Governing Landscape in Way Khilau Micro-Catchment, Lampung Province

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Abstract. Indonesia has strived to combat land degradation towards viable watershed management. Watershed management at a regional scale confronts many challenges as well as socio-ecological conditions. Landscape is defined as physical boundary, a system and a holon. Landscape approach has been recognized as a multiscale mapping unit that reflects the socio-ecological dynamics within the system. Landscape services assessment offers a broader understanding of socio-ecological dynamics for local stakeholders. This study aims to provide a better understanding of building spatial decision-making through the landscape approach at Way Khilau micro-catchment scale. The study area is about 1.162 Ha and is located in the upper basin of Way Bulog, Lampung Province, Indonesia. Driver-Pressure-Impact-Response (DPSIR) framework was used to map the landscape services within the watershed qualitatively. The result showed major physical drivers such as relief configuration took control on the hydrological services. Way Khilau micro-catchment arranged by parallel-narrow ridge, undulating to very steep slope, and valley. Both ridge and slope played a role for the hydrological regulation services and the lowest part provided water resources for the socio-economic activity. Further research of environmental changes needs to be assessed quantitatively to determine the impact of stakeholder’s responses on socio-ecological issues.

1. Introduction

Indonesia has strived to combat environmental degradation towards various management scenarios (see Figure 1). Watershed has become a new paradigm in management planning at regional scale since 1981 (Sudaryono, 2002). Watershed can be defined hydrological system that physically Indonesia consists of 17.088 watersheds which has heterogeneous characteristics. Integrated watershed management is basically implemented to achieve sustainable goals. However, watershed management at regional scale confronts many challenges such as land use change in Brantas watershed (Astuti, 2017); critical land in Randangan Watershed (Suparwata, 2017) and Juwana Watershed (Surtiani & Budiani, 2015); institutional conflicts in Citanduy Watershed (Sudaryono, 2002); and socio-economic conflicts in Citarum Watershed (Kurniasih, 2002). The complexity of both institutional and bio-physical problems hamper to achieve sustainable development goals (Kadri, 2005; Saridewi et al., 2014; Pratama et al. 2017; Pambudi, 2019), lead to land degradation exacerbation.
Figure 1. Policy Scenarios to Encounter Land Degradation at Watershed Level in Indonesia

Landscape approach has been recognized as a tool in achieving sustainability at watershed scale. Landscape can be defined as physical boundary shaped by natural process (Wysokci et al., 2011), a socio-ecological system Westrink et al. (2017); (Kozar et al., 2014) that have same dominant attributes and processes based on the scale of observation (Cullum et al., 2016). Consequently landscape dynamics are influenced by spatiality of landscape elements (Freitas, 2003; Sayer et al., 2013; Kozar et al., 2014; Westrink et al., 2016). Interaction between natural and socio-economic element within the environment form socio-ecological relation (Fagerholm, 2019) that are reflected by landscape services abundance (Fagerholm et al., 2020). Assessment of landscape services offers a broader understanding about socio-ecological process. Landscape services plays role as communication tool to bridge scientific and local stakeholder perspectives (Iverson et al., 2014). Thus, landscape approach emerges as a collaborative management which considers local knowledge through adaptive learning processes (de Graaf et al., 2017). Landscape approach stresses policy integration (Jordan & Lenschow, 2010) of multi-level stakeholder (Kusters et al., 2020), known as landscape governance. Landscape governance aims to achieve balance function as production, consumption and conservation in the landscape system.

Availability of spatio-temporal data challenges in assessing landscape processes at undeveloped areas (Maryani et al., 2015). Driver-Pressure-State-Impact-Response (DPSIR) Framework is a conceptual thinking which allows to simplify a complex relation between societal and natural system. Interaction between physical elements (Drivers) and human activities (Pressures) leads to change the environment (States). Eventually, various impacts (I) influence human in action to manage natural resources (Responses) that relate to sustainable living (Kagalou, 2012). DPSIR initially use for environmental report and usually embed with a practical tool such as dynamic system, Pentatope Model, score matrix etc (Benini et al., 2010; Vannevel, 2018; Rosini & Revelli, 2020 ). The Driver-Pressure-Impact-Response (DPSIR) framework was conducted to assess the socio-ecological process within the landscape (Vannevel, 2018). DPSIR reflects both a causal-effect relationship between environmental attributes and a communication tool for link between public policy and societal community. Therefore, DPSIR is considered as a holistic approach in the spatial decision-making process at watershed level.

Micro-catchment, the unit of watershed, emerges as a pilot project in watershed management through Perdirjen Rehabilitasi Lahan dan Perhutanan Sosial No. P. 15/V-Set/2009 Menhut about Micro-catchment management. Micro-catchment approach emphasizes a collaborative management to achieve balance.
outcomes (Purwanto et al., 2016). The Watershed Management Planning (Rencana Pengelolaan DAS Tahun 2019-2023) document, called RPDAS, represents landscape governance, as a tool to encounter environmental degradation in Indonesia. RPDAS consists of both rules and institutional map. Hence, RPDAS needs to be spatially implemented as a holistic spatial-planning tool, this paper aims to provide a better understanding in building spatial decision-making through landscape approach. Investigates, how the landscape is maintained in micro-catchment by the government. We intend to answer the question by mapping ecoservices and valuing RPDAS implementations in a micro-catchment area using DPSIR framework.

2. Material and Method

2.1. Study Area

Way Khilau micro-catchment is about 1.162 Ha which is situated in Bayas Jaya village, Way Khilau District, Lampung province (5°32’00”- 5°35’00” S dan 104°58’00”- 105°00’00” E). Way Khilau micro-catchment is the upper part of Way Sekampung Watershed with mean slope >21°. Terrain condition shows parallel ridge covering the upper and middle part of catchment, while the lower part consists of undulating configuration. The catchment has tropical monsoon climate with the temperature range 25-30°C and annual rainfall up to 2500 mm/yr. Since 1981, land conversion has been vividly occurred due to increasing population. Forest land has been altered into agricultural land (cocoa, coffee plantation, and paddy field). In 2020, forest land covers 25% of area, while agroforest system with Multipurpose Purpose Tree (MPTS) such as cocoa and coffee plantation predominantly covers 40% of micro-catchment area. Thus, socio-economic condition depends on forestry and agriculture sectors. Cocoa and coffee supply for approximately 60-70% of the household income. Based on BPS data, population of Bayas Jaya in 2020 is 986 household or 3,906 inhabitants. PAMSIMAS, a local community of Bayas Jaya manages the distribution of clean water to every household. Springs are the main clean water resources, beside the water river are used for agricultural activities. The location of Way Khilau micro-catchment can be seen in Figure 2.
2.2. Data Collection

In this study, preliminary data derived from previous CCCD Project by the cooperation between Environment and Forestry Ministry and local government. To complete the data on ecosystem services and DPSIR attributes, we tried to collect information based on Participatory Environmental Appraisal (PEA) methodology. PEA allowed various method in collecting information based on local community’s point of view (Rioux et al., 2017; Rezvanafar & Veisi H, 2007). In this investigation, participatory mapping and structured interview were used to collect data according to the key person. Key person were the local stakeholders such as village chief, committee of SCU Lampung, chief of PAMSIMAS and GAPOKTAN. Local stakeholder took a role as both subject and object of watershed management planning.

2.3. Landscape unit delineation

Landscape can be determined as discrete feature on earth surface according to homogeneity of biophysics attribute at scale and time (Zonneveld, 1989). Interaction between environmental attributes formed Hillslope position and watershed as spatial unit took role in . Hillslope position were practically used to explained spatial variability of hydrological fluxes. Recent studies showed that interaction soil-vegetation characteristics on the hillslope influence runoff generation in the watershed (Azuka & Igüé, 2020; Bachmair & Weiler, 2012). Hillslope position defined Therefore, we assumed that hillslope position influence spatial variability of landscape services in the watershed.
Manual delineation method

Manual delineation used in landscape mapping. The approach used is the break of slope change and uniformity of characteristics (rock, morphology, hydrology) used by (Manfré et al., 2015) (see Figure 3).

2.4. The DPSIR Framework

DPSIR analysis was used to evaluate the Way Khilau Watershed Management Plan (RPDAS) 2019-2023. Determination of DPSIR indicators were based on Bradley & Yee (2015) (see Figure 4).

3. Results and Discussions

3.1. Landscape of Way Khilau Micro-catchment

Way Khilau micro-catchment can be seen as a hierarchical landscape system. Catchment as a whole system arranged by a composite of smaller landscape units. Landscape unit of Way Khilau could be distinguished according to various factor i.e. real factor, conditional factor, positional factor and hereditary factor. Positional factor of landscape unit could represent spatial variability of energy fluxes between landscape
unit and its environment. Hillslope position mostly determined as landscape unit to explain hydrological fluxes in catchment (MacMillan et al., 2000; Cullum et al., 2016). Hillslope position determined a composite of terrain characteristics such as slope gradient slope position, hillslope process that control on soil distribution (Miller & Schaetzl, 2014). Interaction between soil-vegetation influenced water flow downslope to the reach. Hillslope position is one of the factors controlling water-related ecosystem services (Chen et al., 2021) The relationship between hillslope position and hydrological services in the watershed had been studied by previous researchers (Band, 1989; Band et al., 2000; Moore et al., 1988 Moore & Grayson, 1991; Moore et al., 1993a; Moore et al., 1993b O'Loughlin, 1981; O'Loughlin, 1986; O'Loughlin, 1990)...
Slopes could be defined as an adjacent area, connecting ridges and river valleys, and has inclination greater than about 1%. (The National Committee on Soil and Terrain, 2009). Slopes area of way khilau had varied inclination. The upstream area arranged by >55° of slope gradient, whereas downstream area reached >25°. This may influenced on physical soil properties, further influenced on hydrological response of each landscape unit. The land cover was dominated by natural forest and conversion areas. Vegetation cover depicted human-induced on spatial variability of surface runoff in the catchment. Cocoa and coffee plantation with complementary crops such as chili, jackfruit, avocado, banana, pecan durian and others, whereas shrub cover vegetation sporadically patterned over the landscape. Forest cover on the slope area changed into mix gardens such as cocoa, coffee and pepper. Land use changes characterized by vacant land and shrub land which spread sporadically. Thus, interaction between slope element and biophysical properties influenced on hydrological response of micro-catchment.

Water and sediment transport widely took place over the slope areas. Slopes properties (i.e. slope elements, vegetation cover and physical soil properties) tend to controlled typical surface runoff and subsurface flow (Vivoni et al., 2007; Angermann et al., 2017). Previous study showed that slopes area had highest range of C value (0.4-0.5) (CCCD, 2018). Thus, higher surface runoff triggered severe erosional process. Hillslope processes was quite intensive, indicated by the existence of gully erosion over the slope areas. The depth of gully erosion was approximately 0.3-0.6 m. Gully erosions were found in residential areas and mixed gardens (coffee) on a moderate to hilly slopes. Gully erosion was one of the transport media for water- and sediment yield into the river. Therefore, the presence of gully affected on hydrological characteristics, especially the accumulation of surface runoff. The following gully erosion on slope area could be seen in Figure 6.

**Figure 6** Hillslope process in Way Khilau micro-catchment was spotted found at slopes and valley landscape unit.

River valley characterized by >55° of slope gradient at the upper and 3-8° of slope gradient at the lower part of micro-catchment. Land cover was varied, indirectly controlled by slope inclination. Upper part of micro-catchment dominated by mixed gardens and grasses, whereas lower part covered by settlement areas and paddy fields. This condition may lead soil formation in river valley. Based on filed survey soil depth on steep area was shorten rather than undulating valley at the lower part of micro-catchment. Thus, may influenced surface runoff that occurred over the landscape. River valleys of upstream area had higher C value (0.2-0.4) rather than at the downstream area (0.2-0.3) (CCCD, 2018).

Valley system arranged by connected drainage system due to erosion and sedimentation processes. Way Khilau was characterized by narrowed steep-valley at the upstream and widening valley due to
sedimentation process. Flow accumulation generated by cyclic process in the watershed that resulting water yield. Based on the interviews, flows characteristics of the Way Khilau river flew throughout the year. Therefore, rivers and springs became the main sources of clean water. Springs spatial distribution was spotted found at the transition area between valleys and slopes. Springs were used as a provider of clean water sources for domestic and drinking water needs, while river water was used to irrigation, fisheries and domestic water needs. The following characteristics of each landscape unit of Way Khilau micro-catchment could be seen in Table 1.

| Land unit             | Kode | Area (%) | Slope | Soil properties                      | Landuse          | Geomorphic process                                                                 |
|----------------------|------|----------|-------|--------------------------------------|------------------|-----------------------------------------------------------------------------------|
| Undulating ridge     | IBr  | 7.80     | 0-10  | soil depth: 60-100 cm; texture: clay loam | Forest, MPTS, shrub | Not observed                                                                      |
| Hilly slope          | LBB  | 58.08    | 25-60 | soil depth: 60-100 cm; texture: clay | Forest, MPTS, shrub, bareland | moderately to severe erosion rate indicated by gully erosion existence with 0.3-0.6 m in depth, anthropogenic process due to land clearing process |
| Rolling slope        | LBo  | 7.56     | 10-23 | soil depth: >100cm; texture: clay    | MPTS, shrub     |                                                                                   |
| Moderately undulating slope | LBk | 14.19    | 3-23  | soil depth: ±100 cm; texture: clay | MPTS, shrub     | riverbank landslide existence in some spots, erosion process dominantly occurred   |
| Steep valley         | VBb  | 9.02     | 25-60 | soil depth: ±62 cm; texture: clay   | Forest, MPTS, shrub |                                                                                   |
| Undulating valley    | VBr  | 3.35     | 0-10  | soil depth: ±100 cm; texture: clay loam | Paddy field, MPTS, settlement | localized splash erosion indicated by pedestal existence, transportation process, anthropogenic process due to settlement development |

3.2. Valuing Watershed Management Plan of Way Khilau 2019-2023 using DPSIR Framework

Landscape governance of Way Khilau micro-catchment represented in Watershed Management Plan 2019-2023 (Rencana Pengelolaan DAS/RPDAS). RPDAS document entailed two dimension of landscape governance such procedural and substantive dimension. Procedural dimension involved in decision-making process, while substantive dimension included management framework to regulate landscape function (van Oosten et al., 2019). Institution map dealt with clarification of rights and responsibilities of each stakeholder as main actor of management process (Sayer et al., 2013). RPDAS of Way Khilau maintain the management of natural resources to achieve sustainability, by involving multi-stakeholder. Problems based on service potential and environmental problems in the watershed, RPDAS becomes a tool that bridged various parties to be directly involved as management actors. Multi-stakeholder involvement in the Way Khilau RPDAS is expressed in the form of the distribution of rights and obligations in the management process. The following is the Mapping of Policies and Institutions in the 2019-2022 RPDAS. The RPDAS document highlighted forest and land rehabilitation (Rehabilitasi Hutan dan Lahan / RHL) as main program to combat land degradation. The eight main programs can be seen in Table 2.
Table 2 showed land and forest rehabilitation (RHL) entangled both vegetative and mechanical conservation. This study tried to valuing soil and water conservation using DPSIR Framework, primary MPTS plant as the common kind of conservation that implemented in Indonesia. MPTS mostly planted to control erosion and sediment budget, simultaneously improve economic condition of micro-catchment. Since, agriculture and forestry became main income for inhabitants. Meanwhile, primary mechanical conservation concerned on sediment trapping in the channel level by installing gully plug and erosion control dam. In fact, conservation installed at specific site, hence spatial analysis of sediment sources or erosion process necessarily to be measured. Based on field survey there were two types of vegetative conservation which were installed at slopes landscape unit (MPTS) and river valley (KAKISU or riparian vegetation). MPTS was planted on steep slope area due to high erosion indication, while kakisu alongside the river valley. To assess the impact of MPTS plan on socio-ecological function, DPSIR contained framing the driver-pressure-impact-state of micro-catchment both directly and indirectly influenced by the implementation of MPTS plantation.

The implementation of RPDAS required spatial considerations so that it is more targeted. Therefore, DPSIR was used as a practical framework for the Way Khilau micro-catchment management plan in the form of a matrix. DPSIR was a complex framework involving the interaction of various environmental elements. DPSIR had the ability to map the relationship between community responses to environmental changes, so DPSIR was widely used as a communication tool for all levels of society in the context of environmental conservation.
management. The relationship of the community's response to changes in elements could simply be presented in the form of a matrix. The matrix model had been developed as a tool to see the interaction between environmental elements. We tried to analyze DPSIR framework for each landscape unit in Way Khilau micro-catchment. Therefore, it allowed to depict an interaction of socio-ecological function between landscape unit. The following DPISR analysis of Way Khilau micro-catchment could be seen in Table 3.

Table 3 DPSIR Analysis of Way Khilau Micro-Catchment

| Landscape unit | Drivers | Pressures | States | Impacts | Responses |
|----------------|---------|-----------|--------|---------|-----------|
| Undulating Ridge | Slope gradient up to 10° | land clearing | forestry: non timber forest products and timber forest products | Moderate surface run off | habitat of mammals | loss of endemic species | Reforestation |
| | Landuse: forest, mps, shrub | forest alteration into agricultural land | cacao production | Moderate sediment yield | wild animal disturbance | Flora fauna preservation and conservation |
| | Soil depth : 60-100 cm | illegal logging | coffee production | moderate erosion class | decreasing of croplands productivity | |
| Undulating slope-steep slope | Slope gradient up to 55° | land clearing | forestry: non timber forest products and timber forest products | moderate to severe erosion class | Batu Pera Site | habitat of mammals | landslide hazard potential | AgroSilvopasture |
| | Landuse: forest, mps, shrub, settlement | forest alteration into agricultural land | cacao production | sediment yield | loss of endemic species | Reforestation |
| | Soil depth : >60 cm | illegal logging | coffee production | high rate of surface runoff | wild animal disturbance | Flora fauna preservation and conservation |
| | | | water yield | | decreasing of cropland productivity | PAMSIMAS |
| River valley undulating slope (0-10°) | Settlement development | food production : paddy field, fisheries, herbal vegetation | watered slope: morphometry gradient of river, drainage density, Keunumau waterfall as a tourist destination | habitat of mammals and birds | water quality : sediment yield up to 3000 mg/l in rain screen | PAMSIMAS |
| | Landuse: settlement area, paddy field | Poverty and education | main water clean resources for domestic use and irrigation | dimension of channel related to maximum discharge | home industries | flood hazard had been occurred in 2017 | Kakisu plantation (riparian vegetation) |
| | Soil depth : 60-100 cm | Accessibility | moderate erosion class | Gully plug and Dps |
| | morphometry of catchment | Population growth | sediment yield | Community capacity building |
| | waterfall existence | Moderate of surface runoff | PAMSIMAS |

Source: CCCD (2020); Duryat (2018); Diantari (2018)

Table 3 showed that each landscape unit has different characteristics such as relief configuration, vegetation, soil properties at medium scale. Landscape characteristics determined as the main driving factor and influenced socio-ecological function (Martin-Lopez et al., 2017). Generally, socio-ecological system of Way Khilau particularly influenced by relief configuration and soil characteristics, while land cover mostly had a same pattern for each landscape unit. Forest and agroforest system mostly dominated at the upperwhile, lower part of micro-catchment dominated by settlement area and paddy field. Forest and agroforest system covered 25% and 61% of micro-catchment area. Cocoa and coffee became main crop, ultimately over the ridge and slope area. Land use change took role as pressure to the environment. Land clearing particularly occurred at steep slope area and ridge area. Deforestation rate in 2018 reached 11.09 Ha/year while agroforest area was extended up to 8.32 ha/year (Duryat, 2018).

Interrelationship between socio-ecological elements was depicted by landscape services and disservices pattern in each landscape unit (Opdam, 2019). Ridge area took role as regulating function on water related ecosystem services (WES) and provide direct provisioning services related to food production. Slope area...
took a role in both regulating and direct provisioning services (WES and food production). There were several springs which were managed by the local community, called PAMSIMAS. Spring was the main water resources for the Bayas Jaya inhabitant, which had discharge 5 lt/s in dry season. Generally, spring water was used for clean water resource, while other water needs were mostly extracted from the river. River valley played role on flood regulating services and provided non drinking water resources. Channels dimension played role to regulate the river discharge capacity and and channel gradient influenced time of concentration of peak-flow discharged at the outlet (Mokarram & Sathyamoorthy, 2015). Channel and catchment gradient of Way Khilau River were 0,07 and 39,05% respectively, therefore the time of concentration was about 1,75 hr based on calculation using HSS GAMA method. Meanwhile, ecosystem disservices showed by surface runoff and erosion rate over the landscape. Forest alteration led to land degradation, particularly at ridge and slope area. By the field survey in 2021, showed that land clearing tend to occurred on the steep slope. Massive land clearing area affected on high surface runoff coefficient and erosion rate. Slope area particularly had the highest surface runoff coefficient. Surface runoff coefficient of ridge, slope and valley area were ranged 0.2-0.3; 0.4-0.5; 0.2-0.4 respectively. Higher surface coefficient led to high erosion class, especially on the steep slopes, indicated by gully erosion existence (Figure 6). Thus, mitigation and adaptation programs emerged as community’s response to achieved balance outcome at micro-catchment level, which was documented in RPDAS Way Khilau Micro-catchment 2019-2023. Land and Forest Rehabilitation (RHL) was main program that was intended to address land degradation and deforestation. RHL divided into vegetative and mechanical programs. Vegetative programs included agroforest system and vegetative riparian (Kanan Kiri Sungai/KAKISU) intended addressing surface hydrology and sediment fluxes, such as surface runoff regulation and erosion control. Agroforest system plantation mostly planted over the ridge and slope areas, while Kakisu program installed alongside the river channel using bamboo plant. Mechanical programs mainly addressed to mitigate flood hazard. Several gully plugs and DPn had been installed to control sediment yield in the river channel. Besides, incentive mechanism such adaptation programs essentially implemented to achieve balance outcomes, between natural and social system. Adaptation programs such as water treatment, community capacity building, and food security programs focussed on overcoming poverty and community dependence on natural resources.

4. Conclusion

Way Khilau micro catchment consist of three landscape units: ridge, slope, and valley. Characteristic of each landscape unit influenced the socio-ecological process. Complex interaction between biophysics and socio-economics elements influenced on ecosystem services and disservices spatial pattern in Way Khilau micro-catchment. Ridge area tend to provide regulation, while slope area and river valley provided direct provisioning services and regulation services, especially on water related ecosystem services.

Valuing watershed management planning using DPSIR on each landscape unit allowed to show the spatial planning based on the interrelation between socio-economic and natural process within landscape unit and between the landscape unit. Quantitative assessment of DPSIR elements in the future research could give more understanding about interrelationship of socio-ecological system between landscape unit.

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