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Assessing Rice Production Sustainability under Future Landuse and Population in Deli Serdang Regency, Indonesia

Abstract

Rice is the staple food and its cultivation requires a specific land condition. The population growth, urbanization, and plantation expansion together with socio-economic development are the driving factors of the riceland decline in Deli Serdang Regency of North Sumatera, Indonesia. As a consequence, likely availability and sustainability of rice production are threatened. Hence, it is important to understand how the future landuse and population change will affect the riceland area and production. In the lack of spatially simulated information for the future which could be useful in planning the riceland areas, the study objectives were to project the landuse change by 2040 under three scenarios, Business as Usual (BAU), Potential Riceland Protection (PRP) and Conservation Oriented (CO), and to investigate the impact of consumption demand on the sustainability of rice production. Landsat satellite data of 2009 and 2018, several spatial GIS data, and survey data were analyzed in ArcGIS, Dyna-CLUE, and SPSS software to generate the landuse classification and to simulate the future landuses; while the population projection by 2040 was derived from a Geometric Model. The results showed that forest and riceland areas will decrease with the continuous increase of plantation and urban areas under BAU scenario, but could be protected and increased under PRP scenario. The sustainability of rice production depends not only on the total riceland area, but also the productivity, the population growth, the consumption rate, and the policy. The simulated results of three scenarios serve as an important input to planning for protecting the riceland areas and thus sustained rice production in Deli Serdang Regency.

Keywords:
landuse change, population projection, rice production sustainability, scenario-based simulation

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1 Introduction

As the staple food for over half of the population of the world, especially for Asian people, information regarding the spatial distribution of rice area and its production takes an important role. A recent survey reports that the riceland area has been declining over the years and occupies only approximately 11% of the global arable region (Jiang et al. 2018). For Indonesia specifically, maintaining rice production is very important to fulfil the consumption demand because the previous study (Mcdonald 2014) states that there will be additional 67 million of total Indonesian population in 2035. The issue of food security is of increasign concern due to the decreasing riceland area and the increasing demand for rice.

The phenomena of landuse change differs between developed and developing countries (Ningal et al. 2008). In developed countries, it is mostly influenced by economic reasons, such as urban development (Iwona and Andrzej 2022) and large-scale farming, whereas in developing countries, influenced by population growth, social and economic reasons. In terms of riceland change, numerous studies have identified the causal factors behind this phenomenon, such as population growth (Ningal et al. 2008), rapid urbanization (Deng et al. 2009; Satterthwaite et al. 2010; Zul et al. 2014), socio-economic condition (Panuju et al. 2013), plantation expansion (Afriyanti et al. 2016), and agricultural policy (Firman 2004; Zhong et al. 2011).

The simulation modes are frequently used to identify the rate, trend, pattern of landuse conversion, and to predict future landuse situations more practically and quickly (Han et al. 2015). The important aspects that should be considered when generating landuse simulation involve historical and recent landuses, driving forces of land change, spatial interaction and temporal dynamics (Verburg et al. 2002; Verburg et al. 2004). The simulation model enables the researchers in understanding more about the system, involved variables, process, and its impact as well. Currently, simulation models are widely developed and implemented for urban analysis, agricultural and forestry uses (Salazar et al. 2020).

It is important to choose an exact simulation model to predict future landuse change because each model has advantages and disadvantages. Commonly, the simulation model is divided into two classes, the statistical model and the spatially explicit model. The statistical model implements statistical prediction through mathematical equations, such as the Markov model (Gong et al. 2017). This particular model can estimate the magnitude of landuse change, but not the spatial distribution of each landuse type. While, the spatially explicit model is often used to predict the geographical patterns, such as the Cellular Automata (CA) model and the Dynamic Conversion of Land Use and its Effect (Dyna-CLUE) model. These models can simulate dynamics of land use spatially. However, the CA model has no power to compute the interactions between the drivers of landuse change, whereas the Dyna-CLUE model has the advantages of as it can specify the details of landuse change scenarios through the model parameters. Since the Dyna-CLUE is based on a probabilistic logistic regression method, which analyzes landuse systems as a complex multi-level system at the interface of multiple social and ecological systems (Salazar et al., 2020), it can simulate better the landuse change under designed-scenarios by taking into consideration of driving forces, spatial policies and restriction zone (Wang et al. 2019).

In this research, the simulation model is implemented to observe and analyze the dynamic of landuse change, especially for riceland area, by 2040 based on three scenarios: Business as Usual (BAU), Potential Riceland Protection (PRP) and Conservation-Oriented (CO). In case of Deli Serdang Regency, the population growth has increased from 2003 to 2016 by about 3.04% per year, which has accelerated the urban modification. Besides, the government programs, Mebidangro program in 2008 that support the successful of Indonesia–Malaysia–Thailand–Growth Triangle (IMT-GT) (Lindarto et al. 2018) and the establishment of new airport in 2013 contributed to increase urban expansion. Furthermore, the farmers' plantation engaged in oil palm and rubber had expanded rapidly from 2005 to 2015 in Deli Serdang Regency, at the rate of 237 and 32 hectares annually, respectively (BPS-DeliSerdang 2018). The consequence of these phenomena, riceland and forest (including mangrove) are on the decline, which in turn affects the rice production negatively in the area. Through these continuing landuse change experiences, the sustainability of rice production in the future would be threatened, and the environmental balance would be disturbed as well. That is why, the PRP and CO scenarios are considered to be applied to control the landuse change rate. In addition, performing these three simulation models be able to increase the local decision-makers awareness on improving their policy related to landuse management.

A few studies have measured the rice production, consumption and its sustainability in the future, especially by considering the likely change in the number of population and associated landuse in the future. The previous researches measured the historical landuse change without considering the impact in the future spatially (Lindarto et al. 2018; Siagian et al. 2015). Hence, this study aimed to project the future landuse change along with the investigation of the impact on rice production sustainability by 2040 under three scenarios, BAU, PRP and CO. The simulated results of these scenarios serve as important input to planning for protecting the riceland area and thus sustain the rice production. Finally, some strategic actions which consider balancing the socio, economic and environmental aspects, are utterly believed to achieve the future rice production sustainability. Confidently, all output of this study can be considered to be implemented for region with the similar phenomena.

2 Materials and Methods

2.1 Study area

Deli Serdang Regency was selected as the study area because it is among the highest rice production regencies in North Sumatera Province, Indonesia. It is located at the northern part of the province with the elevation range of 0 – 2,200 m above sea level with diverse topography (Figure 1). Deli Serdang Regency, divided by twenty-two districts, has abutted with

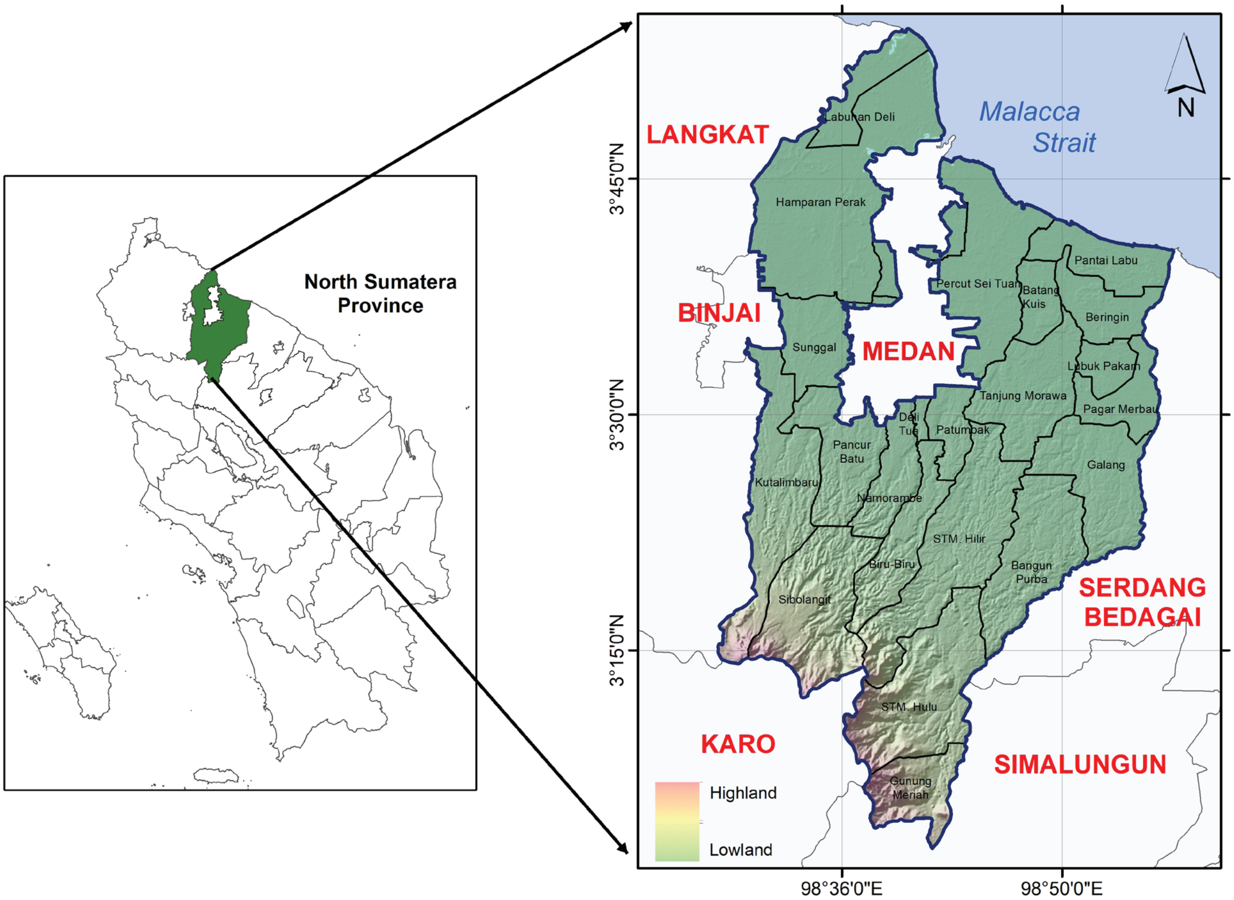

Figure 1. Location of study area.

Medan City and Malacca Strait; and bordered with Karo and Simalungun Regencies at the southern part; while at the western and eastern parts have bordered with Langkat and Serdang Bedagai Regencies, respectively (BPS-DeliSerdang 2018).

2.2 Data used

Landsat satellite imageries, 129Path / 57-58Rows, acquired on 8 March 2009 and 13 February 2018 were downloaded from the USGS Earth Explorer website (https://earthexplorer.usgs.gov/). These dates were selected considering the time of rice cultivation. Indonesia has two distinct seasons, wet and dry season (Apriyana et al. 2021). In the wet season, rice is planted from October to December; from May to August in the dry season.

Several ancillary spatial data, such as road, river, soil type, forest, potential suitability and non-potential suitability zone for riceland, and administrative boundary were obtained from the Development Planning Agency of North Sumatera Province and Centre for Agricultural Land Resources Research and Development at Bogor – West Java, The Shuttle Radar Topography Mission Digital Elevation Model (SRTM-DEM) data downloaded from http://srtm.csi.cgiar.org was used to generate contour, hillshade, slope and elevation data. In addition, data on total population of 2003 and 2016 were gathered from the Statistical Institution of Deli Serdang Regency, which was used to project the total population by 2040.

2.3 Methodology

2.3.1 Landuse classification

As the study area fell into two Landsat scenes, the two scenes of satellite data were combined through the mosaic technique. This combined-image was clipped by study area boundary and continued with the remote sensing image classification. In the process, several composite bands (RGB) of 432, 321, 742, 451, 543, and 754 were created, which were observed for the objects' pattern, size, colour, shape, association and site as interpretation elements for identifying them (Imam, 2019). An unsupervised classification decision rule called as Iterative Self Organizing Data Analysis Technique (ISO-DATA) technique was used to classify the image. This method relies upon a computed algorithm of clusters pixels based on their inherent spectral similarities (Sunitha and Suresh 2015) as the method makes it easier to identify the features for the classifier in the case when there is little or no knowledge about the area, thus allowing and the unique classes to be recognized as they might be unnoticed in the supervised technique (Thakur and Maheshwari 2017). The landuses were classified into seven classes (forest, plantation, mix vegetation, rice, urban, waterbody and barren) and area under each class was calculated for both images.

The classified landuse maps were validated to check out the classification accuracy by comparing the actual ground data. Ground-truthing points or reference points together with the landuse type were collected during the field survey in the study area using GPS. Aside from this, Google Earth satellite images were also used to add the ground-truthing points especially in remote inaccessible areas followed by generation of error matrix (Tilahun and Teferie, 2015). The Cohen's Kappa coefficient was also calculated using below equation (Adam et al. 2013; Tilahun and Teferie 2015).

$$\check{K} = \frac{\text{observed accuracy - chance agreement}}{\text{1- chance agreement}} \quad (1)$$

2.3.2 Future landuse projection

The Dyna-CLUE model is one of the dynamic simulation models that produces future landuse in different scenarios. Together with remote sensing and GIS, it has been considered a powerful tool in various landuse change assessment studies, such as, investigating the effect of spatial policies related to deforestation issue and its impacts on ecological processes (Verburg and Veldkamp 2004), evaluating agricultural land loss, and predicting landuse development (Partoyo and Shrestha 2013), and land suitability mapping (Overmars et al. 2007).

Dyna-CLUE has four main stages, namely data preparation, identification of allocation model, preparation of parameter of landuses changes scenario and preparation of the main parameters (Verburg and Overmars 2009). For data preparation, Dyna-CLUE needs the initial landuse map, thematic landuse map and driving factor which is set in raster format at the same extent and resolution (30 x 30 m). In our case, the initial landuse map was the landuse map of 2009 which is used to project landuse by 2040. These landuses were reclassified and coded as 0, 1, 2, 3, 4, 5, 6 for the forest, plantation, mix vegetation, rice, urban, waterbody and barren, respectively and no data for pixel beyond of the study area. Meanwhile, the thematic landuse map was created from the initial landuse map, but each value of thematic landuse of “1” was assigned to the pixels of selected-landuse, and “0” for pixels other selected-landuse, and “no data” for pixels outside of the study area. Ten individual factors were selected as casuative factors to influence landuse change of future and these were prepared as well in raster format for allocating landuse (Figure 2). These consisted of elevation, slope, distance to the main road, distance to the stream, distance to the capital district, distance to the capital regency, distance to the capital province, population density, potential land and non-potential land. Especially for potential and non-potential land, it was derived from land suitability classification for rice. The highly suitable, moderately suitable and low suitable

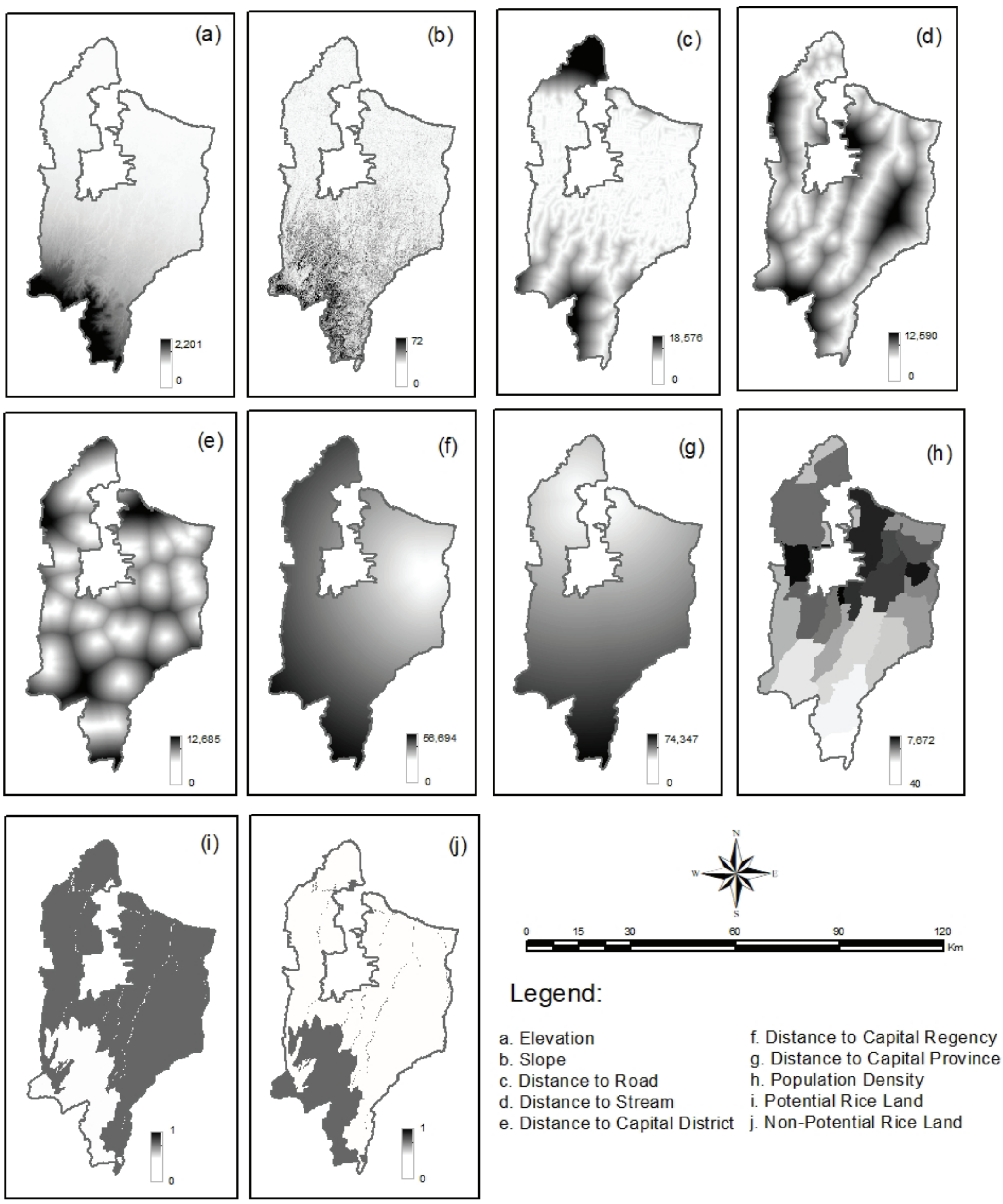

Figure 2. Input factors in Dyna-CLUE

level for rice were grouped as potential land, and unsuitable level was grouped as non-potential land.

The majority factors were in the scale variables, except potential and non-potential which is in the nominal variable. The population density was expressed as total number of people per square km. The descriptive statistics of these factors are presented in Table 1.

Table 1. Descriptive statistics of each factor.

Variable	Mean	Std. Deviation
Elevation (m)	155	287
Slope (degree)	5	5
Distance to road (m)	1403	2696
Distance to stream (m)	2740	2201
Distance to capital district (m)	3309	2321
Distance to capital regency (m)	24489	13609
Distance to capital province (m)	26702	16461
Population density (people/km2)	925	957
Variable	Mode	
Potential land	1	
Non-potential land	0	

For identifying allocation model, the regression analysis was used to relevant factors to the suitability of pixels for different landuse types. While using the binary logistic regression for each landuse type, the dependent variable was pixel value of thematic raster landuse map, which is assigned as “1” for pixel with true value for the respective landuse and “0” for other landuses. The independent variables were the original pixel value of all ten rasters of driving factor. The Dyna-CLUE was used to convert the grid data into a tabular format. The variables were set as columns and data were listed in rows. The data were transferred to SPSS for regression analysis. The Relative Operating Characteristics (ROC) is a method for calibration to find the goodness of fit of each regression model. The ROC of 1 indicates a perfect fit between the reference and predicted map, whereas ROC of 0.5 indicates conformity equivalent to random chance.

$$\ln\left[\frac{p}{1-p}\right]=\beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3+\ldots+\beta_nx_n \qquad (2)$$

where p is the probability of occurrence of a particular landuse type in a selected grid; β_0, β_1, β_2, β_3, …, β_n are the coefficients of the driving factors of x_1, x_2, x_3,…, and x_n (Shrestha et al. 2018).

At the stage of preparation for landuse change scenarios, four parameters on i) land demand, ii) spatial policies, iii) land conversion elasticity, and iv) landuse transition setting were used to produce the three different scenarios, namely Business as Usual (BAU), Potential Ricelnad Protection (PRP), Conservation-Oriented (CO) as described in Table 2. Land demand parameter illustrated the area of each landuse type that would be allocated by the model. It was arranged in tabular format, where landuses type in columns and allocated area in rows. The first row (an initial year or year 0) was filled by the total area (hectarages) of each landuse type which similar to each landuse type in the initial landuse map. The next row was filled by total area for next year according to the prescribed scenario of land demand until the end of simulation period, i.e. 2040. The time step of this allocating procedure is yearly. In consideration of the three scenarios, there were three land demand parameters prepared. Among the proposed scenarios, the first scenario, BAU, assumed the ongoing trend of landuse change with any spatial policy, whereas PRP and CO assumed variable rate of landuse change and implementation of spatial policy.

For the spatial policies, the restricted areas were generated for where landuses changes would not be allowed. The potential riceland and conservation zones were the two raster maps of restriction area applied for the PRP and CO scenarios (Table 2). The potential zone for riceland was derived from the highly suitable area for rice, and the conservation zone was derived from combined-forest (protected forest, nature reserve and conservation forest, productive forest, and limited productive forest). The land conversion elasticity was the reversibility parameter of landuse change required for land allocation in the model with the values ranging from 0 (easy to change) to 1 (irreversible change). The high value was assigned for the urban area because this landuse type is not likely to be converted. The elasticity of forest, plantation, mix vegetation, rice, urban, waterbody and barren were 0.62, 0.65, 0.60, 0.50, 1.00, 0.80 and 0.40, respectively. Meanwhile, the landuse transition setting was the parameter that managed land allocation in the model. The parameter was arranged in a matrix, which has value

"1" for landuse type pairs allowed to process and value "0" for landuse type pairs not allowed to process or a constaint. This arrangement was direct the algorithm of an iterative process in Dyna-CLUE (Verburg et al. 2005). Figure 3 below summarizes the procedure of landuse change simulation.

The Kappa accuracy, as the predictive accuracy measurement, was performed to validate the landuse model. There were two maps used, the reference map of 2018 resulting from the classification process and the predicted map of 2018 resulting from BAU scenario (Adam et al. 2013; Tilahun and Teferie 2015).

Table 2. The scenario description for landuse projection in 2040.

	Business as Usual (BAU)	Potential Riceland Protection (PRP)	Conservation Land Protection (CO)
Landuse projection (2040)	Follows the trend of existing conversion rate (-1.41% for forest; +2.69% for plantation; -0.31% for mix vegetation; -1.44% for rice; +4.73% for urban; -3.04% for waterbody and -0.41% for barren)	The trend of conversion rate will follow: -0.69% for forest; -1.05% for plantation; -0.84% for mix vegetation; +1.64% for rice; +2.33% for urban; -1.58% for waterbody and -12.17% for barren)	Same as the trend of BAU scenario with protect forest and others conservation area in specific conservation zone
Spatial policy	No restriction area	No land conversion allowed on the potential riceland area	No land conversion allowed on the conservation zone

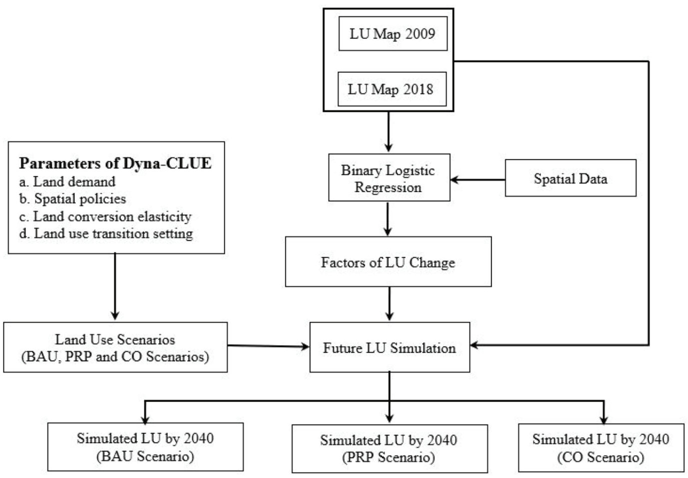

Figure 3. Method to simulate future landuse change.

2.3.3. Assessment of future rice production sustainability

The future rice production sustainability for every scenarios (BAU, PRP and CO) at district level was determined by following five steps: (a) counting total riceland area at district level from simulated-landuse using split raster tool, (b) quantifying the total rice production by considering the total riceland area, the cropping index (2 times/yr), productivity (6.0 t/ha) and lost-production during harvesting and post-harvesting (54%) (BPS-SumateraUtara 2018), (c) projecting the total number of population at district level in 2040, which was derived from geometric model (see Supplementary, Table S1), using equation given below (Agusalim 2016), (d) calculating the total rice consumption for every district by considering the total number of population in 2040 and the total consumption per capita at the rate of 131.64 kg/yr) (Andani, 2018; Pramono et al. 2015; Sari, 2014; Zaeroni and Rustariyuni, 2016), (e) measuring the status of rice sufficiency for every district by subtracting the total rice production with the total rice consumption, and (f) identifying the sustainability level of rice production for every district (Table 3).

$$P_t = P_0\,(1+r)^t \quad (3)$$

and

$$r = \left(\frac{P_t}{P_0}\right)^{\frac{1}{t}} - 1 \quad (4)$$

where:

P_t = Total population in year t
P_0 = The number of populations in the base year
r = Growth rate per year assumed to be constant
t = The distance of time (years) from P_0 to P_t

As the long-term goal of food sustainability is to produce food needs of the present generation without any compromising the ability of future generation to get their own needs; thus it requires focusing on food production and food consumption (Capone et al. 2014; Morawicki and Díaz González 2018). The interpretation of rice production sustainability level adopted in this study is given in Table 3 (Fusco et al. 2014).

Table 3. Classification and interpretation of rice production sustainability level.

Level of Sustainability	Interpretation
Very High (Sustainable)	Indicator of the healthy district, where there is more than 25% the surplus level of rice production. No serious strategic action changes and implementation needed.
High	Indicator of very good condition, where there is up to 25% the surplus level of rice production. A small number of strategic actions and implementation are needed.
Moderate	Indicator of generally good condition, where there is up to 25% the shortage level of rice production. However, there are some indicators that needed to be considered. Thus, a policy is needed to design to manage the condition.
Low	Indicator of high-stress condition, where there is up to 50% the shortage level of rice production. There were so many problems which occurred in socio-economic, environmental and government policy. Thus, great efforts must be implemented including the precise policies to handle all issues. A long-term strategic plan should be generated at this level.
Very Low (unsustainable)	Indicator of highly degraded resources and poor management system, where there is more than 50% the shortage level of rice production. The long restoration together with an integrated plan should be made. Collaboration between society and government should be strengthened to achieve the integrated plan goals.

3 Results

3.1 Landuse classification and landuse change

The classification accuracy gives the level correctness of the classified image. The total of 176 ground-truthing points were used to check the accuracy of classified image. The overall accuracy of the landuse classification for the year 2018 was 87.5% (Kappa Coefficient 0.85) indicating a satisfactory accuracy level of classification. Kappa Coefficient is more than 0.8 categorized as good classification performance, while 0.4 – 0.8 categorized as moderate and less than 0.4 as poor classification performance (Adam et al. 2013).

Comparing the trend of landuses overtime, rice and forest were the dominant landuses in 2009 covering 29.46% and 28.33% of the total area, respectively. The landuse changes occurred in 2018, plantation became the dominant landuse that covered 31.89%, while forest and riceland decreased and covered 25.63% and 24.73% of the total area, respectively. In line with the trend of plantation, urban areas gradually increased more than twofold by 20,834 ha in 2018 (Figure 4). The classified landuse images of 2009 and 2018 show the changes in the forest, plantation, rice and urban clearly (Figure 6 (A) and (B)).

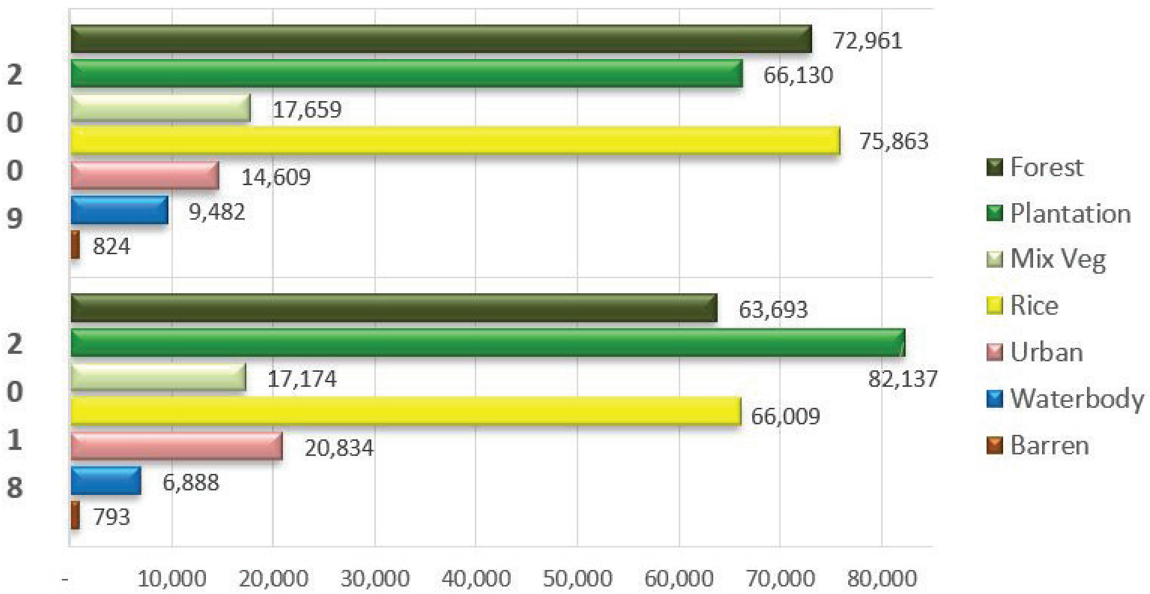

Figure 4. The coverage of classified landuse (ha) in 2009 and 2018.

3.2 Projected landuse for three scenarios

The binary logistic regression was performed to identify the allocation model for each landuse type in the future. The result showed that not all factors significantly contributed to the suitability of pixels for each landuse type, except for mix vegetation (Table 4). Especially for the forest, all factors share significant influence, except for the factor of potential riceland. The factors of non-potential riceland, slope, and elevation share the highest β value of forest by 0.607, 0.065 and 0.007, respectively. It indicates that the majority of forest was located in these zones. Unlike all significant factors for the forest, the factors of the distance to the stream and population density have a negative relationship. It indicates that the area closer to the stream and the less population density had more forest area.

All driving factors contributed significantly to the plantation, rice, urban, waterbody and barren, except the factor of non-potential riceland. The elevation, slope, distance to the main road and population density shared a negative influence on the plantation specifically. It means that the expansion of plantations did not deal with the existence of these factors. In addition, the factor of potential riceland provided the highest positive contribution (β value) for the plantation, rice and urban by 0.429, 0.645 and 0.579, respectively. It indicates the expansion of these three landuse types preferred on the factor of potential riceland zone.

The calibration of landuse prediction model from driving factors was proved by the ROC values, which could be observed in Table 4. The values ranged from 0.63 (mix vegetation) to 0.88 (urban). All the models were satisfactory as a model was considered to be performing well when ROC value is above 0.50 (El-Khoury et al. 2014; Verburg et al. 2002).

The different output of the three scenarios in predicting future land use by 2040 can be observed in Figure 5 and Figure 6 (C), (D) and (E), which is derived from dynamic land use change, resulting from the Dyna-CLUE model. Under the BAU scenario, the plantation and urban expansion continuously grew and covered 44% and 15% of the total area, respectively. On the other hand, riceland drastically decreased, almost 40% from 2018 to 2040. In the second scenario, the PRP scenario made a success to protect and to increase the total of riceland area, which is reached 31% of the total area. Furthermore, this scenario made a success to decrease the total plantation area by 28% compared with the existing condition in 2018. The result from the CO scenario is quite similar to the BAU scenario. The plantation is still the dominant landuse which covered 40% of Deli Serdang Regency, followed by forest and riceland by 22% and 17%, respectively. Unfortunately, total riceland area in this simulation is smaller than the riceland condition in 2018, which is decreased by 32%.

Table 4. Coefficient of location factors of each landuse from binary logistic regression

Variable	Forest	Plantation	Mix Vegetation	Rice	Urban	Water Body	Barren
Constant	**-1.984**	**-2.483**	**-0.615**	**0.358**	**-1.068**	**-1.484**	**-5.066**
β value							
- Elevation	0.007	-0.002	-0.0015	-0.00009	0.0003	-0.004	0.001
- Slope	0.065	-0.024	-0.035	-0.1008	-0.162	-0.065	-0.068
- Dist. to main road	0.00007	-0.00005	-0.00005	-0.00007	-0.0001	0.00003	-0.0002
- Dist. to stream	-0.0001	0.0001	-0.00006	0.00007	0.00008	-0.0002	0.0001
- Dist. to dist. capital	0.00002	0.00001	-0.00001	-0.00002	-0.0002	0.00006	-0.00003
- Dist. to reg. capital	0.00002	0.000004	0.00001	-0.00002	-0.00004	0.00003	0.00001
- Dist. to prov. capital	0.0003	0.00003	0.000009	-0.00005	-0.00005	-0.00002	-0.00005
- Population dens.	-0.0003	-0.00019	0.00004	0.00005	0.0003	0.0001	-0.0003
- Potent. riceland	ns	0.429	-2.283	0.645	0.579	-1.03	0.357
- Non-potent. riceland	0.607	ns	-2.423	ns	ns	ns	ns
ROC	**0.86**	**0.68**	**0.63**	**0.83**	**0.88**	**0.81**	**0.76**

ns = not significant at 0.05 level

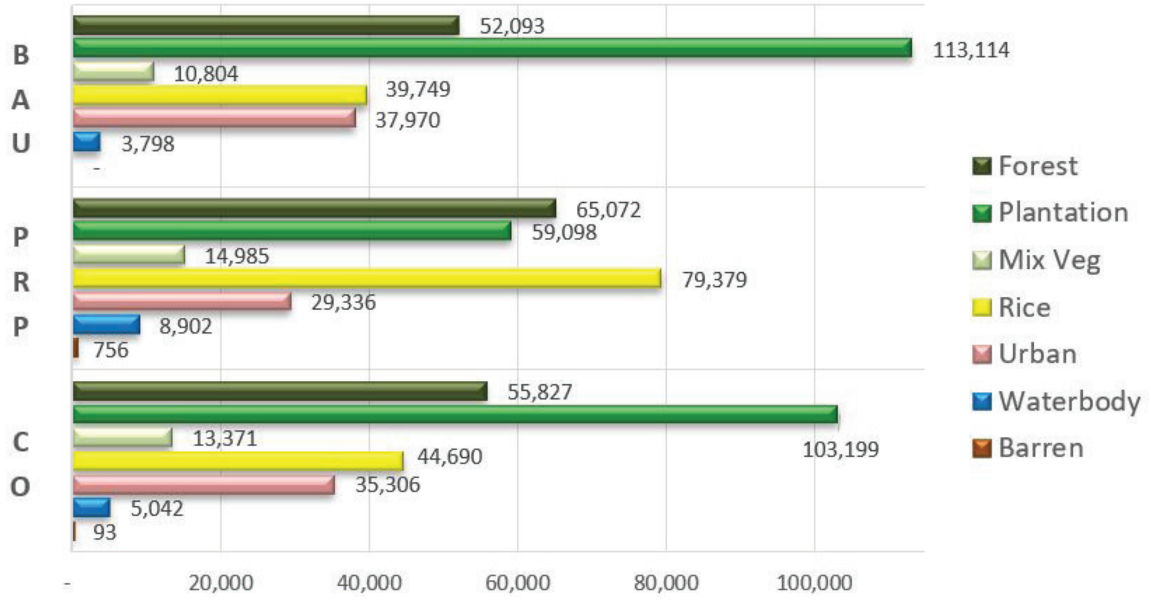

Figure 5. The coverage area of simulated landuse of BAU, PRP and CO scenarios (ha) by 2040.

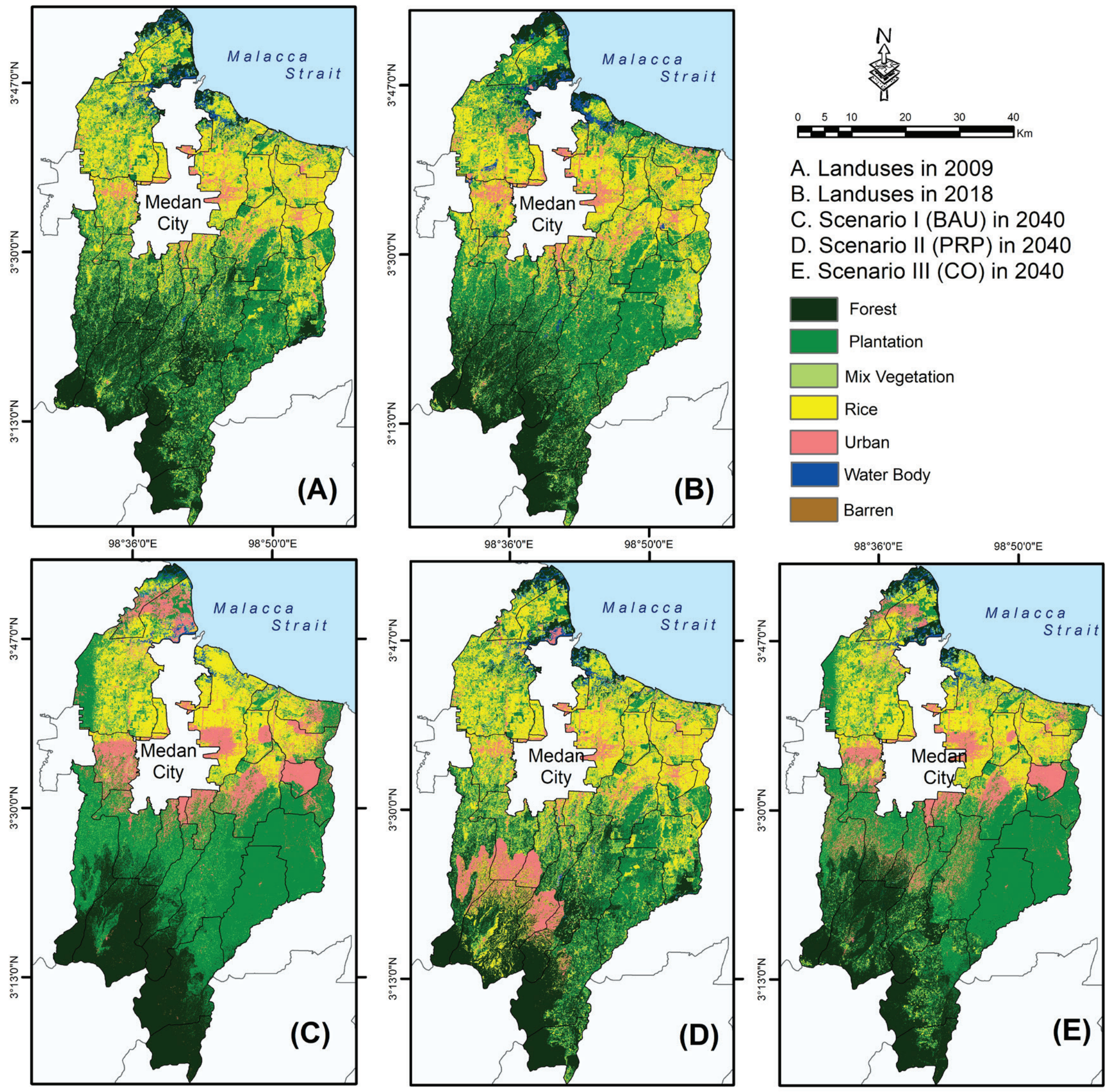

Figure 6. The classified landuse map of 2009 (A) and 2018 (B) and the simulated landuse map for 2040 at BAU (C), PRP (D) and CO (E) scenario.

3.3 Future rice production sustainability under three scenarios

The evaluation of future rice production sustainability was measured under all three scenarios. The evaluation was able to a) identify the districts with high and low of total riceland and production in future, b) identify the districts with high and low total rice consumption, c) identify the rice production sustainability level of each district, and d) find the knowledge base to develop strategic solutions for addressing the sustainability of future rice production.

3.3.1. Rice production sustainability based on BAU Scenario

Table 5 presents the total area of riceland, rice production, the total population, total rice consumption, and the level of rice production sustainability based on the BAU scenario at district level. It can be observed that there were 11 districts with no riceland anymore and 2 districts have riceland below 2 ha by 2040. Concerning population projection by 2040, the Percut Sei Tuan District and Sunggal District, have the highest population accounting to 23.73% and 14.06% of the total population of Deli Serdang Regency, respectively (Table S1). In line with the total population, the highest rice consumption in 2040 will come from these districts by 121,485.92 and 72,000.40 ton of rice, respectively. On the other hand, Gunung Meriah and STM.Hulu districts have the lowest population and rice consumption in 2040. According to the classification of rice production sustainability, most of districts are categorized in the level of very low sustainable and only 4 out of 22 districts are categorized in the level of high and very high sustainable (Table 5 and Figure 7).

3.3.2. Rice production sustainability based on PRP Scenario

As the PRP scenario aims to protect potential riceland, all districts will have the remaining riceland area in 2040 under this scenario. The smallest and largest of riceland area came from Deli Tua District and Hamparan Perak District by 257 and 17,053

Table 5. Rice production sustainability of Deli Serdang Regency by 2040 based on BAU scenario.

District	Riceland (ha)	Rice Production (ton) (a)	Total Population (people)	Rice Consumption (ton) (b)	Balance (a-b)	Status of Sufficiency (%)	Sustainability Level
Gunung Meriah	0	0	3,401	447.51	-447.51	-100	Very Low
S.T.M. Hulu	0	0	23,426	3,082.89	-3,082.89	-100	Very Low
Sibolangit	1.3	8.19	33,187	4,367.46	-4,359.27	-99.8	Very Low
Kutalimbaru	0	0	66,021	8,688.39	-8,688.39	-100	Very Low
Pancur Batu	0	0	166,708	21,938.73	-21,938.73	-100	Very Low
Namo Rambe	0	0	115,880	15,249.77	-15,249.77	-100	Very Low
Biru-Biru	0	0	66,491	8,750.25	-8,750.25	-100	Very Low
S.T.M. Hilir	0	0	65,217	8,582.57	-8,582.57	-100	Very Low
Bangun Purba	0	0	33,457	4,402.99	-4,402.99	-100	Very Low
Galang	0	0	92,590	12,184.91	-12,184.91	-100	Very Low
Tanjung Morawa	2,007.7	13,053.39	403,815	53,142.08	-40,088.69	-75.4	Very Low
Patumbak	0.9	5.85	232,528	30,600.62	-30,594.77	-99.98	Very Low
Deli Tua	0	0	121,184	15,947.77	-15,947.77	-100	Very Low
Sunggal	1,032.8	6,714.85	547,116	72,000.40	-65,285.55	-90.67	Very Low
Hamparan Perak	13,426.5	87,293.54	296,987	39,083.51	48,210.02	123.35	Very High
Labuhan Deli	3,727.8	24,236.66	131,359	17,286.91	6,949.75	40.20	Very High
Percut Sei Tuan	11,619.8	75,547.36	923,145	121,485.92	-45,938.57	-37.81	Low
Batang Kuis	2,344.5	15,243	149,841	19,719.12	-4,476.12	-22.69	Moderate
Pantai Labu	2,731.6	17,759.71	78,859	10,377.86	7,381.85	71.13	Very High
Beringin	2,815.7	18,306.82	111,717	14,702.02	3,604.80	24.51	High
Lubuk Pakam	0	0	145,840	19,192.52	-19,192.52	-100	Very Low
Pagar Merbau	40.4	262.73	81,306	10,699.93	-10,437.20	-97.54	Very Low
TOTAL	39,749	258,432.10	3,890,077	511,934.1			

Rice production = a*2.0*6.0*0.54 or total area of rice*cropping index*productivity*harvesting-lost
Rice consumption = c*0.191 or total population*consumption rate
Status Sufficiency = ((a-b)/b)*100% or ((rice prod- rice cons)/ rice cons)*100%

Table 6. Rice production sustainability of Deli Serdang Regency by 2040 based on PRP scenario.

District	Riceland (ha)	Rice Production (ton) (a)	Total Population (people)	Rice Consumption (ton) (b)	Balance (a-b)	Status of Sufficiency (%)	Sustainability Level
Gunung Meriah	401	2,607.14	3,401	447.51	2,159.64	482.59	Very High
S.T.M. Hulu	1,189	7,730.40	23,426	3,082.89	4,647.51	150.75	Very High
Sibolangit	3,802	24,719.08	33,187	4,367.46	20,351.62	465.98	Very High
Kutalimbaru	2,974	19,335.76	66,021	8,688.39	10,647.37	122.55	Very High
Pancur Batu	2,515	16,351.52	166,708	21,938.73	-5,587.21	-25.47	Low
Namo Rambe	1,732	11,260.77	115,880	15,249.77	-3,989	-26.16	Low
Biru-Biru	1,408	9,154.25	66,491	8,750.25	404.01	4.62	High
S.T.M. Hilir	2,165	14,075.96	65,217	8,582.57	5,493.40	64.01	Very High
Bangun Purba	1,687	10,968.20	33,457	4,402.99	6,565.21	149.11	Very High
Galang	3,939	25,609.80	92,590	12,184.91	1,3424.9	110.18	Very High
Tanjung Morawa	5,128	33,340.20	403,815	53,142.08	-19,801.88	-37.26	Low
Patumbak	1,781	11,579.35	232,528	30,600.62	-19,021.27	-62.16	Very Low
Deli Tua	257	1,670.91	121,184	15,947.77	-14,276.86	-89.52	Very Low
Sunggal	4,062	26,409.50	547,116	72,000.40	-45,590.9	-63.32	Very Low
Hamparan Perak	17,053	110,871.78	296,987	39,083.51	71,788.27	183.68	Very High
Labuhan Deli	3,880	25,226.21	131,359	17,286.91	7,939.3	45.93	Very High
Percut Sei Tuan	9,659	62,798.95	923,145	121,485.92	-58,686.97	-48.31	Low
Batang Kuis	2,728	17,736.36	149,841	19,719.12	-1,982.76	-10.05	Moderate
Pantai Labu	4,075	26,494.02	78,859	10,377.86	16,116.16	155.29	Very High
Beringin	4,299	27,950.38	111,717	14,702.02	13,248.36	90.11	Very High
Lubuk Pakam	1,945	12,645.61	145,840	19,192.52	-6,546.91	-34.11	Low
Pagar Merbau	2,700	17,554.32	81,306	10,699.93	6,854.39	64.06	Very High
TOTAL	79,379	516,090.51	389,0077	511,934.13			

Rice production = a*2.0*6.0*0.54 or total area of rice*cropping index*productivity*harvesting-lost
Rice consumption = c*0.191 or total population*consumption rate
Status Sufficiency = ((a-b)/b)*100% or ((rice prod- rice cons)/ rice cons)*100%

ha, respectively. The PRP scenario provides its best performance by giving double rice production compared to the BAU scenario. It could be recognized that there were 9 districts only in Deli Serdang Regency which were found to have riceland shortage, i.e. the rice production could not fulfil the consumption demand. Fortunately, Deli Serdang Regency still has 4,156 t of surplus rice production in 2040 that come from 13 rice-surplus districts, which is categorized in the level of high and very high sustainable (Table 6 and Figure 7).

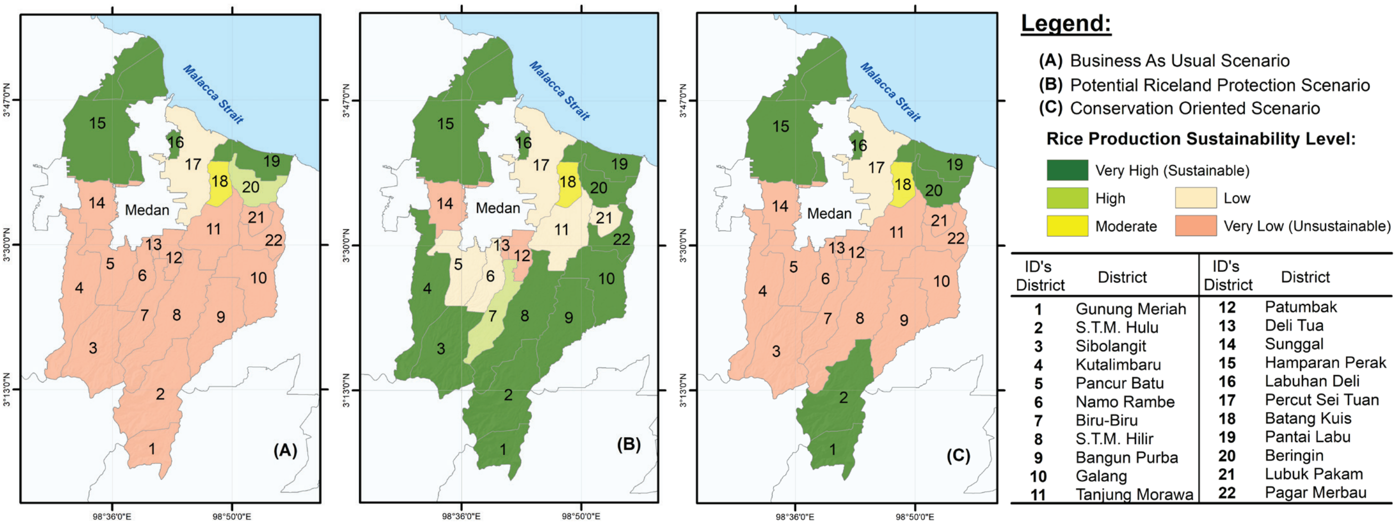

Figure 7. Rice production sustainability map at BAU (A), PRP (B) and CO (C) scenario by 2040.

Table 7. Rice production sustainability of Deli Serdang Regency by 2040 based on CO scenario.

District	Riceland (ha)	Rice Production (ton) (a)	Total Population (people)	Rice Consumption (ton) (b)	Balance (a-b)	Status of Sufficiency (%)	Sustainability Level
Gunung Meriah	146.34	951.44	3,401	447.51	503.94	112.61	Very High
S.T.M. Hulu	752.67	4,893.56	23,426	3,082.89	1,810.66	58.73	Very High
Sibolangit	311.13	2,022.84	33,187	4,367.46	-2,344.62	-53.68	Very Low
Kutalimbaru	229.77	1,493.87	66,021	8,688.39	-7,194.51	-82.81	Very Low
Pancur Batu	15.12	98.30	166,708	21,938.73	-21,840.43	-99.55	Very Low
Namo Rambe	15.3	99.47	115,880	15,249.77	-15,150.30	-99.35	Very Low
Biru-Biru	305.28	1,984.81	66,491	8,750.25	-6,765.44	-77.32	Very Low
S.T.M. Hilir	327.78	2,131.09	65,217	8,582.57	-6,451.47	-75.17	Very Low
Bangun Purba	104.49	679.35	33,457	4,402.99	-3,723.64	-84.57	Very Low
Galang	3.06	19.89	92,590	12,184.91	-12,165.01	-99.84	Very Low
Tanjung Morawa	2,777.58	18,058.71	403,815	53,142.08	-35,083.37	-66.02	Very Low
Patumbak	96.03	624.35	232,528	30,600.62	-29,976.27	-97.96	Very Low
Deli Tua	2.34	15.21	121,184	15,947.77	-15,932.56	-99.90	Very Low
Sunggal	2,108.25	13,707	547,116	72,000.40	-58,293.40	-80.96	Very Low
Hamparan Perak	14,641.7	95,194.48	296,987	39,083.51	56,110.96	143.57	Very High
Labuhan Deli	3,369.51	21,907.21	131,359	17,286.91	4,620.30	26.73	Very High
Percut Sei Tuan	9,536.49	62,002.44	923,145	121,485.92	-59,483.48	-48.96	Low
Batang Kuis	2,529.54	16,446.06	149,841	19,719.12	-3,273.06	-16.60	Moderate
Pantai Labu	3,312.99	21,539.74	78,859	10,377.86	11,161.88	107.55	Very High
Beringin	3,891.96	25,303.97	111,717	14,702.02	10,601.95	72.11	Very High
Lubuk Pakam	0.63	4.10	145,840	19,192.52	-19,188.43	-99.98	Very Low
Pagar Merbau	212.04	1,378.60	81,306	10,699.93	-9,321.33	-87.12	Very Low
TOTAL	44,690	290,556.5	389,0077	511,934.13			

Rice production = a*2.0*6.0*0.54 or total area of rice*cropping index*productivity*harvesting-lost
Rice consumption = c*0.191 or total population*consumption rate
Status Sufficiency = ((a-b)/b)*100% or ((rice prod- rice cons)/ rice cons)*100%

3.3.3. Rice production sustainability based on CO Scenario

Under the CO scenario, all districts will have remaining riceland although the total area was smaller compared with the PRP scenario. The largest riceland area was found in Hamparan Perak and Percut Sei Tuan by 33% and 21% of the total riceland area, respectively. Based on the classification of rice production sustainability, 6 out of 22 districts are categorized in the level of very high sustainable (Table 7 and Figure 7). This scenario output is still better than the BAU scenario.

4 Discussion

4.1 Landuse change (2009 – 2018)

The landuses change in 2009 – 2018 has occurred in Deli Serdang Regency, especially in the forest, plantation, riceland and urban (Figure 4 and Figure 6 (A) and (B)). Many factors behind the landuse change in this regency, such as the unstoppable population increase (Table S1), the low economic income, and the low awareness of the environment. The higher income opportunity from the plantation sector caused farmers convert their riceland to the plantation commodities, especially oil palm (Margono et al. 2014; Schmid et al. 2021). The oil palm expansion and urban development also have changed the mangrove forest in some areas of the eastern coast of Sumatera (Basyuni et al. 2018). Accordingly, urban expansion also occurred during this time period due to the influence of the construction of the new airport, Kuala Namu Airport, and due to the Mebidangro policy. To support the airport and policy, the infrastructure developments, such as roads, hotels, and warehouses are growing faster and more uncontrollable (Lindarto et al. 2018). The landuse change in the study area, which is happening due to population growth, urbanization and inappropriate policy, also occurring in some parts of developing countries, such as Yogyakarta, West and Central Java

Provinces (Indonesia), Gaibandha (Bangladesh) and An Giang Province (Vietnam) (Arjasakusuma et al. 2020; Minh et al. 2019; Partoyo and Shrestha 2013; Rana and Sarkar 2021).

4.2 Projected landuse under three scenarios

In the BAU scenario, the landuses of plantation and urban will increase and cover 44% and 15% of the total area in 2040, respectively, while the forest and riceland will decrease and cover 20% and 15%, respectively. This trend could happen because it follows the trend of existing conversion rate (Table 2). In addition, it is influenced by the contributed-driving factors. All driving factors contributed significantly to the change of plantation, riceland, and urban except the factor of non-potential riceland (Table 4). Moreover, the driving factor of potential riceland shares the highest positive contribution (β value) for these three landuses (0.429, 0.645, 0.579), which means that these three landuses expansions are preferred on the potential riceland zone. This is the main reason why the riceland is drastically decreased in this scenario.

Table 4 also describes that the factors of distance to the stream, population density, and potential riceland have positive contributions to the expansion of riceland. It explained that the existence of the stream and potential riceland would support rice growth and together with population density near to the riceland area. Again, these factors surprisingly have a similar direction (positive contribution) to urban. Thus, there would be similar location preferences for these two landuse types. This result strengthens the issue of the decline of riceland area, which is commonly occurred in developing countries, being affected by urban sprawl (Alam et al. 2021; Partoyo and Shrestha 2013). This scenario shows that the majority of urban development itself took place near the capital regency (Lubuk Pakam) and capital province (Medan City), and also in the densely populated districts as well (Figure 6 (C)).

Meanwhile, the PRP scenario can control the urban development and manage its location where the midland zone with sparsely populated districts, such as Kutalimbaru, Sibolangit and Biru-Biru Districts, can be considered as the location for urban development (Figure 6 (D)). In addition, implementation of spatial policy to protect the potential riceland from conversion issue gives meaningful contribution to the scenario results. By controlling the plantation expansion and urban development, the riceland can reach 31% of the total area in 2040. Some previous studies also confirm how important the spatial restriction on riceland maintains food sustainability in their region (Minh et al. 2019; Wang et al. 2019).

The CO scenario itself has quite similar output to the BAU scenario, which is affected by their similar trends, and differentiate by the spatial policy only. The spatial policy gives the restriction zone on the conservation area. This scenario indeed assumed higher conservation enforcement of current policy. The expected output of the CO scenario is to protect the conservation zones mainly under forests and mangroves, which can have multiple importance related to the issues, such as CO2 emissions (Mohawesh et al. 2015), temperature increase (Guo et al. 2018), increase in runoff/ soil erosion (Mohammady et al. 2018), and declining ecosystem services value (Zang et al. 2011). Zhang et al. (2021) also proved that implementing the national environmental protection policy in China can slow down the trend of ecological land conversion.

4.3 Rice production sustainability by 2040 under three scenarios

The rice production sustainability level was determined by measuring the rice sufficiency of each district by subtracting rice production and consumption. When rice production in a particular district is expected to fulfil the consumption, means that district is at the surplus stage, while the shortage situation is shown with negative values (Panuju et al. 2013).

Table 5 and Figure 7 (A) present that more than 50% of Deli Serdang Regency area stand at a very low level of rice production sustainability (unsustainable) in the BAU scenario. It is because the majority of districts have no remaining riceland due to conversion to other landuses. Furthermore, it was influenced by the increased demand of rice due to the high population. For instance, although Percut Sei Tuan District has high rice production; unfortunately, its production could not fulfil the consumption. It is to note that Hamparan Perak, Labuhan Deli, Pantai Labu and

Beringin are the only districts in Deli Serdang Regency, which were found to have surplus rice production in 2040. Figure 7 (A) also shows that the very low sustainable districts were not only located on the highland but also the lowland. This study output is in line with Premanandh's (2011) investigation informed that food unsustainability is affected by population growth and the decline of arable land. This study also pointed out there was reducing of arable land about 2.4 ha per person in 2006 and a further reduction to as low as 1.8 ha per person is estimated by 2040 globally. By up 50% of arable land in the developing countries has declined due to population between 1960 to 2000. Moreover, half of the current arable land in the world will become unusable in 2050.

In the PRP scenario, the majority districts with low and very low levels of sustainability were influenced by urban development. It is because those districts were bordered by Medan City, the Capital City of North Sumatera Province which is displayed in Figure 7 (B). Fortunately, rice production sustainability in the future can be enhanced, the PRP scenario could serve as an appropriate solution to mitigate the food loss although only 60% of districts were classified as having a high and very high level of sustainability. This would be possible due to the higher rice production from every district to fulfil the rice consumption and also the implementation of the spatial restriction to guarantee the area of riceland against a decrease (Wang et al. 2019).

This kind of PRP scenario was ever conducted in some developing countries. They protect their potential agricultural land from conversion to maintain sustainable food production in the future. Although rice production in Bangladesh has increased three folds in the last few decades, still could not attain sustainable self-sufficiency in food due to the large number of total population (Alam et al. 2021; Minh et al. 2019). Prayitno et al (2021) state that maintaining fertile land and a robust irrigation system are some strategic actions to avoid agricultural conversion in Indonesia. Currently, along with the extremely high population and declining riceland area, the national and local governments have been working on a food estate program in three provinces, North Sumatera, Central Kalimantan and East Nusa Tenggara to enhance food sustainability in the future (Lasminingrat and Efriza 2020).

Table 3. Some strategic actions to achieve the sustainability on rice production.

Aspect	Strategic Action
Social	• Increasing the capacity building of farmers by participating in agricultural organization to increase rice productivity • Strengthening the policy to control population growth • Programming the food diversification and the action of "one day no rice"
Economic	• Stabilizing the rice price at farmers' level for keeping their prosperity and for avoiding them to change or sell their riceland • Planting high yield-rice variety to increase farmers' income • Providing insurance especially for affected-riceland by climate change and environmental issues
Environmental	• Identification, mapping, and protecting the potential riceland • Formulating strict policy on the potential riceland protection, through penalty for those breaching the laws • Rearrange the allocation of urban development through proper urban landuse management • Controlling the plantation expansion and locating in the appropriate zone • Construct and develop irrigation system and water catchment in the potential riceland area

To realize the projected outcome from the PRP scenario, there is a need for strategic actions considering all social, economic and environmental aspects (Table 8), which could help to achieve the sustainability of rice production in Deli Serdang Regency.

Considering the rice production sustainability, the CO scenario output is more sustainable than the BAU scenario. As presented in Table 7, the total of 14 districts will stand at a very low level of sustainability for this scenario, which is however less than in the case of BAU by 16 districts. It is important to note that the implementation of the spatial restriction for the conservation zone assumed in this scenario help increase more comparative sustainability than in the BAU. Although all districts have riceland area, unfortunately, the total rice production from this scenario could not fulfil the consumption demand for rice by 2040 in Deli Serdang Regency. Another advantage of implementing the restriction policy is to reduce the declining trend of landuse conversion in the conservation zone, i.e. forests and mangroves. This kind of restriction policy is ever conducted in China and shares valuable output to maintain their national environment area (Zhang et al. 2021).

5 Conclusion

Riceland is the specific ecosystem that produces rice as the staple food for Indonesian. The riceland areas are declining due to population growth, urban development, plantation expansion and the lack of policy implementation in Deli Serdang Regency, North Sumatera, Indonesia. Hence, it is important to protect the riceland areas both from ecosystem preservation and self-sufficiency in rice production point of views. This study investigated the impact on rice production sufficiency in the future by using three scenarios, Potential Riceland Protection (PRP), Conservation-Oriented (CO) and Business as Usual (BAU),), in view of historical and future landuse change as affected by number of influencing factors in Deli Serdang Regency aiming to maintain the sustainability of rice production.

The future landuse projection by 2040 of riceland area and corresponding rice production and consumption showed that it is only PRP scenario if followed will be able to protect and increase the riceland area of 79,379 ha among three scenarios evaluated. Whereas CO and BAU scenarios projected the total riceland of 44,690 ha and 39,749 ha, respectively by 2040, which is far less than the future demand. The PRP scenario offers the potential to achieve the sustainability of rice production in the future. Compared with the other two scenarios, the PRP scenario maintains the riceland area in each district with a relatively large hectarage. About 60% of the total number of districts in the study area have a chance in the high and very high level of sustainability under this scenario. On the other hand, the majority of districts that classified in the low and very low stages were affected by the higher rice consumption and urban development due to their nearness to the Capital City of North Sumatera Province. To achieve the protection of riceland as projected under PRP scenario requires the implementation of specific actions, such as reducing forest decline, controlling the expansion of plantations, and most importantly restricting potential riceland conversion to urban development. As the limitation of this study which is more concerned with the future riceland production and the projected total number of populations by 2040, it is important to also investigate the mechanism of rice market, rice distribution/trade, and other socio-economic indicators that can influence the riceland area in the future.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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5 Annex – supplementary material

Table S1. Population projection by 2040 in Deli Serdang Regency .

District	Pop. in 2003	Pop. in 2016	The Year-Range (2003-2016)	Annual Pop growth	The Year-Range (2016-2040)	Total Pop in 2040
Gunung Meriah	2,730	2,949	13	0.00595	24	3,401
S.T.M. Hulu	10,977	14,327	13	0.02070	24	23,426
Sibolangit	18,867	23,008	13	0.01538	24	33,187
Kutalimbaru	32,331	41,549	13	0.01948	24	66,021
Pancur Batu	73,918	98,367	13	0.02222	24	166,708
Namo Rambe	24,547	42,346	13	0.04284	24	115,880
Biru-Biru	29,789	39,498	13	0.02194	24	66,491
S.T.M. Hilir	25,595	35,553	13	0.02560	24	65,217
Bangun Purba	21,463	25,086	13	0.01207	24	33,457
Galang	62,185	71,520	13	0.01082	24	92,590
Tanjung Morawa	161,258	222,634	13	0.02512	24	403,815
Patumbak	65,740	102,470	13	0.03473	24	232,528
Deli Tua	52,110	70,097	13	0.02307	24	121,184
Sunggal	196,953	282,009	13	0.02800	24	547,116
Hamparan Perak	129,914	173,708	13	0.02260	24	296,987
Labuhan Deli	49,399	69,655	13	0.02679	24	131,359
Percut Sei Tuan	299,941	445,223	13	0.03085	24	923,145
Batang Kuis	41,435	65,090	13	0.03535	24	149,841
Pantai Labu	38,990	49,938	13	0.01922	24	78,859
Beringin	43,775	60,840	13	0.02565	24	111,717
Lubuk Pakam	74,138	94,033	13	0.01845	24	145,840
Pagar Merbau	30,039	42,621	13	0.02728	24	81,306
TOTAL	1,486,094	2,072,521				3,890,077