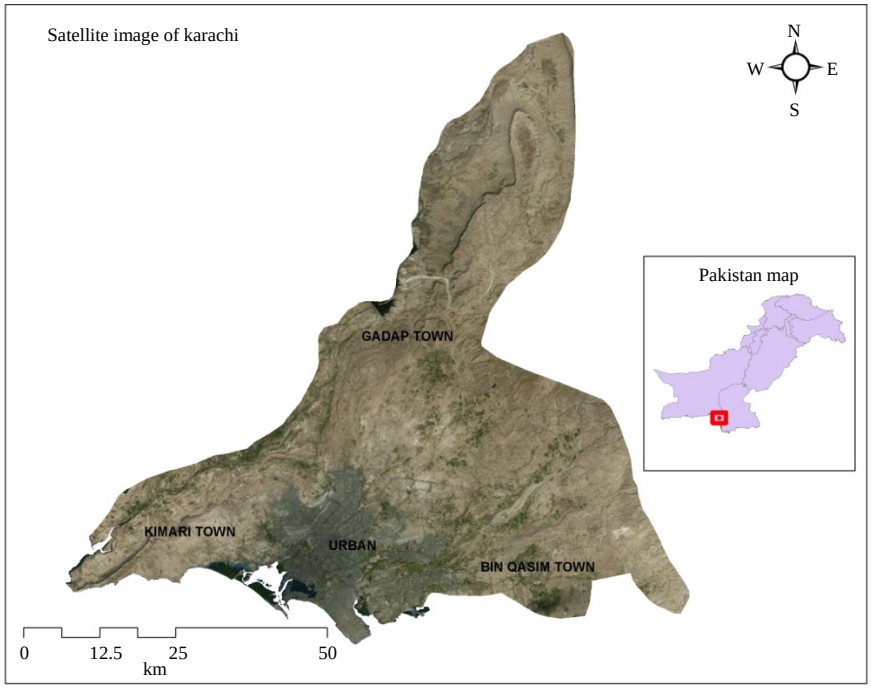

Fig. 1: Location map of study area: the Karachi division

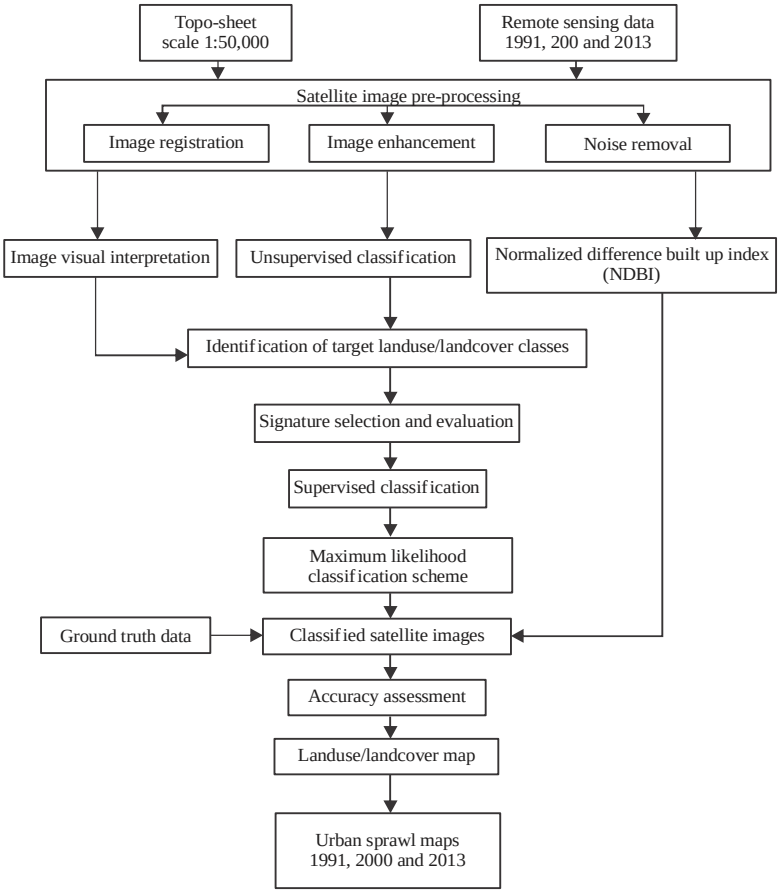

Fig. 2: Flowchart of methodology

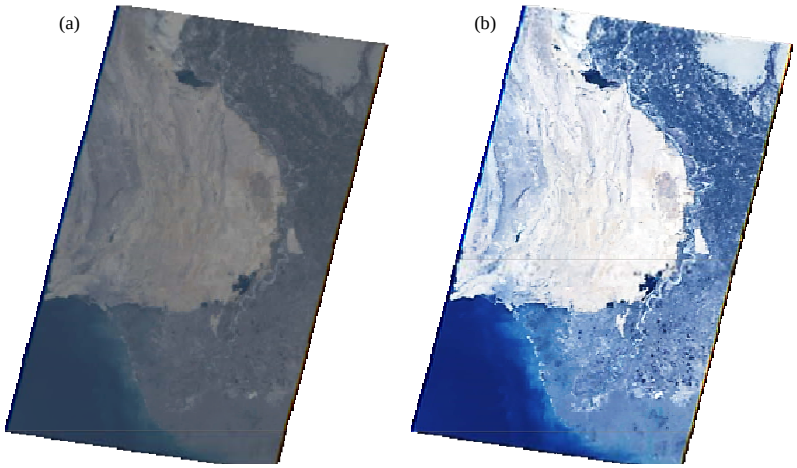

Fig. 3(a-b): Effect of image enhancement and correction, (a) Before and (b) After satellite image

all, atmospheric correction was applied using improved dark object subtraction method to bring all the images at common reference spectral characteristics. Water bodies available in the areas were used as the dark object. Further, these subtracted images were stretched to 8 bit digital number range. As an example, the Fig. 3 shows the before 3(a) and after 3(b) satellite image correction.

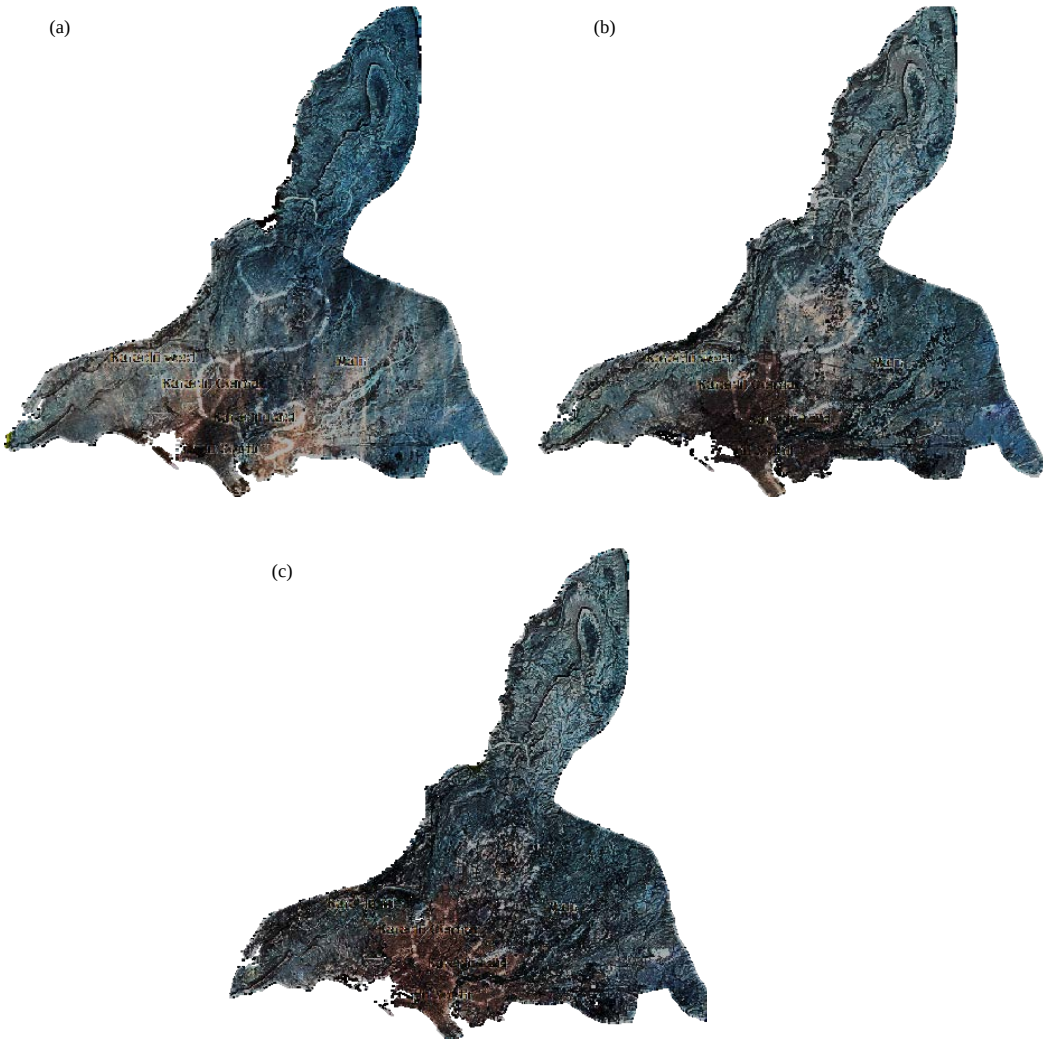

Fig. 4(a-c): Subset of satellite images for year (a) 1991, (b) 2000 and (c) 2013

Table 1: Different type of data used

Type of data used	Scale/resolution	Years
Survey of Pakistan topo-sheets	1:50,000	1995-96
Landsat TM image	30 m	1991
Landsat TM image	30 m	2000
Landsat ETM+ image	30 m	2013
Administrative boundary map	1:25,000	1990

Further, the subset of each year was developed by using the administrative boundary of Karachi division as shown in Fig. 4. Satellite images were studied thoroughly to determine the probable land use classes. Spectral profiles was drawn to determine the separability and relative difference in pixel values of different land use classes in different spectral bands. Five separable land use classes was identified, such as barren land, water, vegetation, built up and mixed class, etc., Initially, supervised classification using MLC algorithm was performed for the classification of various images. To enhance the classification accuracy, knowledge-based expert system was used for post-classification refinement of initially classified outputs.

Then, the accuracy assessment of classified images is performed using ground truth data. More than 100 points for each year are collected and finally an error matrix is generated.

Also a parallel technique normalized difference built-up index (NDBI) is applied which is a popular image processing technique. This technique/algorithm is used to extract the built-up areas automatically from the satellite imagery. This index highlights urban areas where there is typically a higher reflectance in the shortwave-infrared (SWIR) region, compared to the Near-infrared (NIR) region. The equation of NDBI is given as under:

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

NDBI was originally developed for use with Landsat TM bands 5 and 4. However, it will work with any multispectral sensor with a SWIR band between 1.55-1.75 µm and a NIR band between 0.76-0.9 µm.

All these techniques i.e., supervised, unsupervised image classification and NDBI, are applied to map extract and map the urban sprawls over the period of almost twenty years.

RESULTS AND DISCUSSION

By using remote sensing and GIS techniques, urban sprawl of Karachi were identified. Both supervised and unsupervised image classification techniques were applied. The results show that there is a significant increase in urbanization.

Detecting urban growth using supervised classification: The classification of the satellite images into built-up and non-built-up areas for three temporal instants was resulted in the creation land cover of Karachi division (Fig. 5), which define the urban extents of specified times. The results show that over the period of time the barren land decreased, whereas the built-up area had been increased significantly.

The major urban sprawls is on North-West side i.e., towards Kemari Town and Gadap Town.

The square kilometer area graphical information is given in Fig. 6.

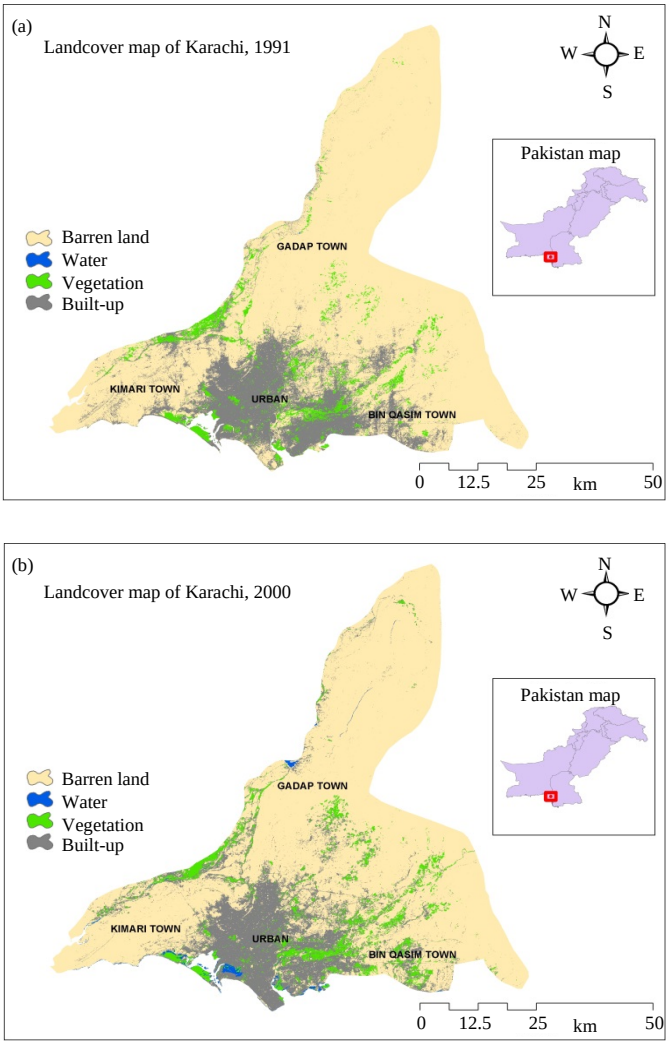

Fig. 5(a-c): Continue

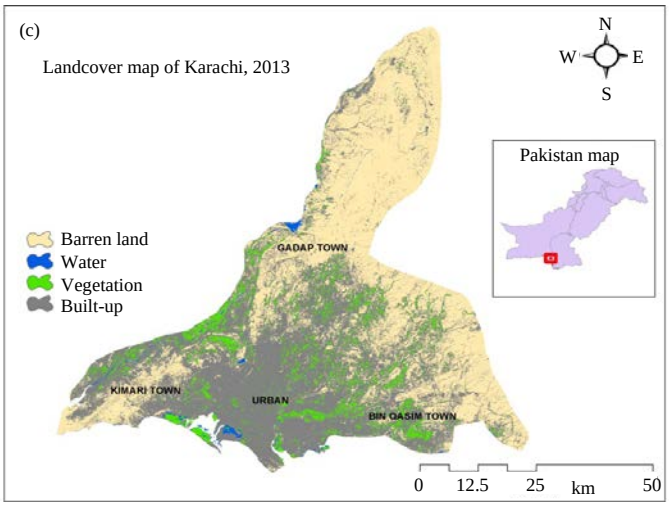

Fig. 5(a-c): Landcover maps of Karachi, (a) 1991, (b) 2000 and (c) 2013 division as per supervised classification technique

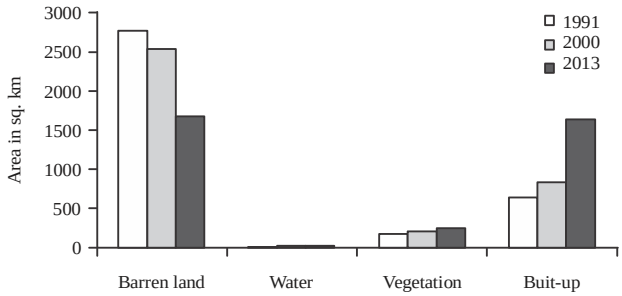

Fig. 6: Area in sq. km of landcover of Karachi division as per supervised classification technique

The overall accuracy of supervised classified images of Karachi division for year 1991, 2000 and 2013 is 70, 76 and 74%, respectively.

Detecting urban growth using unsupervised classification: The second method to classify satellite images into built-up and non-built-up areas is unsupervised classification. The same three temporal instants was resulted in the creation land cover of Karachi division (Fig. 7), which define the urban extents of specified times. The results show that over the period of time the barren land decreased whereas the built-up area had been increased significantly.

The unsupervised classification also shows that the major urban sprawls are on North-West side i.e., towards Kemari Town and Gadap Town. The square kilometer area graphical information is given in Fig. 8.

The overall accuracy of unsupervised classified images of Karachi division for year 1991, 2000 and 2013 is 79, 81 and 83%, respectively.

Detecting urban growth using normalized difference built-up index (NDBI): The built-up area of Karachi division is also extracted using NDBI technique for year 2013 as shown in Fig. 9. The results show that NDBI was overestimated the built-up area as per actual value. The overall accuracy of NDBI of Karachi division for year 2013 is 54%, which means that the results of NDBI cannot be used with high confidence.

The overall urban sprawl of Karachi division for year 1991, 2000 and 2013 is shown in Fig. 10. It clearly indicates that Karachi division is expanding in an irregular way and most of the extension is towards West-North region.

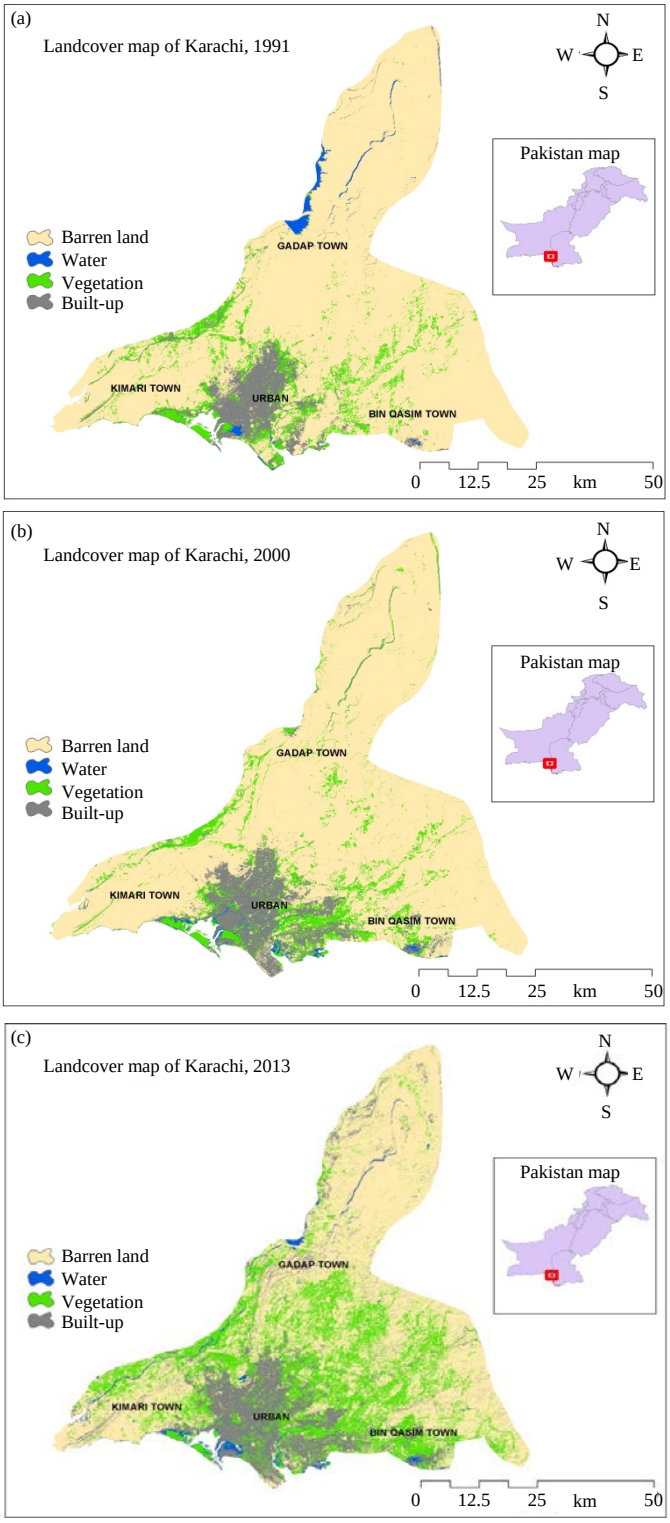

Fig. 7(a-c): Landcover maps of Karachi division, (a) 1991, (b) (2000) and (c) 2013 as per unsupervised classification technique

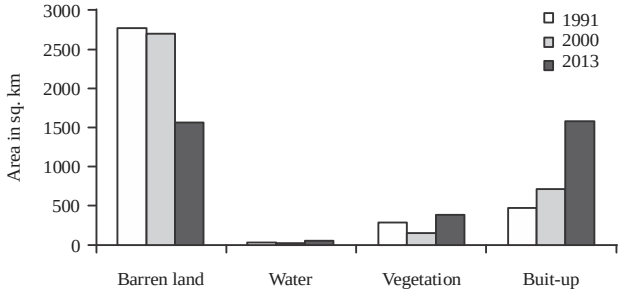

Fig. 8: Area in sq. km of landcover of Karachi division as per unsupervised classification technique

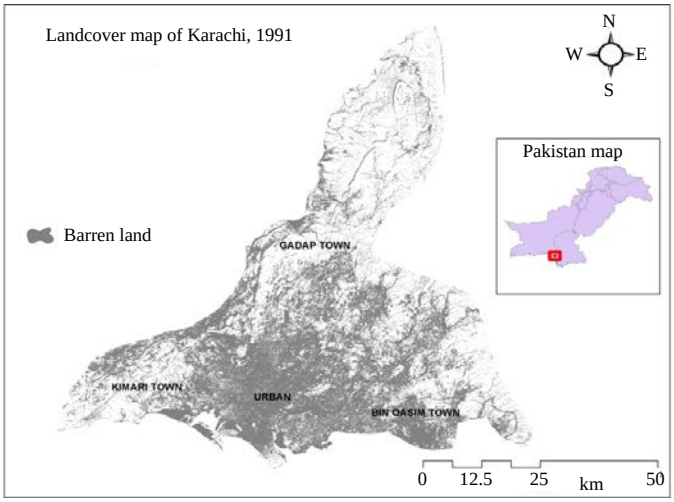

Fig. 9: Built-up map of Karachi division as per normalized difference built-up index technique

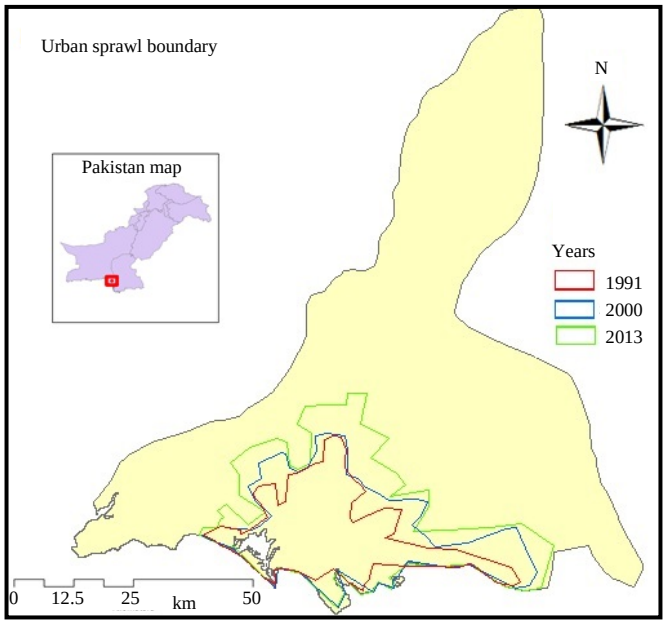

Fig. 10: Urban sprawl boundaries for year 1991, 2000 and 2013

CONCLUSION

The urban sprawl is seen as one of the potential challenge to sustainable development where urban planning with effective resource utilization, allocation of natural resources and infrastructure initiatives are key concerns. The study was aimed to analyze the urban growth of Karachi division from remote sensing data with three different techniques. Unsupervised classification technique proves to be more effective and accurate as compare to supervised and NDBI techniques.

In the future, the spatio-temporal modeling of urban sprawl may be done and will help us to better understand the evolved urban patterns of Karachi division.

Remote sensing technology is essential for dealing dynamic phenomenon, like urban sprawl. Without remote sensing data and GIS analysis, one may not be able to monitor and estimate the urban sprawl effectively over a time period, especially for elapsed time period.

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