Dynamic models of water conservation in sustainable palm oil plantations

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Abstract. The development of Oil Palm Plantations (OPP) in Indonesia faces problems related to land availability and environmental damage. Changes in the hydrological conditions of The Lalindu Watershed in Konawe Utara Regency are caused by the reduction in the extent of forest cover in the river border areas as OPP increase. The purpose of this study is to design a model of OPP to support the conservation of water resources to maximize the ecological, economic and social benefits of land use activities, especially for OPP in watersheds in a sustainable manner. The research method uses a dynamic system model using a number of variables, which are the determinants of OPP sustainability, loop systems, and future behavior models. The results showed that the water conservation model in sustainable OPP consisted of three sub-models, namely: (1) environmental sub-models. The actions of OPP conservation affect the resulting infiltration capacity and runoff discharge so that the OPP will be sustainable. In addition, it can increase the population growth of Anoa (Bubalus spp) and Sulawesi Bear Kuskus (Ailuropsursinus) by 10% as an effort to protect biodiversity, especially Southeast Sulawesi's endemic fauna, (2) sub-economic models. Oil Palm Plantation activities with conservation efforts were able to increase production by an average of 0.86% while OPP without conservation only increased by 0.78%. Corporate income also increases on average 0.8-1.2% per year, farmers 0.76% and RBR 1.24% and (3) social sub-models, will increase the number of workers involved in OPP operations by 0.7% per year while the number of head of a family for the livestock and compost business declined from 2005-2018 with an average percentage of 5.1% and 4.1% and the following year was stagnant. In the activities of rattan cultivation, there was no increase in percentage.

1. Introduction
Indonesia is the largest producer of Crude Palm Oil (CPO) in the world so that it makes a real contribution to the social and economic development of the nation. In 2018, Indonesia was able to export 34.71 million tons of CPO and its derivative products or equivalent to US $ 32.18 billion. In 2019, Indonesian palm oil production touched more than 43 million tons. Around 5.5 million workers are absorbed inside the palm oil industry. However, various negative accusations such as deforestation, forest fires, decline biodiversity and degradation of hydrological conditions [1].

Hydrological conditions in The Lalindu Watershed in the Wiwirano District, Konawe Utara Regency, Southeast Sulawesi has decreased due to reduced area forest cover on the river borders with increasing oil palm plantations. The expansion of oil palm plantations continues to occur and...
is spread almost in all of the North Konawe Regency. Besides soil, palm plantations are managed by the private sector and do not involve the community so that they have not contributed significantly to the welfare of the community [2]. The upstream part of the Lalindu River Basin is the most important area in the Lalindu watershed system as a whole. Upstream the Lalindu watershed changing has implications for downstream areas.

The vision of sustainable development must be implemented in efforts to conserve water in oil palm plantations in the Lalindu watershed. The use of oil palm plantations in the Lalindu watershed must be maintained in its ecological, economic and social functions. The dynamic model system is one model to simulate the balance of ecological functions [3]. Dynamic simulations are observing the behaviour of ecological systems on interventions continuously [4]. Stella’s software is used to simulate the system. This study aims to develop a dynamic model of water conservation in oil palm plantations that is ecologically, economically and socially sustainable to maintain the preservation of natural resources and the environment in the District of Wiwirano.

2. Dynamical System Model

The design of water conservation models in sustainable oil palm plantations is arranged in 3 subsystems, as presented in Figure 1.

- Ecological/environmental subsystem, assessing the impact of changes in land cover on runoff discharge, infiltration capacity, and endemic Southeast Sulawesi fauna population such as Anoa (Bubalusspp) and Sulawesi Kuskus Bear (Ailurops ursinus).
- The economic subsystem examines the impact of community and company economic activities in increasing farmers’ income and oil palm productivity which affect the increase in Regional Budget Revenues (RBR).
- Social subsystem examines labor absorption and the role of community activities, the role of families conducting economic activities in oil palm plantations such as raising livestock and rattan businesses that can affect cooperative institutions and entrepreneurs.

The modeling system is explained as a causal loop, as in Figure 2.

![Figure 1. Water conservation model for sustainable oil palm plantations](image-url)
The initial conditions of the water conservation system in sustainable oil palm plantations illustrate the threat of an increase in the expansion of oil palm plantations [5], causing an increase in water discharge in the Lalindu watershed.

2.1. Ecological/environmental sub-model

Ecological/environmental sub-model in water conservation for oil palm plantations is the main model of the system. This model compares the benefits obtained from oil palm plantations with conservation and non-conservation treatments in the area of oil palm plantations. The variables and parameters used are described in Table 1.

| No  | Variable and Parameter         | Dimension | Value     | Explanation         |
|-----|--------------------------------|-----------|-----------|---------------------|
| 1.  | Palm plantation area           | Hectare   | 5.966,7   | Analysis result     |
| 2.  | Reeds area                     | Hectare   | 3.220     | Analysis result     |
| 3.  | Forest area                    | Hectare   | 10.813,03 | Analysis result     |
| 4.  | Percentage of cover crop in oil palm plantations | % | 100 | Analysis result |
| 5.  | Rainfall                       | mm/year   | 4.320     | Secondary data      |

2.2. Economic Sub Model

The economic sub-model is to simulate the value and production from conservation treatment. The variables and parameters used are described in Table 2.
Table 2. Variable and parameter in economic sub model

| No  | Variable and Parameter                        | Dimension | Value       | Explanation        |
|-----|-----------------------------------------------|-----------|-------------|--------------------|
| 1   | Conservation palm area                        | Hectare   | 4,176.879   | Analysis result    |
| 2   | Non conservation palm area                    | Hectare   | 1,890.091   | Analysis result    |
| 3   | Palm oil with conservation productivity       | kg/hectare| 1.602.03    | Analysis result    |
| 4   | Palm oil non-conservation productivity        | kg/hectare| 455,34      | Analysis result    |
| 5   | Rattan productivity                           | kg/hectare| 320         |                    |
| 6   | Cow productivity                              | tail/ hectare | 0,12 | Secondary data |
| 7   | Compost productivity                          | kg/hectare | 1,2         | Secondary data    |
| 8   | Price of cow                                  | IDR/tail  | 8,000,000   | Secondary data    |
| 9   | Rattan prices                                 | kg/hectare | 2,500      | Secondary data    |
| 10  | Palm prices                                   | IDR/kg    | 1,382,16    | Secondary data    |
| 11  | Compost price                                 | IDR/kg    | 650         | Secondary data    |

2.3. Social Sub Model

The social sub-model simulates how conservation treatment in the area of oil palm plantations can increase the number of workers and benefit from secondary businesses [6], such as cattle ranching, compost, and rattan cultivation. The oil palm plantation business is carried out by involving the community as workers for conservation activities. Other community social activities are efforts to use rattan from conservation forests. In addition, the community carries out livestock rising and compost management on Alang-Alang (Imperata) grass.

The existence of oil palm plantations also contributes to the level of community welfare. The benefits of the economic aspect are (1) expanding employment and business opportunities; (2) improve the welfare of the surrounding community; (3) contribute to regional development. Variables and parameters used in social sub-models are presented in Table 3.

Table 3. Variable and parameter of social sub model

| No  | Variable and Parameter                        | Dimension      | Value         | Explanation        |
|-----|-----------------------------------------------|----------------|---------------|--------------------|
| 1   | Conservation palm area                        | hectare        | 4,176,89      | Analysis result    |
| 2   | Non conservation palm area                    | Hectare        | 1,790,091     | Analysis result    |
| 3   | Forest area                                   | Hectare        | 10,813,03     | Analysis result    |
| 4   | Reeds area                                    | Hectare        | 3,220         | Analysis result    |
| 5   | Number of workers in conservation palm oil    | KK/ hectare    | 0,1           | Secondary Data     |
| 6   | Total compost labor                           | KK/ hectare    | 0,01          | Secondary Data     |
| 7   | Number of cattle business workers             | KK/ hectare    | 0,01          | Secondary Data     |
| 8   | Number of rattan workers                      | KK/ hectare    | 0,01          | Secondary Data     |
| 9   | Number of afdeling workers                    | KK/ hectare    | 2             | Secondary Data     |

3. Simulation and Analysis

3.1. Ecological Sub Model

Land cover patterns affect changes in water in the watershed system [7,8]. Simulation results show that the area of oil palm plantations has increased. On the other hand, there is a reduction in land area from the standing reeds. Reducing water runoff and infiltration capacity in watersheds (see Figure 3).
There is a difference in runoff discharge and infiltration between oil palm plantations with conservation treatment and without conservation treatment. Oil palm plantations with conservation treatment have a better pattern so infiltration change and tend to increase when compared to oil palm plantations without conservation treatment. Runoff discharge on conserved palm oil yields slower when compared to oil palm without conservation treatment. This change ultimately affects the flow pattern of the river flow [9,10]. It further affects the ecology and sustainability of oil palm plantations (see Figure 4).

The conservation treatment of oil palm plantations is carried out by planting cover crops with legumes and mulch [11]. The effect of legume and mulch plants on discharge and infiltration capacity is shown in Figure 5a. Resulting in lower runoff discharge and increased infiltration capacity. Leguminosae plants are reducing data round 6 years of age so that further conservation efforts are carried out with mulch. Also, runoff discharge decreased more than the legume treatment. Likewise for infiltration capacity, mulch treatment infiltration capacity is higher when compared to legume treatment. In addition, changes in land cover also affect the growth of fauna. The decrease in forest area affects the decrease in the population of Anoa (Bubalussp) and Sulawesi Kuskus Bear (Ailurops ursinus)as protected species of fauna (Figure 5b).
3.2. Economic Sub Model
Dynamic system simulations for the economic sub-model in Figure 6 show that oil palm production and income on conservation land have increased. For palm oil conservation, average production increased by about 0.86% and non-conservation palm oil by around 0.78%. In addition, company income increased by about 0.8 - 1.2% per year, farmers’ income increased by around 0.76% and Regional Original Income also increased by around 1.24%.

3.3. Social Sub Model
Dynamic system simulations for social sub-models illustrate the number of workers and cooperatives has increased. This means that there are various activities in the oil palm plantation sector which are directly proportional to the increase in employment. In addition, it also increases the growth of cooperatives that provide a forum for farmers to distribute their crops. The number of workers
involved in the exploitation of oil palm plantations around 0.7% per year while the number of households for cattle ranching and composting has decreased by around 5.1% and 4.1% (see Figure 7 for details).

![Simulation for household and cooperatives](image)

(a) Number of working household  
(b) Garden cooperatives

**Figure 7.** Simulation for household and cooperatives

4. Conclusion

The water conservation model in sustainable oil palm plantations consists of three sub-models, namely: (1) ecological sub-models, (2) economic sub-models, (3) social sub-models. In the ecological sub-model, there is an increase in the population of the Anoa (*Bubaluspyr*) and Sulawesi Kuskus Bear (*Ailurops ursinus*), which reaches around 10%. In the economic sub-model, there was an increase in production of about 0.86% for conservation palm oil and non-conservation palm oil around 0.78%. In addition, the company's income increased by an average of 0.8 - 1.2% per year, farmers' income by around 0.76%, and Regional Original Revenues by 1.24%. Dynamic system simulations for social sub-models illustrate the number of workers and cooperatives have increased. The number of workers involved in oil palm plantation exploitation around 0.7% per year.

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