PART I: Assessment of Model-Input-Data

5 Methodology

5.1 Relief Analysis

Relief Analysis was carried out utilising the software Arc View 3.3, Arc Info 8.2 and 3DEM. The raw data for the digital elevation model (DEM) are Shuttle Radar Topography Mission (SRTM) data and altitude information from topographical maps in the scale of 1:250,000 and 1:50,000, as published by the Ethiopian Mapping Authority.

SRTM data were processed with the freeware 3DEM as follows: First, the raw data were projected into the UTM coordinate system, zone 37 N and then saved as USGS ASCII DEM. The USGS DEM was subsequently imported into Arc View 3.3 and saved as a GRID file with a cell size of 100 by 100 meters. Since the conversion of the grid cell size from SRTM data into the cell size utilised in Arc View was done with the standard tool in Arc Info, no error analyses of aggregation effects was carried out. However, it is known, that conversions of grid cell sizes cause accuracy errors of the grid cell's values.

Topographical maps 1:250,000 and 1:50,000 were geo-referenced in Erdas Imagine and saved as GEO-TIFF. These GEO-TIFF files are the basis for all digitised information as well as the geo-referencing (image to image) of individual images, thematic maps or ground data from the Food and Agricultural Organisation (FAO).

Sinks and sources of the GRID-DEM were levelled and lakes flattened using Arc Info. Areas of digitised lakes and stream lines were reduced in altitude ('burned') according to their stream order after STRAHLER (1964): Order one streams were burned in by one meter in elevation, order two streams by two meters, etc. The highest stream order encountered in the project area is five. In a second step, the DEM was adapted to altitude information from the topographical maps 1:250,000. In doing so, the entire DEM was reduced in altitude by 18 meters to be consistent with lake levels assigned by the Ethiopian Mapping Authority.

This DEM is the basis for all further analysis: flow direction, flow accumulation, slope and aspect as well as plan curvature, profile curvature and complex curvature. All first and second derivative grids have a grid cell size of 100 by 100 meters. They were computed in Arc Info and transferred into Arc View for further analysis.

Additionally, individual DEMs were computed for each study site based on data from topographical maps with a scale of 1:50,000. Contour lines and altitude points as well as stream lines were digitised. These data were then processed in ArcInfo to interpolate the DEM, fill sinks and sources and generate derivatives. The grid cell size here is also 100 by 100 meters.

The analysis of relief and derivatives utilised Arc View functions, such as 'Histogram by Zone' or 'Summarize by Zone'. Extracted data were subsequently transferred to either Excel or SPSS (Predictive Analytics Inside) for further statistical analysis.

5.2 Rainfall – Runoff Analysis

Availability of hydro-meteorological data in Ethiopia is in general acceptable, but sometimes limited. Table five lists the meteorological stations relevant for this research and the availability of data collected at these sites. The availability of data depends mostly on time periods of recording and recording gaps but also on the fact that some recorded data could not be obtained by the author. The spatial distribution of the meteorological stations is displayed in figure 52.

The quality of the discharge data is very poor, because rating curves were typically determined when the gauging stations were established, but were never updated. Also cross-sections of the rivers have been determined only once (unofficial information from the Ministry of Water Resources).

Almost complete time series of precipitation data are only available on a monthly scale for the meteorological stations in the watershed. Hourly and daily precipitation data could therefore only be used either to complete monthly time series or to illustrate relevant rainfall events or general short interval characteristics of rainfall regimes. Point data from the meteorological stations were interpolated using kriging within the software Surfer. The ordinary linear kriging method was chosen, since it is proven useful in many fields. The kriging method is not creating 'bull's eyes' as for instance the 'inverse distance to power' method and therefore it is specially useful to interpolate scattered data along mountainous areas(ABRAMOWITZ & STEGUN, 1972). However, the ordinary linear kriging method used in Surfer 0.7 requires no further specific parameter input. Variogram analysis was carried out to specify nugget-effect, range, minimum and maximum values.

Table 5: Data Availability in the *Bilate* Watershed

Station	Precipitation hourly	Precipitation daily	Precipitation monthly	Discharge monthly
Anchaga		2001-2002	1970-1996	
Alaba Kulito			1970-1996	1975-1996
Aleta Wendo			1970-1996	
Aje			1970-1996	
Awassa			1970-1996	
Bedessa		1987-2004	1970-1996	
Bilate State Farm		1990-2002	1970-1996	
Bilate Tena (Dimtu)		2001-2002	1970-1996	1980, 1981 1984-1987 1989-1992 1998-2002
Boditi		1984-2002	1970-1996	
Butajira			1970-1996	
Fonko		1988-2004		
Hossaina	2001-2002	1984-1988 1990-2004	1970-1996	
Hossaina (Batena)				1987-1995 1997-1999
Hossaina (Guder)				1988-2000
Humbo Tebela		1990-2002	1970-1996	
Mirab Abaya	2001-2002	2001-2002		
Shone		1984-2004	1970-1996	
Sodo	2000-2002	1990-2002	1970-1996	
Wulbareg		2001-2002		
Yirga Alem			1970-1996	

All data derived from Surfer were transferred into Arc View and incorporated into the spatial dataset. Subsequently, the influences of altitude on the precipitation totals were incorporated. The method for predicting spatial rainfall after PRUDOMME (1999) was modified and applied to estimate average monthly rainfall: First, average monthly rainfall totals (1970-1996) of all meteorological stations were correlated to the altitude by month. The spatial distribution of rainfall was then estimated utilising these correlations and the altitude information of the DEM. As a second step, positive and negative differences of monthly precipitation totals between the meteorological stations and the computed spatial rainfall data set were calculated and a spatial difference surface was created using the kriging method. The spatial difference surface was then subtracted from computed spatial rainfall data set. This approach accounts for both the correlation of precipitation totals and altitude, and the lack of data for spatial estimation.

Rainfall intensity data are only available for two meteorological stations. Therefore, a rainfall-intensity-index was designed (chapter 7.1.1.3) based on monthly precipitation totals and maximum precipitation within the same month. The kriging method was subsequently utilised in Surfer to create the spatial distribution of this index. The resulting spatial distribution of the rainfall-intensity-index was then transferred into Arc View.

Volumes of both discharge and precipitation were computed in Excel and Arc View using the 'dbase IV' file format for exchanging data. Further statistical analyses were then carried out in SPSS.

5.3 Assessment of Erosion and Soil Erosion Damages

5.3.1 Field Work

Field work for assessing erosion and soil erosion damages, collecting information from farmers, individual institutes or ministries was conducted during several visits to Ethiopia:

- 2002, March: preparatory work, selection of test sites, collection of data in Addis Ababa
- 2002, August / September: Assessment of erosion and soil erosion damages in study sites in the Western Ethiopian Highlands and the northern part of the watershed; assessment of erosion processes occurring during the rainy season and collection of data in Addis Ababa.
- 2003, February / March: Assessment of erosion and soil erosion damages in the Western Ethiopian Highlands and in the Rift Valley; assessment of erosion processes occurring during dry season; collection of additional information from farmers and institutes.
- 2003, August / September: Mapping and collection of missing information in the entire watershed.

The field work was prepared before each field trip by collecting topographical maps, aerial photographs and satellite images. A selection of potential study areas was determined from topographical maps, scale 1:50,000. During the first field trip eight actual study areas were selected, based on their feasibility for this research. Preconditions were:

- Size of the study area: 3-15 km² (exception is one study area of ~80km²)
- Representative landscape characteristics of the region
- Different land uses within the study area
- The study area encompasses a watershed
- Occurrence of erosion and soil erosion damages and areas without any damages as well as accumulation areas
- Accessibility by car

Since the geomorphological unit 'Valleys and Basin' was hardly accessable, no study site was selected here.

Mapping of erosion and soil erosion damages in the study areas was carried out by ground mapping. Damages as well as soil conservation measures and land use were drawn on enlarged copies of the topographical maps 1:50,000. The enlargement factor was 200%, thus the drawn maps have scale of 1:12,500. The mapping was based on the 'Bodenkundliche Kartieranleitung' (AG BODEN, 1996) as adapted by SCHÜTT & THIEMANN (2001) for the prevailing conditions in Ethiopia and watershed management needs. In addition, digital images were taken for documentation and local farmers were interviewed. The translation was hereby provided by students who joined the field trips or by teachers of local schools.

5.3.2 Remote Sensing

Three types of remote sensing data were utilised:

Digital images were taken during flights across the watershed. The plane was flying approximately 1,000 meters above ground and these pictures therefore provide a very good overview of the landscape and erosion processes taking place. In this research, these pictures have only been used for documentation.

Aerial photographs have been used to assess larger erosion forms, such as barren degraded land. Since the aerial photographs were taken in the 1960's and 1970's, these pictures were only suitable for methodology but not for current assessment of land degradation forms or land use.

Satellite images from Landsat TM 5 and 7 were obtained from the internet. In this research following satellite images were utilised:

Table 6: Utilised Satellite Images

Satellite	Row	Path	Recording Date
Landsat TM 5	168	53	26.03.1986
Landsat TM 5	168	54	21.01.1986
Landsat TM 5	169	55	22.11.1984
Landsat TM 5	169	56	28.01.1986
Landsat TM 7	168	55	05.02.2000
Landsat TM 7	169	54	26.11.2000
Landsat TM 7	169	55	26.11.2000

Landsat TM 5 and 7 data were processed in Erdas Imagine. Since these satellite images were already geo-referenced and corrected for atmospheric errors, the processing of the images was reduced to simple re-projection into UTM coordinate system and clustering of spatial information. The visible spectrum of these data, channels one to three, were used in this study to determine a land cover class index (see chapter 7.4).

5.4 Analysis of Soils and Soil Sediments

5.4.1 Secondary data

FAO (1998) provides soil and terrain data for Ethiopia at a scale of 1:1,000,000. Since thematic maps of Ethiopia are predominantly based on the FAO data or vice versa, the harmonized FAO data have been used in this research. Additional thematic maps are available from the Ethiopian Ministries of Agriculture and of Mines; however these do not provide more detailed data. FAO data for Ethiopia were exported from the FAO software into Arc View, projected into the UTM coordinate system, zone 37 N and converted into an Arc View grid with a cell size of 100 by 100 meters. The soil data utilized from FAO soil and terrain databases were: soil type, total soil depth, and stone coverage.

5.4.2 Primary Data

Additional soil and soil sediment samples were collected during the field surveys. Samples were collected from horizons and layers of 34 profiles, which are spread across the watershed. The samples were dried in the sun in Arba Minch, Ethiopia first. After the transport to Germany, all samples were dried in an oven at 50° C and than sub-sampled. Sub-samples were either milled between 20 min to one hour in an agate ball mill for further analysis such as the determination of minerals, colour, and magnetic susceptibility; or were directly used for the analysis of pH, organic and inorganic carbon content, electronic conductivity, clay minerals and grain size distribution.

Organic and inorganic carbon content was measured using the 'Carmhograph' of the company Wösthoff. Total organic carbon content was measured by heating the sample at 900° C. Treating the oxidized carbon with oxygen reduces it to CO_2. This CO_2 was brought into reaction with caustic sodium hydroxide. Due to the content of CO_2 the electric conductivity of sodium hydroxide changes and these conductivity values indicate the total organic carbon content, which is presented in percent of weight. For determination of inorganic carbon, samples were first brought to reaction with phosphoric acid and in a secondary reaction CO_2 develops in an oxygen flux. Similar to the determination of total organic carbon content, the CO_2 changes the electric conductivity of sodium hydroxide and thus, indicates the percent by weight of inorganic carbon content. The difference of total carbon content to inorganic carbon content indicates the organic carbon content.

PH-Values of the samples were measured with the pH-meter 'pH 320' from the company WTW (Wissenschaftlich-Technische Werstätten GmbH). 10 g of each sample have been brought into solution of 25 ml 0.01 M $CaCl_2$ and shacked 24 hours before measurement. Each sample was measures three times and the average of the three values was calculated. Measuring modes of the pH-values range between 2.0 and 16.0 pH with a resolution of 0.01 pH and an accuracy 0.01 +/- 1 digit with an operating temperature between -10° and +55° C.

EH-Values of the samples were measured by the eH-meter 'LF 91' from the company WTW (Wissenschaftlich-Technische Werstätten GmbH). 10g of each sample were mixed with distilled aqua and shacked 24 hours before measurement. Each sample was measures three times and the average of the three values was calculated. Measuring modes of the eH-values range up to 199.9 mS/cm, whereas the operating temperature should be between -15° and +50° C. Accuracy errors are not given for this eH-meter.

The magnetic susceptibility of the samples was measured with the MS2B Magnetic Susceptibility Meter of the company Bartington. The MS2B–meter runs without any calibration but external influences, such as magnetic fields of any electronic equipment and changes in temperatures prohibit exact measurements and thus, the theoretical metering precision of 0.001 $\mu m^3 \cdot kg^{-1}$ will never be reached (DEARING 1994). After a zero point measurement (without sample) three measurements (K_{sample}) alternating with zero point measurements (K_{zero}) were taken per sample. The arithmetic average of the three measurements was then computed after applying a correction formula to each individual measurement (DEARING, 1994):

$$K_{(cor)} = K_{(sample)} - [K_{(zero1)} + K_{(zero2)}] / 2 \quad (1)$$

Colours of samples were measured with the spectrophotometer CM2500d of the company Minolta. After calibration, three single measures were taken and arithmeticly averaged. The results are expressed in the CIE-L*a*b colour system. This system was converted to the RGB system for display in graphs.

Mineralogical compounds were determined by X-Ray diffractometry. The diffractometer is the PW 1710 from Philips, working with a CuK_{α}-radiation tube. Milled samples were analysed from 2-60° 2θ, whereas steps have been 0.01° 2θ measured for two seconds. The X-ray results were analysed semi-quantitatively with the software X'Pert Highscore, Version 1.0b from Philips. Since some cards (ID of minerals) of the Powder Diffraction File (PDF) miss information on reference intensity correlation (RIR) that is necessary for the semi-quantitative analysis, not all expected minerals could be added to the shortlist. Minerals, which could be used for semi-quantitative analyses (RIR > 0) are: Amphibole, Anorthite, Biotite, Calcite, Goethite, Hematite, Magnetite, Montbrayite, Pyroxene, Quartz and Sanidine.

Clay Minerals were analysed with the same X-Ray diffractometer. During the pipetting of samples for grain size distribution of clay and silt fractions, sub-samples of the clayey suspension were retained and released on an object slide. The suspension was then dried slowly to avoid cracking of the clayey surface. Dried samples were first measured from 2-35° 2θ (step 0.01° 2θ, 1 sec. measurement). A second set of samples was treated with ethylene glycol by 50° C in an oven for 24 hours in order to differentiate between probable occurring Smectite and Chlorite. After an initial X-ray measurement, the samples were heated for 2 hours at 550° C and measured again to identify swellable clay minerals.

The analysis of grain size distribution was carried out in two steps. First, the grain size distributions of the sand fraction were analysed. Samples were wet sieved into classes of grain size according to the '*Bodenkundliche Kartieranleitung*' (FINNERN ET AL., 1996). Secondly, clay and silt fractions of the selected samples were pipetted.

Results of the sample analyses were utilised to determine input factors for ongoing computation of spatial erodibility factor values, which were then used for descriptive comparison of profiles. Additionally these results were utilised for an attempt to verify of FAO ground data. Interpolating point data from the samples into spatial information was carried out using the ordinary kriging method. However, the interpolation of 34 points in a watershed of 5,500 km² can only roughly estimate realistic values. Moreover, the different relief positions of the sample points are not considered, although their influence on the variability of soil characteristics is known.

5.5 Determination of Vegetation Cover and Land Cover

A Land Cover Class Index (LCCI) was designed for this study as follows. It is based on channels one to three of Landsat TM images, which represent the visible spectrum. The utilised Landsat TM images were obtained for free from the internet. Their processing data was January and November 2000, respectively. Satellite images recorded during rainy season are not available for the watershed due to the very high cloud cover during that season. Since these images are free, they only contain the channels one to three. Considering the further utilisation of the developed model – the application in developing countries – the financial aspect was one consideration: Often necessary money for applied research is not available in these countries. Other, free available images for instance for different regions also contain often only the channels one to three. Additionally, the development of the LCCI is based on the three channels, because of its very easy handling and the visual association of the individual classes to vegetation conditions on the ground. Computer based or manual classifications by ground mapping lead to same results in terms of spatial land cover information.

First, the Landsat TM images were re-projected into the UTM coordinate system (UTM Zone 37 N) with 'Erdas Imagine' re-projection tool. Any correction of atmospheric errors was not necessary, since they were already processed.

Second, 20 clusters of the grid cells were automatically unsupervised classified by using the software 'Erdas Imagine' and in a next step classified manually into 6 classes. Manually classification was verified with information from aerial photographs and ground data. To minimize classification errors, first, classes were clustered where ground information were very well known, such as water bodies, grassland or degraded areas. This positive selection leads automatically to classes of different accuracy in relation to the ground data. Clusters of classes with mixed land cover (see chapter 7.4) are less precise than clusters of classes of well separable signals.

Since the recording dates of the satellite images are in November and February, the LCCI represents the vegetation cover for the dry season only. Therefore the classes reflecting mixed vegetation cover are also of less accuracy than classes reflecting degraded areas or perennial vegetation.

The developed Land Cover Class Index shows several accuracy errors that result for instance during the unsupervised classification, but it needs less knowledge in remote sensing than the utilisation of the Normalized Difference Vegetation Index (NDVI). Handling of NDVI data requires base studies of remote sensing, which are not warranted in developing countries and not considered suitable for local users of this model. Additionally, NDVI data of resolution higher than 8•8 km require financial sources, which are not always given. Advantages of time series and high spatial resolution as well as the benefits of this information are known.

The development of the LCCI is based on satellite images from the dry season month January. It is verified with the NDVI data from the same month. Since NDVI data are available in grid sizes 1•1 km, the overlay of LCCI (30•30 m) onto the NDVI has spatial errors, such as offsets; aditionally appr. 1089 LCCI cells are located within one NDVI cell and that prevents proper correlation calculations. Therefore, the spatial relationship of both datasets gives only a rough hint on the quality of the LCCI dataset.