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SUMMARY OF DOCTORAL THESIS

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Title: Effects of land use and management practices on soil loss and soil properties in the Upper Blue Nile basin, Ethiopia

（エチオピア青ナイル川上流域における土地利用と管理策が土壌流亡および土壌特性に及ぼす影響）

Soil erosion is one of the most pressing environmental challenges globally at large and more particularly in the Ethiopian highlands where small-scale agriculture is the main source of livelihood for about 87% of country's population. Average soil loss rates on croplands have been estimated at 42 t ha^{-1} yr^{-1}, but may also reach up to 300 t ha^{-1} yr^{-1} in individual fields which by far exceeds the rates of soil formation. Beyond soil and nutrient losses, accelerated soil erosion is causing rapid sedimentation problem that threatens the life of hydropower or irrigation reservoirs and canals in Ethiopia as well as in downstream countries such as Sudan and Egypt.

In the past few decades, huge financial and labor resources have been invested by both governmental and non-governmental organizations for the implementation of sustainable land management (SLM) practices to mitigate soil erosion in many regions of Ethiopia. The impacts of most SLM practices were better tested and well documented for the dryer areas of the northern highlands, whereas relatively limited SLM practices and studies exist for the wetter and actively eroding regions like the Upper Blue Nile basin. This is due partly to insufficient policy attention and difficulties inherent in collecting sufficient and reliable runoff, soil, and sediment data at wider spatial and temporal scales. This study was, therefore, aimed to improve our current understanding of the rates of soil loss at various spatial and temporal scales and identify SLM practices that can reduce runoff and soil loss and thereby enhance the in situ soil quality properties. The study was conducted in three contrasting agro-ecologies [i.e., Dibatie (lowland), Aba Gerima (midland), and Guder (highland) watersheds] of the Upper Blue Nile basin in northwestern Ethiopia covering the period from 2014 to 2018 and combining field survey, monitoring, and experimentation techniques. The specific objectives were to (i) analyze the variability of watershed scale soil loss (sediment yield) using a paired watershed approach; (ii) quantify the effects of land use and management practices on runoff and soil loss (SL) in different agro-ecologies; and (iii) evaluate the variation in soil quality properties as influenced by land use and management practices. These objectives cover chapters 2–4 of this thesis which comprises five chapters summarized as follows:

Chapter 1 presents the introductory sections (background, problem statement, objectives, and description of the study area) based on the existing literatures, observed data, and facts. It provides condensed explanations of soil erosion and land degradation, and sustainable land management efforts and practices in Ethiopia. It then describes the aims of this study and the overall structure of the thesis.

Chapter 2 analyses the variability of sediment yield (*SY*) in the humid tropical highland watershed (Guder), based on discharge and sediment data monitored at the outlets of adjacent paired watersheds (Kasiry and Akusity), during the rainy seasons of 2014 and 2015. The measurements were done at the gauging stations equipped with automatic flow stage sensors, manual staff gauges and a depth-integrated sediment sampler. Empirical discharge–sediment curves were created for three different parts of each rainy season to calculate *SY*. The results of the Mann-Whitney U test reveal that the daily *SY*s were significantly ($Z > -1.96$ and $P < 0.05$) higher for Akusity than for Kasiry in the two seasons. This could mainly be attributed to lower areal coverage both by soil and

water conservation measures and plantations (Acacia decurrens and eucalyptus tree plantations) at Akusity. The rainy season *SYs* for Kasiry were 7.6 t ha^{-1} in 2014 and 27.2 t ha^{-1} in 2015, while in Akusity *SYs* were 25.7 t ha^{-1} in 2014 and 71.2 t ha^{-1} in 2015. For both watersheds, three peak flow events accounted for a larger percentage (53% to 93%) of the seasonal *SY,* and resulted in extreme variability in daily *SY* (CV = 51% to 685%) during the rainy seasons. This indicates that peak flow events are major determinants of the amount and variability of *SYs*, and thus, careful measurement of such events is crucial to better understand the dynamics of *SY* in small watersheds of tropical highland environments.

Chapter 3 examines the effects of land use and SLM practices on runoff and SL in the three agro-ecologies of the Upper Blue Nile basin. The analyses is based on runoff and sediment data collected using runoff plots (30 m × 6 m) from three land use types (cropland, grazing land, and degraded bushland) in the highland, midland, and lowland agro-ecologies of the basin. Four treatments (control, soil bund, *Fanya juu,* and soil bund reinforced with grass) for croplands, and three treatments (control, exclosure, and exclosure with trenches) for non-croplands (grazing land, and degraded bushland) were investigated during the rainy seasons of 2015 and 2016. The results show that runoff and SL varied greatly across agro-ecologies, land use types, and SLM practices. The highest rates of both seasonal runoff (898 mm in 2016) and SL (39.67 t ha^{-1} in 2015) were observed from untreated grazing land in the midland agro-ecology, largely because of heavy grazing and intense rain events. In all agro-ecologies and land use types, both runoff and SL were significantly lower ($P < 0.05$) in plots with SLM than without, i.e., SLM practices effectively reduced runoff and SL (relative effectiveness ranging from 11% to 68% for reducing runoff, and 38% to 94% for reducing SL, depending of land use and agro-ecology). Soil bund reinforced with grass in croplands and exclosure with trenches in non-croplands were found to be the most effective SLM practices for reducing both runoff and SL, indicating that combined structural and vegetative measures are the best way to control soil erosion and its consequences.

Chapter 4 investigates variations in selected key soil properties among land use types and management practices. In doing so, a total of 162 topsoil (0–20 cm) samples were analyzed for nine soil properties—texture, bulk density (BD), pH, electrical conductivity (EC), cation exchange capacity (CEC), total nitrogen (TN), soil organic carbon (SOC), available phosphorus (P_{av}), and available potassium (K_{av}). The results show that most soil properties substantially varied across the three agro-ecologies, SOC and TN are significantly higher ($P < 0.01$) in the highland agro-ecology (Guder) than in the midland (Aba Gerima) and lowland (Dibatie) agro-ecologies. These results are attributable mainly to differences in factors (climate, soil parent material, and vegetation characteristics) that are principal determinants of soil formation and properties. Likewise, most soil properties showed significant variation among the three land use types in all agro-ecologies ($P <$ 0.05 to $P < 0.001$); pH, CEC, SOC, and TN values were lower in croplands than in grasslands and degraded bushlands. These imply that soil fertility under crop production has been greatly deteriorated by unsustainable cropping systems practiced over centuries. After the implementation of SLM practices, however, sensitive soil properties (BD, SOC, TN, P_{av}, and K_{av}) were markedly improved. This improvement is primarily attributed to the development of a well-established vegetation cover owing to minimum tillage and exclosures, indicating that soil degradation can best be controlled through enhancing vegetation growth and reducing soil disturbance by tillage.

Chapter 5 presents the general conclusions and recommendations based on the key findings from Chapters 2–4. Chapter 2 demonstrates that *SY* substantially varied between two adjacent paired watersheds and consecutive years, and both the amount and variability of *SY*s were controlled by few larger flow events. Thus, careful and site-specific characterization and measurement of larger flow events will be crucial to accurately assess the dynamics of soil loss at watershed scales. Chapter 3 and 4 reveal that runoff, SL, and soil properties widely varied across agro-ecology, land use, and management practices. Regardless of agro-ecology and land use, runoff and SL were significantly lower, and soil quality parameters were improved better in plots with SLM than without. This provides useful information that it is worth investing for the implementation of SLM practices to control soil erosion and land degradation.