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Green Spaces Trends in the City of Port Elizabeth from 1990 to 2000 using Remote Sensing

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ABSTRACT: Given the critical role played by urban green spaces and the emergence of remote sensing as a valuable natural resource management tool, this study sought to identify trends in green spaces within the context of South Africa's transition period (1990 - 2000). Using the city of Port Elizabeth as a case study, three sets of Landsat - 5 Thematic Mapper images (1990, 1995 and 2000) were geo-processed, classified into vegetation density categories and verified using respective aerial photographs. There was a steady decline in areas covered by Very sparse vegetation, Sparse vegetation and Dense vegetation classes. However, areas covered by Very dense vegetation showed a steady increase during the study period. Using remote sensing applications, this study provides an insight into trends in green spaces in the city of Port Elizabeth during the transition period. This study further shows the importance of remote sensing as a mapping tool that can be used to provide information for physical, social and ecological planning to achieve urban socio-ecological sustainability in rapidly changing urban environments.

Key words: Port Elizabeth, Green spaces, Land cover classification, Change detection

INTRODUCTION

Recent studies indicate that over 50% of global human population lives in urban areas (UNEP, 2005). Based on current growth rate, it is estimated that over 60% of global population will be found in urban areas by 2030 (Moeller and Blaschke, 2006). A higher rate of urban growth is expected in developing countries as myriad socio-economic pull factors attract people to towns and cities (Berry, 1990). In the sub-Saharan Africa, population in urban areas grew from 15% in 1950 to 32% in 1990, it is anticipated that 54-60% of the population will be found in urban areas by 2030 (UNEP, 2005). The continued influx to urban areas in sub-Saharan Africa and indeed the rest of the world has caused unprecedented urban environmental challenges (Mundia and Aniya, 2005; Grimm *et al.*, 2000; Alberti, 2005). According to Dong *et al*. (2006) and Picket *et al*. (2001), urban influx has often affected ecosystem functioning at local and global scales and has significantly strained the ecological services in towns and cities. Shao *et al*. (2008) notes that these effects can be spatial, temporal or a combination of both and may include among others deterioration of land and water quality, loss of green spaces, change of urban hydrology and air pollution. Urban green spaces in particular have long been recognized as the most critical environmental resource in an urban ecosystem (Gairola and Noresah, 2010). Urban green spaces include all that have the vegetation and provide a wide range of functions that include air and water purification, mitigation of environmental pollution, carbon sequestration, regulation of micro-climate, habitat for urban wildlife, recreation and spiritual and therapeutic value (Miller, 1997; Milton, 2002; Hague and Siegel, 2002; Gairola and Noresah, 2010; Rasouli *et al.*, 2012; Spanou *et al.*, 2012). Consequently, urban green spaces improve urban environmental quality, urban tourism, pubic health and social integration among others (Randall *et al.*, 2003; Rafiee *et al.*, 2009; Perez-Caldern *et al.*, 2011; Pirani and Secondi, 2011). According to Chameides *et al*. (1994) and Fu *et al.*, (1998) these benefits are often felt beyond the boundaries of the urban area itself.

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Increased population density and spatial expansion transforms urban green spaces to impervious landscapes (Xian *et al.*, 2005). In the recent past, a number of studies in cities like Tabriz (Mahmoodzadeh 2007), Taheran (Faryadi and Taheri, 2009), Jinan (Kong and Nakagoshi, 2006), Mashad (Rafiee *et al*., 2009) Phoenix (Buyantuyev *et al*., 2007) have documented urban growth and consequent loss of urban green spaces. Yuan *et al.* (2005) identify the growth of human settlement on urban fringes as the major cause of loss in green spaces and consequent negative environmental impacts. According to Gairola and Noresah (2010) loss of urban green spaces has been recorded in both developing and developed countries, and is dependent on the rate of urban growth often determined by prevailing socio-economic factors.

Most global cities have experienced "natural" rural urban migration over time. However, unlike the "natural" growth of cities and urban areas in other parts of the world, South Africa's colonial and apartheid laws between 1913 and 1991 moved and restricted majority of black South Africans to rural areas or former homelands (Roberts, 1994; Mabin, 1991). Under the Prevention of Illegal Squatters Act of 1951 for instance, about 860,000 people were moved from major urban areas between 1960 and 1983 (Sihlongonyane, 2003; Seekings, 2000; Christopher, 2001). The scrapping of the Group Areas Act and the demise of apartheid in late 1980s and early 1990s heralded a population influx to urban areas (Christopher, 2001; Collinson *et al.*, 2007). Between 1991 and 1996 for instance, Christopher (2001) notes that South Africa's urban population grew by 27% while Kok and Collinson (2006) observe that there was an increase of 4.3% between 1996 and 2001. In Port Elizabeth, like many South African cities, the increased built environment as a result of sudden urban influx in the late 1980s and early 1990s transformed urban green spaces hence affecting social and environmental (Pillay and Sebake, 2008; Shao *et al*., 2008; Mundia and Aniya, 2005).

Recent concerns on the deterioration of urban environmental quality and emerging efforts towards sustainable development require up to date knowledge on transformation of urban green spaces (Naveh, 1995; Antrop, 2000; Faizi *et al.*, 2011; Kanokporn and Iamaram, 2011; Seifollahi and Faryadi, 2011). Due to possibility for repetitive coverage, consistent image quality, cost effectiveness and well developed change detection algorithms among others, remote sensing has recently emerged as one of the most viable tools for urban mapping. (Longley, 2002; Mas, 1999; Rawashdeh and Saleh, 2006; Singh 1989). Whereas larger classes are often readily visible from temporal or multi-temporal imagery (Fig. 1), changes in smaller and less visible classes can be determined using existing remote sensing software algorithms. In this study, we set to determine changes in size and density of green spaces in the city of Port Elizabeth during South Africa's democratic transition (1990-2000).

Port Elizabeth is the fifth largest city in South Africa. It is situated on the south-eastern coast of South Africa (Fig. 2) at latitude 33°57'29"S and longitude 25° 36' 00"E. Based on 2007 population census, the city had approximately 1 million people and covers approximately 335km^2. The city is located between the Cape Mediterranean region that receive rain during winter and South Africa summer rainfall regions. Consequently, rainfall is evenly distributed across that

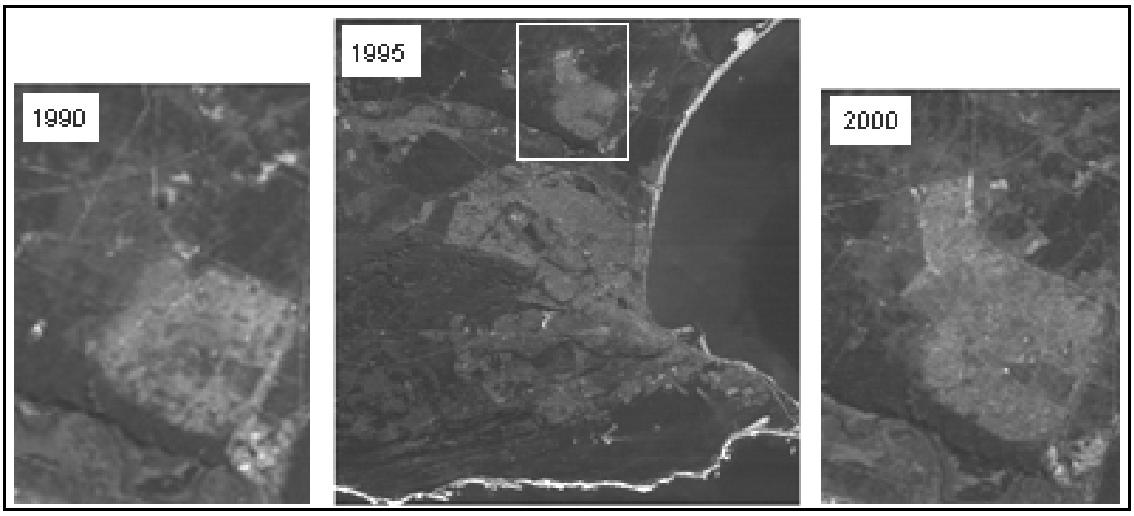

Fig. 1. An example of readily visible multi-temporal change of green space in an area within the city of Port Elizabeth

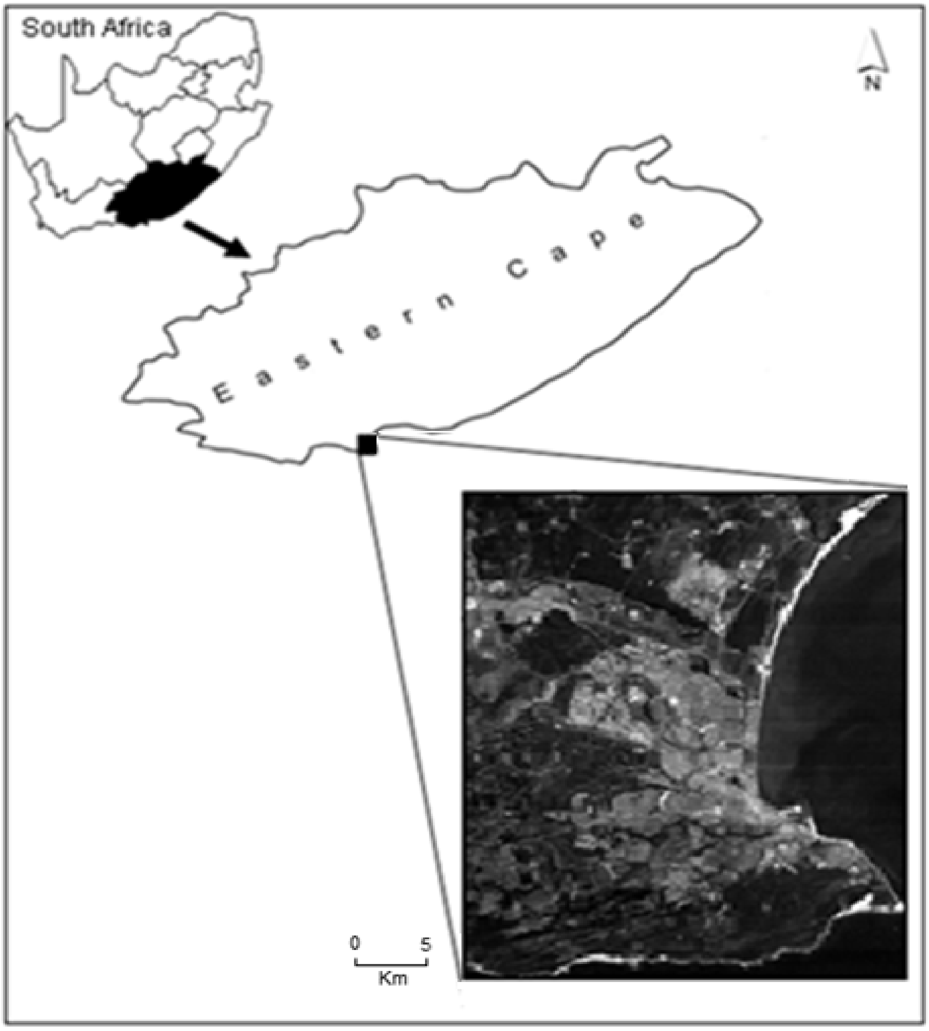

Fig. 2. Location of the study area

year. A 50 year climate data shows that the city has a mean annual daily maximum temperature of 22°C, a mean annual daily minimum temperature of 14°C and a mean annual precipitation of 624mm (South African Weather Service, 2010), the above conditions have made the city a favorable settlement destination. Depending on the type of land-use, the city's population density varies between 10 people/km^2 at its fringes to over 3000 people/km^2 in the inner city. Key land-uses in the city are residential, industrial and retail establishments. Whereas the city has since been incorporated into the wider Mandela Bay Metropolitan that includes smaller towns of Uitenhage and Dispatch, this study was restricted to the area formally occupied by the Port Elizabeth city.

MATERIALS & METHODS

The objective of change detection and monitoring is to compare imagery multi-temporal spatial representation caused by environmental conditions and human activities (Green *et al*., 1994; Singh, 1989). According to Lu *et al*. (2004) and Fuller *et al*. (2003), multi-temporal imagery change detection is premised on the distinguishable reflectance values of land cover types from changes caused by other factors like differences in soil moisture, sun and atmospheric conditions. Several change detection techniques that include among others multi-date composite image change detection (Eastman and Fulk, 1993), image change algebra (Green *et al*., 1994), image regression (Singh, 1986), on screen digitizing (Wang *et al*., 1992), post classification comparisons (Rutchey and Velchneck, 1994) and fuzzy sets and fuzzy logic (Metternicht, 1999) have been developed. The quality of change detection is often affected by thematic, spectral and spatio-temporal constraints. Consequently, the choice of suitable change detection technique from a range of existing ones is critical (Lu *et al*., 2004, Jensen, 1996). Approaches that involve post classification comparisons are the most commonly used (Dewidar, 2004; Jensen, 1996; Foody, 2002; Singh, 1989) and were therefore adopted for this study. Whereas their ability to reduce atmospheric and environmental effects between the image dates is the major advantage of post-classification approaches (Deng, 2008; Lu *et al*., 2004), the validity of results is often dependent on the quality and number of training data used to classify the images (Lu *et al*., 2004; Deng 2008). Common sensor, radiometric and spatial resolution images are essential in change detection analysis (Deng, 2008). Furthermore, images should be of similar or near anniversary dates (Quarmby and Cushnie, 1989). These pre-conditions are aimed at eliminating discrepancies arising from seasonal variations, sun inclination and phenological differences (Deng, 2008; Paolini *et al*., 2006). It is often difficult to obtain same sensor anniversary imagery, consequently, it is common practice in remote sensing to use near anniversary or even same season imagery for change detection (Coppin *et al*., 2004). In this study, we extracted a common relevant area of the city of Port Elizabeth from three sets of Landsat - 5 Thematic Mapper (TM) images detailed in Table 1.

Accurate registration of multi-temporal imagery is paramount in a change detection process (Morisette and Khorram, 2000; Townshend *et al*., 1992). Mas (1999) suggests that image registration for change detection should be less than a pixel as it eliminates errors arising from mis-registration. The imagery and corresponding aerial photos used in this study were first rectified to Universal Transverse Mercator (UTM) projection and World Geodetic System 1984 (WGS84) datum. Fourty five invariable points of features in the 1:50 000 topographic maps identifiable in the images were used for geo-registration process. Well distributed GPS readings of Ground Control Points (GCPs) common to the 1990 image and aerial photos were also collected and used for the geo-rectification process. Since the three image sets were from the same sensor, image to image registration using the 1990 as base image was preferred. The three sets of images were resampled using nearest neighbor interpolation and an accuracy of <0.5 pixel Root Mean Square (RMS) error achieved. Post geo-rectification accuracy was confirmed by GPS readings of clearly identifiable field features and their corresponding readings on the images.

As mentioned earlier, a fundamental requirement in a change detection process is that images used are phenologically and radiometrically comparable. Same season images (refer to Table 1) were used in this study and were therefore assumed to be comparable in phenology. However, other factors like sensor ageing, differences in solar illumination, atmospheric scattering and absorption and change in atmospheric conditions are known to affect multi-temporal change detection results (Mas, 1999; Jensen, 2005; Janzen *et al*., 2006). Radiometric normalization corrects for the discrepancies caused by the above named factors Jensen (2005). Using the process described by Paolini *et al.* (2006) and Jensen (2005), the three sets of images were normalized to a common reference scale. A number of studies - Liu and Chen (2006), Shank (2008), Phillipsa (2004) among others have found a near perfect positive correlation between Normalized Difference Vegetation Index (NDVI) and vegetation density. In this study, NDVIs were generated from the three multi-temporal images and used as proxies for vegetation density. All the areas with negative NDVI values (areas without vegetation) were amalgamated into a single class. With the aid of aerial photographs coinciding with image acquisition dates, positive NDVI values were re-classed and assigned estimated cover densities, see Table 2 and Fig. 3.

A Boolean mask was created for each of the cover densities to show multi-temporal changes in the different categories of green spaces (Fig. 4). To establish trends in green vegetation cover during the study, area for each of the green surface categories was calculated from the sum of the surface pixel counts converted into hectares (refer to Fig. 5).

Table 1. Characteristics of the multi-temporal imagery

Path/Row	Acquisition date and time	Spatial/Spectral resolution	Sun azimuth/ Elevation
171/83	29/05/1990 - 07:30:40	30m/7 bands	E41.88/22.36
171/83	12/06/1995 - 07:16:48	30m/7 bands	E43.94/18.90
171/83	11/06/2000 - 07:47:34	30m/7 bands	E39.91/23.12

Table 2. Image class descriptions and NDVI ranges

Class no.	Description	NDVI value	Vegetation density %
1	No vegetation	<0	<0
2	Very sparse vegetation	0 - 0.2	0 - 25
3	sparse vegetation	0.2 - 0.4	25 - 50
4	Dense vegetation	0.4 - 0.6	50 - 75
5	Very dense vegetation	>0.6	>75

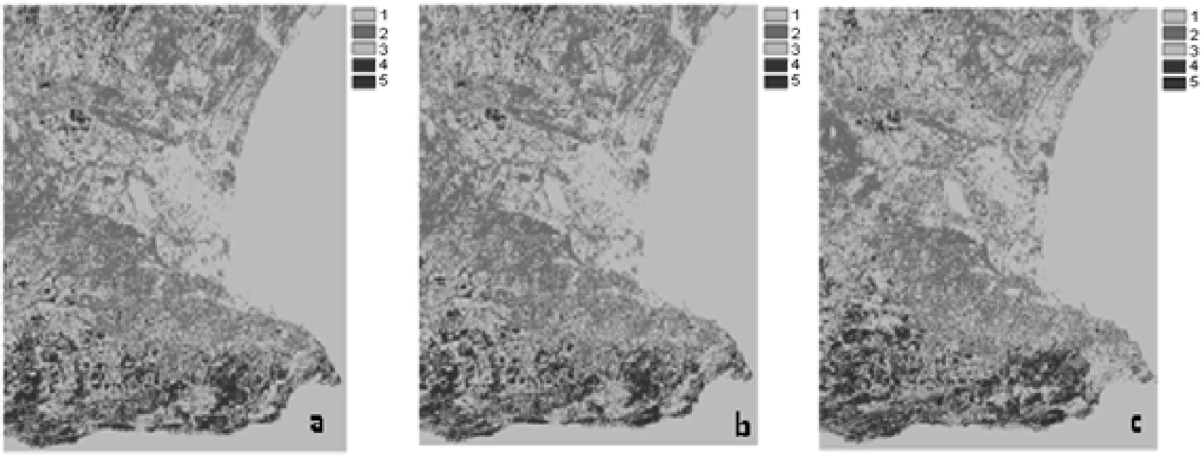

Fig. 3. Cover categories around Port Elizabeth; a-1990, b-1995, c-2000. 1-No vegetation, 2-Very sparse vegetation, 3-Sparse vegetation, 4-Dense vegetation, 5-Very dense vegetation. (See fig. 4 for individual cover categories)

RESULTS & DISCUSSION

There was a general decline in major green vegetation cover types between 1990 and 2010 in the city (Fig. 5). Areas covered by Very low vegetation density showed the most significant changes during the study period. This vegetation category declined by 13.6% between 1990 and 1995. This decline was the highest of all the green vegetation density categories studied in the 10 year period. Between 1995 and 2000, there was an 11.2% decline in Very low vegetation density. This surface class constituted a cumulative decline of 24.8% during the 10 year study period. The area covered by Low vegetation density was the most dominant green space around Port Elizabeth between 1990 and 2000. The area covered 42.2%, 42.0% and 42.1% of the total green spaces in 1990, 1995 and 2000 respectively. This area declined by 6.2% between 1990 and 1995 and 3.1% between 1995 and 2000 which was lower than the 13.6% and 11.2% recorded between 1990-1995 and 1995-2000 respectively for Very low vegetation density. Areas covered by High vegetation density had the lowest general decline in comparison to the Very low and Low cover density categories. These areas declined by 2.8% between 1990 and 1995 and by 9.0% between 1995 and 2000. According to (Flogard, 2004), increasing urbanization exerts pressure on existing green environments often leading to a transformation or clearance of existing green environment. In Port Elizabeth, like in many other South Africa's urban areas, the rapid decline in green spaces can be attributed to urban population influx associated with the transitional period (Christopher, 2001; Collinson *et al.*, 2007). According to McConnachie *et al* (2008) conversion of natural spaces to built up areas in urbanization processes impacts on natural areas through reduction in area, fragmentation and surface transformation. Post apartheid growth of informal settlements and the democratic government's efforts to address the urban housing and other infrastructure backlog through the Reconstruction and Development Programme (RDP) in most of the South Africa's urban areas have particularly led to a steady decline in urban green spaces (Pillay and Sebake, 2008; McConnachie and Shackleton, 2010).

Urban expansion is often determined by natural, legal, political and physical factors - see Yagoub (2004) and Mundia and Aniya (2005). Yagoub (2004) and Mundia and Aniya (2005) note that there is an overt spatial relationship between existing physical and social

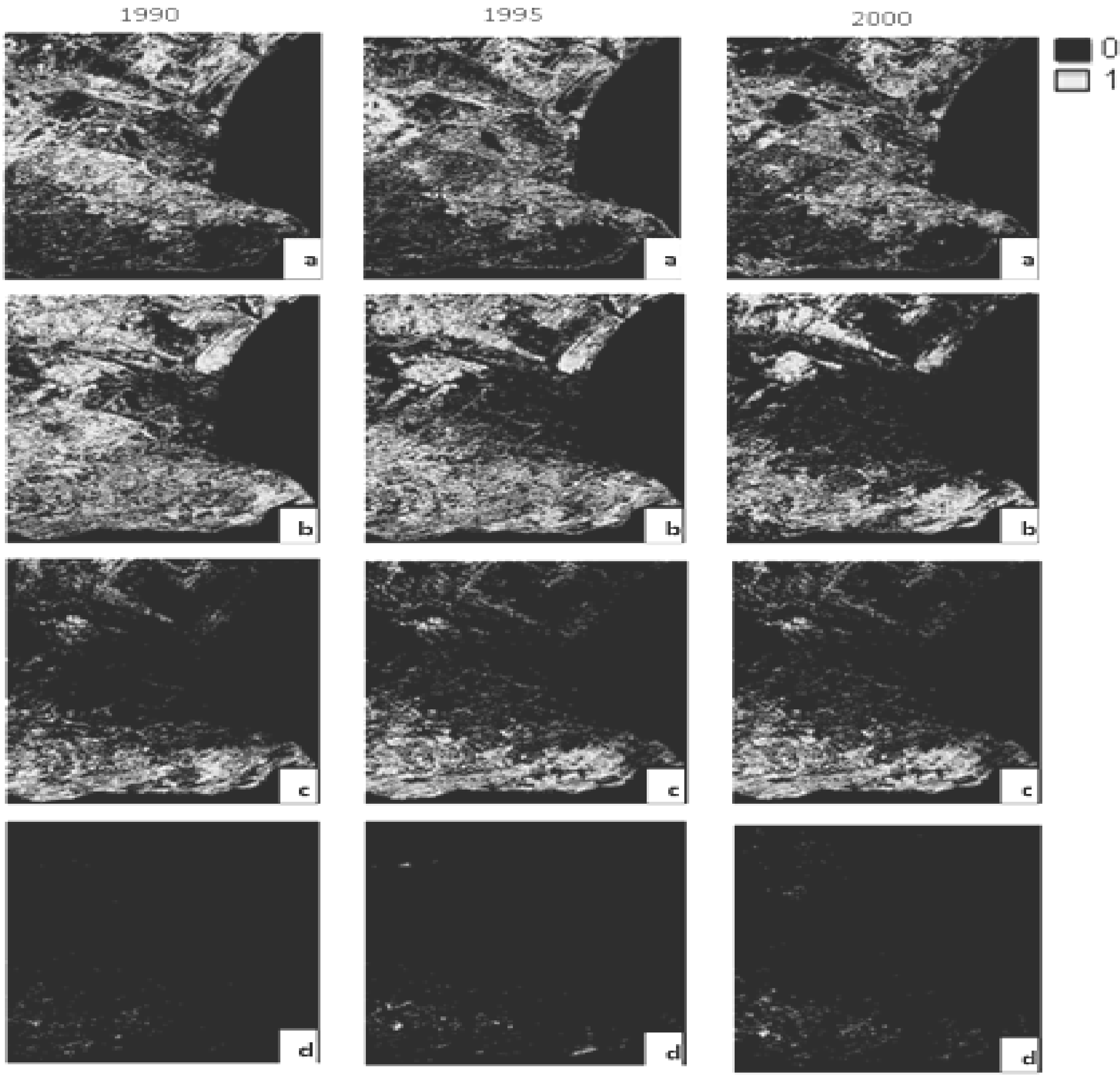

Fig. 4. Boolean images of green vegetation categories; a-Very sparse vegetation, b-Sparse vegetation, c-Dense vegetation, d-Very dense vegetation (1=vegetation class, 0=other vegetation classes and land cover types)

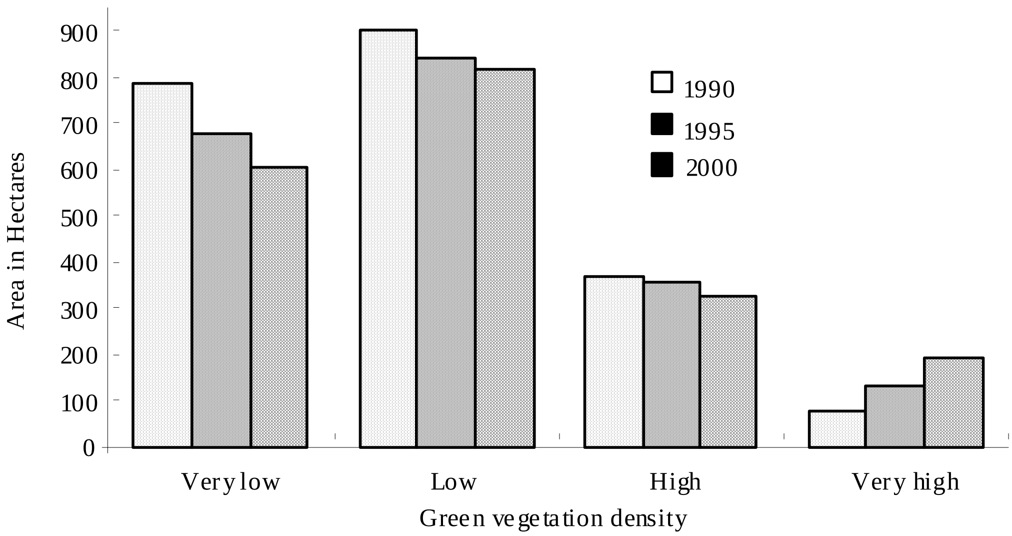

Fig. 5. Change in area for the different cover types during the study

infrastructure and urban internal and peripheral expansion. To reduce costs and enhance service delivery, South Africa's post apartheid government made significant investment in urban low cost settlement later formalized through the RDP in areas with existing social and physical infrastructure. In Port Elizabeth, the most significant decline in urban green spaces were in Very low or Low green vegetation density categories that were adjacent to existing built up areas-areas with little or no vegetation (see Fig. 5). The decline is consistent with Sukopp (2004) and Medley (1995) who note that the density and extent of urban natural environment is determined by human impacts that vary in both time and space. According to Sukopp (2004), urban areas show an inverse relationship between natural vegetation density and human impact along a gradient from the densely populated city centre to the outskirts. The more rapid decline of the two categories of green spaces around Port Elizabeth can be attributed to two major factors, firstly, to nucleate new settlements around existing physical and social infrastructure, areas in close proximity to already existing settlements were often the first to be cleared and secondly, the lower income earning new immigrants who occupied the fringes of the city relied heavily on the surrounding biomass as an alternative source of energy. The centre-outskirts urban ecology gradient approach proposed by Whittaker (1967) is evident in the High and Very high green vegetation density categories that dominate the furthest fringes of the city (refer to Fig. 3). In contrast to the general decline of other green vegetation density categories, there was a steady increase in the area covered by Very high density cover category. This category recorded a cumulative increase of 114.8% in the entire study period with a 63.2% increase between 1990 and 1995 and 51.6% between 1995 and 2000.

Whereas there is a general consensus that urbanization leads to decline in area and density of green spaces, Sharp *et al.* (1986) and Zipperer *et al.* (1990) note that urban areas may also experience gains in size and density of vegetation through reforestation and afforestation. As part of sustainable urban living initiatives, most cities have opted for conservation and improvement of the remnant green environments often found at an urban fringe (Flogard, 2007). In keeping with urban greening trends in most of the global cities, Port Elizabeth is one of the four cities in South Africa that has adopted the Metropolitan Open Space System (MOSS)-(Stewart, 2006). In addition to the MOSS urban greening initiative, the Department of Water Affairs and Forestry under the National Forestry Action Programme of 1997 and the White Paper on Forestry of 1996 have stationed two foresters in the city to establish and coordinate the city's urban greening and forestry programmes (DWAF, 1997). Whereas the reasons for increase in Very dense vegetation category were not investigated in this study, it can be assumed that the dual initiatives named above are part of the reason for the steady increase in this vegetation category.

CONCLUSION

South Africa's historical transformation in the 1990's was accompanied by rural-urban influx and consequent rapid loss of its cities green spaces. In Port Elizabeth, the use of Remote Sensing shows a decline in most categories of green vegetation cover density except in areas occupied by very dense vegetation. This study provides a historical inventory of past spatial green spaces trends that can form a basis for urban greening policy formulation and implementation that can help optimize sustainable urban socio-environmental and physical functions. Analyses using existing and emerging Remote Sensing techniques have become popular in diverse urban ecological applications. This study further illustrates the potential of such techniques in urban ecological mapping in the often dynamic urban environments.

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