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Spatial analysis of the effects of urban expansion on agricultural land use in sub-Saharan Africa: A case of Dar es Salaam region in Tanzania

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Abstract
This study aimed to analyze the effect of urban expansion on agricultural land use in Dar es Salaam. It involved Classification of Sentinel-2 Satellite Imagery to ascertain whether there was a change in land use/land cover for the time period 2016 until 2019 using maximum likelihood algorithm. The classification accuracy was 62% and Kappa Hat coefficient 0.48 for 2016 and 79.15% and Kappa Coefficient 0.75 for 2019 respectively. A total of 17,428.06 hectares of land were detected to have changed from other classes into Urban and built-up.

Keywords: Agriculture, land use, land cover, maximum likelihood algorithm, urban expansion

1. Introduction
Urban expansion comes at a cost of changing the nature and previous use of the land of a particular area (Krannich, Jess M. 2006) [3]. It is associated with landcover changes on features such as urban green areas, wetlands, riparian mangrove forest, and other forest and grassland ecosystems which give way to the construction of new roads, new residential and industrial layouts, recreation and amusement parks, and the like (Ming, *et al*., 2014) [4] and (Sudhira H.S, *et al*., 2003) [5].
In Africa, urbanization and urban expansion are megatrends of the 21st century (Kukkonen, *et al*. 2018) [6]. In large cities, such as Dar es Salaam, some 70 to 80 percent of residents live in informal areas because of an inadequate supply of planned, surveyed, and serviced land parcels (Sarzin, *et al*., 2012) [7].
A major concern related to urban expansion is land-use (LU)/land-cover (LC) change, which can dramatically alter the landscape in areas with high rates of urban expansion (Lizuka *et al*., 2017). It is estimated that urban land cover will increase five to twelve-folds in the region between 2000 and 2050 (Angel *et al*., 2011) [9]. This transformation of fertile and productive land into infrastructures and residences poses a threat to urban farming in terms of space and scarce water resources (Eckert and Sandra, 2011) [10].
Urban farming is practiced all over the world especially in developing countries by low-income dwellers; significantly contributing to food security and food safety and sustainable livelihood in the urban and peri-urban areas (Orsin F. *et al*., 2013). Farming in the city is an indication that there is inadequate, unreliable, and irregular access to food and formal employment by most of the urban poor (Eckert and Sandra, 2011) [10].
We therefore assessed effects of urban expansion on agricultural land use by using Geographical Information System (GIS) and remote sensing analysis techniques for the time-period of 2016 to 2019, in the Tanzania's administrative region of Dar es Salaam.

2. Literature Review
Projections show that urbanization, the gradual shift in the residence of the human population from rural to urban areas, combined with the overall growth of the world's population could add another 2.5 billion people to urban areas by 2050, with close to 90% of this increase taking place

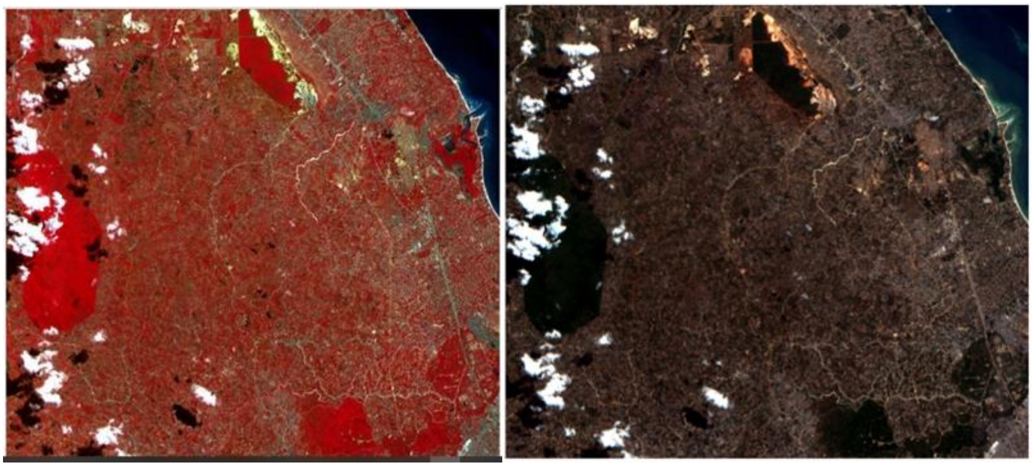
in Asia and Africa (Bocquier and Phillipe, 2003) [12]. Across all regions, urban land expansion rates are higher than urban population growth rates, suggesting that urban growth is ecoming more expansive than compact (Wiesner *et al*., 2012) [13]. However, an unplanned urban expansion which is a challenge in developing countries, brings more harm than good to the economic growth and environment and specifically to the agricultural sector (Sadaf K., and Himanchal, 2019).

This is exemplified in the study undertaken by Tokula A.E, and Ejaro S.P, (2018) [15] on the impact of urban expansion on agricultural land and crop output in Ankpa, Kogi State, Nigeria. It was discovered that; land use and land cover had undergone considerable changes over the period examined with built-up areas expanding significantly while agricultural lands, vegetation, and bare surface declining due to the growths in population and physical developments. Also, Li Jiang, *et al*., (2013) [16] studied the impact of urban expansion on agricultural land-use in China. Their study revealed that urban expansion was associated with a decline in agricultural land-use intensity. Similarly, Sadaf K., and Himanchal, (2019) researched the impact of urban expansion on agricultural land-use in Aligarh, Uttar Pradesh, India. The study showed that there was a gradual decrease in agricultural land. Ayele A. and Tarekegn K, (2020) conducted a study on the impact of urbanization expansion on agricultural land in Ethiopia. The study showed that urban expansion has reduced the areas available for agriculture, which has seriously impacted upon peri-urban farmers that are often left with little or no land to cultivate and which has increased their food insecurity. Also, Bonye S. Z, *et al*., (2021) studied the urban expansion and agricultural land use in Ghana; Implications for peri-urban farmer household food security in Wa Municipality. The results showed over the last three decades hectares of peri-urban agricultural land had drastically changed into residential and infrastructural development leaving urban farmers with no land for agricultural production. Caldwell W. *et al*., (2022) [2], developed a study on farmland preservation and urban expansion; A case study of Southern Ontario, Canada. The study revealed that there has been an overall declining rate of farmland loss across the Greater Golden Horseshoe since 2005 due to implementation of farmland protection policies.

3. Methodology

The current study was conducted in the Dar es Salaam region, which consists of five districts; Ilala, Kinondoni, Temeke, Ubungo, and Kigamboni. It is located at latitude 6°49′24″ South and longitude 39°16′10″ East.

We used remote sensing and GIS-based change detection from 2016 and 2019 Sentinel-2A images downloaded from European Space Agency (ESA) platform, known as Copernicus Open Access Hub (https://scihub.copernicus.eu/). The images were clipped to Dar es Salaam boundaries by using a polygon map of Dar es Salaam region downloaded from the website of Tanzania's National Bureau of Statistics (NBS).



RGB= 7-3-2 Color Composite RGB = 3-2-1 Color Composite

Fig 1: Color composites of the study area

3.1 Data Source

This study made use of MCD12Q1 MODIS/Terra+Aqua Land Cover Type Yearly L3 Global 500m SIN Grid V006 (Friedl, M., Sulla-Menashe, D. ,2019), and Sentinel-2 satellite images of the Dar es Salaam region showing land-use/land-cover (LULC) characteristics between 2001until 2018 (Dezso *et al*. 2005). These images were used to study patterns of land-use/land-cover changes in the region.

Type of Data	Source	Temporal /Spatial Resolution
MCD12Q1 MODIS/Terra+Aqua Land Cover Type.	https://lpdaac.usgs.gov/products/mcd12q1v006/	Yearly/L3 Global 500m SIN Grid V006
Sentinel-2A_MSIL2A	https://scihub.copernicus.eu/dhus/odata/v1/	Yearly/10m resolution
Crop Yield Data (Maize, Cassava, Cow Peas)	Ministry of Agriculture of Tanzania	Yearly (ton/hectare)

3.1.1 Land use/ Land cover classification

Supervised classification (maximum likelihood algorithm) tool of the Semi-Automatic Classification Plugin (SCP) in QGIS software was used to classify the Sentinel-2A images into land use/land cover classes. Maximum likelihood classifier is a method of classification in which a pixel with the maximum likelihood is classified into the corresponding class (Richards, J. A. 2013) [17]. According to Richards, the likelihood (L_k) is the posterior probability of the pixel belonging to class k. It is given by the following formulae,

$$L_k = P\left({}^{k}/_{X}\right) = P(k) * P({}^{X}/_{k}) / \sum P(i) * P({}^{X}/_{i})$$

Where

X: The image data of n bands

$P(k)$: Prior probability of class k

$P(X/_k)$: Conditional probability to observe X from class k, or probability density function.
$P(k)s$ for each class are normally assumed to be equally similar and $\sum P(i) * P(X/_i)$ is also common to all classes. Therefore L_k depends on $P(X/_k)$. Mathematically, a multivariate normal distribution is applied as the probability density function, modifying the likelihood formulae as expressed below;

$$L_k(X) = \frac{1}{(\pi)|\Sigma_k|^{\frac{n}{2}}} e^{\left\{-\frac{1}{2}(X-\mu_k)\Sigma_k^{-1}(X-\mu_k)\right\}}$$

Where;
n: Number of bands
X: Image data of n bands
$L_k(X)$: Likelihood of X belonging to class k
μ_k: Mean vector of class k
$\sum_k$: Variance-covariance matrix of class k
$|\sum_k|$: Determinant of $\sum_k$

3.1.2 Urban Expansion Forecast Model
Urban and built-up area in Dar es Salaam has been increasing gradually over time. This means that there is a constant trend in the time series, therefore a trend line model was used to forecast urban expansion. The trend line model is given as follows;

$$T_t = b_0 + b_1 t.$$

Where;
T_t = Linear Trend Forecast in period t
b_0 = Intercept of the linear trend line
b_1 = Slope of the linear trend line, t = time period

The model was made using time series for urban and built-up for Dar es Salaam from 2001 until 2016, while the data for the three time periods 2017, 2018 and 2019 was used to test the model.
Furthermore, we used Open Street Map to assess the accuracy of the classification ("ground truthing"). The dependent variable, agricultural land use, was measured by the area (in hectares) of agricultural land cultivated for production. The independent variable was urban land expansion. It was measured by the size of areas (in hectares) of urban and built land each year of the time period under study. We then created the supervised classification training input Regions of Interest (ROIs) as displayed in the following table;

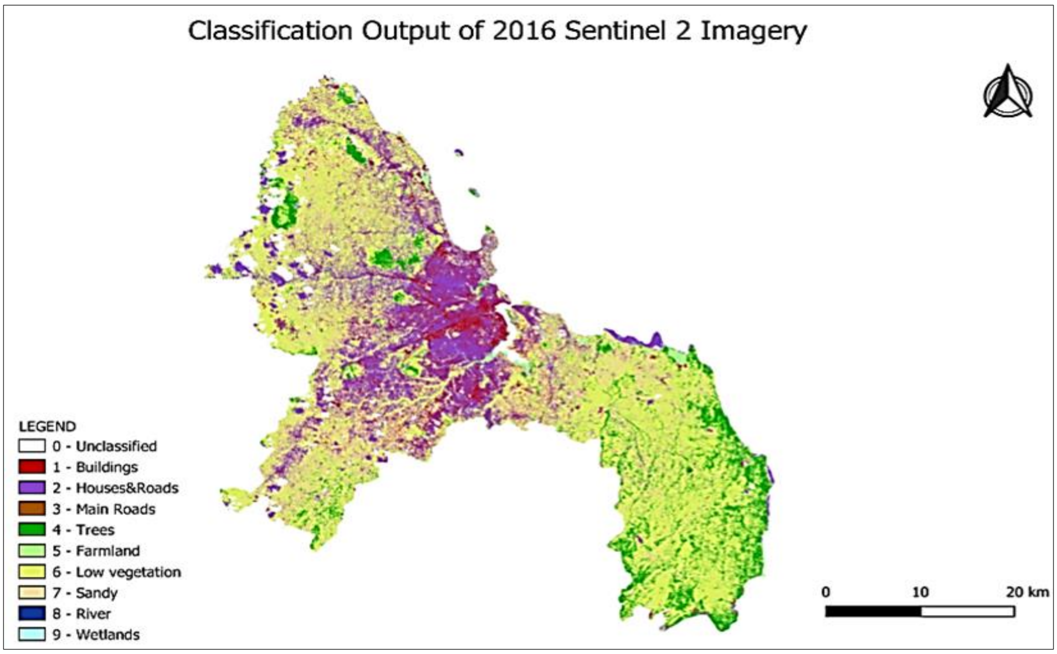
Table 1: Training Input File

Macro class Name	Macro class ID	Class Name	Class ID	Color
Built-up	1	Buildings	1	
		Houses and Roads	2	
		Roads	3	
Vegetation	2	Trees	4	
		Farms	5	
Water	3	Rivers	6	
		Water Channels	7	
Bare Soil	4	Low vegetation	8	
		Sandy	9	
Unclassified	5	Clouds	10	

Source: Researcher's Findings, 2020.

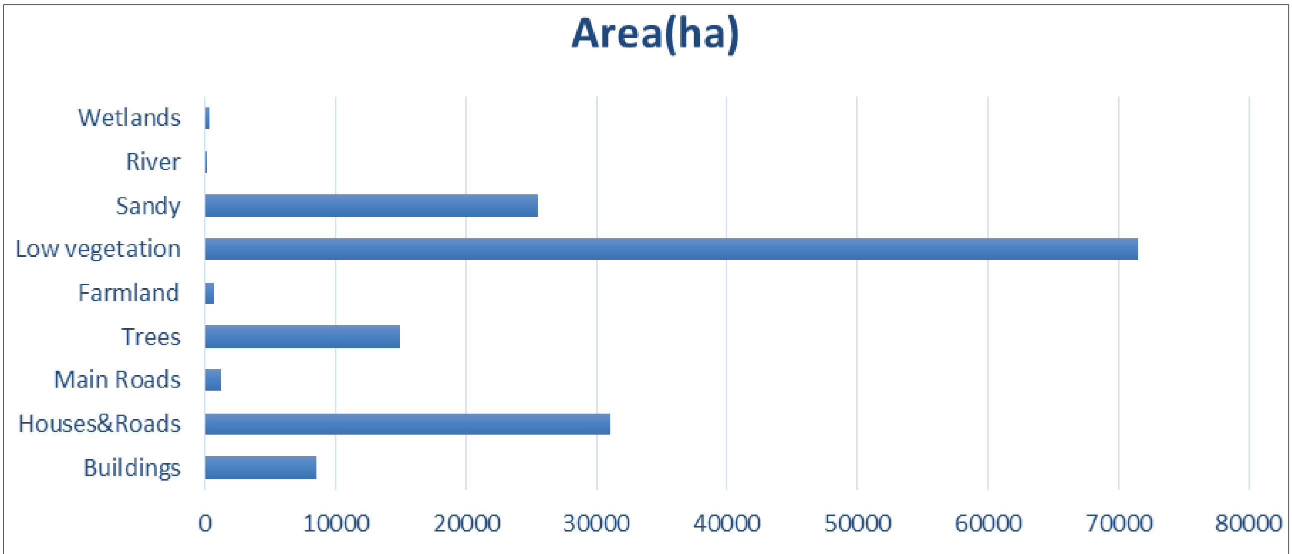
Table 1 above represents the database of spectral signatures designed specifically to identify the land cover classes. The macro classes represent the general categories of land cover within resides the micro classes which further distinguish one class from the other. The macro classes were only five with macro class IDs 1 to 5 and the micro classes were ten (10) with micro class IDs from 1 to 10. The unclassified macro class consists of all the regions whose land cover could not be revealed due to obstruction of clouds.

4. Findings and Discussion
In the change detection analysis, Sentinel-2 satellite images were classified, with the overall accuracy of the classification of 62.15% and 79.15% for the 2016 and 2019 images respectively.



Source: Researcher's Findings, 2020.

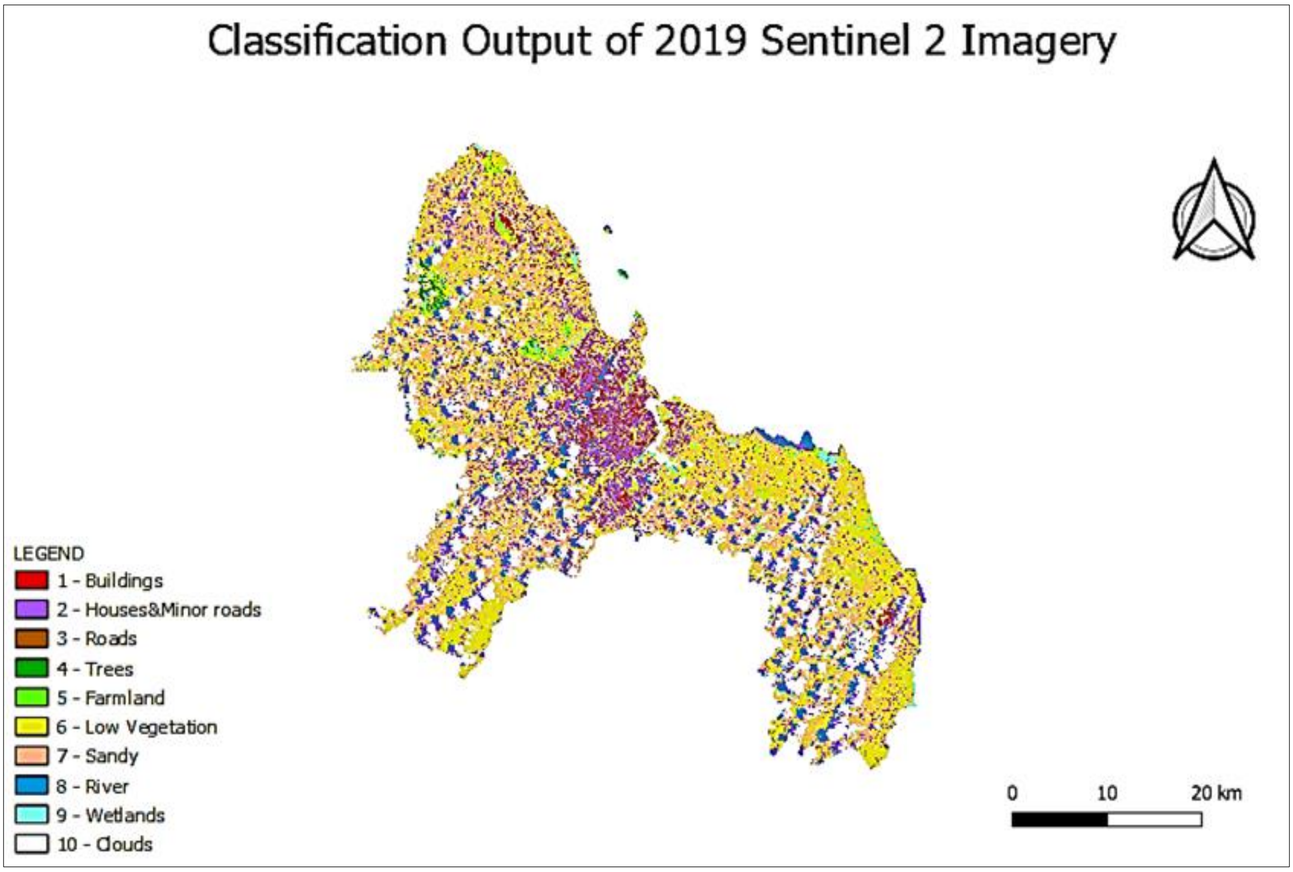
Map 1: Classification Output for Dar es Salaam Region 2016.



	Buildings	Houses&Roads	Main Roads	Trees	Farmland	Low vegetation	Sandy	River	Wetlands
Area(ha)	8484.56	31064.56	1214.04	14897.12	654.96	71492.32	25547.08	21.64	350.52

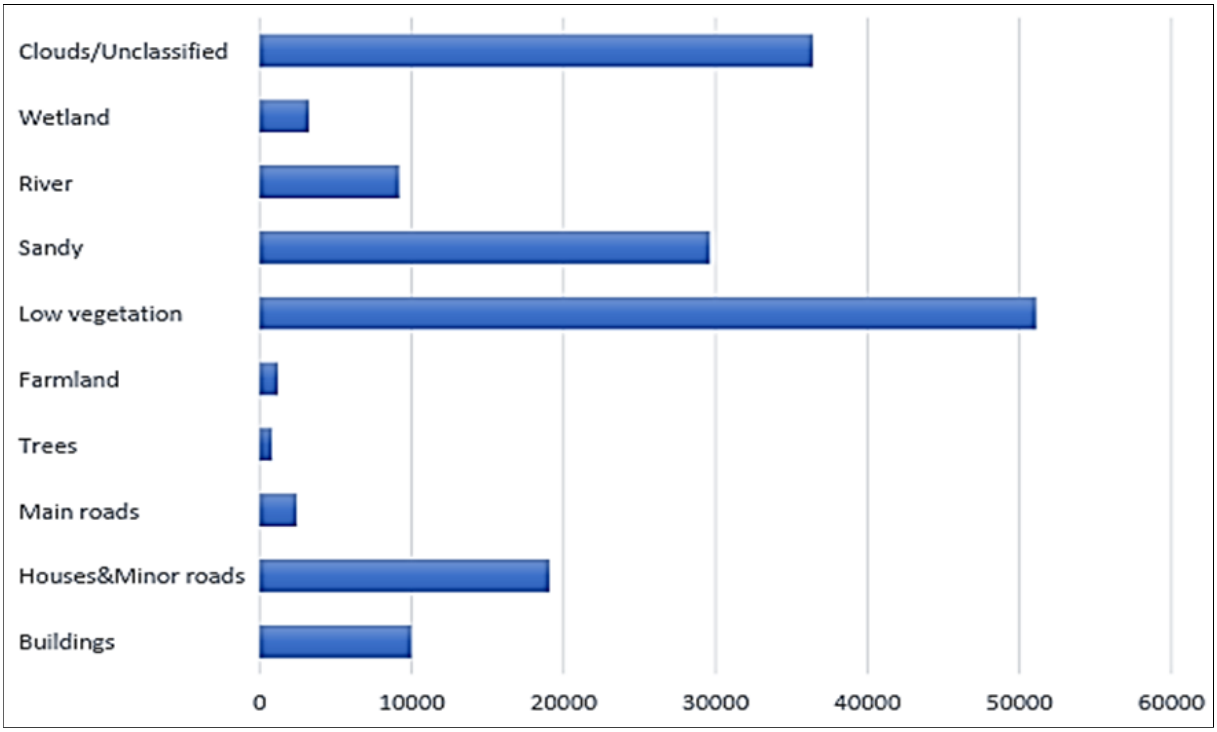
Fig 2: Distribution of Study Area into Classes in 2016.

Figure 2 above shows the distribution of the area of study into the classes used in the classification of Dar es Salaam region. The area covered by low vegetation comprises the largest area of Dar es Salaam for approximately 71,492.32 hectares (47% percent) followed by houses and minor roads areas with 31,064.56 hectares (21% percent). The land cover class with the smallest area is rivers with 21.64 hectares (0.01% percent) followed by Wetlands which comprises 350.52 hectares (0.23% percent).



Source: Researcher's Findings, 2020.

Map 2: Classification Output using 2019 Sentinel-2 Imagery



Source: Researcher's Construction, 2020.

Fig 3: The distribution of Study Area into Classes in 2019

Figure 3 above shows the distribution of Dar es Salaam region into the classes used in the classification. The area covered by low vegetation comprises the largest area by approximately 51,103.49 hectares (31.33% percent) followed by sandy areas with 29,637.94 hectares (18.17% percent). The land cover class with the smallest area is Trees land with 827.69 hectares (0.51% percent) followed by farmlands which comprises 1204.43 hectares (0.74% percent).

Using the two classification outputs above, a LULC change detection was made possible since both were processed under maximum likelihood algorithm.

This post-processing procedure requires setting the oldest classification output (Classification Output for 2016 Sentinel-2 Imagery) as a reference classification, and the latest classification output (Classification Output for 2019 Sentinel-2 Imagery) as the new classification.

In order to have valuable information for interpretation, unchanged pixels between the two time periods were set to be reported in the output. The following table shows the LULC change that has occurred in Dar es Salaam region over the time period under study.

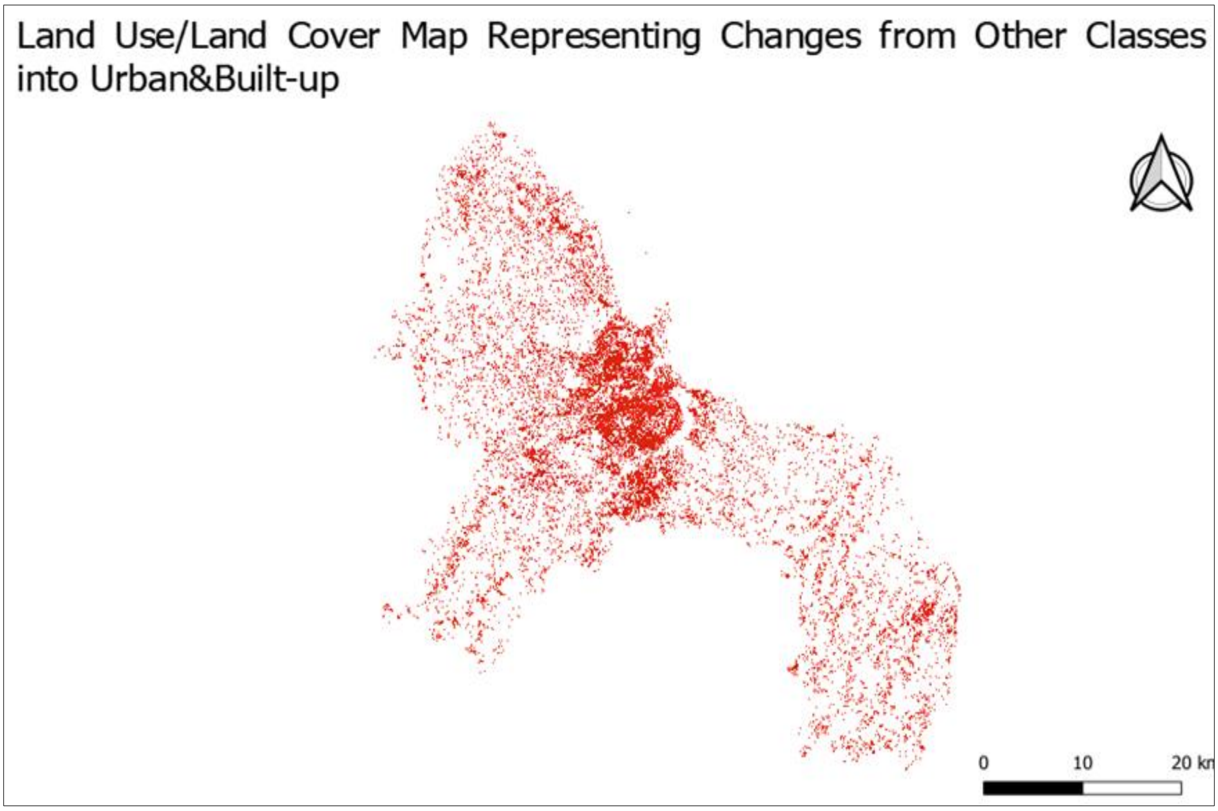
Table 2: LULC Change Detection Output in the time period under study.

S/N	Reference Class (2016)	New Class (2019)	Area (hectares)
1	Buildings	Roads	705.23
2	Buildings	Wetlands	15.54
3	Houses & Minor roads	Buildings	3839.93
4	Houses & Minor roads	Roads	1478.78
5	Houses & Minor roads	Wetlands	154.85
6	Trees	Buildings	163.55
7	Trees	Houses & Minor roads	919.81
8	Trees	Roads	15.66
9	Low vegetation	Buildings	1906.44
10	Low vegetation	Houses & Minor roads	5088.04
11	Low vegetation	Roads	91.19
12	Farmland	Buildings	0.6
13	Farmland	Houses & Minor roads	17.79
14	Farmland	Roads	0.19
15	Sandy	Buildings	728.78
16	Sandy	Houses & Minor roads	2215.26
17	Sandy	Roads	31.25
18	Wetlands	Buildings	4.22
19	Wetlands	Houses & Minor roads	42.79
20	Wetlands	Roads	8.16

Source: Researcher's Findings, 2020.

Table 2 above is the description of the amount of land cover that has changed from one class to another during the time under the study. It shows that 163.55 hectares have transformed from trees to buildings, and 919.81 hectares from trees to houses and roads. Also 0.6 hectares and 17.79 hectares changed from farmland to buildings and houses and minor roads respectively.

On the other hand, 15.66 hectares transformed from trees to main roads, and 0.19 hectares from farmland to main roads. Similarly, 1906.44 hectares transformed from low vegetation to buildings and 5088.04 hectares transformed from low vegetation to houses and minor roads. On the same note, 91.19 hectares transformed from low vegetation to main roads. The transformations of the land cover in Dar es Salaam from 2016 until 2019 indicates that the urban expansion is rapidly taking place. This is similar to the results of the study by (Tokula A.E, and Ejaro S.P, (2018) [15] that discovered that land use and land cover of the study area had undergone considerable changes over the period examined. Built-up areas had expanded significantly during the study period under review.



Source: Researcher's Construction, 2020.

Map 3: Classification Output Indicating LULC Spatial Changes

The analysis involved classification of Sentinel 2 imagery of the year 2016 and 2019 for change detection.

The change detection analysis result indicated that during 2016 until 2019, total of 17,428.06 hectares changed from other classes into Urban and Built-up (Buildings, Houses and Roads, Main roads) category.

Forecasting model for urban expansion was $T_t = 24195.41 + 604.2954t$ with

$R^2 = 0.85$, and $Prob > F = 0.0000$ and $RMSE = 297.31$. This model significantly estimates urban expansion in Dar es Salaam to be 42,324.26 hectares by 2030, which is an increase of 6,042.95 hectares from 2020.

5. Conclusions and recommendations.

The study successfully managed to detect changes in Land use/land cover in Dar es Salaam region. It has been revealed clearly that there is an increase in urban and built-up areas year after year. The study indicated that agricultural land use is affected by urban expansion with the relationship between urban expansion and agricultural land cultivated for Cow peas and Maize both being negative for the time period under study.

Urban expansion can be controlled by having proper urban planning that will define land uses for instance land for agriculture, land for main infrastructures like roads and railways, and land for residence. There must be regulations that limit the interference of the land uses in each category to ensure that there is a balance in the city. Forests should be preserved as forests, wetlands and water channels, and agricultural land should remain in their core uses.

Migration to cities has to be discouraged through improvement of major needs in rural areas such as transport infrastructures like roads and railways, business infrastructures like markets, other needs such as hospitals, and schools so that no need for the population to move to cities seeking better life.

Land use intensity has to be emphasized so as to combat the effect of urban expansion on crop yield. The available land for agriculture has to be used effectively with proper application of manure and fertilizer, together with the use of recommended seeds to improve crop yield.

6. Area for Further Research

The study has only examined the effect of urban expansion on crop yield. However, there are other factors which might affect the crop yield in the area like fertilizer application, knowledge on Agriculture, experience, climatic changes like rainfall and temperature, and labor force. These factors could be considered to formulate a reasonable model explaining crop yield in the area.

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