11 Summary

The focus of this dissertation is on the assessment and modelling of erosion and soil erosion risk in a large river system in Ethiopia. The watershed of the *Bilate River* is located in the southern Ethiopian Rift Valley and partially on the western graben shoulder and the western Ethiopian Highlands. It extends approximately 5,500 km² and includes a wide variety of landscape characteristics. The development of these landscapes is strongly linked to the development of the Ethiopian Highlands and consequently the Rift Valley during the Quaternary. The geology is mostly of basic and partially of inter-medium characteristic; additionally, tertiary sediments occur in the proximity of Lake Abaya. The major soils groups in the watershed are nitisols and luvisols in the highlands, whereas vertisols and cambisols dominate in the Rift Valley (FAO, 1998). According to KÖPPEN (1931) the watershed has Aw and Bsh climatic characteristics in the Rift Valley and Cwb characteristics in the highlands. The climate in the region exhibits high intra- and inter-annual variability, particularly in terms of precipitation. Land use in the Rift Valley is mostly pasture and extensive agriculture, but also includes state farms, which are partially irrigated. The graben shoulder and the highlands are intensively used for small-scale agriculture or sustain a mixed agrosilvipastoral land use system. The population density in the area is comparatively high, compared to the rest of Ethiopia and thus, pressure on natural resources is high (CIA, 2005).

The development of the conceptual model DESER (determination of erosion and soil erosion risk) followed two steps. First, input data were assessed in the field and collected from institutions and ministries. Second, all input parameters were processed and harmonized for modelling. The model itself was verified using erosion and soil erosion damage maps from fieldwork and with the results from satellite image interpretation.

Since the watershed consists of a variety of landscape characteristics, it was separated into three units, characterised by geo-factors, such as altitude, slope, flow accumulation and curvature. These units are (1) *Western Ethiopian Highlands*, (2) *Rift Valley* and (3) *Valleys and Basin*. The relief of the *Western Ethiopian Highlands* is of steep slopes with short slope length and of high degree of relief curvature, whereas the *Rift Valley* is of undulating to flat relief character with small degrees of relief curvature. The *Valleys and Basin* are characterised by hilly relief with moderate gradients of slopes and one large accumulation area. Within the watershed eight representative study sites were selected in order to assess on-site and off-site damages, as well as the causing processes. Additionally, soil conservation measures, land use and anthropogenic activities within the units have been recorded. The study sites *Ana,*

Doyancho, Hage and *Ofi* are located in the *Western Ethiopian Highlands*, *Bedesa* and *Dimtu* in the *Rift Valley* and *Sedebo* and *Agega* in the transition zone from the *Western Ethiopian Highlands* to the *Rift Valley*. No study sites were selected in the geomorphological unit *Valleys and Basin*.

The *Western Ethiopian Highlands* exhibit hilly to mountainous characteristics including steep slopes and well developed drainage systems. Intensive land use and high population density place increasing pressure on natural resources. Today, the entire geomorphological unit is utilized for small-scale cultivation, the exception being some areas that have been closed off from cultivation and grazing. High annual precipitation totals (up to 1,800 mm), a spring-summer rainfall regime and moderate annual temperatures create favourable conditions for agriculture, but also cause significant erosion and soil erosion damages on all scales. Representative study sites are here *Ana*, *Hage*, *Doyancho* and *Ofi*.

The *Rift Valley* exhibits undulating to smooth and even relief characteristics. Farm sizes are larger than in the *Western Ethiopian Highlands*; in addition, three state farms and a military base operate here. Limited water resource availability (very high precipitation variability and totals of less than 1,500 mm/a with high evapotranspiration rates) has resulted in a low population density and extensive grazing systems. The exceptions are the state farms, which are partially irrigated. Erosion and soil erosion damages are pronounced parallel to tributaries, where large barren degraded areas develop. The remaining parts of the *Rift Valley* show little or no erosion and soil erosion damages. Representative study sites are here: *Bedesa* and *Dimtu* as well as the sites *Sedebo* and *Agega* located in the transition zone from the *Rift Valley* to the *Western Ethiopian Highlands*.

No study sites were selected in the geomorphological unit *Valleys and Basin* due to constrained and time consuming access. The unit is of undulating and hilly relief character on very high altitudes reaching almost 3,300 m a.s.l. High altitude, high precipitation totals as well as moderate to cool temperatures allow for lush green vegetation all year round. The unit is primarily used for grazing. Dense vegetation cover prevents severe erosion and soil erosion damages. Only in the southern part of this unit, where Eucalyptus plantations have been established, are gullies and badlands developing. An intra-mountainous basin, the *Bilate Hayk*, is located in the southern part of the unit. Heavy sedimentation causes an almost flat and swampy region that is dominantly used for pasture. Only its margins show some but no distinct erosion and soil erosion damages. Again, severe damages occur only in Eucalyptus planatations.

A rainfall-runoff analysis was performed for the watershed. The available rainfall data allowed the computation of average monthly and annual spatial precipitation data. However, rainfall intensities could not be analysed and determined area-wide, due to lack of spatial and temporal data. A rainfall intensity index was designed based on daily and monthly rainfall totals as a tool to estimate possible intensity. Runoff data are only sparsely recorded within the watershed and thus, an analysis was not possible for certain timeframes. Annual and monthly runoff totals are varying with respect to observed precipitation totals, but the runoff volumes are too inconsistent to allow a verification of computed spatial rainfall totals with discharge volumes.

Analyses of physical and chemical parameters of soils and soil sediments samples did not yield any significant association to the Food and Agriculture Organization (FAO) soil classification. The results highlight the high variation of developed soils and/or the mixture of soil and soil sediments in the profiles. It also emphasizes the influence of the relief position, where the samples were taken. Results of the visual inspection in the field could not be reproduced by laboratory analysis.

The erosion and soil erosion assessment results illustrate, on one side, the high spatial variability of land use, climates and soil parameters in the watershed, on the other side, consistency within the geomorphological units. Within the units the parameters rainfall, runoff and general soil type are relatively uniform and result in typical erosion and soil erosion features. High annual precipitation totals and strong precipitation intensities on soils with properties similar to Nitisols, Luvisols and Leptosols cause the development of rill erosion, small channels and gully erosion in high frequency and magnitude on agricultural fields all over the *Western Ethiopian Highlands*. Lower rainfall totals but higher rainfall intensities in the *Rift Valley* result in the development of large barren degraded areas where soils were originally covered by pyroclastic layers, which are broken down from frequent ploughing. Usually new soil develops on top of the pyroclastic layers. High annual rainfall totals but lower intensity in the *Valleys and Basins* generates moderate erosion and soil erosion damages on Phaeozems. Where Luvisols are developed, erosion and soil erosion damages increase due to intensified land use and typically result in the development of gullies and badlands.

Extent and type of the prevailing erosion forms reflect erosion and soil erosion risk. A conceptual model was developed to simulate the erosion and soil erosion risk for the watershed. First, a land cover class index (LCCI) was designed. It is based on the

interpretation of channels one to three of Landsat TM satellite images, but can also be derived from ground data. The NDVI was not utilised, because a method was needed that could also be used without satellite imagery. The highest LCCI is computed for the *Western Ethiopian Highlands* and the *Valleys and Basin*, whereas in the *Rift Valley* this class is almost missing. There, unconsolidated material and sparse vegetation are the dominant land cover classes. In the geomorphological unit *Valleys and Basin* the class ‘very green’ represents the intra-annual green vegetation, such as grassland. The high occurrence of the class ‘bare soil’ reflects the date (November) of processing of the satellite images which occurred during the dry season.

For modelling spatial data such as the digital elevation model (DEM) and its derivatives (slope, flow-accumulation and relief curvature) were processed in GIS. Additional spatial data sets used for modelling include ground data from FAO such as grain size distribution, stone cover and interpolated point data from laboratory analysis ($C_{org.}$). The DEM is based on data from the Shuttle Radar Topography Mission (SRTM). These data were harmonized with altitude information from topographical maps at a scale of 1:250,000 and 1:50,000. Additional stream channels were ‘burned’ into the DEM to ensure continuous flow-accumulation. All data were transformed into a gridded data set with a cell size of 100 by 100 meters. These data were projected into the coordinate system ‘Universal Transverse Mercator’ (UTM), Zone 37 N, Map Datum Adindan (Ethiopia).

The developed erosion and soil erosion model utilizes the spatial data as follows:

1. The DEM reflects the altitude and thus, the potential energy of material, and based on the vegetation zones after HURNI (1982) it reflects the potential vegetation.
2. Slope gradient influences the erosivity forces of surface runoff.
3. Relief curvature increases or decreases surface runoff due to it concave or convex relief characteristics.
4. Flow-accumulation influences erosivity forces of surface runoff.
5. Soil types have different physical and chemical properties and are thus, vulnerable to erosion and soil erosion at different degrees.
6. Grain size distribution of sand fractions influences erodibility of the soils.
7. Organic carbon content dominates aggregate soils and thus, soil stability.
8. LCCI influences both erosivity forces from rain drops as well as soil stability due to occurrence of roots.

9. Rainfall totals enhance erosion and soil erosion but also increase soil moisture. Thus, positive and negative feedback on erosion and soil erosion is given.
10. Rainfall intensity is reflected by a rainfall intensity index (RII). The higher the index, the higher erosivity forces are.
11. Anthropogenic activities are derived from signals on topographic maps such as the occurrence of buildings or footpaths. These signals indicate high activities and thus the possibility of erosion and soil erosion risk.

All factors were incorporated into the model, and different weighting of the individual factors was performed until results of the modelling matched with the erosion and soil erosion damages from the study areas.

The verification of the results is also of qualitative character. Results were compared with isoerodent maps of Ethiopia, which have been calculated after the 'Universal Soil Loss Equation' (USLE) and were superimposed on erosion and soil erosion damage maps, which had not been used for calibration. Additional information from satellite interpretation was compared with the risk map as well. Overall, the model yields good results and a detailed interpretation of the results demonstrates good consistence of erosion risk areas to catalogued erosion and soil erosion damages.

This model is designed to assess erosion and soil erosion risk in developing countries on semi-arid to semi-humid climate conditions. It is specifically intended for local and regional decision makers and could be further developed as a decision making tool. To support this, the model does not incorporate all physical and chemical input parameters that are difficult to collect, as do numerous other erosion and soil erosion models. The power of this model is its simple control with widely used software and the possibility of utilizing either satellite data or ground mapped data. In addition, the model can easily be extended for further questionnaires.