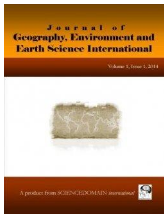

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Geospatial Assessment of Uncontrolled Urbanization and Its Deviation from an Intelligent City: A Case Study of Fort Portal, Uganda

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Authors' contributions

This work was carried out in collaboration between the two authors. Author IW designed the study, wrote the protocol, managed the literature searches and intellectual contribution. Author MK performed the field data collection, remote sensing image analysis, geo-spatial data modelling, statistical analysis and wrote the first draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Uncontrolled urbanization is one of the major geo-environmental challenges facing the developing world today towards attainment of intelligent cities. Various studies have mainly concentrated on impact of uncontrolled urbanization on urban heat island, air quality and housing with little focus on its alteration of urban vegetation cover a major parameter on growth of intelligent cities. This paper uses geo-spatial and remote sensing approaches to assess land cover patterns derived from pixels using maximum likelihood supervised classification of the Landsat data of Fort portal municipality in Uganda using ENVI 5.2 and Arc GIS 10.1. The change detection statistics obtained from land cover transition were analyzed on six years' interval from 1998 to 2016 basing on the principles of intelligent urbanism. Five major land cover classes - built-up, sparse vegetation, thick vegetation, bare ground and water were obtained. There was an increase in the built-up from 6.89% to 27.38%, bare ground from 12.68% to 39.39% and a decrease of vegetation from 80.42% to 32.4%, almost

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constant transition from vegetation to built-up of 169.38 Ha (1998-2004), 185.76 Ha (2004-2010) and 139.14 Ha (2010-2016) and a positive transition from bare ground to built-up of 122.31 Ha (1998-2004), 267.66 Ha (2004-2010) and 384.21 Ha (2010-2016). A rapid transition of vegetation cover to built-up is preventing Fort portal from developing into an intelligent city as it is defying the principle of environmental sustainability. The findings can be used as a check point on transition rate of existing land cover to built-up zones in urban areas and to control the radial and linear expansion of towns/ municipalities/ cities using green belts to achieve intelligent cities.

Keywords: Environmental sustainability; intelligent cities; urbanization; vegetation.

1. INTRODUCTION

Urbanization is a process through which the nation passes as they evolve from agricultural to industrial societies [1]. Urbanization is a gradual increase in the proportion of people living in urban areas and the ways in which each society adapts to the change. [1] define urbanization as a society's transformation from a predominantly rural to a predominantly urban population. Urbanization usually takes place in a radial direction around a well-established city or linearly along highways and uncontrolled urbanization leads to uncontrollable movement of people from rural to urban areas that include gazetted cities, municipalities and town councils and ungazetted trading centers [2] which is attributed to well-paid jobs and other daily life facilities. The transition of urban water shades from their natural forested state to a predominantly urban condition includes the removal of vegetation, compaction of soil, alteration of natural drainage networks among others [3], thus uncontrolled urbanization is responsible for changes in the physical environment and the spatial structure of cities. In many developing countries, uncontrolled urbanization is threatening the environment including vegetation resulting in urban areas characterized by inadequate housing, urban poor, informal settlements and congestion [4]. These urban areas lack the elements of intelligent cities that include balance with nature, balance with tradition, appropriate technology, conviviality, efficiency, human scale, Opportunity matrix, regional integration, balanced movement and institutional integrity [5]. However, some cities have been able to successfully control urbanization, a case in point is the use of Hukou system in China where by law, anyone seeking to move to a place different from where their household was originally registered had to get approval from the Hukou authorities [6]. This was supplemented by China's urbanization and the urban public administration reform since the 1978, which changed public policies in the realms of employment, housing, social insurance and the devolution of government authority by handing over part of public services which used to be delivered by the central government and state-owned enterprises to local governments and to devolve a part of responsibility to the private sector, the social sector and individuals [7] and this was strengthened by more programs to increase impact [8].

In order to understand the impact of uncontrolled urbanization on achieving intelligent cities, this study focused on Fort portal municipality (Fig. 1). It is Uganda's major tourism area located at the foot of Rwenzori Mountains at latitude (00°20'- 1°00') N and longitude (30°0'- 30°30') E with average altitude of 1480 m above mean sea level, total area of 4043 Ha (40.43 Km^2), boundary length of 35.06 Kms and 297 km by road west of Kampala Uganda's Capital [9]. It is famous for the stalagmites, stalactites and Nyakasura falls linked to the rich Chwezi culture and it is surrounded by scenic crater lakes, beautiful tea plantations and the Rwenzori ranges. The municipality has tropical vegetation and experiences tropical wet climate with an average monthly temperature of 20° Celsius and is a gate way to various national parks including Kibaale, Semuliki, Queen Elizabeth, Bwindi Impenetrable, Rwenzori and Toro-Semuliki wildlife reserves.

Since gaining municipality status in 1976, Fort portal has experienced uncontrolled urbanization [10]. This has led to conversion of natural features to sealed surfaces like buildings, parking lots, roads, pavements among others and as such the elements of intelligent urbanism are being altered especially the principle of environmental sustainability. If this growth trend continues, we could soon see urban slums with the least livable conditions for city dwellers in the future as vegetation cover is altered. Thus the need to analyze ways of achieving intelligent urbanism considering vegetation cover as a key component so as to aid in physical planning and urban design using geo-spatial techniques.

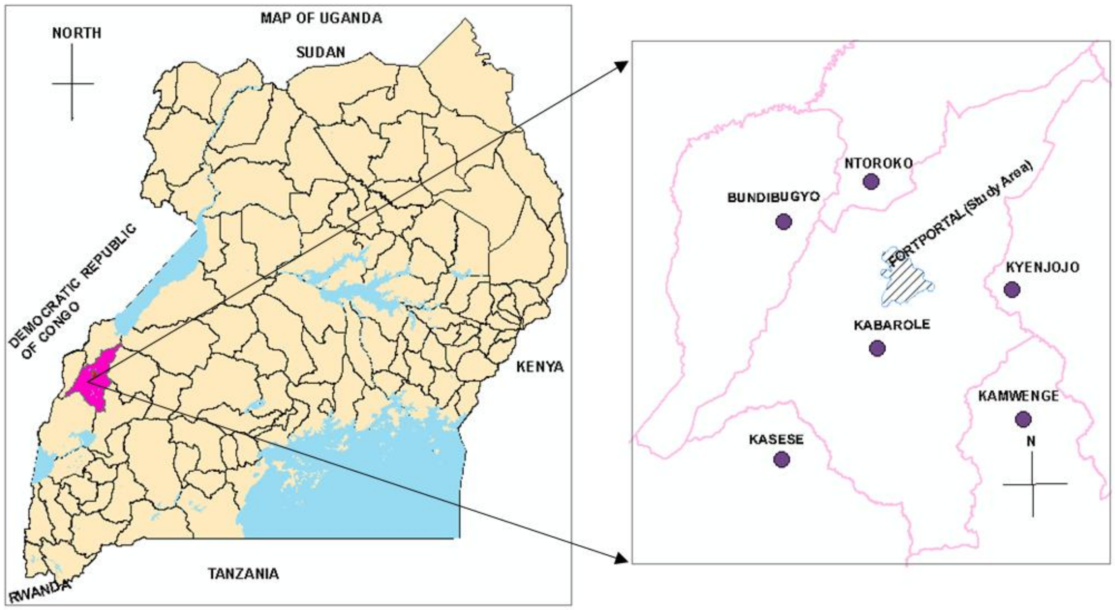

Fig. 1. Location of fort portal in Uganda and its neighboring districts

2. LITERATURE REVIEW

Cities are and will continue to be important as centers for civilization, commerce, innovation and as a home for millions of people including the poor [11]. This lead to congestion due to increased migrations from rural to urban areas, pollution and the emergency of urban slums [12]. Cities are also social melting pots, sites of innovation, cultural interchange and drivers of social change [13]. The current urbanization process in developing countries is indicative of a phenomenon that needs considerable attention not only as a basis for transformation of societies in the developing countries but also for sustainable development [10]. An intelligent city is one that maximizes the possible connections between people and places and as such combines chance and necessity [14]. An intelligent city effectively controls technology, infrastructure, public policy and citizen engagement. Vegetation is an important parameter in intelligent cities as it acts as a wind path against the urban Island. Vegetation helps in temperature mitigation, pollution removal and provision of amenity values for human and habitat biodiversity [5,15].

A city is considered to be intelligent if it is sustainable, efficient and livable at the same time [16]. An intelligent city can be defined as one that is formulated and designed in relation to the following set of axioms; Environmental sustainability, heritage conservation, appropriate technology, infrastructure-efficiency, place making, social access, transit oriented development, regional integration, human scale and institutional integrity [16]. This research was only limited to the principle of environmental sustainability. It refers to a state in which the demands placed on the environment can be met without reducing its capacity to allow all people to live well, now and in the future. Environmental sustainability is a key component in a sustainable city where achievements in social, economic, and physical development are made to last and a thriving city needs to be a healthy environment for human interaction which contributes to a high quality of life [17] and makes a city a place where people want to live and work, now and in the future since people are to use emerging technologies as auto driver in urban environments [18]. Environmental sustainability as a contribute to high quality of life can be assessed also basing on land use indicators like compatible land use diversity and site coverage [19] which are directly related to the parameters considered in this study. It also offers planners and policymakers valuable insights to inform planning and development directions, which development agencies base on to recognize cities' economic importance in terms of attracting investment and innovation in national and regional economies, the healthy living conditions and high quality of life they can provide and their potential to delink a high quality of life from high greenhouse gas emissions and contribute to avoiding dangerous climate change [20].

3. MATERIALS AND METHODS

Geo-referenced multi temporal satellite images captured by Landsat sensors for different years (1998, 2004, 2010 and 2016) were acquired from USGS earth explorer. All data sets had spatial resolution of 30 m and were accessed on path 173 and row 059 all acquired in November and December so as to reduce significant spectral differences among the images caused by seasonal changes. A shape file of the study area was also obtained from Uganda Bureau of Statistics. To aid in visual and digital image analysis using ENVI 5.2 and ArcGIS 10.1, the images were pre-processed including operations like-gap filling (2004 and 2010 datasets), atmospheric and radiometric corrections and PCA to make the bands uncorrelated since multispectral bands are highly correlated. The imagery were RGB false-color composed correspondent with 4, 3, 2 bands for Landsat 5 and 7 and 5, 4, 3 bands for Landsat 8 image. The imagery were subjected to information extraction through maximum likelihood classification so as to derive the land cover classes for the respective years after which accuracy assessment was done to show the correspondence between class labels allocated to a pixel and the true class as directly observed in the field. Statistics indicating the land cover per capita were done. Time series analysis was done to derive the rates of change of land use/land cover for various periods (1998-2004, 2004-2010 and 2010-2016). Post classification change detection was also conducted to derive change matrices to show what classes changed to built up and by what area in the periods (1998-2004, 2004-2010 and 2010-2016). Books, journals and conference proceedings were reviewed for the selected world intelligent cities including Vienna, Seattle, Singapore and Nairobi and compared with the classification results to analyze on how to achieve or preserve intelligent urbanism.

4. RESULTS AND DISCUSSION

The classification accuracy was evaluated using confusion matrices. The overall classification accuracy was 61.90%, 92.94%, 77.78% and 91.30% for 1998, 2004, 2010 and 2016 respectively (Table 1). The errors arising in classification could be due to the same spectral characteristics of some land cover classes like built up and bare ground.

The images for the years of study-1998, 2004, 2010 and 2016 were classified into five land cover classes; built up, sparse vegetation, thick vegetation, bare round and water (Table 2).

A positive trend was observed for built up and bare round, a negative trend was observed for sparse and thick vegetation whereas the trend of

Table 1. Classification accuracy

Year	1998	2004	2010	2016
Overall accuracy	61.91%	92.94%	77.78%	91.30%
Kappa coefficient	0.500	0.915	0.732	0.895

Table 2. Land cover patterns

Land cover	Area in hectares and percentage of total area							
	1998		2004		2010		2016	
	Ha	%age	Ha	%age	Ha	%age	Ha	%age
Built up	280.08	6.89	412.74	10.16	785.52	19.33	1112.49	27.38
Sparse vegetation	1098.54	27.03	825.66	20.32	625.5	15.39	448.11	11.03
Thick vegetation	2169.54	53.39	1120.86	27.58	764.37	18.81	868.23	21.37
Bare ground	515.43	12.68	1653.48	40.69	1844.01	45.38	1600.83	39.39
Water	-	-	0.09	-	3.87	0.1	-	-
Others	-	-	50.76	1.25	40.32	0.99	33.93	0.83
Total	**4063.59**	**100**	**4063.59**	**100**	**4063.59**	**100**	**4063.59**	**100**

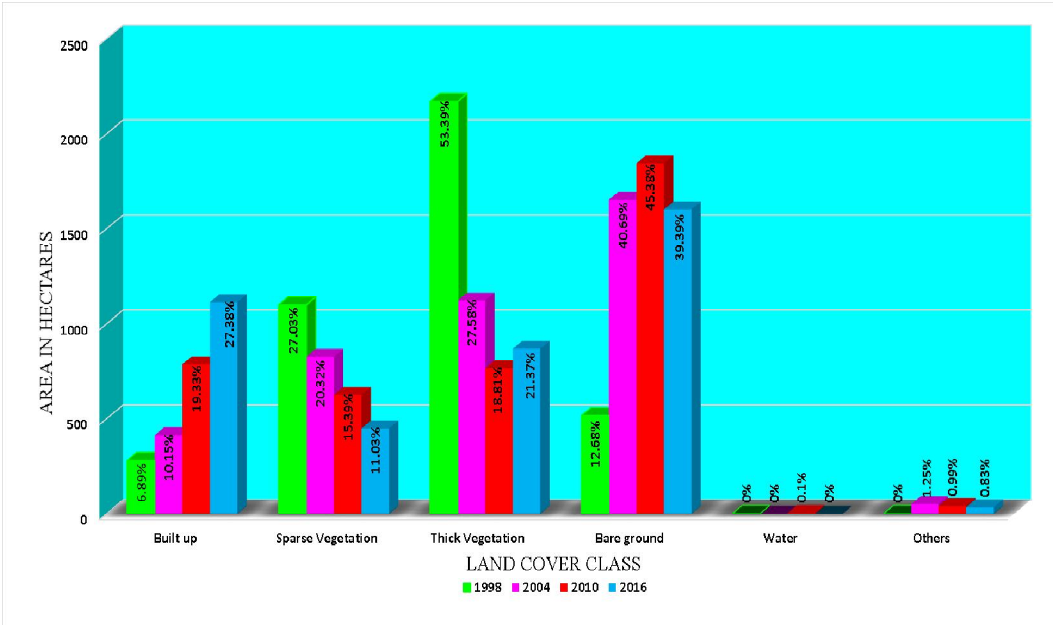

Fig. 2. Graphical representation of land cover patterns

water remained constant. The positive trend in bare ground could be attributed to clearing of land to setup buildings and land clearing for agriculture since the Ugandan government is still emphasizing agricultural products through NAADS especially in western Uganda where the study area is located. The drastic decrease in bare ground in the period 1998-2004 could be attributed to seasonal changes since the latter image was acquired during clearing season and the former was acquired during the season when crops are already planted (Fig. 2).

The above pattern was analyzed and presented spatially to understand the location trends (Figs. 3-6) and it can be observed that vegetation is being replaced with built up and bare ground.

Upon merging sparse vegetation and thick vegetation, the land cover results were also represented per capita increase/decrease as seen in Table 3. The built up per capital has a positive trend. Vegetation and bare ground have a decreasing trend with a more intense change for vegetation observed in the epoch 1998-2004.

4.1 Rate of Change of Land Cover Patterns

With merged sparse vegetation and thick vegetation, changes in Built up, Bare Ground and Vegetation between 1998 and 2016 were obtained prior to overlaying the class in the later and former year (Table 4).

The results showed that the town expands both radially and laterally (Figs. 7-10). The lateral expansion could be attributed to the upgrading of the highways from poor grade gravel surface to bitumen paved standards. The highways include; Fort portal - Mubende highway (176 Kms) from 2001 to 2003, Fort portal - Kasese road in 2006, Fort portal - Bundibugyo road in 2010 and Fort Portal - Kamwenge road (66 kms) between 2014 and 2016. The increase could have also been caused by the general population increase as evidenced by the results from the population census i.e. from 41,000 people in 2002 to 54,275 people in 2014. The increase was also attributed to more need for shelter for students due to the coming up of two private universities in the area - Mountains of the moon university and United Pentecostal University in 2005. Also opening up of branches of other universities like Uganda martyr's university in 2014. These factors could have as well contributed to the decrease in vegetation (Fig. 7) since there is clearing of land for the above anthropogenic activities.

4.2 Transition from Other Land Cover Classes to Built up

Change matrices were generated based on the imagery earlier classified. The extent of change from other classes to built up were determined (Table 5). The results (Figs. 11-14) showed that in all the periods, there was a transition from other classes to built up however, the most significant were conversion from bare ground to built up and vegetation to built up. Thus built up had been increasing overtime as attributed to uncontrolled urbanization.

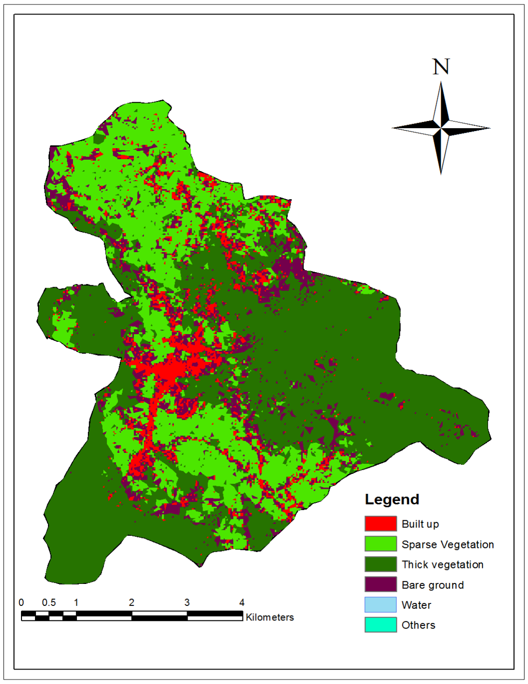

Fig. 3. Land cover in 1998

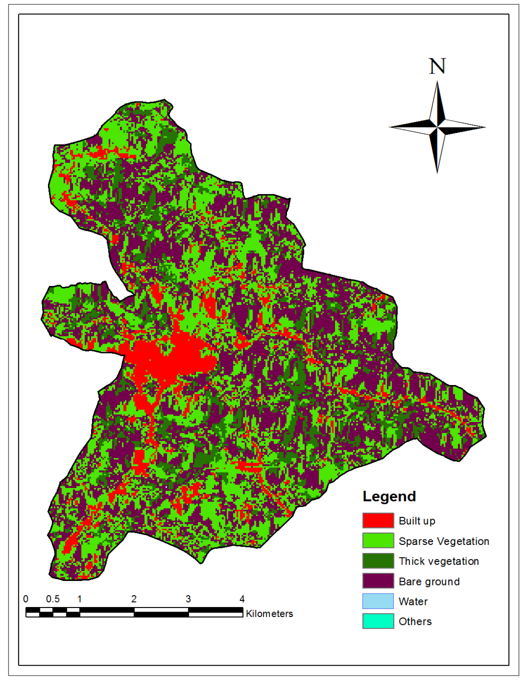

Fig. 4. Land cover in 2004

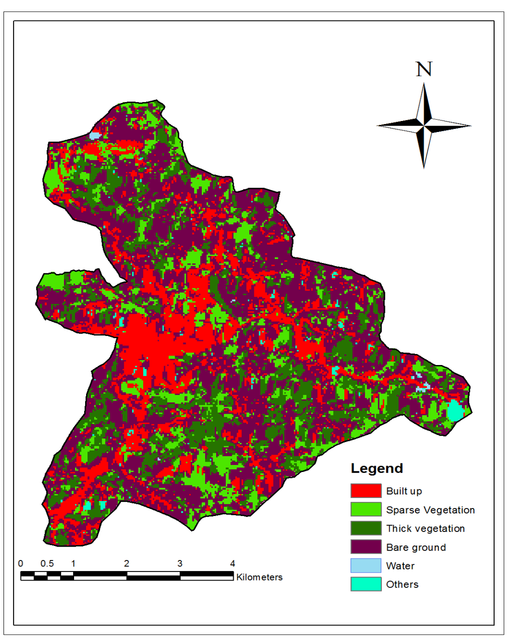

Fig. 5. Land cover in 2010

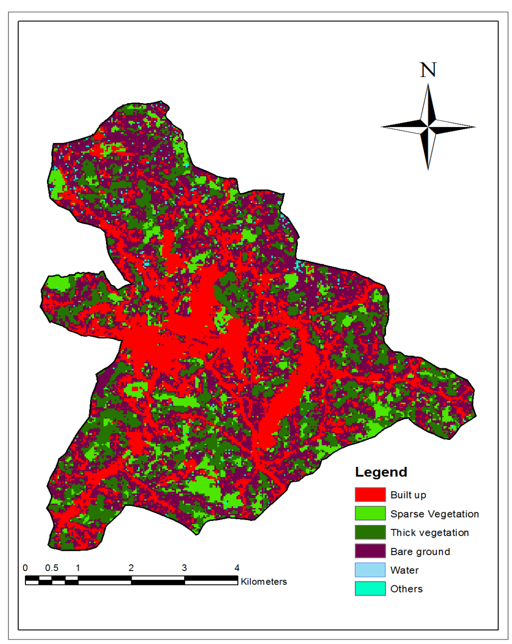

Fig. 6. Land cover in 2016

Table 3. Land cover per capita increase/decrease

Land cover	1998			2004			2010			2016		
	Area (Ha)	Popn	Land cover per capita	Area (Ha)	Popn	Land cover per capita	Area (Ha)	Popn	Land cover per capita	Area (Ha)	Popn	Land cover per capita
Built up	280.08	38010	0.007	412.74	40993	0.01	785.52	47100	0.017	1112.49	54275	0.020
Vegetation	3268.08	38010	0.086	1946.52	40993	0.05	1389.87	47100	0.030	1316.34	54275	0.024
Bare ground	515.43	38010	0.014	1653.48	40993	0.04	1844.01	47100	0.039	1600.83	54275	0.029

Table 4. Rate of change of land cover

Land cover	Change in hectares							
	1998-2004		2004-2010		2010-2016		1998-2016	
	Ha	%	Ha	%	Ha	%	Ha	%
Built up	132.66	3.27	372.78	9.17	326.97	8.05	832.41	20.49
Vegetation	-1321.6	-32.52	-556.65	-13.7	-73.53	-1.8	-1951.7	-48.02
Bare ground	1138.05	28.01	190.53	4.69	-243.18	-5.99	1085.4	26.71

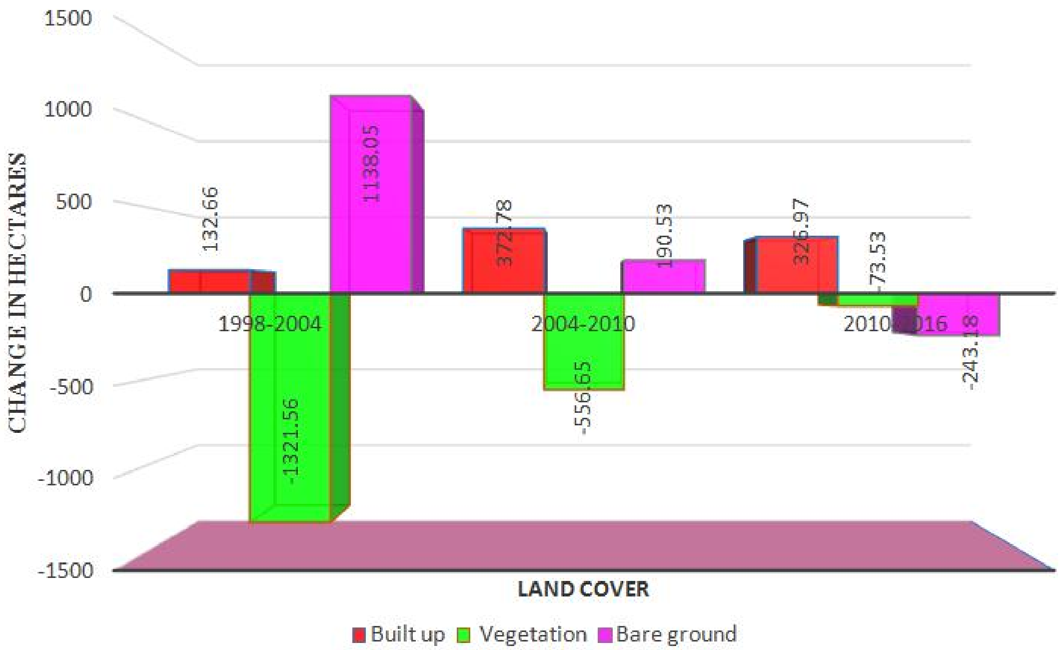

Fig. 7. Rate of change of land cover

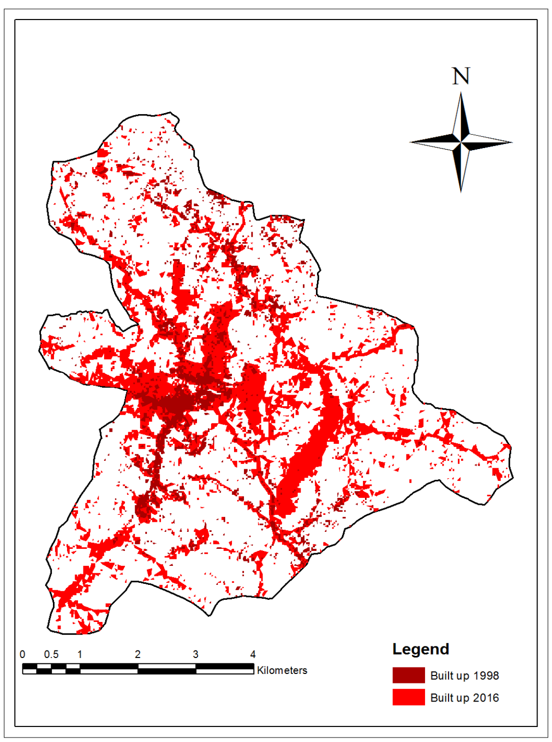

Fig. 8. Built up change 1998-2016

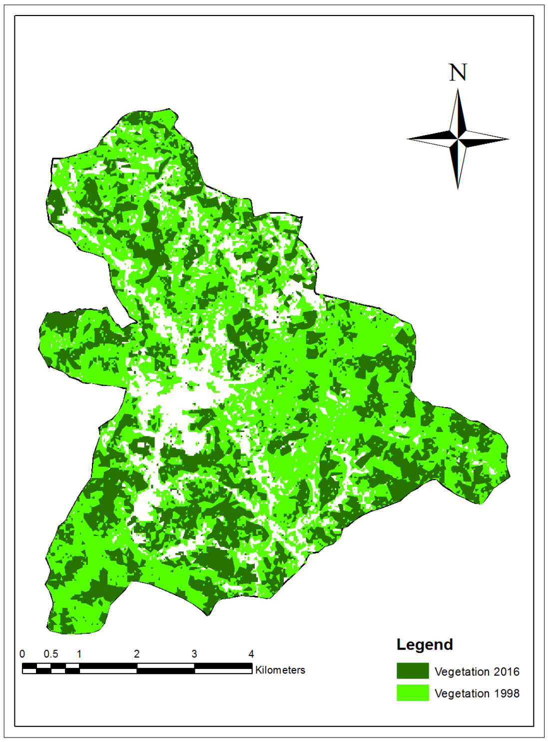

Fig. 9. Vegetation change 1998-2016

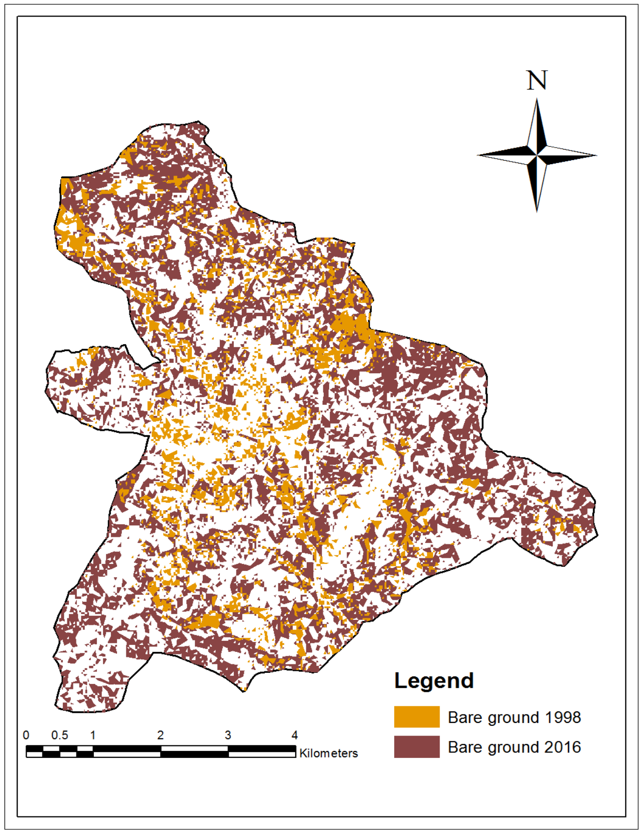

Fig. 10. Bare ground change 1998-2016

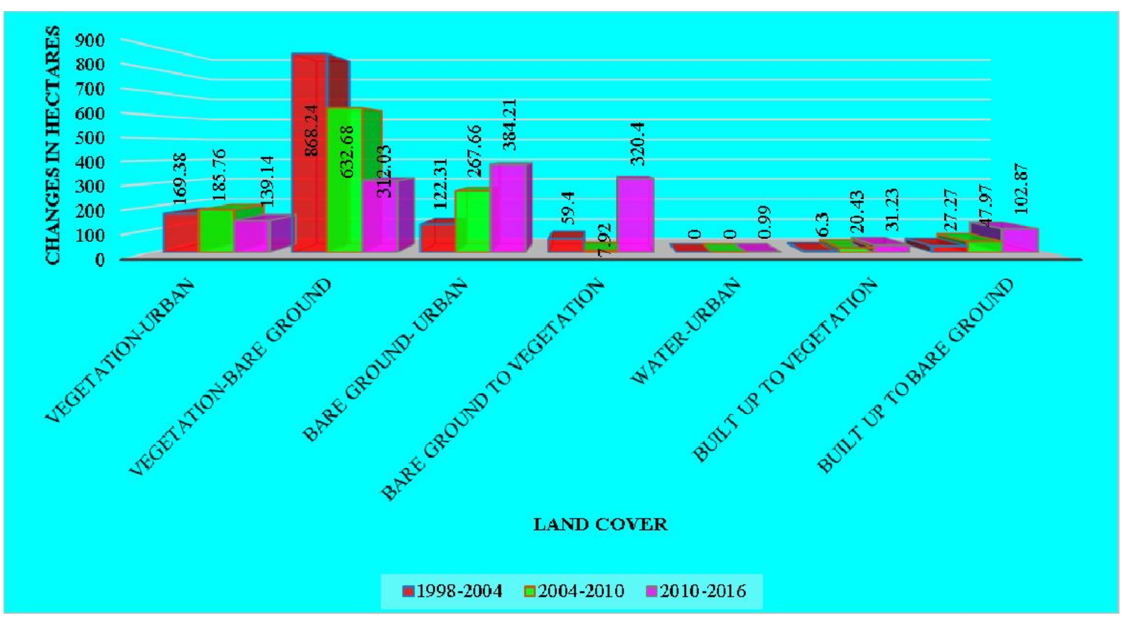

Fig. 11. Land cover transitions to built up

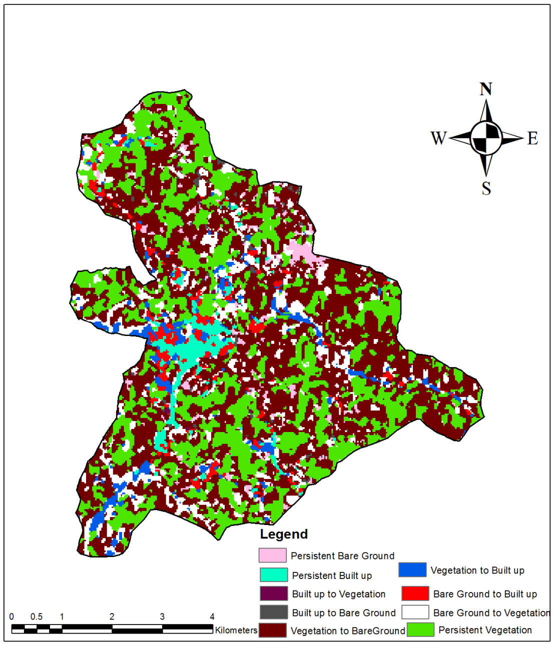

Fig. 12. Land cover transitions 1998-2004

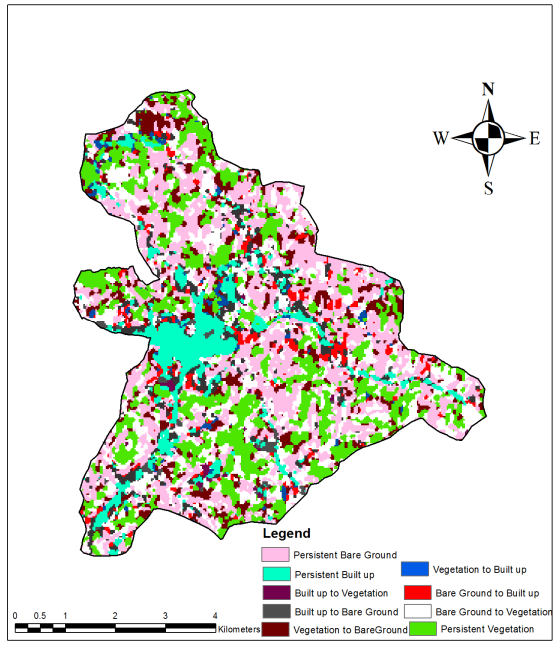

Fig. 13. Land cover transitions 2004-2010

Table 5. Land cover transitions to built up 1998-2016

Land cover	Change in hectares					
	1998-2004		2004-2010		2010-2016	
	Pixels	Ha	Pixels	Ha	Pixels	Ha
Vegetation-Urban	1882	169.38	2064	185.76	1546	139.14
Vegetation-Bare Ground	9647	868.24	7030	632.68	3467	312.03
Bare Ground- Urban	1359	122.31	2974	267.66	4269	384.21
Bare Ground to Vegetation	660	59.4	88	7.92	3560	320.4
Water-Urban	-	-	-	-	11	0.99
Built up to Vegetation	70	6.3	227	20.43	347	31.23
Built up to Bare Ground	303	27.27	533	47.97	1143	102.87

4.3 Comparison of the Land Cover with Those of Intelligent Cities

An analysis of the percentage land covers (built up and vegetation) of the selected intelligent cities was done (Table 6).

Table 6. Analysis of intelligent cities

Name of City	Percentage Built up	Percentage vegetation
Seattle	13.21	48.8
Nairobi	38.88	47.06
Singapore	33.50	58.90
Vienna	35.60	45.50
Average	30.29	50.07

Seattle - Built up is 13.21% and Vegetation is 48.8% (Prior to classification), Nairobi - Built up is 38.88% and Vegetation is 47.06% [21], Singapore - Built up is 33.50% and Vegetation is 58.90%, Vienna - Built up is 35.6% and vegetation is 45.5% [22]. It implies that on average an intelligent city should have built up of approximately 30% and Vegetation of approximately 50%. From the land cover results of Fort portal – Built up is 27.38% and Vegetation is 32.4%. From the transition results, vegetation and bare ground are highly being converted to built up as evidenced by the 169.38 Ha conversion from Vegetation to urban from 1998-2004, 185.76 Ha from 2004-2010 and 139 Ha from 2010-2016.122.31 Ha conversion from Bare Ground to Built up from 1998-2004, 267.66 Ha from 2004-2010 and 384.21 Ha from 2010-2016. Comparing the above classification results and the derived estimates of the selected intelligent cities, the percentages are in different ranges due to the rapid conversion of Land cover which prevents the Fort portal from being intelligent. This can also be evidenced by the decreasing rate of 2.7% p.a of vegetation cover and at such a rate, there will little vegetation in the municipality in decades to come. The alarming reduction in vegetation cover further indicates that the principle of environmental sustainability is defied, thus no intelligent urbanism in the municipality. However, adopting green buildings and emphasizing the green belts can help to achieve intelligent urbanism in the area.

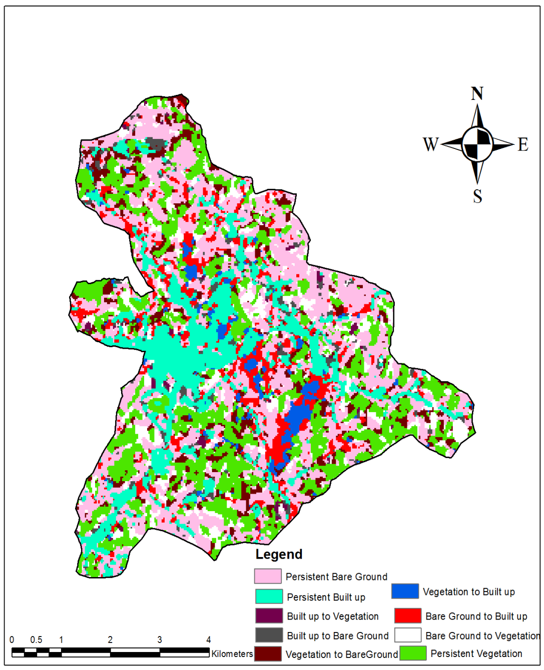

Fig. 14. Land cover transitions 2010-2016

5. CONCLUSION

Vegetation cover is an important parameter for understanding of how uncontrolled urbanization affects growth of intelligent cities. The geo-spatial and remote sensing approach presented in this study quickly determined the trend of urbanization and changes in urban vegetation for present and past years. The land cover patterns of the municipality were determined as Built Up, Sparse Vegetation, Thick Vegetation, Bare Ground and Water. Time series analysis was done for the land cover over the years. The transitions from other land cover classes to built up were also determined. Comparisons of the attained results and the land cover percentages in intelligent cities were made and showed that the municipality was not intelligent and measures on how to achieve intelligent urbanism based on environmental sustainability were made. The study found out that vegetation change exhibited a direct proportionality with intelligent urbanism through environmental sustainability and so the increased conversion of vegetation cover to other land cover led to decrease in the city's green space thus preventing the city from achieving intelligent urbanism. The integration of geospatial techniques showed that uncontrolled Urbanization prevents growth of intelligent cities as it occurs at the expense of other land cover especially vegetation that is essential for environmental sustainability, a key principle of intelligent urbanism.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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