ABSTRACT

Rainfall-triggered Landslides are the most common natural hazard with serious consequences all over the world, including in Ethiopia. Most available methods for predicting rainfall-induced slope instability rely on regional statistical and probabilistic data derived from previous slope failures and rainfall records using GIS tools. Such approaches ignore the underlying effects of many controlling factors, such as variations in rainfall intensity and patterns, as well as geotechnical properties, resulting in subjective and debatable results. Using a physically based model that accounts for hydrogeological and geotechnical parameters to capture the failure mechanism was uncommon, particularly in the Central Highlands of Ethiopia.

The current study developed a numerical model for typical slopes in the region (Adaberga and Jeldu) based on field investigations, geotechnical characterizations, and flume model studies. The unsaturated and saturated soil property models were determined, and the rainfall intensity-duration (ID) threshold was obtained for the use of early warning systems in the region and neighborhood regions of similar characteristics.

In this thesis, a total of eighteen flume experiments were carried out to capture the failure phenomenon and to validate the numerical simulations. The results of the numerical simulation of seepage and slope stability of unsaturated finite slopes (at 25° to 43°) subjected to infiltration (TRIGRS, SEEP/W, and SLOPE/W) are validated with laboratory flume tests on sandy silt soil at identical field density and different rainfall intensities (14 to 47 mm/hr). Empirical correlations are developed based on different combinations of rainfall intensity, slope angles, and a factor of safety from the TRIGRS modeling. Since this soil was derived from a carbonate parent source, the HYDRUS was also used to model solute transport processes such as cation exchange, dissolution, percolation, and precipitation. Analyses were carried out to account for solute transport and the subsequent effects, particularly hydraulic conductivity, which has a significant influence on the rate and magnitude of wetting front advancement into a slope.

XRD and SEM studies were conducted for quantification and the identification of the mineral composition and estimating porosity, respectively.

The rainfall intensity duration thresholds that would cause a landslide (ID plot) are measured in the field and simulated under a controlled environment in the laboratory. The obtained ID plots are used in the numerical simulation with an identical pattern as that of flume experiments. *ImageJ* software was used to observe wetting front advancement based on tracer (potassium permanganate)

movements and sidewall (Flume wall) photo images captured at regular intervals of 10-seconds. Since shallow slope failures account for most occurrences in the regions, only shallow failure mechanisms were considered throughout this thesis.

The GIS framework was utilized to organize, generate, and execute geoprocessing models, and provide interfaces to other ArcGIS components and non-GIS packages dealing with geodata management and visualization.

The flume testing observations revealed that regardless of surface erosion, the failure initiated at the toe of the slope, subsequently extended upslope, displaying columnar failure, and gradually triggered retrogressive shallow slides. From the series of experiments, it was concluded that hydrogeological parameters such as rainfall intensity and slope geometry have a significant influence on the mechanism of slope failure.

The solute transport analysis indicated that concentration increased with depth and time and reached its maximum concentration at nearly about 9 cm below the slope surface. The film layer thickness was determined to be about 3 cm, wherein the peak concentration occurred, and suction was negligible.

The SEEP/W and SLOPE/W analysis revealed that pore pressure development alone is not always responsible for triggering the slope failure, but the loss of suction in the capillary vadose zone can also trigger a shallow landslide.

TRIGRS results after reprocessing were used to map landslide hazard zonation (LHZ). The results of the factor of safety map are validated using ROC/AUC, demonstrating that the model adequately captures the occurrence in terms of both temporal and spatial distribution. The parametric study results using TRIGRS, SEEP/W, and SLOPE/W show that changes in rainfall intensity and hydraulic conductivity have a considerable influence on the factor of safety.