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Abstract: Urbanization has emerged as a prominent phenomenon in the modern era, significantly impacting urban growth. Remote sensing technology has proven to be a powerful tool for observing and monitoring this growth. Malang City, with a population of 846.13 thousand in 2020 (according to BPS Jawa Timur), is a highly urbanized area. Despite this, the city is not immune to urban sprawl, necessitating further investigation into its urban growth patterns. This research employed several approaches, including data selection and image processing, image classification, accuracy assessment, and change detection. This is followed by zonal and directional, also multi-ring buffer analyses to examine the spatial distribution of urban growth This research uses Sentinel 2A image data which is new enough to be used in observing urban growth. The accuracy assessment is conducted using stratified random sampling, followed by ground truth process. The land cover classifications for 2016 and 2022 achieved kappa values of 82.2% and 84.86%, respectively, with corresponding accuracy values of 89.58% and 91.03%. These results can be categorized as good for further observation. The analysis revealed a significant increase in built-up areas in Malang City between 2016 and 2022. This expansion came at the expense of vegetation land cover. Overall, urban growth in Malang City remains unevenly distributed across the entire city. This indicates an uneven distribution of infrastructure supporting urban growth. Therefore, an increase in infrastructure investment across the city is crucial. Equal distribution of infrastructure development can then stimulate development in other areas, fulfilling the need for land availability for housing and settlements. Despite this, ensuring equitable development across Malang City is crucial, avoiding concentration in specific zones or directions.

Keywords: urban growth, land cover, built-up areas, urbanization

1. Introduction

The United Nations estimates that the proportion of people living in urban areas will grow from 56% in 2021 to 68% in 2050. This means that there will be an increase of 2.2 billion people living in urban areas, mainly in Africa and Asia. However, the extent to which cities can accommodate these changes is unknown[1,2]. Urbanization, driven by population migration from rural to urban areas, is the key factor triggering city growth[3–7]. Moreover, there is a trend towards an increase in built-up areas located around peripheral land, one of which is triggered by the affordability of land prices in the area[8,9].

Outer areas leading to the city borders have emerged as a viable option for the development of built-up areas, particularly those with accessibility and complete infrastructure related to housing and settlements. Unbuilt areas around the city center can also be considered, although land prices are relatively more expensive compared to areas leading to the outskirts of the city. This, of course, drives the conversion of land from unbuilt to built-up areas. However, not all infrastructure has been evenly developed in urban areas. This situation, of course, triggers an uneven conversion of land functions to built-up areas[10–12].

One of the impacts of the city's growth is an increase in energy consumption considering that Indonesia in general has experienced an increase in energy consumption[13]. Beyond this, natural features like water bodies can also pose threats, causing various ecological problems to emerge[14]. In other problems, reduced vegetation poses a significant threat to the very existence of agricultural land, a critical component of the global economy[15].

These are the same challenges faced by Malang City. Malang City is the second largest in East Java Province, Indonesia. As a large urban area, Malang is experiencing rapid urban growth. This growth, driven by population increase and migration from other regions due to economic or social factors, has led to a surge in demand for housing and residential land. However, the limited availability of land, especially in areas surrounding the city center, necessitates alternative solutions to address this housing shortage. This phenomenon has also prompted the local government to provide infrastructure improvements in its territory. These circumstances have ultimately led to an increase in built-up area[10,11)].

Malang City which also known as educational city has a population of 846.13 thousand people in 2020[16)]. The city's thriving educational scene, evident in its many universities, contributes to its growth. In this city, there are eight public universities and twenty eight private universities[17)]. In terms of the PDRB rate, the city also has a value above the average, which is 6.32% in 2022[16)]. Because of its proximity to the tourist city of Batu City, Malang City is a popular transit point for tourists [18)]. This makes the need for land slowly increase and lead to increased growth of the city.

City growth can be measured by the extent of urban expansion in the region. Urban expansion is characterized by the transformation of undeveloped land cover into built-up land[12,19)]. In addition to observing land cover changes to assess the city's growth, observations were also made regarding the distribution of built-up land, particularly from the perspective of the concentration of development directions, whether it tends to be dominant in certain directions. Therefore, zonal and directional analysis is needed to determine whether urban growth in Malang City has been evenly distributed in all directions or is only focused on certain areas. In addition, it is also necessary to consider the speed of expansion, how far the expansion has occurred from the city center. In this context, observation of the distribution of urban growth through multi-buffering analysis is required. Overall, these tasks can be accomplished by utilizing remote sensing technology to detect land cover changes between two satellite images[20,21)].

In remote sensing methods, the acquisition of information related to the earth's surface can be carried out without touching the target object being observed[22,23)]. With this technology, observations can be made regarding changes from undeveloped land to built-up land within a certain time span[24,25)]. In this study, Sentinel-2A images were used. By employing Sentinel-2A imagery, this study distinguishes itself from other research.

Sentinel satellites are Earth observation satellites developed by the European Space Agency (ESA) as part of the Copernicus Programme. Sentinel-2A is one of the high-resolution twin satellites. Launched on June 20, 2015, Sentinel-2A is freely accessible and can be directly accessed on the ESA website. Sentinel-2 has a wide spectrum with 13 spectral bands, including four visible and NIR spectral bands with a spatial resolution of 10 meters. The satellite's image data is designed to be an improvement over other publicly available data, such as Landsat imagery[26–30)]

The objective of this research is to investigate the urban growth of Malang City using Sentinel-2A satellite imagery. Urban growth will be assessed based on the expansion of built-up land area between 2016 and 2022. Understanding urban growth will enable further analyses such as zonal and directional analysis, as well as multi-ring buffer analysis. Additionally, this study will calculate the deviation between the built-up land area in 2022 and the planned built-up land area in the Malang City Spatial Plan 2010-2030, derived from the calculation of urban cultivation areas. These areas include residential, commercial and service, industrial and warehousing, military, and public/social facilities.

2. Methodology

The research method used in this study is a quantitative method with a descriptive approach. Data collection relies on secondary sources, specifically Sentinel-2A imagery. The objects of observation in this case are four land cover types (Table 1). This research employed several approaches, including data selection and image processing, image classification, accuracy assessment, and change detection. To gain deeper insights, further analyses were conducted, including zonal and directional analysis, as well as multi-ring buffer analysis[12,20)] and comparison of urban growth with land use planning from the local government (Fig. 1).

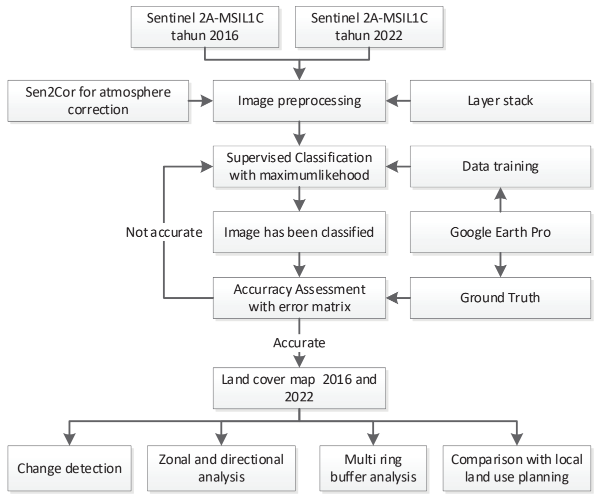

Fig. 1: Workflow diagram

This study utilizes multitemporal satellite imagery data. By employing a combination of RGB spectral bands and the NIR band, observations are conducted with image interpretation using a false-color composite approach. This study analyzes land cover changes, primarily built-up land, using classified satellite imagery acquired on

August 29, 2016, and July 9, 2022. A significant advantage of this study is its ability to observe urban growth in greater detail compared to other open-access satellites like Landsat. A limitation of this study is that the research time interval cannot yet be extended to include additional time intervals due to data limitations associated with the relatively new Sentinel satellite. This is because the most effective way to observe urban growth changes is with a minimum interval of 5 years to accurately track changes in built-up areas[31].

2.1 Study area

Malang City is administratively located in the middle of the Malang Regency area. This city is in the south of East Java Province as shown in Fig. 2 [8]. The city of Malang is surrounded by several mountains, such as Mount Kawi and Panderman on the west side, Mount Arjuno on the north side and Mount Semeru on the east side. Apart from that, the City of Malang is also fed by several rivers such as the Brantas, Amprong and Bango Rivers[32]. As a city that has experienced significant urban growth in recent years, more recent observations are needed[18], especially those that utilize Sentinel 2A as an image source.

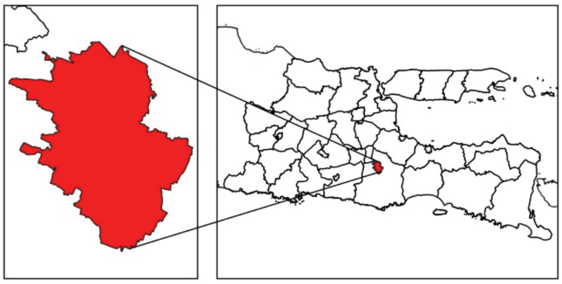

Fig. 2: Study Area

2.2 Data collection and image preprocessing

This study utilized Sentinel-2A imagery with Level-1C processing acquired on 29 August 2016 and 9 July 2022 for the years 2016 and 2022, respectively. Since the initial image was still at Level 1C, atmospheric correction was required using Sen2Cor so that obtained an image with Bottom-Of-Atmosphere reflectance (Level 2A) from before which is still a Top-of Atmosphere[33]. In general, raster cutting or layer stacking for each band is used, namely bands 2,3,4 and 8 which have a pixel resolution of 10 m which is done using QGIS 3.28.

Employing a combination of RGB spectral bands and the NIR band, observations are conducted with image interpretation using a false-color composite approach. (Fig. 3). This facilitates the creation of training data for image analysis. A significant advantage of this study is its ability to observe urban growth in greater detail compared to other open-access satellites like Landsat.

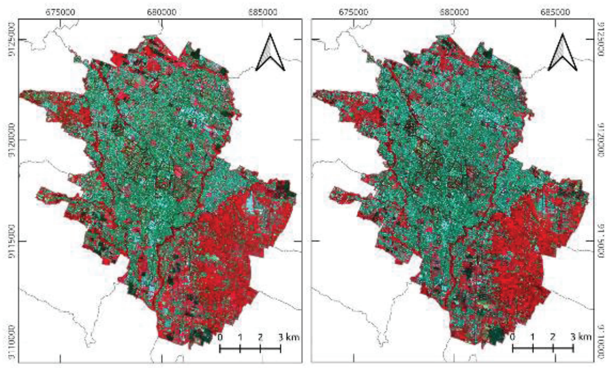

Fig. 3: False composite of Malang City from Sentinel 2A in 2016 (left) and 2022 (right)

2.3 Land cover classification, accuracy assessment dan change detection

To assess urban growth through built-up land changes, we analyzed land cover changes using four classes[12,34]. This research analyzed four land cover classes: built-up land, vegetation, open land, and water bodies. Supervised classification with the maximum likelihood method was used to perform the classification. This method is carried out with the help of the "Semi-Automatic Classification Plugin" which is one of the additional plugins from QGIS [35,36]. The characteristics of the four land covers used are explained in Table 1.

Table 1. Characteristics of land cover in four classes

Land cover class	Description
Built-up areas	The entire built-up area created by humans
Vegetation	Agricultural land, arable land, parks, forests
Bareland	All vacant land and unused land
Water bodies	Entire bodies of water such as rivers, lakes, ponds

In assessing the accuracy of the resulting land cover classification, the multinomial distribution method is used with the worst-case scenario. At least, a minimum of thirty samples for each land cover class using the stratified random sampling method. This is to ensure the representativeness of the sample in each land cover class. After the classification is carried out, additional samples will be added for each land cover class in proportion to the area of land cover that was classified earlier, except for the land cover with the smallest area[37].

In this study, 624 samples were used for accuracy assessment for each land cover class in both 2016 and 2022. Each land cover category has a minimum sample size of 30 points to ensure adequate representation. The remaining points are then distributed proportionally based on the percentage of each land cover class within the study area. The goal is to achieve a kappa value above 80% and an overall accuracy above 85%. Tests are conducted until these thresholds are met. Google Earth will be used to verify the accuracy of the classifications by providing ground truth reference points[37–41]. Following the accuracy assessment, a comparison is conducted between the two classified land cover maps for 2016 and 2022. This analysis aims to identify how land cover has changed between different categories. A specific feature within the Semi-Automatic Classification Plugin for QGIS will be utilized for this change detection analysis.

2.4 Zonal and direction analysis, and multi-ring buffer analysis

This stage involves two analyses: zone and direction analysis, and multi-ring buffer analysis. Zone and direction analysis is used to quantify the extent and direction of observed land cover changes. In this study, we specifically focus on built-up land to identify the direction of change associated with urban expansion. This analysis utilizes eight quadrants, each spanning 45 degrees, emanating from the urban center. These eight quadrants are further subdivided into zones based on the eight cardinal directions. This subdivision allows us to obtain a detailed range of zones, such as northwest-west (NWW), north-north west (NNW), north-north east (NNE), north east-east (NEE), south east-east (SEE), south-southeast (SSE), south-south west (SSW), southwest-west (SWW)[12,20,42].

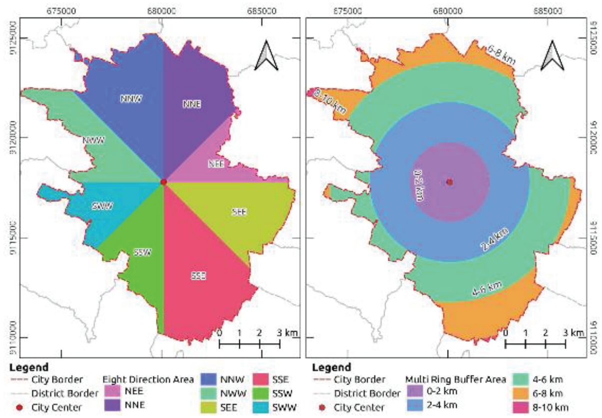

Fig. 4: Eight quadrant in zonal and direction analysis map (left) and multi ring buffer analysis map in 2 km interval (right)

Multi-ring buffer analysis is used to determine the extent of urban expansion outward from the city center. This analysis utilizes rings spaced at 2-kilometer intervals. By analyzing pattern within each buffer zone, researchers can gain insights into the spatial dynamics of urban growth.[12,43,44]. In this study, the administrative center of Malang City serves as the reference point for both analyses (Fig. 4).

3. Result and Discussion

3.1 Land cover classification, accuracy assessment and change detection

For land cover in 2016, it had a kappa value of 82.2% with an accuracy value of 89.58%. For land cover in 2022 it has a kappa value of 84.86% with an accuracy value of 91.03%. These values indicate that both classifications surpassed the initially established thresholds, enabling further data processing to proceed.

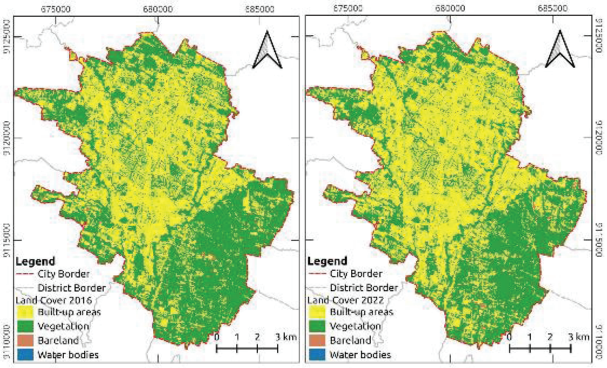

Fig. 5: Land Cover of Malang City in 2016 (left) and 2022 (right)

Based on Table 2 and Fig. 5, it can be seen that in 2016, land cover was dominated by the vegetation class, which was 52.37%. For 2022, the dominance of land cover will change, which is dominated by built-up areas with a percentage of 54.10%. When viewed from the rate of change, in terms of area in the 2016-2022 range there was an increase in the built-up area of 806.35 ha or an increase in area of 7.26%. This situation was of course accompanied by a significant decrease in the area of vegetation land cover classes in an area of 781.28 ha or as a percentage of 7.03%. A shift in land cover dominance is evident, with built-up land becoming the predominant category in 2022 compared to vegetation in 2016. This transformation indicates a surge in urban development within the city, marked by a 7.26% increase in built-up land area between 2016 and 2022.

Table 2. Land cover of statistic of Malang City

Land cover category	Year			
	2016		2022	
	ha	%	ha	%
Built-up areas	5202.22	46.84	6008.57	54.10
Vegetation	5817.14	52.37	5035.85	45.34
Bareland	81.44	0.73	56.90	0.51
Waterbodies	6.06	0.05	5.53	0.05

Table 3. Change rate of land cover in four classes

Land cover class	Change Rate 2016-2022	
	ha	%
Built-up areas	806.35	7.26
Vegetation	-781.28	-7.03
Bareland	-24.53	-0.22
Water bodies	-0.53	0.00

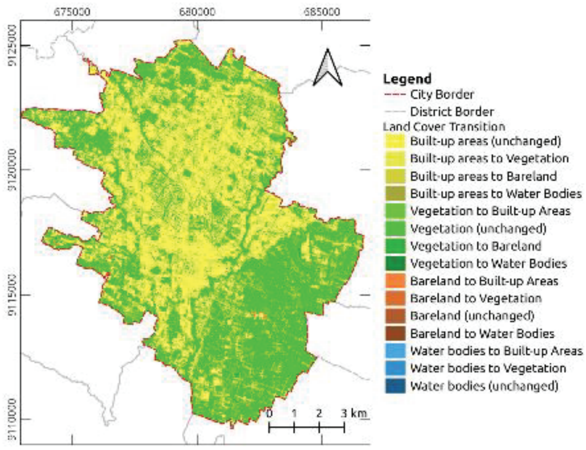

Fig. 6: Land Cover Transition of Malang City from 2016 to 2022

In the context of urban expansion, land cover changes primarily focus on the conversion of non-built-up classes, such as vegetation, bareland, and water bodies, to built-up areas. As shown in Table 4 and Fig. 6, a significant conversion of vegetation land cover to built-up land occurred between 2016 and 2022, totaling 1162.31 hectares. Conversion from bare land was considerably lower, at only 27.7 hectares. Overall, the analysis reveals that the increase in Malang City's built-up land area is primarily driven by the ongoing transformation of vegetation land cover, which continues to experience a significant reduction.

The conversion of land cover into built-up land is driven by the increasing demand for housing and settlements. This demand is further fueled by the rising population in the city. The increase in population can stem from various factors, including natural population growth (births) or population migration[11]. The availability of diverse infrastructure in Malang City can also serve as a pull factor for migration. These factors collectively trigger the transformation of land cover from vegetation into built-up areas.

Table 4. Change rate of land cover in four classes

	Land Cover Class	2022			
		BU*	V*	BL*	WB*
2016	BU*	4818.31	374.63	9.04	.24
	V*	1162.31	4608.70	42.66	3.48
	BL*	27.70	48.99	4.75	.00
	WB*	.25	3.54	.45	1.82

Note: BU*-Builtup, V*-Vegetaion. BL*-Bareland, WB*-Waterbody

3.2 Zonal and direction analysis

Based on zonal and directional analysis (Table 5 and Fig. 7), urban growth is evident in nearly all zones between 2016 and 2022. The SSE zone experienced the most significant increase in built-up land, reaching 167.4 hectares (Fig. 8). This zone also boasts the highest expansion rate at 30.9% (Fig. 9), followed by the SEE and SSW zones at 27.7% and 14.9%, respectively. Notably, the SSE zone leads in both total urban growth and expansion rate. Overall, Malang City's urban growth exhibits a spatial disparity, with the SSE zone experiencing the most significant expansion and overall growth. This uneven development pattern necessitates further investigation into the factors influencing this trend and the development of strategies to promote more balanced urban expansion in the future.

Table 5. Directional change of built-up areas in eight quadrants in Malang City

Zone	Area (ha)		Change rate (ha/6 years)	Expansion rate (%)
	2016	2022	2016-2022	2016-2022
NNE	1036.0	1172.4	136.4	13.2
NEE	389.9	440.3	50.4	12.9
SEE	389.7	497.7	108.0	27.7
SSE	542.0	709.5	167.4	30.9
SSW	611.9	702.9	91.0	14.9
SWW	493.1	557.6	64.4	13.1
NWW	626.1	672.8	46.7	7.5
NNW	1113.4	1255.4	142.0	12.8

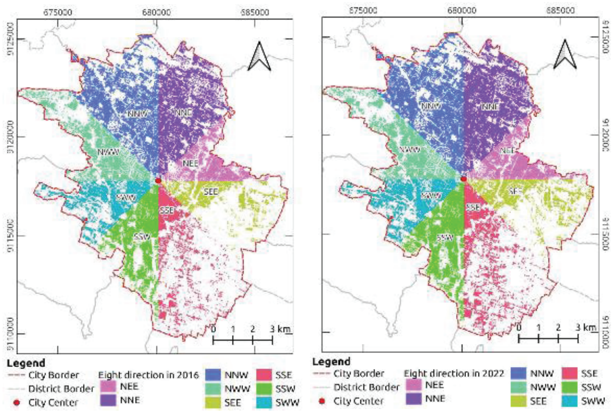

Fig. 7: Zone and directional analysis in eight quadrant map of Malang City

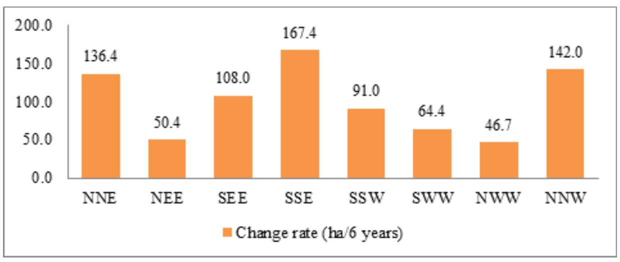

Fig. 8: Change rate of built-up areas based on zonal and directional analysis from 2016-2022

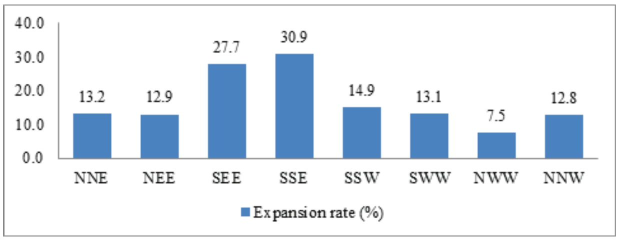

Fig. 9: Expansion rate of built-up areas based on zonal and directional analysis from 2016-2022

3.3 Multi-ring buffer analysis

Based on Table 6 and Figure 10 show a clear trend of urban expansion in the study area. This growth is primarily driven by the increase in built-up areas. The zone 2-4 km from the urban center experienced the largest increase in area, namely 336.9 ha, although when viewed from the perspective of the rate of urban expansion, it is in third place (Fig. 11). The largest rate of expansion (48.8 km²) is observed in the outermost zones (8-10 km) of Malang City, despite this zone having the smallest total area increase (2.3 ha) (Fig. 12). This is because these zones cover a relatively small portion of the city. Furthermore, the analysis reveals a trend of increasing land cover transformation from non-developed to built-up areas with increasing distance from the urban center.

Table 6. Multi-ring buffer analysis of built-up areas in Malang City

Zone	Area (ha)		Change rate (ha/6 years)	Expansion rate (%)
	2016	2022	2016-2022	2016-2022
0-2 km	898.5	951.8	53.3	5.9
2-4 km	2164.3	2416.8	252.5	11.7
4-6 km	1667.9	2004.8	336.9	20.2
6-8 km	466.8	628.2	161.4	34.6
8-10 km	4.7	6.9	2.3	48.8

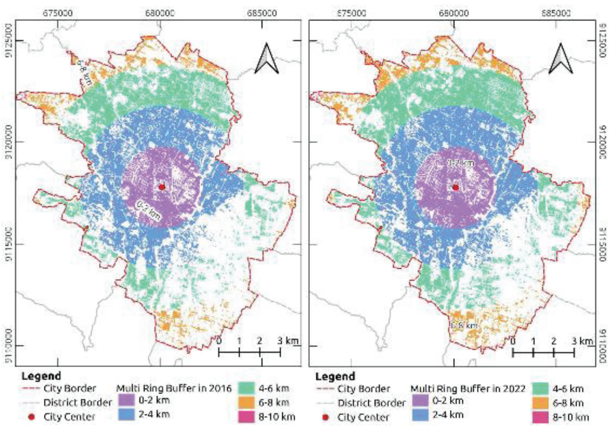

Fig. 10: Multi Ring Buffer Analysis Map of Malang City in 2016 (left) and 2022 (right)

The outward expansion of cities is driven by several factors, including the limited availability of undeveloped land in central urban areas. Additionally, the presence of accessible and well-developed infrastructure in outlying areas also contributes to this trend. The availability of affordable undeveloped land in these outlying areas further fuels this urban expansion.

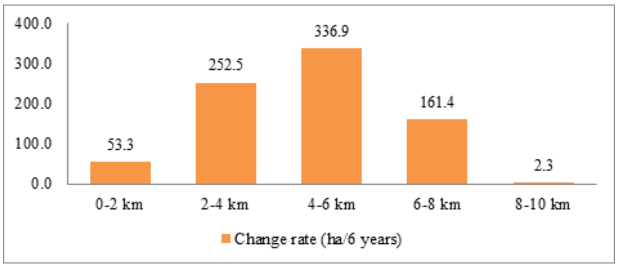

Fig. 11: Change rate of built-up areas based on multi ring buffer analysis from 2016-2022

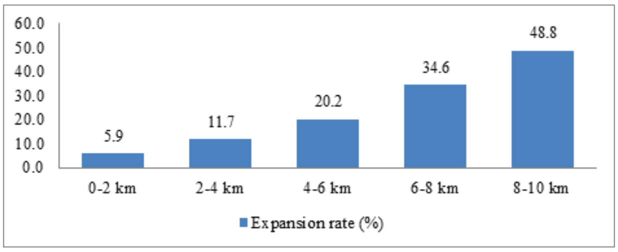

Fig. 12: Expansion rate of built-up area based on multi ring buffer analysis from 2016 to 2022

3.4 Comparing with local land use planning

At this stage, the analysis involves comparing land cover data with the government's land use plan to assess their suitability[45]. This comparison focuses on built-up land cover and land uses designated for development in the plan, including settlements, commercial and service areas, military zones, industrial and warehousing districts, and public/social facilities.. Based on Table 7 it can be seen that the city growth that occurred in 2022 is close to the planning that has been planned by the City Government of Malang (Malang City RTRW plan for 2010-2030)

Table 7. Comparing with local land use planning in Malang City (ha)

Category class	2022	RTRW Malang City 2010-2030	Deviations
Built-up areas	6008.57	5927.38	81.19
Vegetation	5035.85	5122	86.15
Bareland	56.90	52	4.9
Waterbodies	5.53	5.53	0
Total	11.106.85	11.106.85	172.24

This study is based on a single time frame. For future research, it is recommended to employ a minimum of two observation periods, each lasting at least five years, to effectively observe urban growth patterns[31]. Alternatively, a single observation period with a longer duration of ten years could be utilized, extending beyond the current six year period between 2016 and 2022. Future research should aim to incorporate two observation periods with a minimum interval of 5 years. Moreover, in terms of spatial resolution, this study utilized Sentinel-2A imagery, which is anticipated to produce a distribution that may differ but is nonetheless comparable to that obtained using other satellite imagery, such as Landsat.

4. Conclusion

In 2016, vegetation was the dominant land cover type, comprising 52.37% of the total area. By 2022, this dominance has shifted to built-up areas, which now account for 54.10%. From 2016 to 2022, the built-up area increased by 806.35 ha, representing a 7.26% increase. Notably, there was a significant conversion of land cover from vegetation to built-up land during this period, totaling 1162.31 hectares. This analysis reveals a substantial shift in land cover dominance between 2016 and 2022. There has been a clear decline in vegetation cover, while built-up areas have expanded considerably. This trend suggests potential environmental concerns, highlighting the need for sustainable urban planning strategies to mitigate the loss of natural landscapes.

Analysis of zonal and directional changes between 2016 and 2022 reveals that both the magnitude of area converted to built-up land and the rate of expansion are concentrated in the SSE direction. This indicates a rapid pace of development in this zone compared to other areas. The availability of infrastructure and developable land likely drives the growth in this particular zone. The uneven distribution of built-up land in Malang City can be attributed, in part, to the uneven distribution of infrastructure across the city. To address this issue, it is crucial to strive for equitable infrastructure development throughout the city.

Analysis of the multi-ring buffer from 2016 to 2022 reveals that the most significant increase in built-up land area occurred within a radius of 4-6 kilometers from the city center. This area, situated between the urban core and the outer periphery, offers several advantages that have fueled its development. These include the availability of ample undeveloped land and a relatively short distance from the city center. Additionally, the expansion of built-up land is observed to be moving towards the outer periphery of the city. Factors such as improved accessibility and ease of acquiring housing are likely contributing to this trend.

The analysis revealed a deviation of 172.24 hectares between the land cover observed in this study and land use planning from local government. The largest discrepancy is in vegetation cover, with an observed area of 86.15 hectares differing from the plan. The significant expansion of built-up areas highlights the need for close government attention to ensure adherence to the land use planning from local government and avoid further deviation This will ensure that future development is in line with the planning that has been carried out.

Overall, it can be said that vegetation land cover has been a significant source for the expansion of built-up areas in Malang City between 2016 and 2022. However, urban growth remains unevenly distributed across the region. As distance from the city center increases, the magnitude of land cover change towards built-up areas appears to be greater. Encouragingly, despite the unevenness, existing urban development appears to be approaching the city's planning targets. Furthermore, ensuring equitable development across Malang City is crucial, avoiding concentration in specific zones or directions. It is hoped that further research can be conducted in the future to identify the factors that influence urban growth

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