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Research paper doi: 10.30822/arteks.v9i1.2655

Prediction of potential deviations in settlement area space patterns based on cellular Automata in Mapanget District, Manado City

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ARTICLE INFO

Article history:
Received September 19, 2023
Received in revised form Jan. 12, 2024
Accepted January 26, 2024
Available online April 01, 2024

Keywords:
Cellular automata
Deviation
Land use change
Land use Sim
Settlement

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ABSTRACT

Mapanget District is one of the administrative parts of Manado City which has service functions, namely housing and new settlements, tourism, and trade and services. The Mapanget District is part of the new city planning in the 2015–2019 RPJMN to account for unequal development in the city core. Predicting the development of residential land use is crucial to avoid uncontrollably detrimental effects on suburban communities. To forecast land development over 20 years, from 2022 to 2042, this study will employ spatial analysis based on the Geography Information System-Cellular Automata and weighting analysis using the Analytic Hierarchy Process (AHP) technique to analyze potential deviations in the spatial pattern development of Manado City settlements, particularly Mapanget District. The software used for this research's simulation procedure is LanduseSim 2.3.1, QGIS, and Archmap 10.8. According to the projection results, residential land use will vary during the following 20 years, starting in 1956.75 Ha, or a 201% increase, resulting from the most important driving factor, which is closeness to existing towns. 1106.79 Ha is the possible deviation depending on the direction of the spatial pattern plan for residential structures. It is advised to plan tall buildings, particularly for settlements, as the current residential land in Mapanget District exceeds both the carrying capacity and the land capacity as of 2042, according to the prediction results.

Introduction

In comprehensive spatial planning, one of the most significant components is the transformation of land use (Latif et al. 2021). Zoning regulations will be created based on land use directives to guarantee the long-term viability of urban development. Boundary zones are one of the key driving forces that impact changes in land use in an area (constraints) (Pratomoatmojo 2018b).

Analyzing changes in land use is crucial to understanding how different land types have been used recently, what land types are predicted to be in the future, and what factors are responsible for these changes (Regasa, Nones, and Adeba 2021).

Demographic factors such as rapid population growth have a tendency to contribute to the overexploitation of natural resources in some places. For instance, urban areas only cover 2% of the earth's surface, but more than half of the world's population lives in urban areas (Addae and Oppelt 2019). Every year, Indonesia's urban population grows, which affects the country's ability to meet its housing needs while enhancing its urban infrastructure. The emergence of new areas, the majority of which are being constructed in suburban regions, is what defines this state (Surya et al. 2020).

Based on BPS Manado City Publications in 2023, the population of Mapanget District is 64,380 people with a population growth rate of 1.03%. The population has increased significantly since 2018, when there were only 54,926 individuals. The changes in land use that were before limited to the city center region but have now expanded to outlying areas will be impacted by the increase in population. According to available data, when viewed as a time series, the Mapanget District's land use has shifted from plantation land—which predominated there for a while—to built-up land to accommodate human requirements.

The increasingly rapid changes in land use occurring in Mapanget District are due to the development of activity centers which are no longer focused on urban areas due to the lack of vacant land in these areas but have expanded towards the outskirts of the city (Margono et al. 2021; Muljadinata and Widiantoro 2023; Morakinyo et al. 2023).

The new city development plan in Manado City concurs with the land use adjustments that were implemented in the Mapanget District. The development of Kota Baru Manado will be centered around the district following the Mayor's Decree No. 128/Kep/B.01/BAPELITBANG/ 2017 about the determination of the demarcation of Kota Baru Manado. Mapanget. To stop uncontrolled settlements brought on by urbanization in the adjacent autonomous city, the creation of this new city is concentrated on creating a brand-new, livable residential center backed by sociocultural and economic amenities. (Ngangi, Franklin, and Mononimbar 2018).

It is vital to use the Geography Information System, or GIS, to construct spatial projections since the new city development plan raises the possibility of large land use changes in the Mapanget District. Several studies that employ a spatial approach have demonstrated that changes in land use intensity and cover can have an impact on urban expansion (Rimal et al. 2018). Furthermore, to increase accuracy, land use change modeling can be performed by combining Cellular Automata (CA) (Gharaibeh et al. 2020).

John Von Neumann developed the concept of cellular automata in the 1950s. The spatial dynamics of numerous environmental phenomena, including changes in land use and cover, the spread of forest fires, plant population dynamics, and urban sprawl, can be modeled using cellular automata.

A particular kind of discrete dynamical system is the CA concept. Space will be divided into temporal cells using this system. Every cell in this system has a condition that is constantly updated based on the time entered, local regulations, the state of the cell itself, and the neighboring cells' conditions from the previous time (Tatashev and Yashina 2019; Ou et al. 2019). The elements that make up CA, encompassing cell, state, neighborhood, transition rules and time-step (Xia and Zhang 2021).

Several software has been developed based on CA algorithms to predict land use/cover changes in GIS. Further investigation reveals that practically all CA models are employed to forecast trend-based comparisons as opposed to scenario-based future development. New software has been developed utilizing GIS-based LanduseSim to fill in the planning gaps that are likely to be future scenarios based on the available facts (Pigawati et al. 2020).

Several research review findings, such as the prediction of spatiotemporal urban growth trends, employ the LanduseSim simulation process to foresee changes in land use (Khan and Sudheer 2022), modeling the growth of built-up land as a prediction for agricultural land in Karanganyar regency (Dyan Syafitri and Susetyo 2019), simulation of the consequences of industrial area development (Sadewo and Buchori 2018), land use prediction with CA in Mataram City (Putra and Rudiarto 2018).

This study employs a methodology that has been used in some other studies, however, for this type of research, Manado City's location is unusual in and of itself. In addition, there are variations in how the AHP technique, which incorporates stakeholders, is employed to determine elasticity values. Potential discrepancies between estimates and the intended residential spatial patterns in the Manado City RTRW are also examined in this study.

N.A. Pratomoatmojo developed the CA-based concept with LanduseSim as software for land use forecasts, which naturally turns out to have advantages compared to other applications after evaluation (Pratomoatmojo 2018a). Therefore, projections of land development and probable deviations in the development of residential spatial patterns in Mapanget District are carried out using a spatial strategy based on LanduseSim-CA. The better it is to anticipate the shift of land use over the next 20 years from 2022 to 2042. The more accurately one can predict how land use will change over the following 20 years, the less of an impact the area will experience.

Methods

Regional overview

The Mapanget district is the general description of this study location. Mapanget district is a part of Manado City administratively. Mapanget District covers 5360.61 hectares. It shares immediate borders with Singkil District to the west, Tikala district to the south, North Minahasa regency to the east, and North Minahasa regency to the north. Mapanget district is identified in figure 1 as having 10 sub-districts, namely Bengkol, Buha, Kairagi Dua, Kairagi Satu, Kima Atas, lapangan, Mapanget Barat, Paniki Bawah, Paniki Dua, and Paniki Satu.

With a prominent height of 40–80 meters, Mapanget district is situated at an elevation of 6-188 meters above sea level. In the meantime, topography in this area with flat features ranging from 0-8% dominates the slope.

The administrative map of the research location can be seen in the figure below (figure 1).

Figure 1. Map of research locations in Mapanget district
Source: Manado City RTRW 2014-2034

Research methods

1. Research approach

This study method employs raster data and pixel analysis units to conduct quantitative research on a spatiotemporal basis.

Data for this study, including maps of the Mapanget District, were created by digitizing Google Earth photos. Additional information gathered from earth maps created by BIG (Indonesian Geospatial Information Agency), Manado City RTRW 2014–2034, Manado City Geoportal, and the outcomes of primary surveys performed in the Mapanget District area in 2023 were also utilized as motivators. In the study, LanduseSim 2.3.1 and Archmap 10.8 are used in this processing.

2. Data collection methods and driving variables

Primary and secondary data-gathering techniques are employed in the Mapanget District to forecast land development. Direct observation in the Mapanget District, along with interviews and the distribution of questionnaires to pertinent stakeholders, served as the main methods of data gathering. We acquired secondary data collection techniques from pertinent organizations and sectoral papers that were accessible. This process is essential for the stage where the AHP method is used to allocate variable weights. Collecting data in the form of maps and land use conditions from Manado City RTRW papers. In the meanwhile, the outcomes of literature searches and assessments of field circumstances were utilized to collect data for study variables in the form of driving factors and constraint variables.

The literature search revealed study variables based on biophysical, social, and economic features, spatial planning rules, as well as spatial interactions and surrounding land use characteristics, that were employed as driving factors and constraint variables. More specifically, driving factors are defined as those that impact surrounding land use change to specific land use, like accessibility and distance to the city center, land use zoning status, and factors related to personal preferences such as socioeconomic growth and political systems involving population growth and the central business district (Wahyudi and Liu 2016).

3. Analysis method

The weight of the driving factors was taken into consideration when building the land use change prediction model using a CA technique. The quantitative parts of the CA model are weak, and it is unable to accommodate the factors that propel urban growth. As a result, it can be reduced throughout the simulation process by combining it with other quantitative models, like the frequency ratio models, Markov Chain, and Analytic Hierarchy Process (AHP) (Fitawok et al. 2020). The AHP model is a method that supports the Land useSim-CA simulation process, which was introduced by Thomas L. Saaty.

This decision model can describe various problems in the form of complex multi-factors or multi-criteria so that a hierarchy is formed (Cabrera and Lee 2019; Yannis et al. 2020). Based on the score results for each variable, we can employ the AHP technique to calculate the weight of the variables that affect land conversion as well as the degree of effect. The following step is transformation using a CA technique in simulation to determine projected land changes (Kafy et al. 2021).

A variety of approaches that can be utilized to regulate every factor that would be simulated were used in this study. Certain factors, like driven factors, zoning, and infrastructure scenarios, predicted growth in cell sizes, land use simulations, and the potential for new land use development, are controllable (Pratomoatmojo 2018c).

The method of creating a neighborhood-by-neighbor simulation in LanduseSim-CA begins with a map process that is entered as an initial transition map. This approach will build a transition potential map utilizing an overlay technique.

A spatial multi-criteria evaluation method based on a suitability map and a weighted overlay technique produced the first transition map (Noviani et al. 2023). LanduseSim-CA's ability to support both top-down and bottom-up approaches to spatial planning is an advantage for land use modeling that has not yet been discussed (Sumarmi, Purwanto, and Bachri 2021).

The transition potential (TP) map in the LanduseSim method provides a simulated direction of land use growth that may be characterized using mathematical equations. Transition potential map values are generated by equation 1 and can be interpreted as follows:

$$TPixy = \sum_{z=0}^{n} \left(N_{i(z-n)x,y} . ITP_{i(z-n)x,y} \right)$$

TP*ixy* = Transition value of land use i in a particular cell (x, y) (number of filter operations)

Ni(z→n) x, y = Neighborhood filter process by certain filters and accumulation at the cell center (x, y), where n is the total number of neighboring cells with or without cell centers

ITPi(z→n) x, y = The initial value of the transition map for a particular land use i or can be represented by a suitability map for the growth of a particular land use.

The LanduseSim-CA iteration process is utilized to replicate the expansion of specific land uses, as demonstrated by the class formed by adhering to the second mathematical equation below:

$$LU_{ix,y}^{t+1} = f(Lu_{x,y}^{t}, Gi_{x,y}, Ci_{x,y}, Ei_{x,y}, Zi_{x,y}, TS)$$

$LU_{i_{x,y}}^{t+1}$ = Growth (Change in condition) of land use I at time t+1 in a certain cell (x, y)

$LU_{x,y}^{t}$ = Changes in land use classes before being simulated in certain cells

$TP_{i_{x,y}}$ = Landuse i transition map in a particular cell

$G_{i_{x,y}}$ = The number of cells expected to grow from land use/land cover i at time t+1

$E_{i_{x,y}}$ = Elasticity of change for certain land uses converted into land use (i)

$C_{i_{x,y}}$ = Barrier land is represented by certain land uses that cannot be converted to land use i or areas that are conserved or protected

$Z_{i_{x,y}}$ = Zoning systems such as land use plans, disaster areas, growth zones are promoted

TS = Time step of CA iteration

The initial stage of this research was to examine the literature to investigate different references, including the findings of earlier studies. To gather information that has a significant impact on changes in land use, this step is crucial. The conditions encountered in the research region have been considered when modifying the variable formulation.

The study's factors are identified as the primary causes of land use changes, after which pertinent stakeholders will be contacted for information. The government, society, and academics comprise the persistent stakeholders. Sampling approaches are used in the strategy to determine the sample of stakeholders as responders. This research technique uses a non-probability sampling model. This method is cognizant of the fact that not every member of the population has an equal chance of being selected for inclusion in the sample. The AHP approach is employed to process analysis to process values or scores from stakeholders to acquire weight values.

The following stage involves simulating the expansion of built-up land using LanduseSim-CA, a concept that may be considered as a grid or cell-based idea that uses land use raster data as a spatial property (Subandi, Widiatmaka, and Ardiansyah 2019).

Analysis of the application of LanduseSim-CA land use change modeling in Mapanget

District through 3 phases, namely the data preparation phase, the simulation phase and the visualization phase. The following table provides a clearer explanation of the Land useSim-CA research procedure.

Table 1. Cellular Automata research stages with LanduseSim

Preparation	**Simulation**	**Map and data visualization**
1	2	3
ArcGIS editor, or GIS, is utilized for all procedures. Steps in the preparation process: a. Construct a map of the driving factors' closeness. b. Modify cell size and rasterize maps c. Convert raster maps to ASCII format so that LanduseSim can process them.	Processed data: a. Import data b. Standardization of data with fuzzy c. Overlay data to obtain initial transition potential map d. Setting rules to the simulation process	Data and maps are employed to depict the results of the simulation. Both Landuse-Sim and ArcGIS are utilized in the map visualization process (Pratomoatmojo 2021)

Source: Dyan Syafitri and Susetyo 2019

Results and discussion

A. Analyzing driving factors

At the point when a test is deserted, there are Mapanget district is a fast-growing area that experiences a fairly rapid increase in population every year.

Due to the high levels of urbanization that would follow from this rapid population growth, the city's periphery will eventually experience an impact from unrestrained urban expansion, which will cause the city's physical appearance to extend outward (urban sprawl).

Based on mutual agreement with stakeholders, driven elements resulting from the urban sprawl phenomena will be evaluated to analyze changes in land use and weighting in Mapanget district. Manado City Bapelitbang, Manado City Housing and Settlement area service, Mapanget district government, academics, and local leaders are among the stakeholders who have been recognized as examples or representatives.

The arterial road network, collector road network, office areas, trade and service areas, transit facilities, health facilities, educational facilities, water and power networks, and existing settlements are the factors that were employed in the analysis.

The following table displays the outcomes of weighting residential land that has been processed using the AHP method based on characteristics that were previously identified.

Table 2. Determination of variables as driving factors

No	Driving factors	Weight
1.	Arterial road	0.1287
2.	Collector street	0.1457
3.	Office area	0.0539
4.	Trade and service area	0.1058
5.	Transportation facilities	0.1098
6.	Health facility	0.0419
7.	Education facility	0.0399
8.	Water network	0.1078
9.	Electric network	0.1168
10.	Existing settlements	0.1497
Total		1

The following is a map of supporting factors that influence land use changes which can be seen in the following figures 2.

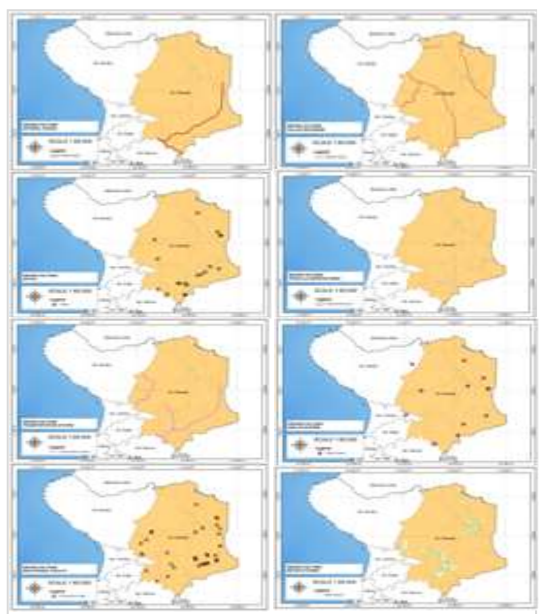


Figure 2. Map of driving factors

The weighting results indicate that the three factors that have the biggest weights in affecting land growth are the availability or closeness of existing settlements, the collector and arterial road network, and the electrical network. On the other hand, proximity to educational institutions demonstrates the least weight. There is only one weighting for residential land overall.

According to the AHP method's processing results, the location of educational institutions has the lowest weight score of 0.03 and the proximity to existing settlements the greatest weight score of 0.1497.

The Mapanget District's urban sprawl phenomena and changes in land use are primarily caused by the infrastructure that already exists.

B. Prediction of land use changes

These 17 land use classes—which include water bodies (land use code 1), road bodies (land use code 2), airports (land use code 3), forests (land use code 4), industry (land use code 5), urban infrastructure (land use code 6), tourism (land use code 7), cemeteries (land use code 8), trade and services (land use code 9), offices (land use code 10), plantations (land use code 11), defense and security (land use code 12), residential areas (land use code 13), bushes (land use code 14), parks (land use code 15), empty land (land use code 16), and final disposal site or TPA (land use code 17) are the results of image analysis and Manado City RTRW data.

This coding is performed to ensure that the land use data that has been recognized complies with the LanduseSim software algorithm, which processes data that is based on numbers. Future projections will take into consideration the current land use as codes.

To ascertain the likelihood of land conversion in the Mapanget District during 20 years, from 2022 to 2042, land use projections were conducted. The existence of a new city development plan in Mapanget District, which may result in changes to the land use in the area, prompted the usage of LanduseSim-CA-based simulations.

Following codification, the land use data is processed to create an initial map of possible land change transitions in the Mapanget District. This map is crucial to the LanduseSim-CA process. This is so because each land use's transition value serves as the foundation for expansion. This study utilizes a transition map for residential land development.

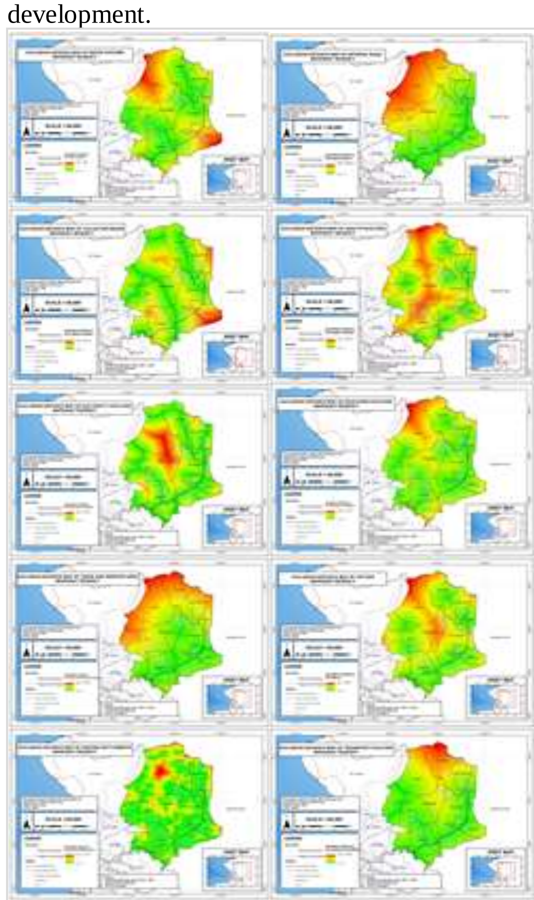


Figure 3. Map of distance as a driving factor

The next stage, as indicated in figure 3, is to construct a variable coverage area for built-up land growth. The method is carried out by Euclidean distance analysis or distance which is handled in the QGIS toolbox, specifically distance variable. This can be interpreted as the separation, for instance, between two educational establishments.

The next step is converting it into raster form in ASCII format using distance information from each factor so that LanduseSim may use it. The objective of this step is to remove the raster's coordinates by transforming the cell data in the raster into text (.txt) format. The next step is to create a transition map for the Mapanget District's land growth. The steps taken to create a transition map based on the variables specified are as follows:

a. Create fuzzy set membership values using the data from each factor's Euclidean distance map. After being converted to raster format (.tif), each factor is examined and transformed into raster data based on actual numbers. Each distance map will be standardized with a value between zero and one, which is the idea that this technique explains. One (1) is meant to represent the closest distance, and zero (0) represents the farthest. The determination of fuzzy values for every variable in this study is decreasing monotonically (Gerami Seresht and Fayek 2019). This illustrates that the closer you are to the driving factors, the greater the potential for land development.
b. Apply the overlay technique to the maps that resulted from fuzzy set analysis. A weighting procedure is utilized to carry out the computations in this stage. The weights utilized are in the range of 0 to 1 and are derived from the early-stage AHP analysis results. The underlying idea is that a component will have a stronger impact on changes in constructed land the higher its weight value.
c. The next stage is to enter into an area of constraint, which prevents or restricts development. The Mapanget district area's limitation zone is evident in figure 4. It is evident that the greater the likelihood of this map being developed into built-up territory, the lighter the color; on the other hand, if the color appears deeper, the lesser the likelihood of this happening.

The limiting factors for residential land development are shown in table 3 and include water bodies (Land Use Code 1), road bodies (Land Use Code 2), airports (Land Use Code 3), industry (Land Use Code 5), tourism (Land Use Code 7), public cemeteries (Land Use Code 8), trade and services (Land Use Code 9), offices (Land Use Code 10), defense and security (Land Use Code 12), and final disposal site or TPA (Land Use Code 17). In this research, the bounding zones are obtained from spatial pattern maps, specifically protected areas, which include river border areas.

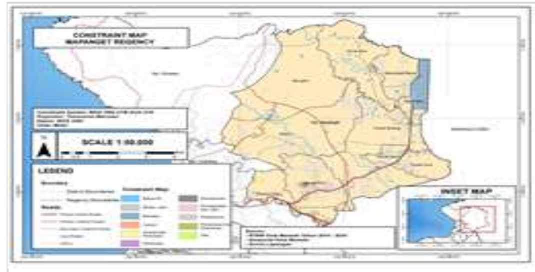


Figure 4. Map of limiting factors (constraints)

d. The following step is the neighborhood computation procedure that utilizes a grid method. In contrast to a 5x5 filter, a 3x3 filter is employed more frequently when creating a neighborhood filter (NF). This study's simulation also makes use of NF 3x3, intending to improve the urban growth model's accuracy. This is due to NF 3X3's propensity to address elements with greater focus, which implies it will have an impact on the development or growth of the land.
e. The next stage is to determine the elasticity of land change. The chance to turn land into residential land is valuable at this point. Using the AHP approach and the 2014–2034 Manado City RTRW document as a guide, interviews with pertinent stakeholders yielded the elasticity value for this study.

Table 3. Land Use Elasticity

No	Elasticity value	Land use
1.	0.1232	Forest
2.	0.0458	Trade and services
3.	0.0358	Office
4.	0.139	Plantation
5.	0.1963	Shrubs
6.	0.0831	Park
7.	0.3768	Vacant land

f. Determining the transition rules comes next. This phase determines the direction of anticipated land development and contains the land's potential development value. Table 4, the transition rules table utilized in this study, is displayed below.

Table 4. Transition rules for land use growth and limitations

LU code	*Land use*	*Growth cell*	LU barrier
13	Settlement	31309	1, 2, 3, 5, 6, 7, 8, 9, 10, 12, 17

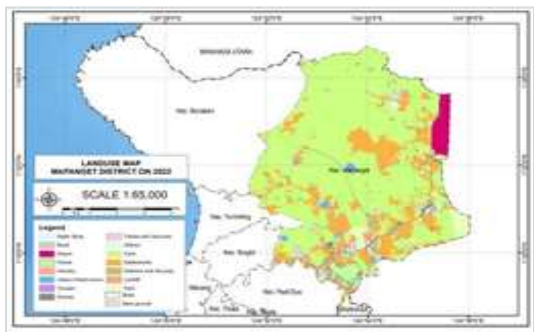
g. The simulation procedure follows next. The amount of time steps is a significant aspect to consider. This study projects from 2022 to 2042 using 20-time steps, or 20 iterations. According to the results of the simulation, residential land will be developed during the next 20 years. Where residential land in the research area in 2022-2042 overall experienced a growth of 1956.75 Ha or 201%. Figure 5's growth every five years can be explained by more thorough simulation findings. There was a 50% increase in 2027, a 33% increase in 2032, a 25% increase in 2037, and an additional 20% increase in 2042. This increase in residential building land was due to the intervention of 1648.13 Ha of plantation land, 153,813 Ha of vacant land, 95.6875 Ha of forest land, 56.1875 Ha of bush land, and 2.9375 Ha of park land.

In addition to the growth in residential property, plantation land and vacant land in the Mapanget District are being converted due to trade, services, and office space. The growing need for housing, such as those seen on commercial properties and ringroads, is beginning to indicate this as the population grows yearly. In addition, this corresponds with the beginning of the government center and office complex in Manado City, which will shortly be relocated to the Mapanget district. The graph below illustrates how Mapanget district's land area has changed over the past 20 years depending on the type of land.

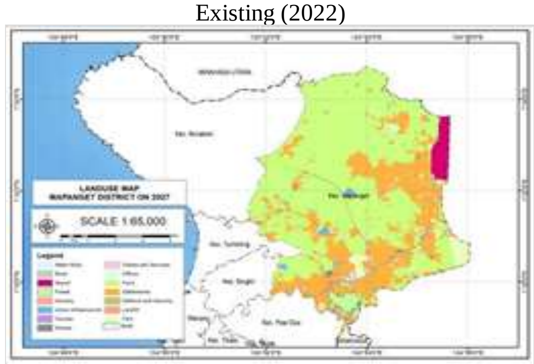
Figure 5. Graph of land use changes in Mapanget district for 2022-2042

One of the worst effects of this land conversion, which will occur if it is not carefully controlled, will be a deterioration in the quality of the environment.

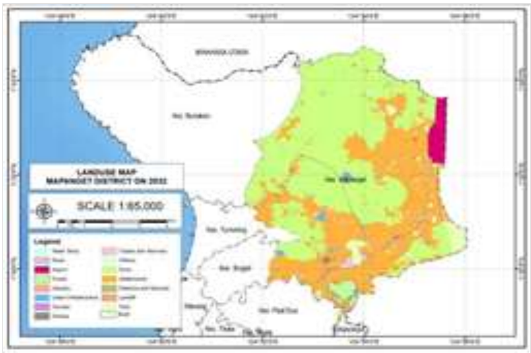
The land changes in Mapanget district over 20 years, from 2022 to 2042, are represented on the accompanying map every five years.



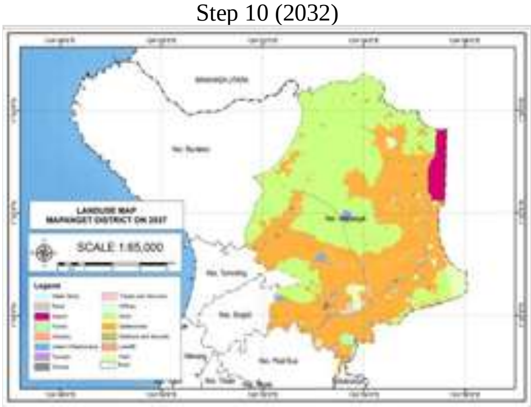
Existing (2022)



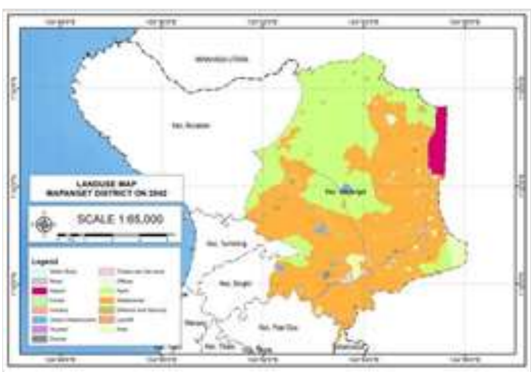
Step 5 (2027)



Step 10 (2032)



Step 15 (2037)



Step 20 (2042)

Figure 6. Predictions of land use changes in Mapanget district for 2022-2042

A comparison between simulation results and pre-existing maps is the validation strategy utilized for modeling findings. The land use maps from 2022 that are currently in use and the 2042 land use simulation map are employed in this study. A very good prediction accuracy of 95.44% is demonstrated in the validation results utilizing the LanduseSim software land use change analysis and validation tool.

C. Potential deviations in prediction results on residential spatial patterns

The process of identifying possible deviations is then carried out following the execution of a simulation projecting settlement growth until 2042. The findings of residential projections with residential space patterns that have been regulated in the Manado City regional spatial planning (RTRW), particularly for the Mapanget district, will be evaluated at this juncture to identify any potential deviations. The results of the examination will reveal any possible deviations or differences between the development plan's prepared directives and the actual development.

The area between the projected settlement development in 2042 and the spatial pattern settlement directions in Mapanget district based on Manado City's RTRW are compared in the table below (table 5), along with the results of the investigation of potential deviations from each sub-district in Mapanget district.

Table 5. Directions for settlement space patterns in Mapanget district

Village	Width	%
Bengkol	2076.741792	13.89
Buha	2554.460071	17.09
Kairagi dua	564.7370361	3.78
Kairagi Satu	191.2786733	1.28
Kima Atas	2210.745023	14.79
Lapangan	2064.848842	13.81
Mapanget Barat	386.2609552	2.58
Paniki Bawah	2741.616485	18.34
Paniki Dua	222.5305315	1.49
Paniki Satu	1935.838924	12.95
Total	14948.9732	100

Source: RTRW of Manado City 2014-2034

Table 6. Predictions of settlement development in Mapanget district

Village	Width	%
Bengkol	2905.625	10.10
Buha	2877	10.00
Kairagi dua	2870	9.98
Kairagi Satu	2873.8125	9.99
Kima Atas	2875.3125	10.00
Lapangan	2870	9.98
Mapanget Barat	2875.8125	10.00
Paniki Bawah	2871.125	9.98
Paniki Dua	2870.75	9.98
Paniki Satu	2869.8125	9.98
Total	28759.25	100

Table 7. Potential Deviation in Mapanget district

Village	Width	%
Bengkol	2076.741792	6.72
Buha	2554.460071	25.15
Kairagi dua	564.7370361	16.83
Kairagi Satu	191.2786733	17.28

Village	Width	%
Kima Atas	88.33682767	7.98
Lapangan	15.42622848	1.39
Mapanget Barat	40.14056662	3.63
Paniki Bawah	164.7194919	14.88
Paniki Dua	40.34546075	3.65
Paniki Satu	27.5685607	2.49
Total	1106.798686	100

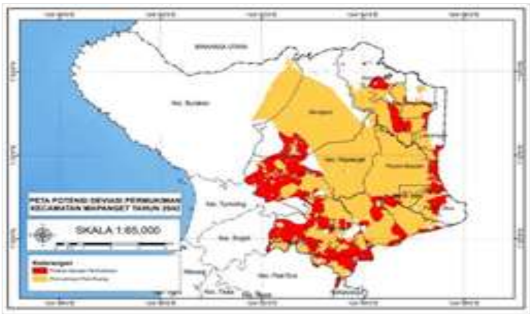


Figure 7. Potential deviation in Mapanget district

The allocation of spatial pattern directions in the future refers to the Manado City spatial pattern plan showing that the residential space allocation in Mapanget district until 2042 is 14948.9732 Ha, however after performing simulations by reviewing population needs it demonstrates that until 2042 the estimated growth of residential buildings to 28759.25 Ha. The results of the study indicate that, of the settlements predicted by the RTRW spatial pattern, Buha Village has the biggest potential departure (25.15%), while field village has the least possible deviation (1.39%). There would be differences in the evolution of spatial patterns in Mapanget district and the RTRW of Manado City based on the analysis's findings. Deviations or nonconformities in development can harm the environment's quality or disturb the land's natural equilibrium. Based on the calculations, the prediction results demonstrate that the existing residential land in Mapanget district in 2042 will already exceed the carrying capacity and capacity of the existing land, to answer this problem it will be recommended to plan vertical buildings, especially for residential areas.

Conclusions

Cellular Automata-based land use change studies in Mapanget district, which were processed with software using ArchMap, QGIS and LanduseSim, revealed that significant changes had occurred. According to the estimate, land use will grow during the next 20 years, from 2022 to 2042, and by 1956, there will be more built-up land, primarily residential buildings.75 Ha or 201% of the total, with 1648.13 Ha of intervening plantation property, 153,813 Ha of empty land, 95,6875 Ha of forest area, 56,1875 Ha of shrub land, and 2,9375 Ha of park land. The AHP hierarchy analysis reveals that the existing settlement factor, with a value of 0.1497, is the highest weight driving land use, while educational facilities have the least weight, at 0.0399. This condition is induced by the proximity to multiple driving factors. Prediction results and spatial pattern plans indicate potential deviations that could occur, with the highest departure happening in Buha Village. These deviations indicate that residential property will be developed outside the 1106.79 Ha spatial pattern plan. The results of this analysis will help the local administration in Mapanget district review and amend its spatial planning guidelines.

Acknowledgements

The author expresses gratitude to Sam Ratulangi University's Institute for research and community service (LPPM) for funding research under the Unsrat superior basic research plan. Additionally, a particular thank you to the academic community and leaders in the Mapanget district, the Manado City Housing and settlement area service, the Mapanget district government, and other stakeholders who participated as respondents in this study. Similarly, thanks to Sam Ratulangi University students studying urban and regional planning who participated in the research area survey process.

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Rieneke Lusia Evani Sela contributed to the research concepts preparation, methodologies, investigations, data analysis, visualization, and revisions.

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