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A Projection of Land Needed for Settlements and Conversion of Paddy Fields in Solok City

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Abstract. *The city of Solok, despite being a growing urban area, cannot entirely abandon its agricultural sector due to its influence on the development of the region and its contribution to maintaining national food security. The development of settlement in the city of Solok needs to consider the existing paddy fields while avoiding unnecessary conversion, which should be a last resort. Infrastructure development should not be directed to the existing and potential paddy fields, since, generally, settlement development prefers these areas. This study aimed to estimate the land needed for settlements based on population projections, the assessment of land suitability for paddy field by a spatial analysis and a simulation of land use change considering infrastructure as driving factor. The methods used in this study are the Saturation Model, Spatial Analysis, Markov Chain and Cellular Automata (CA) Analysis. The results demonstrate that: (1) the estimated population in 2031 using the saturation model will be 71,524 inhabitants, which would require 223.08 Ha of settlements; (2) the existing paddy fields cover 971.27 Ha, some parts were categorized unsuitable due to its slope but this was overcome by the construction of terraces; and (3) the Markov Chain and CA analysis predicted over 150 Ha of paddy field conversion in Solok by 2024. The road development plan in Solok City tends to follow the market trend directed at the existing and potential paddy field areas. The study predicts a significant loss of paddy fields, especially in areas with a high suitability class.*

Keywords. *Paddy Fields Conversion, Land Use Change, Saturation Model, Land Suitability, CA Markov.*

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Abstrak. *Walaupun secara administratif berstatus sebagai sebuah kota, Kota Solok tidak dapat begitu saja meninggalkan sektor pertanian karena masih kuatnya pengaruh sektor tersebut dalam pembangunan wilayah dan adanya kepentingan mempertahakan ketahanan nasional. Pembangunan permukiman di Kota Solok perlu memperhatikan eksistensi lahan sawah yang ada dan sebisa mungkin menghindari alih fungsi yang tidak seharusnya dan harus benar-benar sesuai kebutuhan. Pengembangan infrastruktur permukiman sebaiknya tidak diarahkan pada lokasi-lokasi sawah eksisting dan lahan-lahan yang potensial untuk sawah. Namun pengembangan permukiman pada umumnya lebih memilih untuk mengalih fungsi lahan sawah yang ada dan potensial. Penelitian ini bertujuan 1) memperkirakan kebutuhan lahan untuk kawasan permukiman berdasarakan proyeksi pertumbuhan penduduk 2) analisis kesesuaian lahan untuk komoditas padi sawah dan 3) mensimulasikan perubahan penggunaan lahan dengan mempertimbangkan infrastruktur sebagai faktor yang berpengaruh. Metoda yang digunakan adalah Model Saturasi, Analisis Spasial, Markov Chain dan Cellular Automata*

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(CA). Hasil penelitian ini menunjukkan bahwa: 1) Perkiraan populasi penduduk kota Solok dengan model saturasi pada tahun 2031 mencapai 71.524 jiwa yang akan membutuhkan lahan seluas 223,08 Ha untuk kawasan permukiman 2) Luas lahan sawah aktual sebanyak 971,27 Ha, sebagian terkategorikan tidak sesuai karena faktor lereng, namun faktor penghambat tersebut telah diatasi dengan pembangunan terasering 3) Diperkirakan akan terjadi pengurangan luas lahan sawah lebih dari 150 Ha pada tahun 2024. Rencana perluasan jaringan jalan di Kota Solok terbukti cenderung mengikuti trend pasar yang diarahkan pada lokasi sawah-sawah eksisting dan potensial, alih fungsi lahan sawah diperkirakan tetap akan terjadi dalam jumlah yang cukup tinggi terutama pada lahan-lahan berkesesuaian baik.

Kata kunci*. Konversi Lahan Sawah, Model Kejenuhan, Perubahan Penggunaan lahan, Kesesuaian Lahan, CA Markov.*

Introduction

The key to food security lies in the availability, affordability, and stability of its supply. The availability of food is related to aspects of production and supply for food to be available at all times. Affordability is an aspect of access in terms of economy and security. Meanwhile, stability is an aspect of distribution (Arsyad and Rustiadi, 2008). There are two main approaches to food security, i.e., an environmental approach that seeks to develop sustainable food systems and a social justice approach aims to eliminate poverty. Both approaches are in accordance with the two main dimensions of food security; the production and supply of food in adequate quality and quantity, and the ability of people to access food (Longo, 2016). There is a variety of policy perspectives on food security. Some put emphasis on the market, while others emphasize the population. Some consider the state a facilitator, while others consider the state oppressive. Some see price as a combination of all prices, while others consider price as an externalization of costs that need to be internalized. Some consider the issue of food security limited to developing countries, while others consider it a challenge for the world food system with different problems at each development level (Lang and Barling, 2012).

Sustainability does not mean keeping everything the same; change is something important. However, changes must be manageable and take place in their proper scope, scale, and pace (Thiele, 2013). One of the challenges for the sustainability of food production is rampant land conversion.

Population growth is one of the factors that affect land use change. Meyer and Tuner (1992) suggested that population exerts a significant impact on land use change. In developing countries, population growth propels the clearing of forests. In the case of Solok, forest conversion is limited because of its protected status. Another type of land use change that often occurs is the conversion of paddy fields into settlements.

On the other hand, the development of urban areas can be seen as a positive process that generates new economic activities, such as new small, medium and large businesses that can reduce unemployment and contribute to local revenue. However, the process of urban development can create significant challenges to urban planning that are strongly associated with urban land use conversion (Rahmawati, 2015). The population growth in urban areas increases density and urban activities that consequently cause spatial changes in the urban periphery. Peri-urban rural areas gradually change into typical urban residential areas (Vitriana, 2017).

An important aspect of food security involves controlling function changes of land used for growing food crops. A variety of factors may cause the conversion of paddy fields. According to Ilham et al. (2005), various studies on the micro level suggest that land prices, the economic activities of a region, the development of settlements, and the competitiveness of agricultural products are economic factors that affect paddy conversion. On the macro level, the conversion of paddy fields has a positive correlation with the growth of GDP, while it has a negative correlation with the farmer's exchange rate. Both correlations are in line with findings on the micro level. On the micro level, the development of settlements affects the conversion of paddy fields. However, on the macro level, the development of settlements proxied by a population increase does not show a positive relationship. This indicates a trend that houses are not only places to live but also as an investment. The social factors prevailing in society tend to trigger the conversion of paddy fields. Meanwhile, land regulations have been unable to control the rate of paddy field conversion.

Rice being the main food source for most Indonesians, paddy fields need more attention in maintaining food security and the sustainability of food availability. According to Nurmalina (2008), seven key factors are very influential in the system of rice availability, i.e., production, productivity, land conversion, paddy field development, land suitability, per capita consumption, and population size. Nurmalina (2008) adds that the systems of rice availability in Java and Sumatra are sufficiently sustainable, while Kalimantan, Sulawesi, and other regions are less sustainable. This suggests that the regional development of rice, in addition to focusing on Java, should also be directed to Sumatra. According to Mulyani et al (2011), the intensive rate of paddy field conversion in Java and large cities during the last two decades cannot be balanced by the rate of paddy field development outside Java. This situation will threaten national food security and sovereignty. Therefore, it is important to optimize the utilization of land resources and the application of various technologies to support the national rice production enhancement program (P2BN). In addition, the land conversion should be controlled and the development of new paddy fields should continuously increase. By 2050, to meet food needs, the cumulative need for paddy field expansion is 6.08 million ha and 11.75 million ha of dry agricultural land.

Part of the conversion of paddy fields to non-agricultural use is unavoidable, for example, to meet the needs for settlements. In this context, the pace of paddy fields conversion can be reduced indirectly through policies and spatial planning based on a long-term vision, which essentially means that zoning in spatial planning must carefully consider the direction of changes in the economic structure, population growth, and socio-cultural change (Sumaryanto et al, 2001). Irawan (2005) stated that paddy field conversion outside Java (132,000 ha/year) exceeds the conversion in Java (56,000 ha/year). Approximately 58.68% of the conversion is intended for non-agricultural activities, the remainder for non-paddy field agriculture. Most of the non-agricultural activities consist of housing developments (48.96%) and public facilities (28.29%). The majority of conversion of paddy fields in Java is for housing (74.96%), while outside Java paddy field conversion is mostly intended for the development of public facilities (45.59%). According to Pasandaran (2006), there are three policy alternatives to control the conversion of irrigated paddy fields, i.e., control through a central authority; the provision of incentives for the developing of new paddy fields and for owners of irrigated paddy fields that need to be protected; and capacity building for local farmer collectives to control paddy field conversion.

According to Law No. 22/1999, urban areas primarily consist of non-agricultural activities, with a functional arrangement for an urban settlement; centralization and distribution of government services; social services; and economic activities. However, in practice, there are cities, especially growing small cities surrounded by agricultural centers that cannot just abandon the agricultural sector because a large number of people are still working in the sector and the administrative area still contains a significant agriculture area. Solok City is one of the small cities with such characteristics and it still has a strong agrarian culture. Solok City has a strategic geographical position at an intersection of the Sumatra Highway and is surrounded by several *Nagari* (traditional villages) in Solok Sub-district, where Solok City has a central role in supporting the economy of the city and Solok Sub-district in general. The development of settlement areas is a necessity for cities but in the case of Solok the agricultural sector, especially paddy fields, cannot be abandoned. Due to the importance of the balance between the development of settlements and the conservation of paddy fields in Solok it is necessary to formulate development directives for Solok City to fulfill the need for settlements, while still observing the conservation of paddy fields. This research is intended to examine which degree the development of road infrastructure influences the spatial pattern of settlement development in Solok City.

The objectives of this research are 1) to develop a projection of the availability and demand for settlements in Solok City; 2) to identify the physical suitability of land and the existing condition of paddy fields for the development of Sustainable Food Agricultural Land (LP2B) in Solok City; and 3) to make a simulation of the conversion to non-paddy field agriculture through the development of road infrastructure.

Research Methods

The research was conducted in Solok, West Sumatra is located at 0º32” N– 1º45” S and 100º27” – 101º41” E. The city covers 57.64km^2, which is 0.14% of the total of West Sumatra. The research process from preparation; field data collection; data processing and analysis; and preparation of the thesis lasted seven months from June to December 2015.

The data used in this study consist an administration map; Solok City Regional Spatial Planning maps; land use maps of 2004, 2010, and 2014; a slope map (each on a 1:50,000 scale) from the Solok City Regional Development Planning Agency; a flood risk map (scale 1:25,000) of the Solok Regional Disaster Management Agency; a soil map (scale 1: 50,000) from the Center for Agricultural Land Resources Research and Development; and population data from 1990 to 2013 from the Solok Central Statistics Agency. In particular, for the second research objective, the data is supplemented by primary data from interviews with the population in flood-prone areas as a basis for preparing a map of flood hazard classes. The tools used are 1) a GPS receiver, 2) Computer devices equipped with ArcGIS, Statistica 7, Idva Selva, and Microsoft Office.

Analysis of Population and Settlement Land Requirements

The estimation models commonly used in simulating population growth include quadratic, exponential, and saturation models. To determine the population growth model to be used, the authors made estimations using each of these models and then compared the results. The data used is the population data of Solok in the years 1990-2013 from the Solok Central Statistics Agency. The quadratic and exponential models obtained confidence levels of 95%, while the saturation model obtained an R^2 value of 0.97377. This means that the population growth pattern of Solok City most resembles the saturation model.

Munibah et al (2009) conducted a study on population growth and its relation to the size of agricultural and settlements land. They projected population growth by using the saturation and the exponential models. In the study, the trends in population growth patterns in 33 villages were determined to find out if the pattern follows the saturation or the exponential models. The study also used the R^2 value as an indication of the model of population growth of an area.

The formula of the saturation model that is used is a modification of the of the saturation model as used by Munibah et al (2009) to model population growth, namely:

$$Y = \frac{\mathrm{a}(\exp(b.X))}{1 + (\exp(b.\mathrm{X}))}$$

Where Y is the total population in year X, and X is the difference between the projected year-with year 1 (in this study year 1 is 1990), while *a* and *b* are the constants. Furthermore, non-linear estimation with Statistica 7 was used to determine the value of the constants. The estimated need for settlement areas is calculated based on the national standard SNI 3-1733-2004 on the procedures for planning the urban housing environment. Calculating was started with by estimating the minimal need for plots, assuming that the buildings that will be constructed have one floor and five people per household. Then, public service facilities were based on the number of sub-districts, urban villages, and community units. Finally, this is added with the estimated need for other settlement support facilities (education, health, religion, commercial, social, cultural and recreational), calculated based on population size. The total of the minimum need for plots, public service facilities and settlement support facilities is calculated as the need for settlement areas.

Analysis of the Physical Suitability Classes for Paddy Fields

The suitability analysis of land for rice plants was done using an overlay method between the maps of administration, slope, rainfall, land system, soil and flood hazard. Subsequently, land suitability classes were determined for each land characteristic based on a table of land suitability criteria (Hardjowigeno and Widiatmaka, 2007). Land suitability classes are determined based on the lowest limiting factor in each polygon of the map overlay. Furthermore, land suitability was categorized into five classes: S1 (very suitable), S2 (suitable), S3 (conditionally suitable), N1 (unsuitable) and N2 (very unsuitable).

Then, the area size available for the development of paddy fields is calculated by considering existing land use, built-up land, and protected areas. The available land class map is then overlaid with the land use map of 2014 to find out the physical suitability class of the existing paddy fields. In addition to the spatial analysis, the existing conditions were checked in the field at a number of observation points that are paddy fields on the land use map.

Simulation of Land Use Changes with the Implementation of the Road Infrastructure Development Plan

To estimate future land use changes, especially in paddy fields, a spatial analysis was carried out in the form of a Markov Chain and Cellular Automata (CA) simulation based on the land use maps of several years. Eastman (2012) stated that the Markov process is the state of a system at the second state that can be predicted from the state of the system at the first state by compiling a probability matrix from one land cover class to each of the other classes. Mynt and Wang (2006) concluded that in general, the combination of Markov Chain analysis and a simple

CA filter is effective in predicting the likelihood of a change in land use or land cover. According to El-Hallaq and Habboub (2015), the application of a Markov analysis is used to study estimated land use change and the effect of land use. However, one of the shortcomings of the Markov Chain is a lack of spatial orientation; thus, it is it preferable to combine it with the CA model. According to Wang et al (2012), CA is a discrete dynamic network model where time, space, the state of everything discrete, spatial interactions, and causality of time is entirely determined in the context of local relations. CA is suitable for studying spatial-temporal complex geographic systems. CA is mainly used for urban land use and has become an essential tool and research focus in modeling changes in land use/land cover in urban areas.

This analysis considers infrastructure as a factor that affects land use changes. Mushchamp (1995) in Elmer and Leigland (2014) defined infrastructure as the connective network that brings together people, places, social institutions and the natural environment into a coherent urban relationship. Investing in the development of infrastructure, especially main roads, has an impact on the economic growth in various regions in Indonesia (Purwoto and Kurniawan, 2009). According to Jubaedi (2003), accessibility is often taken into consideration in choosing the location for residences and business, thus, the proximity to land transport infrastructure is very important. Proximity to the transportation infrastructure refers to the proximity to bus terminals and to roads. The analysis in this study uses two scenarios:

1. Business as usual without considering road infrastructure development plans. This scenario uses the existing road network map with a buffer of 100 meters as the factor affecting land use change in CA analysis.
2. Taking into account the road infrastructure as one of the factors that influence the development of settlement areas. This scenario uses maps of the road network development plan with a buffer of 100 meters as the factor affecting land use changes (see Figure 1).

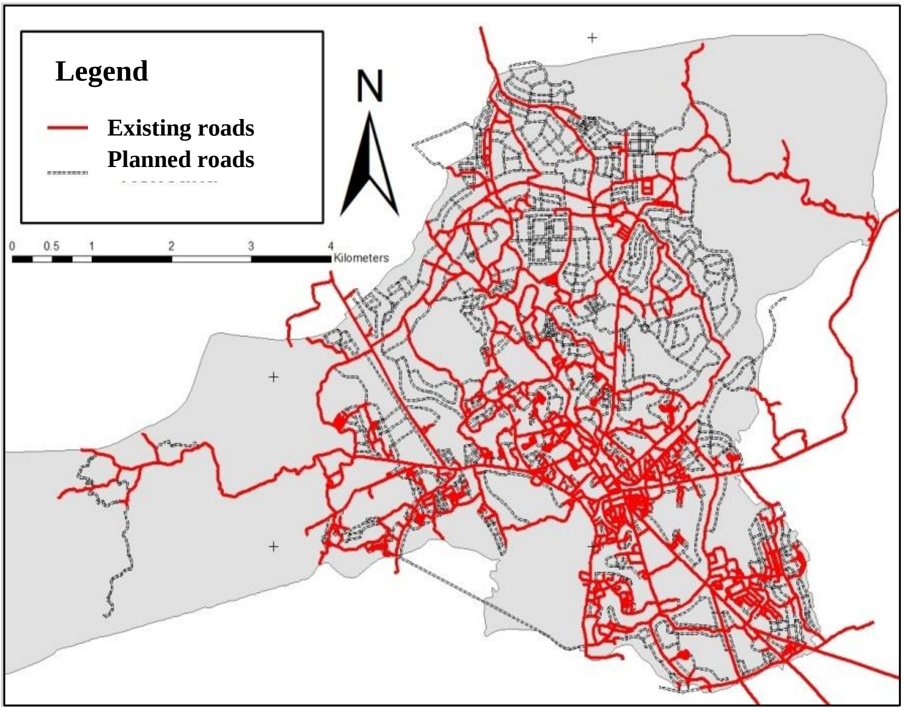

Figure 1. Road Network Development Plan of Solok City.

The map of available land use was projected up to 2024. The outcome of the simulations of both scenarios were then compared to determine the effect of infrastructure development on the level of paddy field conversion. The simulation of land use change requires the same amount of land use classes in each map (Table 1). Meanwhile, the available maps have different numbers of land use classes, 24 (2004) and 25 (2010 and 2014). Therefore, it is necessary to reclassify the land use classes before the simulation, in order to get the same number of land use classes. In this study, the authors reclassified land use into seven classes.

Table 1. Classification of Land Use.

No.	Land Use Classes	Code
1.	Forest	1
2.	Paddy fields	2
3.	Settlement	3
4.	Mining activities and other agricultural cultivation	4
5.	Other built-up land	5
6.	Open area	6
7.	Waterbody	7

Results and Discussion

Projection of Availability and Need of Land for Settlements in Solok City

The non-linear estimation resulted in a constant value a = 78893.9 and b = 0.055429 with the value R = 0.97377. The value of the constant is further used in the above formula to estimate the population growth and the saturation point of population growth in Solok City (see Figure 2-3).

In 2031, the estimated total population of Solok will reach 71 524 inhabitants. Based on this model, the population growth of Solok until 2031 is still far from the saturation point of over 78,800 inhabitants, which will be reached around 2112. Moreover, the estimated population growth is used to estimate the needs for settlement area (see Figure 4-5).

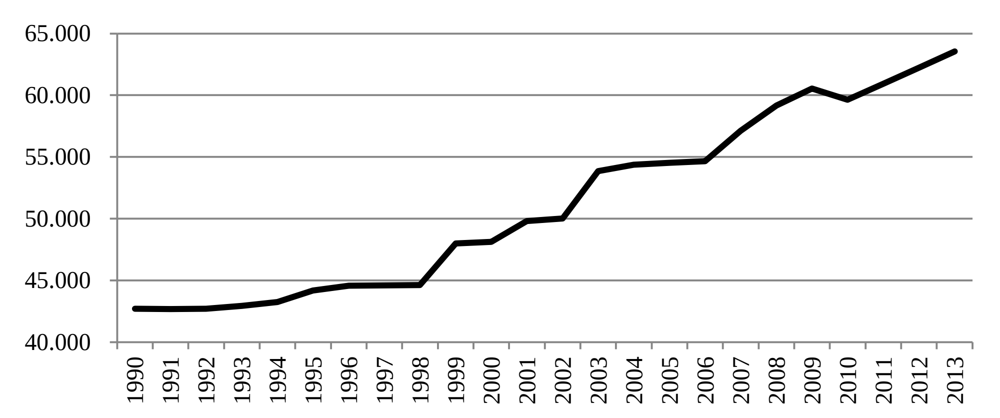

Figure 2. Total population of Solok in the years 1990-2013. (Source: Solok Central Statistics Agency)

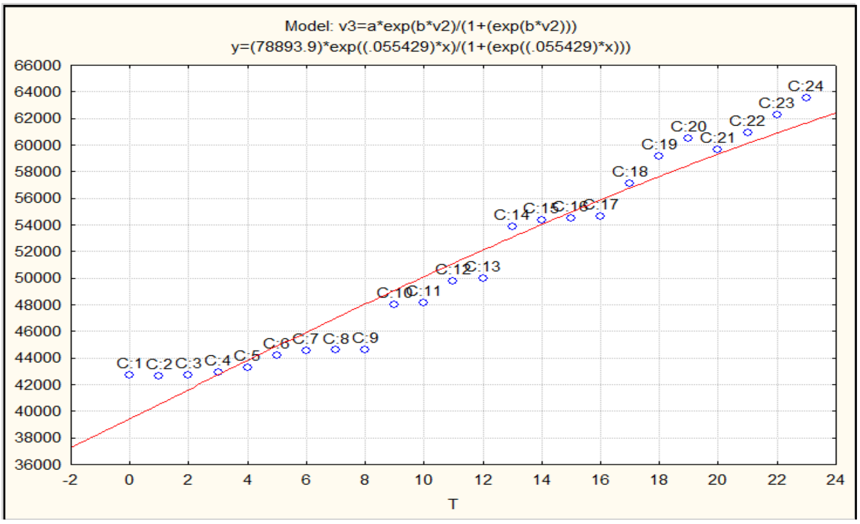

Figure 3. The non-linear estimation and the estimation formula of population growth in Solok using a saturation model.

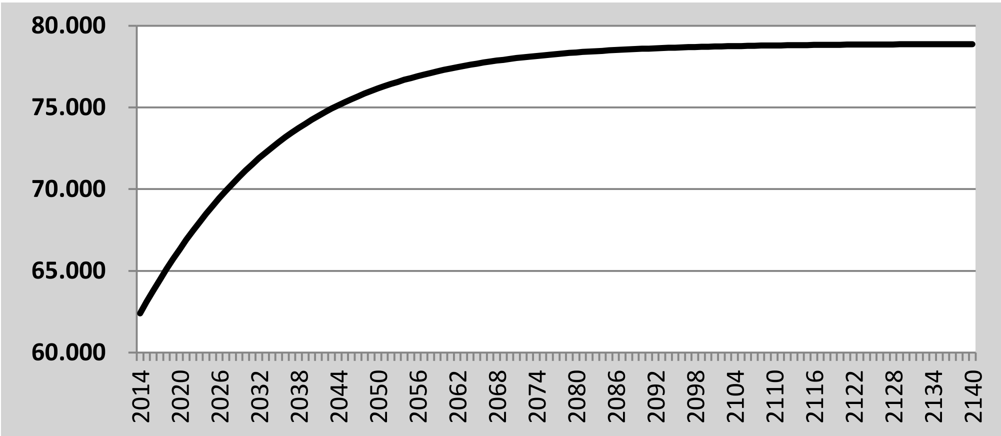

Figure 4. Estimated population growth of Solok using a saturation model

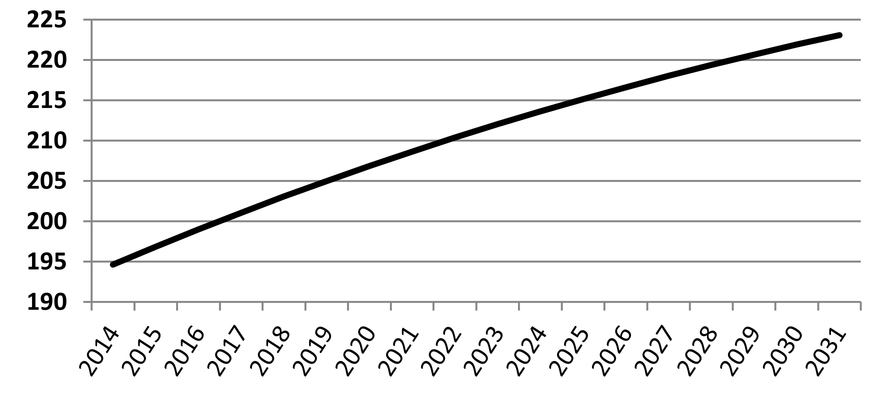

Figure 5. The estimated minimum land requirement for settlements and residential support facilities in Solok City for the years 2014-2031.

Based on the estimated population growth of Solok using a saturation model the need for land for settlements and supporting facilities in 2031 is estimated at 223.08 ha. This is still far below the amount of 1,770.07 Ha allocated for settlement areas in Solok as stipulated in the Solok City Regional Spatial Plan 2012 - 2031. This shows that the development of settlement areas is still in line with efforts to maintain paddy fields in Solok City as long as the development of new settlement areas will be directed to non-paddy field areas such as open land, fields or other dry agricultural land (see Figure 6).

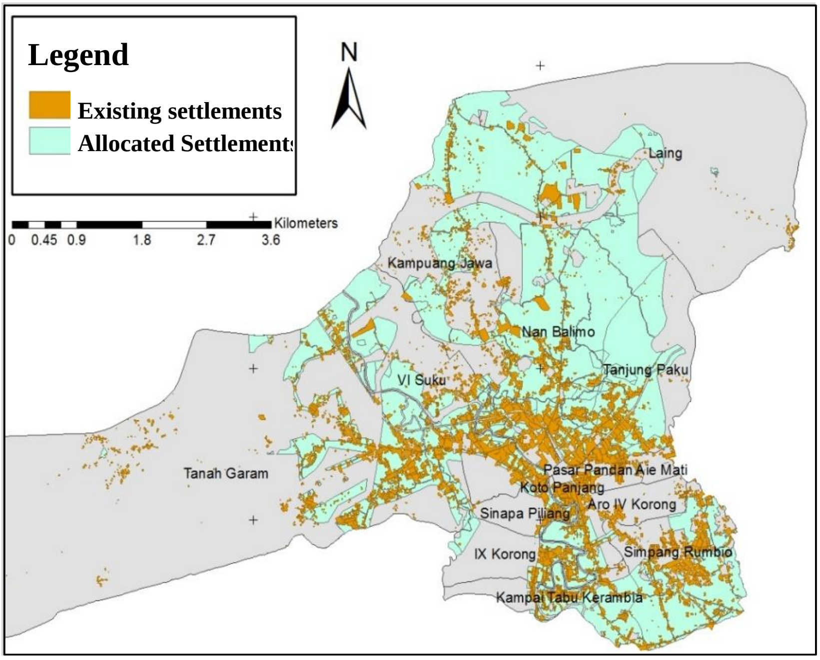

Figure 6. The existing settlements and the allocation of land for settlements in the Solok City spatial pattern.

Identification of the Physical Suitability of Land and the Condition of Existing Paddy Fields for the Development of Sustainable Food Agricultural Land (LP2B) in Solok City

The analysis of land suitability for rice crops was done by an overlay of the administration, slope, rainfall, land system, soil, and flood hazard maps. Subsequently, the land suitability class was determined for each land characteristic based on Table 2 of land suitability criteria. Land suitability classes are generally determined based on limiting factors the form of characteristics with the lowest class in each polygon of the map overlay.

Table 2. Land Suitability Criteria for Rice Crops.

Land Quality/ Characteristic	Symbol	Land Suitability Class				
		S1	S2	S3	N1	N2
Temperature	(t)					
- Annual average (°C)		24 - 29	>29 - 32 22 - <24	18 - <22 >32 – 35	n/a	< 18 > 35
Water availability	(w)					
- Dry moon (<75 mm)		<3	3 - <9	9 - 9,5	n/a	>9,5
- Rainfall/year (mm)		>1500	1200 - 1500	800 - <1200	-	<800

Land Quality/ Characteristic	Symbol	Land Suitability Class				
		S1	S2	S3	N1	N2
Rooting Media	(r)					
- Drainage		Impeded	Impeded,	Medium, good	Fast	Very fast
- Texture		SCL, SiL, Si, CL	SL, L, SiCL, C SiC	LS, Str C	n/a	Gravel, sand
-Effective depth (cm)		>50	>40-50	>25-40	20-25	<20
Peat						
-Maturity		-	Strongly decomposed	Medium decomposed	Medium-weakly decomposed	Weakly decomposed
-Thickness (cm)		<50*	50 – 100*	100 – 150	>150 – 200	> 200
Nutrient retention (nr)	(f)					
-Soil CEC		> medium	low	Very low	n/a	-
-Base saturation (%)		>50	35-50	<35	-	-
Soil pH		>5,5 – 7,0	>7,0 - 8,0 4,5 - 5,5	>8,0 - 8,5 4,0 - <4,5	-	>8,0 <4,0
-C-organic (%)		>1,5	0,8-1,5	<0,8	-	-
Toxicity	(x)					
-Sulfidic depth (cm)		>75	60 - 75	40 - <60	30 - <40	<30
Nutrient availability	(n)					
-Total N		≥ Medium	Medium	Very low	-	-
-P2O5		> High	Medium	Low- very low	-	-
-K2O		>Medium	Low	Very low	-	-
Land preparation	(p)					
- Rocks on the surface (%)		<3	3 - 15	>15 - 40	n/a	>40
Erosion risk	(e)					
- Slope (%)		< 3	3-8	>8 - 15	>15 – 25	> 25
Flood risk	(b)	F0-F1	F2	F3	F4	F4

Note: n/a = not applicable; texture: S = sand, Si = silt, Cl = clay; L = loam; StrC = structured clay; Nutrient status assessment based on PPT (1983); Source: Hardjowigeno and Widiatmaka (2007).

The spatial analysis of the suitability of land for paddy fields in Solok city resulted in land suitability classes S2, S3, N1, and N2. The details of each class can be seen in Table 3.

Table 3. Land Suitability Classes for Paddy Fields in Solok City (area size before deducting built-up land and protected areas).

No	Class	Area Size (Ha)
1.	S2	1,107.40
2.	S3	2,615.17
3.	N1	980.26
4.	N2	1,061.10
	Total	**5,763.93**

In this map (see Figure 7), built-up and protected areas are not yet considered. Deducting these areas results in the potentially available land for the development of paddy fields of 3,388.24 ha. The land use map shows that the existing paddy field area is 971.27 ha. The details of existing and potential land area can be seen in Table 4.

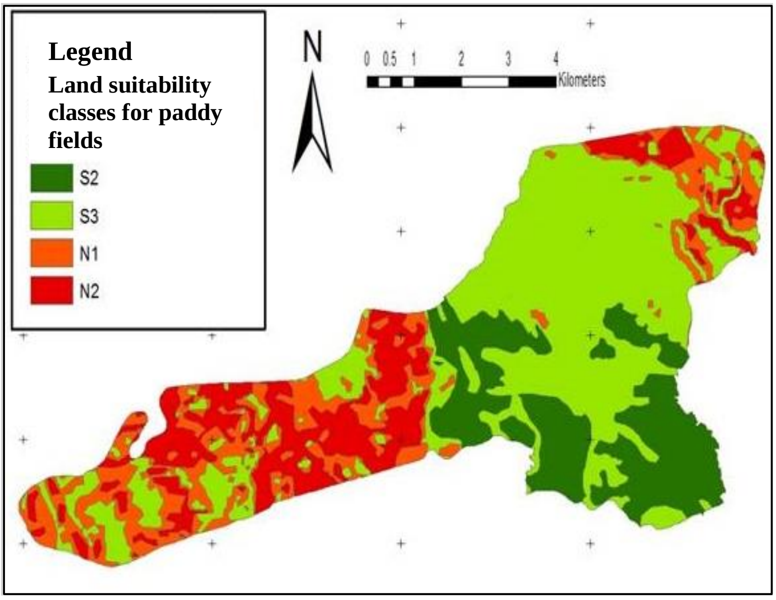

Figure 7. Land suitability classes of for paddy fields in Solok.

Table 4. Comparison of Potential/Available Land for Paddy Fields and Existing Land Based on Land Suitability Classes.

No	Class	Available Land (Ha)	Existing Paddy Fields
1.	S2	832.69	701.30
2.	S3	1,632.63	227.70
3.	N1	386.53	28.59
4.	N2	536.39	13.68
Total		**3,388.24**	**971.27**

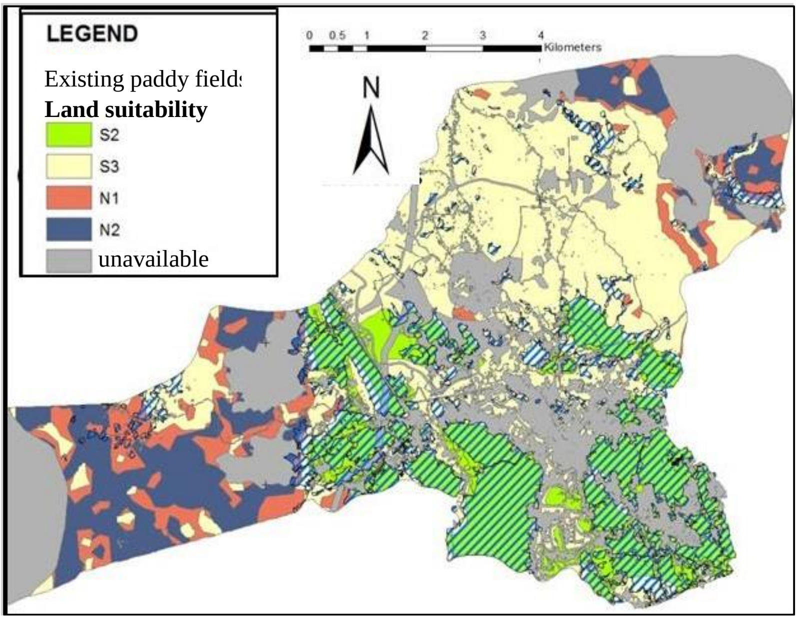

Figure 8. Suitability classes of existing paddy fields in Solok.

Land with class N1 and N2 have limiting factors such as a slope of more than 15% - 25% (N1) and over 25% (N2). However, these limiting factors can be overcome if farmers develop terraces. Field observations in a number of places confirmed the application of terracing for paddy fields on hillsides (see Figure 8).

Available and existing paddy fields are compared with the land allocation for the paddy fields in the Solok City spatial pattern map. The comparison of area size in Table 5 shows that more than half of the existing paddy fields are allocated paddy fields in the spatial pattern plan. This indicates that Solok City can still accommodate the conversion of paddy fields within certain limits. Conservation efforts are required for land that in the spatial pattern plan is allocated as paddy fields in order to maintain its function (see Figure 9).

Table 5. Comparison of actual wetland with spatial pattern.

No	Paddy fields	Area (Ha)
1.	Available	3,388.24
2.	Existing	971.27
3.	Allocation in spatial pattern plan	567.69
4.	Existing, included in the spatial pattern plan (needs to be maintained)	512.94
5.	Existing, not included in spatial pattern (can be converted)	458.32

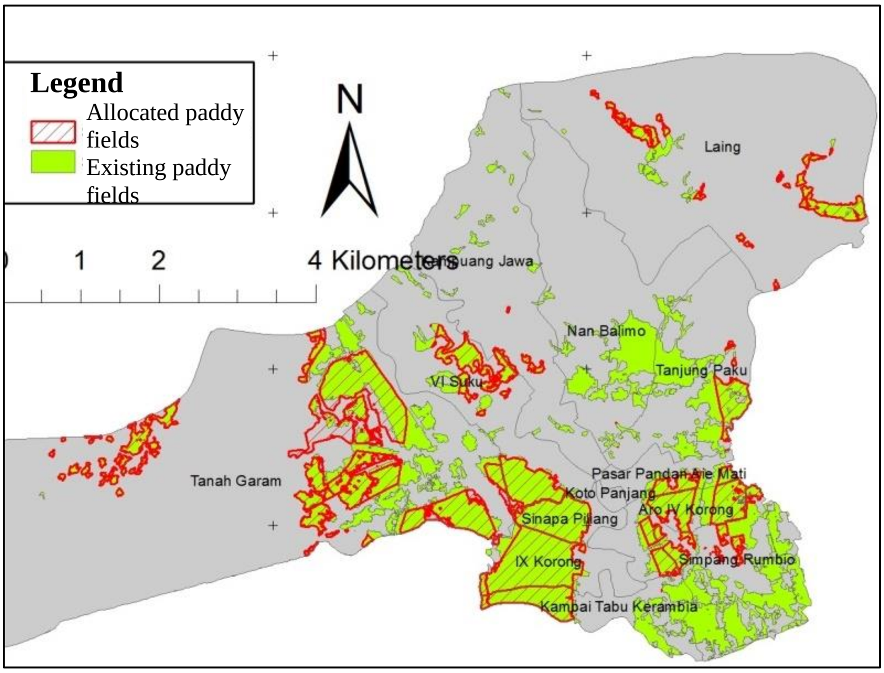

Figure 9. Comparison between existing paddy fields and the allocation of paddy fields in the spatial pattern plan of Solok City.

Simulation of Land Use Change Based on the Implementation of the Road Infrastructure Development Plan

Land use change is simulated using the Markov Chain analysis supplemented with CA analysis. According to El-Hallaq and Habboub (2015), the Markov analysis is used to study estimated land use change and the effect of land use. The Markov analysis of changes in land use has been integrated with Geographic Information System (GIS), producing a tool for visualizing and projecting possible changes between land use categories. However, one of the shortcomings of the Markov Chain is the lack of spatial orientation so it is advisable to add the Cellular Automata model. The same is stated by Mynt and Wang (2006), namely that the significant deficiency of the Markov analysis is that this method does not take into consideration the spatial position of each observed class. In order for the output of the Markov analysis to be more informative and easier to understand, it needs to be added with a Cellular Automata (CA) approach. Wahyudi and Liu (2015) added that using conventional spatial models for microscale urban planning is considered too expensive. Advances in computer technology and complexity theory enable creating urban growth simulations of micro-interactions. CA is a promising tool for urban models because it is appropriate for cities containing complex systems. CA is the most appropriate concept to represent the shape and development of a city.

The simulations resulted in a projected reduction of paddy fields in Solok in 2024 of over 150 hectares compared to the situation in 2014. The comparison between the existing paddy field area, the estimation in both scenarios, and the allocation of paddy fields in the spatial pattern plan can be seen in Table 6.

Table 6. Comparison between the existing paddy field size and the estimated paddy field size of the CA analysis.

No.	Scenario	Paddy Field size (Ha)	Estimated Reduction in Paddy Fields (Ha)
1.	Existing 2014	971.27	-
2.	Estimated 2024 "business as usual" scenario	821.25	-150.01
3.	Estimated 2024 "development of main road infrastructure" scenario	821.20	-150.0 7
4.	2031 Spatial Pattern Plan	567.69	-

Table 6 shows that the "business as usual" and the "development of main road infrastructure" scenarios both project a reduction of paddy fields of more than 150 hectares. There is only a very small difference of 0.056 hectares or only 0.0068%. The small difference between the scenarios may be caused by the adequacy of the existing main road network of Solok that already serves most of its territory. The development of road infrastructure does not significantly change the spatial orientation of settlements in Solok but tends to follow the market trend of settlement development. The future development of Solok could lead to a decline in paddy field area in both scenarios. Therefore, in addition to infrastructure development, it is also needed to include other approaches to control the rate and direction of paddy field conversion. A possible policy approach is to establish specific paddy fields that are suitable and are considered necessary to maintain and become Sustainable Food Agricultural Land (LP2B).

The green parts in Figure 10 represent the approximate distribution of paddy fields in Solok in 2024 in the "business as usual" scenario, while the red parts show the increase in paddy fields if the infrastructure improvement scenario is applied. The increase is very little, which is expected because the distribution of roads in Solok is already quite extensive and dense in the "business as usual" scenario, so implementing the “infrastructure improvement" scenario does not have a significant effect.

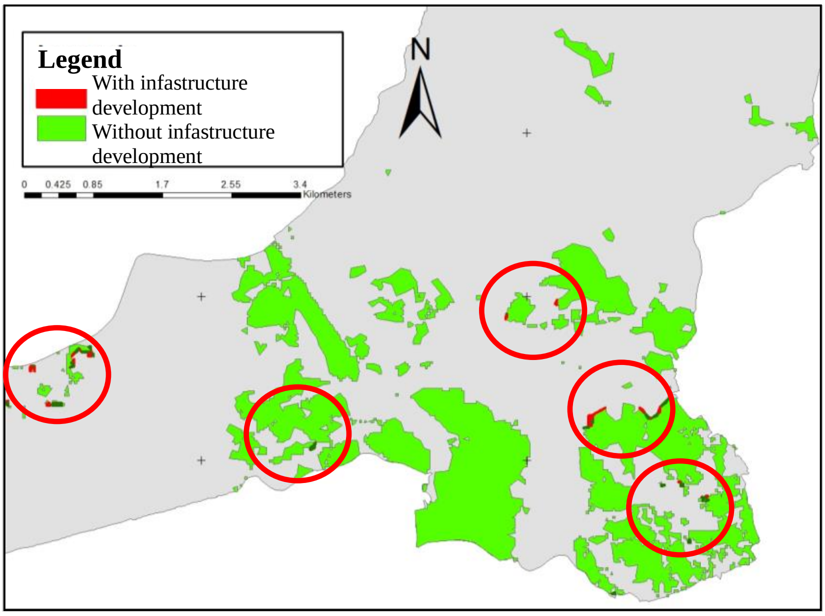

Figure 10. The difference between the estimated distribution of paddy fields in Solok in 2024 based on the "business as usual" (without improved infrastructure) scenario and the "infrastructure improvement scenario".

Tables 7 and 8 show that paddy field conversion tends to occur more frequently in the relatively good land suitability classes, i.e., S2 and S3. Thus, policies aimed at maintaining existing paddy fields, particularly those with good land suitability, need to be applied accurately and consistently. The policies need to be supported with efforts to direct land use, especially the development of settlements and support facilities to agricultural non-paddy field land. Land use policies such as in the flowchart in Figure 13 can be applied where decision-making is based on the status of the area, land suitability, spatial planning and the existing land use.

Table 7. Comparison of paddy field suitability classes existing and projected in 2024.

Scenario	Area (Ha)			
	S2	**S3**	**N1**	**N2**
Existing in 2014	70130	227.70	28.59	13.68
Projected in 2024:				
1. Business as usual	656.23	139.53	16.78	8.72
2. Infrastructure development	656.27	139.67	16.63	8.63

Table 8. Estimated decrease in paddy field area in Solok City based on land suitability classes.

Scenario	Decrease (Ha)			
	S2	**S3**	**N1**	**N2**
1. Business as usual	**45.07**	**88.17**	11.81	4.96
2. Infrastructure development	**45.03**	**88.03**	11.96	5.04

The following Figures 11-12 present a field documentation undertaken by the authors at a number of paddy fields in Solok. The figures show the process of the conversion of paddy fields into settlements at some locations, while at other locations in the outskirts there are still paddy fields undisturbed by urban activity.

Figure 11. The conversion process where paddy fields are converted settlements near the center of Solok. Coordinates: 100°40'14,44"E 00°47'34,33"S.

Figure 12. Paddy fields on the outskirts of Solok. Coordinates: 100°41'43,54"E 00°45'43,54"S.

Recommendations on Regional Development Directives for Solok City

The below flowchart (Figure 13) is the basis for preparing a map of the land use directives as can be seen in Figure 12. The figure shows 473.09 Ha of paddy fields that need to be preserved in the form of Sustainable Food Agricultural Land (LP2B). Of this, 49.21 Ha should be under close control due to its high potential for land use changes (based on the simulated changes in land use).

346.45 hectares of land is prioritized for the development of settlements. In addition, 424.68 hectares of land that is also intended for settlement development but it is recommended to be postponed until it is necessary because the existing land use is paddy fields. Furthermore, there are 44.77 hectares of land where settlement development is limited because the spatial pattern plan has designated it for paddy fields (see Figure 14).

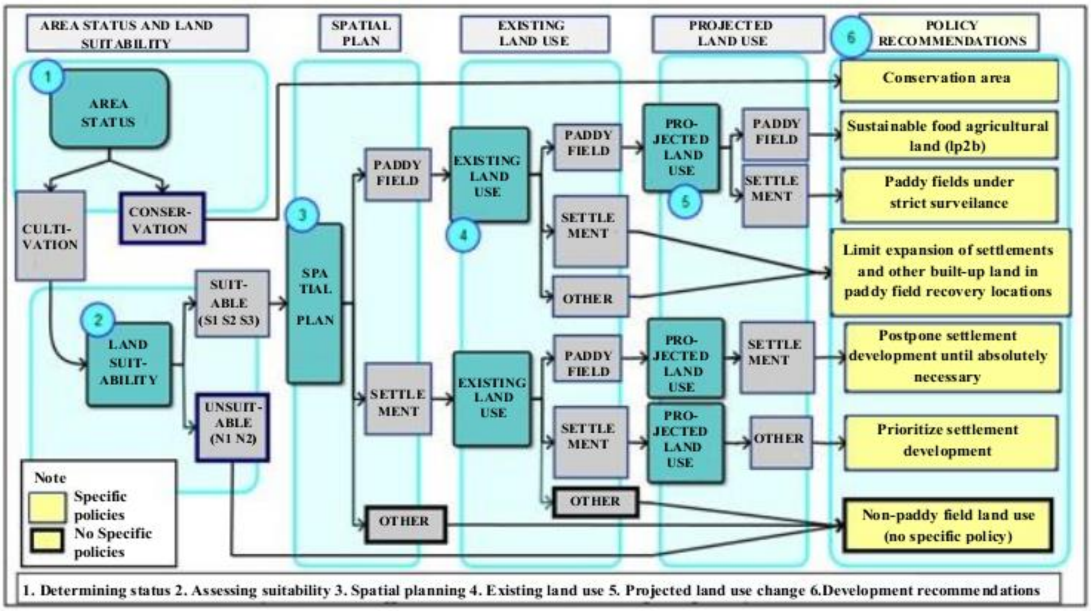

Figure 13. Flowchart of development directives for Solok City.

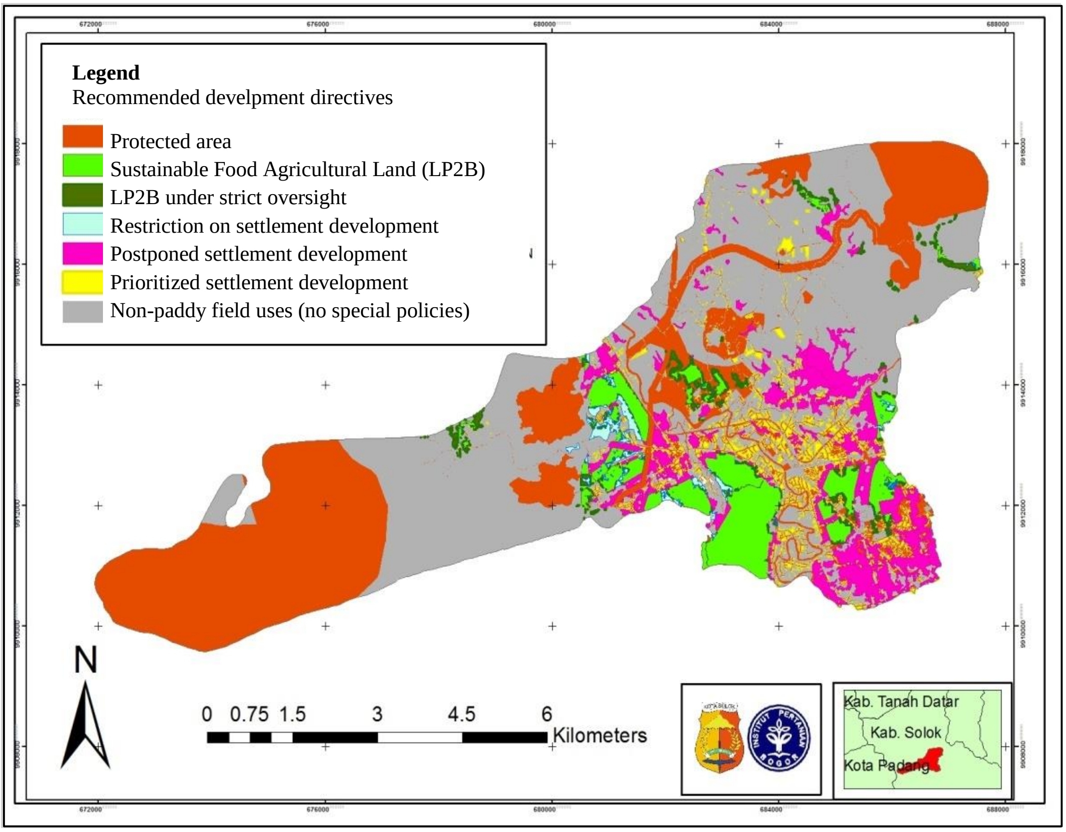

Figure 14. Development recommendations for Solok City.

Conclusion

Solok is projected to have enough space for the development of settlements. Based on the saturation model projections, the population of Solok is still far from its saturation point. This projection shows that the estimated need for land for settlements and supporting facilities in 2031 is far below the amount of land allocated for settlements in the Solok Regional Spatial Plan 2012-2031. As stated by Meyer and Tuner (1992), population size significantly influences land use change. This also occurs in Solok where population growth goes hand in hand with an increase in settlements and a reduction in paddy fields. This needs attention in the long-term development planning in Solok.

In Solok, 3,388.24 Ha of potential land is available for the development of paddy fields. The existing size of paddy field areas in Solok is 971.27 hectares; most of this is categorized as suitable land (class S2 and S3).

Two scenarios of land use changes estimate a decrease of over 150 Ha of paddy fields in Solok; most of the decrease occurs in land with a relatively high suitability. With or without the implementation of the road network expansion plan, paddy field conversion is expected to occur extensively, especially in highly suitable land.
The development of settlement infrastructure in Solok tends to follow the trend of business as usual by preferring to convert existing and former paddy fields. Road infrastructure planning does not yet support the development of settlements away from existing and potential paddy fields. In relation to paddy field conservation in Solok, the development of settlements needs to consider a number of aspects such as land suitability classes, allocation of land in the regional spatial plan, the presence of Sustainable Food Agricultural Land (LP2B), and the potential of land use changes.

Recommendations

The appropriate policies should be implemented to balance urban settlement development by preserving paddy fields in certain parts of Solok. Several steps that can be taken include prioritizing infrastructure development in non-paddy field agricultural land areas, open areas and areas that the spatial pattern plan allocates for settlements. These steps can be supported by policies, among others, the establishment of Sustainable Food Agricultural Land (LP2B), delays in issuing permits for paddy field conversion outside conservation areas and facilitating the issuing of land conversion permits the non-paddy farmland.

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