Assessment of Urban Sprawl of Islamabad Metropolitan Area Using Multi-Sensor and Multi-Temporal Satellite Data

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RESEARCH ARTICLE - EARTH SCIENCES

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Assessment of Urban Sprawl of Islamabad Metropolitan Area Using Multi-Sensor and Multi-Temporal Satellite Data

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Abstract The present research relates to the exploitation of remote sensing and geographic data to study the metropolitan expansion, land use patterns and land cover classification of Islamabad. The metropolitan development based on growth direction and expansion trends from the city centre was observed for a period of 38 years. Landsat satellite data from three sensors, that is, multi-spectral sensor, thematic mapper and enhanced thematic mapper plus, were used in this study. The classification of the complex spatial assemblage of urban environment and its expanding precincts was done using temporal data collected during the period 1972–2009 and geo-referenced to a common coordinate system. The information regarding agriculture farms, bare land, dense forest, mixed vegetation, shadowy regime, sparse residential areas, thickly populated areas and water bodies was extracted. The extent of urban conurbation growth was computed and analyzed. Our results show that the urban development is expanded by 87.31 km^2. In addition, the urban growth is accompanied by the loss of forest and other natural habitat in the city and has influenced the spatial patterns and structure of urban development. It is concluded that the remote sensing and GIS techniques supplemented with census data are very efficient and effective for studying the metropolitan growth patterns.

Keywords Pakistan · Islamabad · Landsat · Remote sensing · GIS

الخلاصة

يتعلق هذا البحث باستغلال البيانات الجغرافية والاستشعار عن بعد لدراسة التوسع العمراني/ أنماط استخدام الأراضي و تصنيف الغطاء الأرضي في إسلام اباد. وتعتمد التنمية العمرانية على اتجاه النمو وأساليب التوسع وسط المدينة التي لوحظت لفترة زمنية لمدة أربعين عاماً تقريباً. وقد استخدمت في هذه الدراسة ثلاثة أجهزة استشعار تسمى مستشعراً متعدد الأطياف (MSS) والمخطط الجذري (TM) والمخطط الجذري المحسن الإيجابي (+ETM) التي أقيمت على القمر الصناعي لان سات. وهذا التقسيم للتجمع المكاني المعقد في البيئة الحضارية وتوسعه في المناطق المحيطة تم باستخدام بيانات زمنية مؤقتة جمعت خلال فترة 1972- 2009 م من مراجع جغرافية لنظام المنسق المشترك وبيانات إحصاء السكان. وقد تم استخراج المعلومات المتعلقة بأنواع الزراعة والأراضي الجرداء والغابات الكثيفة والنباتات المختلطة والنظام المظلل والمناطق السكنية المتناثرة والمناطق المأهولة بالسكان بشكل كثيف والكتل المائية. وقد تم حساب وتحليل امتداد نمو المجتمعات العمرانية، حيث أظهرت نتائجنا أن التنمية العمرانية توسعت بحوالي 87.31 كم. لقد أثر النمو الحضاري على الأنماط المكانية والتركيبية للتنمية الحضارية، إضافة إلى أن التوسع العمراني قد اقترن بفقدان الغابات والموائل الطبيعية الأخرى في المدينة. أخيراً فقد وجد أن الاستشعار عن بعد وتقنيات نظم المعلومات الجغرافية GIS مضافةٌ الى بيانات إحصاء السكان كانت فعالة وذات كفاءة في دراسة أنماط نمو المدن الكبرى.

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1 Introduction

Remote sensing data is a potentially useful source of land cover information. Urban land covers have been identified and mapped using remotely sensed data with a fine spatial resolution [1–6]. The integration of remote sensing and geographic information systems (GIS) has been widely applied and recognized as an efficient tool for urban growth monitoring, mapping and land use land cover (LULC) changes [7–10]. Remote sensing is a cost-effective technology and is being used rapidly for the analysis of urban growth and change detection [11–14]. LULC is one of the most visible results of modification of the terrestrial ecosystem by humans. In addition, it has a significant impact on the local, regional and global environment [15]. In South Asia, many studies have been attempted to monitor the urban growth development using remote sensing and GIS technique [16–22]. Jat et al. [23] studied the urban change detection of Ajmer city in India over a period of 25 years (1977–2002). Their classified maps of the city for the years 1977, 1989, 2000 and 2002 are based on ten land cover classes (barren land, exposed rocky terrain, fallow land, mixed vegetation, rocky terrain, sandy soil, urban area, shrub land, water and wet soil). Similarly, Dewan and Yamaguchi [24] defined the six land cover classes (water bodies, wetlands/lowlands, built-up areas, cultivated land, vegetation and bare soil/landfill) to study the LULC change detection of Dhaka city in Bangladesh for the years 1975, 1992 and 2003. In another study conducted by [25], six land cover classes (shrubs, forest, water, urban/built-up area, open space and agricultural land) are defined to monitor the LULC change detection for the Kathmandu valley in Nepal using satellite data for the years 1967, 1978, 1991 and 2000. In this study, we have used the remote sensing GIS technique to study the metropolitan growth of Islamabad.

Islamabad territory, under this study, lies between 33° 28′ N and 33°48′N latitude, 72°23′ E and 72° 48′ E longitude. The geographical location of Islamabad is shown in Fig. 1. The city has an overall extreme weather of hot summer with monsoon rain in July and August, and fairly cold winter with occasional snowfall over the hills and sleet in and around the city. The development of Islamabad started in the 1960s and is the only planned

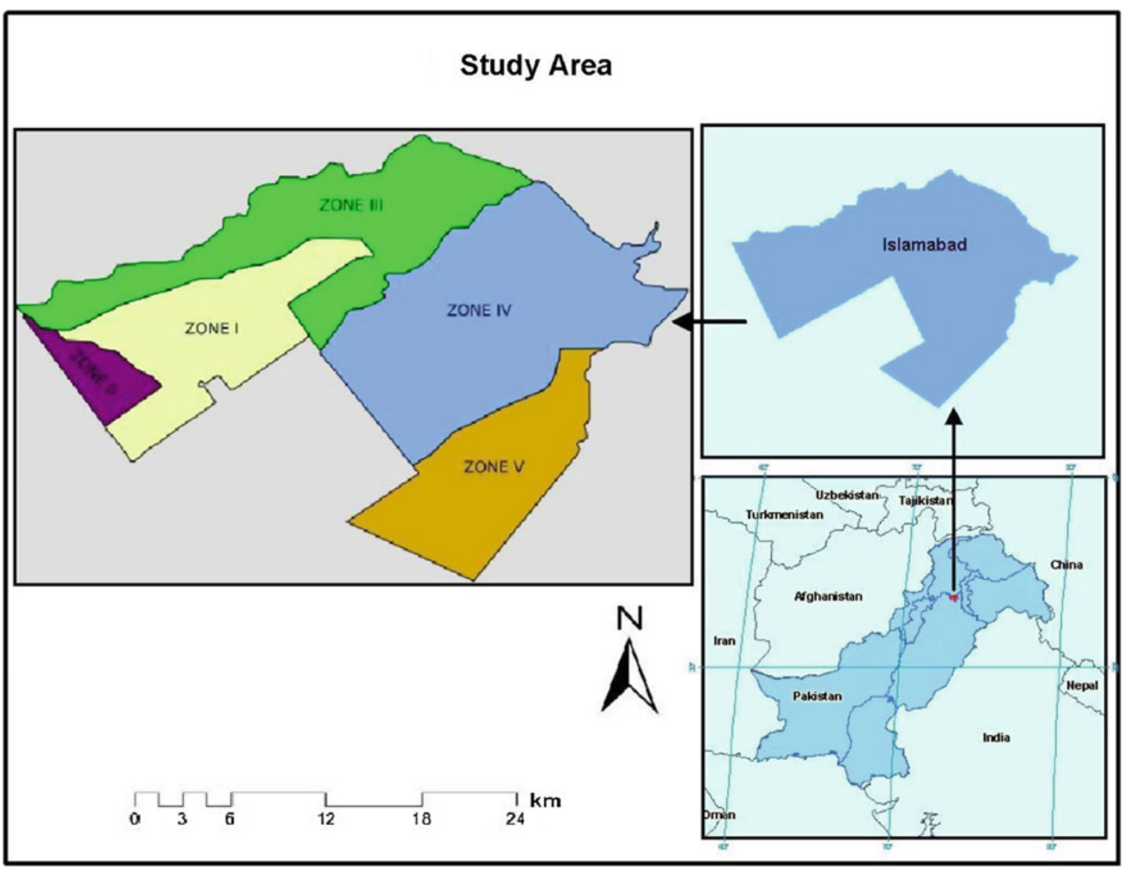

Fig. 1 The location of the study area Islamabad (Pakistan)

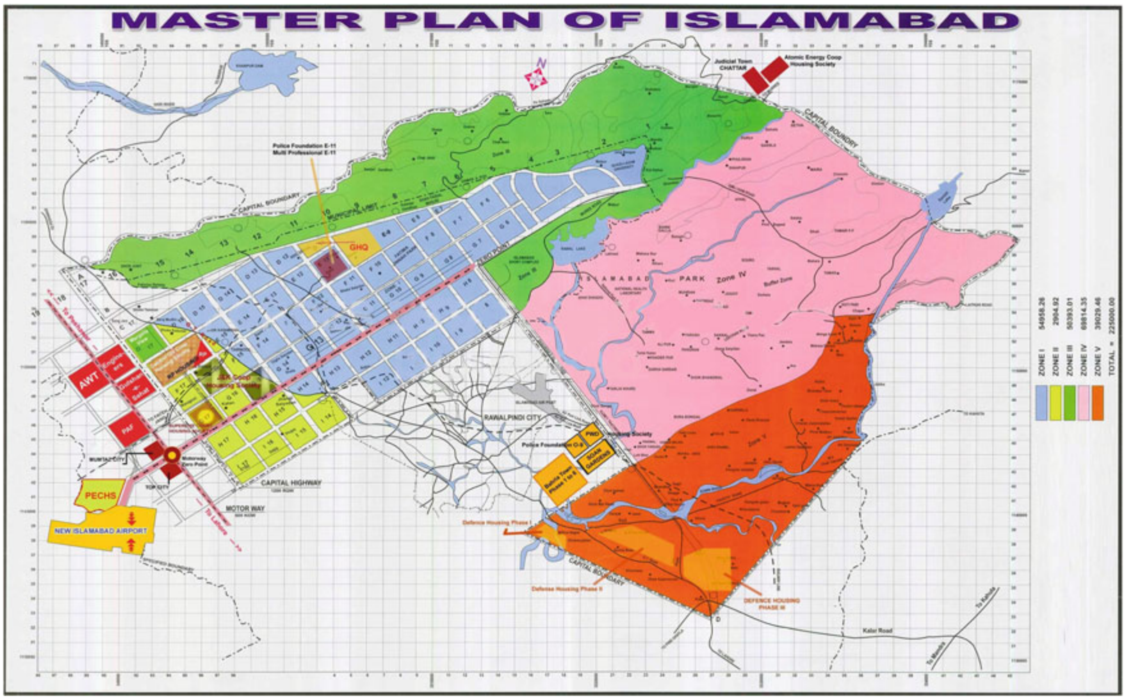

Fig. 2 Master plan of Islamabad (Pakistan)

Table 1 Landsat satellite data of MSS, TM and ETM+ acquired from 1972 to 2009

S. no.	Acquisition date	Satellite series	Sensor	Path	Row
1	07 September, 1972	Landsat-1	MSS	161	37
2	07 September, 1979	Landsat-3	MSS	161	37
3	09 September, 1992	Landsat-5	TM	150	37
4	05 September, 1998	Landsat-5	TM	150	37
5	02 September, 2000	Landsat-7	ETM+	150	37
6	19 September, 2009	Landsat-5	TM	150	37

city of Pakistan. Its master plan covers 906 km^2 and is divided into five zones (Fig. 2). The urbanization as shown in Fig. 2 has been planned in nine sectors from A through I and some isolated settlements in other zones. Each sector is 2 km^2 in area and is divided into four sub-sectors having a central shopping mall, park etc. [26]. Islamabad has been expanding rapidly. Its population in 1961 was approximately 117,669 which increased to 805,235 according to the 1998 census report [27]. Due to this rapid increase of population, the city has undergone many predicted as well as unpredicted changes. The continuous growth of the man-made structures and increasing population posed many environmental challenges. With the increase in population, the number of vehicles has multiplied enormously polluting the environment.

In this study, we are taking an account of the percentage of LULC classification of Islamabad and predict its future situation on the basis of the results. For that we have collected the data set from 1972 through 2009 from sensors multi-spectral scanner (MSS), thematic mapper (TM) and enhanced thematic mapper plus (ETM+) onboard Landsat 1–7 satellite series (Table 1). Since, the number of images and signatures have increased and the time span is widened, the accuracy of the results is expected to be more consistent with the visual data. It is envisaged that the current study would be very beneficial for the planning of the future urban expansion of Islamabad and also for the development of other residential areas in the country.

2 Data Acquisition

The Landsat series of satellites provide the longest continuous record of satellite-based observations. As such, Landsat is an invaluable resource for monitoring global changes and is a primary source of medium spatial

Table 2 Characteristic of Landsat satellite sensors used in this study

Satellite	Landsat (1–3)	Landsat (4,5)	Landsat (7)
Sensor	MSS	TM	ETM+
Operation period	1972–1982	1982–1998	1999–2009
Temporal resolution (days)	18	16	16
Altitude (km)	920	705	705
Swath width	185 km × 185 km	185 km × 185 km	185 km × 185 km
Spatial resolution	79 m ×79 m	30 m × 30 m	30 m × 30 m
Radiometric resolution (bits)	4	8	8
Spectral resolution			
Blue		(1) 0.45–0.52 μm	(1) 0.45–0.52 μm
Green	(1) 0.50–0.60 μm		
Red	(2) 0.60–0.70 μm		
Near infrared	(4) 0.80–1.10 μm	(4) 0.76–0.91 μm	(4) 0.77–0.90 μm
Mid infrared		(5) 1.57–1.78 μm	(5) 1.55–1.75 μm

resolution Earth observations used in decision-making [28–34]. The Landsat data archive at the United States Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center holds a distinct 38-year record of the Earth's surface and is available at no cost to users via the Internet [35].

Although the urbanization of Islamabad began in the 1960s, the remote sensing satellite (Landsat) used in this study was launched in early 1972 [36]. Six Landsat satellite images of different sensors (two MSS images for the year 1972 and 1979, three TM images of 1992, 1998 and 2009 and one ETM+ image taken in the year 2000) from the year 1972 to 2009 were obtained from the USGS through file transfer protocol (FTP) are summarized in Table 1. These images were geo-referenced using the universal transverse mercator (UTM) Zone 43 North coordinate system and were used for identifying the urban growth and land cover classification.

The characteristics of the bands of MSS, TM and ETM+ sensors are given in Table 2. All three sensors have different characteristics in terms of spectral, spatial, temporal and radiometric resolution.

Finally, the census data are also attributed to the respective locations of classes to make various analyses of social significance. Many researchers, for example, [37], have used varying population density sprawl and functions, either monocentric or polycentric models, analyzing urban population distribution.

3 Methodology

Several techniques for example, multi-date classification, image differencing, vegetation index differencing, principal component analysis and change vector analysis have been used in context with the simultaneous-analysis method. Our methodology is based on the principal component analysis (PCA), normalized difference vegetation index (NDVI) and supervised classification methods. PCA and NDVI are used to extract specific training sites (LULC classes) and finally, the maximum likelihood supervised classification technique is used to produce satellite-derived LULC maps. Landsat satellite data of various years (Table 1) are analyzed by using the image processing software ERDAS Imagine version 9.0 [38]. ArcGIS version 9.1 [39] is used to generate various thematic maps. The steps taken to process the data are shown in the accompanying flowchart Fig. 3.

Digital image processing techniques are used to define unique training sites (LULC classes) for classification of the study area. The image classification procedure is applied to automatically categorize all pixels into land cover classes or themes on the basis of training sites defined in an image.

3.1 Principal Component Analysis (PCA)

Principal component analysis (PCA) is used to convert raw remote sensing data of multi-spectral imageries into a new principal component image, which is more interpretable [40,41]. The PCA technique is found to be very suitable in overcoming repetitions and redundancies in different bands of the satellite images. The redundancy in the image data is due to the presence of correlations among the bands of multi-spectral images. Furthermore, PCA analysis is very helpful to compress the information content of a number of bands into just two or three transformed principal component images [6] such that the resultant component images contain information of each band. In addition, PCA technique is very helpful to identify principal axes of variability in the data sets. Each principal component is representing a weighted average of all the bands. In the current study,

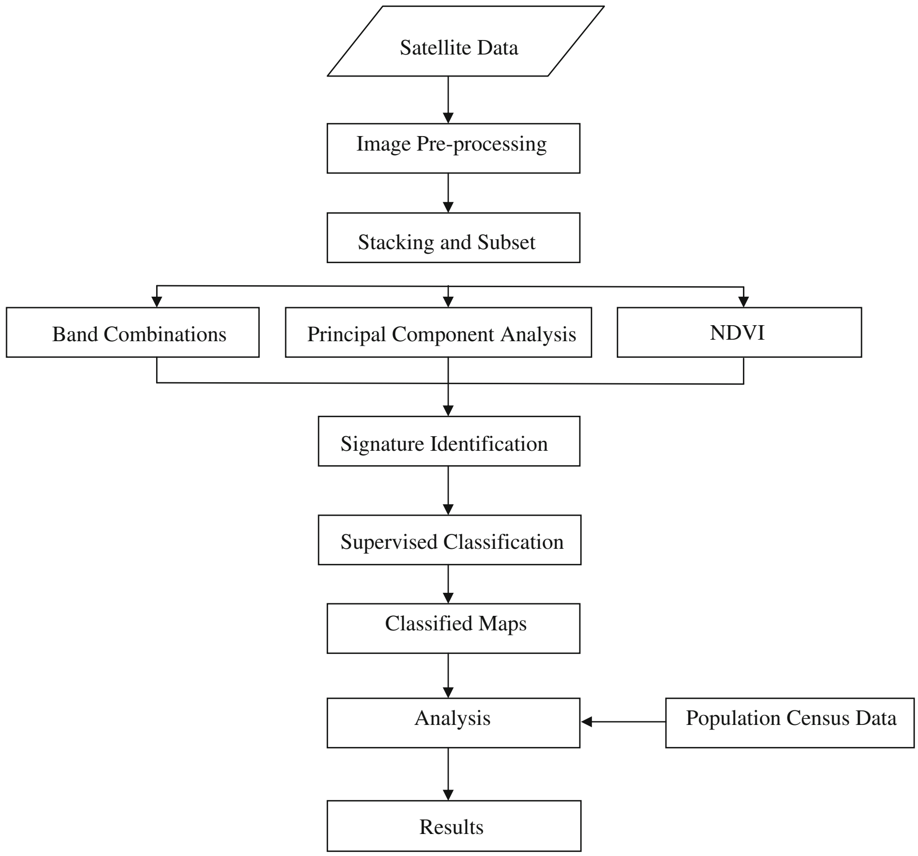

Fig. 3 Methodology and flow chart used for acquisition and preprocessing of satellite data and census data analysis

the first three principal components of each satellite image are represented with the maximum contingency of different land cover classes of study area as shown in Fig. 4a–f.

3.2 Normalized Difference Vegetation Index (NDVI)

Normalized difference vegetation index (NDVI) is a band ratio technique (commonly called complex ratio technique). The purpose of this technique is to reduce the multiple bands of data down to a single band that accesses the vegetative ground cover [6]. The NDVI (sum and differences between spectral bands), as given in Eq. 1, is applied to each satellite image.

$$\text{NDVI} = \frac{(\text{Band } 4 - \text{Band } 3)}{(\text{Band } 4 + \text{Band } 3)} \tag{1}$$

where Band 3 is the red band and Band 4 is the near infrared band of Landsat satellite system.

In current study, the PCA and NDVI techniques are used to achieve high separability and contingencies of each land cover type. Intrinsic dimensionality of the data set and identification of the principal axes of variability within the data are derived using PCA technique. Simultaneously, the NDVI is applied to extract the vegetation cover extent of the study area from each satellite image. In the current study PCA and NDVI techniques are found to be very useful to improve the results.

3.3 Image Classification

Image classification technique is performed to extract land use and land cover types in remote sensing data [42]. Remote sensing supports a variety of techniques for image classification, for example, supervised, unsupervised and knowledge-based expert system for urban growth monitoring [43–47]. The supervised classification

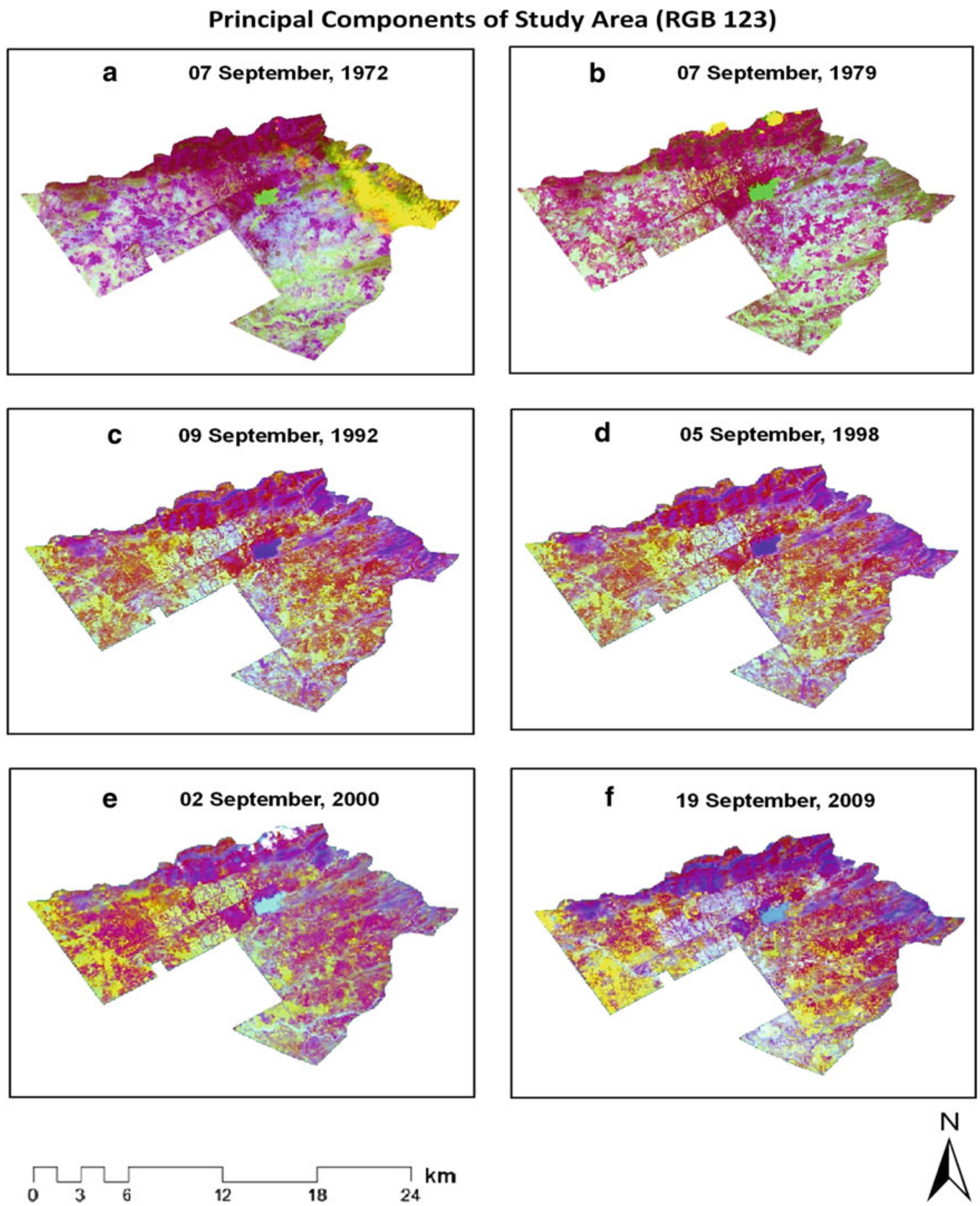

Fig. 4 First three principal components of the study area are shown in RGB format for the years **a** 1972, **b** 1979, **c** 1992, **d** 1998, **e** 2000, **f** 2009

is the most time consuming and accurate system used to extract surface features manually from remote sensing images [23]. In addition, it is generally considered as including the knowledge-based expert classification systems depending on reference maps and thus likely to improve the accuracy of the classification process [48,49]. In this study, we have used the supervised classification for the analysis of remote sensing data. The maximum likelihood classification method is used in the current study, because it can be more effective than the often used minimum distance algorithm (MDA) and Mahalanobis distance algorithm (MDA) when the number of training sites per class is larger [6].

Table 3 Land use/land cover classes for satellite derived land use/cover maps

Class name	Description
Agriculture farms	Cropland, horticultural farms, greenhouses, other agricultural crops
Bare land	Bare, exposed areas and transitional area
Dense forest	Lush green forests, mixed forests with higher density of trees, little or no under storey vegetation
Mixed vegetation	Bush land dense shrubs, perennial grass, sparse trees, impoverished woodlands near the forests, very sparsely distributed, low-lying scrub species
Shadowy regime	Areas under terrain shadows
Sparse residential areas	Newly build areas, sparse settlements, small villages etc.
Thickly populated areas	Urban/built-up areas residential, commercial and services, industrial, transportation, communication and utilities
Water bodies	Water reservoirs and water channels

Keeping in view the human impacts on the landscape, there is a need to establish baseline data sets so that changes in the land cover and land used can be assessed [50]. Anderson et al. [51] defined nine different classes to develop the generalized classification system from remote sensing data for LULC system in the USA. Landsat imagery with a moderate spatial resolution of 30 m has been effectively used to classify urban areas [52]. Keeping these characteristics in view, we have classified eight different categories (agriculture farms, bare land, dense forest, mixed vegetation, shadowy regime, sparse residential areas, thickly populated areas and water bodies) with appropriate combination of bands and the color reflections from various degrees of urbanization as given in Table 3. The temporal changes in the said classes from 1972 to 2009 are highlighted in Fig. 5a–f respectively.

3.4 LULC Change Detection

The selection of an appropriate algorithm is critical in LULC change detection [6]. Two basic approaches are used for LULC change detection; one is related to post classification comparisons while the other is with the simultaneous analysis of multi-temporal data. The post classification method needs highly accurate training areas either extracted from high resolution imagery or obtained from local knowledge of the study area. The accuracy of the resultant classified map depends on the individual accuracies of each defined class. On the other hand, simultaneous analysis method requires data with similar atmospheric and seasonal conditions to investigate LULC changes.

3.5 Classification Accuracy Analysis

In current study, ground truth data and available reference maps from various agencies are used to validate (extent of correspondence between remotely sensed data and referenced information) the classified images. It is assumed that these reference maps are the most accurate maps available to measure the accuracy of the prediction. Supervised image classification accuracy assessment was carried out for each of the six data sets using a reference data set of more than 200 randomly selected pixels. Land use for these pixels was determined using data from [53–56] and maps from [57,58]. The geographical locations of some of the key features, for example, important buildings, playgrounds, water bodies and vegetated areas were also collected during field visits and are used as ground truth data. In addition, the original satellite data are also used for accuracy assessment to avoid errors in the reference data set. Error matrices were developed to highlight the classification accuracy for all the images and are presented in Table 4. The error matrix for each image shows the relationship between the reference data and the classified map. The aforementioned classification accuracies are dependent on the applied methods used to define unique land cover classes. Overall classification accuracy is found to be more than 88% for all the images. The higher level of accuracy is achieved in the case of Landsat MSS Image data set dated 07 September 1979, because that image contained more spectrally separable features than those in the image data sets of the other dates. 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 data sets, areas of sparse population converted into those of thick population over a short period of time. Hence, transformation occurs from spacious to congested city environs and from rural agriculture land to urban residential/commercial land within the study area.

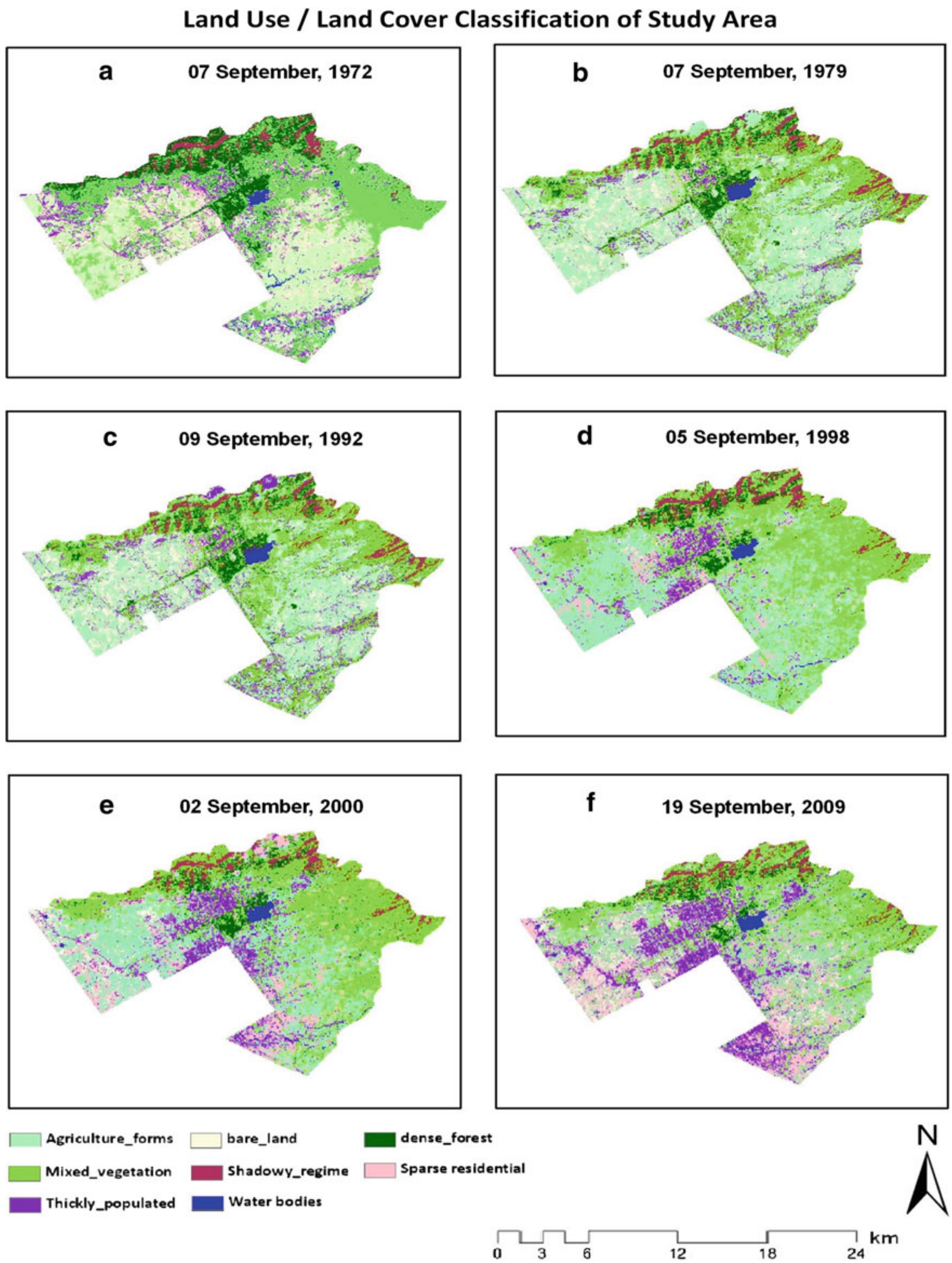

Fig. 5 Land use/land cover classified map of the study area for the years **a** 1972, **b** 1979, **c** 1992, **d** 1998, **e** 2000, **f** 2009

4 Results and Analysis

The area of the current study primarily comprises bare land, rocks, vegetation and water, with negligible small scattered population prior to its development in the 1960s. After the urban development there is a rapid

Table 4 Accuracy analysis (percentage) of land cover/land use maps derived from Landsat data

	Agriculture farms	Bare land	Dense forest	Mixed vegetation	Shadowy regime	Sparse residential areas	Thickly populated areas	Water bodies
Landsat MSS 1972 (classification accuracy: 86.45%)								
Agriculture farms	69.64	5.06	0.00	6.59	0.00	3.26	0.00	0.00
Bare land	25.21	94.94	0.00	0.00	0.00	0.00	0.00	0.00
Dense forest	0.00	0.00	93.01	44.86	0.00	0.00	0.00	0.00
Mixed vegetation	4.19	0.00	6.99	48.44	2.33	0.00	2.17	1.67
Shadowy regime	0.00	0.00	0.00	0.00	97.67	0.00	0.00	0.00
Sparse residential areas	0.83	0.00	0.00	0.00	0.00	96.74	0.00	0.00
Thickly populated areas	0.14	0.00	0.00	0.12	0.00	0.00	97.83	0.00
Water bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	98.33
Landsat MSS 1979 (classification accuracy: 92.74%)								
Agriculture farms	81.03	2.22	0.20	8.43	0.00	4.11	0.56	0.00
Bare land	0.45	95.56	0.00	0.02	0.00	0.34	0.34	0.00
Dense forest	0.19	0.00	96.55	7.83	0.00	0.00	0.00	0.00
Mixed vegetation	16.01	0.00	3.04	82.96	0.83	0.00	0.17	0.00
Shadowy regime	0.00	0.00	0.20	0.27	99.17	0.00	0.00	0.00
Sparse residential areas	1.99	2.22	0.00	0.02	0.00	90.75	2.99	0.00
Thickly populated areas	0.34	0.00	0.00	0.45	0.00	4.79	95.94	0.00
Water bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Landsat TM 1992 (classification accuracy: 84.87%)								
Agriculture farms	69.41	5.06	0.00	6.59	0.00	3.26	2.02	0.00
Bare land	25.21	94.94	0.00	0.00	0.00	0.00	0.00	0.00
Dense forest	0.00	0.00	93.01	44.86	0.00	0.00	0.00	0.00
Mixed vegetation	4.19	0.00	6.99	47.63	2.33	0.00	1.52	1.67
Shadowy regime	0.00	0.00	0.00	0.00	97.67	0.00	0.00	0.00
Sparse residential areas	0.83	0.00	0.00	0.00	0.00	95.65	14.14	0.00
Thickly populated areas	0.37	0.00	0.00	0.92	0.00	1.09	82.32	0.00
Water bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	98.33
Landsat TM 1998 (classification accuracy: 89.47%)								
Agriculture farms	75.41	3.89	0.00	4.27	0.00	1.53	1.00	0.00
Bare land	2.21	92.05	0.00	0.00	0.00	0.00	0.00	0.00
Dense forest	19.36	0.00	95.54	20.36	0.00	0.00	0.00	0.00
Mixed vegetation	4.19	0.00	4.46	72.76	1.13	0.00	1.52	2.22
Shadowy regime	0.00	0.00	0.00	0.00	98.87	0.00	0.00	0.00
Sparse residential areas	2.83	4.06	0.00	0.63	0.00	97.38	11.46	0.00
Thickly populated areas	0.19	0.00	0.00	1.98	0.00	1.09	86.02	0.00
Water bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	97.78
Landsat ETM+ 2000 (classification accuracy: 85.90%)								
Agriculture farms	73.45	0.55	1.75	24.66	0.00	16.39	1.59	0.00
Bare land	2.87	97.80	0.00	0.13	0.00	1.17	0.83	0.00
Dense forest	0.54	0.00	96.67	6.83	0.00	0.00	0.00	0.00
Mixed vegetation	19.55	0.00	1.58	64.78	0.75	0.50	0.32	0.00
Shadowy regime	0.00	0.00	0.00	0.07	99.12	0.00	0.00	0.00
Sparse residential areas	2.58	1.65	0.00	2.85	0.00	72.74	13.95	0.13
Thickly populated areas	1.02	0.00	0.00	0.68	0.13	9.20	83.31	0.52
Water bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.35
Landsat TM 2009 (classification accuracy: 89.95%)								
Agriculture Farms	81.53	0.38	0.88	8.95	0.00	0.77	1.11	0.07
Bare land	4.31	84.29	0.00	0.05	0.00	12.16	0.62	0.00
Dense forest	0.00	0.00	93.20	8.40	0.08	0.00	0.00	0.00
Mixed vegetation	10.95	0.00	5.85	81.96	0.82	0.00	0.00	0.29
Shadowy regime	0.00	0.00	0.06	0.09	99.10	0.00	0.00	0.00
Sparse residential areas	2.71	15.33	0.00	0.14	0.00	84.89	2.34	0.64
Thickly populated areas	0.49	0.00	0.00	0.41	0.00	2.18	95.93	0.29
Water bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	98.71

population influx in the study region. The satellite data for the period 1972 to 2009 were acquired in order to find the changes in the LULC with the year 1972 being taken as the base year. The changes in the area of the eight classes are given in Table 5.

It is evident from Table 5 that the total area covered by agriculture farms is continuously reducing from the year 1972 to 1979. In the year 1991, due to certain administrative plans by the local administration, the city has an increasing trend in the agriculture farms as evident from the data of 1992 (Table 5). However, the

Table 5 Results of classified images of eight classes include bare land, dense forest, mixed vegetation, shadowy regime, sparse residential areas, thickly populated areas and water bodies

Land cover features	1972 (km^2)	1979 (km^2)	1992 (km^2)	1998 (km^2)	2000 (km^2)	2009 (km^2)
Agriculture farms	332.14	328.02	300.07	327.01	323.90	313.80
Bare land	54.80	53.38	65.13	58.20	49.86	45.99
Dense forest	36.57	35.53	40.01	42.19	34.57	28.72
Mixed vegetation	272	265.01	262.13	238.70	232.63	218.83
Shadowy regime	32.87	33.02	32.45	32.84	33.56	33.13
Sparse residential area	79.07	84.12	90.33	91.32	110.28	123.49
Thickly populated area	85.93	95.10	103.13	105.20	107.56	128.82
Water bodies	12.33	11.52	12.43	10.25	13.36	12.92
Population data (millions)						
Population	0.237549	0.300152	0.520179	0.805235	0.86245	1.22

city once again has the decreasing trend in terms of agriculture farms from the year 1992 onwards. The area of bare land is reducing from the year 1972 to 1979 (Table 5), but from the year 1992, it starts increasing and afterwards it again reduces till the year 2009. Thus, the bare land class has the mixed trend in the region. Similarly, it is clear from Table 5 that the areas of dense forest and mixed vegetation are reducing from the year 1972 to 2009 whilst the variation in the area of shadowy region on all of the images is not very prominent on each satellite image for the year 1972 to 2009. It is also evident from Table 5 that the sparse residential area, thickly populated areas and urban class are continuously increasing from the year 1972 to 2009. Finally, Table 5 clearly shows that the total area covered by water bodies has a mixed value from the year 1972 to 2009.

Similarly, the LULC changes of all eight classes (agriculture farms, bare land, dense forest, mixed vegetation, shadowy regime, sparse residential areas, thickly populated areas and water bodies) from the year 1972 to 2009 are highlighted in Fig. 5a–f. It is evident from Fig. 5a–f that the area of agriculture farms is continuously reducing from the year 1972 to 2009 in zones I, IV and V, whereas for zones II and III there is either very little or no change in the area of agriculture farms. However, the area of mixed vegetation is continuously decreasing from the year 1972 to 2009. Similarly, the area of urban class is continuously increasing from the year 1972 to 2009 in zones I, II, IV and V, whereas for zone III, there is either very little or no change in the area of urban development whilst, the sparse residential area and thickly populated area has rapidly increased from the year 2000 to 2009. Analysis of Fig. 5a–f also indicates that only zone III has the minimum area covered with bare land. Mostly bare land has been covered with urban development in the period of 37 years according to our results. It is also evident from Fig. 5a–f that the Rawal Dam is mainly seen in all the images whilst the Simly Dam (although Simly Dam is partially seen in the imagery) and the Khanpur Dam are not within the Islamabad region, and thus are avoided in the current study. The underground water used for some agricultural and domestic purposes is not included in our image analysis. The underground water of the region and around has been studied in separate research by [59,60]. The variation in the area of the water bodies in all the images is not very prominent on each satellite image for the year 1972–2009.

As the urban development of Islamabad has rapid growth affecting other classes simultaneously, the trends of the bare land, vegetation and water have been changing in different years depending on some man-made additions. In the initial stage of the city development, the bare land and rocks did cover large areas, as observed from the classified maps in Fig. 5a–f and Table 5. Due to urbanization the man-made structures, machines, industries, roads etc. increased tremendously. The urbanization class generally has a higher absorption of solar radiation and greater thermal capacity and conductivity thus leading to a relatively higher temperature in the urban areas as compared with the surrounding rural areas that contain a high percentage of vegetation [61,62]. It is clear that increased urban development in the city with the passage of time changes the land cover each year thereby affecting the environment.

There is a relationship between the urban development and population. Thus, census data are fully incorporated in this study. The population data of Islamabad was derived from the census report of Pakistan and is given in Table 5. The contents of the census data used in this study comprise census code, population and area measured in acres. It was very difficult to integrate aggregate census data with un-compiled land-use data. The relationship of population data encompassing all eight classes are shown in Fig. 6. We observe (Table 5) that from 1972 to 1981, the population of Islamabad increased at a slow rate while, from 1981 to 1998, it increased rapidly. The urban growth has not increased at the same rate as the population of the city.

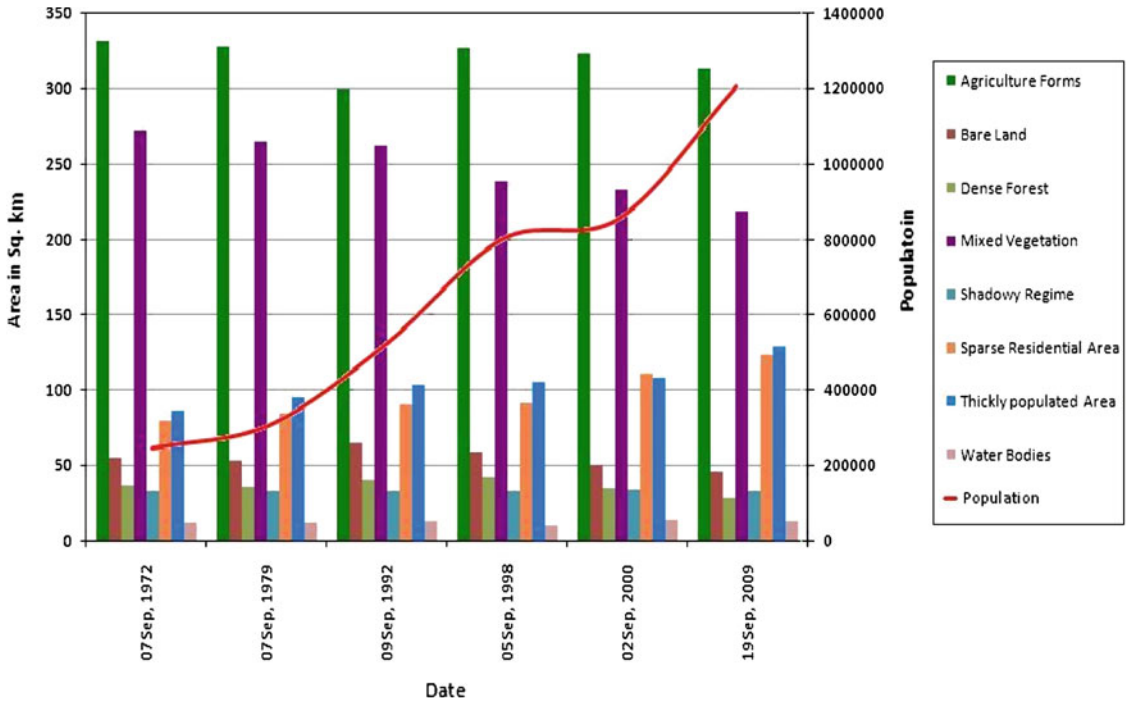

Fig. 6 Area of land covers classification of Islamabad in square kilometers with respect to population data

All the analyses in this study are carried out and synthesized depending on satellite images. Variations in the imagery observation are partly attributed, to some extent, to the factor of spatial, temporal, spectral and the radiometric resolution of sensors. However, the meteorological conditions, prevailing at the time of taking images and observing the urbanization conditions, seem to be the major reasons for the large fluctuations in observations. All these changes seen on the satellite sensor could not be explained just by interpreting the remote sensing imageries. Thus, other information (meteorological data and the city planning data) are essential for explaining the anomalies observed by the remote sensing imageries.

5 Conclusion

In this paper, we address eight major land cover classes (agriculture farms, bare land, dense forest, mixed vegetation, shadowy regime, sparse residential areas, thickly populated areas and water bodies) in the study area. The conversion of vegetated surface and land cover through the processes of urbanization is identified and mapped (Fig. 5a–f) using remotely sensed data. The results of various analyses, carried out by using the combination of census and thematic data, indicate that in the 1960s (at the initial stage of the development of Islamabad) most of the region comprised agriculture farms, bare land or vegetation with some natural water resources. The imageries show that from 1972 to 2009, urban development (sparse residential areas and thickly populated areas) increased from 18.2 to 27.85%, mixed vegetation decreased from 30.03% in 1972 to 24.16% in 2009, agriculture farms decreased from 36.67% in 1972 to 34.64% in 2009, dense forest decreased from 0.04% in 1972 to 0.03% in 2009, bare land has some turbid, but ended up being reduced from 0.06% in 1972 to 0.05% in 2009, water bodies and shadowy regimes are not highly affected according to our classification results. Graphical representation of the variations in each land use/land cover class from 1972 to 2009 is shown in Fig. 6.

The comparison of eight classes show that the urban growth has increasing trend while agriculture farms, bare land, dense forest, mixed vegetation and water bodies have decreasing trend in the study area from the year 1972 to 2009. The urban development is made mostly in the Zone-I and Zone-II (Fig. 1). During the period of rapid urban development, the change in the bare land was modulated while the large amount of natural vegetation was replaced by impervious surfaces such as asphalt and concrete. At the same time the city started massive plantation and had encouraged the public to do the same. At one point, the city enforced a law of planting three trees for one removed. This made a very positive impact on the city's environment. For example, the total area covered with vegetation (agriculture and forest) in 1972 was 40.7% which decreased to 37.54% in 1992. However, due to the aforementioned effort of the city government, the area covered by vegetation (agriculture and forest) from 1993 to 1998 increased by 3.21%.

The results of this work were also compared with the work conducted by Dewan and Yamaguchi [24] for the city of Dhaka and by Thapa and Murayama [25] for the city of Kathmandu. The results of the current study show that for Islamabad, the area of urban expansion has increased from 165 km^2 in 1972 to 252.31 km^2 in 2009 while the area of agricultural land/vegetation has decreased from 640.71 km^2 in 1972 to 561.35 km^2 in 2009. Thus, there is an increase of 87.31 km^2 (an increase of 2.36 km^2 per year) in the area of urban development and a decrease of 79.36 km^2 (a decrease of 2.14 km^2 per year) in the area of agricultural land/vegetation over a period of 37 years (1972–2009) in Islamabad. A similar trend has been reported by Dewan and Yamaguchi [24] and Thapa and Murayama [25] in their independent studies. For example, for the city of Dhaka, results of Dewan and Yamaguchi [24] show that the area of urban expansion has increased from 55.50 km^2 in 1975 to 161.04 km^2 in 2003 (an increase of 105.54 km^2 with an average increase of 3.77 km^2 per year) whilst the area of agricultural land/vegetation has decreased from 186.25 km^2 in 1975 to 124.58 km^2 in 2003 (a decrease of 61.67 km^2 with an average decrease of 2.20 km^2 per year) over a period of 28 years. Similarly, for the city of Kathmandu, Thapa and Murayama [25] reported that the area of urban expansion has increased from 20.10 km^2 in 1967 to 97.17 km^2 in 2000 (an increase of 77.07 km^2 with an average increase of 2.33 km^2 per year) while the area of agricultural land/vegetation has decreased from 492.12 km^2 in 1967 to 440.04 km^2 in 2000 (a decrease of 52.08 km^2 with an average decrease of 1.57 km^2 per year) over a period of 33 years. These studies show that, in all three capital cities (Islamabad, Dhaka and Kathmandu), the urban development has been increasing while the agricultural land/vegetation area has been decreasing in the last two decades at almost similar pace. However, the most alarming thing from the point of view of environmentalists is that the urban development is growing at the cost of agricultural land/vegetation area in the region.

The present research focused on using geospatial techniques for combining multi-concept image data sets, geospatial themes and census data to study various surface features in the environs of Islamabad. Since the differences in image variations are attributed to the meteorological conditions prevailing at the time of the observation and urban development inhabitation rate, the time of taking the satellite data is important. These factors are important and an investigation on this aspect is presently underway. Furthermore, we can present the population census data to their respective features, such as age, height and gender, digitizing it into thematic layers of geospatial information, which can then be developed into valuable information for performing various demographic analyses corresponding to spatial distribution of urban as well as rural localities. Thus, the combination of satellite imagery in multi-spectral mode, GIS layers, and census data can be effectively exploited for studying the metropolitan growth in detail. Finally, it is recommended that such studies be repeated at regular 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 in high spatial detail.

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