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SUMMARY OF DOCTORAL THESIS

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SOIL EROSION STATUS AND SUSTAINABLE LAND MANAGEMENT IN AN AGRICULTURAL WATERSHED IN WEST SUMATRA, INDONESIA

インドネシア西スマトラの農業集水域における土壌侵食と持続的な土地管理

Soil erosion in Indonesia is one of most serious environmental degradation problems. Soil erosion in watersheds and subsequent deposition in rivers are of great concern for two reasons. Firstly, rich fertile soil is eroded from watersheds. Secondly, there is a reduction in reservoir capacity as well as degradation of downstream water quality. Indonesian forest has lost soil by about 2 million $ha^{-1}y^{-1}$ by deforestation including land use conversion to agriculture. Deforestation increased soil erosion rate by 6 – 12 Mg $ha^{-1}y^{-1}$ which caused economic loss of US $ 340-406 million per year in 1989 by the reduction of agriculture production in Java island.

Sumani watershed is the main rice producing area in West Sumatra facing to Lake Singkarak (107.8 km^2, 364 m asl) which supplies electricity by hydro power plant for West Sumatra and Riau Province. As the watershed has hilly topography and high rainfall more than 2400 mm y^{-1}, it is susceptible to erosion. The heavy rainfall also has induced flooding and landslide, which has brought economic risk and endangered human life in the watershed.

We have to make a better land management planning of the watershed to mitigate above problems by reducing soil erosion. In order to realize this, we need to assess present status of soil erosion and its influence on soil properties in relation to land use pattern in the watershed. In the present study, I tried to estimate soil erosion and to make a recommendable land use planning using Universal Soil Loss Equation model (*USLE*) in Sumani watershed. I also investigate the influence of soil erosion on soil nutrient distribution to discuss better land management methods in the watershed.

Soil samples were collected based on land use types, soil types and topography positions in the watershed. I determined following soil properties: total carbon (TC) and total nitrogen (TN), exchangeable cations (Ca, Mg, K, Na), available Si, available P, 0.1M HCl extractable (extr.) heavy metals (Pb, Cd, Cu and Zn), soil pH, organic carbon, soil structure, soil texture, and soil permeability.

Soil erosion was determined by *USLE*. It has been used as a soil conservation evaluation tool throughout Indonesia, as the other models require detail data and have some technical constraints. *USLE* consists of following factors: *R* (rainfall erosivity), *K* (soil erodibility), *LS* (length and slope), *C* (crop) and *P* (soil conservation). *K*-factor ranged from 0.001 to 0.48 and 96% of soils investigated in Sumani watershed, showed higher values more than 0.04 indicating susceptible property to soil erosion. In terms of land use change in the watershed, forest area decreased by 13% from 1992 to 2002. In this period, the forest was generally converted to agriculture fields such as mixed and vegetable gardens and some parts of agricultural fields were changed to shrub and settlement during that period. These land use changes affected *C*- and *P*-factors. Average soil erosion rate in whole Sumani watershed increased from 43.13 Mg $ha^{-1}y^{-1}$ in 1992 to 58.9 Mg $ha^{-1}y^{-1}$ in 2002. Soil erosion rates greater than 100 Mg $ha^{-1}y^{-1}$ were found at areas on steep slope in both periods. The areas exhibited the highest *R*-, *K*- and *LS*-factors in the watershed, indicating strong influence of these natural factors on soil erosion.

A recommendable land use planning was designed to be more realistic by keeping current land uses as much as possible. In sites with the soil erosion rate less than the tolerable erosion rate (*TER*), 14 Mg ha^{-1} y^{-1}, set by Indonesian government, the land use was kept as it was in the planning. When soil erosion rate was higher than *TER*, a new land use with a *CP*-factor smaller than the original one was selected in order to reduce the soil erosion rate. In the recommended land use planning, vegetable garden that shared 19.3% of the watershed was changed into new land uses such as vegetable with terrace (10%), vegetable with contour cropping (1.8%) and sawah (7.5%). Recommended land use planning could reduce soil erosion from 58.9 to 7.1 Mg ha^{-1} y^{-1}, with the reduction of 2.8% in profit from agricultural production in whole Sumani watershed.

Nutrient distribution in the watershed was influenced by the land use and soil erosion status. TC content in soil was relatively high in the west side of Mt. Talang where Andisol soil distributed and less soil erosion was observed by forest cover. Available P content was 82.8 mg P_2O_5 kg^{-1} in average and was high in agricultural fields, indicating the effect of fertilizer application. Although N was also applied as fertilizer, TN content in sawah was not as high as that in vegetable gardens. In forest, bush and rubber plantation with no fertilizer application, available P and TN were relatively low. At area with higher soil erosion rate, TC, TN and available P contents tended to be less. Soil erosion probably transported surface soil rich in these nutrients to the lowland or river. Exchangeable Ca, Mg, K and Na were relatively high in lowland, which might be due to accumulation of soil particles eroded from upland.

PO_4-P and NO_3-N concentrations in streams and irrigation water in Sumani watershed range 0-09-1.8 mg L^{-1} and 3-6 mg L^{-1}, respectively, from August 2006 until February 2007. These concentrations were beyond the level of the environmental standard in Indonesia. Eutrophication was worried in lower stream of the river and lake Singkarak. In fact, abnormal algal and aquatic plant blooming has been observed in the watershed. This result suggested that nutrient rich surface soil or P and N derived from fertilizer was transported into the river through soil erosion. Not only to sustain soil fertility, but also to protect water environment quality we must control soil erosion and excess fertilization t in vegetable gardens.

I also focused on soil available Si that is essential for successful rice production. At the upland area with higher soil erosion rate tended to be less in soil available Si content. Soil erosion transported available Si to the lowland area and river as well as the other nutrients. According to Bollich and Matichenkov (2002) and Sumida (1992), available Si contents less than 600 and 300 mg SiO_2 kg^{-1} were defined to be “low” and “deficient” for rice plant growth. Based on these criteria, most of the sites in the watershed were grouped into the categories of “low” or “deficient“. However, the area close to Mt. Talang and lowland sawah showed relatively high available Si content. In these areas, available Si supply through volcanic ash deposition and irrigation water was expected. In the area with low available Si level, blast diseases was frequently observed. The result suggested the necessity of Si fertilization. Possible silica sources is coal fly ash that is commonly produced in Indonesia.

In general, concentrations of extr. heavy metals in soils were low in Sumani watershed. Extr. Cd was relatively high in the area close to Mt. Talang where Andisol distributed. Volcanic ash could be the source of extr. Cd and high TC content might retain it. Extr. Cu and Cd contents were relatively low in the area with high soil erosion rate, indicating the transport by soil erosion. In the aread close to trunk roads, relatively high extr. Pb content was observed, which indicated that car emission caused Pb contamination in soil. Soil TC also looked to contribute accumulation of extr. Cu through the adsorption.

The results of this study could be basic information for planning of sustainable watershed management. In order to implement the planning, scientists, land users and policymakers have to collaborate. I hope I can contribute it as a scientist through my research activities.