The dynamics of rice-field conversion in the surroundings Cipali toll-roads of Subang Regency

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Abstract. The increasing need of land for building roads, settlements, and other facilities leads to the changes of agricultural land to other uses. Uncontrolled changes in rice fields may negatively impact economic, social, and environmental aspects. This study aims (1) to analyze the dynamics of land-use change for lowland rice in the surrounding Cipali toll road of Subang Regency; (2) to delineate rice-fields being converted to other uses in the vicinity of the Cipali toll road; (3) to assess the impact of rice-fields conversion to rice production; and (4) to understand monitoring system for rice field conversion being implemented in Subang Regency. This research employed random forest classifier, post-classification change analysis, and analytic hierarchy process. Three Landsat imageries were used to identify change processes, span between 2000 and 2020. Random forest classifiers generated accuracy at 99%, 96%, and 96% in 2000, 2010, and 2020. The results showed a decrease of rice fields in the surrounding toll roads by 560.36 hectares from 2000 to 2010, followed by an increase in the next decade by 98.79 hectares. Revitalization of regional farm fields appears to effectively sustain production areas, albeit conversion occurred in the surrounding toll roads. Generally, rice field conversions were controlled following the regulation that was enacted to sustain land for crop production.

1. Introduction
Economic and population growths encourage infrastructure development, such as roads, industry, and settlements [1]. The need of land for constructing infrastructure and facilities at a relatively fixed supply causes competition among land uses. Land-use change becomes an important issue when the competition involving several agents with various purposes in a limited area [2]. Theoretically, less profitable land uses will be converted into more profitable ones [2]. Controlling land-use change processes is fundamental for effective conservation and management strategies as well as for obtaining a balanced model of future land use.

The likelihood of agricultural land to be converted is somewhat higher than other land uses. On the contrary, built-up area are considered irreversible, unlikely to be converted back to agricultural or forest areas [3]. For ensuring regional and national food production, controlling rice field conversion is vital. The effort is a necessary condition to warrant food security.

Policies, strategies, and efforts are required to improve the development of agricultural sector and control rice field conversion. The surveillance system to control land-use change is essential, particularly in the primary production area. As the third largest rice producer in West Java after Indramayu and Karawang, Subang regency needs this system. The rice fields of Subang Regency in 2019 was 84,570...
ha, or around 41.21 percent of the total area. In 2020 Subang Regency produced 1,365,438.30 tons rice with yield at 7,252 tons/ha [4]. Located on the north coast transportation route of West Java, Subang is highly accessible leading to rapid development and encourages land-use changes. Former studies demonstrated a decrease of rice fields in Subang Regency within 6 years (2007-2013), from 46.90 percent in 2007 to 46.75 percent in 2013 [5]. The decreasing rice fields would reduce rice production and affect food security since rice is the food staple of most Indonesians. Cipali toll road was mostly constructed on the rice fields, causing substantial conversion at the surroundings. Uncontrolled changes of rice fields may negatively affect economic, social, and environmental aspects [6]. Land-use and land cover changes are so pervasive, since it may significantly affect key aspects of earth system functioning [7]. Quantifying land-use change dynamics is important in tackling global challenges such as food security, climate change, and biodiversity loss [8]. This research aims to analyze the dynamics of land-use change for lowland rice in the surrounding Cipali toll road of Subang Regency, to describe rice-fields being converted to other uses, to assess the impact of rice-fields conversion to rice production, and to understand the monitoring system for rice field conversion being implemented in Subang Regency.

2. Methods
The study was conducted in the surrounding Cipali toll roads of Subang Regency, West Java, Indonesia, consisting of 10 sub-districts and 18 villages. The regency is located between 107°31' - 107°54' E; 6°11' - 6°49'S. The total area is 2,051.76 km² or about 6.34 percent of West Java. Subang Regency is designated as one of the primary rice producers in West Java and Indonesia, having rice fields area of 84,570 hectares in 2019 or about 41.21 percent of the region. The study area is presented in Figure 1.
This research was carried out in several stages as illustrated in the following flow chart:

![Figure 2. Research procedure](image)

Three Landsat imageries took in 2000, 2010, and 2020 were used to identify change processes. Land use classified into five classes, i.e. plantation, mixed cropland, water bodies, built-up areas, and rice fields. The image classification was processed with random forest (RF). RF is fast and easy to implement, produce highly accurate predictions, and can handle a very large number of input variables with less overfitting [9]. The method was found superior comparing to other machine learning techniques such as support vector machine (SVM), gradient boosting tree, or classification and regression tree [10]. Besides the land-use map, the image classification results a confusion matrix for accuracy assessment [11].

In this research, a monitoring system for rice field conversion being implemented in Subang Regency was investigated by Analytical Hierarchy Process (AHP). AHP has been called as one of promising techniques to quantify experts perception [12]. To formulate the decision-making, a hypothetical hierarchy was constructed based on enacted laws, as can be seen in Figure 3.

![Figure 3. Hypothetical hierarchy of monitoring system for rice field conversion in Subang Regency](image)

The experts involved in the surveys included officials of Subang Regencies in Agriculture Service, Regional Research Development Planning Agency (BP4D), the National Land Agency (BPN), Center for Appropriate Technology Development (PPTTG LIPI), and two academics of Bogor Agricultural University.
In this study, the score to indicate priorities was determined manually using Excel. The final priority was evaluated based on the score and its consistency index. A consistency ratio (CR) was to indicate the consistency of expert choices. A CR that is less than 10% shows an inconsistent choice.

3. Result and Discussion

3.1. The accuracy of classification

User's accuracy and producer's accuracy are presented in Table 1, along with overall accuracy and Kappa. Based on Table 1, the highest user's accuracy generated from datasets of 2000 was for rice field and plantation, while the lowest user's accuracy at 82% was for water bodies. This may due to the extent of water bodies that was relatively trivial comparing to other uses in the study area.

The highest producer's accuracy at 100% was for mixed cropland, water bodies and built-up areas in 2000, and water bodies in 2010. The lowest producer's accuracy was for mixed cropland by 91%. In general, overall accuracy and Kappa indicates that RF generated robust model to map land uses for three time points, 2000, 2010 and 2020 ranging from 95% to 98% for Kappa and 96% to 99% for overall accuracy. Considering that minimum accuracy for land cover/land-use maps is 85% [13], the result is reasonable for further analysis.

Table 1. User’s accuracy, producer’s accuracy, and overall accuracy (%)

| Land Use          | 2000    | 2010    | 2020    |
|-------------------|---------|---------|---------|
|                   | Users' Accuracy | Producer's Accuracy | Users' Accuracy | Producer's Accuracy | Users' Accuracy | Producer's Accuracy |
| Rice fields       | 100     | 99      | 98      | 98      | 99      | 97      |
| Plantation        | 100     | 99      | 99      | 97      | 97      | 98      |
| Mixed cropland    | 97      | 100     | 94      | 93      | 91      | 91      |
| Water bodies      | 82      | 100     | 86      | 100     | 86      | 95      |
| Built-up areas    | 98      | 100     | 94      | 97      | 95      | 98      |
| Overall accuracy  | 99.08   | 96.95   | 96.67   |
| Kappa             | 98.64   | 95.5    | 95.08   |

3.2. The Dynamics of Land-use Change at the Surrounding Cipali Toll Road

Land use at the surrounding Cipali toll road in 2000, 2010, and 2020 dominated by rice fields, with an area of 7643.01 ha, 7082.77 ha, and 7134.74 ha respectively. Generally, rice field was decreased at the surrounding toll roads with a slight increase between 2010 and 2020 due to agricultural revitalization being implemented by the regional government. The analysis showed that rice fields also experienced the greatest change among other land uses. Plantation has decreased from 3357.67 ha in 2000, to 3125.55 ha in 2010, and 1595.41 ha in 2020. Mixed cropland decreased by 4356.11 ha from 2000 to 2010 and increased by 4463 hectares in 2020. The water bodies increased by 150.06 ha from 2000 to 2010 followed by a decrease of 67.29 hectares in 2020. Meanwhile, built-up areas continued to expand from 1347.63 ha, 2063.21 ha, and 3469.44 ha respectively in 2000, 2010, and 2020. The dynamics of land use was summarized in Figure 4.
Figure 4. Land-use areas (hectares) for 2000, 2010, 2020

The classification resulted transition matrices for data pairs 2000-2010 and 2010-2020 as presented in Table 2 and Table 3. As can be seen from the table, all land uses except built-up areas changed to other types of uses. In this study, built-up areas are assumed irreversible referring to former studies. The conversion of agricultural land uses would usually be accompanied by changes in the community's economic, cultural, and political orientation [3].

Spanned from 2000 to 2010 plantations decreased by 232.12 ha, the same as rice fields which decreased by 560.36 ha. Most rice fields were converted into mixed plantation. Various studies indicated that mixed cropland was a transitions type, a common strategy for landowners to avoid breaching the regulation that prevents direct changes from rice fields to built-up areas [3]. It was indicated that Cipali toll road construction began in August 2010. The toll road was built with a length of 40,332 kilometers and a road width of 63-66 meters [14]. The use of water bodies increased by 12.84 ha, mixed plantation increased by 64.06 ha, and built-up areas increased by 715.58 ha.

Table 2. Land-use transition matrix 2000-2010

|        | Water Bodies | Plantation | Mixed cropland | Built-up | Rice Fields | Total | Losses |
|--------|--------------|------------|----------------|----------|-------------|-------|--------|
| 2000   | 45.32        | 1.56       | 12.98          | 0.27     | 77.09       | 137.22| 91.90  |
| 2010   | 9.65         | 2058.10    | 999.79         | 101.59   | 188.55      | 3357.67| 1299.57|
|        | 26.35        | 702.91     | 2617.16        | 154.04   | 791.60      | 4292.06| 1674.90|
|        | 0.00         | 0.00       | 0.00           | 1347.63  | 0.00        | 1347.63| 0.00   |
|        | 68.74        | 362.98     | 726.19         | 459.67   | 5978.72     | 7596.30| 1617.58|
| Total  | 150.06       | 3125.55    | 4356.11        | 2063.21  | 7035.95     | 16730.88|        |
| Gain   | 104.74       | 1067.45    | 1738.96        | 715.58   | 1057.23     |       |        |
| Net change | 12.84   | -232.12    | 64.06          | 715.58   | -560.36     |       |        |

From 2010 to 2020, an increase of rice field at 98.79 ha was observed. The expansion was in accordance with Medium Term of Regional Development Plan (RPJMD) of Subang Regency for 2018-2023. The policy covers increasing agricultural production by optimizing agricultural land to succeed the appointment of Subang as national rice barns. However, the extension of rice fields was
incomparable to the previous reduction. Subang Government should continuously revitalize and restore converted rice fields to strengthen food security.

Plantations continuously decreased from the previous decade by 1530.14 ha within the period of observations. Within 20 years (2000-2020) plantations including rice fields were converted into mixed cash-crops. The conversion could be as a strategy of farmers to supplement their revenue, by cultivating some profitable commodities.

Water bodies decreased by 82.77 ha. Most of water bodies turned into rice fields. This could be related to seasonal condition of rice field which is easily misclassified as waterbodies due to temporary flooding field requires during rice cultivation or semiaquatic crops being managed by combining rice growing and aqua culture. Plantation and built-up areas increased by 107.89 ha and 1406.23 ha respectively within two periods.

| Table 3. Land-use transition matrix 2010-2020 |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
|                             | 2010                        | 2020                        |                             |                             |                             |                             |                             |
|                             | Water Bodies                | Plantation                  | Mixed cropland              | Built-up                    | Rice Fields                 | Total                       | Losses                      |
| Water Bodies                | 17.90                       | 8.54                        | 10.33                       | 2.83                        | 110.46                      | 150.06                      | 132.16                      |
| Plantation                  | 6.55                        | 1089.64                     | 1228.70                     | 194.34                      | 606.31                      | 3125.55                     | 2035.90                     |
| Mixed cropland              | 7.49                        | 387.95                      | 2370.01                     | 401.20                      | 1189.47                     | 4356.11                     | 1986.10                     |
| Built-up                    | 0.00                        | 0.00                        | 0.00                        | 2063.21                     | 0.00                        | 2063.21                     | 0.00                        |
| Rice Fields                 | 35.35                       | 109.28                      | 854.96                      | 807.86                      | 5228.50                     | 7035.95                     | 1807.45                     |
| Total                       | 67.29                       | 1595.41                     | 4464.00                     | 3469.44                     | 7134.74                     | 16730.88                    |
| Gain                        | 49.39                       | 505.76                      | 2093.99                     | 1406.23                     | 1906.24                     |
| Net change                  | -82.77                      | -1530.14                    | 107.89                      | 1406.23                     | 98.79                       |

The classification and post-processing resulted land cover maps as presented in Figure 5. As can be seen from the figure, land-use changes have occurred quite massively in the sub-districts around the toll road. Built-up area increased steadily, being concentrated along main roads. Significant increase of built up areas were observed in 2020, following the Cipali toll road operation, indicating the dynamics of the economy around the Cipali toll road.

**Figure 5.** Land-use map of 2000, 2010, and 2020
The distribution of rice fields conversion to other uses (2000-2010 and 2010-2020) and agricultural to built-up areas (2000-2010 and 2010-2020) are presented in Figures 6 and 7. The figures show that the changes of rice fields to other uses and agricultural to built-up areas spreaded around the Cipali toll road. Rice fields converted to other uses at 1617.58 ha between 2000 and 2010, and it was 1807.45 ha from 2010 to 2020. The loss of rice fields lowered the opportunity to produce agricultural products and led to the declining rice production. In addition, the conversion might cause environmental damage since rice fields are catchment areas and reservoir for excess of runoff. The loss might decrease the availability of water resources in the converted land area.

Figure 6. Distribution map of changes from rice field to non-rice field uses

Figure 7. Distribution map of changes from agriculture to built-up

The change of agricultural land into built-up areas within 2000 and 2010 was 715.304 ha, and 1406.23 ha for the next decade. The former studies showed that agricultural land conversion to built-up areas in Subang Regency was influenced by several factors such as soil type, spatial pattern, and distance to the city centre [5].

3.3. The Decrease of Rice Production
The decrease in the area of rice fields from 2000 to 2010 by 560.36 ha could reduce rice production in Subang Regency. The declining rice production was due to the loss of harvested area, decreasing yields, or changing cropping patterns [15]. If the average cropping index (IP) is two times a year and the average productivity is 7.25 tons/ha [4], then the decrease of rice grain from 2000 to 2010 could be 8123.40 tons per year. Meanwhile, from 2010 to 2020, rice fields rose at 98.79 hectares, increasing production by
1432.45 tons per year. To suffice the demand, Subang Government should add up grain production at 6690.95 tons annually.

Rice fields conversion to other uses and increasing rice fields at the region appear incomparable. The growth of residential or industrial areas at the surrounding toll roads may potentially cause the shrinking of rice fields and decreasing food production in the future. As a strategic commodity and staple food for Indonesian, rice provides a source of carbohydrates for more than 200 million people. Protection of rice field is necessary to maintain sufficient production and avoiding imports, leading to self-reliance, resilience, and national food sovereignty. Considering that Subang Regency is one of the rice barns of West Java province and in Indonesia, this is an important issue to be solved.

3.4. Monitoring System for Rice Field Conversion in Subang Regency

The consistency ratio of stakeholders’ perception from the AHP for the criteria (level 2) was 0.04, while for optional strategies (level 3) was 0.07. Both indices were smaller than 0.1 which mean consistent. The results were then illustrated in three groups, i.e. government officials, academics, and general perceptions. The priority motives of monitoring system for the conversion of rice fields in Subang Regency is presented in Figure 8.

![Figure 8](image)

**Figure 8.** Important motives for monitoring system of rice fields conversion in Subang Regency, according to: (a) government officials, (b) academics, (c) general

The graph showed that there were differences in the order of priority between government officials and academics. According to government officials, the respective motives for monitoring system of rice field conversion in Subang Regency were to sustain agricultural systems, support national food sufficiency, and minimize environmental impacts. Whereas, researchers and academics said that the order should support national food sufficiency, sustain agricultural systems, and minimize environmental impacts, respectively. The experts concluded that the respective order of criteria could be to sustain the agricultural systems, support national food sufficiency, and minimize environmental impacts.

The preference of monitoring strategy to control rice fields conversion in Subang Regency is presented in Figure 9. The figure showed different priorities according to government officials and
academics. The government officials prioritized incentives for rice farmers, while academics preferred regular monitoring and evaluation as the best strategy. Generally, experts and decision-makers concluded that routine monitoring and evaluation was the best strategy, followed with incentives for rice farmers, permit mechanisms related to land conversion, disincentives to the delinquent, and community outreach.

Based on interviews, we found that current control and supervision mechanism for agricultural land, especially rice fields was ineffective. This may be due to several things, related to compliance with regulations and laws, and the management of regulations or government policy. For instances, no regulations prohibit individual landowners from converting their land, either rice fields or other uses. In addition, the law guarantees the freedom of farmers to choose plant types to be cultivated which opens the possibility to convert rice fields to other uses.

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**Figure 9.** The preference of monitoring strategies to control rice fields conversion in Subang Regency, according to: (a) government officials, (b) academics, (c) general

4. **Conclusion**

There was a substantial land-use change at the surrounding Cipali toll road of Subang Regency. The most converted land uses were rice fields and plantations. Built-up areas increased considerably in 2020, just after the built of toll roads and the start of toll operation. The economic activity appears to be highly dynamics at the surrounding Cipali toll road.

Rice fields decreased substantially in 2000-2010 by 560.36 ha, reducing grain production by 8123.40 tons per year. Nonetheless, there was a slight increase of rice fields between 2010 and 2020 by 98.79 ha, adding the grain production by 1432.45 tons per year. This disproportionate figure should be a concern of local government, especially the Subang Regency by controlling and monitoring rice fields conversion. The general conclusion of experts regarding rice fields monitoring systems indicated that respective motives to control the conversion should be to sustain agricultural systems, support national
food self-sufficiency, and minimize environmental impacts. Moreover, the strategy to be implemented to control rice field conversion in Subang Regency by respective order was routine monitoring and evaluation, incentives for farmers owning rice fields, the permit mechanism related to land conversion, disincentives for the disobediences, and community outreach. The monitoring system should be implemented effectively to maintain Subang as the center of rice production leading to national food sovereignty.

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