Using Geographic Information System Technology for Land-Use Modelling on Developing area of Tanah Datar Sumatera Barat

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Abstract **– GIS technology has advanced rapidly in recent decades to become a standard tool for managing and analyzing spatial data to solve spatial problems. Spatial modelling is one of the GIS products that can be used as a reference for future policy development for effective spatial management. This research aims to create land use models for the Tanah Datar area of West Sumatra in 2025 and 2035. The model is created using the Cellular Automata method and remote sensing data. The land use data from 1989 and 2002 became the model's base year, and 2019 served as the basis for testing the model's accuracy. According to the modelling results, there are several trends in land use change. Dryland agriculture expanded significantly, indicating an improvement in the pattern of agricultural land use. This condition suggests that regional development should focus more on potential and good spatial management.**

Keywords **–Spatial Data, GIS, Land Use, Cellular Automata, Spatial Modeling**

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1. Introduction

The management of spatial data for rural and urban areas has now developed and led to the use of geographic information systems (GIS) as one of the standard tools [12]. Methods of using GIS in solving spatial problems have become things that continue to be discovered even though GIS technology has been developing for more than 60 years [25]. The continuous technological development and the progressive electronization of more and more areas of social and economic life undoubtedly influence the development of GIS technology applications [25].

Remote sensing and GIS-based analysis methods are fast, practical, and accurate, particularly in the thematic spatial analysis [8]. Changes in land use and land cover are one of the focal points of the spatial analysis, which is critical to understanding environmental change, particularly in terms of change speed, driving factors, and consequences, all of which significantly impact national and regional policies [16]. Land use and land cover changes are directly related to spatial planning, food security, and rural and urban development [22] [21]. In developing countries, the use of green spaces is increasing as built-up areas become uncontrollable due to a lack of good spatial planning [17] and tends to encourage land conversion for various sectors, both agricultural and non-agricultural (industry, infrastructure, and settlements) [10].

Land use and land cover information in the form of statistical data and maps are essential for spatial planning and management [6]. The growing demand for information on land use and land cover emphasizes the importance of using appropriate methods for projecting future land use and land cover as a policy basis [1]. Remote sensing and geographic

information system (GIS) research focuses on developing technical methods for extracting information about land use change. Satellite imagery is now publicly available and accessible to the public, thanks to advancements in remote sensing technology and GIS, making it easier for stakeholders to obtain critical information for understanding the landscape and carrying out spatial planning [15]. Information on land use change on a spatiotemporal basis is also useful in understanding future trends in land use change. With this data, stakeholders can assess past management and forecast the future impact of current management on land [23].

Modeling in GIS can be defined as an operation that processes spatial data at one time or within a specific period of time to produce spatial information, even for the prediction of future conditions using specific parameters and can assess various scenarios based on data obtained from multiple data sources data [21]. Land-use change understanding is often studied and gained through the modelling process which is an empirical analysis of changes in land cover or land use patterns [3]. Cellular Automata (CA) based models are generally prediction or simulation-oriented [18]. Fuzzy logic, like the Spatial Multi-Criteria Evaluation model, can be applied as a method in the decision-making process (Spatial Decision Support System) in regional planning using a simulation model with several criteria and factors [5]. In this regard, it is necessary to provide geospatial information on land resources which includes information about the growing conditions for coffee commodities and the dynamics of future land use, especially in studying the development pattern of coffee plantations. Remote sensing and geographic information systems (GIS) are powerful tools for obtaining accurate and timely information about the spatial distribution of land use or land cover changes over a large area [2].

In Tanah Datar, West Sumatra, there has been very little research on land use change, particularly on future land cover modelling. Land use research is solely concerned with land use change and its impact on villagers [19]. This study analyses land use in Tanah Datar using GIS and spatiotemporal land use data to predict future land use, which will be useful as a basis for stakeholders' policymaking information.

2. Methods

This research was conducted using the Cellular Automata method based on remote sensing and geographic information systems, generally carried out by processing raster-based spatial data.

a. Study Area

The research was conducted in Tanah Datar Regency, Sumatera Barat Province (Figure 1). The Tanah Datar Regency covers 133,600 Ha. The 374,431 inhabitants of Tanah Datar Regency cover 14 sub-districts that make up the entire population in 2021. More than 70% of the people of Tanah Datar Regency work in agriculture, including food crop agriculture, plantations, fisheries, and animal husbandry [4].

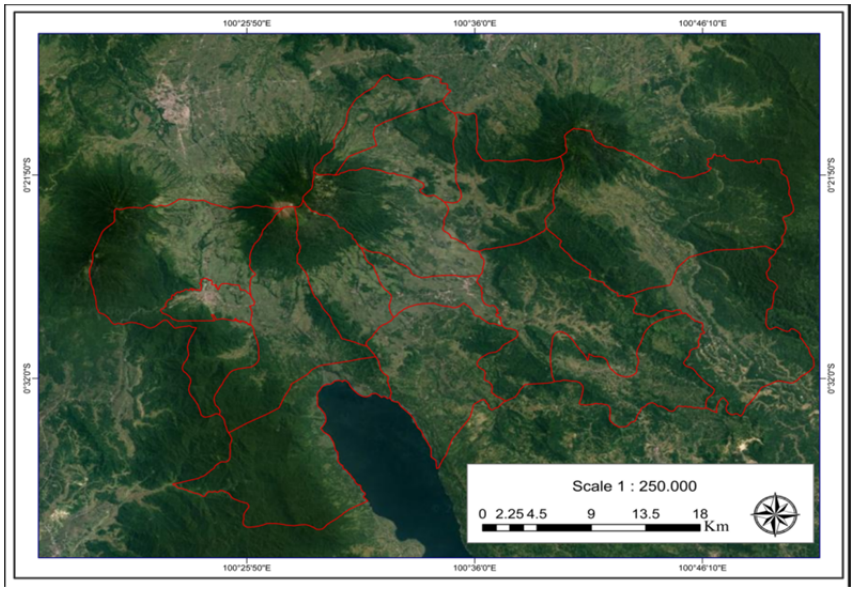


Figure 1. The location of the research area

Geographically, Tanah Datar Regency is located around the foothill of Mount Merapi, Mount Singgalang, and Mount Sago, and is also enriched by 25 rivers. Lake Singkarak, which is quite wide, is part of the Tanah Datar Regency area, which is located in South Batipuh and Rambatan Districts [4].

b. Materials

In this study, the Tanah Datar region of West Sumatra was covered by multispectral and multitemporal Landsat imagery from 1989, 2002, and 2019. The USGS offers free access to open-source Landsat images that are available for download. The 1989 Landsat image is an image from the Landsat 5 Multispectral Scanner (MMS) satellite which has a spatial resolution of 60 m [26], the 2002 image is the Landsat Enhanced Thematic Mapper image, and the 2019 image is the Landsat 8 OLI image [13]. The images were selected carefully by avoiding cloud cover in the research area's image to maintain the analysis's quality and accuracy.

c. Data Preparation and Analysis

Using Arcmap, ENVI, and IDRISI software, Landsat images are processed in three stages: preprocessing, processing, and postprocessing. The bands in the image are composited during the preprocessing stage, and then a clipping method is used to constrict the research area. Additionally, geometric and atmospheric corrections are made before land use is classified using the supervised image classification approach and the maximum likelihood technique. Images from 1989 and 2002 are overlaid to show how land use has changed. Furthermore, for the accuracy of interpretation, data on land usage in 2019 is utilized as a reference.

Land use change data is further processed using Markov's cellular automata model to provide land use modelling in 2025 and 2035. CA- Markov is a great method for creating land use prediction models because it uses input data on the spatial element distribution to produce future land use distributions and transitions [20]. Based on input data on land use changes between 1989 and 2002, this analysis predicts how land will be used in 2025 and 2035. By contrasting them to land use in 2019, it is possible to validate the land use models for 2025 and 2035. The test is performed using the Kappa Index to assess model accuracy. In remote sensing, image interpretation requires an accuracy test[7]. The classification algorithm's accuracy and validity are evaluated using the Kappa method. The accuracy of land cover mapping is primarily represented by the kappa coefficient value [27].

3. Result and Discussion

The cellular automata method is used to process raster data containing information on the geographical appearance of the research area. Data processing generates information about future land use changes and forecasting.

a. Landuse Change Analysis

From the results of the classification of Landsat images, the type of land cover and area in Tanah Datar Regency is obtained as shown in table 1 and the distribution of land use in the year of observation is presented in figures 3 and 4. The most dominant land cover types in Tanah Datar Regency were croplands at 38.44 per cent and primary forest at 28.40 per cent. The rest, under 10 per cent of the total area, is sequentially dominated by secondary forest, scrub, dry land agriculture, wetland agriculture, built-up area, open land, and grass. The comparation of landuse between each observed year is presented in Figure 2.

Table 1. Landsat image classification results

No	Land Use	1989 (Ha)	2002 (Ha)	2019 (Ha)	Percent	% Change (1989-2019)
1	Forest Primary	39,747.15	36,984.96	36,980.82	28.40	-6.96
2	Secondary forest	14,148.54	12,823.20	12,680.10	9.74	-10.38
3	Cropland	44,542.98	45,839.34	50,054.40	38.44	12.37
4	Dryland Agriculture	6,906.87	9,519.03	9,576.00	7.35	38.64
5	Wetland Agriculture	7,539.21	7,126.38	7,184.52	5.52	-4.70
6	Shrubs	14,085.54	14,247.00	10,407.96	7.99	-26.11
7	Grass	904.41	904.41	538.38	0.41	-40.47
8	Open ground	1,092.33	1,112.13	806.40	0.62	-26.18
9	Built up area	675.90	1,086.48	1,322.10	1.02	95.61
10	Waters	557.10	557.10	649.35	0.50	16.56
	Total	130,200.03	130,200.03	130,200.03	100.00	

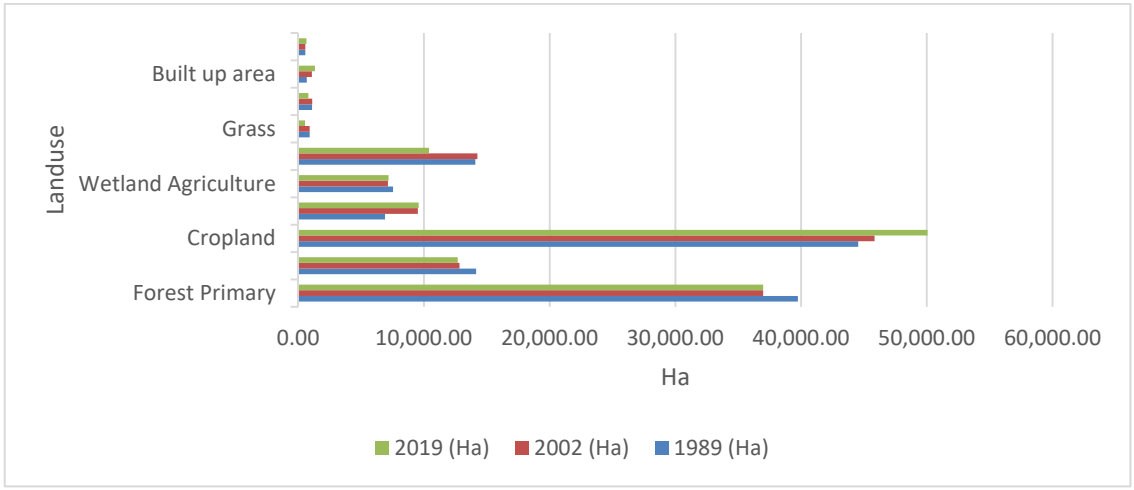
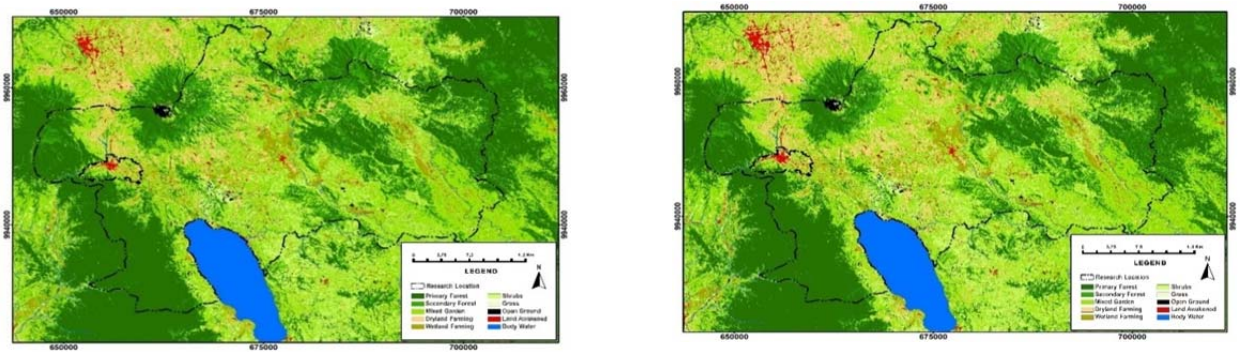


Figure 2. Landuse in Tanah Datar

From 1989 to 2019, a significant change in land cover occurred in the type of built-up area cover, which had increased by 95.61% over the last 30 years. Meanwhile, secondary forests decreased by 10.38%. Basically, the observation of land use in a certain period will provide information about the conversion of land from one use to a certain use. In general, in the period between 1989-2019, land use that changed functions in Tanah Datar Regency was non-productive land, including shrubs (- 40.47 per cent), open land (26.18%), shrubs (26 1.11%) and secondary forest (10.38%) which turned into productive land, including built-up land (95.61%), dry land agriculture (38.64%), and plantations (12.37%).



(a) *(b)*

Figure 3. Land cover map in 1989 (a) Land cover map in 2002 (b)

b. Land cover prediction and validation

Before making a prediction model for the required years, the prediction results must be tested for their accuracy using land use extracted directly from the image, namely 2019 (Fig. 4), by making predictions for 2019 first.

As a model, the resulting Kappa value can show the proportion of the similarity between predicted land uses and factual land uses [24]. The strength of the prediction results can be said to be strong when obtaining a Kappa value above 85%. The calculation was carried out in this study, the Kappa value obtained was 92,20%.

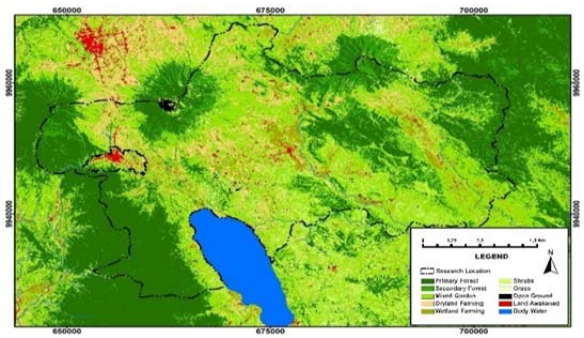


Figure 4. Land cover map in 2019

The land cover maps that have been classified will be compared based on differences in years. The land cover of 1989 and 2002 will be the main reference in looking at land use change. The detection of changes in land cover between the two years is calculated through an overlay technique that can show the difference in the area of each type of land use.

The two series of years are the basis for predicting future land use, where the needs of land use development trends will be analyzed with economic growth and the contribution of pollutants.

Table 2. Land Area Change in 2020-2025

No	Land Use	2020 (Ha)	2025 (Ha)	% Change (1989-2019)
1	Waters	587	586	-1
2	Secondary forest	9256	8638	-618
3	Wetland farming	6972	6890	-82
4	Shrubs	14106	14178	72
5	Open ground	1038	1038	0
6	Forest primary	37579	37575	-4
7	Dryland farming	20290	23121	2831
8	Cropland	39627	37357	-2270
9	Land awakened	1256	1331	75
10	Grass	872	869	-3
Total		130,200.03	130,200.03	

From 2020 to 2025, land use in the Tanah Datar area changed dramatically. Table 4 demonstrates that there has been a shift in the location of each type of landuse According to the classification results, cropland land use with an area of 39627 Ha is the most dominant land use in 2020, while forest primary land use with an area of 37575 is the most dominant land use in 2025. Water, secondary forest, wetland farming, forest fimary, cropland, and grass are examples of land uses that have reduced land area. Meanwhile, shrubs, dryland, and land awakened experienced an increase in land area. Despite a 4% decrease in land area from 2020, forest primary land use will remain dominant in 2025. Dryland land use has experienced a relatively large change in land area from 2020 to 2025, increasing land area by 2831 Ha, whereas Cropland land has experienced a relatively large decrease in land area from 2020 to 2025, decreasing by 2270 Ha.

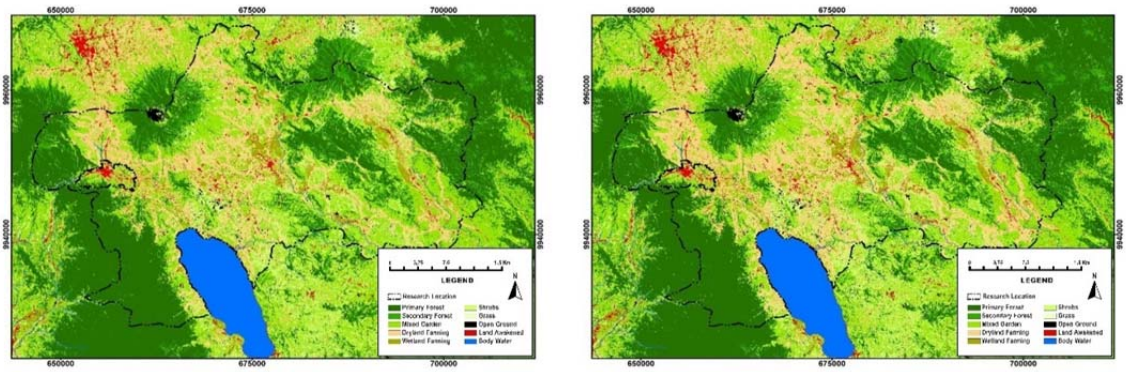
For land use prediction in 2025 and 2035 (Table 5), forest primary land use has a land area of 37575 Ha in 2025 and 37582 Ha in 2035. Secondary forest, wetland farming, cropland, and grass are examples of land uses that have reduced land area. Meanwhile, land uses with increased land area included water, shrubs, primary forest, dryland, and land awakened. Dryland land use experienced a fairly large change in land area, increasing by 5070 Ha from 2025 to 2035, while cropland land use decreased by 4483 Ha from 2025 to 2035

Table 3. Land area change in 2025-2035

Land Use	2025	2035	Landuse Change (Ha)
Waters	586	587	1
Secondary forest	8638	7919	-719
Wetland farming	6890	6666	-224
Shrubs	14178	14322	144
Open ground	1038	1038	0
Forest primary	37575	37582	7
Dryland farming	23121	28191	5070
Cropland	37357	32874	-4483
Land awakened	1331	1541	210
Grass	869	863	-6
Total			

From the prediction results, information was obtained that the area of land cover in Tanah Datar District experienced several trends, especially in several types of land cover such as secondary forest, croplands, dry land agriculture, and urban area. The primary forest has undergone a slight change that does not cover the 1000 ha figure in 5 years.

This is different from the secondary forest which decreases by up to 500 hectares for 5 years and croplands up to 2000 hectares per five years. Another type of land cover that has decreased is wetland agriculture, which has decreased by about 200 hectares over 5 years. The graph of the predicted land cover change can be seen in figure 5a and figure 5b.



(a) (b)

Figure 5. Land cover prediction map in 2025 (a) and Land cover prediction map in 2035 (b)

Dry land agriculture is predicted to increase significantly from 2020 to 2035. This is because agriculture is one of the sectors that contribute to Indonesian trade [14]. This increase is accompanied by a decrease in croplands, which indicates that the agricultural pattern in Tanah Datar Regency is getting better, from poorly managed croplands to dry land farming which is relatively filled with similar crops and is taken care of either in the form of cropland or paddy fields. Wetland agriculture tends to decline slightly, most of which is predicted to turn into settlements or urban areas.

Tanah Datar regency has a total area of 130,200.03 Ha. The result of Landsat image classification has obtained the type of land cover and its area in Tanah Datar Regency. The most dominant types of land cover in Tanah Datar Regency are croplands at 38.44 percent and primary forests at 28.40 per cent. The rest, under 10 percent of the total area, is sequentially dominated by secondary forests, shrubs, dryland farms, wetland farms, urban area/settlement, open land, and grass. Over the period from 1989 to 2019 there was a very significant change in land cover occurring in the type of land cover that has increased by 95.61% over the last 30 years. Secondary forests were reduced by 10.38%. determining the change in land cover from the classification of imagery that the land cover class has obtained based on that period, 3 main variables encourage changes in land use: variable slopes, distance, from the river, and distance from the road. The change from agricultural land to built-up areas was facilitated by an extensive road network and the development of major public projects such as international airports, railway stations, and toll road intersections [11].

The results of the prediction were obtained information that the area of land cover in Tanah Datar. Regency experienced several trends, especially in land cover types such as secondary forests, croplands, dryland farms, and built-up areas. Primary forests have experienced an insufficient 1,000 ha of change in 5 years. In contrast, secondary forests are reduced to 500 hectares over 5 years and croplands up to 2000 hectares per five years. Another type of land cover that has decreased is wetland farming which decreased by about 200 hectares over 5 years.

Changes in land use as a result of anthropogenic processes in the Tanah Datar area are the result of changes in human resource needs in that location and can be modeled using geographic information system-based technology. Because of its accuracy, land use modeling based on cellular automata is appropriate for displaying and simulating spatial processes on spatial policies [9]. It is also an effective method for explaining and estimating land use change, and it has proven to be one of the most useful methods for land use policy formulation.

4. Conclusion

Land cover/ landuse in Tanah Datar Regency in the 1989-2019 period shows that the land cover/landuses class experienced significant land cover changes occurring in the built-in type of cover which has increased 95.61% over the last 30 years. The prediction results showed that the area of land cover in Tanah Datar District experienced several trends, especially in several types of land cover such as secondary forest, croplands, dry land agriculture, and urban areas. Dryland farming is predicted to increase significantly from 2020 to 2035. This increase was accompanied by a decrease in croplands indicating the improvement of agricultural patterns in the District of Tanah Datar from poorly managed croplands to dry land farms that are relatively filled with similar crops and well managed in the form of gardens and fields.

References

[1]. Ahmad, F., Goparaju, L., & Qayum, A. (2017). LULC analysis of urban spaces using Markov chain predictive model at Ranchi in India. *Spatial Information Research*, *25*(3), 351-359. https://doi.org/10.1007/s41324-017-0102-x

[2]. Aspinall, R. (2004). Modelling land use change with generalized linear models—a multi-model analysis of change between 1860 and 2000 in Gallatin Valley, Montana. *Journal of environmental management*, *72*(1-2), 91-103. https://doi.org/10.1016/j.jenvman.2004.02.009

[3]. Hafif, B., Prastowo, B., & Prawiradiputra, B. R. (2014). Pengembangan perkebunan kopi berbasis inovasi di lahan kering masam. *Pengembangan Inovasi Pertanian*, *7*(4), 199-206.

[4]. BPS. (2022). Provinsi Sumatera Barat Dalam Angka. *Unduh Publikasi, Indonesia.*

[5]. Chen, J. (2014). GIS-based multi-criteria analysis for land use suitability assessment in City of Regina. *Environmental Systems Research*, *3*(1), 1-10. https://doi.org/10.1186/2193-2697-3-13

[6]. Chinnasamy, P., Misra, G., Shah, T., Maheshwari, B., & Prathapar, S. (2015). Evaluating the effectiveness of water infrastructures for increasing groundwater recharge and agricultural production–A case study of Gujarat, India. *Agricultural Water Management*, *158*, 179-188. https://doi.org/10.1016/j.agwat.2015.05.009

[7]. Chowdhury, M. S., & Hafsa, B. (2022). Multi-decadal Land Cover Change Analysis over Sundarbans Mangrove Forest of Bangladesh: A GIS and Remote Sensing Based Approach. *Global Ecology and Conservation*, 37. https://doi.org/10.1016/j.gecco.2022.e02151

[8]. Erdem, F., Atun, R., Avdan, Z. Y., Atila, I., & Avdan, U. (2021). Drought analysis of Van Lake Basin with remote sensing and GIS technologies. *The Egyptian Journal of Remote Sensing and Space Science*, *24*(3), 1093-1102. https://doi.org/10.1016/j.ejrs.2021.10.006

[9]. Gharbia, S. S., Alfatah, S. A., Gill, L., Johnston, P., & Pilla, F. (2016). Land use scenarios and projections simulation using an integrated GIS cellular automata algorithms. *Modeling earth systems and environment*, *2*(3), 1-20. https://doi.org/10.1007/s40808-016-0210-y

[10]. Hidayah, S., Nofialdi, N., & Ifdal, I. (2019). Analisis Risiko Produksi Kopi Robusta Di Jorong Pincuran Tujuah, Nagari Batipuh Baruah, Kecamatan Batipuh, Kabupaten Tanah Datar. *JOSETA: Journal of Socio-economics on Tropical Agriculture*, *1*(2). https://doi.org/10.25077/joseta.v1i2.149

[11]. Huang, S. L., Wang, S. H., & Budd, W. W. (2009). Sprawl in Taipei's peri-urban zone: Responses to spatial planning and implications for adapting global environmental change. *Landscape and urban planning*, *90*(1-2), 20-32. https://doi.org/10.1016/j.landurbplan.2008.10.010

[12]. ICMA, & ESRI. (2018l). A guide for Smart Communities: Using GIS Technology for Local Government Management. Retrieved from: https://www.esri.com/en-us/landing-page/industry/government/2018/icma-smart-communities [accessed:10 August 2022].

[13]. Ihlen, V. (2019). *Landsat 8, Data User Handbook.* Landsat Missions.

[14]. Jailani HY, Nofialdi, & Zulvera. (2019n). Analysis of Factors Affecting Coffee Farmer Behavior in Tanah Datar District. *International Journal of Sciences: Basic and Applied Research (IJSBAR)*, *48*(3), 278-290

[15]. Kaliraj, S., Chandrasekar, N., Ramachandran, K. K., Srinivas, Y., & Saravanan, S. (2017). Coastal landuse and land cover change and transformations of Kanyakumari coast, India using remote sensing and GIS. The Egyptian Journal of Remote Sensing and Space Science, 20(2), 169-185. https://doi.org/10.1016/j.ejrs.2017.04.003

[16]. Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., ... & Xu, J. (2001). The causes of land-use and land-cover change: moving beyond the myths. Global environmental change, 11(4), 261-269. https://doi.org/10.1016/S0959-3780(01)00007-3

[17]. Lee, D., & Choe, H. (2011). Estimating the impacts of urban expansion on landscape ecology: Forestland perspective in the greater Seoul metropolitan area. J. Urban Plan. Dev.(ASCE), 137, 425-437. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000090

[18]. Mulyani, A., Ritung, S., & Las, I. (2011). Potensi dan ketersediaan sumber daya lahan untuk mendukung ketahanan pangan. Jurnal Litbang Pertanian, 30(2), 73-80.

[19]. Mutiara, V. I., Febriamansyah, R., Hariance, R., & Utami, A. S. (2020, October). Farmers' resilience towards land use change case study in Padang City, West Sumatra, Indonesia. In IOP Conference Series: Earth and Environmental Science (Vol. 583, No. 1, p. 012014). IOP Publishing. https://doi.org/10.1088/1755-1315/583/1/012014

[20]. Mwabumba, M., Yadav, B. K., Rwiza, M. J., Larbi, I., & Twisa, S. (2022). Analysis of land use and land-cover pattern to monitor dynamics of Ngorongoro world heritage site (Tanzania) using hybrid cellular automata-Markov model. Current Research in Environmental Sustainability, 4, 100126. https://doi.org/10.1016/j.crsust.2022.100126

[21]. Paegelow, M., Camacho Olmedo, M. T., Mas, J. F., Houet, T., & Pontius Jr, R. G. (2013). Land change modelling: moving beyond projections. International Journal of Geographical Information Science, 27(9), 1691-1695. https://doi.org/10.1080/13658816.2013.819104

[22]. Paegelow, M., & Olmedo, M. T. C. (2008). Modelling environmental dynamics. Berlin Heidelberg: Springer. https://doi.org/10.1007/978-3-540-68498-5

[23]. Srivastava, A., & Chinnasamy, P. (2021). Investigating impact of land-use and land cover changes on hydro-ecological balance using GIS: insights from IIT Bombay, India. SN Applied Sciences, 3(3), 1-19. https://doi.org/10.1007/s42452-021-04328-7

[24]. Tewolde, M. G., & Cabral, P. (2011). Urban sprawl analysis and modeling in Asmara, Eritrea. *Remote Sensing*, *3*(10), 2148-2165. https://doi.org/10.3390/rs3102148

[25]. Turek, T., & Stępniak, C. (2021). Areas of Integration of GIS Technology and Smart City Tools. Research findings. *Procedia Computer Science*, *192*, 4681-4690. https://doi.org/10.1016/j.procs.2021.09.246

[26]. USGS. (1997). Landsat Data, A Brief History of the Landsat Program. Retrieved from: https://pubs.usgs.gov/fs/1997/0084/report.pdf [accessed: 17 September 2022].

[27]. Verma, P., Raghubanshi, A., Srivastava, P. K., & Raghubanshi, A. S. (2020). Appraisal of kappa-based metrics and disagreement indices of accuracy assessment for parametric and nonparametric techniques used in LULC classification and change detection. *Modeling Earth Systems and Environment*, *6*(2), 1045-1059. https://doi.org/10.1007/s40808-020-00740-x