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Mapping of Land Use Changes in Urban Catchments. A Case of Msimbazi Catchment in Dar es Salaam, Tanzania

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Abstract

Rapid urbanization activities put significant pressure on catchments around the globe as they are also associated with changes in land use and land cover. Despite the availability of satellite images, information about their applicability for assessing the trend of land use and land cover in highly urbanizing catchments is still scarce. This study used GIS-based techniques to investigate land use and land cover changes in the Msimbazi River catchment in Dar es Salaam, Tanzania. The Landsat images of the selected study years (1998, 2009, and 2018) were processed in the ArcGIS software. The land use classes were grouped into five groups: water bodies, forests, low-intensity, medium-intensity, and high-intensity development. The study observed a significant change in land use and land cover in the Msimbazi catchment from 1998 to 2018, with an estimated 40.54% decrease in low-intensity developed areas and a 15.95% increase in high-intensity developed areas defined with 80 to 100% impervious cover. Approximately 61.67% of the catchment's total area was covered by low-intensity developed areas in 1998. The low-intensity developed areas, however, rapidly reduced from 21.13% of the total area in 2009 to only 16.82% in 2018. On the other hand, the proportion of land surface occupied by medium-intensity developed regions has been generally increasing over time. Additionally, it was noted that the trend of high-intensity development has been increasing; in 1998, the coverage of this type of development was approximately 3.82%, but by 2009, it had increased to 13.42%, and by 2018, it had reached 19.77%. In addition, the extent of development and the impervious surface cover was observed to be increasing downstream approaching the Indian Ocean coast.

The entire phenomenon is a reflection of the catchment's reality, which includes higher upstream forest cover, particularly in the Kisarawe hills. The results derived from this study can be useful in the planning and implementation of catchment management practices.

Keywords
Geographic Information System; land use and land cover; Landsat images; urban catchment; rapid urbanization

Introduction

In this modernized world, is crucial to understand spatial patterns of land use and land cover change in urban catchments as one of the critical water resources. The execution of mega-projects, including rapid transit infrastructure, brings spatial changes to many cities worldwide (Tang *et al.*, 2020). The global urban population will keep expanding for the majority of this century, further urbanizing the planet. Urban growth, when cities spread out and take in the surrounding area, is a substantial result of this demographic transformation (Hutchings *et al.*, 2022). The state of surface cover in a catchment determines a lot in terms of the behavior of rivers and other water bodies within the particular catchment (Lisenby, Fryirs and Thompson, 2020). Unfortunately, urban catchments are subjected to significant stress from development activities as cities develop, these, in turn, change the catchments' natural state, leading to highly impervious surfaces (Miller *et al.*, 2014; Guan, Sillanpää and Koivusalo, 2015). The impervious surfaces affect how runoff is absorbed or runs on the surface to a nearby stream (Metsäranta, Kotola and Nurminen, 2005).

Moreover, impervious cover or surface tends to decrease the amount of rainwater that can naturally infiltrate into the soil, increasing the volume and rate of stormwater runoff. As a result of these changes, more frequent and severe flooding is witnessed, and therefore potential damage to public and private property. For example, in the study conducted by (Wijayanti, Zhu,Hellegers,Budiyono & Van Ireland, 2017) on estimating river flood damages in Jakarta, Indonesia, flood damage worth US$ 0.5 million for the residential sector and US$ 0.7 million for the business sector was observed. Also, according to (Shah *et al.*, 2020), Pakistan has witnessed total direct cumulative losses to the tune of about US $ 30 billion, resulting in a loss of

10,668 precious lives in the past 60 years. Therefore, understanding how land use and land cover have been changing in a catchment is of fundamental significance in devising appropriate control measures.

Some other effects of land-use change in urban catchments are the considerable change in terms of hydrological processes and patterns that can also be associated with the change in the surface runoff and water quality. These effects can further be highly linked to the alteration of biotics and ecosystems. According to (Cordier *et al.*, 2021), human-induced land use and land cover changes are termed to be the most important drivers of biodiversity loss, and amphibians and reptiles represent the most threatened groups of vertebrates globally.

Msimbazi catchment in Dar es Salaam, Tanzania, is an excellent example of a highly urbanizing catchments (Sawe, Shilla and Machiwa, 2021). The phenomenon is linked to the catchment being located at the centre of Tanzania's largest city. As a result, the land demand for establishing new settlements and public and business centres in the catchment has been rapidly increasing. One of the key indications that something has been changing is the high recurrence rate of the flash floods that come with high demolishing power. For instance, identifying high-intensity development areas can help city planners classify and prioritize areas needing immediate action towards achieving sustainable cities. In such a context, investigating the land use and land cover change trend within the catchment becomes significantly essential.

Many urban catchments have been subjected to relatively high flooding incidents; researchers are trying to link the incidents with rapid urbanization scenarios. For instance, (Du, Cheng, Zhang, Yang & Xu, 2019) tried to investigate different flooding behaviors due to varied urbanization levels within the river basin in the Xiang River Basin, China; Kefi, Mishra, Masago,& Fukushi, (2020) tried to analyze flood damage, and some influencing factors in Manila, Philippines, and Jakarta, Indonesia; Bahrawi, Ewea, Kamis & Elhag (2020) tried to investigate the potential flood risk due to urbanization expansion in arid environments in Saudi Arabia.

However, this type of study is always challenged by the availability of data and appropriate methodology due to a complex nature of a land surface. In this era of advanced technology, geographical information systems (GIS) and remote sensing (RS) have become important tools in geographical-related studies of water resources. GIS can be applied in several cases in water resources management, including surface and groundwater modelling, water supply and sewer system modelling, stormwater, and nonpoint source pollution modelling. Furthermore, the information on the potential applicability of Landsat images in investigating the trend of land use and land cover with time in urban catchments is still scarce.

This study investigates the extent of land use and land cover changes for the Msimbazi catchment in Dar es Salaam, Tanzania using Landsat images. A GIS-based approach is used to investigate how the land surface cover has been changing within the catchment from 1998 to 2018.

2. Materials and methods

2.1 Description of the study area

The Msimbazi catchment is one of the river watersheds in Dar es Salaam, Tanzania, located between latitudes 6°27' and 7°15 S and between longitudes 39° and 39°33' E. The river flows across Dar es Salaam City from the higher areas of the Kisarawe District (Kisarawe hills) and discharges into the Indian Ocean (Figure 1). Because of its location, as it passes through the centre of the city, it has been associated with numerous flood-related disasters, especially for the residents residing along the riverbanks.

Also, the River is one of the longest in Dar es Salaam covering approximately 36 kilometres (from the Kisarawe Hills to the shores of the Indian Ocean). The rate of people establishing their settlements along the River has been increasing, especially towards downstream, where disastrous events are witnessed every year. It is estimated that more than 65,000 people live downstream of the catchment within 200 meters from the riverbank. During the rainy seasons, some of the houses along the catchment get completely immersed in flooding water.

Moreover, the catchment experiences torrential rains that often cause floods almost during every rainy season. The catchment is characterized by annual precipitation amounting to 1,150 mm, with a maximum from March to May, while April is termed as the rainiest month with 255 mm (Justin, Bergen, Emmanuel, & Roderick 2018), whereby it is estimated that the catchment sustains average annual losses of $47 million as a result of flooding (Sauka, 2019).

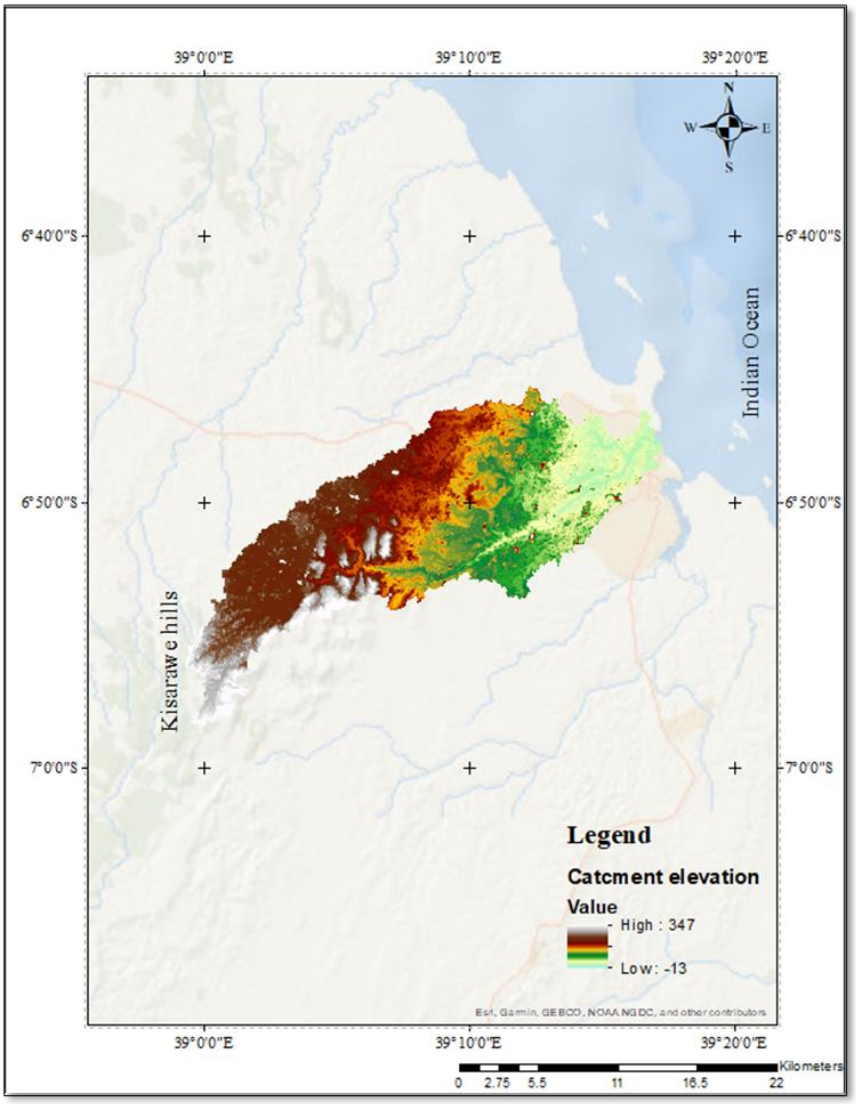


Figure 1. Location of the case

2.2 Landsat images processing

The study years have been divided into a span of approximately ten years from one group to another (1998 - 2009 and 2009 - 2018). The other reasons for selecting study years include the availability of the data, quality, and consistency. The analysis of the Landsat images is achieved using the supervised approach in ArcGIS 10.3 software. In addition, Google Earth Satellite historical images are also used to investigate and validate the potential changes in land use and land cover within the catchment over time. Landsat images for the selected study years were collected from the United States Geological Survey (USGS) official website and then processed in ArcGIS. The criteria used for the land use and land cover classification (Table 1) have been adopted from (Homer and Fry, 2012).

Table 1: Descriptive information of the classified land uses

Land use/land cover class	**Description**
Water	All areas of open water.
Developed, Low Intensity	Areas with Barren Land, Grassland, Cultivated Crops, (20%-49%) impervious cover percent of total cover.
Developed, Medium Intensity	Areas with a mixture of constructed materials and vegetation.
Developed, High Intensity	Highly developed areas where people reside or work in high numbers.
Forest	Areas dominated by trees that are generally greater than 5 meters tall.

Field investigations were done in selected parts of the catchment for the study area characterization and existing situation analysis. Also, as previously mentioned, the satellite images for 1998, 2009, and 2018 years covering the entire catchment were selected based on the quality of data and the available resolution and then processed in ArcGIS using the supervised method of the Image Analysis tool. The combined bands (previously in GCS_WGS_1984 raster format) were then projected to the Universal Transverse Mercator (UTM).

The projected Landsat images were clipped to the size of the catchment using the shapefile of the case study. For proper visualization of the Landsat images, the individual bands in 1,2,3 (Red, Green, and Blue

(RGB) true color) were changed to 5,4,2 RGB (true color) combinations. The colors could be arranged in many other ways, but the 5,4,2 RGB combination was used in this study. The selection of this color arrangement is based on the fact that it provides better visualization of the land surface features within the catchment.

2.3 Land use classification

As previously mentioned, the Interactive Supervised Classification and the Maximum Likelihood Classification methods were used to perform the land use and land cover image classification. As a result, five main categories of land use in the catchment were identified: developed, low intensity; developed, medium intensity; developed, high intensity; water bodies; and forest. The general summary of the procedures is presented in Figure 2.

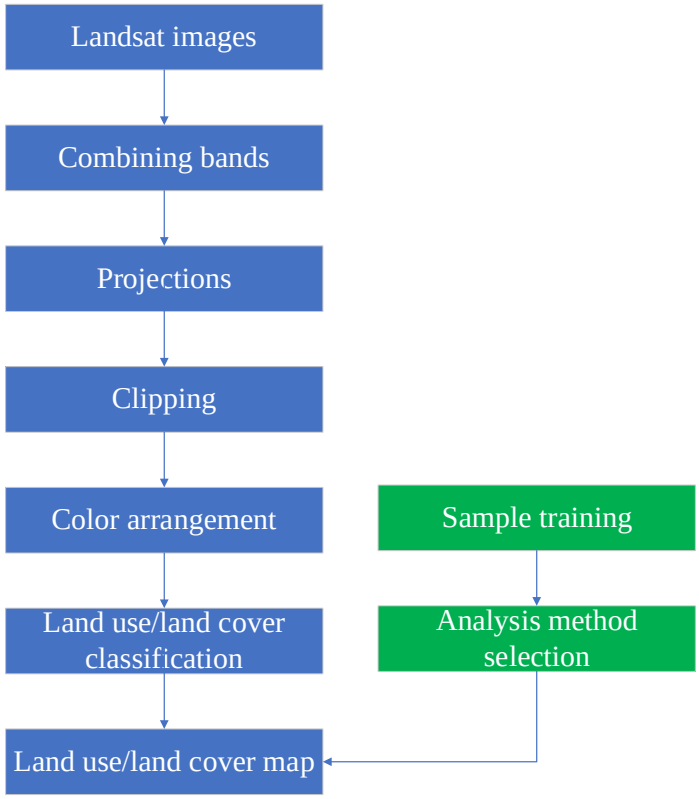
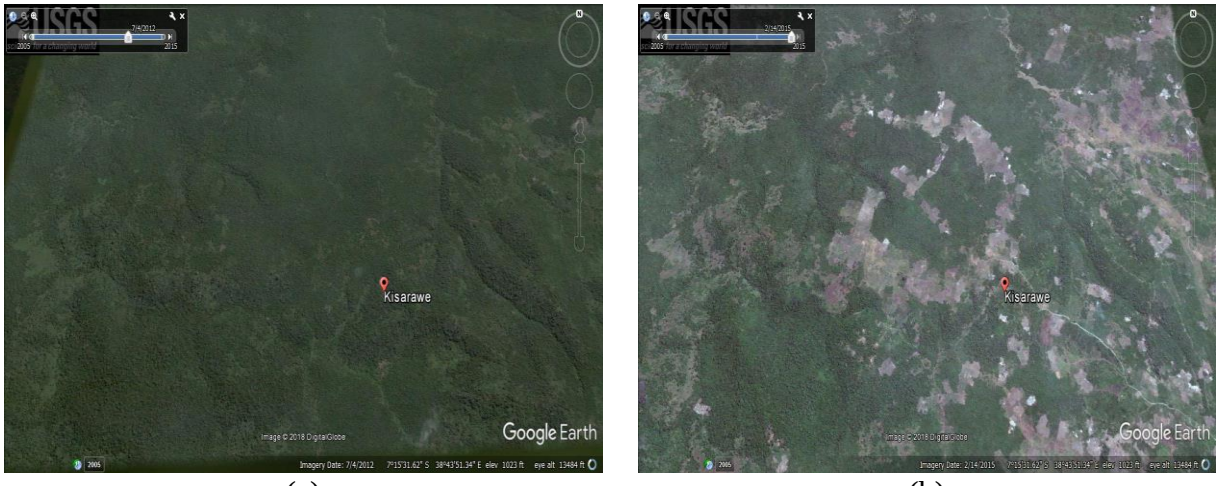


Figure 2. Flow chart

3. Results and discussion

The Kisarawe sub-catchment is the origin of the Msimbazi River, and the area has also been subjected to a relatively high urbanization rate. Likewise, the Kinyerezi sub-catchment was considered an outskirt area of Dar es Salaam City due to its location but is currently among the highly urbanized areas. As the population keeps increasing in Dar es Salaam, also land demand for settlements has been rapidly increasing (Figure 3). Kinyerezi is one of the areas in Dar es Salaam with a high rate of new settlements establishment. The sub-catchment is currently under high development pressure, experiencing large-scale real estate's developments such as the construction of villas, apartment complexes, office buildings, hotels, and shopping malls, driven by the enormous demand for residential housing, industrial and commercial premises. Figure 3 provides an overview of the situation in the sub-catchments. It is also worth noting that microclimate (Tahir, Muhammad, Mahmood, Ahmad, & Ullah, 2015), surface water dynamics, groundwater recharge (Minnig, Moeck, Radny, & Schirmer, 2018), stream geomorphology (O'Driscoll *et al.*, 2010; Vietz, Walsh and Fletcher, 2016), biogeochemistry (Grimm *et al.*, 2004), and stream ecology (Roy *et al.*, 2016) are all affected by urbanization.



(a) (b)



(c) (d)

Figure 3. (a) Kisarawe sub-catchment 2005 (b) Kisarawe sub-catchment 2015 (c) Jagwani 2005 (d) Jagwani 2015

From the classified images (Figure 4), it can be observed that the downstream of the catchment close to the Indian Ocean shore is highly developed, and the extent of urbanization (development) decreases as you move upstream towards the Kisarawe hills where the catchment originates. In this area, the trend moves from high-intensity development to medium intensity followed by low-intensity. The whole phenomenon reflects the reality of the catchment, where forests are also more seen upstream, especially in the Kisarawe hills. The literature states that the development of coastal regions is linked to the fact that cities have been formed around ports throughout history because ports gave opportunities for trade, jobs, and transportation; For these reasons, people have chosen to relocate to seaside cities (Bowen *et al.*, 2019). For instance, New York City and Boston, two of the largest cities in the United States, grew up around ports (Smith, 1987).

Furthermore, from the results, it was observed that the land-use coverage has been changing over time. In 1998 a large part of the catchment was occupied by the low-intensity developed areas covering about 61.67% of the total area. However, in 2009 the low-intensity developed areas decreased drastically to 21.13% of the total area and only 16.82% in 2018. On the other hand, the medium intensity developed areas have been increasing over time; whereby in 1998, the land surface occupied by the medium intensity developed areas was 25.97%, then increased to 50.49% in 2009 and 61.12% in 2018. It was also observed that the trend of high-intensity development

has been increasing; in 1998, the coverage of high-intensity development was about 3.82% which increased to 13.42% in 2009 and then to 19.77% in 2018.

From Figure 4, it can have observed that the red colour presenting the highly developed areas has been increasing towards the upstream of the catchment over time, and the green colour representing the medium level of development also increases towards the upstream of the catchment; while the yellow colour which represents the low developed areas has been reducing with time. The general phenomenon reflects the real situation within the catchment.

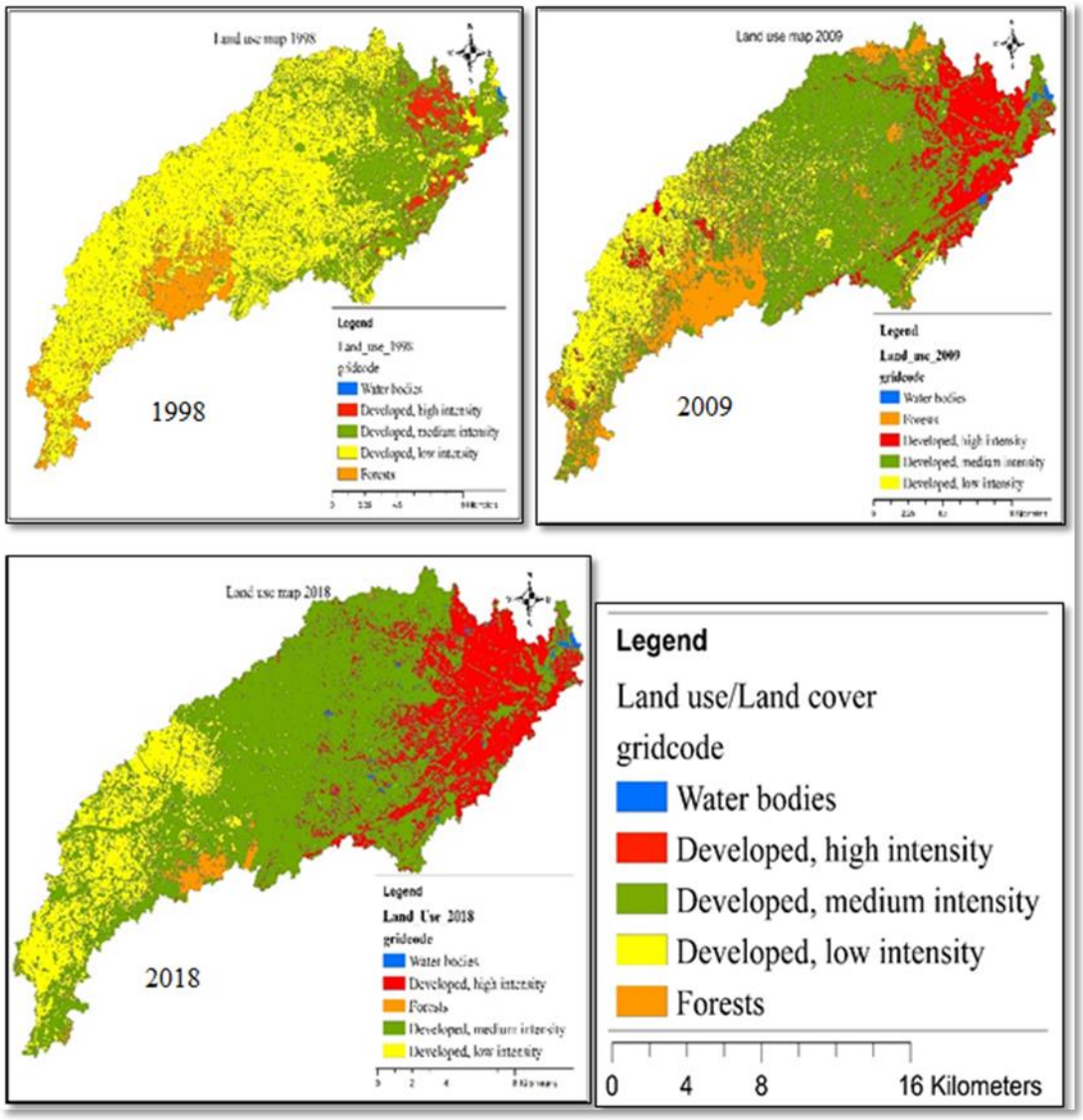


Figure 4. Classified land use within the catchment from 1998 to 2018

From Figure 5, it can be observed that there was a sharp decrease in the extent of low-developed areas from 1998 to around 2010, and then from there to 2018, the decreasing trend is relatively gradual. The phenomenon is most likely due to the fact that the majority of the available spaces in the catchment were occupied between 1998 and 2010. Likewise, the catchment is experiencing a sharp increase in the medium level of development, as shown in Figure 5. Also, it can be observed that the extent of the areas covered by high-intensity developed areas has been increasing since 1998, although at a slower rate compared to that of the medium level.

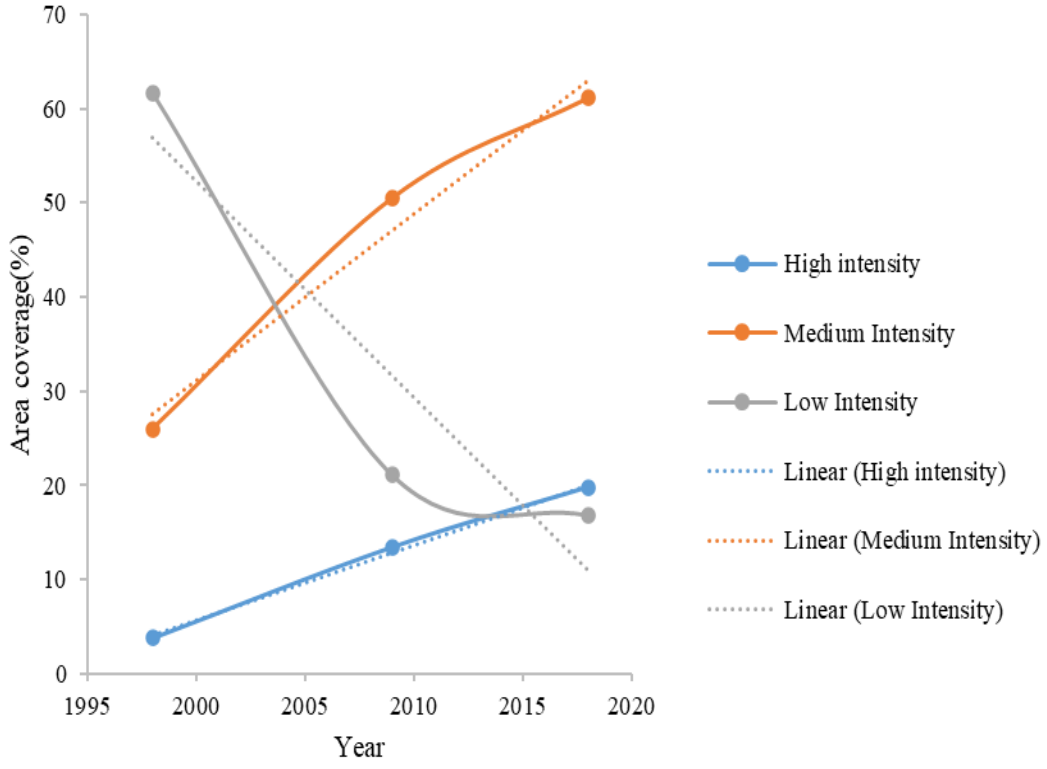


Figure 5. The trend of land use coverage

In summary, efficient land use management practices may help our communities against catastrophic events such as flash floods resulting from land use/land cover change (Chen and Huang, 2013). Today, land use planning plays a significant role in government initiatives. For the purpose of resource management, planning, and global monitoring studies, it is crucial to identify, delineate, and map the land cover. The baseline from which monitoring operations (change detection) can be carried out is established by identifying the land cover, which also supplies the ground cover data for baseline thematic maps. It is worth noting that, increased impervious surfaces due to land-use changes magnify the demolishing power of floods as it increases the amount of stormwater runoff generated (Li *et al.*, 2019). As previously highlighted, increased impermeable areas result in more floods and less infiltration into aquifers as a result of urbanization. The literature shows that stormwater and yields increase by nearly seven times when impervious areas and urban rivers are channeled (Tucci, 2017).

Future expansions in land-based production must put more of an emphasis on increasing current production systems in a sustainable way. Because land use intensity is a complicated, multifaceted concept and because we lack relevant datasets to evaluate land use intensity across large geographic extents, our grasp of the patterns of land use intensity on a global scale is inadequate, which is unfortunate (Kuemmerle *et al.*, 2013).

Moreover, it is worth highlighting that GIS greatly simplifies territorial planning by analyzing relevant data and spatial relationships, allowing for more complicated assessments of the situation and providing a foundation for more precise and scientifically justified land-use decisions (SEJATI *et al.*, 2020). In general, sustainable land management is required to satisfy the demands of an expanding population. For example, suppose the land does not receive enough water from cultivating the flora responsible for creating the food utilized to nourish residents in a region. In that case, it becomes difficult to feed additional people (Ameyaw and de Vries, 2021).

This study identifies that land use and land cover in the Msimbazi river catchment have been changing over the years. The findings serve as an alert to the authorities to begin formulating adequate strategies for striking a

balance between rapid development activities and the environment. Settlement establishment within the catchment is the major activity altering the land use and land cover within the catchment due to the rapid urbanization rate in Dar es Salaam.

Effective countermeasures and adaptation strategies should be devised to control the state of land use and land cover change within the catchment, which will make sure that the natural setting of the catchment is maintained. Planting trees and other means of restoring vegetation cover should be e emphasized for the sustainable protection of the catchment. Land cover changes have effects that can be identified and addressed by new land use practices through environmental impact assessments and knowledge of present development practices. Local governments may put these reforms into effect by offering incentives, enforcing the law, or launching public awareness campaigns and educational initiatives to promote sustainable behaviors and technologies. If residents are informed about the effects and prospects for change, they can implement the same steps on their own.

4. Conclusions

The potential applicability of GIS-based techniques with Landsat to investigate the land use and land cover changes in an urban catchment for the case of the Msimbazi River catchment in Dar es Salaam, Tanzania, has been investigated. From the results, it was observed that in 1998 a large part of the catchment was occupied by low-intensity developed areas, with 61.67% coverage, which in 2009 reduced to 21.13% and 16.82% in 2018. The medium intensity developed areas have been increasing from year to year; whereby in 1998, the land occupied by the medium intensity developed areas was 25.97%, then increased to 50.49% in 2009 and 61.12% in 2018. This study also observed that the trend of high-intensity development has been increasing; in 1998, the coverage of high-intensity development was about 3.82%, which increased to 13.42% in 2009 and then to 19.77% in 2018. According to the findings of this study, development activities have a considerable impact on land use and land surface cover in catchments. In addition, the findings suggest that land use and land cover analysis using satellite images could be a beneficial approach for monitoring the extent of land surface cover changes towards proper water resource management. Furthermore, the results offer helpful information to engineers and water

resource managers on the need to include land use and land cover evaluations throughout the execution of water-related projects within catchments. Moreover, the results derived in the study provide a piece of useful information for policy making towards protecting natural resources while preserving and improving the natural environment. Encourage wholesome economic development, expansion, and redevelopment. During the planning horizon, where appropriate, encourage orderly new growth.

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