Original article

Monitoring the extent and impacts of watershed urban development in the Lake Victoria Basin, Kenya, using a combination of population dynamics, remote sensing and GIS techniques

Dancan O. Onyango^{1*}, Christopher O. Ikporukpo², John O. Taiwo², Stephen B. Opiyo³
¹Pan African University, Life and Earth Sciences Institute (PAULESI), University of Ibadan, Ibadan, Oyo State, Nigeria

²Department of Geography, University of Ibadan, Ibadan, Oyo State, Nigeria

³Department of Environment and Natural Resources, Faculty of Agriculture and Natural Resources Management, Kisii University, Kisii, Kenya

E-mail address (*corresponding author): dancanthomas@gmail.com

ORCID iD: Dancan O. Onyango: <https://orcid.org/0000-0002-3795-5519>; Christopher O. Ikporukpo: <https://orcid.org/0000-0002-0278-4297>; John O. Taiwo: <https://orcid.org/0000-0001-9290-379X>; Stephen B. Opiyo: <https://orcid.org/0000-0003-3157-5192>

ABSTRACT

Several urban centres of different sizes have developed over time, and continue to grow, within the basin of Lake Victoria. Uncontrolled urban development, especially along the lake shore, puts environmental pressure on Lake Victoria and its local ecosystem. This study sought to monitor the extent and impacts of urban development (as measured by population growth and built-up land use/land cover) in the Lake Victoria basin, Kenya, between 1978 and 2018. Remote sensing and GIS-based land use/land cover classification was conducted to extract change in built-up areas from Landsat 3, 4, 5 and 8 satellite imagery obtained for the month of January at intervals of ten years. Change in population distribution and density was analysed based on decadal census data from the Kenya National Bureau of Statistics between 1979 and 2019. A statistical regression model was then estimated to relate population growth to built-up area expansion. Results indicate that the basin's built-up area has expanded by 97% between 1978 and 2018 while the population increased by 140% between 1979 and 2019. Urban development was attributed to the rapidly increasing population in the area as seen in a positive statistical correlation ($R^2=0.5744$) between increase in built-up area and population growth. The resulting environmental pressure on the local ecosystem has been documented mainly in terms of degradation of lake water quality, eutrophication and aquatic biodiversity loss. The study recommends the enactment and implementation of appropriate eco-sensitive local legislation and policies for sustainable urban and rural land use planning in the area. This should aim to control and regulate urban expansion especially in the immediate shoreline areas of the lake and associated riparian zones.

KEY WORDS: Lake Victoria, watershed urbanization, population growth, built-up area, remote sensing and GIS

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1. Introduction

A landscape region that drains water to an explicit water body such as a river, lake or wetland is called a watershed (FLOTEMER SCH ET AL., 2016). Watersheds are also commonly known as basins or catchment areas (BRUTSAERT, 2005). The interactions of geomorphological elements contribute to the flow of water in a watershed (YU & DUFFY, 2018).

Watersheds are important systems that provide essential life-supporting ecological goods and services including provision of water, fuel wood, food and material cycling, among others (TOGNETTI ET AL., 2017). The most essential functions of watersheds are the regulation of water chemistry, hydrology, sediment regime and temperature, alongside habitat provision (USEPA, 2012; EDWARDS ET AL., 2015). The ability of watersheds to provide

these services is heavily influenced by natural and human pressures (WALKER & SALT, 2012). One of the greatest anthropogenic pressures affecting watersheds around the world is urbanization. In the last four decades, the world has witnessed rapidly increasing urbanization (MCGRANAHAN & SATTERTHWAITE, 2014), hence it has been estimated that at least 60% of the global population will be living in urban areas by 2050 (MCNICOLL, 2005). While urbanization is mainly driven by a rising population, it is also associated with other factors such as economic and industrial advancement, migration patterns as well as the availability of amenities and natural resources (BHAT ET AL., 2017).

According to ABUYA (2019), urbanization is an anthropogenic factor resulting directly in changes in urban landscape, which are manifested in the form of urban growth and urban sprawl (HEPCAN ET AL., 2013). This brings to focus three terminologies commonly used in urban studies: urbanization, urban growth and urban. Generally, urbanization is defined in demographic terms as the process by which the population becomes permanently concentrated within relatively smaller areas (UN, 2018). In this regard, the proportion of a population living in urban settlements is a measure of the level of urbanization and the change in this population per unit time defines the urbanization rate (UN, 2018). On the other hand, urban growth and urban sprawl are two closely-related phenomena whose differences are defined by their processes (ROSNI & NOOR, 2016). While urban growth takes both spatial and demographic dimensions, urban sprawl involves only a physical expansion of the borders of urban areas in order to provide more room for the increasing population (BHATTA, 2010). COMPAGNON (2004) believes that urban growth is when the area of towns and cities increase with increasing population size, while urban sprawl occurs when the boundaries of towns and cities extend due to other factors besides population increases, for example, industrialization. According to COMPAGNON (2004), perhaps the greatest similarity between these two urbanization phenomena is that they both contribute to transforming the urban fabric through increasing built-up landscapes. In most instances, the two terms are used interchangeably.

In recent decades, technological advancements in geospatial science have revolutionized the study of urban growth (GOLDBLATT ET AL., 2018). Conventional approaches prior to the 1970s involved the use of household surveys. However, these were costly to gather and generated information infrequently. It was also difficult to measure aspects like the physical extent of urbanization from such methods (GOLDBLATT ET AL., 2018). After the 1970s,

advancement in remote sensing and geographic information systems (GIS) technologies revolutionized urban studies, with the availability of improved satellite imagery. New approaches, such as remote sensing methods to transform terrestrial earth-observation data into useful information on the nature and rate of change in urban landscapes and human settlements, have been developed (SETO ET AL., 2011). The delineation of urban land through remote sensing is capable of capturing various dimensions of urbanization, such as built-up land cover or land use and population dynamics (SINGH & CHANG, 2014; PETERS, 2019). Measuring the spatial extent of urbanization in watersheds is usually based on quantifying the proportion of pervious to impervious landscapes in built-up areas (SINGH & CHANG, 2014). Remote sensing and GIS provide better prospects for rapidly and accurately mapping and measuring watershed urbanization (FAROOQ & AHMAD, 2008).

Urban growth, with the associated increase in built-up land in watershed areas around the world, has the effect of modifying the structure and functioning of watershed ecosystems (WANG ET AL., 2011). This is because urbanized watersheds often have extensive impervious surfaces comprising of rooftops, pavements, asphalt roads and parking spaces, replacing naturally vegetated areas and organic soils (O'DRISCOLL ET AL., 2010). These are responsible for impairing rainfall water storage capacity and infiltration mechanisms hence escalating the volume of runoff to water bodies, especially streams (WENGER ET AL., 2009). The increased runoff results in increased occurrence and rigor of flooding catastrophes within the watershed (WANG ET AL., 2011). WANG ET AL. (2011) further mention that temperature and energy regimes of water are also modified by the elevated runoff and diminished infiltration capacity of the watershed, an occurrence which can have a disrupting effect on aquatic life. Increased runoff may also cause soil erosion and alteration of the structure of river channels and riverbeds (ROSEMOND ET AL., 2015). Additionally, urbanized watersheds experience elevated input of toxic materials and nutrients into water bodies, which has dire ramifications on their ecosystem health as well as on public health (WANG ET AL., 2011).

The increasing environmental implications of urban expansion in watershed landscapes have been linked to environmental disasters, poverty and biodiversity loss around the world and have therefore attracted scientific attention as mitigation measures are urgently needed (WANG ET AL., 2011; FLETCHER ET AL., 2013; STODDARD ET AL., 2016). A study by XIAN ET AL. (2007) carried out on the Tampa Bay watershed in Florida found an increase in

urbanization and population in the watershed, with high imperviousness correlating well with high population density. These increases were found to affect water resources within the watershed directly. Water quality degradation was noted from non-point pollutants which collected on the impervious surfaces and are washed into water bodies during rainfall events. Population density was found to correlate with loading rates of some pollutants within the study area though there was a spatial variation of non-point source pollutants (XIAN ET AL., 2007). They concluded that watershed urbanization affects the available water resources in several dimensions ranging from pollution (due to dumping of wastes) to thermal stresses and flash floods from the physical urban environment. A similar study was carried out in the Donghu Lake Watershed, central China, using ground-based information and Landsat TM images for 1987, 1993 and 1999 (LI ET AL., 2006). Results showed that the urban area is continuously expanding to cater for an expanding urban population. This was at the expense of water and forest cover, which were seen to have decreased over the study period. They observed that these alterations resulted in significant negative environmental effects like lake decline, deterioration in water and air quality, and general loss of biodiversity.

Another study carried out in the rapidly urbanizing southern United States found that the percentage of total impervious area is directly related to frequency of flash floods, a phenomenon that has been on the rise globally in recent years, especially due to global climate change (O'DRISCOLL ET AL., 2010). That study further established that urban surfaces heat up faster therefore raising the temperatures of surface runoff. This can have diverse effects on temperature dynamics of the receiving water bodies thereby affecting aquatic life. ASTUTI ET AL. (2019) attributed the increased surface runoff, resulting from urban-related land use and land cover changes, to enhanced flow of nutrients and sediments into the receiving water bodies. Enhanced erosion of river banks due to flash storms, as a consequence of urbanized surfaces, transports a load of contaminated nutrients and sediments into water bodies thereby compromising the water quality (EYLES & MERIANO, 2010). High nutrient content in water bodies is generally known to increase eutrophication with adverse impacts on aquatic biodiversity.

In recent decades, the Lake Victoria basin has witnessed increased urban development as seen in the emergence of numerous urban centres, towns and cities along the shores of Lake Victoria, mainly in Kenya, Uganda, and Tanzania (USAID, 2014).

On the Kenyan shoreline of the lake, several small beach settlements are now steadily urbanizing, attracting large populations from other areas and thriving in various economic activities and infrastructure development (UN-HABITAT, 2016). The notable towns include Muhuru Bay, Sindo Gwasi, Sori (Karungu Bay), Homa Bay, Mbita, Kendu Bay, Kisumu City, Bondo and Siaya all which were very small settlements a few years ago but are now considerable large urban centres. The uncontrolled nature of urban development in this area, with no regard for any protected riparian areas along the lake, poses serious environmental pressure on both the lake and its watershed, potentially threatening the integrity of life-supporting natural resources. While considerable research (e.g. LUNG'AYIA ET AL., 2001; ODADA ET AL., 2009; NJIRU ET AL., 2010; JUMA ET AL., 2014) has been directed towards evaluating most of these environmental problems, the evolving pattern of urban growth, and its potential impacts, has hardly been analysed. This study sought to investigate the extent and potential environmental impacts of urban growth in the Lake Victoria Basin, Kenya, between 1978 and 2018. More specifically, the study monitored historical urban growth as measured by built-up land use and population growth patterns in the area over these years. The study also estimated a statistical correlation between built-up land use and population size. The findings provide a basic scientific framework for local urban and land use planning for the future sustainability of the lake and its watershed.

2. Materials and methods

2.1. Study area

Lake Victoria is an important regional natural resource for Eastern Africa. Located at an altitude of 1134 m above sea level, the lake lies between latitudes 0°20'N–3°S and longitudes 31°39'E–34°53'W (JUMA ET AL., 2014). The actual surface of the lake spans about 68,000 km² making it the world's second-largest freshwater lake by surface area. This is shared amongst Kenya (6%), Uganda (43%) and Tanzania (51%). By volume, Lake Victoria holds an estimated 2750 km³ of water (OWUOR ET AL., 2012) 80% of which is attributed to direct rainfall while 20% results from inflowing streams and rivers. The water balance in Lake Victoria is majorly characterized by precipitation and evaporation since the basin experiences an average annual rainfall in the range of 900 mm – 2600 mm and average annual evaporation rates in the range of 1100 mm – 2400 mm (ZHOU ET AL., 2014). The lake

has a maximum and average depth of 80 m and 40 m, respectively, hence is considered somewhat shallow (MUYODI ET AL., 2010).

Lake Victoria has a catchment area (Lake Victoria Basin) of about 250,000 km² spread across Kenya, Uganda, Tanzania, Rwanda and Burundi. This basin provides ecological resources and services estimated to support livelihoods of over 40 million people in the region (OCHIENG ET AL., 2013). According to OCHIENG ET AL. (2013), it is estimated that about 22% of the total Lake Victoria basin area falls within Kenyan boundaries. This constitutes the Kenyan portion of the basin. The Kenyan Lake Victoria Basin (KLVB) lies in the western part of Kenya covering the entire Nyanza region and parts of the Western and Rift Valley regions (formerly

provinces). Within the KLVB, in the immediate shoreline of the lake, there are five administrative counties bordering (sharing boundaries with) the lake namely, Busia, Siaya, Kisumu, Migori and Homabay. According to the Kenyan Constitution (2010), counties are regional/devolved governance units, the equivalent of states. It was on the basis of the administrative boundaries of the five Kenyan lakeside counties that our study area was delineated (Fig. 1). This was on the assumption that it is this area that urban-related anthropogenic land uses have a direct impact on the lake. Counties are further sub-divided into sub-counties, divisions, locations and sub-locations, the smallest administrative units, upon which population density maps for the study area were considered.

Fig. 1. Map of the Kenyan Lake Victoria basin

2.2. Methodology

Urban growth was analyzed through integration of two types of data; remotely-sensed data and demographic data. A flowchart summarizing the step-by-step methodology of the entire study is shown in Figure 2. A breakdown of the methodology undertaken for each of the study objectives is summarized in this section.

Measuring Urban Growth by Built-Up Land Use and Cover. Remote sensing and GIS techniques were used to classify, extract, quantify and analyze changes in built-up land use and cover in the study area between 1978 and 2018 at intervals of ten years. An interval of 5 or 10 years is mostly recommended for analyzing land use land cover changes of a particular region using Landsat imagery (ALAWAMY ET AL., 2020). To detect significant urban change

at every interval, this study adopted the 10-year interval. The study used data sets obtained from Landsat images acquired for the dry month of January for 1978 (Landsat 3 Multispectral Scanner); 1988 (Landsat 4, 5 Thematic Mapper, TM); 1998 (Landsat 4, 5 Thematic Mapper, TM); 2008 (Landsat 4, 5 Thematic Mapper, TM) and 2018 (Landsat 8 Operational Land Imager – Thematic Infrared Sensor). The images were obtained from United States Geological Survey (USGS, 2020). The Landsat TM and OLI-TIRS imageries (path/row: 170/60) were of spatial resolution of 30 m whereas Landsat 3 MSS (path/row: 170/60) imageries were of spatial resolution of 79 m. The imageries downloaded were of excellent quality having been acquired for the dry season in January characterized by low cloud cover.

The acquired imageries were exported to ERDAS Imagine (Version 2015) software where they underwent enhancement processes of geometric

and radiometric corrections. This was followed by a supervised classification process using the Maximum Likelihood Algorithm to generate land use and land cover (LULC) classes (GITHUI, 2007). This classification allows the analysts to select the pixels that represent the desired LULC classes (GITHUI, 2007). The LULC classes of interest were therefore defined as forest cover, agricultural land, water bodies, grasslands & vegetation and built-up areas. Six ground-truth polygons signifying the defined classes were randomly chosen and digitized based on aerial photographs and visual analysis of the locations on Google Earth maps. One training sample polygon contained 17 pixels, hence for the six training samples a total of 102 pixels were used. Upon successful training of the images using signature editor, the algorithm of Maximum Likelihood was run a number of times to generate the defined classes in the image.

Fig. 2. Flowchart methodology summarizing the spatial analysis of urbanization using remote sensing and demographic data

Since the focus of the study was on the built-up area land use class, the other LULC classes were ignored and the built-up area classification was extracted from the maps for the years 1978, 1988, 1998, 2008 and 2018. Finally, built-up area maps with appropriate cartographic features were

generated using the ArcMap interface in ArcGIS (ArcGIS Desktop, Version 10.5.1) software. This process basically involved loading the map of the classified images on the ArcMap software through which the frame of the maps was set, the titles of the maps, the legend, the scale of the maps and

the coordinate system and grids were added onto the maps. After verification, the maps were exported in image format, critically interpreted and analysed. Upon successful production of classified images, ground truthing was executed in the KLVB through fieldwork involving recording the GPS coordinates of 100 ground reference points (Appendix A). The information from ground reference points was compared against the data from the classified built-up area (land use/land cover of interest) maps in order to obtain an accuracy assessment. The confusion/error matrix was calculated by using the formulae given in CONGALTON & GREEN (2009), after the accuracy reports were developed for each of the images. Further, change detection analysis was undertaken to show the aerial coverage of built-up land in each of the maps in square kilometres for each of the study years (1978, 1988, 1998, 2008 and 2018). Finally, a comparison between various years was made and conclusions deduced.

Monitoring Urban Growth by Population Dynamics. In addition to land use change, the second indicator of urbanization considered in this study was population. Population was considered as two aspects namely, population growth/size and population density. Population census datasets were obtained from the KENYA NATIONAL BUREAU OF STATISTICS (KNBS, 2019) database. KNBS keeps census data obtained every 10 years as well as mid-term population projections up to the smallest administrative areas (sub-location) in Kenya. The population datasets of the study area were obtained from the census years 1979, 1989, 1999, 2009 and 2019. These datasets were obtained in the form of spread sheets. The files of the sub-locations in each county were also obtained as a representation of the smallest administrative unit within population statistics.

The acquired demographic data was subjected to a series of analyses. The first step entailed data cleaning where the dataset was screened for any errors, inconsistencies or omissions. This was followed by a data capturing procedure in which the population data was attributed in the shape files (spatial data format embedded in ArcGIS) of their respective sub counties. In this procedure, file Geodatabase for the population data was created in ArcGIS (ArcGIS Desktop, Version 10.5.1) software environment. Feature datasets were then created inside the file geodatabase after this feature classes which define the shape files of the population data were created. Feature classes were properly defined with appropriate UTM ZONE 36S and 36N. The population data was then joined with the attribute tables of the created population shape

files to have a complete population shape file. At this stage, the population maps for various census years were produced. In order to compute the population density, the population density field was calculated in ArcGIS 10.5 by dividing the total population of each sub location with the total areas of the respective sub location to give the population density as the number of people per square kilometer. Finally, the attributed shape file of sub locations with all the required information was loaded into ArcGIS (ArcGIS Desktop, Version 10.5.1) software, and it was symbolized using the population density field and a range of five (5) categories (0-571, 571-1377, 1377-3355, 3355-7682 and 7682-23547) which were set with different colour graduations. The boundaries of sub-locations were then set as transparent to avoid its interference with the final population densities. Population density maps were then produced for the various census years. After creating the population maps and population density maps, they were interpreted and analyzed as shown on the respective maps.

Correlating Built-up Area and Population Growth. After computation of the multi-temporal built-up area coverage and the acquisition of the population census data for the various years, the datasets were organized in Microsoft Excel (Microsoft Office Professional Plus 2010, version 14.0.7128.5000) and imported into SPSS (IBM SPSS Statistics for Windows, Version 24.0) software. A simple linear regression analysis was computed between built-up area expansion (as dependent variable) and population growth (as independent variable). The relationship between the two variables was then presented as a scatter plot diagram.

3. Results and analysis

3.1. Built-up area and urban growth

The trends of built-up area coverage in the study area can be seen in the developed/built-up area maps presented in Figure 3. From these maps, it was observed that spatial urban growth proceeded in almost all directions starting from the shores of Lake Victoria and moving outwards. The computed built-up area coverages over the years were summarized as shown in Table 1. Observations from the built-up area maps, together with the results shown in Table 1, collectively demonstrate that built-up area coverage has been on the rise exponentially from 1978 to 2018. In 1978, only about 2.5% of the study area was built up. This increased by nearly 100% to 4.18% of the total land area by 1988 (Table 1). Between 1988 and 1998, the aerial coverage of built-up landscape

rose to 4.33%. In the following decade (1998-2008) built-up areas continued rising though with a slight margin reaching up to 4.41% by 2008. In the final decade (2008-2018), built-up areas grew significantly to the 4.86% aerial coverage registered

in 2018 (Table 1). Generally, the coverage of built-up areas continued to rise through each subsequent decade with increasing population, although the rate of that growth over the years from 1988 tended to be relatively constant as shown in Table 1.

Fig. 3. Built-up area maps of the Lake Victoria basin for 1978, 1988, 1998, 2008 and 2018

Table 1. Statistics of the built-up areas in the Kenyan Lake Victoria from 1978 to 2018

Year	Area (km ²)	% Cover
1978	388.15	2.46
1988	647.65	4.18
1998	682.19	4.33
2008	695.11	4.41
2018	766.82	4.86

Nearly similar trends of urban expansion in the region can be seen through the increased coverage of built-up areas in various counties over the years (Table 2). County-wise analysis of built-up area evolution in the KLVb revealed that Siaya County consistently had the greatest percentage of built-up areas over the years with the other counties closely following (Table 2). Noticeably from Table 2, in 1978 the counties of Busia, Siaya and Kisumu all had larger built-up areas than the rest, with

their developed land coverage oscillating between 1.13% and 1.48%. During the same period, the two counties of Homabay and Migori had smaller built-up area coverages of 0.59% and 0.66% respectively. However, by the year 1988, the built-up area coverages of all five counties were almost the same, oscillating a little over 1%. Apparently, by 1988, the two counties of Homabay and Migori

had more than doubled their built-up area coverages from the ones they registered in 1978. After 1988, not much variation in the built-up areas was observed among the counties over the subsequent decades, as they all seemed to have been growing at relatively similar rates. This implies that the urban development in the region was largely uniform after 1988.

Table 2. County-wise statistics of the built-up areas in the Kenyan Lake Victoria from 1978 to 2018

County	Total surface area [km ²]	Built-up areas									
		1978		1988		1998		2008		2018	
		Area [km ²]	% Cover	Area [km ²]	% Cover	Area [km ²]	% Cover	Area [km ²]	% Cover	Area [km ²]	% Cover
Busia	1819.40	20.52	1.13	22.59	1.42	27.57	1.52	32.24	1.77	43.65	2.40
Siaya	3706.88	54.78	1.48	66.19	1.87	72.99	2.08	92.68	2.64	100.12	3.00
Migori	3166.12	21.03	0.66	49.11	1.55	50.96	1.61	57.7	1.82	74.94	2.37
Homabay	4759.57	28.07	0.59	67.07	1.41	86.08	1.78	113.78	2.39	131.83	2.77
Kisumu	2680.32	34.51	1.29	46.73	1.74	66.16	2.47	69.04	2.58	75.56	2.82

3.2. Population dynamics and urban growth

The populations of the KLV from 1978 to 2018 are represented by the Kenyan population censuses conducted between 1979 and 2019 as shown in Figures 4 and 5. Over the 40-year period analysed, there has been a threefold population growth in the basin, from the 2,632,944 initially recorded in 1979 to 6,341,977 recorded in 2019, representing a 140% increase (Fig. 4). The population in the basin has been rapidly increasing over the years as demonstrated by the trend observed in both Figures 4 and 5. The increasing population observed in the region over the years (Fig. 4), directly corresponds to the increasing built-up areas in the basin as shown in Table 1.

Fig. 4. Population growth in the Kenyan Lake Victoria Basin, 1979–2019

The population distribution in the study area during each census year from 1979 to 2019 was

further shown by the GIS generated population maps (Fig. 6). In these population maps, the areas (sub-locations) with shades of dark brown colour represent higher population distribution and as the colour intensity reduced so was the population distribution down to the lowest. And in this case, the intensity of the dark brown colour in the Lake Victoria population maps increased from 1978 over the subsequent years to the more intense shades of dark brown colour observed for 2018 (Fig. 6). This is clear evidence that over the years from 1978, the population has been rapidly increasing. Based on the population maps, the region was generally highly populated in 2018 as compared to the low population distribution of 1978. The trend of spatial concentration of the population over the years was also evaluated using GIS generated population density mapping for each census year occurring between 1979 and 2019 (Fig. 7). In these population density maps, the regions with shades of dark brown colour represent higher population density and as the colour intensity reduced, so did the population density to the lowest. From the observations from these maps, it was revealed that the population density in the basin has increased over the years from 1978 to 2018 (Fig. 7). Based on the population density map in Figure 7, the populations were majorly concentrated in fringe areas near the lake but as the years go by the population concentration has gradually shifted to areas a little further from the lake.

Fig. 5. County-wise population growth in the Kenyan Lake Victoria Basin, 1979 - 2019

Fig. 6. The distribution of the population in the Lake Victoria Basin in 1979, 1989, 1999, 2009 and 2019

Fig. 7. Population density in the Lake Victoria Basin for 1979, 1989, 1999, 2009 and 2019

3.3. Relationship between population growth and built-up area expansion

Results of the statistical regression analysis were as presented in the scatter diagram shown in Figure 8. The statistical correlation value of the regression analysis (R^2) was found to be 0.5744 (Fig. 8). This implies that 57.4% of the variation in the built-up area is generated by the population growth. Therefore, a positive correlation exists between the built up area and the population. This relationship was further observed through a side-by-side comparison of results of built-up area coverage and population growth in the Lake Victoria basin, in which it was established that as the population increased from 2,632,944 in 1979 to 6,341,977 in 2019, so did the built-up area increase from 158.91 km² in 1978 to 426.1 km² in 2018.

Fig. 8. Relationship between population and built-up areas

Moreover, decadal analysis of population increases alongside the built-up areas was carried out to further demonstrate the intimate relationship between built-up areas and population growth

(Table 3). The results of that analysis indicated that during the period between 1979 and 1989, the population increased by 622,956 producing a corresponding 259.5 km² net increase in built-up areas during the same period. Between 1989 and 1999, the population increased by 453,620 causing a corresponding 34.54 km² net increase in the built-up area landscape of the region. Between 1999 and 2009, the population increased by 272,436 leading

to a corresponding 12.92 km² net increase in the built-up region in the basin. Finally, between 2009 and 2019, the population in the basin registered a net increase of 2,360,021 causing a net increase of 71.71 km² in built-up landscapes. Generally, the built-up areas have increased by 388.15 km² over the period from 1978 to 2018, representing a 97% increase (Table 3).

Table 3. Decadal net changes in population and built-up areas

	Decadal net changes			
	1979 - 1989	1989 - 1999	1999 - 2009	2009 - 2019
Net population growth	622.956	453.620	272.436	2.360.021
	1978 - 1988	1988 - 1998	1998 - 2008	2008 - 2018
Net built-up area change (km ²)	259.5	34.54	12.92	71.71

4. Discussion

The 97% overall built-up area expansion observed in the study area can be attributed to rapid population growth. JUMA ET AL., (2014) considered that rapid population growth and economic development are the major drivers of urban expansion in the entire Lake Victoria Basin. The variable rates of urban growth by built-up area observed in the study counties, especially in the earlier decades of the study, therefore implies a variation in the levels of historic physical development (infrastructure) in the study counties (formerly districts before 2010). Such variations are also in tandem with trends reported in other parts of the country where physical urban infrastructure development varies across the country. According to ODADA ET AL., (2009) the variations can also be attributed to differences in population growth rates among counties and an associated demand for natural resources to support socio-economic development, climate variability factors, and infrastructure advancements during that period (ODADA ET AL., 2009). From the 1980s to 2018, the rate of increment of built-up area was relatively similar in the counties, implying that the urbanization rate in the region was relatively uniform. It is important to note that currently, the counties, as the regional administrative units in Kenya, happen to be the basis for economic development (since 2010) and as such they annually receive colossal amount of government financing for developing various infrastructures, a key element of urban expansion.

The implication of increasing built-up areas over the years in the region is that numerous dispersed lands under various land cover such as

vegetation, bare lands, forests and agricultural lands have been converted to developed areas over the years, and extensively developed through construction of relevant infrastructures to accommodate the ever-burgeoning population and economic expansion in the Lake Victoria Basin (JUMA ET AL., 2014). CAREY ET AL. (2013) stated that anthropogenic modification of urban land cover from natural landscapes to built-up ones is a key threat to watersheds. This is because the underlying characteristics of these built-up lands is the existence and/or extension of large impervious areas of rooftops, pavements, asphalt roads and parking spaces which replace natural vegetated areas and organic soils, thereby causing runoff problems (O'DRISCOLL ET AL., 2010).

Overall, in terms of population, the study area has witnessed 140% growth, representing nearly a three-fold increment over the study period. This is clearly evident in the population maps which showed an intensity in the dark brown colour increasing from 1978 through 2018. This implies that urbanization in this region has been on a rising trend. According to some earlier studies by COHEN ET AL., (1996) and JUMA ET AL. (2014), increasing lakeside urbanization (by population) is instigated by the economic significance attached to Lake Victoria. According to Kenya's Commission for Revenue Allocation (CRA, 2011), the population of KLVb has been rapidly increasing over the years in tandem with national population growth in the country. The net effect of this growth is expansion of cities and urban areas to accommodate the increasing population (WANG ET AL., 2012). The International Monetary Fund (IMF, 2012) estimated population growth rate in Kenya over the past two decades at about 3%, and said that this would continue to soar

in subsequent years. More recently, according to the [WORLD BANK](#) (2019), the current annual national population growth rate in Kenya stands at an average of 2.3%. However, the population of the KLVb is increasing at a rate of 3.5% each year, which is among the fastest in the world ([MIRITI](#), 2021). Based on these statistics, the population in the KLVb could be expected to continue growing in the coming years, with the implication being high densities which would potentially worsen the environmental degradation.

Concerning the spatial concentration patterns of the growing population over the years, the increasing intensity of the dark brown colour during each subsequent decade in the population density maps clearly revealed that the population density in the basin has been increasing over the years. According to [JUMA ET AL.](#), (2014), the Lake Victoria basin is one of the most densely populated areas in East Africa. [MIRITI](#) (2021) estimated a mean regional population density in the area of 250 people per square kilometre. This is much higher than Africa's average of 36 people per square kilometre ([WORLD BANK](#), 2021). From the analysis in this study, it is imperative to note that the rate of population growth (140%) was greater than the rate of built-up land turnover (97%) during the study period. The implication is that open land conversion to urban land was happening at a lower rate compared to the high rate of population growth in the region hence the high population density over the years. This points to a situation in which a small urban infrastructure is meeting the needs of a greater population, which could have adverse socio-economic impacts such as emergence of informal settlements with deplorable living conditions and strain on available socio-economic resources and amenities. In fact, [WANG ET AL.](#) (2012) had observed that even though urban growth in the region has been rapid, it is mainly in the form of informal settlements (commonly known as slums and shanties).

The high population density observed in the region could also be a consequence of massive rural-urban migration which is promoted by the search for better economic opportunities and the reduction in livelihood means for the rural populace ([JUMA ET AL.](#), 2014). It is documented that the Lake Victoria basin has the densest rural populace ([NASA](#), 2006). However, since the capacity of the lake basin's natural resources to support rural livelihoods has been deteriorating over time ([WORLD BANK](#), 2016), it is forecast that rural-urban migration will continue rising in the study area. This is consistent with global trends whereby it has been projected that above 50% of the world population

will reside in urban areas due to the current rates of rural-urban migration patterns ([PHAM ET AL.](#), 2011). As the developing urban centres continue to attract more people, it can be anticipated that the situation could get worse unless the government comes in with appropriate and sustainable local development, land use and urban plans. Another important aspect is that in 1978, the populations were majorly concentrated on fringe areas near the lake. Over time, this concentration has gradually shifted to areas a little farther from the lake. This phenomenon is attributable to the fact that fisheries were the major economic activity in the early years but this has since changed due to continued reduction in the fishery potential of the lake ([NJIRU ET AL.](#), 2010) due to the combined effect of pollution, invasive species infestation and land degradation. This might have motivated migration to other areas within the basin in pursuit of alternative economic opportunities to supplement earnings from fisheries.

A positive correlation was found between the built-up area and population growth/size. This is in line with the findings of [HUSSAIN ET AL.](#) (2020) who observed a positive correlation between population growth/size and the growth of built-up areas. Apparently, as the population increases, the built-up area increases in equal measure. On the other hand, a decrease in population would prompt a decrease in the rate of built-up area growth. Notably, the ratio of a region's total population to its total built-up area is a metric for measuring sprawl ([RAHMAN ET AL.](#), 2010). From the foregoing discussion, it is evident that as the population keeps growing within the KLVb, the built-up areas should be expected to expand since necessary infrastructure would have to be constructed to accommodate the residential, commercial and industrial needs of the burgeoning population. [MUGO ET AL.](#) (2020) associates the rapid growth to economic growth characterized by industrialization, commercial development, better amenities, tourism and hospitality, and advances in technology and education in the basin over the years. These attract huge urban migration as well as spurring natural population growth due to the better livelihoods of the populace.

The cumulative impact of rising urban land use, as seen in this study, is that natural landscapes (under vegetation and water) are converted to built-up areas through construction of human residences and associated socio-economic amenities to accommodate the growing population ([JUMA ET AL.](#), 2014). Basically, growth in the population and economy brings an increased demand for natural resources which in turn brings greater utilization

of these resources than are naturally replenished, hence negative impacts on the ecosystem. This could already be the case in the KLVb. A study by LUNG'AYIA ET AL. (2001) established that the high population density in the Lake Victoria region has greatly influenced the environmental integrity of the lake itself. This has been found to majorly drive eutrophication indirectly (WRI, 2009). Pollution, eutrophication and invasive species infestation represent some of the numerous perennial problems in Lake Victoria (JUMA ET AL., 2014). The potential sources of aquatic pollutants from urbanized environments arise from the urban systems of water supply, sewage management, solid waste management and runoff collection ponds (KAUSHAL ET AL., 2014; HOSEN ET AL., 2014). Generally, fresh water shortages, soil erosion, reduction of biodiversity, gradual loss of wetlands, deterioration of coastal areas, water resource contamination, management of agriculture, commercial, and domestic waste, emergence and re-emergence of pathogens, the water hyacinth problem (an invasive species), and natural disasters such as floods are all serious environmental problems related to increasing urban development in the Lake Victoria basin as well as the world over (UNEP, 2006; UNITED NATIONS, 2012). Many of these environmental risks emanating from increasing urbanization of watersheds call for control and regulation of urban expansion in fragile ecosystems such as lake basins. In this respect, periodic monitoring of urban land use and land cover is essential for informing sustainable planning and management that considers ecological, economic and social factors.

5. Conclusions

This study assessed the dynamics of urban expansion in the KLVb between 1978 and 2018 using a combination of remotely-sensed land use and population data. Urban growth was found to have increased by 97% by built up area and 140% by population over these years. A direct statistical correlation ($R^2=0.5744$), between built-up area expansion and population growth, was reported. Spatial urban growth in the area was found to be proceeding in almost all directions starting from the fringe of the shores of the lake, moving outwards. Urban development in the basin and population pressure is causing great losses in forest cover, agricultural areas and wetlands as these lands are being converted to built-up areas over the years through infrastructure construction of various amenities. This might be the cause of the current environmental degradation in the basin. To this end, the study recommends enactment

and implementation of appropriate legislation, and formulation of policies to control, plan and regulate urban sprawl. A robust urban planning system that incorporates scientific conservation approaches in promoting development of urban systems while limiting negative environmental impacts in the entire Lake Victoria basin is warranted.

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