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Research Article

Land and water conservation practices in tropical agricultural watershed

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Abstract: Large-scale land cultivation practices for agriculture which disregard conservation principles are resulting in land degradation problems in tropical regions. The differences of environmental condition become the main concern for determining proper strategies to overcome this problem. The present study aimed to evaluate the application of land and water conservation (LWC) practices in tropical agricultural watersheds. The conservation practices (in the form of regreening bare areas and construction of LWC structures i.e. small-scale dam, terrace and stone weir) were performed in a partnership scheme involving government, higher education institution, local inhabitant and private party. The result showed that the partnership approach made conservation activities possible in a shorter time and a lower risk of failure. Economically, it reduced the unit cost of the conservation structures construction up to 70%. We also assessed the dam performance for LWC purpose. The assessment indicated the dam could effectively increase soil water storage and control the river sedimentation. The use of local resources (community and materials for conservation structures) enabled the sustainable of LWC practices on a watershed scale.

***Keywords**: agricultural watershed, conservation structure, land degradation, land protection*

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Introduction

As a hydrological unit, watersheds are bounded by topographical boundaries. In a spatial point of view, a watershed comprises of the upper, middle and lower (downstream) area with its characteristics (Guzman and Reyes, 2003; Edwards et al., 2015). The upper (upstream) area is mostly covered by hilly area which has a high risk for exploration. Therefore, this area should be used for conservation purposes, especially for rainwater harvesting. The middle area of the watershed which is commonly covered by moderate and steeply sloping is more possible for exploration in a limited quantity. While, the lower area is the most possible for exploration (farming, settlement, fishery etc.) This area commonly is occupied by flat terrain with a low sloping. In the tropics especially developing countries, land exploration for farming increases massively. Even, people cultivate land reach the upper area of the watershed with limitary conservation practices (Shrestha et al., 2014; Didonéa et al., 2017). Life necessities pressure due to population growth is causing excessive land cultivations. Ultimately, land degradation problems (soil loss, sedimentation, flood, landslideetc.) are significantly increased.

The present situation is also faced by the tropical country of Indonesia. Land degradation due to excessive soil cultivation in watersheds dominated by farmland is highly accrued (Suwartha et al., 2006; Aflizar et al., 2010;

Leukas, 2014; Sitorus and Pravitasari, 2017). High socio-economic pressure becomes one of many factors which is influencing land degradation problem. Shortly, strategies for problem-solving are required. Application of good LWC practices provides a probable strategy to control land degradation problem in a watershed scale (Brown et al., 2009; Nyssen et al., 2009; Peng et al., 2011; Govers et al., 2017). Mostly, LWC programs are applied on a big scale which is causing significant effects on the local environment especially physical and socio-economic aspects (Poeppl et al., 2015; Mango et al., 2017). Furthermore, big scale programs are costly and takemuch time; consequently, it needs long planning. In the present study, small-scale LWC program in some agricultural watershed (the area was dominated by farmland) was applied and assessed for the period from 2009 to 2018. Engineering method by constructing LWC conservation structures using local material for the construction was used in the study site.

Materials and Methods

Study site

Integrated LWC practices were applied in six sites of four watersheds in the province of Central Java (Figure 1) which were dominated by agricultural land such as Serayu watershed (site of Kebasen Subdistrict Banyumas Regency, site of Batur Subdistrict Banjarnegara Regency and site of Kejajar Subdistrict Wonosobo Regency), Sempor watershed (site of Sempor Subdistrict Kebumen Regency), Wadaslintang watershed (site of Wadaslintang Subdistrict Wonosobo Regency) and Progo watershed (site of Ngadirejo Subdistrict Temanggung Regency). The study site of those four watersheds lied in a tropical environment with more than 3,000 mm/year rainfall. The upper area of the watersheds characterized by steep sloping area was largely used for farming without good conservation practices. LWC program is important for the study site.

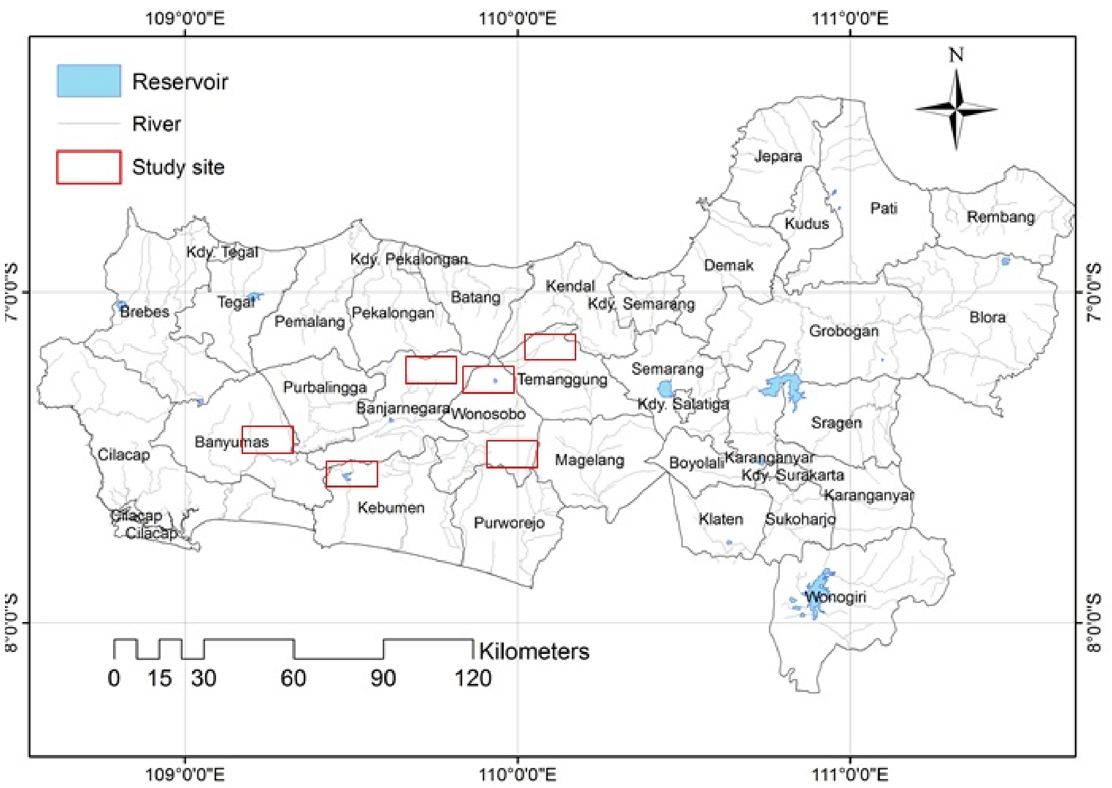

Figure 1. Map of the study site

Methods

The study was begun by the socio-economic survey (participatory rural appraisal) as the basis for continuing the next activities, i.e. construction of LWC structures, regreening bare (deforested) areas and dam performance assessment for LWC purpose, especially for river sedimentation control. The capacity of small-scale dams or check dam (see Figure 2) was estimated by using equation (1) (Achmad, 2006).

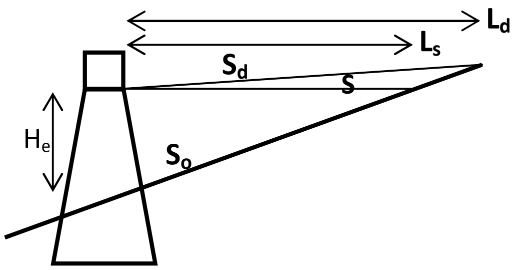

Figure 2. Small-scale dam design in the study site

$V_t = 1/2 \times H_e \times W \times L_d$ ……………………….(1)

where V_t is the total storage of dam, H is the effective height of dam, S_o is the riverbed original slope, S_s is the static slope of riverbed (1/2 S_o), S_d is the riverbed slope dynamic (3/4 S_o), L_s is the horizontal length of S_s, L_d ($H/(S_o-S_d)$ is the horizontal length of S_d and W is the width of dam

The implementation of LWC practices involved the Serayu Opak River primary office (BBWSSO) which provided the main funding and material (gabion for small-scale dam construction), private party which provided additional funding, local inhabitant which participated in structures construction and regreening barren areas, and we (higher education institution) provided human resources as the expert in the implementation of LWC practices program. BBWSSO is a division under the ministry of public works.

Results and Discussion

LWC practices

LWC practices are mostly applied for land protection in the upland as indicated in previous studies (e.g. Nyssen et al., 2009; Govers et al., 2017). In a critical watershed, the handling of land degradation impacts is required for short and long-term. Therefore, adequate types of LWC practices are required to control land degradation in critical watersheds as applied in the present study. The survey mainly aimed to socialize the program and to assess socio-economic aspects and aspirations of the local inhabitant. Socio-economic surveys were completed by in-depth interviews, questionnaire and village monograph in each site. These surveys were attended by about 30-50 people in each site (representing the whole head of households in the site). Figure 3 shows survey activities in two different sites. The result of the survey indicated that the LWC practices program was fully accepted by the local inhabitant. Mostly, they were people which worked in agricultural fields with limited education and a few skills for working in other fields; therefore, the local inhabitant had a high dependence on the land for farming. Figure 4 shows an example of socio-economic survey result in a site which was conducted in 2010. Education background affected the distribution of work types in the site.

Figure 3. Socio-economic survey in the site of Kejajar Subdistrict, Wonosobo Regency in 2010 (a), and Kebasen Subdistrict, Banyumas Regency in 2011 (b)

It was commonly found in developing countries and had the same situation as found in other sites of this study. Meanwhile, LWC structures were constructed for some form such as terraces, small-scale dam and stone weir. All structures were designed by the expert and constructed by involving the local inhabitant. The terrace construction aimed to reinforce slopes. It was constructed by the year 2010 in Batur Subdistrict Banjarnegara Regency (upper of the Serayu watershed). Meanwhile, the small-scale dams were constructed by the year 2009 in the form of stone dams in sites of Sempor Subdistrict Kebumen Regency (upper of the Sempor watershed) and Wadaslintang Subdistrict Wonosobo Regency (upper of Wadaslintang watershed), by the year 2013 in Ngadirejo Subdistrict Temanggung Regency (upper of the

Progo watershed) and in the form of gabion dam by the year 2010 in Kejajar Subdistrict Wonosobo Regency (upper of the Serayu watershed). At the same site in Kejajar Subdistrict, we also constructed stone weir. The gabion was provided by the BBWSSO, while, the material of stones for the construction were hugely available in the study site. The stone weir controlled the effect of riverbed's slope and reduced riverbeds degradation and stream bank erosion. We also introduced fish farming technology in the river (Kebasen Subdistrict Banyumas Regency) by using the fish cage for the local inhabitant in 2011. The field survey revealed that sand and stone mining were uncontrolled; hencethe introduction of an alternative livelihood (fish cage) was important to reduce the mining activity. Figure 5 shows some structures in study sites.

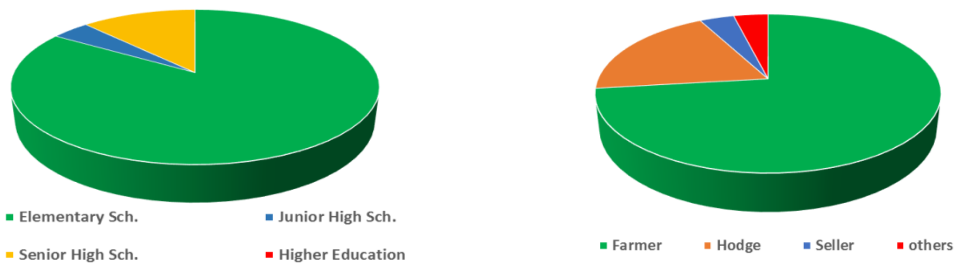

Figure 4. Education background (a) and livelihood of the local inhabitant in the site of Kejajar District, Wonosobo Regency

Figure 5. Small-scale dam construction from gabion (a) and stone weir (b) in Kejajar Subdistrict Wonosobo Regency, rock small-scale dam in Ngadirejo Subdistrict Temanggung Regency (c) and fish cage in Kebasen Subdistrict Banyumas Regency (d)

Sites of conservation structures were selected after field surveys. Topographic Map of Indonesia (Peta Rupa Bumi Indonesia) was used for fieldguidance of surveys. Small-scale dams were constructed for an area with 5 % of riverbed slope (S_o) and 8 meters of river wide (W) with the high (H_e) was about 2 meters. Hence, each dam had a 1,300 m^3 storage capacity (calculated using equation 1). The dimension of small-scale dams was determined based on river morphology condition in the site. Meanwhile, the regreening bare land was applied in small rivers (stream order 1) and upland (farmland) in Batur Subdistrict in 2010 (Figure 6). Generally, the integrated program for LWC practices was successfully executed as planned. The local inhabitant was fully involved in the regreening bare land through farmer groups in each site.

Meanwhile, the structure's construction needed people with special expertise and experience in construction. Though the local inhabitant participation was high enough, full-time participation of people was hard to realize. The construction was time-consuming, at the same time, mostly the local inhabitant (farmer) was majority using their time for farming. The social approach is required for the future program for determining a more appropriated approach and schedule.

Figure 6. Terracing in the steep sloping area (a) and regreening bare land (b) in Batur Subdistrict Banjarnegara Regency (upstream of the Serayu watershed)

The effectiveness of LWC practices

The effectiveness of LWC practices in study sites was evaluated based on the conformity between plan and implementation and the physical impact in the study site. The result showed all programs were completely implemented. The local inhabitant, the private sector and government involvement and utilization of local materials reduced the cost for the structure construction. Event for gabion small-scale dam construction, the using of local rocks (90 m^3) and gabion donated by BBWSSO reduced 70% of total cost. Meanwhile, the physical impact was evaluated based on effectiveness small-scale dams in capturing water and sediment. The conservation practices in this study were performed in small scales; hence, a physical impact assessment was hard to assess except for the small-scale dam construction. Structure of DAM has been proven effective for an LWC purpose (Brown et al., 2009; Nyssen et al., 2009). Some constructions of conservation structures in both, small and big scale were also builtfrom 2009 to 2017. Presently, they showed a good function for LWC purposes.

Field monitoring showed that structures (small-scale dams) have a good function in storing water and sediment, especially bed load type (Figure 7). Water inundation upstream the small-scale dam increased soil water storage by increasing infiltration. As characterized by itsmain material, field monitoring from 2009 to 2018 indicated that rock small-scale dams had a longer service life (> 8 years) than gabion small-scale dam (± 5 years). The lifetime of structures was affected by the environment condition.

Small-scale dam performance for river sedimentation control was assessed in the site of Serayu watershed. This site was selected due to field measurement data of sediment deposit was available (calculated in the reservoir downstream of the watershed). As reported by PT. Indonesia Power (Marhendi and Ningsih, 2018), the average sediment flow of the Serayu watershed was recordedin a scale of 4 million m^3/year or equal to 3.9 mm/year. Meanwhile, the tolerable sediment deposit from the watershed was about 2.4 million m^3/year for the total of catchment area (1,022 km^2). Tolerable sediment deposit (flow) from the watershed was determined by considering the lifetime of the reservoir (Mrica reservoir) downstream (60 years). The assessment of small-scale dam performance for river sedimentation control was performed for an upstream area of the Serayu watershed (Figure 8). It covered about 135 km^2 area with 530,967 m^3 annual sediment yield and 318.58 m^3 tolerable sediment flow (gained from the value of total existing and tolerable sediment yield of the Serayu watershed which was calculated by using area weighting method). There were two structures (small-scale dams) in this site (Kejajar Subdistrict Wonosobo Regency) with a capacity 1,300 m^3 (Figure 5a and Figure 7a).

Figure 7. Gabion small-scale dams constructed in Kejajar Subdistrict Wonosobo Regency (a) and rock small-scale dam constructed in Wadaslintang Subdistrict Wonosobo Regency (b)

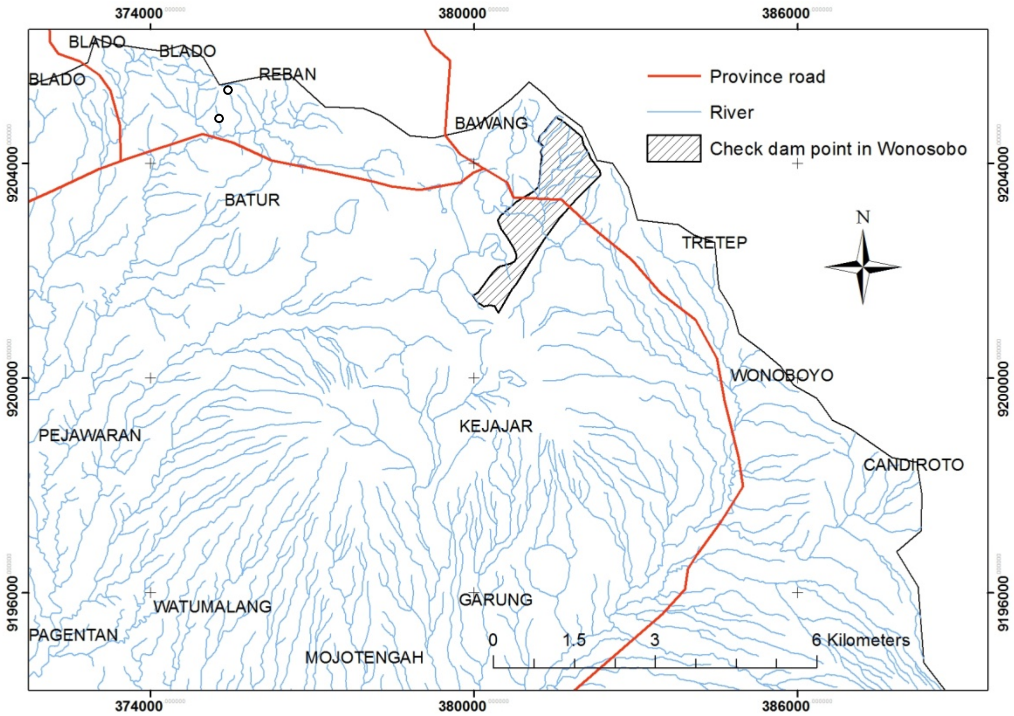

Figure 8. Map of the upstream Serayu watershed

The upstream areas were largely occupied by steep sloping areas, hence, to reduce the adverse effects due to land cultivation, the upstream area was a priority for LWC practices applications. It also provided a good strategy for reducing sediment flow whole of the watershed, where sediment source point can be eliminated significantly. By using the constructed small-scale dam (with a capacity 1,300 m^3), an assessment of dam’s performance was applied. The assessment indicated that 400 small-scale dams were required to reduce the total sediment flow from the site. While sediment flows control to meet the tolerable value, standard was obviously needed about 150 small-scale dam constructions (Figure 9). Though the effectiveness of small-scale dam has often been neglected, it seemed that the small-scale dam was effective for LWC practices in a small catchment area. Moreover, the inclement effect of the small-scale dam on the local environment was not significantly found in the study site. Meanwhile, a study by Poeppl et al. (2015) reported local environment change (river channel morphology) due to small dam construction. In a larger site (watershed), a larger number of the small-scale dam could be effectivefor protection or quality improvement of critical land or watershed. Brown et al. (2009)

reported multiple effects (e.g. human and ecological systems) of big scale dam construction. Hence, the partnership scheme for small-scale conservation practices is reasonable for improving critical watershed, particularly in developing countries with lower inclement effects on the environment. Involvement of the private sector, government, higher education institution and community and local materials utilizationhas obviously reduced the expense of structures construction. The uses of other local materials (e.g. wood and bamboo) can be considered for structures construction. This scheme also reduced total cost for LWC practices. Other than that, a combination of LWC practices methods can be applied for optimizing land degradation control in a watershed scale. Peng et al. (2011) noted that a combination of engineering, botanical and farming practices succeeds to control land degradation problem, mainly caused by soil erosion in the Three Gorges Reservoir, China.

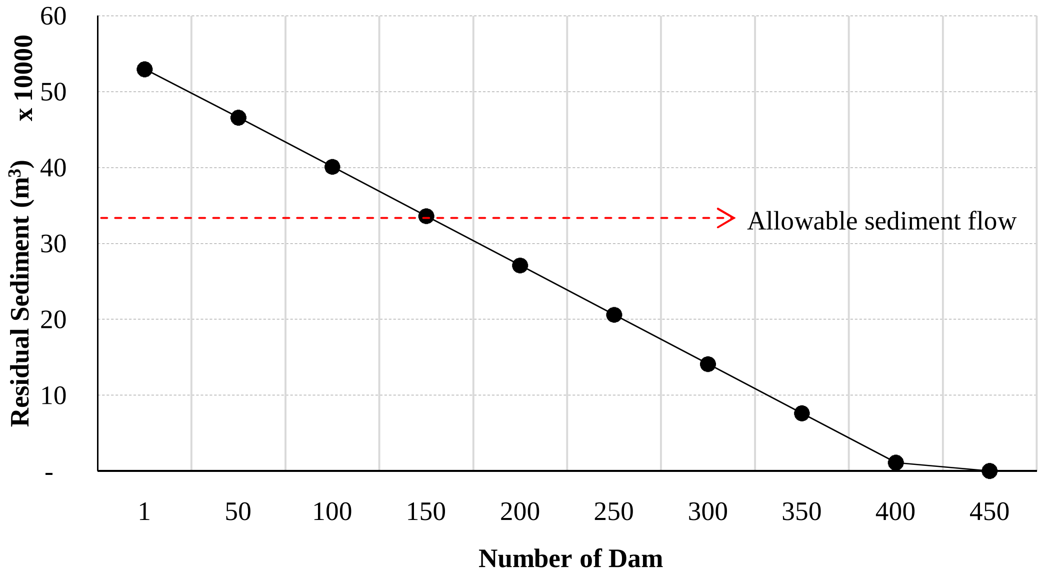

Figure 9. Small-scale dam performance for sediment flow control

Conclusion

The partnership scheme by considering local potential including socio-economic aspects was reliable for LWC practices application on a watershed scale with a lower cost. Small-scale conservation structures for a small catchment area in the present study were environmentally friendly, where there were no significant impacts on local environmental change. Local materials which were largely available in the tropics provided many alternatives for LWC practices application. Combination of LWC practice methods can be applied for the future activity of research on a larger scale by adopting the same approach as used in the present study.

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