3 Literature Review

Research on erosion and soil erosion topics has a long scientific history and the underlying fundamentals of erosion processes have been investigated for many decades. But research is still ongoing and increasingly focuses on very detailed topics of erosion and soil erosion processes as well as its modelling. Parallel to the detailed modelling of physical processes, such as the splash effect or the influence of clay content on erodibility, strong efforts are undertaken to develop universally applicable erosion and soil erosion models. The concepts behind these models differ extremely; consistent modelling has not been attempted to date.

The following literature review is concentrating on the relevant topics in terms of erosion and soil erosion detection as well as the assessment of input parameters that are of interest for developing the DESER model. Moreover, the literature review is primarily focusing on the scientific literature of the last several years.

3.1 Erosion- and Soil Erosion Models

Numerous erosion and soil erosion models have been developed in the past decades, utilising different scientific methods and modelling approaches. In general, three different kinds of models exist:

Empirical models are a simplified representation of natural processes based on empirical observations. They are based on observations of the environment and thus, are often of statistical relevance (NEARING ET AL., 1994). Empirical models are frequently utilised for modelling complex processes and, in the context of erosion and soil erosion, particularly useful for identifying the sources of sediments (MERRITT ET AL., 2003). Table one lists some common empirical models and their sources.

Table 1: Empirical Models

Model	Reference
Musgrave Equation	Musgrave (1947)
Equation (MUSLE) Sediment	Renfro (1975)
Delivery Ratio Method	Dendy and Boltan (1976)
Universal Soil Loss Equation (USLE)	Wischmeier and Smith (1978)
Soil Loss Estimation Model for South Africa (SLEMSA)	Elwell (1978)
Dendy-Boltan Method Flaxman Method	Flaxman (1972)
Pacific Southwest Interagency Committee (PSIAC) Method	Pacific Southwest Interagency Committee (1968)

Physically based models represent natural processes by describing each individual physical process of the system and combining them into a complex model. Physical equations hereby describe natural processes, such as stream flow or sediment transport (MERRITT ET AL. 2003). This complex approach requires high resolution spatial and temporal input data. Physically based models are therefore often developed for specific applications, and are typically not intended for universal utilisation. Physically based models (tab. 2) are able to explain the spatial variability of most important land surface characteristics such as topography, slope, aspect, vegetation, soil, as well as climate parameters including precipitation, temperature and evaporation (LEGESSE ET AL., 2003).

Table 2: Physically Based Models

Model	Reference
Erosion Kinematic Wave Models	Hjelmfelt, Piest and Saxton (1975)
Quasi-Steady State	Foster. Meyer and Onstad (1977)
Areal Non-point Source Watershed Environment Response Simulation (ANSWERS)	Beasley et al. (1980)
Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS)	Knisel (1980)
Water Erosion Prediction Project (WEPP)	Laflen et al. (1991)
European Soil Erosion Model (EUROSEM)	Morgan (1998)

Conceptual models are a mixture of empirical and physically based models (tab. 3) and their application is therefore more applicable to answer general questions (BECK, 1987). These models usually incorporate general descriptions of catchment processes without specifying process interactions that would require very detailed catchment information (MERRITT ET AL., 2003). These models therefore provide an indication of quantitative and qualitative processes within a watershed.

Table 3: Conceptual Models

Model	Reference
Sediment Concentration Graph	Johnson (1943)
Renard-Laursen Model	Renard and Laursen (1975)
Unit Sediment Graph	Rendon-Herrero (1978)
Instantaneous Unit Sediment Graph	Williams (1978)
Sediment Routing Model	Williams and Hann (1978)
Discrete Dynamic Models	Sharma and Dickinson (1979)
Agricultural Catchment Research Unit (ACRU)	Schulze (1995)
Hydrologic Simulation Programme, Fortran	Walton and Hunter (1996)

Commonly used erosion and soil erosion models developed in the last decades tend to shift in their methodology from empirical approaches in the 1970s to physically based and conceptual approaches in the present (tab. 4).

Table 4: Erosion and Soil Erosion Models

	Model	Reference
USLE	Universal Soil Loss Equation	Wischmeier & Smith, 1978
RUSLE	Revised USLE	Renard et al., 1991
dUSLE	Differentiated USLE	Flacke et al., 1990
CREAMS	Chemical runoff and erosion from agriculture management systems	Knisel, 1980
ANSWERS	Areal Nonpoint Source Watershed Environment Response System	Beasley & Huggins, 1982
WEPP	Water Erosion Prediction Project	Lane & Nearing, 1989
OPUS	Advanced simulation model for nonpoint source pollution transport	Ferreira & Smith, 1992
EROSION2D	Erosion- 2D	Schmidt, 1991
PEPP	Process-oriented erosion prognosis program	Schramm, 1994
KINEROS	Kinematic Erosion Simulation	Woolhiser et al., 1990
EUROSEM	European Soil Erosion Model	Morgan et al., 1991
LISEM	Limburg Soil Erosion Model	De Roo et al., 1994

Another differentiation between commonly used erosion and soil erosion models is their spatial exposure. Models are either lumped or distributed. Lumped models use unified areas, whereas distributed models differentiate areas into detailed spatial structures.

WISCHMEIER & SMITH (1978) are the first to introduce individual input factors in the Universal Soil Loss Equation (USLE). Further implementation of these factors in erosion and soil erosion models have been discussed by EL-SWAIFY & DANGLER (1976), ROOSE & SARRAILH (1989) or RENARD ET AL. (1997). AUERSWALD (1987) represents the K-factor (erodibility of the soil) as part of the USLE and its revised versions. However, although the disadvantages and uncertainties of USLE are very well known, the USLE and its revised versions are widely used in the scientific and engineering world, because of its relatively easy application.

JETTEN ET AL. (2003) summarize the results of model comparison workshops. They concur with the generally held viewpoint that the predictive quality of distributed models is reasonably good for total discharge at the outlet and fair for net soil loss. The difficulties associated with calibrating and validating spatially distributed soil erosion models are due to the large spatial and temporal variability of soil erosion phenomena and the uncertainty associated with the input parameter values used in the models. JETTEN ET AL. (2003) conclude that these difficulties will not be overcome by constructing even more comprehensive and therefore more complex models. The situation may be improved by using 'optimal' models, describing only the dominant processes within a given landscape (JETTEN ET AL., 2003).

A framework for quality assurance guidelines including terminology and the foundation for methodologies is given by REFSGAARD & HENRIKSEN (2004). In addition, a distinction is made between conceptual models, the model code and the site-specific implementation. The newly developed model DESER in this study is a conceptual model and is generally based on the terminology and the methodological framework of REFSGAARD & HENRIKSEN (2004).

FINLAYSON & MONTGOMERY (2003) recognize that stream power models have become standard for large-scale erosion modelling in Geographic Information Systems (GIS) because they can be applied over broad areas without the need for detailed knowledge of stream characteristics. HABIB-UR-REHMAN ET AL. (2003) provide a process based approach for modelling erosion and soil erosion at regional scale. LEGESSE ET AL. (2003) use a physically based distributed model to investigate the hydrological response of a catchment to climate and land use changes in south central Ethiopia.

With more models being developed during the past decades, increasing attention to sensitivity and uncertainty assessment of these models was also necessary. CROSETTO ET AL. (2000) point out that good modelling practice requires the evaluation of the confidence in the model and an assessment of the uncertainty associated with the model results. In a sensitivity analysis each input factor into the model and its influence on the outcome of the model is quantitatively analysed, while uncertainty analysis can support a stochastic approach in the evaluation of the results of a model. HWANG ET AL. (1998) focus on the necessity of uncertainty analysis in a GIS based environment. GOOVAERTS (2001) provides an uncertainty modelling method and presents accuracy and precision of uncertainty models using cross-validation. PHILLIPS & MARKS (1996) highlight model uncertainties when model inputs are interpolated from irregularly scattered measurements.

3.2 Causes of Erosion and Soil Erosion in the Tropics

The causes of soil erosion have been intensively discussed during the past 40 years. Soil erosion is a natural erosion process that is enhanced by human activity (RICHTER, 1998) and occurs in all landscapes and under different land uses. Besides the influence of human activities, soil erosion processes are also caused by morphometric characteristics of the land surface, the erosive forces of rainfall and the erodibility of soils and soil surfaces.

The damages resulting from soil erosion is also classified: definition of gullies and explanation of gully development is given by MORGAN (1996), as well as HUDSON (1995) who additionally focuses on individual causes of the development of gullies. TOY ET AL. (2002) give detailed definitions of soil erosion features and processes such as sheet erosion and inter-rill erosion, rill erosion, as well as ephemeral and permanent gully erosion. They also describe the influence of changing land-use on stream channel erosion. HOGG (1982) defines sheet-flood, sheet-wash and sheet-flow in terms of a hydrologic and geomorphic based classification system: a) sheet-flood is unconfined floodwater moving downhill; b) sheet-flow is a high -frequency, low magnitude overland flow; c) sheet-wash is superseded by the more meaningful term rain-wash, which is defined as the washing action of rain on slopes.

The causes of both erosion and soil erosion processes are amply described in the standard literature (DIEKAU, 1986; SUMMERFIELD, 1991; PRESS & SIEVER, 1994; STRAHLER & STRAHLER, 1995; AHNERT, 1996; RICHTER, 1998). Intensity of soil erosion is mainly influenced by three factors:

a) erosivity of water,

b) erodibility of soils, and

c) human activities.

Physical aspects of erosivity forces of water are independent of the locally prevailing climate conditions. In reality, different climatic conditions reveal different erosivity forces of rainfall. VAN DIJK ET AL. (2002) critically review published studies of rainfall intensities and kinetic energy in order to derive a generally predictive exponential equation. They favour standardised measurements to evaluate rainfall intensity – kinetic energy relationships.

In the tropics, erosivity of rainfall is significantly higher than in moderate and cold climates. The semi-arid to semi-humid tropics are characterised by very high rainfall intensities and totals alternating with periods of no or little rainfall. Rainfall events during dry seasons are of high intensity and thus, erosivity forces are very strong.

Research on rainfall intensities and erosivity was conducted by NYSSEN ET AL. (2005) for the north-western Ethiopian Highlands. LAL (1998) measured rainfall erosivity, drop size distribution and kinetic energy for two rainy seasons in Nigeria. Rainfall variations by ground measurements as well as by satellite radar data were measured and discussed. SELESHI & DEMAREE (1995), NICHOLSON ET AL. (1997), HULME (2001), SCHUMACHER & HOUZE (2002), GIANNINI ET AL. (2003) and FERNANDEZ-ILLESCAS & RODRIGUEZ-ITURBE (2004) provide different methods of assessment and appraisal of rainfall variations in Sahelian and sub-Sahelian areas.

Causes for inter-annual rainfall variability are discussed by numerous authors such as THOMPSON (2000), GASSE (2000), MAYEWSKI ET AL. (2004), ADAMS & PIOVESAN (2005) or MENDOZA (2005).

The prediction of rainfall totals for mountainous areas has been investigated by GOOVAERTS (2000), who presents multivariate geostatistical algorithms for incorporating a digital elevation model into the spatial prediction of rainfall. PRUDHOMME (1999) introduces a method similar to GOOVAERTS (2000) for predicting spatial rainfall volumes in mountainous areas in Scotland. He also uses the relationship between precipitation and topography. The erosivity factor R, known from USLE or RUSLE, was focus of a study by WANG ET AL. (2002). He predicts the development of new isoerodent maps, since the uncertainty of the R-factor values estimated from isoerodent maps is unknown.

Next to erosivity by rainfall drops (‘splash-effect’), forces by surface runoff (‘overland flow`) are part of the erosivity. Saturated overland flow and Horton’s surface runoff occur both in tropical semi-arid and semi-humid landscapes. ZEHETNER & MILLER (2006) studied the runoff-erosion behaviour of soils developed from volcanic ash bedrock and ROCKSTROM ET AL. (1998) pursued water balance modelling with a special focus on runoff producing surfaces for sandy soils in Niger. For Vertisols, FREEBAIRN ET AL. (1986) monitored surface runoff on agricultural fields and its influence on soil surface cover and soil moisture, whereas DUBREUL (1985) gives a general overview of runoff generation in the tropics.

MAKSIMOVIC ET AL. (1991) investigated measurement uncertainties of tipping bucket rain gauges. MOLINI ET AL. (2005) present a methodology to minimize measuring errors particularly for heavy rainstorm events and compare measured and designed rainfall.

WHALLEY ET AL. (2001) in their case studies describe the reliability and uncertainty of flow measurement techniques such as the current meter gauging used in England. GYAU-BOAKYE & SCHULTZ (1994) illustrate the deficits of water resource projects due to the lack of appropriate data or incomplete time series.

The erodibility of soils has not been rigorously defined (BRYAN ET AL., 1989); BRYAN (2000) highlights the importance of the inherent resistance of soil to erosion processes. Results of his research show that many components of erosion response, such as threshold hydraulic conditions for rill erosion, rill network configuration and hill slope sediment delivery, are strongly affected by spatially variable and temporally dynamic soil properties (BRYAN, 2000).

VEIHE (2002) examines the spatial variability of erodibility of soil types based on a case study in Ghana. The estimation of K-factors from soil types can in general be problematic because soil classifications are often not based on parameters reflecting erodibility.

Erodibility of tropical soils is highly dependent on grain size distribution, clay content and organic carbon content, which influence the stability of soil aggregates. LE BISSONAIS (1996) identifies four main mechanisms by which soil aggregates break down: slaking, differential swelling, raindrop impact and physio-chemical dispersion caused by osmotic stress. BARTHES & ROOSE (2002) analyse topsoil aggregate stability and compared these results to susceptibility to erosion. MBAGWU & BAZZOFFI (1998) investigate the resistance of dry soil aggregates against rain drops. VALMIS ET AL. (2005) correlate inter-rill erosion to aggregate instability, rainfall intensity and slope gradient.

Influence, as well as detection and assessment, of clay minerals and clay content are discussed by WADA (1989), who describes physical and chemical properties of disordered materials, such as allophane. ALLBROOK (1985) also studied the effect of allophane on soil properties. SEDOV ET AL. (2003) studied buried Andosols and buried Luvisols of the Nevado de Toluca Late Quaternary tephra-paleosol sequence.

COUPER (2003) demonstrates how subaerial processes vary with the silt-clay content of riverbank soil and considers these variations in the context of erosion observed in the field. He also shows intra-annual influence of soil moisture and swelling of tropical soils on erosion processes.

Macro-cracks, as the result of shrinking soils, react to soil moisture changes by opening and closing, as well as by the reorganisation of the clay particles. In heavy clay soils infiltration and lateral water flow are dominated by macro-pore flow. Thus, three components of porosity of this soil influence water infiltration: matrix, structural and macro-cracks (RUY ET AL., 1999). MARTINEZ-CASASNOVAS ET AL. (2004) reveal that gully sidewall processes are influenced by either potential energy changes associated with variations in soil moisture content or, in unsaturated conditions, by the development of undercut hollows.

SCHOLTEN (1997), DUIKER ET AL. (2001), HOWES & ABRAHAMS (2003), ZELEKE ET AL. (2004) and VIGIAK ET AL. (2005) present additional case studies with topics on soil properties and infiltration rates of semi-arid to arid soils.

Infiltration rates of soils are also influenced by the morphometric characteristics of the land surface. YAIR & RAZ-YASSIF (2004) investigated the influence of slope length and gradient on soil erosion. For arid and semi-arid areas he assumes increasing soil erosion with increasing slope length, whereas the gradient is a minor factor. MONTGOMERY (2003) and PARK & VAN DE GIESEN (2004) contribute research on spatial soil hydrological properties and their relation to landscape characteristics. WANG ET AL. (2001) show that heterogeneity of soil in time and space tends to support the concept that soil erodibility depends dynamically and spatially on specific soil properties.

Soil moisture, in addition to infiltration rates, also depends on evaporation rates. ANDRÉASSIAN ET AL. (2004) highlight that sensitivity studies of rainfall-runoff models with regard to the uncertainty of their inputs have focused quite exclusively on rainfall and only few studies consider the sensitivity of potential evapotranspiration estimation. Research on actual and long term potential evapotranspiration summarizes that 'average annual evapotranspiration curves appear to be as meaningful as any readily available discrete information' (BURNASH, 1995). AYENEW (2003) quantifies actual evapotranspiration from spectral satellite data for the Rift Valley Lake Region, Ethiopia. JHORAR ET AL. (2003) highlight the positive effect of using evaporation when estimating soil hydraulics in semi-arid to arid areas and AUERSWALD ET AL. (1994) explain the influence of soil moisture content changes on soil erosion.

The varying erodibility of different soils causes different erosion and soil erosion damages. RENSCHLER & HARBOUR (2002) provide an overview of soil erosion assessment tools from point to regional scales. GOBIN ET AL. (1998) present an assessment of soil erosion in south-eastern Nigeria and BEWKET & STERK (2003) report results of a field scale erosion assessment utilising survey methodology for rills in the north-western Ethiopian Highlands. SCHOLTEN (1997) and VEIHE (2002) discuss erodibility and its relation to soil types and bedrock in Swaziland and Ghana, whereas BOARDMAN ET AL. (2003) explain the development of badlands and gullies in the Great Karoo Mountains, South Africa. HURNI'S work (1986, 1999) is most commonly used as standard guidelines for assessing erosion and soil erosion damages as well as conservation measures in Ethiopia. Several attempts to assess gully erosion with remote sensing techniques have been published: DABA ET AL. (2001), GUTIERREZ ET AL. (2004) or VAN LYNDEN & MANTEL (2001). A standard tool to record and assess soil characteristics and properties as well as erosion damages is the "*Bodenkundliche Kartieranleitung*" from FINNERN ET AL. (1996).

The anthropogenic impacts on landscape, water budget and erosion are widespread and often closely linked to socio-economic conditions. NYSSEN ET AL. (2004) discuss the socio-economic development and changes in Ethiopia and Eritrea during the late Quaternary and its influence on landscape changes in detail. SHIFERAW & HOLDEN (1999) provide information regarding the current economic situation of Ethiopia and the influence of erosion and soil erosion damages and the cost of conservation measures on the economic situation. GEBREGZIABHER ET AL. (2005) also highlight the socio-economic situation of Ethiopia as it relates to development and the utilisation of the traditional plough *Maresha*. Traditional farming systems are investigated by D'ANDREA ET AL. (1999).

SCHÜTT & THIEMANN (2001), SCHÜTT ET AL. (2002), BEKELE (2001), BECK ET AL. (2004), SCHÜTT & THIEMANN (2005) and THIEMANN ET AL. (2005) provide case studies on the association of human activities and soil erosion as well as sedimentation for the Lake-Abaya-Chamo Basin in southern Ethiopia and for the western Ethiopian Highlands. Additional case studies on human activities and its influence on landscape changes are provided by FIEDLER & BELAY (1988), LEGESSE ET AL. (2001), ZELEKE & HURNI (2001), FEOLI ET AL. (2002) and NGIGI (2003).