Design and Development of Settlement Spatial Dynamics Model Using Dynamic and Neural Network Systems

S Arif¹, B Harimei², I Alimuddin³, Paharuddin⁴ and Sakka⁵

¹,²,⁴,⁵ Geophysics, Hasanuddin University, Makassar, South Sulawesi, Indonesia
³ Geology Department, Hasanuddin University, Makassar, South Sulawesi, Indonesia

samsu_arif@unhas.ac.id

Abstract. The general objective of this study is to project the distribution of settlement land through the development and application of spatial dynamics models using dynamic system methods and neural networks, while the specific objectives are: 1) Compiling spatial data on land characteristics and evaluating settlement land in Maros Regency; 2) Multitemporal mapping of settlement and non-residential land in 2010, 2016 and 2017; 3) Compile Causal loop diagrams and model simulations to determine the dynamics of population projections and the size of residential land needs until 2038; 4) Synchronizing land requirements with the allocation of space utilization in Maros Regency Spatial Planning. 5) Design and build a spatial model to predict the development and direction of settlement land using change prediction of Artificial Neural Network (ANN); and map the projected spatial distribution model of residential land every 5 (five) years. This research conducted a recent approach to multi-temporal observation and spatial optimization studies by integrating dynamic systems with neural network methods in solving settlement land management problems. The approach with the population growth projection model relates to the spatial dynamics of residential land use using the neural network to facilitate policy makers in decision making for settlement land management. The method used consists of 5 stages: stage I. analysis of land characteristics and land use of multi-temporal settlements, through land surveys, laboratory analysis, and spatial characteristics of land; then the land suitability analysis uses matching method; Phase II: mapping multi-temporal land use in 2010, 2016 and 2017 using analysis and extraction of satellite image information. The image used is Landsat medium resolution satellite imagery; stage III: arranging units and interactions and behaviour between units in a system of population growth dynamics, then making causal loop diagrams and then implementing dynamic software systems to simulate population growth used and residential land needs every five years; stage IV: testing the synchronization of the allocation of space utilization in the Spatial Planning document of the District with the settlement land resulting from the projection; stage V: build a residential land use projection model which begins with change analysis, transition potential, and change prediction with the neural network method; then the projection result of settlement land needs is mapped every 5 years interval from 2018 - 2038 based on the results of the analysis. The implication of the results of the study will provide an overview of the harmony between the pattern of space and the trend of the development direction of the settlement, so that the resulting method can be used as a basis for revising the spatial planning in the future.

Keywords: dynamic systems, neural networks, residential land, natural resource management
1. Introduction

FAO data (2012) shows that the projections of the earth's population will swell rapidly around the next half century, especially in poor and developing countries. In 2011 the total population of the earth was 7 (seven) billion and is projected in 2050 to be 9.1 billion. This phenomenon also occurs in Indonesia, with a population of 254.9 million in 2015 (Central Bureau of Statistics, 2016), projected to increase to close to 400 million by 2050 assuming a population growth rate of 1.48% per year continues.

According to Webster (2002) the phenomenon of random and unplanned urban growth (urban sprawl) occurs in almost all metropolitan cities throughout the world. Although the impact of this phenomenon is very detrimental, most countries have difficulty controlling it. Based on the results of the study (Galent, et al., 2004) it can be seen that the cause of this growth is the emergence of new residential areas as a place to accommodate population growth, housing development, industry and commercial activities.

The land management model, where evaluation of land as a fundamental appraisal device at the conventional method level will experience constraints and limitations of analysis in dealing with very complicated phenomena on land and land use, especially residential land. Land suitability evaluation is very important because each unit of land has different characteristics that are suitable for certain uses (Heacock, et al., 2011; Kliskey, 2000; Marull et al., 2007; Park, et al., 2011; Pourebrahim, et. al., 2011). Data compatibility in the same format and dimensions is difficult to realize, from the aspect of resolution, qualitative and quantitative aspects, as well as aspects of data dimensions. Uncertainty in the results of spatial and non-quantitative distribution models depends on data quality, model quality, and the way data and models interact (Burrough et. Al., 1998). The use of GIS functions in data inventory, data compatibility and standardization, and model development can be done, but that is not enough.

The complexity of residential land management so that a design study is needed on the model of spatial dynamics of planning and use of residential land that involves complex spatial problems with multicriteria by developing integrated models to resolve conflict between agroecological, socio-economic and government policies. Until now there is no standard tool or framework that helps the government to identify strategic land for settlements (Musakwa, et. All, 2017). This is what will be solved in this study by taking a case study in Maros Regency, which can later be applied to other regions in Indonesia. The results of this research are outlined in the form of a spatial model of the distribution of residential land needs by integrating dynamic systems and neural networks.

2. Material and Method

2.1. The Study Site

The study was conducted in Maros Regency which consisted of 14 (fourteen) sub-districts. Geographically located at 4°43’7.8” to 5°12’43.0” South latitude and 119°27’58.4” to 119°58’21.3” East longitude.

![Figure 1. The study site located in “Gowa” (South Sulawesi, Indonesia)](image-url)
2.2. Dataset

The data used in the model consist of GIS vector and raster structure, obtained from various sources with descriptions as shown in Table 1. Since the model works on raster-based data, all vector data are converted to raster. Before being converted to raster data, scale-adjustment is done by involving supporting data (spatial data and field data).

| Theme                  | Source database and (spatial/time) resolution | Type of file | Data used | Parameter (obtained by dataset) | Applied Model | Examples of modul output |
|------------------------|---------------------------------------------|--------------|-----------|---------------------------------|---------------|--------------------------|
| Administrative units   | district boundaries from BIG*               | Vector Polygon | Administrative Boundaries | Area of study | Cliping spatial from database, rasterization | Environmental data within administr. Boundaries slope data in the study |
| DEM                    | 30 x 30 meter from SRTM                     | Grid         | Elevation pixel based | Spatial coordinates, elevation, slope | Cliping spatial from database, rasterization and fuzzyfication | Accessibility using euclidean distance in the study |
| Road                   | Scale 1: 25.000 from BIG*                   | Vector polyline | Road units | proximity to the road | Cliping spatial from database, rasterization | Limiting factor on land suitability index |
| Landosystem            | Scale 1:250.000 From RePPProT               | Vector polygon | units of land maps | base producing parameter maps | Cliping spatial from database, rasterization | Soil data in the study |
| Soil                   | Soil mapping database/1:50.000               | Vector polygon | Main soil, physical parameters | Soil organic matter content, texture data, soil depth, classification and physical parameters | Cliping spatial from database, rasterization | |
| Climate                | 30 x 30 meter Climate mapping from Globalweather | Grid          | Climate observation points | Temperature, Precipitation | Cliping spatial from database, rasterization and fuzzyfication | Climate data in the study |
| RTRW (District Spatial Planning) | Policy Planning From Local Government Maros Scale 1:100.000 | Vector Pologyn | Allocation of space utilization | Spatial pattern | Cliping spatial from database, rasterization | Policy Planning land food |

*BIG (Badan Informasi Geospasial = Geospatial Information Agency)

2.3. Method

This research was carried out in 6 (six) stages on an ongoing basis, namely stage I. Analysis of land characteristics and multi-temporal settlement land use, through land surveys, laboratory analysis, and spatial characteristics of land; then the suitability analysis of residential land uses a matching method; stage II: mapping multi-temporal land use in 2012, 2015 and 2018 using analysis and extraction of satellite image information. The image used is Landsat medium resolution satellite imagery; stage III: compile units and interactions and behavior between units in a system of population growth dynamics, then make causal loop diagrams and then implement in dynamic system software to carry out simulations, simulation results are used as the basis for calculating residential land requirements every five years; stage IV: test the synchronization of space utilization allocations that exist in the Regency Spatial Planning document with the projected settlement land; stage V: build a projected model of residential land use that begins with change analysis, transition potential, and change prediction with the neural network method; the projection of residential land needs projection will be mapped every five-year interval from 2018 - 2038 based on the results of the analysis at stage V.

In stage I, analysis of land characteristics is based on secondary data obtained from various sources, such as: 1) Base map of BIG (Geospatial Information Agency), 2) DEM (Digital Elevation Model) obtained from SRTM data (Shuttle Radar Topography Mission), 3) Carry out mapping of groundwater depth. The settlement land suitability analysis uses using criteria as shown in Table 1. Information extraction methods use an integrated approach in remote sensing, which includes
geometric correction, radiometric correction, making color composite images, supervised classification with the maximum likelihood algorithm, and the ground truth. The multi-temporal classification results were used as earlier land cover images and later land cover images, as well as model validation. Validation of classification results is based on the results of ground truth (see Brown et al., 2005), while model validation is done comparing the results of the model in a given year with the same land cover. DEM data is used to reduce the slope map.

In Phase II, the information extraction method uses an integrated approach in remote sensing, which includes geometric correction, radiometric correction, making color composite images, supervised classification with the maximum likelihood algorithm, and the ground truth. The multi-temporal classification results were used as earlier land cover images and later land cover images, as well as model validation. Validation of classification results is based on the results of ground truth (see Brown et al., 2005), while model validation is done comparing the results of the model in 2018 with the same land cover, if validation is above 80%.

In Phase III, Identify the units involved in the system under study, such as: Number of population, fertility, mortality, per capita land needs, land area built, land availability, pace of development. Each unit that builds the system will be examined for interactions and behavior between units, based on these things then made causal loop diagrams to illustrate the interrelationships between units. Next is a simulation using a dynamic system software.

In Phase IV, Calculate the area of residential space allocation that is on the spatial planning document to see the adequacy of land for the next 20 years as mandated by the Act. No. 26 of 2007 Spatial Planning. If the allocation of space for settlements is insufficient, the results of the land evaluation conducted in the case of I. are used.

In Phase V, modelling and projection with stages: change analysis, transition potential, and change prediction. In the change analysis phase, the 2010 land use map was used as an earlier land cover image and the 2016 land use map was used as a land cover image. The stages of change analysis will produce change classes called dependent variables. The transition potential stage aims to predict locations that have the potential to experience changes in land use. The making of land use projections is carried out in the change prediction stage. In the change prediction stage, a neural network algorithm is used. At this stage filtering can be carried out on land that has a high conformity index based on the area of land needed in the given year. Thus the distribution of residential land needs every five years can be mapped.

The five stages are the main components of research, as shown in the fish bone diagram (Figure 2).

---

**Figure 2.** Fish bone diagram regarding the outline of the research activity.
3. Results and Discussion

3.1. Settlement Land Suitability Analysis

The results of the analysis used a map of land characteristics as a parameter in the suitability assessment of residential land using the Overlay Union analysis method to obtain 2 (two) types of residential land suitability classes, including the corresponding class (S) and class Not Corresponding (N) can be seen in Figure 3. The map is a settlement land suitability map, where there are 2 suitability classes, namely the corresponding class is represented in dark blue and the inappropriate class is represented by orange. On the map, there are several sub-districts that have suitable classes and some sub-districts are in the wrong class. Based on the calculation of the land area for settlement land suitability as in Table 2, where the Tanralili Subdistrict which includes the First class has an area of 15,382 Ha and Mallawa Subdistrict has an appropriate land area of only 792 Ha, while the Non-Matching class has the highest land area in Mallawa Subdistrict amounting to 21,805 ha and the Turikale District area having the lowest land area of 174 ha.

![Figure 3. Settlement Land Suitability Map](image)

| No. | Sub-district | According to Settlements (Ha) | Not according to settlement (Ha) |
|-----|-------------|-------------------------------|---------------------------------|
| 1   | Bantimurung | 6.714                          | 8.582                           |
| 2   | Bontoa      | 4.554                          | 1.832                           |
| 3   | Camba       | 2.942                          | 11.567                          |
| 4   | Cenrana     | 6.086                          | 12.688                          |
| 5   | Lau         | 3.374                          | 765                             |
| 6   | Mallawa     | 792                            | 21.805                          |
| 7   | Mandai      | 3.848                          | 80.88                           |
| 8   | Maros Baru  | 3.333                          | 921                             |
| 9   | Marusu      | 3.484                          | 884                             |
| 10  | Moncongloe  | 3.839                          | 335                             |
| 11  | Simbang     | 6.237                          | 2.827                           |
| 12  | Tanralili   | 15.382                         | 817                             |
| 13  | Tompobulu   | 13.174                         | 15.146                          |
| 14  | Turikale    | 2.271                          | 174                             |
|     | Total       | **76.037**                     | **78.428**                      |

*Table 2. Extent of settlement land area (ha) according to District in Maros Regency*

*Source: Analysis and calculation results (2018)*
3.2. Approach to Using A Dynamic System

The system approach in this study is used to calculate the amount of population growth from 2018 to 2033. Based on the dynamics of population growth, the next step is to calculate the space requirements for settlements. If the population growth rate in Maros Regency is 1.58%, the total population growth based on the simulation uses a dynamic system as shown in Table 3.

### Table 3. Projected population growth from 2018 – 2033

| No | Years | Total Population | Area of Land Requirement (Ha) |
|----|-------|------------------|------------------------------|
| 1  | 2018  | 342.890          | 4.560                        |
| 2  | 2023  | 370.847          | 4.932                        |
| 3  | 2028  | 401.085          | 5.334                        |
| 4  | 2033  | 433.788          | 5.769                        |

3.3. Maros Regency Spatial Planning

The plan for the regional spatial pattern of Maros Regency is a spatial distribution plan within the district that includes a plan for spatial allocation for protected functions and a spatial designation plan for the cultivation function.

In this study, it was directed at synchronizing residential areas until 2032, based on the area per sub-district as shown in Table 3 dan Table 4.

Based on the settlement land suitability analysis, the area of settlements allocated in the Spatial Planning is still within the area suitable for settlement. All sub-districts in Maros Regency have land according to settlements that is larger than the allocation in the spatial planning.

3.4. Land Use Prediction Model Using a Neural Network

Detection of changes in land cover is done to get information about the transition or changes that occur in two different time vulnerable. In this study, change detection was grouped into two periods, namely 2012-2015 and 2015-2018. Overlap is done on each map, and cross tabulation (crosstab) is done to see the pattern of land cover changes that occur.

The projection of land change results in a land cover model can be seen in Table 5. Simulated land cover change is a 2012 and 2015 land cover map as a base map (initial input) in the Artificial Neural Network module to predict land cover models in 2023, 2028 and 2033 for the study area. This land cover model is validated based on the 2018 land cover map. Validation is carried out to see the suitability between the land cover model and the 2018 land cover map.

### Table 4. Areas allocated for settlement land in spatial planning document

| No | Sub-district | Spatial Planning Settlements (Ha) | According to Settlements (Ha) |
|----|--------------|----------------------------------|------------------------------|
| 1  | Bantimurung  | 392                              | 6.714                        |
| 2  | Bontoa       | 59                               | 4.554                        |
| 3  | Camba        | 363                              | 2.942                        |
| 4  | Cenrana      | 206                              | 6.086                        |
| 5  | Lau          | 247                              | 3.374                        |
| 6  | Mallawa      | 165                              | 792                          |
| 7  | Mandai       | 516                              | 3.848                        |
| 8  | Maros Baru   | 218                              | 3.333                        |
| 9  | Marusu       | 306                              | 3.484                        |
| 10 | Moncongloe   | 115                              | 3.839                        |
| 11 | Simbang      | 257                              | 6.237                        |
| 12 | Tanraliți    | 420                              | 15.382                       |
| 13 | Tompobu      | 79                               | 13.174                       |
| 14 | Turikale     | 488                              | 2.271                        |
| **Total** |                  | **3.831**                        | **76.030**                   |
Table 5. Extensive land change year 2018-2033

| Land Cover       | Areas (Ha) |
|------------------|------------|
|                  | 2018       | 2023       | 2028       | 2033       |
| Forest           | 54.841     | 54.353     | 53.970     | 53.590     |
| others           | 267        | 268        | 267        | 267        |
| Agriculture      | 80.480     | 79.704     | 78.356     | 76.984     |
| Settlement       | 7.494      | 8.821      | 10.544     | 12.288     |
| Body of water    | 1.243      | 1.243      | 1.243      | 1.243      |

4. Conclusion

Based on the results of the research obtained, it can be concluded that the prediction of changes in residential land can be done by using a spatial dynamics model using dynamic system and neural network methods, and providing good results, especially in urban areas. The results showed an accuracy of 80.51% in urban areas and around 62.71% if averaged for rural areas.

Evaluation of residential land for the study area obtained suitable land suitability of 76,037 ha and 78,428 which were not suitable. The results obtained based on spatial analysis with parameters: slope, proximity to the road, rainfall, coastal boundaries, river boundaries, flood vulnerability.

Mapping of residential and non-residential land with multi-temporal data shows that settlement land has increased over time. Settlement area in 2012 amounted to 5,469 Ha, in 2015 amounted to 6,721 Ha, and in 2018 amounted to 7,494 Ha.

The simulation results with dynamic systems predict that the population needs of 2033 are 5,769 Ha.

Based on the allocation of space utilization in the Maros Regency RTRW of 3,831 Ha, while the results of the projections for residential land requirements in 2033 with facilities and infrastructure are 5,769 Ha. Thus it is necessary to revise the RTRW document in connection with the allocation of space utilization for settlements.

5. References

[1] Ahmed, B. and Ahmed, R. 2012. Modeling urban land cover growth dynamics using multi-temporal satellite images: a case study of Dhaka, Bangladesh. ISPRS International Journal of Geo-Information, 1: 3-31 Arif, S. 2016. A Spatial Decision Support System for Agricultural Land Management in Maros Region, Indonesia, International Journal of Information Engineering and Applications, Vol. 5 No.7 Edisi Juli 2015.

[2] Arsanjani, J.J., Helbich, M., Kainz, W., and Darvishi, A. 2013. Integration of logistic regression, Markov chain and cellular automata models to simulate urban expansion - the case of Tehran. International Journal of Applied Earth Observation and Geoinformation, 21: 265-275.

[3] Baja, S., Mustafa, M., and Arif, S. 2011. Spatial dynamic of land use/land cover in South Sulawesi Province, Indonesia. Asia Geospatial Forum: 10th Annual Asian Conference & Exhibition on Geospatial Information, Technology, and Applications, Jakarta, 17-19 October.

[4] Baja, S., Nurmiati, and Samsu Arif. 2014. GIS-Based Soil Erosion Modeling for Assessing Land Suitability in the Urban Watershed of Tallo River, South Sulawesi, Indonesia. Modern Applied Science, 8: 50-60.

[5] Balai Penelitian Tanah dan Agroklimat. 2001. Petunjuk Teknis Penyusunan Peta Pewilayahan Komoditas Pertanian Berdasarkan Zona Agro Ekologi (ZAE) Skala 1 : 50.000. Pusat Penelitian Tanah dan Agroklimat, Balitbang Pertanian, Deptan, Bogor.

[6] Burrough, P.A., 1994. Principles of Geographical Information System for Land Resource Assesement, Oxford University Press Inc., New York.

[7] Heacock, E., & Hollander, J. (2011). A grounded theory approach to development suitability analysis. Landscape and Urban Planning, 100(1–2), 109–116. http://dx.doi.org/10.1016/j.landurbplan.2010.12.001.
[8] Kliskey, A. D. (2000). Recreation terrain suitability mapping: A spatially explicit methodology for determining recreation potential for resource use assessment. Landscape and Urban Planning, 52(1), 33–43. http://dx.doi.org/10.1016/S0169-2046(00)00111-0.

[9] Koomen, E., Stilwell, J., Bakema, A., and Scholten, H.J. 2007. Modelling Land Use-Change. The Geojournal Library, Springer, America.

[10] Lillesand, T.M. and Kiefer, R.W. 1994. Remote Sensing and Image Interpretation. 3rd Edition. John Wiley & Sons, New York.

[11] Maleczewski, J. (2006b). GIS-based multicriteria decision analysis: A survey of the literature. International Journal of Geographical Information Science, 20(7), 703–726.

[12] Marull, J., Pino, J., Mallarach, J. M., & Cordobilla, M. J. (2007). A land suitability index for strategic environmental assessment in metropolitan areas. Landscape and Urban Planning, 81(3), 200–212. http://dx.doi.org/10.1016/j.landurbplan.2006.11.005.

[13] Moghadam, H.S. and Helbich, M. 2013. Spatiotemporal urbanization processes in The Megacity of Mumbai, India: A Markov ChainsCellular Automata Urban Growth Model. Applied Geography (Elsevier) 40: 140-149.

[14] Nurmiaty and Baja, S. 2014. Using Fuzzy Set Approaches in a Raster GIS for Land Suitability Assessment at a Regional Scale: Case Study in Maros Region, Indonesia. Modern Applied Science; 8: 115-125.

[15] Nurmiaty, and Baja, S. 2013. Spatial Based Assessment of Land Suitability and Availability for Maize (Zea mays L.) Development in Maros Region, South Sulawesi, Indonesia. Open Journal of Soil Science, 3: 244-251.

[16] Park, S., Jeon, S., Kim, S., & Choi, C. (2011). Prediction and comparison of urban growth by land suitability index mapping using GIS and RS in South Korea. Landscape and Urban Planning, 99(2), 104–114. http://dx.doi.org/ 10.1016/ j.landurbplan. 2010.09.001.

[17] Pourebrahim, S., Hadipour, M., & Bin Mokhtar, M. (2011). Integration of spatial suitability analysis for land use planning in coastal areas; case of Kuala Langat District, Selangor, Malaysia. Landscape and Urban Planning, 101(1), 84–97. http://dx.doi.org/10.1016/j. landurbplan.2011.01.007.

[18] Puertas, O. L., Henríquez, C., & Meza, F. J. (2014). Assessing spatial dynamics of urban growth using an integrated land use model. Application in Santiago metropolitan area, 2010–2045. Land Use Policy. 38(0), 415–425. http://dx.doi.org/10.1016/j.landusepol.2013.11.024.

[19] Webster, D. (2002). On the Edge: Shaping the Future of Peri-urban East Asia. Stanford University. Stanford.

Acknowledgements
We would like to thank Research and Community Service Centre of Hasanudin University, Ministry of National Education, the Republic of Indonesia through the Internal grant Hasanudin University and Regional Research and Development Center, Spatial Planning and Spatial Information Hasanuddin University in cooperation with the Government of Maros Regency.