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SUMMARY OF DOCTORAL THESIS

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Title: Spatio-temporal modeling of gully erosion in the Upper Blue Nile basin, Ethiopia
(エチオピア青ナイル上流域におけるガリー侵食の時空間モデリング)

Soil erosion remains one of the most challenging global issues resulting in severe onsite and offsite environmental problems. Albeit Ethiopia is blessed to be the 'water tower of Africa', the Ethiopian highlands are also among the top global hotspot areas for soil erosion by water. As a largest river basin in the county with a significant share in the Ethiopian highlands, the impacts of water erosion in the Upper Blue Nile (UBN) basin affect not only Ethiopia but also downstream countries like Sudan and Egypt. Gully erosion is one of the most extreme land degradation processes in the basin that exhibits spatial and temporal variations depending on several environmental factors. Topography, soil, climate, and human activities such as land use/land cover (LULC) and land use management (LUM) are known to influence the spatio-temporal dynamics of gully erosion.

Most studies on gully erosion susceptibility and initiation focus on medium- and large-scale watersheds located in temperate, arid, and semi-arid climates with the least attention given to small-scale watersheds found in humid and sub-humid climates. Even those few studies have not adequately considered all potential controlling factors and explicitly investigated their separate and combined impacts on gully erosion across different agro-ecological environments. The overall objective of this research was, therefore, aimed to evaluate gully erosion dynamics under different scenarios of climate and human activities in three paired watersheds under various treatment conditions across different agro-ecological environments of the UBN basin in Ethiopia by coupling extensive field observations with high-resolution remote sensing products and alternative modeling tools. The study was conducted in three adjacent paired watersheds found in three representative agro-ecological environments of the basin: Kasiry and Akusity at Guder (highland), Kecha and Laguna at Aba Gerima (midland), and Sahi and Bekafa at Dibatie (lowland). The specific objectives covered in this study were to: (i) model the spatial distribution of gully erosion susceptibility and identify its controlling factors, and (ii) simulate the separate and combined impacts of rainfall and land use and management on gully erosion. The studies with the above specific objectives are presented in Chapters 2 and 3 of this thesis and summarized below together with the general introduction (Chapter 1) and general conclusions and recommendations (Chapter 4).

Chapter 1 presents a general introduction. This chapter provides background information on land degradation due to soil erosion, soil erosion by water, modeling of gully erosion susceptibility, the role and impact of controlling factors on gully erosion, and a description of the study areas. In addition, it explains the research problems and objectives of the study and summarizes the structure and methodological framework of the thesis.

Chapter 2 integrates detailed field investigations with high-resolution remote sensing products to assess gully erosion susceptibility and identify its controlling factors using the Random Forest (RF) model in all six watersheds across the three agro-ecological environments of the basin. Data for 20 controlling factors were extracted from datasets at eight different pixel resolutions ranging from 0.5 to 30 m in a geographic information system environment. About 70% and 30% of the dataset in each watershed were randomly selected for model training and validation purposes, respectively. Multicollinearity and correlation analyses were performed to identify variables with collinearity problems and explain their statistical relationships among the other variables. RF predicted gully erosion susceptibility and the relative importance of the controlling factors. The model showed outstanding performance when the finest-resolution dataset was used. Elevation, height above nearest drainage, runoff curve number-II, distance from streams, drainage density, soil type, and land use/land cover were found to be the most important factors controlling the spatial distribution of gullies in all six watersheds, irrespective of the watershed treatment conditions and agro-ecological settings. Thus, the most susceptible land to gully erosion was low-lying grazing and cultivated lands with sensitive soil of high runoff-generation capacity located within short horizontal and vertical distances from drainage networks. Therefore, basin- and watershed-scale gully management strategies need to consider the relative importance and interaction of the controlling factors, including the previously unaccounted runoff curve number-II, and should give priority to the most susceptible areas.

Chapter 3 investigated the impact of changes in rainfall, LULC, and LUM practices on gully erosion in two midland watersheds (treated Kecha and untreated Laguna) by using the LANDPLANER model in combination with intensive field measurements and remote sensing products. Gully erosion was simulated under past (in 2005), present (in 2021), and three potential future curve number conditions, each time under four rainfall scenarios (10, 30, 60, and 100 mm) using the dynamic erosion index (*e*), static topographic (*esp*), and erosion channel (*esp_channel*) thresholds. Density plot analyses showed that gullies frequently occur in low-lying gentle slope areas with relatively higher curve number values. The best predictions of gullies identified through true positive rates (TPR) and true negative rates (TNR) were achieved considering the static *esp_channel* > 1 for Kecha (TPR = 0.667 and TNR = 0.544) and the dynamic *e* > 0.1 for 60 mm of rainfall in Laguna (TPR = 0.769 and TNR = 0.516). Despite the 10 mm rainfall having negligible erosion-triggering potential in both watersheds, the 60 and 100 mm rainfall scenarios were 4–5 and 10–17 times, respectively, higher than the 30 mm rainfall scenario. While the LULC change in the untreated Laguna watershed increased the impact of rainfall on gully initiation by only 0–2% between 2005 and 2021, the combination of LULC and LUM significantly reduced the impact of rainfall in the treated Kecha watershed by 64–79%. Similarly, the gully initiation area in Kecha was reduced by 28% (from 33% in 2005 to 5% in 2021) due to changes in LULC and LUM practices, whereas Laguna showed little increment by only 1% (from 42% in 2005 to 43% in 2021) due to LULC change. In addition, the future predicted alternative land use planning options showed that gully initiation areas in Laguna could be reduced by 1% with only LULC conversion; 39% when only LUM practices were implemented; and 37% when both were combined. These results indicate that rainfall has a significant impact and LUM practices outweigh the impact of LULC on gully erosion in the studied paired watersheds.

Chapter 4 presents the general conclusions and recommendations based on key findings obtained from Chapters 2 and 3. Chapter 2 clearly showed that the selection of pixel resolution of datasets influences the prediction of gully erosion susceptibility and its controlling factors. Thus, appropriate pixel resolutions need to be selected considering the size of gullies in the target areas. Chapter 3 also indicated that changes in the rainfall and LUM practices significantly impacted gully erosion, and LUM practices outweighed the impact of LULC on gully initiation in the study watersheds. The findings of this thesis, therefore, have paramount importance towards improving the spatio-temporal modeling and management of gully erosion in the UBN basin and similar environments. Hence, future research and gully management activities in the basin should pay attention to rainfall magnitudes and LUM practices in addition to the key controlling factors of gully erosion.