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EFFECT OF INFRASTRUCTURAL DEVELOPMENT ON LAND USE AND COVER OF URBAN AREAS IN SWAZILAND; CASE OF MBABANE CITY

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ABSTRACT

This is an exploratory study that examined the role and influence of infrastructural development on land use and land cover (LULC) change, in light of sustainable development, in Mbabane city. It employed Geographic Information System (GIS) on time series data retrieved from analogue maps that were scanned, geo-referenced and then digitised, to produce land use maps for the years 1976, 1992 and 2006. These were then compared to observe extent, direction, causes, and effects of changes in LULC, and prominent land features. Infrastructural development (residential area/settlements and permanent buildings) was found to have increased by expanding the urban boundary and at the expense of 'native' LULC, namely; cultivated land and forests/plantations which were found to have either vanished or diminished down the years. It highlighted the significance of LULC change studies for informing the selection, planning and implementation of land uses; critical elements in the drive towards sustainable development.

Keywords: Infrastructural development, Land use and land cover (LULC) change, LULC map, Land use planning (LUP), Geographic Information Systems (GIS), Sustainable development

INTRODUCTION

Land use and land cover (LULC) pattern is an outcome of natural and socio-economic factors and their utilization by man spatio-temporally (Baboo & Devi, 2010; Monalisha, Kamal & Subudhi, 2006). Bhagawat (2011) noted that LULC has become a central component in current strategies of sustainably managing natural resources and monitoring environmental changes. This is more so because, according to Bajracharya, Uddin, Chettri, Shrestha & Siddiqui (2010), LULC changes are the most important and easily detectable indicators of global ecological change that directly impact biological diversity, while contributing to local, regional, and global climate change. Such also has the potential of causing land degradation through altering ecosystem services and livelihood support systems, thereby disrupting the socio-cultural practices and institutions associated with managing them (van der Linden & Hostert, 2009; Bhagawat, 2011).

Urbanisation is an index of transformation from traditional rural economies to modern industrial, resulting from the progressive concentration of population in an urban unit (Verma, Kumari & Tiwary, 2008). Even though the least developed in the world, Sub-Saharan Africa has been experiencing the highest population growth rate of 4.7%, rural-urban migration being the key driver (Tevera & Zamberia, 2010). Many a times, the positive aspects of urbanisation are overshadowed by deterioration in the physical environment and quality of life caused by the widening gaps between supply and demand for essential services and infrastructure. Urban expansion has significant implications for resource extraction and use, waste generation, and land transformation through built footprint expansion and changed LULC patterns (Van der Linden & Hostert, 2009). Rapid urbanisation, as highlighted by Bhagawat (2011), has therefore brought about serious losses of arable land, forest land and water bodies. Ultimately, it places an increasing demand on not just the land, but even on housing, services and infrastructure (Tevera & Zamberia, 2010) Such has led to LULC being a major concern of global environment change. It raises questions about urban areas' current and future ecological sustainability, and the types of interventions that may be required to move it towards greater sustainability (Gasson, 2002).

Verma *et al*. (2008) and Mengistu (2008) argued that urbanisation becomes inevitable when pressure on land is high, agriculture incomes are low and population growth rate is high, a common scenario in developing countries (Dlamini, 2000b; Tevera & Zamberia, 2010). In as much as urbanisation is desirable for human development, when uncontrolled, it has been found to be responsible for many of the problems experienced in urban areas (Baboo & Devi, 2010). Among others, these include sub-standard living environment, acute problems of drinking water, noise and air pollution, disposal of waste, traffic congestion (Verma *et al*., 2008; Dlamini, 2000a; Dlamini, 2000b). Hence, information on LULC changes, especially within the urban boundary, is essential for the selection, planning and implementation of land use schemes to sustainably meet the increasing demands for basic human needs and welfare (Baboo & Devi, 2010). Precisely, area or city-specific information of such changes in LULC is essential for land use planning and monitoring aimed at wise resource management. This also ensures the maximisation of the productivity of the land within them.

However, in most developing countries; Swaziland inclusive, information on these changes is either lacking or unavailable, especially at town or city level. This leads to difficulty in making generalisations as doing so could lead to erroneous conclusions (Mengistu, 2008). As alluded to, data shortage compromises the planning and monitoring exercise. Primitive approaches such as actual ground surveys that have been used for planning and monitoring lacked the spatio-temporal factor (Lucas, Rowlands, Brown, Keyworth & Bunting, 2007). It was in light of such limitations on such approaches that technological advancement birth GIS and Remote Sensing (RS). This is a technology that boasts of a strong capacity in data integration, analysis and visualisation (Kraak and Ormeling, 2003). Trung, Tri, Van Mensvoort & Bregt (2007) acknowledge that nowadays GIS and RS has become the main tool in land use planning (LUP). Its main advantage is its ability to perform multi-disciplinary and complex analysis both in time and space. This attribute makes it important for the monitoring, modelling and mapping of LULC changes across a range of spatial and temporal scales, in order to assess the extent, direction, causes, and effects of the changes (Mengistu, 2008).

This study employed the GIS tool to examine the role and influence of infrastructural development on LULC change and changes on the urban boundary of Mbabane City through the use of time series data retrieved from analogue topographical paper maps of the area. It explored the usefulness of analogue paper maps for incorporation into present day data structures and datasets as a source of invaluable historic LULC, and evidence of LULC changes for sustainable policing and future planning purposes as it availed tangible, empirical data on the impacts and environmental threats this expansion is posing on the ecosystems and environment of the city. It highlights the need for a carefully planned and monitored process of urbanisation, which if unattended to has the potential of adversely affecting the physical, human and socio-economic environment, and thus undermining the drive towards sustainable development by local municipalities.

Project Objectives

Specific objectives for the project were;

1. To geo-reference the 1:50 000 topographic map sheets showing Mbabane City for the years 1976, 1992 and 2004 to the LO31+ coordinate system.
2. To digitise the urban boundary and the different LULC and features within the urban boundary for the respective years into vector data.
3. To incorporate the newly produced vector data into a GIS system, and undertake an analysis on the effects and influence of infrastructural development on LULC changes in the city, and on sustainable development.

LITERATURE REVIEW

History of map production and use

The early 18th century introduced paper map production, motivated by the need to keep records of estates and boundaries amongst land owners. But it was not until the mid 19th century that accurately surveyed maps were produced. All these spatial information sources lacked true spatial aspect as they were analogue maps with just named collection localities (Raes, Mols, Willemse & Smets, 2009). New technological advances primarily backed by military intentions saw the introduction of aerial photographs in the 20th century, which went a long way in improving paper maps (Chang, 2010). By the late 20th century there was a massive breakthrough in electronic technology which led to the faster production of more accurate and geo-referenced maps using GIS.

Different needs, commonly being spatio-temporal analysis, birth the need for old analogue maps for reference and comparison purposes. The greatest challenge with these analogue maps is their lack of geographic location. Educational libraries, governmental ministries, departments, divisions and units, as well as ancient and historical monuments have amassed and avail tons of stored historic analogue maps, especially hard copies. Locally, the responsibility of mapping and map production for the country solely lies with the Surveyor General's department. Up until early 1992, the department employed manual means of data mapping.

Urban population growth, LULC and Sustainable Development

As early as 1996, Mbabane was already reported to be faced with a rapid rate of population growth, coupled by lack of resources to cater for them (Fraser, 1996). This has led to large populations being found in the city, with the municipality falling short of supplying these populations with standard services such as water, electricity, sewage system and road networks (Tevera & Zamberia, 2010). Worse off, the municipality has struggled even when it comes to the most basic need; housing. This has fuelled the mushrooming of slums and squatters, usually found in the urban periphery, which are without the basic needs. Moreover, these developments are found to be amongst those that lead to LULC change as past studies found them to be eating into agricultural land and forested areas. For example, a study undertaken by Monalisha *et al*. (2006), in Bhubaneswar city of India found that new urban region development was growing largely along main transport routes of the city, and mainly occurring on vegetation and agricultural land. Such are serious threats to sustainable development at the local level, and even at national level.

Highlighted key threats to sustainable development in Swaziland include the country's high dependence on natural resources (for example; the use of fuel wood as a source of energy), loss of biodiversity and increasing threats to existing ecosystems as a result of veld burning, overgrazing, demand for fuel-wood, land conversion and expansion of agricultural schemes. Others include population growth and human settlement, water stress for both human and environmental requirements, land issues, particularly equitable access to land and natural resources, but including land degradation. Most importantly, the challenge of ensuring that development and industrialization are sustainable and appropriate, and improving access to existing knowledge and technologies was highlighted (Tevera & Zamberia, 2010; Swaziland Environment Authority, 2002).

Growing population pressure and its associated problems, such as the increasing demand for land and trees, poor institutional and socio-economic settings, and also unfavourable government policies, such as lack of land tenure security and poor infrastructure development, have been the major driving forces behind LULC changes (Wang, Mitchell, Nugranad-Marzilli, Bonynge, Zhou & Shriver, 2009; Tevera & Zamberia, 2010). Those types of human-induced LULC changes transform natural habitats and pose the greatest single threat to biodiversity. Hence, more sustainable development efforts are needed through the introduction of sustainable land resource uses and management practices, secure land possession systems, regulated population growth, and integrated environmental rehabilitation programmes (Mengistu, 2008).

Unfortunately, for most developing countries, or rather urban areas within them, it takes a while before such land resource uses and practices are attained as noted by Tevera & Zamberia (2010). Many a times, by the time they are, there would have been a lot of unsustainable or even unplanned LULC changes that have taken place. To reverse or at least maintain the adverse alterations thereafter, knowledge of the past both in time and space is critical. As Mengistu (2008) highlighted, it is the source of data on the extent, direction, causes and effects of such LULC changes. This point is further qualified by Wang *et al.* (2009), who says that knowledge of historical trends of land cover change, not only how much has changed but also where and when changes have occurred, can help land managers identify key resource and ecosystem stressors, as well as prioritize management efforts. This is critical for sustainable development as it ensures that sound and sustainable land use planning (LUP) approaches are employed.

The use of GIS and RS for LUP and LULC change analysis/monitoring

A sustainable LUP approach requires a lot of data integration, multi-disciplinary and complex analysis. Moreover, it needs faster or more precise information for the participants in the LUP approaches (Mengistu, 2008). Current technologies such as GIS and RS provide a cost effective and accurate alternative to understanding landscape dynamics (Lucas *et al.*, 2007). Digital change detection techniques have demonstrated a great potential as a means to understanding landscape dynamics. These mainly include detection, identification, mapping, and monitoring differences in LULC patterns over time, irrespective of the causal factors (Bhagawat, 2011). This is because GIS and RS have a strong capacity in data integration, analysis and visualisation. Therefore, it has become the main tool to support LUP approaches (Trung *et al.*, 2007). It is important for the monitoring, modelling and mapping of LULC changes across a range of spatio-temporal scales.

Earth observation from space is now crucial for understanding the influence of man's activities on the environment temporally. In situations of rapid and often unrecorded land use change, observations of the earth from space provide objective information of human utilization of the landscape. Nowadays, RS data has become vital in mapping the Earth's features and infrastructures, managing natural resources and studying environmental change (Baboo & Devi, 2010).

However, the GIS and RS technology is most rewarding, especially spatio-temporally, if it employs geo-referenced data. Unfortunately, only recently undertaken projects during the GIS era are to such standard. Most of the masses of data, especially in developing countries like Swaziland, are in analogue format (paper maps). These datasets are a haven of crucial historic information such as LULC, and thus can enable the study of LULC changes in them in any area or region of interest. Since these maps are not geo-referenced, their use is minimal; especially in as far as their incorporation into a GIS system is concerned. Even upon acquiring analogue data in map or photographic format, for one to effectively use it for purposes such as comparisons especially in a GIS system, it has to be first registered, digitised, before it can successfully be introduced into a GIS (Anonymous, 2009).

Moreover, such technology is most effective in the developed countries where high resolution time-series data is reasonably and readily available. Swaziland, being a developing country, has the problem of RS data scarcity, mostly propagated by high cost associated with acquiring it (Lucas *et al.*, 207). It was in view of these facts that the study sought to employ the readily available datasets in the form of historic paper maps to study trends and patterns of LULC change in Mbabane. This also enabled the exploration of the usability of such data for enhanced sustainable development through improved assessment and monitoring of LULC, and changes.

METHODS

The study aimed at examining the role and influence of infrastructural development on sustainable development through consideration of LULC change and changes on the urban boundary of Mbabane urban area.

Study area

The Kingdom of Swaziland is one of the smallest countries on the African mainland. It is landlocked, with a land area of approximately 17 364 km^2 and lie between latitudes 25°43'S and 27°19'S and longitudes 30°47'E and 32°08'E in south-eastern Africa. It is divided into four administrative regions, and six agro–ecological zones based on elevation, topography, climate, geology and soils (Masarirambi, Manyatsi & Mhazo, 2010).

Mbabane, which is the capital city of Swaziland, lie between latitudes 26^{o}16'S and 26^{o}23'S, and longitudes 31^{o}05'E and 31^{o}11'E. It is located in the north-west of the country, under Hhohho administrative region (Figure 1), and in the Highveld by agro-ecological zones. The city centre lies at approximately 25km east of Ngwenya/Oshoek border gate, one of the major border gates leading to South Africa. According to the 1997-2007 Mbabane Structure Plan, Mbabane covers 8 035ha of land (Mbabane City Council, 1996). It is typically hilly to mountainous in terrain, ranging between 1050m and 1400m above sea level (Dlamini, 2000a). The climate of Mbabane is characterised by wet summers and dry winters, and annual rainfall averaging 1 500 mm. The vegetation is mainly sour mountain grassveld. Temperatures vary between a maximum of 33^{o}C in mid-summer and 0ºC at night in mid-winter, while mean annual temperatures are cool, at about

16°C (UNISWA Consultancy &Training Centre, 2008; Dlamini, 2000b; Monadjem, 1999). The main rivers draining the area are Mbabane River and Pholinjane River.

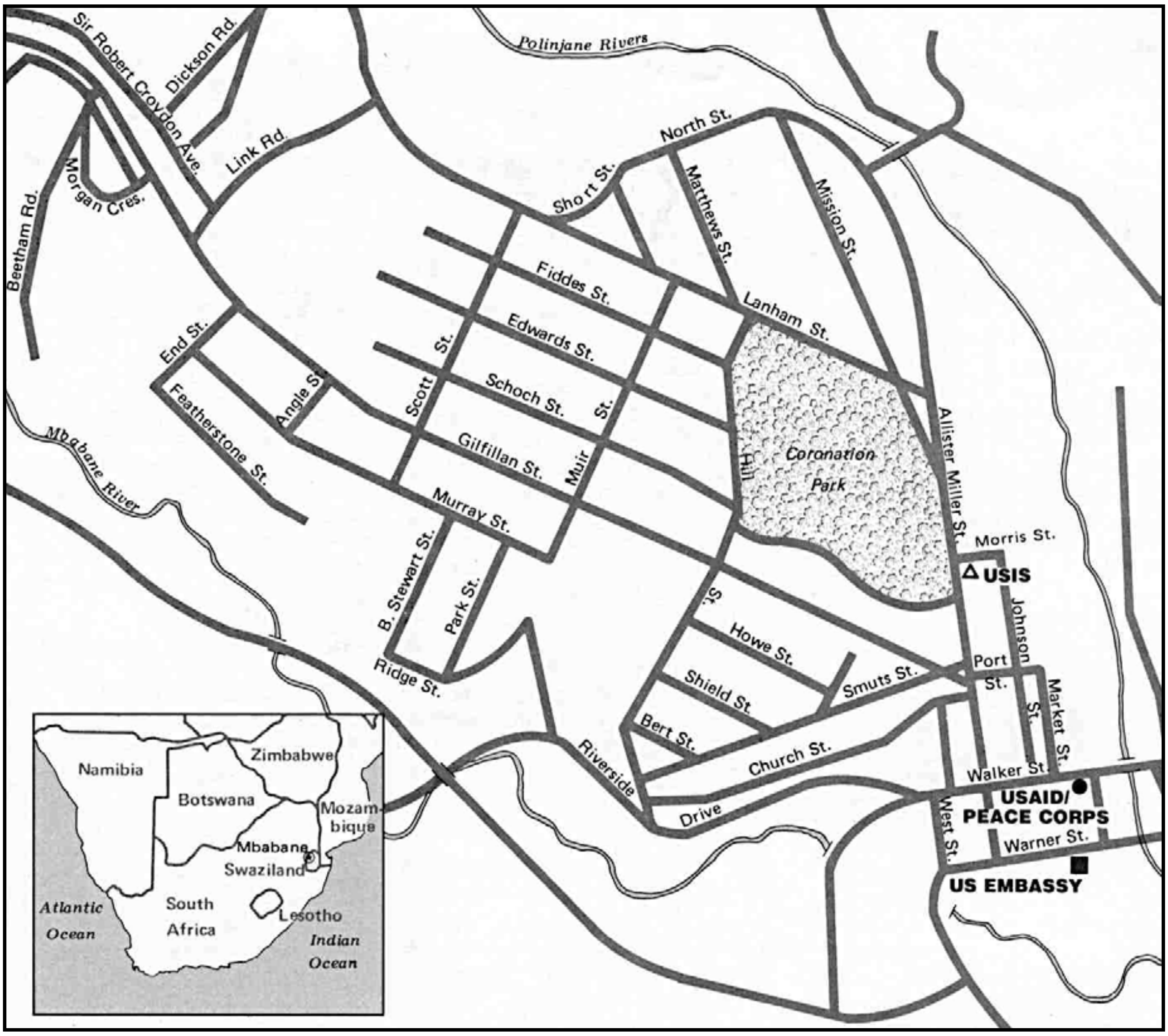

Figure 1: Location of the study area, Mbabane urban area in north-western Swaziland as shown on the insert map
Source: NationMaster, 2012

Sources of data and its preparation

The study primarily employed data from analogue paper maps for the years 1976, 1992 and 2004. These, specifically, were 1:50 000 topographic maps sourced from the Surveyor General’s office. Mbabane urban area falls within one topographic map sheet. On the 1976 and 1992 versions, it falls within sheet number 11 (Surveyor General’s Office, 1988) while on the latest sheet divisions, it falls within sheet 10 (Surveyor General’s Office, 2005). A set of corrected colour aerial photographs of Mbabane, captured in the year 2006, were used. The aerial photographs making up Mbabane urban area were then created into a mosaic in ArcMap software using the Arc toolbox. This RS data was selected because it provided suitable cloud-free spatial coverage with relatively high spatial and spectral resolutions (Golmehr, 2009).

Georeferencing of analogue paper map scans

The paper maps for the respective years were scanned, and the resultant scans for each year were saved as tiff files. Before registration was undertaken, the paper map scans for the respective years were trimmed/cropped of redundant scan parts that fell outside of the study area, which resulted in neat map scans as shown in Figure 2. These cropped tiff files were then introduced into a GIS (ArcMap 9.3). Registration of the pre-scanned paper maps was then undertaken. According to Golmehr (2009), accurate registration of RS data is essential for analyzing LULC conditions of a particular geographic location.

However, for such data to be incorporated into a GIS and to employ it meaningfully for the analysis there had to be a geo-referenced dataset (raster image) which would serve as a base map. Kraak and Ormeling (2003), highlight that for one to successfully combine any two or more datasets in order to execute spatial analysis or a cartographic compilation, the sets have to be referenced in a common coordinate. The colour aerial photographs mosaic, which was projected to the local grid system (LO31+), served this purpose; ensured that the paper map scans assumed the same coordinate system during registration.

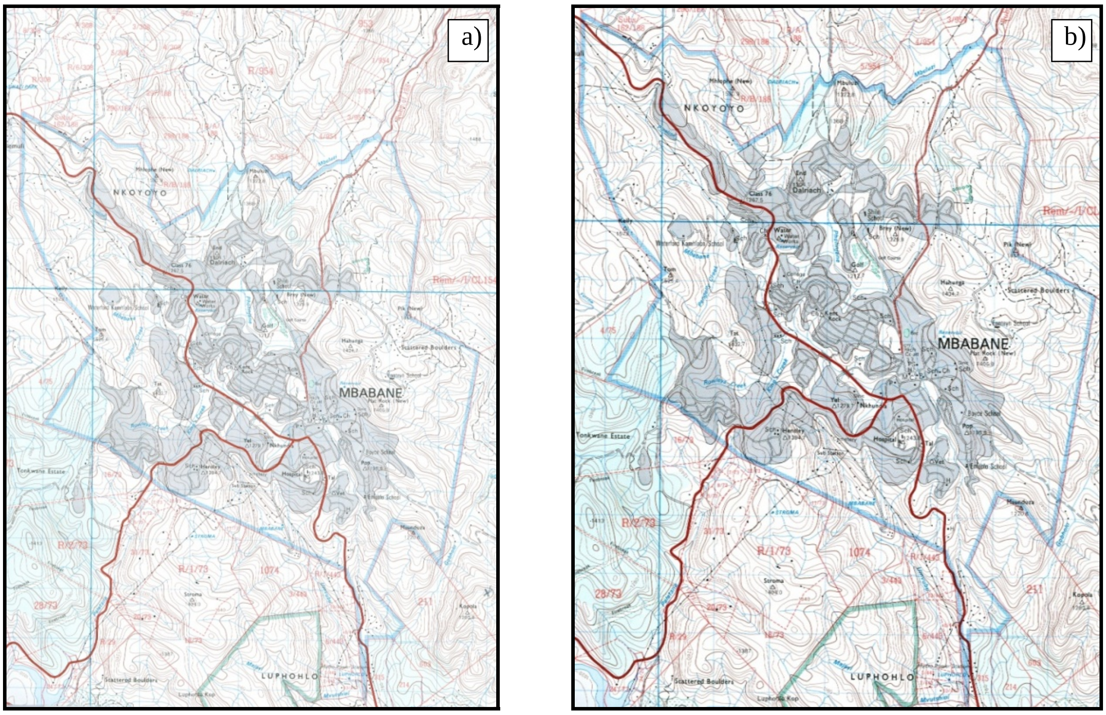

Figure 2: a) An example of a paper map scan: part of 1:50000 toposheet number 11 for the year 1992 and b) showing a crop of Mbabane urban boundary (blue solid line) in the scan

This was followed by locating permanent features and points visible on both the base map and the non-geo-referenced map scans. These were then used as control points to geo-reference the three topographic paper maps for the respective years using the geo-referencing tool in ArcMap software.Then these points in the map scans that were initially used as reference points were pulled to the corresponding points in the base map. This ensured that the end product (registered map) had the same coordinate system and scale as the base map. A constant check on residual and Root Mean Square (RMS) errors was used to ensure best-fitting of the paper maps. The registration process was done with RMS of 0.324, 0.356 and 0.317 the 1976, 1992 and 2004 map scans respectively.

Digitization for different LULC and features

The resultant corrected images were then digitised for the urban boundary; different LULC and features within the boundary through performing on-screen digitising. This is a process which is known to be reliable, but challenging in terms of being tedious and time consuming (Kraak and Ormeling, 2003). It involves creating shapefiles for each of the respective classes and features that were to be classified. Then through the editor tool, points and polylines of different features and polygons of different land covers were digitised and saved into their respective classes. This resulted in digital/geo-referenced land use maps for the respective years. According to van der Linden and Hostert (2009), aerial photography has been successfully used for urban area cover delineation. The 2006 colour aerial photograph was therefore used to update the resultant 2004 topographic map. The three resultant LULC maps for the respective years were then compared to observe trends, patterns and changes in LULC, and prominent land features. The results, even though also given through other representations, were mainly presented in map form.

FINDINGS AND RESULTS

This research work sought to observe the urban boundary of Mbabane City, as well as changes in LULC and features within the urban boundary using time series data for three years; 1976, 1992 and 2006.

Mbabane urban boundary

Table 1 depicts that the urban boundary of Mbabane has increased down the years. In the year 1976, the total urban area of the city stood at 39.07 km^2. By 1992, it had increased by over 16 km^2 (42.3%) to 55.09 km^2. However, in the next ten years, a decline in the expansion rate of the urban boundary was observed as it increased by just over 8 km^2 (14.9%) to a coverage area of 63.87 km^2. The observed growth in the urban boundary was notably in the north easterly and south westerly direction for both the years 1992 and 2006 (Figure 3).

Table 1: Land coverage area of Mbabane urban boundary for the years 1976, 1992 and 2006

Year	**1976**	**1992**		**2006**	
Urban area boundary coverage	Coverage area (km^2)	Coverage area (km^2)	% change	Coverage area (km^2)	% change
	39.07	55.59	42.28	63.87	14.90

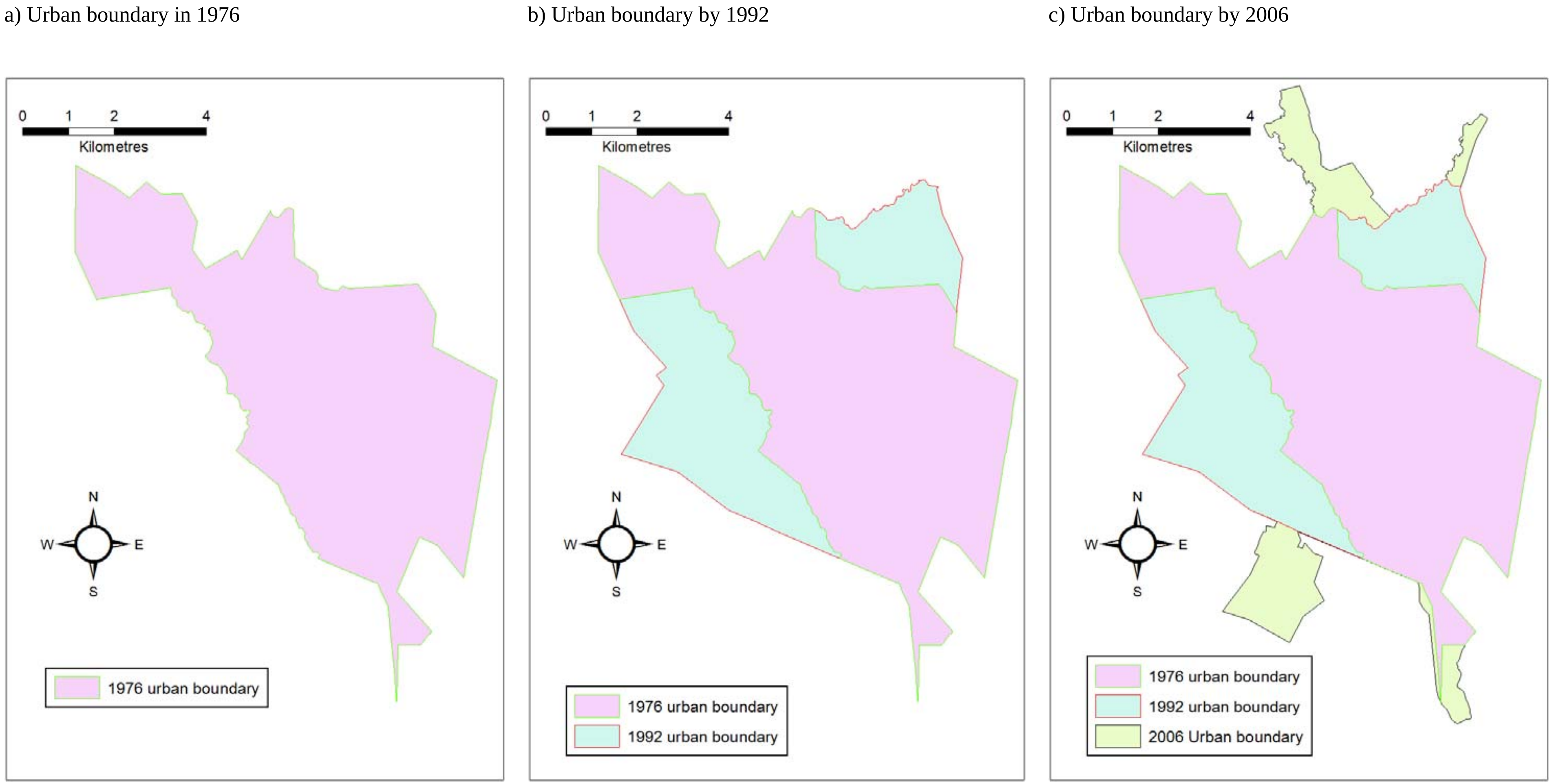

Figure 3: Urban boundary of Mbabane urban area for the years 1976, 1992 and 2006 respectively

Mbabane LULC maps

Land features within Mbabane urban boundary

The key features that were digitized for in the LULC maps of the three respective years included main roads, secondary roads, other roads, motorable tracks, foot paths and rivers, as shown in Table 2. Other features that were found in the 1976 map included kraals, huts, villages and water reservoirs. However, these were not found on the 1992 and 2004 maps (Figure 4). The 1992 map had a strip of trees which were probably planted as windbreakers on the mountainous Fonteyn area. Unlike the 1976 and 1992 maps, the 2006 map had a lot of settlements in the form of individual homes on the outskirts of the town, where infrastructural development is not as concentrated and thus not classified as permanent buildings.

Table 2: LULC and features of Mbabane urban area for the years 1976, 1992 and 2006

Land feature (km)				**Land use or land cover (km^2)**			
Year	**1976**	**1992**	**2006**	**Year**	**1976**	**1992**	**2006**
Main roads	21.62	18.61	22.95	Forest plantation	4.68	2.25	3.1
Secondary roads	6.09	6.06	12.63	Permanent buildings	4.20	17.15	20.81
Other roads	48.71	106.98	152.33	Recreational land (Golf course)	-	0.08	0.08
Motorable tracks	24.10	3.57	1.86	Cultivated land	0.22	0	0
Foot paths	48.40	18.41	0.91	Dams	0.33	-	-
Rivers	107.21	104.65	63.78	Open land	29.93	36.10	39.88

LULC within Mbabane urban boundary

Six key LULC classes were found within Mbabane urban boundary for the three respective years. Figure 4 shows the LULC maps of Mbabane urban area for the years 1976, 1992 and 2004 respectively. The LULC found were forest plantations, permanent buildings, cultivated land, recreational land (golf course), dams, and open land. A summary of the total coverage area of the different LULC and changes in their spatial coverage down the years is shown in Table 2.

a) LULC map for 1976 b) LULC map for 1992 c) LULC map for 2006

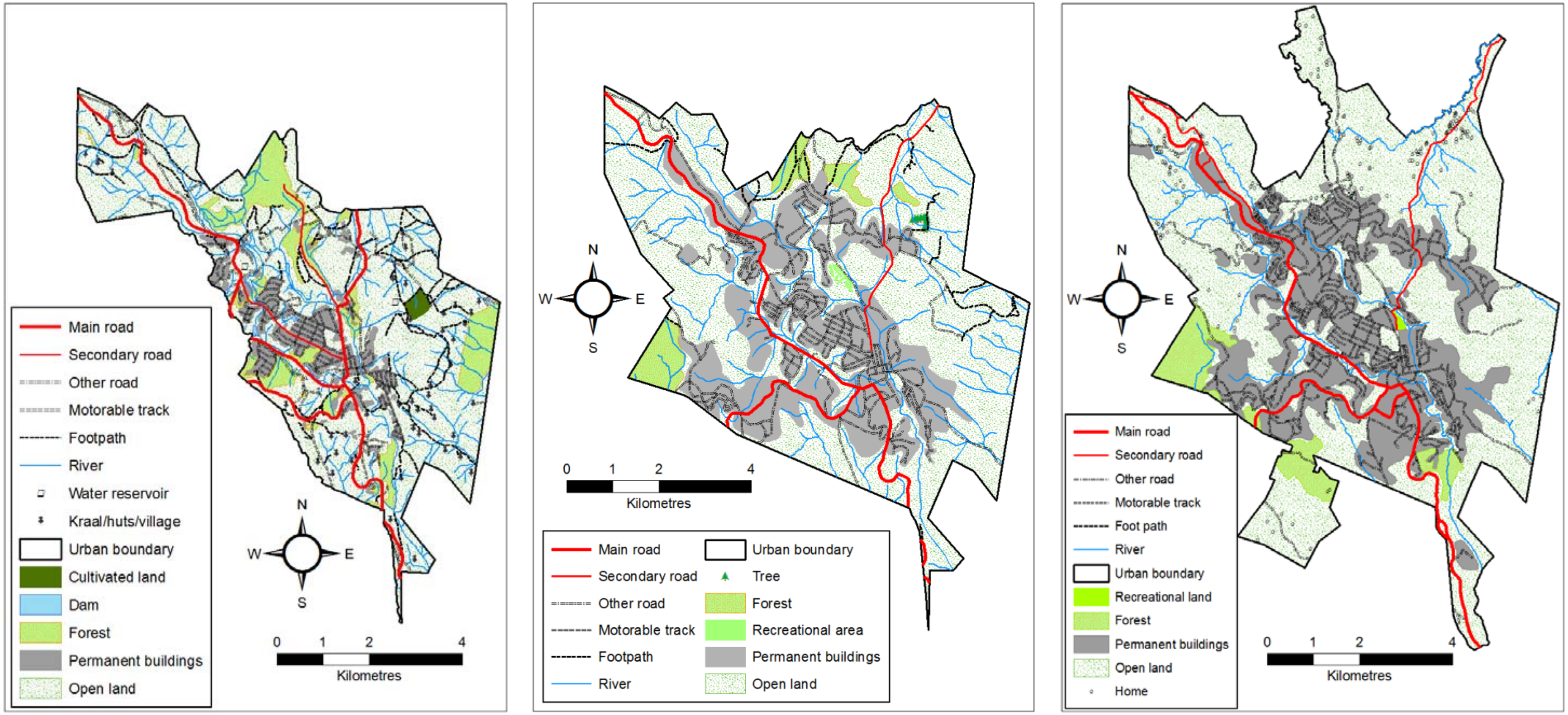

Figure 4: LULC map of Mbabane urban area for the years 1976, 1992 and 2006 respectively

DISCUSSION OF RESULTS

Limitations of time series data

Unlike with the urban boundary, it has to be highlighted that due to different ages of the time series data and, most likely, different cartographers mapping and producing the maps for these years, the keys of these maps were found to be inconsistent for some land features and LULC. This resulted in some features and LULC being prominent in some years, but missing or unclassified in the other. This somehow had a limitation on the analysis of changes. For example, the 1976 map showed dams and reservoirs yet in the 1992 and 2004 maps, these were not shown.

LULC and LULC changes within Mbabane urban boundary

Urban boundary expansion

The urban boundary of Mbabane was found to have expanded down the years. However, the expansion rate (42.3%) between the years 1976 and 1992 was much higher than the rate experienced thereafter to the year 2006 (14.9%). This could be an indication that this was the era where there was maximum urban development within Mbabane. The pattern of the boundary expansion highlight, amongst others, the role landscape features have on the direction it takes. Mbabane city is bounded by the Dlangeni hills on its eastern part. Due to the financial implications associated with the development and provision of amenities and services on areas with such terrain, the eastern boundary has remained the same in all three respective years. The same held true for the mountainous Nkoyoyo and Waterford areas where the boundary has tended to shy away from the hills. Growth seemed to easily move in the north easterly and south westerly directions for both the later years; 1992 and 2006 (Figure 3), in the direction of relatively sloping terrain.

Changes in land features within Mbabane urban boundary

An analysis on the patterns and changes of the land features down the years shows a very strong influence of infrastructural development on them. Between the years 1976 and 1992, there had been no change on the total distance covered by secondary roads within the urban boundary. However, by the year 2006, there had been a major change on it as its total distance had doubled from just over 6.06km to 12.63km (108.42% increase). This is partly due to the extension of the urban boundary towards Mbuluzi area, which is now serviced by a secondary road. Mainly, as shown in the north-western part of Figure 4c, it was due to the establishment and development of Makholokholo Township, and Ngwenya-Mbabane road network (infrastructural development).

Notably, all the LULC maps (Figure 4) depict that the built-up area which is made up of the CBD and residential areas are mainly serviced by the road feature type called 'other roads'. As proof that massive infrastructural development has taken place, between the years 1976 and 1992, other roads within Mbabane urban boundary increased from 48.71km to 106.98km, an increase of about 120% (Table 3). With continued urban boundary expansion and infrastructural development, by the year 2006 (Figure 4c), the total distance of other roads stood at 152.33km, an increase of 42.4% (Table 3). This is in agreement with studies such as Monalisha *et al*. (2006), which also found new urban development growing largely along main transport routes of the city. However, there is a cause for concern as it has been found that this propagates unsustainable LULC (Swaziland Environment Authority, 2002).

Table 3: Changes in land features within the urban boundary for years 1976, 1992 and 2006

Year	1976	1992		2006	
Land feature	Coverage area (km)	Coverage area (km)	% change	Coverage area (km)	% change
Main roads	21.62	18.61	-12.92	22.95	23.32
Secondary roads	6.09	6.06	-0.49	12.63	108.42
Other roads	48.71	106.98	119.63	152.33	42.39
Motorable tracks	24.10	3.57	-85.19	1.86	-47.90
Foot paths	48.40	18.41	-61.96	0.91	-95.05
Rivers	107.21	104.65	-2.39	63.78	39.05

A closer analysis on the three LULC maps (Figure 4) for the three respective years shows that a bigger portion of the new other roads feature were resulting from upgrading of motorable tracks and foot paths, which might have been done to accommodate the higher population and infrastructural development setting in on areas that were previously lightly settled upon. Motorable tracks decreased from a total distance of 24.1km in the year 1976 to a meager 3.57km in 1992 and 1.86km in 2006 (Table 3). Even though by infrastructural standards this may be deemed as a good advancement, this might not have been the case in view of sustainable development if the environment was not prioritized during the road upgrades. Motorable tracks tend to be dirty tracks usually with very low traffic and hardly any environmental disturbance. However, besides the engineering works that goes into the construction of 'other roads', there is a lot of disturbance on flora and fauna during works, and as a result of increased traffic flow as a result of increased settlements.

On the same note, foot paths declined from a total distance of 48.4km in the year 1976 to 18.41km in 1992, and only 0.91km by 2006. However, it has to be highlighted that some changes could be as a result of differing prioritization of LULC and features during data mapping for the different years. Different surveyors tend to perceive and classify the same piece of land differently. Specifically, the mapping of an area is quite subjective and may differ between surveyors depending on their knowledge, perception and ability to delineate and classify mosaics (Lucas *et al*., 2007). Clearly, infrastructural development led to the diversion of some rivers, destruction and draining of some river sources such as wetlands (Figure 4). This land feature, therefore, reduced down the years; in terms of total distance, and this has an implication on sustainability.

Changes in LULC within Mbabane urban boundary

As the total coverage area within the urban boundary increased, it was found that so did the advancement of infrastructure within it. The influence of infrastructural development on LULC and its influence on sustainable development was the main focus of the paper. The most evident land use directly linked to infrastructural development within Mbabane urban boundary was found to be permanent buildings. In 1976, permanent buildings only occupied 4.20 km². However, sixteen years later (in 1992) their coverage had hiked to 17.15 km² (308.33% increase). This indeed lined up with the observed 42.3% increase in the urban boundary and the massive hike (120%) in the other roads feature that services them, between the years 1976 and 1992 (Table 1 and Figure 3). The same proportionality was observed even fourteen years later (2006) as the area occupied by permanent buildings had increased to 20.8 km² (a 21.3% increase), while urban boundary had increased by 14.9%. Permanent buildings are closely linked to roads because once a structure has been put into place; accessibility to that structure has to be ensured through availing a road network to it. It was therefore expected that increased permanent buildings coverage would be accompanied by an increase in the total distance covered by the road network, as the study showed (Table 2 and Figure 4).

Table 4: Changes in land use within the urban boundary for the years 1976, 1992 and 2006

Year	**1976**	**1992**		**2006**	
Land use or cover	Coverage area (km^2)	Coverage area (km^2)	% change	Coverage area (km^2)	% change
Forest plantation	4.68	2.25	-51.92	3.10	37.78
Permanent buildings	4.20	17.15	308.33	20.81	21.34
Recreational land (Golf course)	-	0.08	N/A	0.08	0.00
Cultivated land	0.22	0	-100.00	0	0.00
Dams	0.33	-	N/A	-	N/A
Open land	29.93	36.10	20.61	39.88	10.47

Importantly, for such infrastructural development to take place, not only was the urban boundary being expanded to cater for such (that is open land being expanded into), rather land that had been occupied by other LULC was taken. This meant a change in LULC in those respective parts of Mbabane. It was found that forests, plantations and cultivated land were being cleared to allow the implementation of more infrastructural construction. For example, in the year 1976, forests within the urban boundary, as shown in Figure 4, accounted for a spatial coverage of 4.68km^2. However, even though the urban boundary had expanded yet into more forested area in the western part of the city, the overall spatial coverage of forests had plunged by over 51% to only 2.25km^2 in the year 1992. Even the slight increase in the total forested area observed in the 2006 was as a result of continued urban boundary expansion into forested areas. This highlights that, just as depicted by the time series LULC maps in Figure 4, this land cover had predominantly been replaced by permanent buildings and roads.

A land use that was totally changed, and in the process eliminated within the urban boundary is cultivated land. In the year 1976, cultivated land covered 0.22km^2, which was gone by 1992 and 2006. This aligns with Monalisha *et al*. (2006) that new urban region development mainly occurred on vegetation and agricultural land. This is yet another cause for concern in sustainable development context as these are exactly the highlighted key threats in Swaziland (Swaziland Environment Authority, 2002). However, it is worth mentioning that the portion of land that had been classified as cultivated land in the year 1976 was classified as open land in the 1992, but as permanent buildings in 2006. Unless cultivation was abandoned completely and the land was left to lie fallow in the year 1992, this could highlight the inconsistency that was observed in the legend and level of classification of LULCs used by the cartographers in the three paper maps for the respective years.

CONCLUSION

From this study, it was concluded that indeed GIS and RS is a critical tool for sustained and responsible LUP, as it has proven to boast of a strong capacity in data integration, analysis and visualisation. Even though the focus was just on the retrieval of historic data, primarily from analogue paper maps, the study showed that this technology is important for monitoring, modelling and mapping of LULC changes across a range of spatial and temporal scales as it enables the assessment of the extent, direction, causes, and effects of these changes.

The study concluded that, indeed infrastructural development has a critical role and influence on the landscape and the LULCs practiced in an area. It highlighted that urban development, other than through the expansion of the urban boundary, mainly comes through inherent change in LULC. The expansion of built-up areas with permanent buildings in Mbabane was found to mostly affect forested areas and cultivated land as such land uses were found to have diminished and eventually disappeared down the years. Expansion of the urban boundary was found to be mainly inspired by the need for more residential areas outside of the CBD, which most likely is being exacerbated by the high rate of rural-urban migration, and thus the hike in the city's population. As a result of this population hike, the demand for built up areas (both for business and residential use) was essential to meet the bigger needs of this larger society. Unless outmost care was and is being taken care of, this may have a huge effect on the drive towards sustainable development in the city and nationally, as the necessity for infrastructural development may outweigh the importance of a sustainable tomorrow.

Such knowledge and consideration is critical for enlightening planners and policy-makers on the challenges and implications that may be brought about by urban development and inherent change in LULC, especially in the Swazi context. Swaziland, as previously mentioned, is a country highly dependent on natural resources for the sustenance of the economy as well as social living of citizens. Thus the urgent need for policy-makers and planners to prioritize such critical factors, as failure to do so would result in a bleak future in the country's development. The costs of mitigating effects of ill-planned developments are extremely high and not an options for a developing society. This study therefore, highlighted the significance of LULC change studies in informing the selection, planning and implementation of land uses that will sustainably meet the increasing demands of societal needs.

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