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SUMMARY OF DOCTORAL THESIS

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Title: Effect of watershed management practices on hydrological response and soil erosion in the semiarid highlands of northern Ethiopia
（北エチオピア半乾燥高地における水文応答と土壌侵食に対する流域管理の効果について）

Land degradation by soil erosion is the most serious environmental threat in the Ethiopian highlands that led to substantial socio-economic and ecological problems. In response, the government of Ethiopia with the support of various non-governmental organizations has been promoting implementation of different soil and water conservation (SWC) measures to curb land degradation by soil erosion. Tigray region of northern Ethiopia is one of the drought-prone areas where resolute efforts have been under way to remedy environmental degradation through implementation of proper watershed management practices, especially in the past two decades. The objectives of the watershed management practices were threefold: (i) to restore degraded areas, (ii) to secure water supply for agriculture and domestic uses, and (iii) to promote food security. In view of these objectives, Agula watershed was one of the target areas in the region where massive SWC measures have been implemented. The components of the SWC practices include: construction of stone bunds with or without trenches on cultivated lands and on hill-slopes, check dams across gullies and rivers, and establishment of exclosures with or without enrichment plantation.

Several previous studies have reported on the effectiveness of SWC practices at plot and small-scale watersheds (<100 km^2) in erosion control, runoff and sediment yield reduction, soil fertility restoration, and changes in land use/land cover (LULC) as a result of vegetation regeneration. Despite the massive mobilization of resources for SWC, only very few studies have been done to analyze the impacts of SWC measures with respect to hydrological response, soil erosion and LULC change at medium- or large-scale watersheds (>100 km^2) which are of great interest to land managers and policy makers. The main objective of this study was therefore to estimate the changes in hydrological response and soil erosion for medium-sized watershed (area = 442 km^2) in the semiarid highlands of northern Ethiopia and to link these changes to watershed management practices and associated changes in LULC. This research focused on three studies covering the following: (i) to quantitatively estimate to what extent watershed management practices and changes in LULC affect streamflow response; (ii) to assess watershed-scale changes in soil erosion as a result of the watershed management practices and LULC change; and (iii) to analyze morphometric parameters of the watershed to better understand the hydro-geologic and erosion characteristics of the watershed for improved planning, management, and decision making to ensure sustainable use of watershed resources. The studies are summarized as follows:

The first study evaluated changes in streamflow in response to climate variability and human activities such as watershed management practices and LULC change. The non-parametric Mann-Kendall (MK) and Mann-Kendall-Sneyers (MKS) tests were used to analyze trends and abrupt change-point of hydro-meteorological series for the period 1992-2012. The LULC change was assessed by classification of multi-temporal Landsat images of years 1990, 2000 and 2012 and post-classification change detection techniques. A runoff model, driven by rainfall and potential evapotranspiration was established to estimate the effect of climate variability on streamflow; then the effects of climate variability and human activities (watershed management practices and LULC change) on streamflow were separated. The MK

test result showed significant downward trends for annual and wet season streamflow; while dry season streamflow showed an upward trend. For the same period, no significant trend was detected for seasonal and annual rainfall records. Based on the MKS test, an abrupt change-point in annual streamflow occurred around 2000; and hence the streamflow record was divided into two periods: a baseline period (1992–1999) and a change period (2000–2012). The mean annual and wet season streamflow decreased by about 36% and 49%, respectively during the change period compared to the baseline period; however, dry season streamflow increased by 57%. The LULC change analysis showed improved shrub land and forest cover that led to restoration of about 36 km^2 of bare land. Model estimations revealed that climate variability accounted for 22% of the total reduction in mean annual streamflow; whereas the reduction due to human activities was about 78%. This study demonstrated that human activities primarily proper watershed management practices and associated changes in LULC play a more pronounced role in driving the changes in streamflow of Agula watershed.

The second study evaluated the changes in soil erosion for the years 1990, 2000 and 2012 as a result of watershed management practices and associated changes in LULC using the Revised Universal Soil Loss Equation (RUSLE). The RUSLE factors were computed using spatial data obtained from different sources in a geographic information system (GIS) environment for 30×30 m raster layers. The results revealed significant reduction in soil loss rates by about 55% from 28 to 12 t ha^{-1} yr^{-1} in 1990–2000 and an overall 64% reduction from 28 to 10 t ha^{-1} yr^{-1} in 1990–2012. This change in soil loss is attributed to improvement in surface cover and stone bund practices which resulted in the decrease in mean *C* and *P*-factors respectively by about 19% and 34% in 1990–2000 and an overall decrease in *C*-factor by 29% in 1990–2012. Between 1990 and 2012, the severe (20–40 t ha^{-1} yr^{-1}) and very severe (>40 t ha^{-1} yr^{-1}) erosion categories decreased by about 40% and 80%, respectively. During the same period, significant reductions in soil loss were observed for bare land (89%), cultivated land (56%) and shrub land (49%). Furthermore, the reduction in soil loss was more pronounced in steeper slopes where very steep slope and steep slope classes experienced over 70% reduction. However, it is important to note that for the recent year (2012) about 14% of the watershed experience soil erosion rate in excess of 20 t ha^{-1} yr^{-1}. This implies that further planning and implementation of SWC measures is required to reduce the soil erosion from areas experiencing severe and very severe erosion. Validation of soil erosion estimations using field observed points showed an overall accuracy of 69%, which is fairly satisfactory. Overall, the watershed management efforts undertaken in the past few decades have resulted in remarkable restoration of degraded semiarid lands that could serve as a basis for sustainable planning of future developments of areas experiencing severe land degradation due to water erosion.

The third study analyzed 28 morphometric parameters for 26 sub-watershed of Agula watershed to characterize the watersheds' behavior in terms of runoff generation potential and soil erosion risk. Analysis of morphometric parameters was carried out from four perspectives: drainage network, watershed geometry, drainage texture, and relief characteristics. The longest flow path of Agula watershed was about 48.5 km; with changes in slope of the river bed from steep gradient (0.018 m m^{-1}) at the upper reach which gradually flattens near its outlet (0.008 m m^{-1}). Knickpoints with abrupt changes in elevation also developed along the main river which could be attributed to change of lithology resulting in differential erosion as well as the presence of major faults which are common along the rift escarpments. Agula watershed has elongated shape suggesting low peak flows for longer duration and hence easier flood management. The drainage texture parameters revealed that Agula watershed was characterized by fine drainage texture; which implied that the watershed is dominated by impermeable soft rock with low resistance against erosion and sparse vegetation cover. Furthermore, high relief and steep slopes dominated; by which rough landforms, including hills, breaks, and low mountains made up 76% of the watershed. At sub-watershed scale, the derived morphometric parameters from four perspectives were further grouped into three clusters (that represented low, moderate, and high values); and considerable spatial variability was observed. The results of this study provide useful information to better understand the watersheds' characteristics and serve as a basis for improved planning, management, and decision making to ensure sustainable use of watersheds' resources.