The impact of land-use changes and economic losses of paddy field conversion: a case study of Ciampea Sub-district, Bogor Regency, West Java Province

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Abstract. The study aims to analyze the land-use changes from paddy fields to non-paddy fields, examine the future sustainability of the paddy fields, and analyze the impact of the paddy fields' conversion on the socio-economic and environmental aspects. The study was carried out at Ciampea Sub-district, Bogor Regency, West Java Province. Conversion of paddy fields was analyzed through visual interpretation of Ciampea Sub-district 2016 and 2019 imageries using GIS software of ArcGIS 10.5. and later was used to measure the average annual conversion rate and predict the future sustainability of the paddy field, and to measure the impact of the land conversion using the economic valuation method (financial analysis and replacement cost approach). The results showed that, first, during the year of 2016 to 2019, the paddy fields in Ciampea Sub-district transformations were dominated by settlements. Second, the conversion rate was relatively high, by 51.45 hectares per annum. Third, the impact of reduction of paddy field area was relatively high: a potential loss of 3,098.06 tons of food crop production. Meanwhile, the cost for replacing the function of flood, erosion, and sedimentation control reached IDR 257.68 billion.

1. Introduction
The capital of Indonesia, Jakarta, has become a driving factor for the growth of its surrounding urban and rural areas such as Depok City, Bogor, Tangerang, Bekasi, and Cianjur Regency [1]. In Bogor Regency, for example, the population growth reached 2.13% per annum [2]. The high population growth indicates that Bogor Regency has experienced a suburbanization phenomenon. This phenomenon shows that the concentration of population and its urban supporting infrastructure move from Jakarta to its surrounding regencies [3,4,5,6,7,8,9], including Bogor.
Between 1989 and 2013, the total area converted of paddy fields in Bogor Regency reached 24,180 hectares (33.59%) [10]. Meanwhile, The Agricultural Land Statistics showed that in 2014-2018, the total area of paddy fields in Bogor Regency continued to decline, with the land conversion rate reaching 4,579 hectares per annum [11]. It can be said that in the last two decades, large-scale conversion of agricultural land in Bogor Regency is taking place, particularly the conversion of food cropland into other uses, such as for settlements, industrial estates, and different types of development of non-agricultural use [12,13,14]. These massive land-use changes become one of the strategic issues for the future regional development of the Bogor Regency.

The food cropland conversion mainly occurs in flat-land paddy fields close to settlements and public facilities [10,15]. If the transformation of paddy fields continues to happen, it will impact regional food resilience in the future. Furthermore, the transformation also implies the loss of the multi-functionality of paddy fields, both on socio-economic aspects of the community, such as job and employment creation, poverty alleviation, and rural development [16]; and on the ecological aspects such as flood control, erosion and sedimentation control, groundwater conservation, organic waste disposal, preserving biodiversity, and air purification [17,18]. The study aims to analyze the land-use changes from paddy fields to other non-paddy field uses, examine the sustainability of paddy fields in the future, and analyze paddy fields' conversion on socio-economic and environmental factors at the Ciampea Sub-District of the Bogor Regency.

2. Research Methodology

2.1. Research Area
This research was conducted in Ciampea Sub-district, Bogor Regency, West Java Province. The research site encompassed 13 villages used as a spatial unit for analysis.

![Figure 1. Research Area](image)

2.2. Land-Use Changes Analysis
The paddy field's land-use change is analyzed using the Geographic Information System (GIS) software of ArcGIS 10.5. An overview of evolution is taken by comparing SPOT 6 imagery coverage of the Ciampea Sub-district in 2016 and 2019. The SPOT 6 imageries were obtained from PUSTEKDATA Lapan. The Administrative Map, road, river, and spatial planning map of the Ciampea Sub-district were obtained from Indonesia Geospatial Portal (BIG) and Litbang Bappeda of Bogor Regency, respectively. The paddy field land-use change is also compared with the spatial plans (RTRW Kabupaten Bogor
period 2016-2036) to understand the causes of land conversion due to the overlapping land-use issue between paddy field cover and spatial planning. The future sustainability of the rest existing paddy field is analyzed by measuring the average land conversion rate per annum. The average land conversion rate is used to make a projection of the future paddy field survival period, based on the constant rate of annual land conversion and an assumption that there is no significant change in the Regency's spatial policy in the future.

2.3. Impact Analyses of the Paddy Field Conversion

The impact of the conversion is measured based on the losses of the multifunctional role of paddy fields using the economic valuation method. The data references for this analysis were obtained from secondary sources and literature studies. Economic valuation aims to estimate the values of goods and environmental services of the paddy fields that encompassed the value of direct and indirect use [19,20]. First, the two direct uses of paddy fields, food production, and employment creation, are used to calculate direct use-value using simple financial analysis. Second, the two indirect use, flood control, and erosion-sedimentation control are used to calculate indirect use-values using the replacement cost approach. The result of direct and indirect use-value is determined as the losses of the multifunctional role of the paddy field and can be presented in terms of the value of money or other relevant units of measurement.

Simple financial analysis is used to estimate the amount of potential loss of food crop production (in IDR per ha per year), the potential loss of agricultural employment opportunities (in man-day per year), and potential loss of net income from paddy productions [21]. The replacement cost approach is used to estimate the costs incurred for artificial efforts that are considered capable of replacing the lost functions of paddy fields: flood control, erosion control, and sedimentation functions [17,21,22]. Each loss of direct value/benefit of the paddy field is calculated using the equation as follows:

a. Loss of Direct Use Value: Food Crop Production

\[
DUV_{CP} = \sum_{i=1}^{n} \left[ (A_i \times CI_i \times P_i \times Pv_i) - (C_i \times A_i) \right]
\]

Where:
- CI = Cropping index (%/year)
- P = Selling price (Rp ton\(^{-1}\))
- Pv = Productivity (ton ha\(^{-1}\))
- C = Cost of production (Rp/ha)

b. Loss of Direct Use Value: Employment Opportunity

\[
DUV_{EO} = \sum_{i=1}^{n} (A_i \times CI_i \times M \times W_i)
\]

Where:
- CI = Cropping index (%/year)
- M = Workforce (man day ha\(^{-1}\))
- W = Labor wage (Rp man day\(^{-1}\))

C. Loss of Indirect Use Value: Flood Control

\[
IUV_{FC} = (BPp - BPnp) \times A \times C
\]

Where:
- BPp = Paddy field water buffer potential (m\(^3\) ha\(^{-1}\))
- BPnp = Non-paddy field water buffer potential (m\(^3\) ha\(^{-1}\))
- A = Converted paddy field area (ha)
- C = Cost Component:
Kd = Dam construction cost (Rp m$^{-3}$)  
Dd = Dam depreciation (Rp m$^{-3}$ year$^{-1}$)  
Md = Dam maintenance cost (Rp m$^{-3}$ year$^{-1}$)

d. Loss of Indirect Use Value: Erosion and Sedimentation Control

\[ IUV_{ES} = (E_{npf} - E_{pf}) \times A \times SDR \times C \]  

(4)

Where:

- \( E_{npf} \) = Erosion from the non-paddy field land-use (ton ha$^{-1}$ year$^{-1}$)  
- \( E_{pf} \) = Erosion from paddy field (ton ha$^{-1}$ year$^{-1}$)  
- \( A \) = Converted paddy field area (ha)  
- \( SDR \) = Sediment delivery ratio  
- \( C \) = Cost Component:
  - Kd = Dam construction cost (Rp m$^{-3}$)  
  - Dd = Dam depreciation (Rp m$^{-3}$ year$^{-1}$)  
  - Md = Dam maintenance cost (Rp m$^{-3}$ year$^{-1}$)

3. Result

3.1. The Spatial Distribution of paddy field area in Ciampea Sub-district.

The SPOT 6 imagery interpretation found that the paddy field area is primarily concentrated in the southern part of Ciampea. On the contrary, the paddy field is not found in the northern part of Ciampea, such as at Benteng Village and Cibanteng Village. In those two villages, the land-use is dominated by dry upland farming and settlements. By comparing the type of land-use in 2016 and 2019 (Figure 2), it
is pretty clear that the paddy field area decreased in the last three years, whereas settlements and dry upland farming increased. Bojong Rangkas and Cibadak are two villages that show those changes.

3.2. Conversion of Paddy Field and Its Future Sustainability

During 2016-2019, a total reduction of paddy fields was 205.08 hectares, promoting a change in the entire area of paddy fields by 11%. Comparing the land cover in the years 2016 and 2019 revealed that most of the paddy field was transformed into settlements (89%), dry upland farming (9%), and mixed upland farming (2%). The rest unconverted paddy fields were left 1709.15 hectares.

Figure 3 showed that the conversion of paddy fields in Bojong Rangkas Village and Cibadak Village was the most, with a proportion of loss of each village of 51% and 50%, respectively from the entire paddy field area in 2016. The driver for changes in both villages is the growing settlement area right in the centrum of the Ciampea Sub-district. Hence, both villages experienced the most converted paddy fields among the others.

![Figure 3: Total land conversion of paddy field in Ciampea Sub-district between 2016-2019](image)

During 2016-2019, many agricultural lands such as paddy fields, plantations, and dry upland agriculture have been lost due to the settlement expansion in Ciampea Sub-district. The highest loss is the paddy fields area (reached 183.89 hectares). The Bogor Regency's Spatial Plan (RTRW Kabupaten Bogor) pointed out that a large amount of land in Ciampea should be allocated for settlement rather than lowland agriculture (see Table 1). Consequently, in 2019, 73% of previous paddy field areas, particularly at Bojong Rangkas Village and Cibadak Village, have become settlement areas.

Furthermore, there is the fact that between 2016 and 2019, the inconsistency of non-paddy field landuses is increased, as the expansion of settlement, dry upland farming, mixed upland farming, and water body have overlapped the function of lowland agriculture area. The increase of overlapping irreversible settlement area, reached by 88%, was the highest among other non-paddy field land uses. That situation primarily occurred in the Village of Cicadas, Bojong Jengkol, Tegal Waru, Cinangka, and Bojong Rangkas, where the settlement expansion increased more than 50% from the previous condition in 2016.
Table 1. Comparison between paddy field and settlement land-use, and spatial planning in Ciampea Sub-district

| Land-use | Existing Area (ha) | Spatial Planning Period 2016-2036 | Proportion to Total Sub-district Area (%) |
|----------|--------------------|-----------------------------------|-----------------------------------------|
|          | 2016               | 2019                             | Allocation (ha)                         | Proportion to Total Sub-district Area |
| Paddy Field | 1,914.95           | 1,712.01                         | 1,515.88                                | 45%                                    |
| Settlement | 642.38             | 871.36                           | 1,794.95                                | 54%                                    |

According to the data from 2016 to 2019, it is estimated that the average land conversion rate of paddy fields is 51.45 hectares per annum. Assuming that land conversion continues at a constant rate per annum (without spatial policy intervention), it is estimated that in the next 34 years (the year 2053), all paddy fields in Ciampea Sub-district will be transformed entirely into non-paddy domain uses.

3.3. The Impact of Paddy Field Conversion.

3.3.1. Loss of Food Crop Production and Sources of Agricultural Income.
From 2016 to 2019, most of the paddy fields in the Ciampea Sub-district were used for food crop production such as rice and second crops, i.e., sweet potatoes, taro, and peanut. Average rice cropping index (CI) per annum in the lowland area is 150% which means that rice is cultivated once to 2 times a year, while the second crop is once a year. According to the total area converted of paddy field during 2016 to 2019, and assuming that in a year, paddy field is cultivated with rice-rice-sweet potato rotation, it is estimated that potential loss of food crop production, respectively from rice and sweet commodity was 1,918.35 tons and 1,179.71 tons.

Table 2. Average of annual food crop production, productivity, and cropping index according to commodities, Ciampea Sub-district

| Commodities | Production (ton) | Productivity (ton ha\(^{-1}\)) | CI (%) |
|-------------|-----------------|-------------------------------|--------|
| Rice        | 5,790           | 6.2                           | 150    |
| Sweet potato| 3,768           | 17.2                          | 33     |
| Taro        | 262             | 16.4                          | 2      |
| Peanut      | 26              | 1.4                           | 2      |

The potential economic loss of net agricultural income is estimated at around IDR 6.86 billion. The calculation was based on the 2019 market price. The selling price (at the farmer level) for rice and sweet potato commodities, respectively, is IDR 5 482.45 kg\(^{-1}\) of dry unhulled rice (GKP) and IDR 2 493.80 kg\(^{-1}\) of wet tubers. The cost of rice production for two growing seasons is IDR 24.79 million, and the cost of sweet potatoes production for one growing season is IDR 7.27 million.

3.3.2. Loss of Agricultural Employment Opportunity.
Based on the similar assumption of cropping pattern rice-rice-sweet potato, the total absorption of agricultural workforce from paddy fields is 470.39 man-days ha\(^{-1}\) year\(^{-1}\), consisting of 391.41 man-days ha\(^{-1}\) year\(^{-1}\) for rice cultivation, and 78.98 man-days ha\(^{-1}\) year\(^{-1}\) for sweet potato cultivation. Considering the total conversion of paddy field area from 2016 to 2019, the potential loss of workforce absorption is 96 805.35 man-days. With the average rate of agricultural labor wage in 2019 of IDR 64,590.29 man-day\(^{-1}\), it is estimated that the potential economic loss due to paddy field conversion reaches IDR 6.25
billion. This agriculture employment loss is equivalent to 372 permanent workers (assuming the effective working days for a permanent worker per year is 260 days).

3.3.3. Loss in The Capability of Flood Control.

The flood control capability is assessed based on the value of water buffer potential, which is obtained from measuring the difference between the height of the embankment and the water level before the rain. However, this measurement does not involve the contribution of water from plant interception and water absorbed in the soil pores, because the total surface area of the canopy that can intercept water is tiny, and the soil is on saturation condition, which has relatively constant water content [22].

Based on a literature study, paddy fields' water buffer potential values at 1,380 m³ ha⁻¹ [21]. Meanwhile, the water buffer potential of other land-uses such as forests, dry upland agriculture, mixed upland agriculture, and settlement/industry areas are valued at 1,510 m³ ha⁻¹, 580 m³ ha⁻¹, 480 m³ ha⁻¹, and 200 m³ ha⁻¹, respectively [22]. Therefore, assuming that the water buffer potential of agricultural land and settlements among the West Java region is relatively similar, the paddy field conversion in Ciampea Sub-district had caused 236,266.96 m³ of excess water from rainfall, which transformed into surface runoff.

3.3.4. Loss in The Capability of Erosion and Sedimentation Control.

The erosion phenomenon is a natural process that can occur in various land cover conditions, because of erosion-carrier agents [23]. In paddy fields, the highest erosion occurs during the land tillage stage, where the plowing and silting process caused the soil to be dispersed into released particles and temporarily dissolve with the flow of irrigation water. In a terraced system, different water discharges on each paddy plot may cause the upper paddy plot (near irrigation canal) to have higher soil erosion than in the lower plot. Meanwhile, erosion produced at the planting, manuring, or weeding stage will be minimal because the water flow of the paddy plot will be blocked partially or temporarily so that the soil erosion will be settled. Meanwhile, farmers will keep the embankment blocked until all water is fully drained naturally in the harvesting stage. Thus, the paddy field has the advantage of inhibiting the rate of soil erosion produced by itself and preventing soil erosion carried by upper irrigation flow [24].

Based on study literature, the average of annual erosion in the Upper Cisadane sub-watershed, in various types of land-uses such as forest, paddy fields, settlements, dryland farming, and mixed dryland farming, respectively is 7.95 tons ha⁻¹ year⁻¹, 10.14 tons ha⁻¹ year⁻¹, 9.42 tons ha⁻¹ year⁻¹, 584.98 tons ha⁻¹ year⁻¹, and 221.68 tons ha⁻¹ year⁻¹ [25]. Therefore, transforming paddy fields into dry upland farming and mixed upland farming would lead to additional potential soil erosion, 574.84 tons ha⁻¹ and 201.54 tons ha⁻¹, respectively. Meanwhile, although the soil erosion produced by settlement areas is lower than paddy fields, a transformation from paddy fields into settlements is generally preceded by transforming land into dryland or abandoned land. Therefore, in other words, the settlement area originated from the conversion of paddy fields and contributed to the formation of additional erosion of 574.11 tons ha⁻¹. Thus, the total potential of soil erosion caused by the conversion of paddy fields in Ciampea is 116,527.38 tons.

Reduction of area of paddy fields in Ciampea Sub-district causes soil particles and mud carried by erosion, to be quickly discharged into nearest water bodies around the Cisadane sub-watershed. Thereby it is potentially increasing the total sediment that settled in water bodies. The total deposit formed can be calculated by multiplying the erosion value from each land-use transformation of land-use with an SDR (sediment delivery ratio) of 8.5%. Hence, the total value of additional sediment formed is 9,904.83 tons.

3.3.5. The Replacement Cost of Flood, Erosion and Sedimentation Control.

Loss of environmental functions of paddy field contributes to the vulnerability of Cisadane sub-watershed to flood risk through increased potential runoff water and sediment. Therefore, it may need prevention and control activities that create costs. Paddy fields are naturally produced environmental
functions of flood, erosion, and sedimentation control. However, later, those environmental functions must be shifted to other artificial infrastructures assumed equally to replace paddy fields.

Assuming that the local government does not yet prepare any infrastructure that aims to control the risk of flood, erosion, and sedimentation, one of the most feasible plans to suppress the risks is to utilize the capacity of water bodies. However, the Upper Cisadane sub-watershed capacity to accommodate surface runoff water and sediment is gradual decreases due to river silting and sedimentation [26,27,28]. Thus, the infrastructure that can represent the formation of replacement costs is building a new dam that can accommodate the excess of surface runoff water and sedimentary soil resulting from additional erosion. By assuming that the capability of several dams, to accommodate excess runoff and sedimentary soil, in West Java Province are relatively similar, it is possible to estimate control costs required by calculating under the scenario of with and without constructing a new dam.

Table 3. The potential economic losses of flood control due to paddy field conversion in Ciampea Sub-district

| Scenario | Type of Land Conversion | Area (ha) | Loss of Water Buffer Potential (m³ ha⁻¹) | Economic Losses (billion IDR) |
|----------|------------------------|----------|------------------------------------------|-------------------------------|
| ND       | P > UA                 | 17.52    | 900                                      | 16.50                         |
|          | P > MUA                | 4.39     | 800                                      | 3.68                          |
|          | P > S                  | 183.89   | 1,180                                    | 227.14                        |
|          | **Total**              | **205.80**| **2,880**                                | **247.32**                    |
| WND      | P > UA                 | 17.52    | 900                                      | 0.24                          |
|          | P > MUA                | 4.39     | 800                                      | 0.05                          |
|          | P > S                  | 183.89   | 1,180                                    | 3.35                          |
|          | **Total**              | **205.80**| **2,880**                                | **3.64**                      |

Notes: Scenario under New dam development (ND), without new dam development (WND). Type of land conversion: Paddy field to dry upland agriculture (P > UA), paddy field to mixed upland agriculture (P > MUA), paddy field to settlement (P > S)

Table 4. The potential economic losses of erosion and sedimentation control due to paddy field conversion in Ciampea Sub-district

| Scenario | Type of Land Conversion | Area (ha) | Additional Erosion (ton ha⁻¹) | Sediment Formation (ton) | Economic Losses (billion IDR) |
|----------|------------------------|----------|-----------------------------|--------------------------|-------------------------------|
| ND       | P > UA                 | 17.52    | 574.84                      | 855.97                   | 0.896                         |
|          | P > MUA                | 4.39     | 201.54                      | 75.21                    | 0.079                         |
|          | P > S                  | 183.89   | 574.11                      | 8,973.65                 | 9.393                         |
|          | **Total**              | **205.80**| **1,350.49**               | **9,904.83**             | **10.368**                   |
| WND      | P > UA                 | 17.52    | 574.84                      | 855.97                   | 0.013                         |
|          | P > MUA                | 4.39     | 201.54                      | 75.21                    | 0.001                         |
|          | P > S                  | 183.89   | 574.11                      | 8,973.65                 | 0.138                         |
|          | **Total**              | **205.80**| **1,350.49**               | **9,904.83**             | **0.153**                     |

Notes: Scenario under New dam development (ND), without new dam development (WND). Type of land conversion: Paddy field to dry upland agriculture (P > UA), paddy field to mixed upland agriculture (P > MUA), paddy field to settlement (P > S)

The total replacement cost needed to carry out flood control in Ciampea Sub-district through new dam construction reaches IDR 247.32 billion. However, flood control can still be carried out without
constructing a new dam, for example, by optimizing the use of the existing dam but still carrying out maintenance costs and dam depreciation per m$^3$ year$^{-1}$, with an estimated replacement cost of IDR 3.64 billion per annum. Under a similar scenario, the total replacement cost needed to carry out erosion and sedimentation control reaches IDR 10.37 billion with a new dam building. In contrast, the replacement cost of controlling erosion and sedimentation without constructing a new dam is IDR 152.80 million per annum.

4. Conclusion

From 2016 to 2019, most of the paddy fields in the Ciampea Sub-district have already transformed into settlements. This situation occurs with the support from The Bogor Regency's spatial planning, which has allocated the valuable paddy field area in Ciampea less than the settlement area. Consequently, in 2019, the paddy fields only left a small fraction of land and located within the settlement area. The conversion of the paddy fields area to non-agriculture uses directly and indirectly impacts. Several pieces of evidence are found in this research as follows.

First, in Ciampea Sub-District, the average conversion rate of paddy fields reached 51.45 hectares per annum. Assuming that land conversion continues at a constant rate in the future, and there are no changes in the spatial planning policy of the Bogor Regency, hence it is estimated that in the next 34 years (2053), all paddy fields in Ciampea Sub-district will be wholly transformed into non-paddy field domain. If adequate governance is not present, the future of food crop production of the Ciampea Sub-District is unsustainable.

Second, the paddy fields conversion is more than about losing potential food crop stock. Reduced agricultural employment opportunities and increased risk of surface runoff and sedimentation lead to floods are considerable impacts and risks of the loss of paddy fields area. Further, the potential economic losses will be even more significant in the future, especially losses arising from environmental aspects. A study of economic losses from wider multifunctional aspects of paddy fields is needed as this research has limited resources to implement it.

Lastly, this study can contribute to determining the proper governance and method for controlling paddy field conversion for future sustainable food development, not only for Ciampea Sub-district and Bogor Regency but also for all paddy areas throughout Indonesia.

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