A Combination of Remote Sensing and Social Media Data for Assessing Urban Sprawl in Morogoro, Tanzania

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Abstract: Urbanization in Africa is occurring at an unprecedented rate and it threatens attainment of the sustainable development goals. Urban sprawl has resulted in unsustainable urban development patterns from a social, environmental and economic lens. To date, remote sensing has been a source of data for urban sprawl and combining remotely sensed data with social media has proven to yield better insights about cities and towns. This is one of the first examples of research in Africa to combine remote sensing data with Social Media data to determine urban sprawl and its impact on sustainable urban development and ecosystem services in the Morogoro urban municipality, Tanzania. This study integrates remote sensing satellite imagery and social media data in order to: (i) identify urban sprawl in a continuous spatial and temporal pattern from 2011 to 2017; and (ii) determine the impacts on sustainable urban development and in particular ecosystem services for the city. The Supervised Vector Machine method for imagery classification was applied to accomplish these goals and location-based social media data was obtained through a Twitter Application Programming Interface. The results from the satellite imagery indicate that the expansion of the city has impacts on sustainable urban development and the provision of ecosystem services that have also turned into ecosystem disservices. Similarly, social media data highlights that residents are concerned about the sustainability trajectory of Morogoro.

Keywords: urbanisation; ecosystem services; sustainable urban development; remote sensing; social sensing data; Twitter; Morogoro

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1 Introduction

The earth's land cover has experienced numerous changes due to technological abundance and advances mainly in developing countries (Cobbinah & Darkwah, 2016; Mosammam et al., 2017). Urban sprawl is one of such transformations recorded due to population agglomeration in urban centers. It generally refers to the "unrestricted growth in many urban areas of housing, commercial development, and roads over large expanses of land, with little concern for urban planning" (Fouberg, 2012) but has been defined by various scholars to reflect the purpose for their respective studies.

Growth in urban populations worldwide is considered as the factor directly responsible for the unprecedented rate of urban sprawl being witnessed across the world; as the population of an urban center increases, its need for infrastructure such as transportation, water, sewage, etc. and facilities such as housing, commerce, health, schools, recreation, etc. increases, most often resulting in the phenomenon known as urban sprawl (Ujoh et al., 2010; Shao et al., 2019b).

In understanding global environmental changes (some of which occur as a result of urban sprawl), a consideration should be made to the conditions and changes in land cover engendered by changes in land use; the rates of change in the conversion, modification and maintenance processes of use; and the human forces and societal conditions that influence the kinds and rates of the processes (Fenta et al., 2017; Ujoh, 2013). It is therefore, instructive to understand that the potentials of African cities can only be maximized if the spatial form of urban development is optimized for economic development, service provision, and responsible consumption of resources as suggested by Xu et al. (2019a).

Cobbinah et al., (2017) argue that the physical characteristics of urban growth in Africa is also largely influenced by the legacy of colonialism where it is common to find the city sprawling along the lines of distinctive classes (neighborhood for upper, middle and lower classes). It is within this context that Chai and Seto (2019) explain that the "trend of development of peri-urban areas around African cities have thus, followed a trend better described as a coping mechanism for survival for those looking for better economic opportunity while simultaneously being forced to relocate due to demographic pressure".

Planning to combat urban sprawl and enthrone sustainability in Africa, is therefore, a policy-relevant consideration given that most cities in African countries are in the process of designing and building their infrastructure network, making decisions that will shape their urban form moving into the future.

For Africa to consistently leverage sustainable urbanization, there must be the institution of strong urban planning and policy mechanisms to combat what is often termed "colonial path dependency" (single family buildings) while encouraging compact, mixed-use, and mixed-income development as a step towards the optimization of land resources, and also as a solid foundation for future development and urban growth not only to promote inclusivity, but also the economic competitiveness of African cities (Xu et al., 2019a).

Recent global instruments (such as the UN Sustainable Development Goals, the UN New Urban Agenda, the UNFCCC, etc.) have dwelt on promoting social changes and environmental policies that emphasize sustainable development, and a better understanding of the changes occurring in the global environment (Lyu et al., 2018; Xu et al., 2019b). Policy makers, citizens and scientists now closely monitor human-environment synergy since global warming and its consequences are already affecting humans around the world (Qin et al., 2017). Remote sensing is by no means a new technology and has been in use for a half-century (Haigang et al., 2002) as aerial photographs and satellite images for a quarter-century (Singh, 1989), data acquired from remote sensing has the potential to be used for further research on human-environment synergy. The observation of urban sprawl especially benefits from the use of this technology to better comprehend human-environment synergy.

With the advancement in technology, it has become possible (and indeed cost and time effective) to monitor rapid LULC changes (Lyu et al., 2018; Sumari et al., 2017; Shao et al., 2019c). Recently, there have been considerable advances in geospatial technologies such as Geographic Information System (GIS), and remote sensing, enabling urban planners and managers to study and monitor urban conditions and growth at a scale and depth which were not possible previously (Huang, Wang, & Li, 2018; Tanveer et al 2019; Sumari et al., 2019).

Additionally, the combination of remote sensing and global positioning systems (GPS) have increased the precision with which urban sprawl can be observed and analysed. Researchers are now discovering the processes of land use transformation and degradation. To track deforestation, changes in cultivation, ecosystem and land use transformation patterns, airborne and satellite remote sensing are very precise and useful (Ujoh, 2013; Nzunda and Midtgaard, 2019; Ujoh et al., 2019). Combining them with socioeconomic surveys, social sensing data, censuses, and other biophysical information collection methods have brought a better understanding of land cover and use patterns and the factors behind them (Cattani et al., 2018; Lee et al., 2014). Remote sensing is especially useful when researchers are looking to study populations. For instance, Zhang, Weng, & Shao (2017) and Xu et al., (2019c), identify three ways in which population estimates can be attained through remote sensing. These are (i) individual dwelling units count , (ii) measuring urban extent, and (iii) climate change. Another instance would be the use of night-time lights as proxies to estimate population (Bennett & Smith, 2017).

This paper contributes to the discussion on the use of emerging technologies to addressing the real-time problem (i.e. rapid and unplanned urbanization) and its implication on sustainable development in developing countries. The expanding footprint of cities implies greater expenditure on infrastructure provision to adjoining fringes which is often not available in developing countries. It is therefore, common to find that developed areas on the urban periphery are not provided with infrastructure, leading to the informal provision that can pose economic hardship and environmental hazard in the short, medium and the long term.

This study therefore, integrates remote sensing satellite imagery and social media data for modeling location and direction of urban sprawl in Morogoro Municipal Council (MMC) in order to: (i) identify urban sprawl in a continuous spatial, and temporal pattern from 2011 to 2017; and (ii) determine the impacts on sustainable urban development and in particular ecosystem services for the city.

Our contribution is organized into four sections. Section 1 provides the introduction of the study. Section 2 describes the research area and the methodology used. Section 3 presents findings and discussion of the study. Finally, the study's conclusion is contained in Section 4.

1.1 Related work

Understanding spatial and temporal patterns contribute to a variety of planning and decision support activities (Hu et al., 2018; Cattani et al., 2018; Ernest, Nduganda & Kashaigili, 2017). The interaction among population groups has implications for various social and environmental features (Hu et al., 2018; Cobbinah & Darkwah, 2016; Shao et al., 2019a). The key aspect of analysing development patterns is to identify the individual spatiotemporal interaction patterns that rely on tracking data for individuals. A travel diary is a common data source to study human activity patterns, but it is expensive to collect (Zhou & Zhang, 2016). GPS devices are widely adopted (e.g. cell phones) to simplify the travel diary-type data gathering, but do not cover a large number of users from different social groups.

With the respect to pattern studies, social media data are originated by user and allow information to their personal accounts to be geo-located, and to be accessed through built-in GPS. This information is useful for activity pattern analysis as shown by Monsivais et al. (2017). Other studies include: research that developed a framework to harvest ambient geospatial information to support situational awareness of human activities (Stefanidis et al., 2011); combination of remote sensing and social sensing data in fine grained urban land use mapping (Zhang et al. 2017; Li et al., 2018); applied spatiotemporal analysis in urban environment with human activity (Monsivais et al., 2017); and, determination of users' locations, tweets, home area, from Twitter data to understand the individual patterns (Correa, Sureka, & Sethi, 2012; Khan et al., 2017; Zhou & Zhang, 2016).

From the sustainability context, the natural environment and its ecosystems are the delivery medium of all products and services that humans rely on for survival but with the dynamic change in climate, these services have since been altered in terms of effectiveness and quality assurance (De Groot et al., 2010). Ecosystem services refer to the benefits that ecosystems provide for both human societies and the earth itself with reference to regulation, provision and cultural significance. These include provisioning services such as food, water, timber, and fiber; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosyn-thesis, and nutrient cycling (Yevide, 2015). Human beings depend on these ecosystems services and they are vital for human well-being.

Maintaining ecosystem services is vital for the achievement of the Sustainable Development Goals (SDGs) (Zhao, 2018), and considered a powerful tool that planners can use for land-use and environmental planning (De Groot et al., 2010; Musakwa & Wang, 2018). It is clearly necessary for planners and decision makers to have a better understanding of the tradeoffs between different development scenarios through the adoption of the SDG number 11 which generally focuses on Make cities and human settlements inclusive, safe, resilient and sustainable (United Nations, 2015).

2 Study Area and Methods

2.1 Study area

Morogoro Urban (MU) is the main city within Morogoro Region, also known informally known as "Mji kasoro bahari" which translates as "city short of an ocean/port" (NBS, 2004) (Figure 1). Morogoro Municipal Urban Council's current vision is to have a community of people with the highest standard of living with sustainable socio–economic development. The Council's Mission is "to offer unique socio- economic services to residents and beyond while creating trust by managing its resource base effectively for the benefit of the Council's residents and beyond" (NBS, 2006; 2013)

MU is located at longitude 37^0E and latitude $4^0$48'S of Equator and it borders Morogoro rural district on the East and the South; and Mvomero district to the North and West.

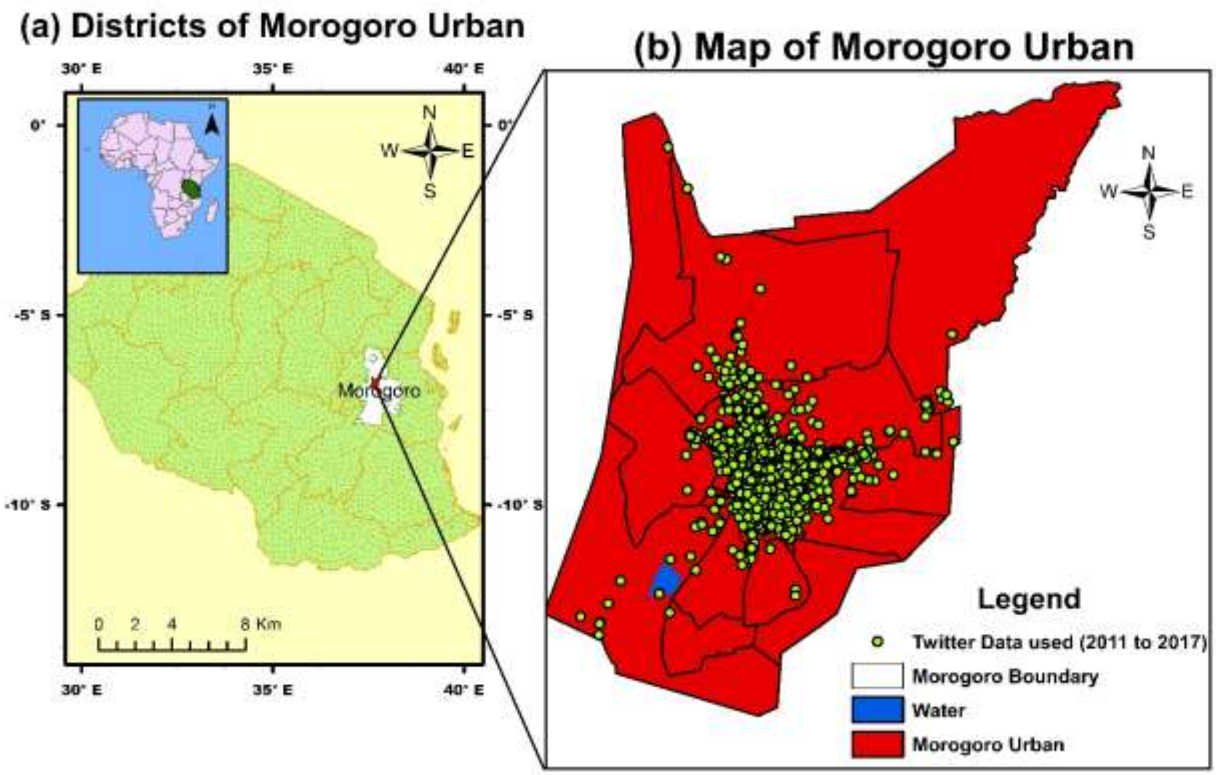


Fig. 1 Location of study area and Twitter data use from 2011 to 2017

2.2 Methodology

2.2.1 Overview of the research approach

The overview of research methodology (Figure 2) shows two data processing steps: Twitter data and Remote sensing data processing. For both data, we analyze spatio-temporal patterns, extracting data from Landsat as well as twitter database. From the twitter, we then develop Kernel function method to identify the weighting use of social medial in the area, and finally, we integrate both Landsat data and twitter data to create a model of inference for urban sprawl in the study area.

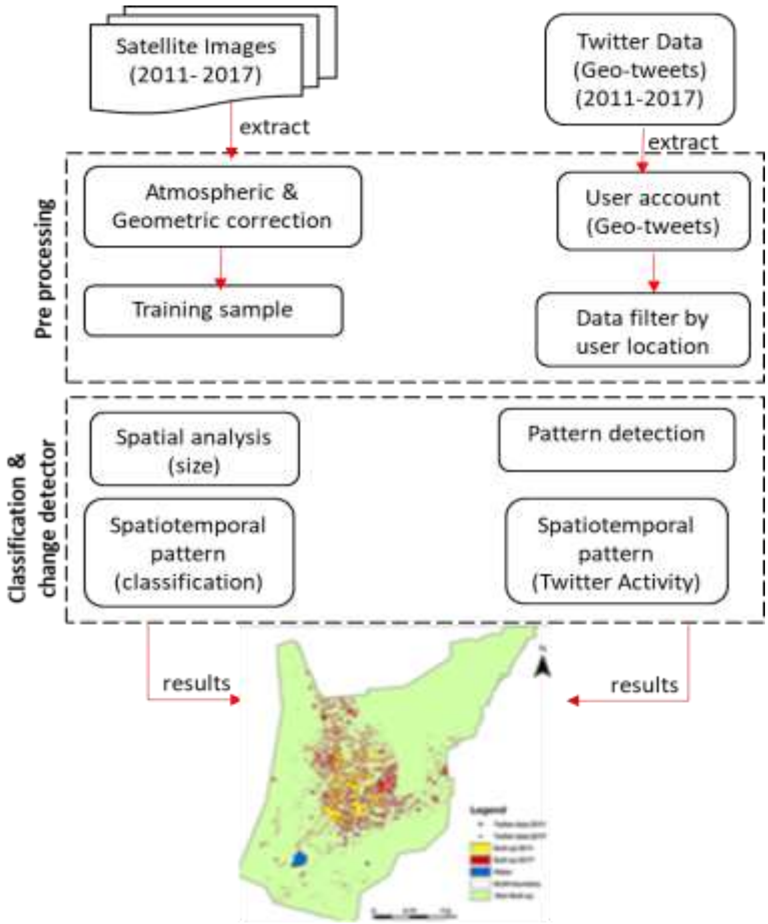


Fig. 2 Overview of our research approach

2.2.2 Processing Twitter Data

Twitter is one of the most popular online news and social media networking platforms for interacting and sharing information with millions of users breaking news, advertisement and locations through messages known as "tweets". A Twitter message (tweet) contains a short message of up to 140 characters and metadata information such as time, hashtags, likes and the number of followers. This was doubled to 280 characters in November 2017. The widespread availability of GPS equipped phones has made it possible for tweets to be geo-tagged, making such spatial information available for millions of users to see. From the Twitter account, two options are given to a user (Zhou and Zhang, 2016). First is to set a location which is automatically captured by a built-in Global Positioning System (GPS) receiver in the mobile equipment, recording the user's position in the form of longitude and latitude. The second option is that a user can select a location from a list of places provided by Twitter. In this case, Twitter records the estimated location of the mobile device or the Internet Protocol (IP) address, providing several possible locations (e.g. a building, a neighborhood, a city, even a country) based on geocodes for selection. However, the two options will differ in terms of the accuracy of the location. Location by the GPS itself has a relatively precise accuracy at a magnitude of several meters (Hu et al., 2018; Lee et al., 2014). Generally, the user selected location provided by Twitter will be accurate within 30 to 3000 meters in general (Lee et al., 2014) while the location generated by the IP address is also not precise with the positional accuracy depending on the method which is used to convert the IP address to coordinates (Lee et al., 2014). This study apdopted the use of geo-tagged tweets that show longitude and latitude as they are more accurate.

For this study, a total of 1597 geo-locations were extracted from users' accounts from 2011 to 2017 within the study area boundary using Twitter Stream API (https://dev.Twitter.com/streaming) based on their account location mentioned in the user profiles. These processed tweets were stored and managed in a database.

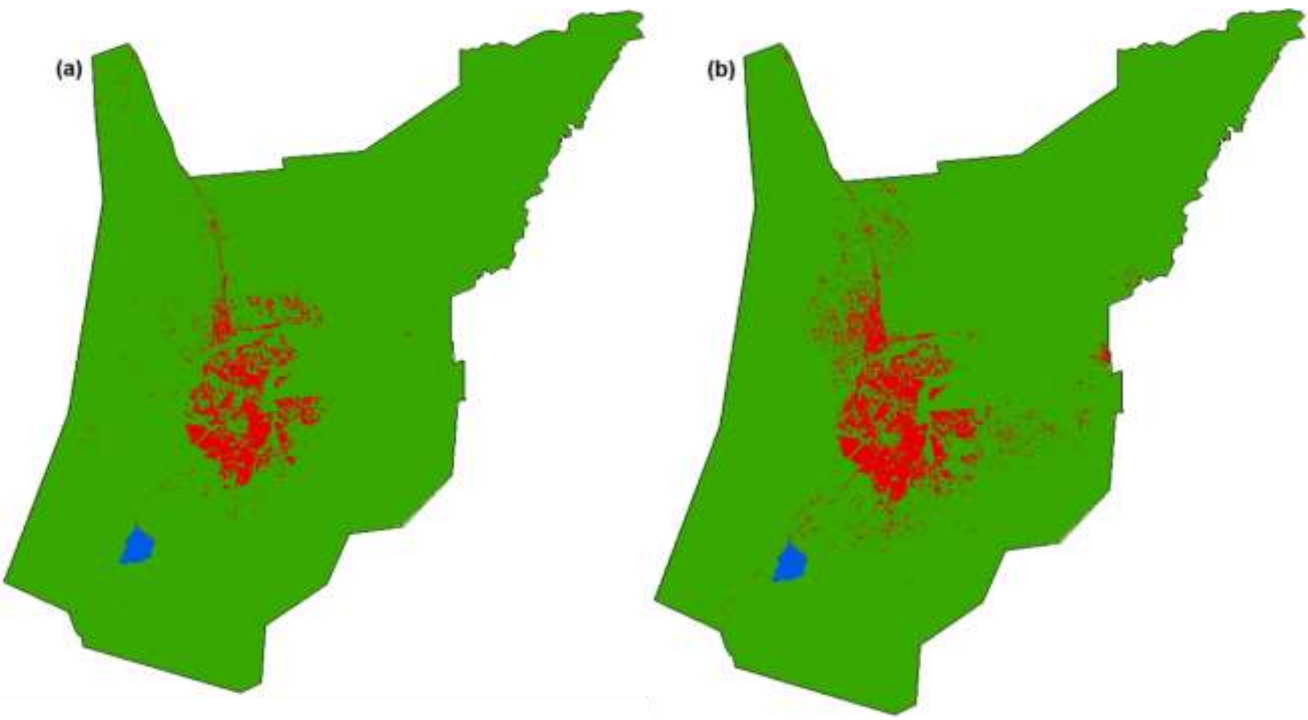
2.2.3 Remote Sensing Data

Remote sensing satellite images with 30 meters spatial resolution (Landsat 7) were downloaded from the USGS website (http://eartheplorer.usgs.gov/) and used in this study. Time series consisted from 2011 to 2017, and the chosen satellite imageries were acquired on the path: 167 and row: 65 of the seven years and during times of minimum cloud coverage. All images were geo corrected (radiometric and geometric corrections) and registered to Universal Transverse Mercator projection (UTM- Zone 37 South) in the World Geodetic System (WGS84) datum. Supervised vector machine classifier was used to classify all the imageries by training pixel based of the three classes, built-up area, non-built up and water.

3 Results and Discussion

3.1 Quantification of urban sprawl using classified Remote Sensing data (2011 - 2017)

Supervised vector machine classification was used to produce a spatial pattern of built up and non-built up as shown on the land cover classification maps generated from years 2011, 2013, 2015 and 2017 (Figure. 3). Quantifying the urban growth over the period is proportional to the measurement of the spatial expansion of the urban built-up area. However, the increase in built-up area is generally related to population growth since population growth is a significant driver for built-up area expansion. Comparison of growth rates of population and built-up area helps analyze the characteristics of urban growth. Xu et al. (2019) showed that urban growth could be measured by changes in built-up area expansion and population growth. Table 1 shows in each land cover that the MU grew since the 1990s. Clearly, the statistics on Table 1 reveal that development has increased most during 2015 and 2017 study epoch.



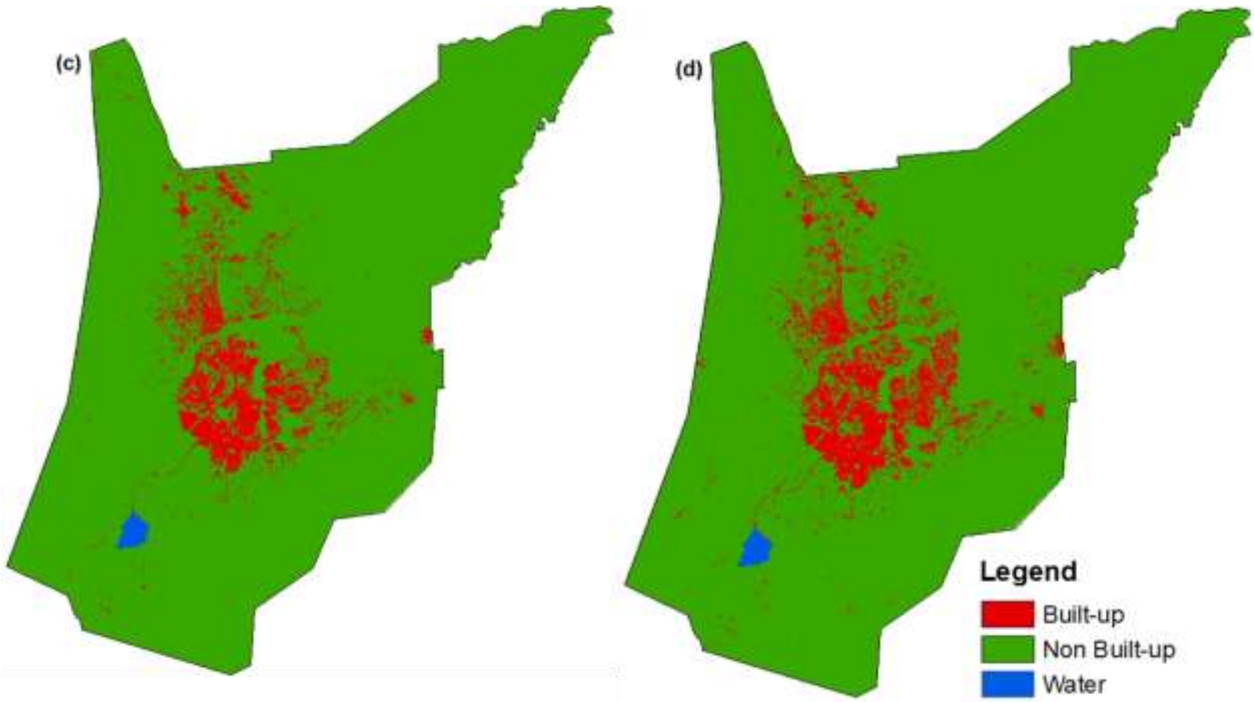


Fig. 3. Land cover distribution change of Morogoro Urban in (a) 2011 (b) 2013 (c) 2015 and (d) 2017

3.2 Observed spatio-temporal pattern of remote sensing and social sensing ("Twitter")

In the case of spatio-temporal pattern of twitter usage (Figure 5), we analyze each twitter user and the location of the user's profile information. We then retrieved all the Tweets sent from locations within the study area from 2011 to 2017 so that we can assess the top usage area of twitter as inference for development while ground truth using handheld GPS ultimately confirms sprawl. We then compare number of twitter users with population (Figure 4) which infers that increase in population reflects as increase in number of twitter users at an annual level. The results indicate that people tend to tweet more in the city center than outside the city center. To further validate this pattern, we analyzed another method (Kernel function) to measure the location of users within a 25Km buffer from the center of the city.

From integrating Tweets classified and remote sensing classification images from 2011 to 2017 (Figure 9), the result shows that, the center area of Morogoro urban is more developed but declines outward in a radial form (Figure 6). The assumption is that telecommunication infrastructure and related internet connectivity services to support twitter (as well as other social media platforms) can be found mostly in the city center, and less as one moves out of the city center. It is expected that this pattern also applies to other infrastructure and services such as roads, electricity, water, schools, healthcare facilities, etc, and consequently, the standard of living.

Figure 4 shows a general annual increase in twitter usage over the 7 years of study. This is tied to population increase and increase in urban sprawl over the same period.

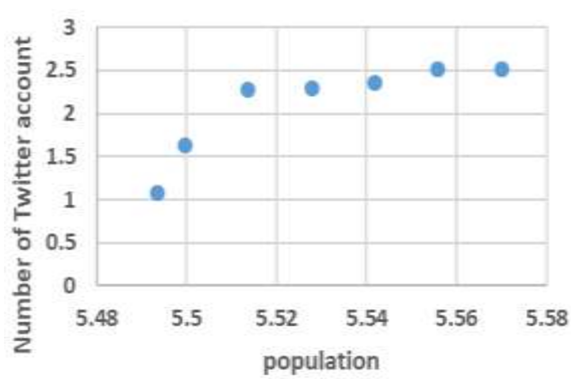


Fig. 4: Number of Twitter accounts and Population

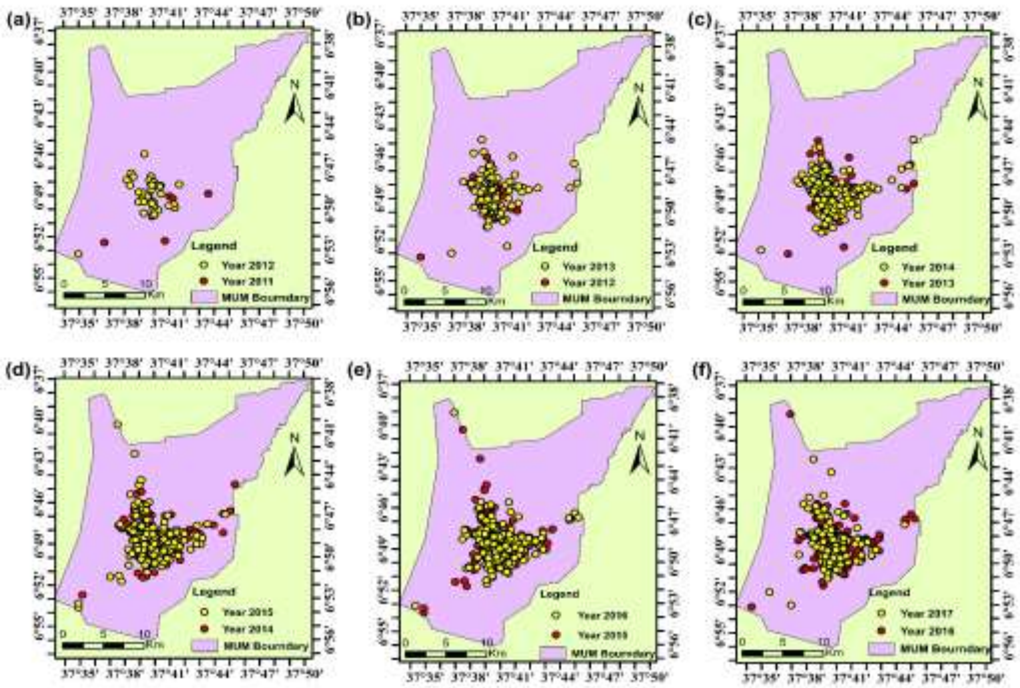


Fig. 5: Twitter distribution pattern of (a) 2011-2012, (b) 2012-2013, (c) 2013-2014, (d) 2014-2015, (e) 2015-2016 and (f) 2016-2017

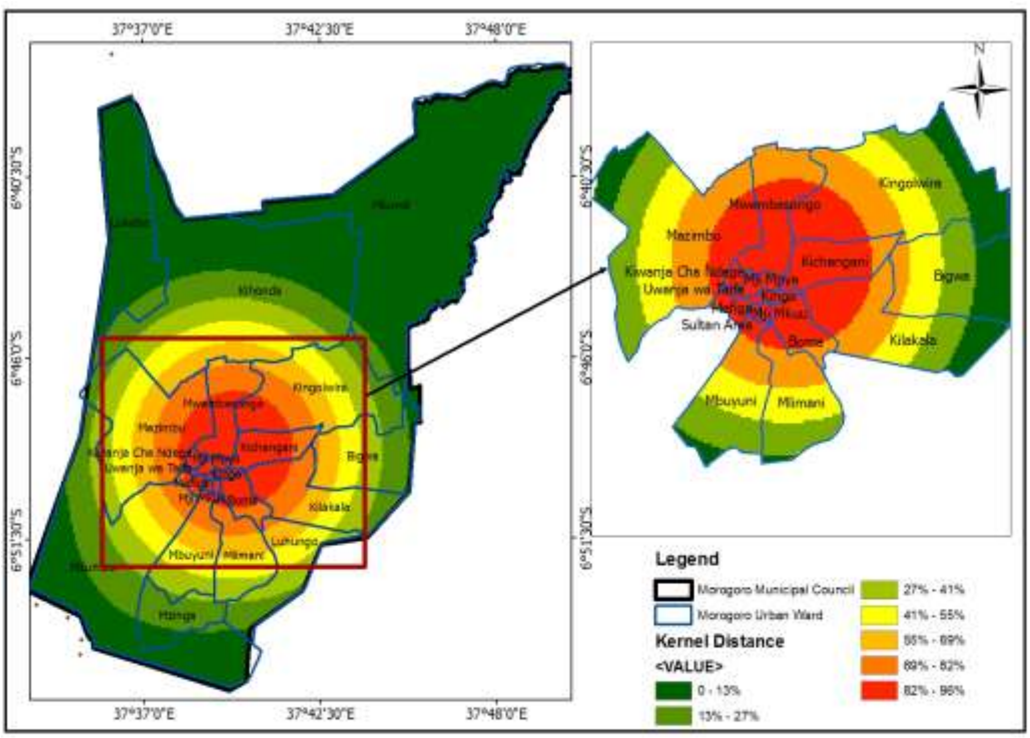


Fig. 6 Kernel Distance value increasing of new user account and Tweets location for seven years

3.3 Implication for social, economic and environmental sustainability

Population size is a crucial indicator of socio-economic development (Bennet and Smith, 2017). It acts as a resource for labour provision during production as well as consumers of various products. Therefore, the size of the population is among the significant parameters for social, economic and environmental sustainability in any locality. In 2002, approximately 73% of the people in Morogoro resided in the rural area with about 27% residing in the urban area (NBS, 2004; 2016). Hence, the assessment of the size and distribution of people and trends in the population growth is crucial (Figure 7).

The rapid expansion and population growth of the urban area must have affected the ecosystems in the area in terms of land degradation, water supply, loss of agricultural land, etc. because of the increase in demand for food, infrastructure and facilities (water, energy, roads, drainages, healthcare facilities) and other natural resources, hence the increase in consumption of natural resources (Assessment, 2005). In this regard, the high population can lead to increased incidences of environmental degradation especially where demand exceed supply of food, infrastructure and services. Also, improving the quality of a population requires sufficient provision of social services like waste management and sanitation services, education, health, water, transport and housing implying additional pressure on financial and natural resources to serve the growing population. The inability of Government authorities to adequately provide these critical infrastructures and facilities create a vicious cycle of extreme lack, poverty, and low quality of life. It is, therefore, potentially significant to control urban sprawl as a prerequisite to sustainable socio-economic, environmental and urban management. The uncontrolled urban sprawl has resulted in the loss of good agricultural land close to the city, thus affecting the source of livelihood of the vast population that depends on agriculture.

In reality, critical infrastructure has not been able to keep up with rapid urbanization of MU. The lack of basic infrastructure and services (such as water, sanitation, electricity, and waste management services) can be observed in Morogoro. For examples, public regulatory and service provision agencies are yet to reticulate piped potable water to 50% of the area and as a result, most people rely on borehole and hand-dug wells. Exacerbating the issue, the majority of these facilities are located outside the households forcing the population to travel distances of up to 200m to access water. Most residents of Morogoro di have to travel as far as 300m to reach a solid waste disposal centre. This has led to some residents to dump their waste in unauthorized collection points. This coupled with the lack of drainage facilities has led to annual urban floods, while liquid waste is dumped in the open creating sanitation challenges. It is obvious that planning for the expanding fringes in Morogoro is not done prior to development.

3.4 Impact of urban sprawl on ecosystem services

Pertaining to changes in land cover and its impact on ecosystem services, the overall impact of land cover change in Morogoro is negative resulting in ecosystem disservices (Table 1). The increase in built-up areas is not ideal for ecosystem services because it has led to, massive road congestion, CO_2 emissions, pollution, unsustainable land development, a decrease in public spaces and increased pressure on public services. Consequently, residents of Morogoro are experiencing ecosystem disservices for example pollution causes health problems, whereas the unsustainable land development, poor access to public spaces denies residents of cultural ecosystem services and reduced capacity to absorb CO_2 due to the declining forests & woodlands cover. Furthermore, other negative impacts of the rapid and unplanned urbanization in Morogoro are the gradual disappearance of indigenous populations, lack of critical infrastructure and transformation of indigenous population's livelihoods (Figure 7). These indigenous populations are predominantly small-holder farmers, finding themselves locked out of the land market due to high prices and their livelihoods altered by residential or commercial developments leading to loss of farmland and consequently, livelihoods loss as well. However, despite loss of farmland in MU, urban agriculture appears to be prevalent and perhaps promoted leading to only a slight decrease in agricultural land from 106 km^2

to 98 km^2 between 2011 and 2017. This is as a result of the practice of urban agriculture which ensures food security as residents engage in agriculture on their plots and open spaces. There are also reserved land parcels by the government (north of Morogoro) for farming.

Table 1. Urban change in Morogoro and the impact on ecosystems services

Class Name	2011 (%)	2011 Km^2	2017 (%)	2017 Km^2	Impact on ecosystems services
Built up	4.3	22.4	9.3	49.9	negative
Agriculture	18.6	98	20.6	106.1	positive
Water	0.4	2.6	0.3	2.7	positive
Woodland	61.1	355	59.2	322	negative
Bare land	4.6	25	3.5	23.4	negative
Wetland	3.4	18	3.4	16.2	positive
Forest	4.2	25.6	4.9	27.2	negative

There was also a significant decrease in woodland by 4% and forests by 0.7% which would alter the provisioning and regulatory ecosystem services as the amount of carbon sequestered is expected to reduce. Similarly, the destruction of vegetation and increase in bare land alters the general aesthetics of Morogoro and is a major cause of soil erosion which could lead to increase in suspended solids and deteriorating water quality in Morogoro River and Mindu dam, thereby increasing the cost of water treatment for the city. This is compounded because Morogoro is part of the Eastern Highlands of East Africa already experiencing high soil erosion and land degradation (Cobbinah and Adams, 2018). Furthermore, the vegetation destruction in Morogoro is cited as a major cause of habitat fragmentation and reduction in biodiversity (Ligate, Chen and Wu, 2018; Kilawe, 2018). The continued destruction of vegetation (forest and woodland) in Morogoro is a threat to achieving SDG 15 on protecting, restoring and promoting sustainable use of terrestrial ecosystems. For example, the loss of vegetation reduces the city's capability to mitigate against climate change (see Fig 8) effects. The heavy rains being recorded (Ernest, Nduganda & Kashaifili 2016) is already leading to landslides and loss of lives and properties. It is such a critical issue that Morogoro Council has already started a tree planting program to mitigate against climate change related impacts.

Wetlands in Morogoro have increased and overall status improved from 2011 to 2017 and this works well for environmental and biodiversity conservation, and climate change mitigation and adaptation (Figure 9). Wetlands provide services to human beings such as recharging ground water, controlling floods, preventing eutrophication of rivers and lakes and supporting specific biota.

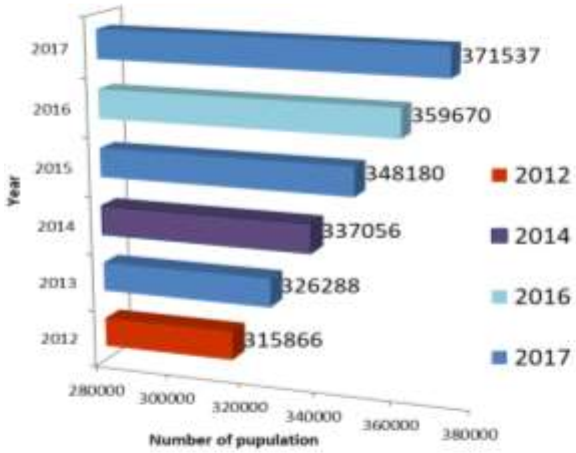


Fig. 7: Increased population from 2012 to 2017 in Morogoro

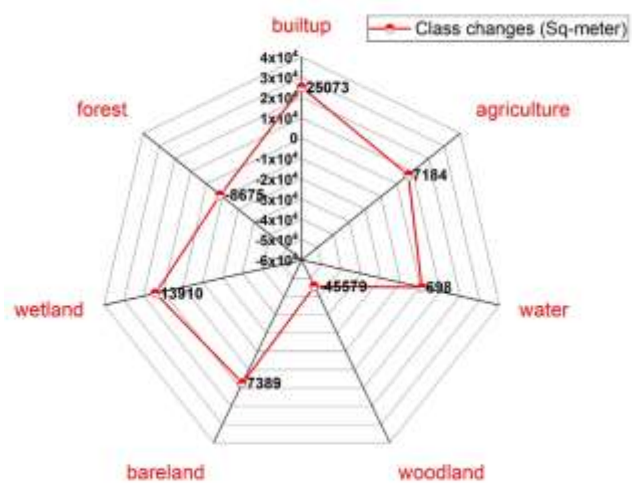


Fig. 8: Land use change from 2011 to 2017 (in m^2)

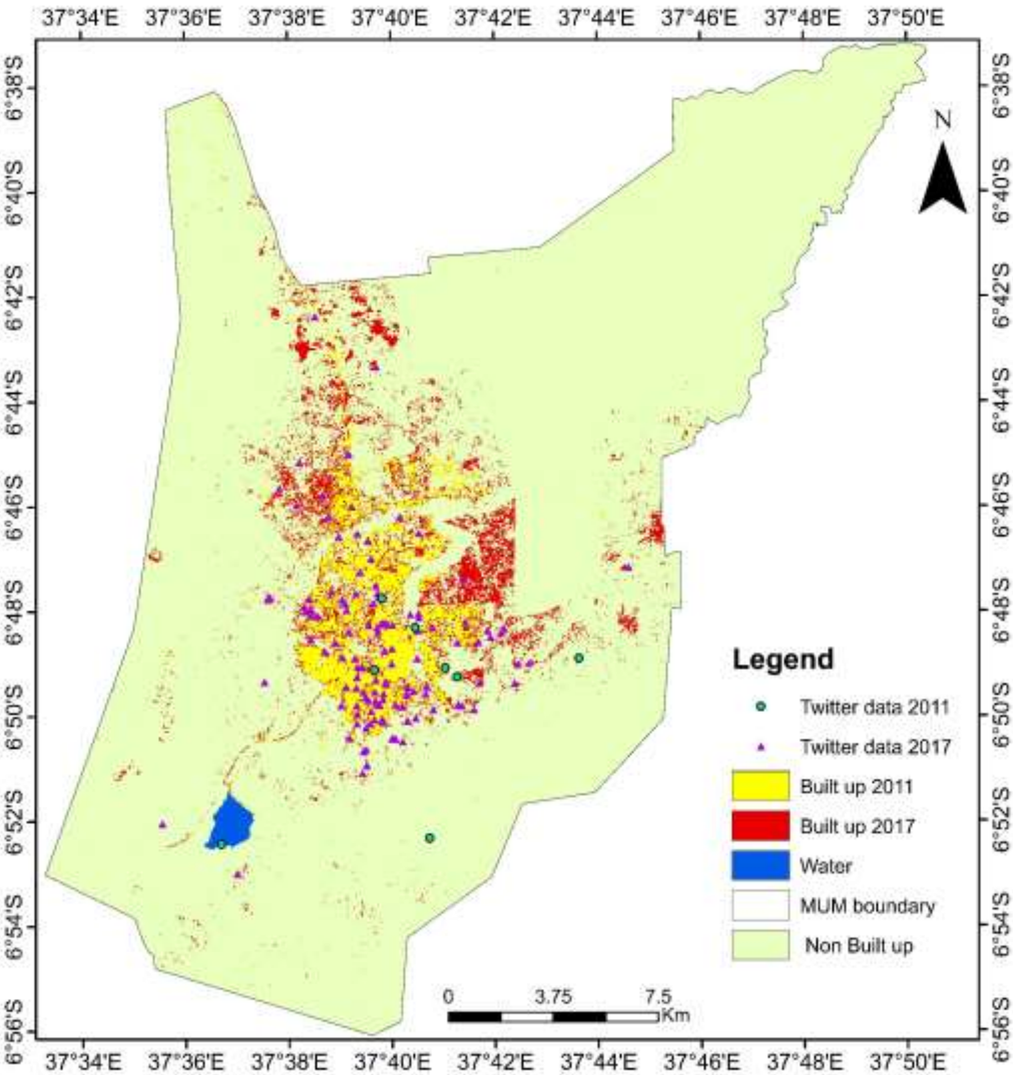


Fig 9: Overlay classification imagery of year 2011 and 2017 with Twitter data of 2011 and 2017

4 Conclusions

The temporal and spatial land use show an integration of remote sensing images, population data and twitter usage data to model urban sprawl in an outwardly radial form around the city of Morogoro. While this trend has caused significant loss of agricultural land (along with it, ecosystem services), the pattern also shows that infrastructure and services are not adequately provided over the sprawl area. This is exemplified in the increase of twitter usage within the city center whereas the increase in twitter usage at the adjoining fringes of the city is limited over the years, signifying lack of telecommunications as well as other forms of infrastructure at the fringes of MU. Explicitly, this pattern of urban expansion has had significant impacts on poverty, living conditions and environmental quality within the sprawl areas of the city, hence the decline in ecosystem

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services in the area to support human and natural populations.

The Morogoro Strategic Plan should set out implementation strategies for providing key infrastructure in planned layouts on the outer fringes of the city. Infrastructure provision could be commercialized (where government is unable to provide same) so that residents enjoy high living standards while payment for these critical infrastructure and services are made over an extended period. This style of planning and regulation would lead to a planned and sustainable MU that will be ecologically sensitive, support conservation and biodiversity, and provide a safe habitation for city dwellers.

Although Twitter data was useful as a proxy for poverty, availability of infrastructure and access to services, the major shortcoming is that Twitter data is unable to ascertain the residential locations of users. For example, it is possible that some users depend on Wi-Fi networks within their offices (at the CBD) while unable to use the internet after office hours. In this case, twitter usage data may not be able to accurately estimate the rate of expansion of the city. Also, the locational accuracy of the tweets is dependent on the accuracy levels of the in-built GPS of the phones sending out the tweets, a factor beyond the control of this research. Therefore, the GPS accuracy is an area that can be potentially improved upon through further studies. Nevertheless, the proposition delivered in this study provides an alternative inferential source for documenting urban sprawl where adequate cadastral data and resources are a major challenge.

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