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SUMMARY OF DOCTORAL THESIS

Name: Mulatu Liyew Berihun

Title: Modeling hydrological and sediment responses to human activities and climate variability in the Upper Blue Nile basin, Ethiopia

（青ナイル川上流域における人間活動と気候変動に対する水文学的応答および堆積物応答のモデリング）

Soil erosion-caused land degradation is a serious global environmental challenge, and this is more severe specifically in the least developed countries like Ethiopia. The rate and impact of soil erosion are more visible in the Ethiopian highlands, particularly in the Upper Blue Nile basin that even affects downstream countries like Sudan and Egypt. This is mainly because of unsustainable human activities such as land use/land cover (LULC) change and poor soil and water conservation (SWC) practices being driven by population growth and climate variability. On the other hand, there are few cases of afforestation practices that have been implemented through the initiative of the local community. These human activities and climate variability are strongly influencing the hydrological and sediment responses.

Previous studies on hydrological and sediment responses mainly focus on plot-scale while the few watershed-scales studies rarely addressed the separate or combined effects of three factors such as LULC changes, climate variability, or SWC practices under contrasting environments. The watershed-scale studies either focused on specific sites that constitute a single agro-ecological environment or specific factor. This is profoundly due to fragmented, limited, and lack of observational data such as runoff, sediment, and climate at wider spatial and temporal scales as well as lack of adoptable methodologies to evaluate the impacts. Therefore, the central objective of this study was to understand the single and combined impact of human activities (LULC changes and SWC practices) and climate variability on the spatiotemporal dynamics of hydrological and sediment responses by integrating field observations, spatial analysis, and modeling approaches. The study was conducted in three drought-prone watersheds located in different agro-ecological environments of the Upper Blue Nile basin: Guder (highland), Aba Gerima (midland), and Debatie (lowland). The study addressed the following three specific objectives: (i) explore and evaluate LULC change, drivers and their possible implications; (ii) examine hydrological responses to LULC change and climate variability and (iii) examine runoff and sediment responses to SWC practices through employing alternative modeling approaches. These case studies are presented from Chapters 2–4 of this thesis, which comprises a total of five chapters, including the introduction and the general conclusions and recommendations, as summarized below:

The first Chapter presents the Introductory section. It provides an overview of land degradation, LULC change, climate variability, SWC practices, and their influences on hydrological and sediment responses. In the end, it presents the aims of this study and the overall structure of the thesis.

The second Chapter discusses the change in LULC, drivers, and their implications in the three sites. The changes in LULC were analyzed by integrating field observations, very high-resolution remote sensing data [0.5–3.2m], and geographic information systems. The study revealed that, from 1982 to 2016/17, forest land, bushland, and grazing lands respectively decreased by about 76%, 58%, and 30% in Guder; 54%, 63%, and 52% in Aba Gerima; and 69%, 45%, and 43% in Debatie. During the same period, cultivated land increased by approximately 38%, 97%, and 492% in Guder, Aba Gerima, and Debatie, respectively. In contrast, between 2012 and 2017, plantation cover increased

by 241% in the Guder watersheds, mainly at the expense of cultivated land, which decreased by 32% for the same period. Population growth and associated changes in the farming practices were the major driving forces for the observed LULC changes in the three watersheds. The traditionally deleterious impacts of human activities on the environment have been recently reversed at an unprecedented rate, particularly at Guder and to a lesser extent at Aba Gerima, following the shift from the traditional annual cropping to more economically attractive tree-based farming practices such as *Acacia decurrens* plantation in Guder and khat (*Catha edulis*) cultivation in Aba Gerima. The continued expansion of cultivated land combined with population growth is directly linked with the increase of gully erosion and runoff potential in the study watersheds particularly, in Aba Gerima and Debatie watersheds. The loss of natural vegetation and subsequent conversions to cultivated lands showed the prevalence of land degradation in the three watersheds.

The third Chapter examines the separate and combined effects of LULC change and climate variability on hydrological (annual surface runoff and evapotranspiration) responses after validating the empirical models in the three study watersheds. The observed LULC changes over the study period (1982–2016) resulted in runoff increases ranging from 4% in Kecha to 28.7% in Kasiry. Climate variability in terms of annual rainfall had no significant effect on estimated runoff. In contrast, evapotranspiration was affected by both LULC change and climate variability. Though climate variability increased evapotranspiration from 33.6% in Kecha to 42.1% in Kasiry, the LULC change related to the reduction in natural vegetation had an offsetting effect, which led to overall decreases in evapotranspiration ranging from 15.8% in Kasiry to 32.8% in Kecha. Overall, the hydrological responses in the watersheds are largely controlled by how the land is being used and managed, which either mitigates or exacerbates the effects of climate variability.

The fourth Chapter evaluates the separate and combined effects of SWC practices, LULC, and climate variability on runoff and sediment yield responses using two approaches in Aba Gerima paired watersheds. In the first (paired watershed) approach, we compared the treated (Kecha) and untreated (Laguna) watersheds. In the second approach, we compared data before (baseline) and after (2011) the implementation of SWC practices for the Kecha watershed. The SWAT model was adopted for both treated and untreated watershed conditions. Evaluations using the paired watershed approach revealed that the SWC practices reduced the runoff in the treated (Kecha) watershed by about 28–36% and sediment yield by about 51–68% as compared to the untreated (Laguna) watershed. Similarly, compared with the baseline data (before 2011) in Kecha watershed, the SWC practices alone reduced the runoff and sediment yield by about 40% and 43%, respectively, which is accounting for about 65–78% of the total changes brought by LULC change, climate variability and SWC practices. This signifies a greater effect of SWC on sediment yield than on runoff. Moreover, compared to runoff, the effect of SWC is more important in sediment reduction by about 23–32%.

The fifth Chapter presents the general conclusions and recommendations based on the key findings obtained from Chapters 2–4. Overall, an unprecedented natural vegetation degradation has been observed mainly driven by population growth, however, this has been reversed since recent years in the highland site following the shift in farming practices through the introduction of the fast-growing *Acacia decurrens* plantation for the rehabilitation of degraded area as well as to improve income through the sale of charcoal. This unprecedented LULC change has brought positive consequences on the hydrological and sediment responses in all sites. Climate variability had also positive and negative consequences on the evapotranspiration and sediment responses, respectively. However, the implementation of SWC practices has effectively counteracted the effects of LULC change and climate variability. Moreover, the single effect of SWC practices had considerably a higher impact on the response of sediment than surface runoff. Furthermore, this study provided an important methodological basis for evaluating the effect of SWC practices by showing the pros and cons of two different alternative modeling approaches. The findings of this study, therefore, provides useful information to devise future land and water management strategies for sustainable use of watershed resources. Future research should consider future LULC and climate change scenarios combined with land management scenarios to evaluate future hydrological and sediment responses to mitigate land degradation in the Upper Blue Nile basin and beyond.