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Characterization and Quantification of Urban Expansion and Impact on Urban Planning Practice in Morogoro Municipality, Tanzania

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Globally, there are extensive concerns about urban expansion. In response, urban expansion detection and assessing land use and land cover (LULC) changes have become significant methods to support decisions about suitable land resource use. The major concern with urban expansion aside from habitat destruction, is the distribution of human resources and basic needs especially to the community living in the newly settlement patches. This study applied a series of Landsat images to quantify the rate and characterise the pattern of urban expansion and assess its impact on urban planning practice over a 30 years period from (1990 to 2020). Change detection was supported by images and supervised classification method. Random Forest (RF) classification method was used to achieve imagery classification, and from classification results were validated by Kappa index of Agreement (KIA) and overall accuracy (OA) methods. To analyze these changes, we used Urban Expansion Intensity Index (UEII) landscape metrics to characterize the changes in the spatial patterns across Morogoro landscape and it's impact of urban expansion on other types of land cover.

The findings indicated that from 1990 to 2010 built up areas have been experiencing an increase of 3.9% to 18.1% respectively, while non-built up areas have decreased from 96.1% to 81.9% respectively within 30 years period time .Urban planning practice in 1990 to 2020 increased of planned land where by plan before development on land increase from 0.8% to 6.6% while the plan after development increase from 0.2% to 10.8% of the total urban area in the same year.

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In significant changes in urban expansion and urban planning practice experienced were highly correlated in 2010 to 2020. Based on the outcomes of this study, it is recommended that municipal authorities should consider initiatives in urban planning to reverse the existing trend of urban development in order to recover the sustainability and resilience of the urban situation. The conclusions clarified the spatial pattern of urban change and its influencing factors in Morogoro municipality over the past 30 years and could provide helpful reference for the future urban planning.

Keywords: Urban expansion; urban planning; urban expansion intensity index; remote sensing and GIS technology.

1. INTRODUCTION

The most fundamental and critical challenge faced by urban areas in most developing countries, particularly in African countries is the crippling weakness of institutions of urban development planning and management. In the sub-region and the place and role of urban planning in promoting sustainable urban development in the countries of the region in the context of the prevailing dominance of informal economic activities and increasingly uncontrollable urban sprawl [1].

Urban Planning is the process of programming the coordination of the direction, structure and pattern of the development, growth and management of urban settlements with the goal of ensuring that all necessary land-use needs (i.e including economic, social, environmental, institutional, cultural, recreational and leisure needs), for all the socio-economic population groups in the society are provided for in compatible and symbiotic location relationships and densities (Devas, 2001). Generally, traditional urban planning has been reliant on the existence of stable, effective and accountable local government, as well as a strong civil society, in order to play a positive role (Devas, 2001). Failures of the urban planning authorities and developers to administer and manage land related processes are significant in sub-Saharan Africa countries countries (Kira & Sumari, 2020; Korah et al., 2017)

Previously, a number of researchers identified different measurement indices to indicate urban morphological techniques based on remote sensing data by exploring the spatial and temporal dynamics of these indices [2,3]. One of these indices, Urban Expansion Intensity Index was popularly used to measure and characterized growth in emerging urban areas at the given period of time [4-9]. Moreover, some researchers used statistical or diagrammatic methods to investigate the main indices of urban expansion, in order to reveal how these indices change as the distance from the city core increases [10-12]. For instance, Sumari *et al*. [2] used diagrammatic method to demonstrate the circular pattern of urban expansion in Yangtze River Delta. Jiao [12] used logistic curve to fit the urban land densities of 28 major cities in China, and found that the urban land density is related to the distance from the urban center in an inversed S-shape way, which suggested that urban land has high density in center area and low density in marginal area.

Recent studies identify rapid and unplanned urban settlement of the moja threat. Cobbinah et al. [13]. Africa is expected to become home to nearly a quarter 1.3 billion of the world urban population in 2050. The finding from this study will therefore enhance sustainable urban planning for urban settlement expansion through reliable analysis on how urban settlements are growing with different rate and direction.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is Morogoro Municipality in Fig. 1 is one of the nine districts in Morogoro region including Kilosa, Ifakara, Kilombero, Malinyi, Mvomero, Gairo, Ulanga and Morogoro Rural. Morogoro region occupies 72,939 km^2 that is approximately 8.2% of the total area of Tanzania mainland. The municipality is the capital of Morogoro region and it covers 540 km^2, which is 0.74% of the total area of Morogoro region [14].

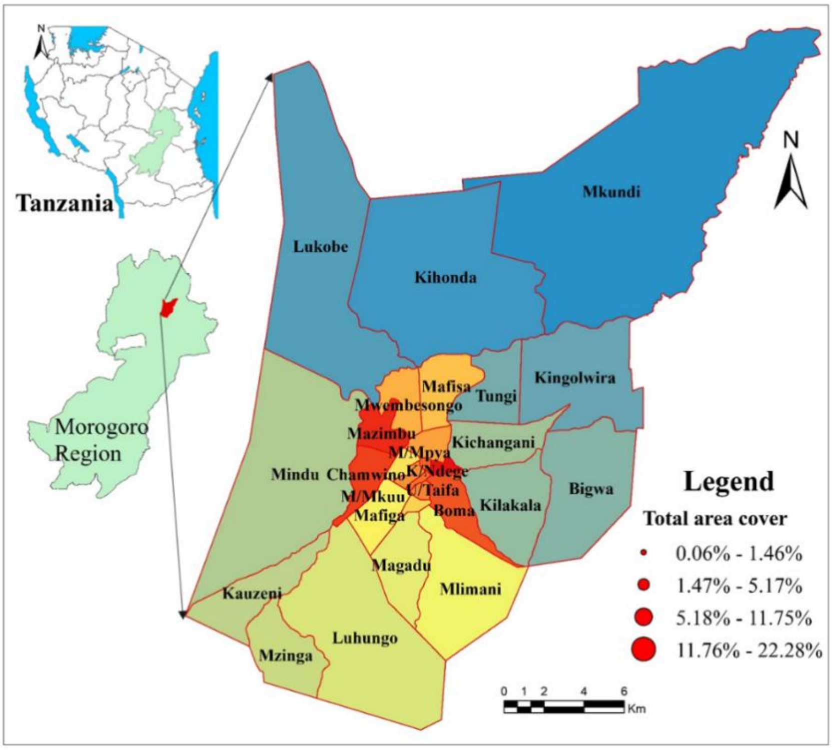

Fig. 1. The area of the study, Morogoro Municipal located in Morogoro region, Tanzania

2.2 Methodology

Fig. 2 shows the workflow of the study which is separated into three sections. Firstly, the acquisition of satellite imagery data, and preprocessing, secondly, change detection technique was been applied while the third part is spatial distribution detection using landscape metrics as the final results of the classification.

Data collection for this study involved spatial data and non-spatial data. Satellite Remote sensing data for 1990 to 2020 of ten yearly interval for the years 1990-2000, 2000-2010, and 2010-2020 were obtained from the USGS Earth-Explorer (USGS-EE) website (https://explorer.earthengine.google.com) Table 1 summarizes the datasets and their sources.

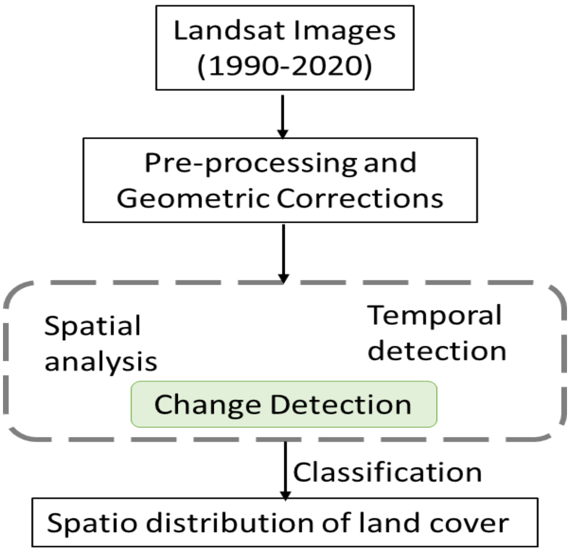

Fig. 2. Flowchart of the processing of spatio distribution of land cover in this study

Table 1. Data used

Type of Spatial data	Type of data	Source	Purpose
Satellite data	Landsat imagery (1990-2000,2000-2010 and 2010- 2020)	USGS EE Website	To monitor urban settlement expansion
Spatial data	Administrative Boundaries	Morogoro Municipality	For preparation of the study area map
	Scanned Detailed layout plans	Ministry of lands, housing and human settlement development	To Justify impact of urban expansion on urban planning practice

2.2.1 Data Pre-processing

Based on the study area the images were acquired from the United States Geological Survey Earth-Explorer (USGS EE) website. The images have been specified together with data set from United States Geological Survey Earth-Explorer (USGS EE) website (https://explorer.earthengine.google.com) . Data set include Landsat collection 1 level 1, Landsat 4-5 TM C1 Level 1, Landsat 7 EMT+C1 Level 1 and Landsat 8 OLI/TIRS C1 Level 1. Downloaded images had several bands which were composed by using Arc GIS Software, whereby Landsat 4-5 TM C1 Level1, Landsat 7 EMT + C1 Level band 1 to band 7, and Landsat 8 OLI/TIRS C1 Level 1 bands 1 to band 7 and band 10 were combined together by using Composite Bands tool in ArcGIS Program. For this study, three Landsat time series of 7th July 2000, 13th September 2007 of Landsat 7, and 13th September 2016 of Landsat-8 8 Day Top-of-Atmosphere (TOA) Reflectance Composites on path 167/ row 65 were used from the GEE Landsat collections and pre-processed. Using Fmask technique and Geo too on PCI Geomatic2015, all images which has cloud (Fig. 3). All Landsat images were obtained from http://earthexplorer.usgs.gov/ website of United States Geological Survey (USGS) from the path/row number 167/065. ENVI version 5.3 was used for image classification, with ERDAS Imagine version 2014 for accuracy assessments and ArcGIS version 10.3 for image data processing, visualization, and map generation. All images were registered to UTM coordinate system with WGS 84 datum zone 37 South for consistency, after that the images were clipped based on the boundary of the study area.

2.2.2 Classification, Change Detection and Validation

All the satellite images were applied for LULC classification. Random Forest (RF) supervised classification were been used using the training sample size in the statistical process(Demarchi et al., 2014). Two classes (built-up areas and non-built-up areas) were generated from the study area which was presented in each classification results.

The classification results can be influenced by a variety of problems, including classification errors, registration errors, and training quality issues [16-20]. The most significant criterion for evaluating classification performance is accuracy. In this research, Kappa Index of Agreement (KIA) method for accuracy assessment was used. The Kappa Index of Agreement is a statistical measure adapted for accuracy assessment in remote sensing fields [21]. It is used to check for accuracy of classified satellite images versus some real ground-truth data as shown in the equation 1.

$$k = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r}(X_{i+} * X_{+i})}{N^2 - \sum_{i=1}^{r}(X_{i+} * X_{+1})} \quad (1)$$

Where by r: number of row in the error matrix, xii: number of combinations along the diagonal, xi+: total observations in row i, x+i: total observations in column i. N: total number of cells.

To verify how accurately the pixel was sampled into the proper land cover class, the ground truthing technique together with Google earth pro were employed. A hand held GPS (Garmin) was used for field data collection of location data (Coordinates) together with Google earth whereby a total of 200 points for two land use types (built up and non-built up) were collected on the field ,each land use types carried 100 points collected from the field as shown in Fig. 4.

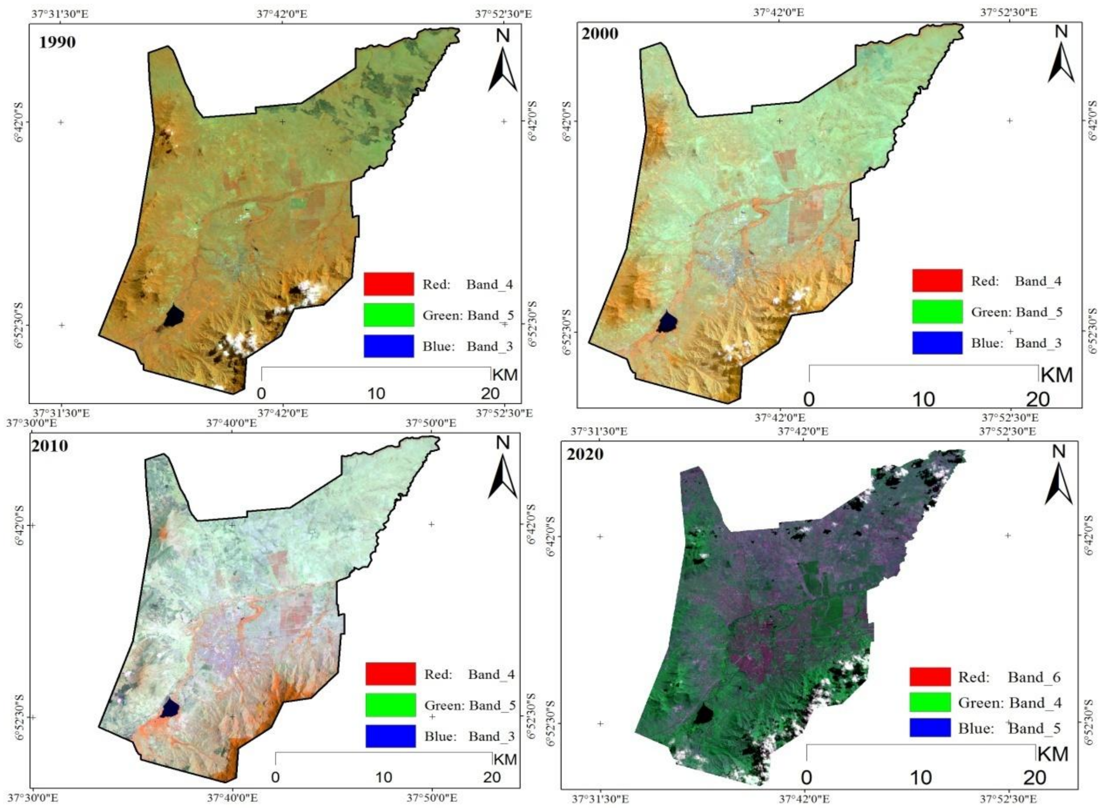

Fig. 3. Show the clipped processed images from 1990 to 2020 of the study area

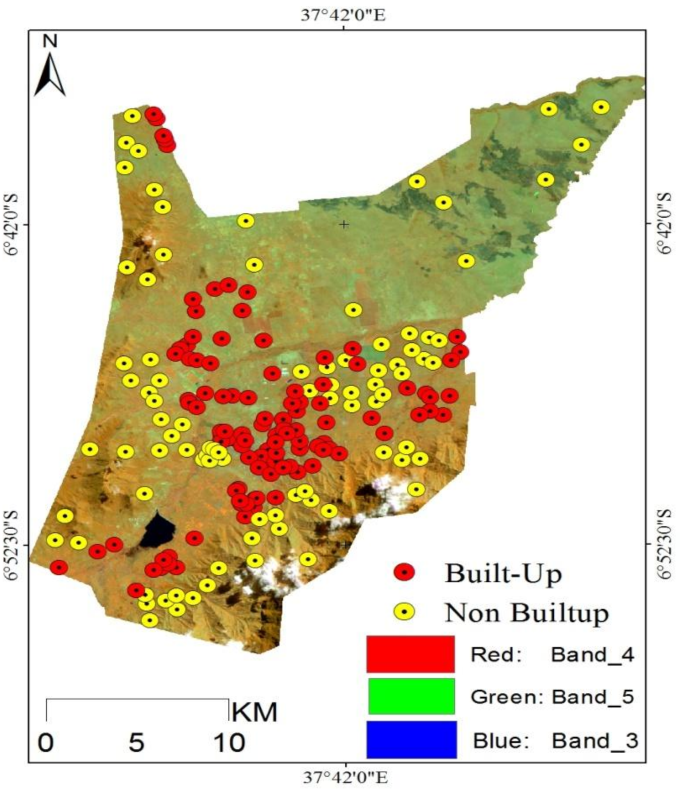

Fig. 1. Random sampling of built up and non built up points of the study area

2.2.3 Urban expansion intensity index (UEII)

Previously, number of researchers identified different indices for measurement urban morphological based on remote sensing data by exploring the spatial and temporal dynamics of these indices. One of these indices, Urban Expansion Intensity Index was popularly used to measure and characterized growth in emerging urban areas at the time [22]. The classified images were used to detect and monitor urban expansion in the study area and one spatial metric/index was adopted. Urban Expansion Intensity Index (UEII). (Eq:2.2) was used to compute the average annual proportion of newly increased built-up land of a spatial unit, standardized by the total area of that spatial unit [23]. In this study urban expansion intensity index of each ward was calculated the UEII using Equation 1.2, in the study area to characterize the spatial distribution of urban expansion for urban planner and policy makers.

$$UEII_i = \frac{(ULA_i^{t2} - ULA_i^{t1})}{TLA_i \times \Delta t} \times 100 \qquad (2)$$

Where,
Where UEII; is Urban Expansion Intensity Index of unit i; ULA^{t2}_i and ULA^{t1}_i are the areas of built-up land at time t2 and t1 respectively; TLA_i is the total land area within the study area i and Δt is the study time period. The division standard for interpreting UEII values is as follows. This ranges from<0.28 (very slow expansion): 0.28–0.59 (slow expansion): 0.5–1.05 (medium-speed expansion): 1.05–1.92 (high-speed expansion): and>1.92 (very high-speed expansion), [24].

2.2.4 Urban planning practices

Urban planning should play an important role in guiding and regulating urban expansion from the perspective of overall spatial structure and orderly development pattern. This study used scanned map data obtained from the Ministry of Land ,Housing and Human Settlement Development to develop a map showing zoning area covered by neighbourhood planning schemes prepared before urban development and after development (regularization Planning schemes) as shown in the Fig. 5. Georefencing tool in Qgis was used to register coordinate system of all scanned image in Universal Transvere Mercator Zone 37M_.All images were then lie within the Zone 37M Zone. Shape file polygon file was created in QGIS to enable digitization of boundary covering area of each detail planning schemes for both planning schemes created before development and after development .After digitization of all planning scheme symbology were used to differentiate between the planning developed after and before urban development within the area of Morogoro municipality [25-29].

3. RESULTS AND DISCUSSION

3.1 Accuracy Assessment

To determine the accuracy of land cover classifications, accuracy assessments of classified images were performed. Accuracy assessment was performed using stratified random sampling and kappa coefficient and overall accuracy percentage for all the classified images for the year 1990, Kappa Index of Agreement (KIA) was found to be 87.0%, for year 2000 it was 83%, 89% for 2010, and 93% for 2020, the overall accuracy for the study period 1990, 2000, 2010 and 2020 are 95% ,92% ,94% and 97% (Fig. 6), accuracy of classified Land sat images are statistically significant and acceptable for further studies. The methodology was used to test the approach for a large and diverse region where urban expansion is often uncoordinated and patchy, and consequently, where urban maps are most challenging to produce, yet most needed.

3.2 Land Use Land Cover Classification

The supervised classification method and images date provides tremendous results in detecting urban changes in Fig. 6. Images classification accuracy was validated by Kappa Index of Agreement (KIA) and overall accuracy methods (Fig. 5). For the years 1990, 2000, 2010, and 2020, the two LULC classes (built-up areas and non-built-up areas) were defined. (Fig. 7), and the area for each LULC classes has been presented in (Table. 2). Morogoro Municipality has experienced tremendous and very rapid urbanization. In 1990 to 2020 built-up increased from 3.9% to 18.9% of the total urban area of Morogoro municipality while non built up LULC class decreased from 96.1% to 81.9% of the total urban area of Morogoro municipality. Spatial distribution of the built-up extent and urban growth from 1990 to 2020 are depicted in (Fig. 7). Built-up growth tended to expand outward towards all directions but mainly in the north-west.

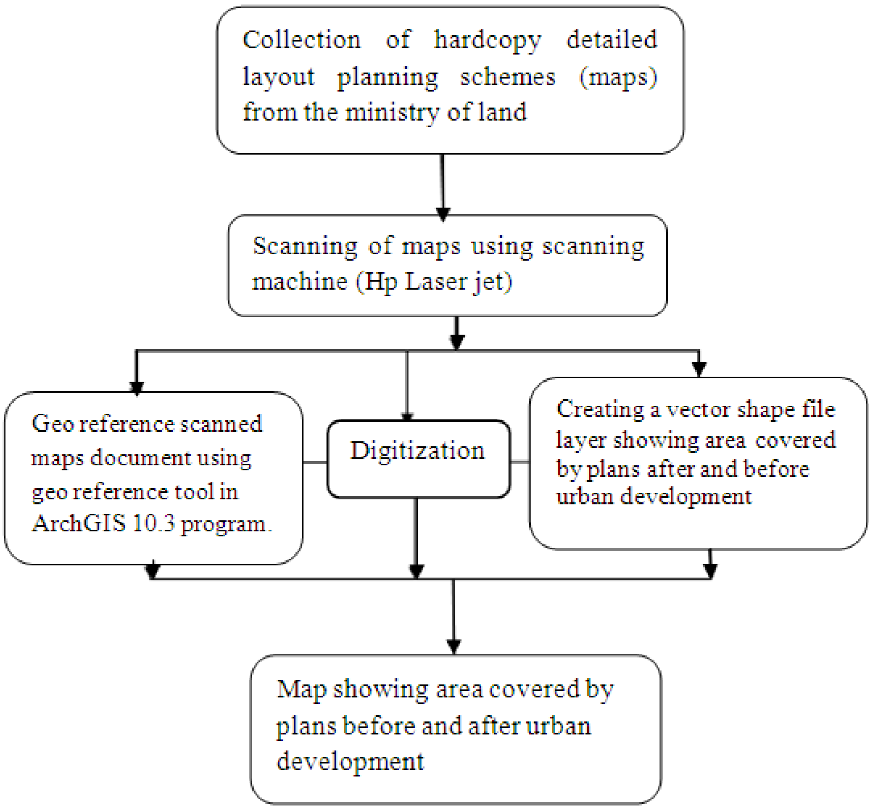

Fig. 5. The workflow on GIS technology monitoring detailed planning schemes before and after urban development plans

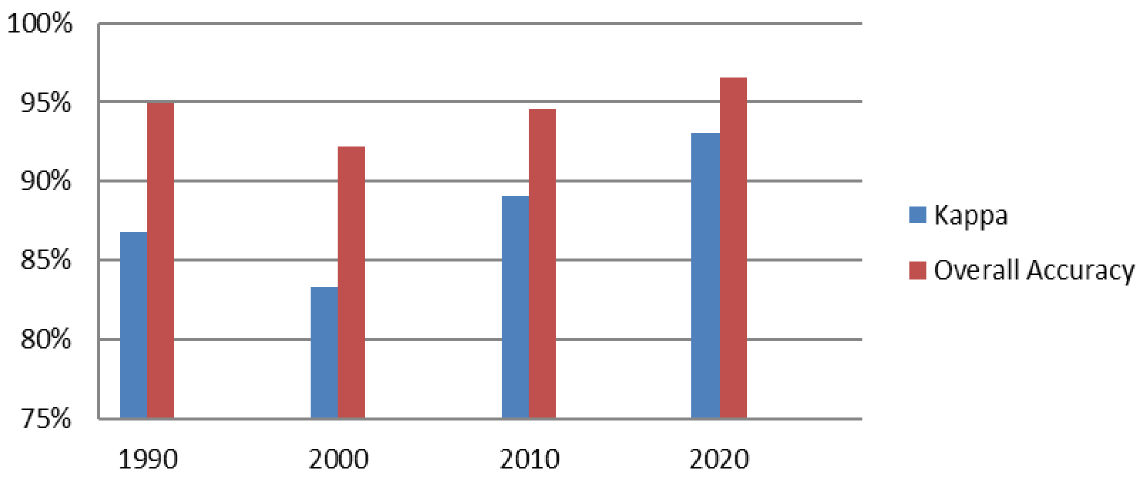

Fig. 6. Accuracy assessments of the classified images based on the two classes

Table 2. Percentages of Urban expansion from 1990 to 2020

LAND	1990	2000	2010	2020
	%	%	%	%
Built-up	3.9	4.8	6.6	18.1
Non Built-up	96.1	95.2	93.4	81.9

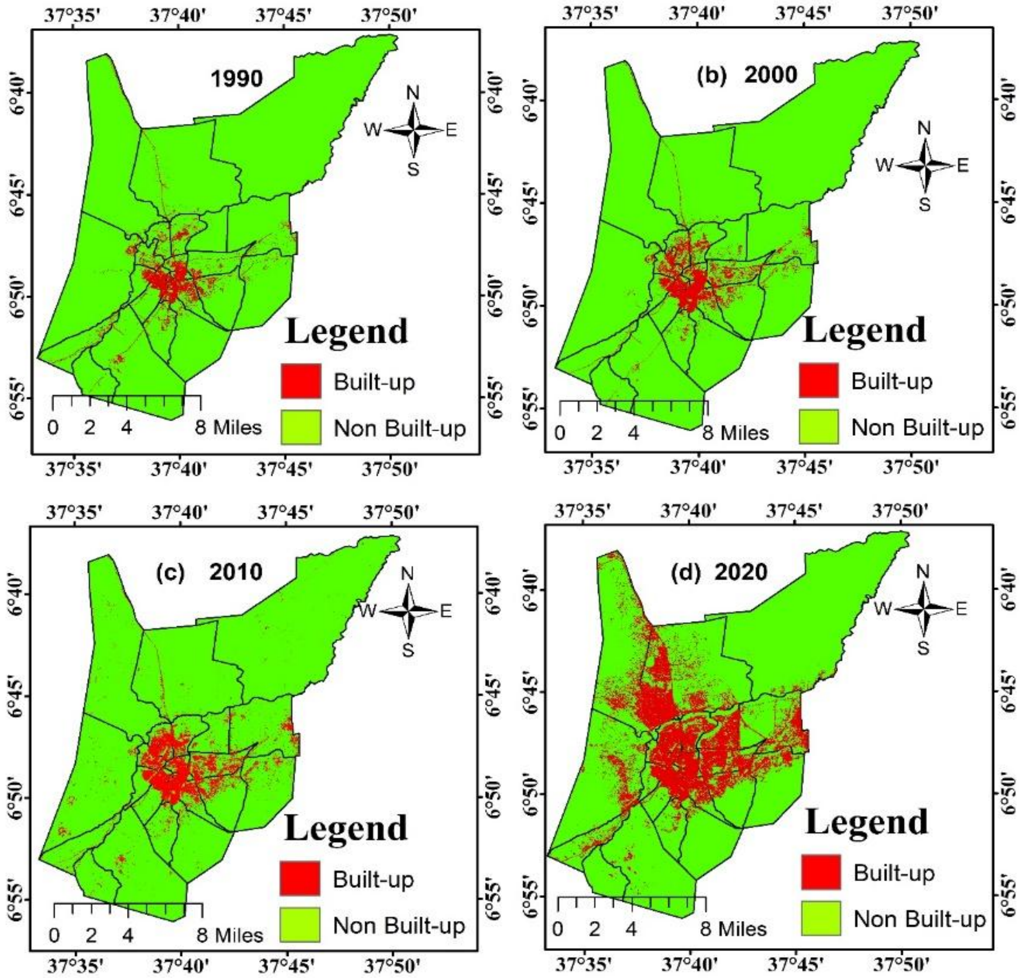

Fig. 7. Change of of built-up area in Morogoro Municipality from 1990 to 2020

3.3 Urban Expansion Patterns in Morogoro

Changed analyses and quality discrepancies between photos of the same area taken at different time series were used to detect land use and land cover change. Urban development pattern as shown in (Fig. 7) demonstrates the classified images of four different time series obtained by calculating the area of different covers and observe the changes at the same place which shows land use increase in urban built-up area from the city centre. Calculation of the quantified built-up of wards for each time period was done in order to examine the change expansion of urban form from non-built up to built-up (Fig. 8).

Fig. 8 shows that the rate of increase of built-up area of Morogoro Municipality from 1990 to 2020 was high for the three time period (i.e. 1990-2000, 2000-2010, and 2010-2020 interval). Fig. 9. Urban expansion of built-up land in Kihonda, Lukobe, Kichangani and Kingolwira increased by 1.6 km^2, 1.6 km^2, 0.6 km^2, and 0.8 km^2 respectively, compared to the rest of the wards between the period 2010 and 2020.

3.4 Analysis of Urban Expansion and LULC Changes

Urban expansion intensity index has revealed urban growth of Morogoro municipality as very slow speed expansion during 1990 to 2000, 2000 to 2010 experienced very slow speed expansions while in 2010 to 2020 experienced medium speed expansion as it shown in Table 3.

The amount of UEII was used mainly as a quantitative measure and an indicator of urban expansion, and the pattern observed thereof. The UEII in Mji Mkuu ward is higher than the rest of the wards for the period 2010-2020 toping an index value of 0.58, revealing a disproportionate distribution with the other time periods (1990-2000 and 2000-2010) in that section of the town as shown in Fig. 10. Tungi is another fast-growing ward during the 2010-2020 study periods as the result of this UEII reveals. These wards are less developed hence land is economically affordable by the middle-class members of the society and more dependable option once the city center wards (Mji mpya, Mwembesongo, Kiwanja cha Ndege and Sabasaba were occupied) and the value have raised. City center wards such as Mji-mpya, Mwembesongo, Kiwanja cha Ndege and Sabasaba had a very high expansion speed in the beginning of the study period (1990-2000) and the rate was observed to decline towards 2010-2020 study periods.

3.5 Growth of Urban Planning Practice

Urban planning growth has be revealed that the land covered by detailed layout plans (plan after and before development) from 1990 to 2020 in Morogoro municipality are increasing continually although plans after development tends to overpass plans before development at the begin of 2010 as shown in Fig. 12. In 1990 to 2000 plans before development was dominated on land than plan after development while in 2010 to 2020 plan after development become more dominated on land than plan before development as shown in Fig. 11.

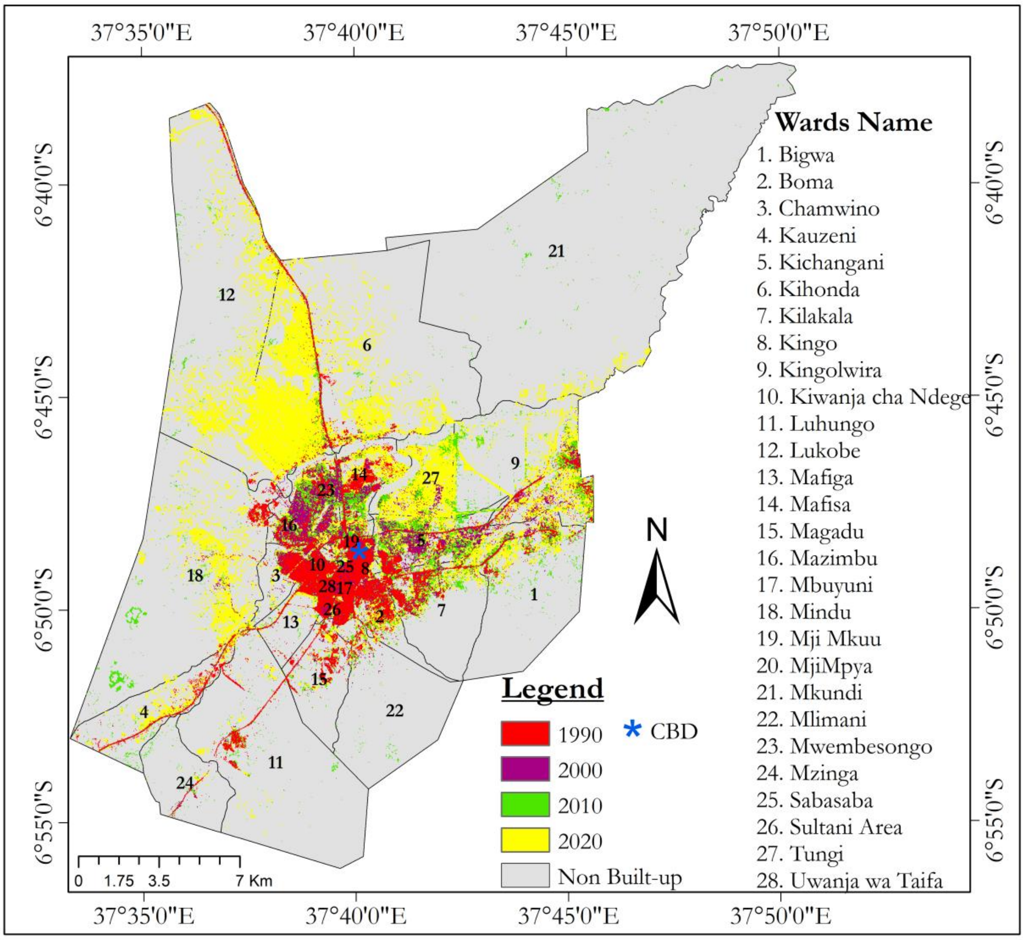

Fig. 8. Spatial pattern of built-up expansion for study area from 1990 to 2020

Table 3. Urban expansion intensity of Morogoro Municipal from 1990 to 2020

Years	1990_2000	2000_2010	2010_2020
UEII	0.10	0.20	1.10
Speed Status of Expansion	Very Slow Speed Expansion	Very Slow Speed Expansion	Medium Speed Expansion

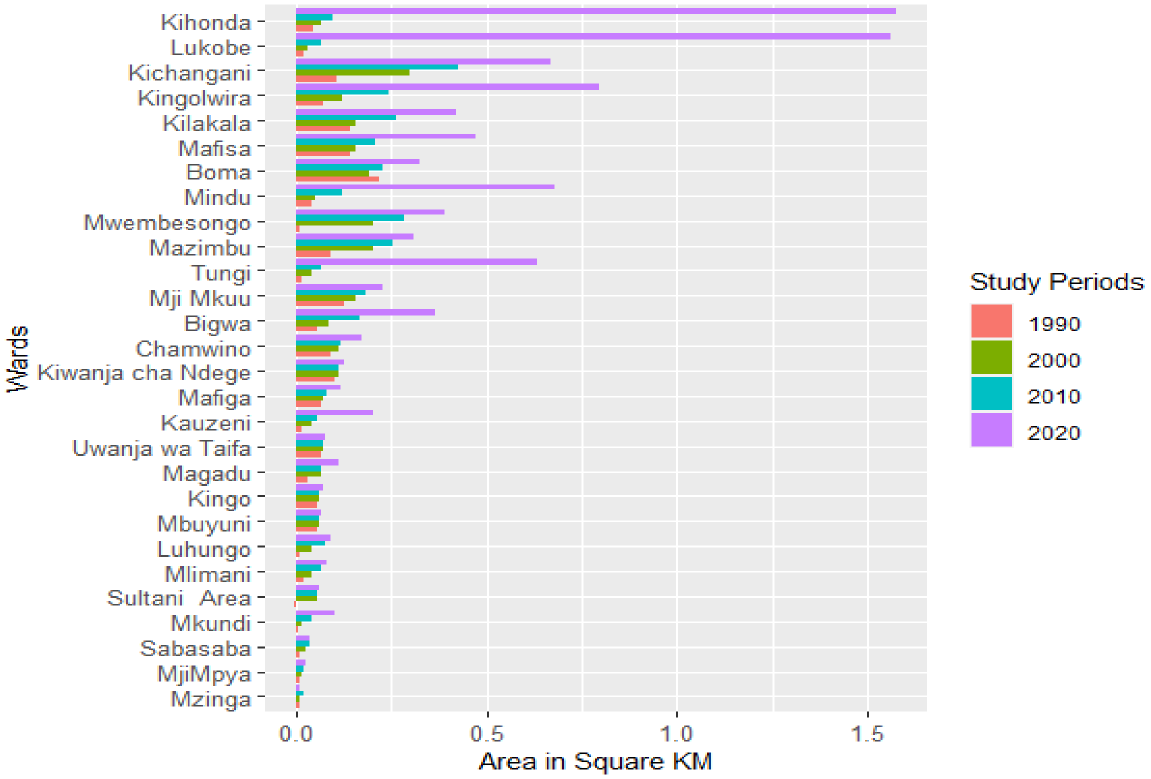

Fig. 9. Spatial temporal distribution of urban area in wards from 1990 to 2020

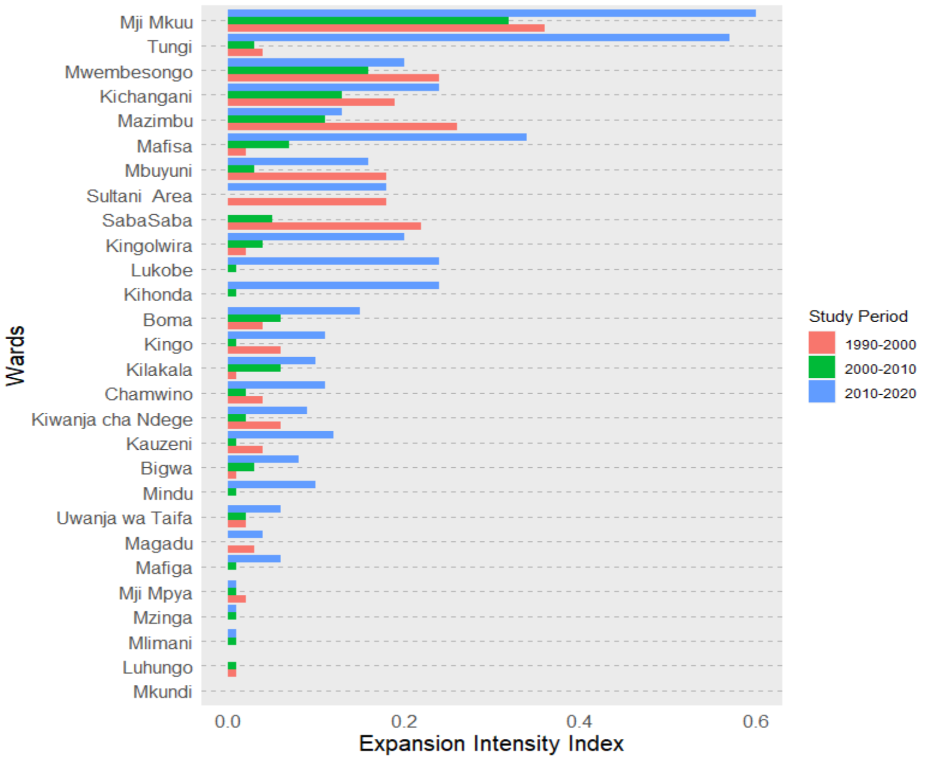

Fig. 10. Urban Expansion Intensity Index (%) from 1990 to 2020

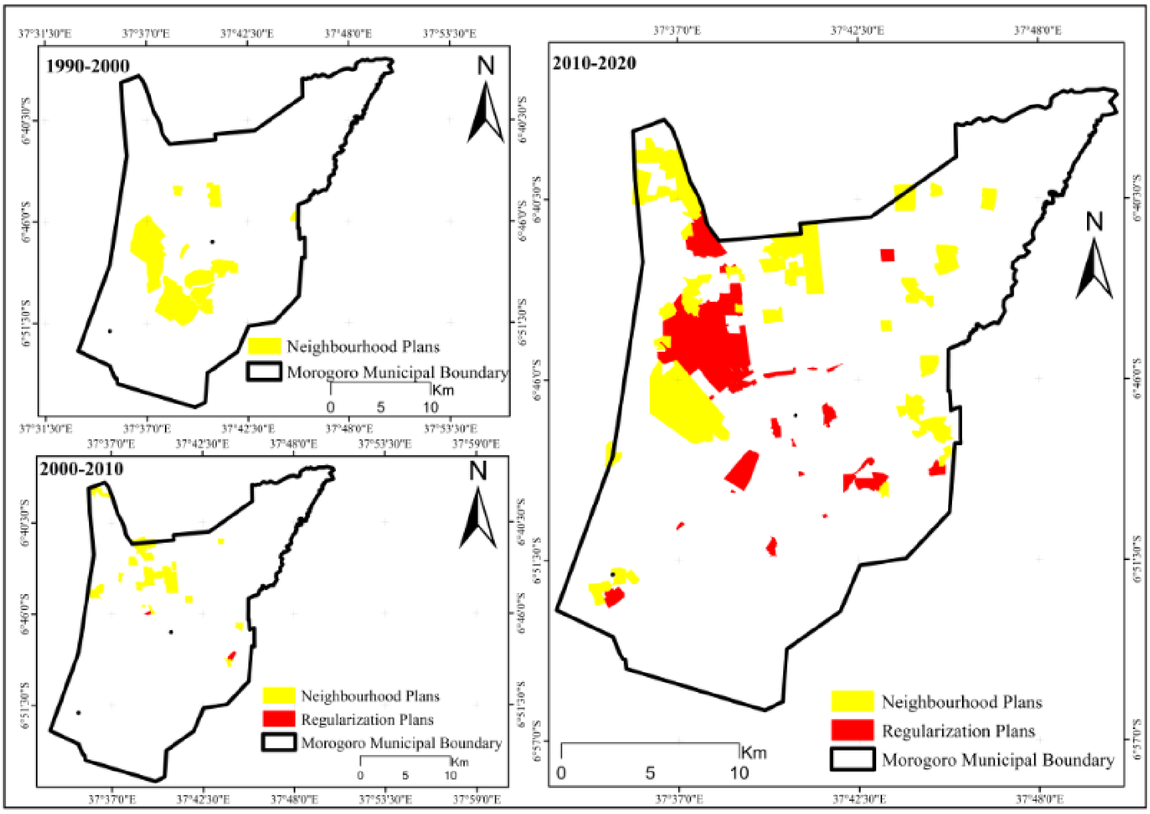

Fig. 11. Trend of urban plans after development (regularization layout plans) and before development plans (Neighbourhood layout plans) from 1990 to 2020

Land registration in Tanzania is a demanding process both in term of money and time. For the land owner to register the piece of land he or she is supposed to pay land technicians to assist the process which also takes time until the land use is title is implemented on the urban planning schemes by the authority. For that reason, majority of the residents in Morogoro opts to develop a land and register the land use later once obliged to (Fig. 12).

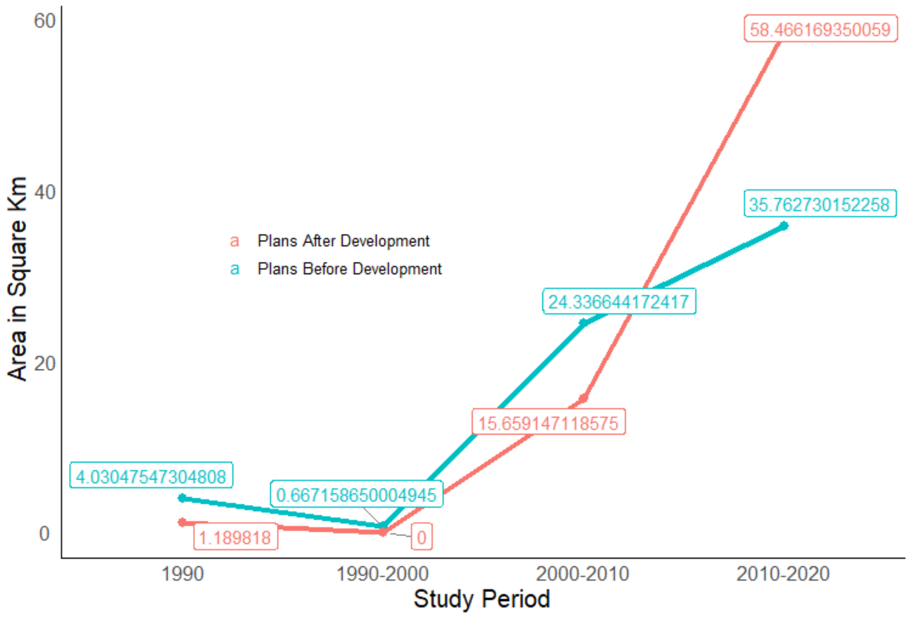

Fig. 12. Growth of urban layout plans, plans after and before development from 1990 to 2020

3.5 Urban Expansion Versus Urban Planning Practice

The study has revealed that Morogoro municipality has experiencing urban expansion and urban planning growth over 30 years study period from 1990 to 2020. Within 30 year study period it has been shown that urban expansion outpaced urban planning practice where by urban expansion increased 18.1% of total urban area while urban planning practice increased 17.4 % of total area of urban area as shown in (Table 4). In urban planning practice plans after development are dominant by 10.8 % while plans before development occupied 6.6 % of total urban area see in (Table 4). It indicates an upward trend in the urban expansion and planning practise whereby urban expansion increased from 4.8% area coverage in 1990to 2000 and 18.1% in 2010 to 2020 while urban planning practice increased from 1% coverage in 1990 to 2000 and 17.4% in 2010 to 2020 (Table 4). This pattern can be linked to ongoing development as a result of increasing demand for housing over time, as a result of a fast growing population.

Table 4 and 5 shows trends of urban planning practice and unplanned settlements within 30 years study period. Urban planning practice includes plans before development and plans after development. Between the time periods 2010 to 2020 plans before development decreased from 67.7% to 36.6 and plans after development increased from 43.7% to 59.8% of urban expansion area as shown in (Table 5). In this study urban planning practices experienced depression and acceleration growth. Urban planning practice experienced acceleration by 20.4% in 1990 to 2000 and 111.4% in 2000 to 2010, but in 2010 to 2020 experienced depression from 111.4% to 96.4% over total urban expansion area, while un-planned settlements experienced the opposite whereby in 1990 to 2010 experienced depression growth from 79.6% to 0% and acceleration started in 2010 to 2020 from 0% to 3.6% of urban expansion area (Table 5). This trend is attributed to outdated laws, un-cleared urban planning policies and political influence.

Fig. 13 shows the implication of urban expansion to urban planning practices. In this study urban expansion is seen as having influence and as determinant factor for urban planning practice growth. Fig. 13 shows that urban expansion always has higher speed of expansion over urban planning practice growth over the 30 year study period. In 1990 to 2010 urban planning practices experienced growth percentage range from 0.2% to 4.5% while urban expansion percentage range was 4.8% to 6.6% of total urban area. This implies that there is a decrease of un-planned settlements. In 2010 to 2020 urban planning practices experienced growth % range from 4.5% to 10.8% of total urban area. The higher percentage of land covered by urban planning practice and low parentage of urban expansion area implies that there is low risk of increasing unplanned settlement versus the low percentage of land covered by urban planning practice and higher percentage of urban expansion area the higher risk of increasing unplanned settlements.

Table 4. Percentages of urban planning area and urban expansion area over total urban area for the period 1990 to 2020 of the study area

Years	PBD%	PAD%	DLP%	UEA%	TUA %= 540 km2
1990-2000	0.8	0.2	1	4.8	100
2000-2010	4.5	2.9	7.4	6.6	100
2010-2020	6.6	10.8	17.4	18.1	100

**PBD =Plans before Development, PAD= Plans after Development, UEA=Urban Expansion area, TUA= Total Urban Area, DLP = Detail Layout Plans*

Table 5. Percentages of urban planning area over urban expansion area

Years	PBD %	PAD%	UPS%	TDLPA%	UEA in km 2
1990-2000	15.8	4.6	79.6	20.4	25.9
2000-2010	67.7	43.7	0	111.4	35.9
2010-2020	36.6	59.8	3.6	96.4	97.9

**PBD =Plans before Development, PAD= Plans after Development, TUA= Total Urban Area, UPS= Unplanned settlements, TDLPA = Total Detail Layout Plans Area, UEA=Urban Expansion area*

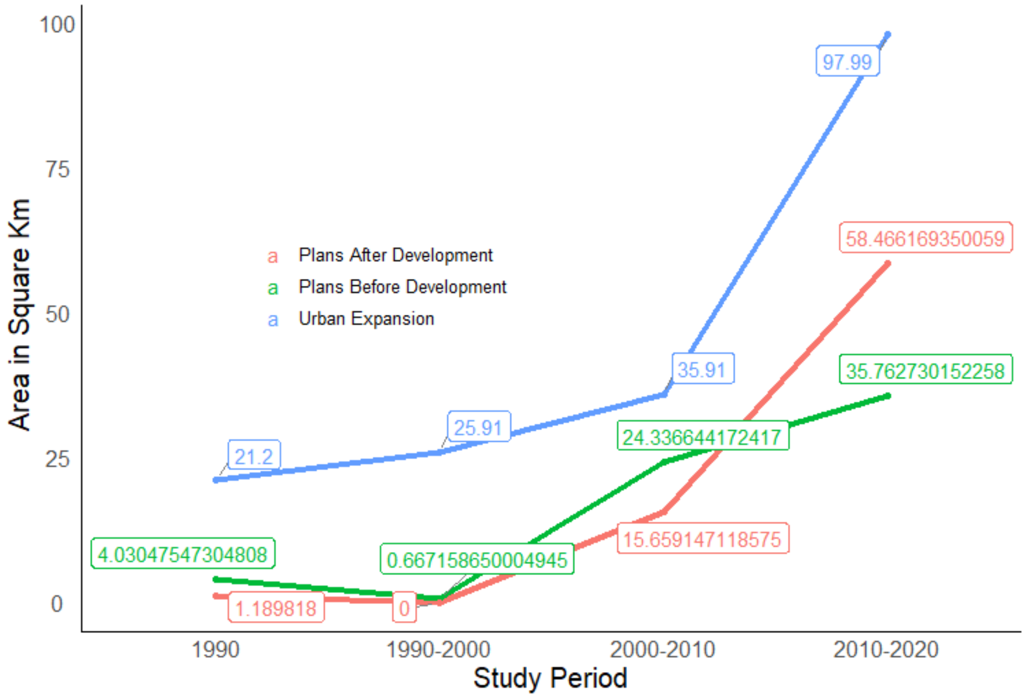

Fig. 13. Urban expansion versus urban planning practices from 1990 to 2020

4. CONCLUSION

Urban expansion using series Land sat imagery based on three-time interval phases (1990-2000, 2000-2010 and 2010-2020) has quantify urban expansion and pattern of the study area. The outcome of this study indicated that from 1990 to 2010 urban expansion have been experiencing an increase of 4.8% to 18.1 % while non-built up areas have decreased from 96.1% to 81.9% within 30 years period .Urban planning practice in 1990 to 2020 increased of planned land where by plans before development on land increase from 0.8% to 6.6% and plans after development on land increase from 0.2% to 10.8% of the total urban area. Both urban expansion and urban planning practice experienced highest increase in 2010 to 2020. . This rise is likely due to population growth and migration from rural areas . Morogoro municipality can be described as Omni-directional (scattered and leapfrog) since the urban spread occurs in all directions (admittedly, constrained by the municipality boundary in the current study), spreading farther from the town centre, but mostly biased on the northward side of the town centre. This could be mainly because the northward side has more space that is flat with gentle slopes that favour for settlement development and the west northward side is an upcoming leafy suburb with controlled development schemes. In this study, undeveloped areas are likely to experience more instances of urban expansion in the future.

5. RECOMMENDATIONS

Based on the results of this study, it is recommended that Strong urban planning interventions should be carried out to minimize the growth speed of unplanned settlements by the Central governments investing more in the urban planning sector based on planning before development rather than invest more in planning after developments. Local government and policy makers should provide clear policy and sufficient funding for the urban planning sector. Undeveloped land in urban area should be planned with the provision of required infrastructure such as roads.

Central government should facilitate supply of required remote sensing data and GIS technology to urban planning experts in every city, municipality and town ship to ensure easy application of sophisticated technology that will enhance urban planning for sustainable development.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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