>> OCCASIONAL PAPER <<

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Heft 20

Watershed Management in the Abaya-Chamo Basin, South Ethiopia

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Preface by the Editor

In 2003 the second International Class on Watershed Management, integrating lecture elements, field studies and project work was carried out at Arba Minch Water Technology Institute, Arba Minch, Ethiopia. During this time 20 students of geography and engineering from Germany (FU Berlin, Univ. Siegen) and Ethiopia (AWTI) worked on a project to assess the landscape sensitivity of a small catchment in the southern Ethiopian Rift Valley. The special focus of this project work was on the assessment of soil erosion risk and water balance problems due to an expected doubling of population by 2025. The teaching target of the course was the application of knowledge by utilising simple tools, supplemented by the skills to recognise and to structure information within a given theory or schematic order. These targets were reached by incorporating self-reliant and practical work. During the course it became apparent that the special value of the course was the survey of primary data and their immediate processing during project work – and the public presentation of the results in a workshop.

The International Class on Watershed Management is a pilot study within the framework of '*Network Watershed Management*'. The project management of this university cooperation is conducted as a corporate challenge by G. Förch, Civil Engineering Department, University of Siegen and B. Schütt, Geoscience Department, Free University of Berlin. This interdisciplinary and international university cooperation is supported by the DAAD for the 2004-2007 period to build up a MSc programme on '*Integrated Watershed Management*' in Eastern Africa.

The course on Watershed Management and logistics of field work would have not been possible without support by the DAAD. Also the DAAD agreed to finance the publication of the results from the 2003 course on Watershed Management.

Brigitta Schütt
Free University of Berlin
Berlin, December 2003

Preface by the DAAD

In international discussions on the effectiveness and sustainability of collaboration for development, high priority is now being given to direct cooperation between well-defined groups for the fulfilment of concrete proposals of mutual interest. Academic cooperation takes this form. The basic prerequisite for a successful, long-term partnership between universities is their collaboration as equals. This is created and maintained through shared responsibility and equality of status and is achieved in concrete projects. For these reasons the Federal Ministry for Economic Cooperation and Development is promoting various programmes of cooperation between universities and scientific institutes, such as the programme called "Subject-related partnerships with universities in developing countries" to give fresh impetus to cooperation between universities.

Financial support for university partnerships is intended to stimulate and strengthen university collaboration for development. In particular, this support aims at pursuing the following objectives:

1. To further raise the standards of universities in developing countries in their teaching, research, services and management methods ('institutional development');
2. To stabilise university cooperation agreements by financial support over a period of several years, which in turn permits long-term institutional ties to be formed;
3. To promote the education and training of the participating members of the universities in the developing countries (professors, junior faculty, students), and to advance experience in international cooperation;
4. To create networks between German universities and their partner institutions, as well as 'South-South-Networks';
5. To raise the sensitivity and awareness of German universities and their staff members for development policy problems. Knowledge of the needs and the particularities of the individual developing countries is to be increased; by passing on this experience to students, the current and future availability of experts can be expanded;
6. To raise the appeal of German universities and strengthen Germany's position as an international centre for science, research and education.

Presently the DAAD is supporting 83 subject-related partnerships worldwide. One of those is the new 'Network Watershed Management' which includes 4 different countries in Eastern Africa. The University of Siegen and the Free University of Berlin started this network already in 2003. From the beginning of 2004 it will be supported by the DAAD. To interlink 5 universities in 4 different countries may be the greatest challenge for all persons involved.
We wish every success to all participants and the project.

Anke Stahl
DAAD
Department of Development Cooperation,
Alumni and Partnership Programmes
Bonn, December 2003

Table of Contents

Occasional Paper Geographie	Heft 20	S. 7 - 14

International MSc 'Integrated Watershed Management' (IWM)

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1. Introduction

Watershed Management became an integrated part of development co-operation over the last ten years. It has been increasingly accepted as a measure in regional and inter-regional programmes, e.g. in the programmes of the Nile Basin Initiative comprising all riparian countries of the Nile or bilateral agreements on focal areas of intervention. Thus, it appears to be necessary and reasonable to establish an MSc programme with

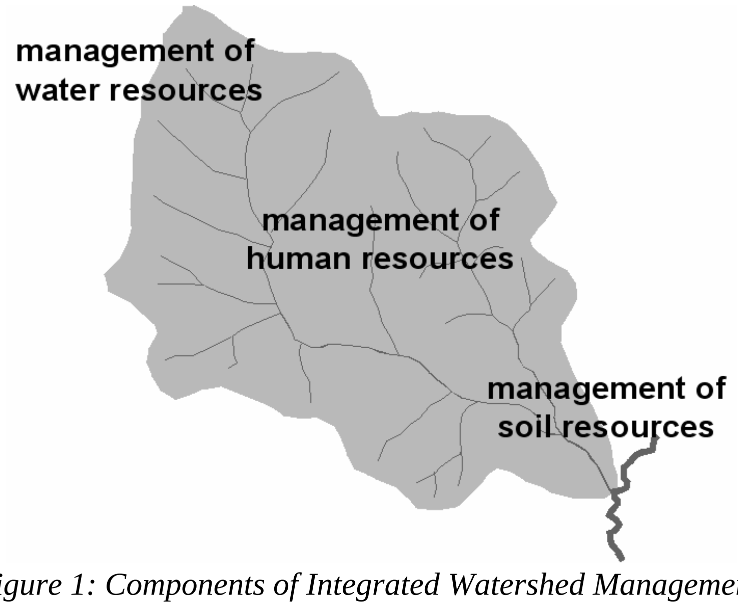

Figure 1: Components of Integrated Watershed Management.

regional focus on Eastern African countries. The major topic of the programme is Watershed Management as a planning tool, which enables the utilisation of available resources for the benefit of the local people in a defined river catchment area.
A discipline-oriented university co-operation project between Germany and several Eastern African countries is the basis for the establishment of a network of university

institutions with the aim to establish a MSc programme for "*Integrated Watershed Management*". The African partners offer individual teaching modules which, in combination should lead to an MSc degree. The African university partners may build their offers upon successful courses from running master programmes. These may be supplemented by special modules covering integrative and inter-disciplinary aspects of watershed management. The network coordinates the individual partner contributions (like teaching modules) and guides the MSc students through the programme targeted at an efficient and successful study.

2. Aims of the discipline-oriented university co-operation

This discipline-oriented university co-operation project supports the establishment of the interdisciplinary and internationally oriented MSc Programme "*Integrated Watershed Management*" with a regional focus in Eastern Africa. The two project managers took the initiative in 2001 to establish the programme. Based upon various discussions with different long-term partners in Ethiopia and Kenya and the further integration of university institutions in Uganda and Tanzania the following partners were selected and agreed to commonly establish the network:

1. Kenyatta University, Nairobi, Kenya – Geography Department,
2. Arba Minch University, Arba Minch, Ethiopia - Arba Minch Water Technology Institute,
3. Makarere University, Kampala, Uganda – Institute of Economics and Institute of Environment and Natural Resources,
4. Sokoine University of Agriculture, Morogoro, Tanzania – Faculty of Agriculture,
5. University of Dares Salaam, Dares Salaam, Tanzania – Department of Water Resources Engineering.

The master degree shall be awarded for a minimum number of modules to be taken from at least three different partner universities. A practical module must be part of the programme, where available resources and risk potentials of a defined river catchment area or watershed need to be determined, presented and evaluated with regard to the population present in the area. This module was organised by the two German partners already twice an 'expert seminar' composed of an international and interdisciplinary students' group. The experiences gained shall be utilised for the programme. Each of the partner universities has its specific focal areas and experiences based upon international and national master programmes in operation, which supplement each other. The direct communication of partners, the harmonization of separate modules and concepts at the different universities, and the coordination of these for achieving a master degree in "*Integrated Watershed Management*" with qualified results essential for professional application and international acceptance, are the objectives of the joint workshops.

The formulation of learning targets is a special interest of the German partners. Not only knowledge accumulation as the basis for its reproduction from memory, but also the orientation within this knowledge base is of importance. Consequently, applying the new skills by utilising simple tools needs to be supplemented by the capability to recognise and structure information within a given theory or schematic order. The students need to obtain the capability to describe and analyse complex structures (identify causes) as well as to observe and understand processes and impacts of measures. They need to be able to correctly use standard terms for a specific object, to document observations and to repeat these or present the findings. These targets shall be reached by incorporating self-reliant and practical work (e.g. field exercises and studies) into the curriculum.

3. The IWM Programme

The sustainable management of natural resources such as soil and water will become increasingly important in future. This applies especially to semi-arid up to sub-humid regions because of their ecological fragility. Due to the high landscape sensitivity, growing pressure on land resources by man and cattle shows a more rapid effect than in the temperate zones. Traditional coping mechanisms of indigenous people avoided destructive overuse and allowed for sustainable land-use for centuries. Under modern political and demographic circumstances, however, these traditional measures of land-use and resource management are no longer feasible and traditional knowledge might eventually get lost. Additionally, increasing population and coinciding migration frequently cause displacement of indigenous people and their traditional knowledge accompanied by the introduction of inappropriate resource utilisation.

The necessity of a future sustainable management of natural resources demands special training programmes where as well as specific techniques interdisciplinary teamwork and holistic thinking are taught.

4. Aims of IWM curriculum

Based on skills of holistic thinking and decision making students will learn to analyse problems, to develop strategies and to achieve applicable solutions. In the programme education will focus on developing concepts and solutions for sustainable development (management) of limited water and soil resources in tropical and sub-tropical regions. It will be taught that the development potential of a region needs to be assessed by using regional analyses of natural (e.g. soil productivity, soil erosion, groundwater recharge) and cultural potentials (e.g., mobility, legal basics, education, age distribution, land tenure system, traditional knowledge) integrated into action plans based upon specific scenario developments.

A main concern of the training programme will be to teach that sustainable socio-economic and ecological development may be reached by combining traditional knowledge about water and soil management with modern techniques of agricultural and water resources engineering, in order to meet the current socio-economic demands for the rural environment. Concepts and solution strategies will be developed by the students including the necessities of future regional planning measures. For the approaches generated it will be essential that they are not only utilisable for local and regional governments as planning tools for sustainable use of water and soil resources, but at the same time also for all actors on different levels (farmers, planners, politicians).

5. Study Area

Eastern Africa is an excellent area to impart the knowledge and skills described: It is one of the original development zones of the globe. There are abandoned arid, semi-arid, and sub-humid environments. There is a large number of independent indigenous people with preserved traditional knowledge as farmers and pastoral herdsmen, but in modern times increasingly affected by influences from outside and thus endangered. At the same time, the geologic, climatic and geomorphic conditions cause distinct variations of landscape character on a regional scale.

As the MSc-programme will be predominantly implemented by project work, several areas in Eastern Africa provide ideal ‘laboratory conditions’ for training. Nairobi, i.e. Kenyatta University, could be the training centre, integrated into an international network of experts originating from universities of neighbouring countries. The network indicated needs to be imbedded into an organisational frame by establishing an international university cooperation.

6. Measures of discipline-oriented university co-operation

In general, the communication between the partners is based on using the internet. However, especially the course contents offered at the individual university locations need to be harmonised by direct discussions, that is through workshops. Consequently, the combined programme needs to be agreed upon if international quality standards for this new MSc Programme on “*Integrated Watershed Management*” are to be met. Workshops as a major communication tool shall take place regularly and at least once at each of the partner universities during the project lifetime of four years. This procedure enables the participants to get to know each other better, both personally and with regard to the capabilities of the partner institutions. The two German project managers oversee the whole process as peers.

The structure of the programme and the basic organisational questions shall be discussed and agreed upon during the first workshop to be held in Nairobi in June 2004. A major question to be answered is how coordination of the programme will be organised in future, who should operate the enrolment of students and take care of the accreditation of the programme. The contents of the various modules in question need to be harmonised.

Based upon this step it will be decided which new modules need to be developed to fulfill the aims of the programme. It is essential to accept in writing the results, modules and credit points of the partner institutions (as agreed in general by the East African University Council). The first programme workshop shall decide which of the modules offered in already running master programmes can be incorporated into the programme on "*Integrated Watershed Management*", which shall start with the Academic Year 2004/05. Consequently, programme announcements and course offers need to be available in summer 2004.

South-south-co-operation is planned to improve communication between the African partners. This exchange of leading teaching personnel will help to harmonize course contents and to better co-ordinate their implementation by individuals. Internet communication is not sufficient for this task. Similar aims, the improved communication between the African partner universities, the coordination of courses and modules, shall be reached by training measures for lecturers (south-south-exchange). At least one lecturer per year should be offered a study visit (north-south-exchange) to Germany, with the aim to incorporate German and international standards into the curriculum. At the same time north-south student exchange should be made possible for students with a focal area in watershed management and development co-operation. North-south and south-north student exchange calls for an agreement on credit transfer points as well.

The funding of students joining this MSc programme (south-south-exchange) needs to be realized from several external sources. "Sur place" scholarships might be an important option for this purpose. Student exchange south-north should be made available for limited student numbers as study visits for finalizing the master thesis. Next to this, other funding possibilities for students need to identified and discussed. Additional programme tools offered by various associations and foundations should be implemented into the master programme, such as short-term lectureships, study visits, expert seminars, summer schools and alumni programmes. As well, the whole process of building the MSc programme will be continuously evaluated by the project managers, who at the same time take the position as peers. The evaluation is aimed at ensuring quality of teaching and clarifying discrepancies between modules taught.

These regular measures of the university co-operation scheme need to be supplemented by other teaching and co-operation instruments, like summer schools and expert seminars. Such measures need to comply with the concept and aims of the MSc programme "Integrated Watershed Management". Students of all partner universities should be able to attend. Measures to enable inter-cultural communication between students from Germany and Africa may be utilised as well, such as joint excursions and practical field exercises.

7. Study Programme

Learning targets

Students will learn to understand and to assess the processes characterizing environments. Process analysis will focus on soil and water resources as the major base for food security. The complexity of interacting processes will consider different scales which may limit the applicability of theoretical concepts and models. The development of sensitivity for scale also includes the awareness of disciplinary and interdisciplinary limits. The limitations of disciplinary concepts will be demonstrated, as they need to be overcome to identify sustainable solutions. Technical skills together with certain soft skills are essential to reach this target. Teamwork or the ability to work in teams and to participate in scientific discussions are decisive skills to be developed by the participants. Thus, advisor-teams and the participants themselves need to be recruited from different disciplines and cultural backgrounds.

Character of the programme and teaching concept

Studies require a high standard of student self-organization and self-responsibility. Teachers act more as advisors and supervisors than as typical instructors. This concept needs to apply a specific teaching concept. Topics will be grouped in interdisciplinary modules focusing on problems and holistic concepts rather than disciplines. They comprise tools like *Geographical Information Systems*, the integration of traditional knowledge and participatory approaches in sustainable resource management.

Curriculum - MSc IWM

1st semester	PM	4 cp	**Soil and water interaction**
	CM	2 cp	Slope dynamics
	CM	2 cp	River bed dynamics
	BM	2 cp	Field and laboratory measurements
2nd semester	PM	4 cp	**Landscape sensitivity**
	CM	2 cp	Qualitative and quantitative environmental analysis
	CM	2 cp	Traditional knowledge and modern techniques
	BM	2 cp	Processing spatial and temporal data
3rd semester	PM	4 cp	**Soil and water conservation**
	CM	2 cp	Water and soil resources management
	CM	2 cp	Environmental education and capacity building
	BM	2 cp	Modeling and planning
4th semester		10 cp	**Master thesis**

Organization

Organization and realization of the International Master's-Programme "*Integrated Watershed Management*" is enforced by a peer group. The peer group is put together by German university professors each assigned to the subject groups chairing the study course: water resources engineering, physical geography, socio-economics, and agriculture.

A restricted number of students from Eastern Africa countries will be enrolled for the MSc programme. Admission requirement is a BA or BSc degree in a discipline relevant for Integrated Watershed Management, the GPA or final grade must be better than average.

The Master programme on '*Integrated Watershed Management'* is created as a 4-semester curriculum. Each semester is composed of:

1 Basic Module (**BM**) where basic methods and techniques are obtained,

2 Core Modules (**CM**) where expertise on special questions will be deepened,

1 Project Module (**PM**) where complex interrelations of problems relevant to the programme will be processed self-dependently by the students.

The four modules are connected with each other. Thus, each semester modules build a sequence to an overall topic which corresponds to the topic of the *Project Module*. Each core and basic module is composed of several segments which cover different disciplinary topics. In the *Project Module* the interaction of the corresponding disciplinary approaches and their limitations will be demonstrated in a concrete project-orientated context and the necessity of using interdisciplinary approaches will be demonstrated. Successfully finalized semesters can be certified separately e.g. as short courses. The Master's course ends with the Master thesis in the 4th semester.

8. Project-Module 'Landscape Sensitivity'

Topics will be grouped in interdisciplinary modules focussing on problems and holistic concepts rather than disciplines. Project Module focuses on the interaction of corresponding disciplinary approaches and their limitations in a real project-orientated context. In this way the necessity of interdisciplinary approaches to be used handling environmental problems is demonstrated. It is intended that the students develop concepts for the sustainable management of limited water and soil resources. To do so students have to combine tools like GIS, the integration of traditional knowledge and participatory approaches in sustainable resource management. Understanding the processes of erosion and water balance in space and time in a watershed is the central objective of any project module within the MSc programme.

The aim of the project-module 'Landscape Sensitivity' is that students learn to understand processes of erosion and water budget in space and time in a defined watershed. The module is composed of three components:

- an introduction, including lectures, field trips and presentations by students,
- field training and a seminar, where data investigated during field training together with secondary data are evaluated, modelled, put together in a report and
- presented in a final workshop.

It is expected that students are able to work independently. Furthermore, students must have excellent computer skills for data management, processing and evaluation.

The students will work in small groups and in the filed they have to map environmental characters such as soil erosion damages, soil conservation measures, land use pattern, soil types, and specific characters of the drainage system (i.e., bank erosion, bed conditions). Further, students are obliged to incorporate field surveys in a digital data base (GIS) and additionally to integrate information from secondary data (geology and drainage pattern derived from air photographs into the GIS).

The objective of the final seminar is the evaluation of the investigation, considering primary as well as secondary data. Additional objective of the seminar is the presentation of the results in a written report and a poster, which will be introduced by an oral presentation.

9. Acknowledgments

The DAAD is funding the establishment of the international and interdisciplinary MSc programme "*Integrated Watershed Management*" as a project within the subject-oriented university co-operation scheme from 2004-2007.

Occasional Paper Geographie	Heft 20	S. 15- 73

Soil erosion risk and water balance in the Gina River Catchment

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1. INTRODUCTION

At the present Ethiopia in most of its areas faces serious threats concerning food production and rural livelihood mainly induced by population growth and unsustainable resource management. Land degradation by soil erosion is one of the major issues within these increasing problems, causing a decline of soil fertility and, hence, a decrease of agricultural productivity.

In order to prevent land degradation and soil erosion it is necessary to record soil erosion processes, and to assess the factors controlling them as well as their impact. Concepts for a sustainable management of the limited water and soil resources are based on such assessments.

The second International Course on Watershed Management at the Arba Minch Water Technology Institute (AWTI, Ethiopia) dealt with this challenge. Between the August 1st

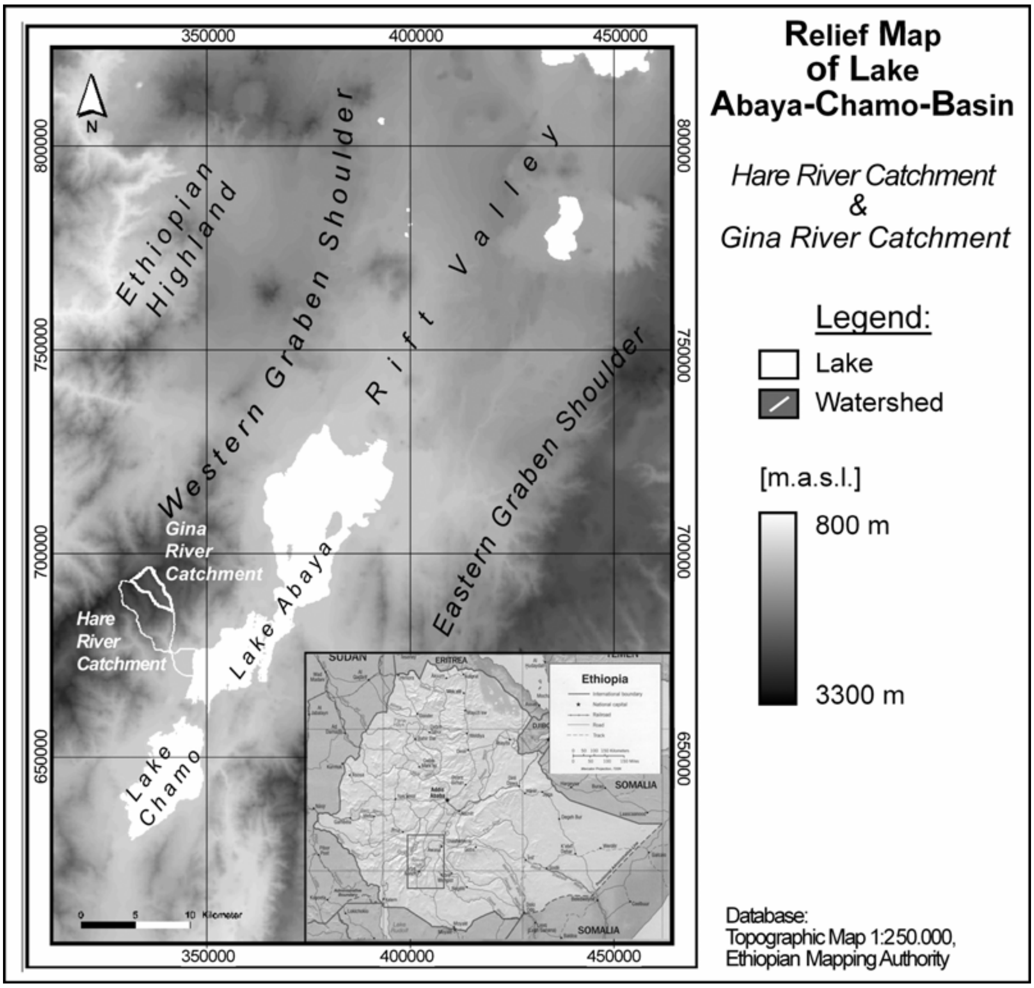

Figure 1: Relief of Lake – Abaya – Chamo basin and major landscape units. Gina River basin is a tributary of the Hare River, located in the south west of Lake Abaya (modified after KRAUSE et al. 2004).

and September 6th 2003 students from the Freie Universität Berlin, the Universität Siegen (both in Germany) and from the Arba Minch Water Technology Institute, Ethiopia, accomplished a course on *Watershed Management*. Special focus of that course had been on the assessment of soil erosion risk and water balance in the Gina River catchment, a tributary of the Hare River in south Ethiopia (Figure 1). Due to this target several characters of the Gina River drainage basin were recorded. A special focus was on the water – soil – land use interaction and the resulting processes. Therefore, especially soil type and texture, land use and soil conservation measures as well as the natural and human induced relief forming processes were mapped. Based on these spatial data modelling approaches to estimate soil erosion risk and water balance were applied and evaluated. Additionally, future scenarios for the year 2025 were developed and implemented into the modelling approaches to generate a base for rural planning.

2. STATE OF ART

Erosion is a natural process resulting in a relief levelling. As a consequence, erosion of hill slopes is one of the major sources of sediment yield in rivers and of downslope sedimentation (colluvial deposits, fandeposits). The amount of surface runoff available and the given energy determine the intensity the of erosion processes. However, factors influencing generation of surface runoff are interacting in a multidimensional and non-linear relationship, with varying load of factors due to the individual local preconditions – such as summarised in the term ‘landscape’. Those factors also comprise the human impact causing changes in landscape balance, predominantly in vegetation cover and soil character. Thus, in most cases human impact causes an aggravation of erosion processes which then are called ‘soil erosion’. Soil erosion is a relentless process, frequently sneaking – and, thus, not always directly apparent –, difficult to control and usually delicate to stop. Accelerated erosion has had, and still is having, an adverse effect on human welfare (DREGNE 1982). Soil erosion might occur in all areas affected by man, mostly in agricultural used areas. Major processes of soil erosion occur by water and by wind.

Soil erosion causes direct, ‘on-site’ damages like rills or gullies, which frequently reach dramatic and irreversible dimensions and then form badland areas. Removed soil in many cases is transported only for short distances and gets deposited at the base of hill slopes, where the inclination declines, covering vegetation and building ‘off-site’ damages. Next to these direct and instanteneous impacts soil erosion processes determine long-term effects on landscape, for example by cut-off soil profiles or tillage edges as-well as by distinct changes of soil texture (RICHTER 1998).

Methods Detecting Soil Erosion Damage by Water

A wide range of methods are available to record processes of soil erosion since the soil erosion and its influences on the natural ressources of a region has become into the focus various disciplines (Figure 2). In the beginning, soil erosion research focused on a qualitative assessment of damages and their occurrence dependent on landscape chracters such as relief or parent rock (cf. HEMPEL 1953). Ongoing, quantitative approaches with a restricted adaptability on a large scaled range rose later due to the necessity to balance erosional processes and with the improving software and PC capabilities. Various studies give an illustration of the factors influencing soil erosion. A multiply of publications refer to this topic. Among others MORGAN (1979), KIRKBY & MORGAN (1980) and ZACHER (1982) provide basic work. As in tropical areas landscape characters underly special conditions due to seasonal inclinations of rainfall and intensive chemical weathering processes these conditions are compiled i.e. by LAL (1988, 1991).

The qualitative approach to investigate soil erosion by water includes mapping of soil erosion damages, which appear in consequence of heavy rainfall. Direct and indirect damages will be mapped, where direct damages are visible forms of soil degradation such as rills, gullies and grooves, whereas indirect damages involve mostly 'creeping' soil erosion or slowly preceding processes of soil erosion, which do not show dramatic effects on the landscape, but in a long range cause effective soil degradation.

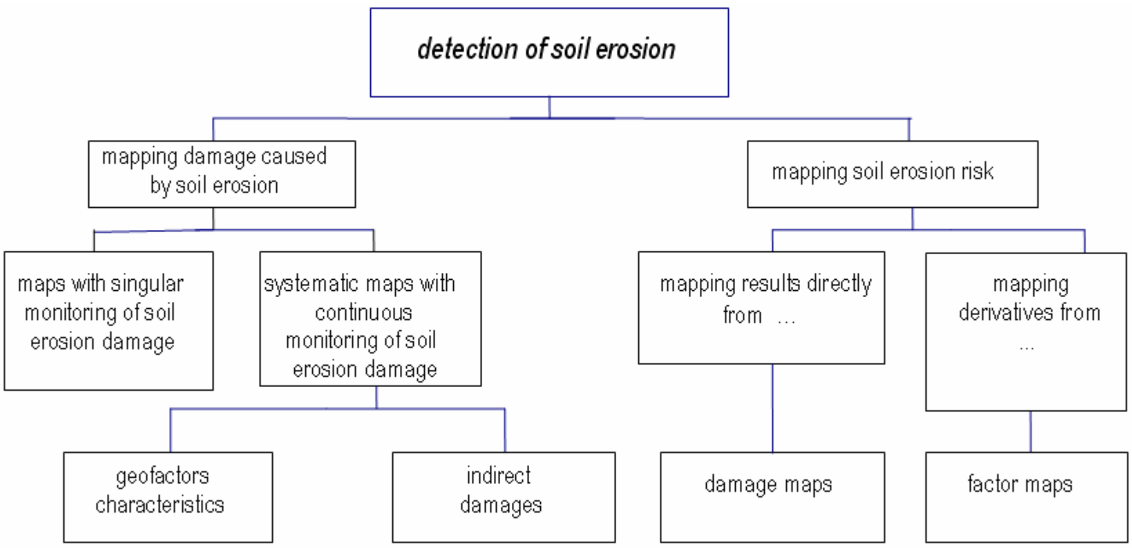

Figure 2: Methods to assess soil erosion risk (modified after SCHÜTT 1988).

On the other hand, quantitative approaches use surveys about complete acquisition of the soil loss data in a defined area as a base for the assessment of soil erosion risks and factors influencing soil erosion risk. Most recently a multiply of tools to estimate soil erosion risk are available, such as the Universal Soil Loss Equation (USLE; WISCHMEIER & SMITH 1962, 1978), the European Soil Erosion Model (EUROSEM; Morgan et al. 1991) and the Water Erosion Prediction Project (WEPP; FLANAGAN & NEARING 1995).

Analysing the overall studies on soil erosional processes it is clearly shown that due to the complexity of the factors influencing soil erosion processes most of the investigations focus only on parts of the overall topic.

Potential Erosion Risk and Current Soil Erosion Risk

Potential erosion risk by water is determined by processes generating surface runoff that are dependent on a variety of factors:

- relief,
- bedrock,
- soil texture,
- soil organic matter,
- skeleton content,
- stone coverage,
- vegetation cover and
- rainfall chracter.

Since human impact affects morphodynamics erosional processes are summed up to soil erosion, which, in general, shows an increased intensity compared to natural erosion processes. Human impact like clearing, agriculture and farming, in general, causes a reduction of natural vegetation cover and in the worst case its complete destruction. This interaction scheme between land use, vegetation cover and soil erosion risk can be referred having mainly negative effects on soil erosion potential such as ploughing and harrowing, which disturb the soil's macro- and micro-aggregates and, thus, reduce the stability of the soil.

But also positive effects of human impact can be recorded, having a stabilising effect on the landscape such as man made forests and reforestations, which cause an increase canopy cover, a formation of litter and a dense rootled bed. Also some techniques of cultivation might have stabilizing effects. Ie., fertilization with manure increases contents of soil organic matter and, thus, supports, formation and stability of soil aggregates. Additionally, ploughing and, thus, formation of coarse macro-aggregates causes a strong roughness of surface, (HUDSON 1993) which impedes surface runoff and promotes infiltration. Evaluating human impact on soil erosion processes it can be pointed out that effects accelerating soil erosion predominate stabilising effects. Summarising erosional processes decrease efficiency of cultivation and have additional consequences on the overall environment such as decreasing of groundwater recharge, increasing of flood – frequency and aggravating siltation of reservoirs. Thus, since cultivation was intensified, in some regions latest since Bronce age, soil conservation measures were implemented man has to minimise soil erosion risk by improving infiltration processes and reducing formation of surface runoff (JÄGER 1984).

3. METHODS

3.1 Field research

Landscape character of the Gina River catchment is recorded by mapping land use, soil characters, soil damges and soil conservation measures. Human impact can be differentiated into:

- landuse as the expression of present utilisation and humanpressure on an area and
- soil conservation measures as an expression to prevent an area from degradation or destruction in consequence of land use. Correspondingly, land use (Table 1) as soil conservation measures (Table 2) are recorded. Various farms of land use are comprised into ten groups, considering the different types of agricultural cultivation as well as pasture land, wood land, settlements and paths.

Table 1: Legend for the mapping of land use.

Afforestation	Plantation of eucalyptus
Cereals / fallow	Barley, wheat, maize; less canopy cover vegetation
Mosaic cropping	Different types of crops combined, patchily arranged (ensete & row crops)
Ensete / legumes	Ensete and nutrient fixing crops; affecting soil ecology
Pasture land	Area - wide short grass used for grazing
Woodland	Trees intermittently distributed
Forest	Tree accumulation with continuous canopy cover
Grassland	High standing grass, not used for grazing (>20 cm height)
Settlement	Village (Mesho) and Huts with homeside gardens (Tukuls)
Paths	Unfortified foot trails of various sizes (more and less than 1 m width)

Soil conservation measures practised in the Gina River catchment are only few. Thus, recording of soil conservation measures concentrates on terraces and walls as the most popular measures (Table2). Contour ploughing is also practised widespread in the Gina River catchment, but due to the period of field investigation could be recorded only randomly and, thus, is not considered here.

Table 2: Legend for the mapping of soil conservation measures.

Terraces	Outward – sloping bench type terraces – length 10-150 m, hight 1-1,5 m.
Walls	Stone walls – length 20-150 m, height 0,5-0,8 m, width 0,3-0,5 m.

Physical characters of the soil are one of the most important factors controlling erobility. A multiply of soil characters such as content of soil organic matter, aggregate size, grain size distribution etc. are well known for their effects on soil erosion risk. Corresponding to the rainfall–runoff–modelling (chapter 3.4.) recording of soil characters is reduced to

Table 3: Legend for the mapping of soil characters.

a) textures	sandy loams
	clay loams

	clay soils
b) colours	reddish
	brownish
	greyish

the reception of texture as it is required for the application for the curve – number method (chapter 3.3). Dditionally, soil color is recorded as it provides information on the genesis of the soil and soil sediment respectively (Table 3b).

Recording of soil erosion damages focuses predominantly on the direct – visible on-site damages (Table 4). In tropical environments such as the Gina River catchment in-situ soils, in general, show deeply weathered profiles. Thus, evaluation of a profile cut-off as thy typical indicator for indirect damages is not feasible. Next to this, off-site damages are not considered as the clayey material of the deeply weathered soils in most cases is transported out of the catchment area as suspended load and do occur omly rare as colluvial deposits or small fans.

Table 4: Legend for he mapping of soil erosion damages.

Talus edges	Considerable amount of soil breaks out of the structure next to paths
Rill erosion	Vertical channels, width <30 cm and depth <20 cm (with differentiation in active and inactive)
Gully erosion	Vertical channels, width >30 cm and depth >20 cm
Sheet erosion	Uniform removal of soil in thin layers
Mass movements	Downward movement of thicker soil layers
Badlands	Area – measured soil degradation with exposed bedrock

Mapping was accomplished on map scale 1:10.000 and field data were transformed to map scale 1:25.000.

3.2 Data preparation

Map digitizing

Field data become digitised with the program ArcView. Next to this, the Digital Elevation Model (DEM) from the Gina River catchment area was generated on tha base of the topographic maps 0637 -c2, -c4, -d1 and -d3, scale 1:50.000. Data of the DEM are provided with 50 x 50 m² cell size.

Precipitation

For modeling soil erosion risk data on precipitation is essential. To evaluate precipitation distribution in the Gina River catchment a regression-model describing the relation between monthly resp. annual precipitation and hypsographical location is applied. To generate the model data from 15 meteorological stations located in the Abaya – Chamo Basin of the western rift valley area for the period 1988 to 1994 were available. The locations of the stations are characterised by an increase in elevation from about 1200 m a.s.l. up to 3500 m a.s.l. with a horizontal distance of less than 20 km (Table 5).

Table 5: Average annual rainfall data of the meteorological stations in the Abaya – Chamo Basin for the period 1988 to 1994.

Station	lat.	long.	elevation [m] a.s.l.	p [mm/a]	std. dev. [mm/a]*
Arba Minch (Farm)	06°05’	37°35’	1220	805	-
Arba Minch (AWTI)	06°05’	37°35’	1240	894	180
Wajifo	06°28’	37°45’	1240	896	-
Mirab Abaya	06°18’	37°47’	1260	745	256
Daremello	06°15’	37°14’	1320	732	-
Morka	06°26’	37°24’	1400	1008	-
Saki	06°55’	38°00’	1580	1072	-
Humbo (Tebella)	06°40’	37°45’	1590	1087	-
Gesuba	06°07’	37°38’	1710	1160	-
Bedessa	06°07’	37°38’	1750	1160	-
Sodo	06°51’	37°45’	1800	1121	-
Kemba	06°03’	37°10’	1850	1261	-
Boditi (School)	06°57’	37°51’	1860	1208	-
Dinka	06°32’	37°30’	2010	1279	-
Chencha	06°15’	37°34’	2680	1348	178

* Data for single years are not available for most of the stations, so the std.dev. could not be calculated.

3.3 Curve Number Method

The Curve Number Method (developed 1972 by the Soil Conservation Service SCS) is a simple method for determing direct runoff through an empirical equation that requires rainfall and a watershed coefficient as input data. The watershed coefficient is called curve number (CN), which describes the runoff potential of the land cover-soil complex. Although the statistical model is designed for a single storm event, it can be scaled to find average annual runoff values. The relation between the surface runoff and the precipitation (P) is based on the assumption that a constant ratio exists between the amount of direct discharge (Q) from surface runoff, and the amount of discharge still to be formed from surface runoff (MEINDERTSMA 1998, NAYAK & JAISWAL 2003).

std.dev.

$$c = \frac{Q}{P - I_a - Q} \qquad (1)$$

with: Q = discharge [mm]
I_a = initial abstraction [mm]
P = precipitation [mm]
C = constant

The initial abstraction (I_a) is the amount of precipitation which will not lead to discharge. It consists mainly of interception, infiltration, and surface storage, all procedures before runoff begins. This amount cannot increase infinitely, thus a maximum surface storage (S) is introduced which describes the potential maximum retention after runoff begins. Due to the assumption that the ratio between P-I_a and S is constant equation 1 can be modified (MEINDERTSMA 1998):

$$\frac{Q}{P - I_a - Q} = \frac{P - I_a}{S} \qquad (2)$$

with: S = surface storage [mm]

Based on this information Q can be expressed:

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \qquad (3)$$

Equation 3 is an empirical equation based on trends in recorded data, which is physically subject to the restriction that $P \geq I_a$. Equation 3 can be simplified taking the relationship of I_a to the potential maximum retention into account. Thus I_a is defined by its linear dependency from S, corresponding to known fractions of surface storage (MEINDERTSMA 1998):

$$I_a = 0.2 \cdot S \qquad (4)$$

With this assumption equation 3 can be simplified by using only three variables (WALKER et al. 1998):

$$Q = \frac{(P - 0.2 \cdot S)^2}{(P + 0.8 \cdot S)} \qquad (P \geq 0.2S) \qquad (5a)$$

$$Q = 0 \qquad (P \leq 0.2S) \qquad (5b)$$

Applying this method the estimation of the potential maximum retention (S) of a watershed is complicated. To solve this problem the concept of the dimensionless curve number (CN) is adopted to estimate S. CN and S are related like expressed in the following equation:

$$S = \frac{1000}{CN} - 10 \qquad \text{(when water depth is expressed in inches)} \qquad (6a)$$

$$S = \frac{25400}{CN} - 254 \qquad \text{(when water depth is expressed in mm)} \qquad (6b)$$

Theoretically the CN-Values range from 1 to 100, where 1 corresponds to 100% surface runoff and 100 expresses no surface runoff. Most CN ranges between 55 and 95. As the CN is describing the runoff potential of the land cover soil-complex it is dependent on several characteristics. These characteristics are outlined in three categories (MEINDERTSMA 1998):

Hydrologic soil conditions

The American Soil Conservation Service has classified more than 8500 soil series according to their infiltration characteristics. To reproduce the spatial differentiation of the hydrologic soil conditions the CN-method distinguishes four hydrologic soil groups. The infiltration rate under wet circumstances is classified in Table 6.

Table 6: Infiltration rate classes.

Infiltration class	Infiltration rate [mm/h]
very low	<3
low	3-5
moderately low	5-20
moderate	20-65
moderately high	65-130
high	>130

The first hydrologic soil group (*Type A*) is characterised by a high infiltration rate even when thoroughly wetted and a low runoff potential, like mainly deep, well drained sands or gravels. Soils with a moderate infiltration rate in thoroughly wet conditions, like moderately deep, well drained soils of fine to course texture are joined to *Type B*. Soils of *Type C* have nearly the same characteristics as Type B only with a reduced (low) infiltration rate. Soils with the lowest infiltration rate and a high potential for runoff are grouped in *Type D*. They are chiefly *clay soils* with a high swelling potential, soils with a permanently high water table, soils with clay pan at or near the surface and shallow soils over nearly impervious materials.

Landuse, soil treatment and soil coverage

Once the hydrologic soil group has been determined, the curve number of the site is determined by cross-referencing land use and hydrologic condition to the soil group. The factors land use, soil treatment and soil coverage have a major influence on the generation of surface runoff. Soil treatment and soil coverage are accounted for in the hydrologic condition.

Antecedent moisture condition

AMC ist the index, which yields different runoff conditions for the same rainfall condition. It considers five days earlier rainfall conditions according to the criteria in Table 7.

The Antecedent Moisture Conditions (AMC) is the index that estimates the soil wetness for a specific storm based on the five-day antecedent. The parameter includes rainfall depth wether and whether the storm appears in wet or dry season. The AMC classification is shown in Table 7. AMC I is for low runoff potential with soil having low antecedent moisture suitable for cultivation. AMC III is for wet conditions prior to the storm event. AMC II is for average soil moisture conditions in case of annual floods (LARRANDO-PETRIE & FRANCE 1995).

Table 7: CN-Method Antecedent Moisture Conditions (LARRANDO-PETRIE & FRANCE 1995).

Antecedent Moisture Conditions (AMC)		Total Five-day Antecedent Rainfall Depth [mm]	
Group	Description	Wet Season	Dry Season
AMC I	Dry soils. Lowest runoff potential. Although soils are dry, they are not wilted	< 15	< 42,5
AMC II	Average soil moisture for the case of annual floods. No water drainage by gravity in the soil	15-35	42,5-60
AMC III	Nearly saturated soil due to heavy rainfall the previous five days. Highest runoff potential	>35	>60

In case in a catchment different CN-values occur, it is possible to calculate an area weighted average CN-value which is used for the estimation of the total runoff in the catchment. Table 8 shows the resulting CN-values for different land uses with AMC II. These CN-values are the result of the combination of the three categories mentioned, and thus describe the runoff potential of the land cover soil complex.

3.4 Rainfall-Runoff modelling

For the rainfall-runoff modelling the software Watershed Modelling System 6.1 is used. The software includes several tools such as the HEC-1 for surface runoff modelling. HEC-1 was developed for analyzing the hydrologic processes of flood events in river basins varying in size and complexity from small urban catchments to a large multi-basin river systems.. HEC-1, in general, is applied as a basic tool to determine runoff from synthetic as well as historical events. Fundamentally, the HEC-1 program has the capability to simulate the precipitation-runoff process and computes flood hydrographs at designed locations in a basin. Data preparation for the application of HEC-1 requires compilation of the drainage basin`s physical characters which are represented by an interconnected system of geographic and hydrologic components. The basin boundaries are delineated and the land area is divided into sub-basins on the basis of study objectives and hydrologic characteristics. The basic hydrologic components of the model include land-surface runoff from each sub-basin, channel and reservoir routing, and the combining of hydrographs at confluences (HOGGAN 1989). The hydrologic processes can be represented by model parameters which reflect average conditions within the sub-basins. The model parameters represent temporal as well as spatial averages.

Model simulations are limited to single storm events due to the fact that provision is not made for soil moisture recovery during periods of no precipitation. Also streamflow routings are performed by hydrologic routing methods and do not reflect the full St. Vernant equation which is required for very flat river slopes.

Table 8: Curve Numbers for different land uses with AMC II (http:// www. bsyse.wsu.edu/saxton/spaw/Appendices/AppendixI.htm).

Land use	Treatment or Practice	Hydrologic Condition	Hydrologic Soil Group			
			A	B	C	D
Fallow	Straight Row	---	77	86	91	94
Row Crops	Straight Row	poor	72	81	88	91
		good	67	78	85	89
	Countered	poor	70	79	84	88
		good	65	75	82	86
	Terraced	poor	66	74	80	82
		good	62	71	78	81
Small Grain	Straight Row	poor	65	76	84	88
		good	65	75	83	87
	Countered	poor	63	74	82	85
		good	61	73	81	84
	Terraced	poor	61	72	79	82
		good	59	70	78	81
Close-seeded	Straight Row	poor	66	77	85	89
legumes or rotation		good	58	72	81	85
Meadow	Countered	poor	64	75	83	85
		good	55	69	78	83
	Terraced	poor	63	73	80	83
		good	51	67	76	80
Pasture or Range	Natural	poor	68	79	86	89
		fair	49	69	79	84
		good	39	61	74	80
	Countered	good	47	67	81	88
		fair	25	59	75	83
		good	6	35	70	79
Meadow	Natural	good	30	58	71	78
Wood	Natural	poor	45	66	77	83
		fair	6	60	73	79
		good	25	55	70	77
Farmstead	---	---	59	74	82	86
Roads	(dirt)	---	72	82	87	89
	(hard surface)	---	74	84	90	92

For a stream network simulation, the river basin is subdivided into a system of stream network components based on geographic information as slope, landuse, percentage of impervious area, soil type, and intensity and duration of precipitation. Each sub-basin present an area of average or similar geographic conditions (Figure 3). As rainfall and infiltration are assumed to be uniform allover a sub-basin area, the resulting rainfall excesses are routed by the Unit Hydrograph or Kinematic Wave technique to the outlet of the sub-basin producing a runoff hydrograph.

The Unit Hydrograph method produces a runoff hydrograph for the drainage basin outlet, that means the most downstream point of the sub-basin. The application of the Unit Hydrograph method includes four major steps:

- determination of the rainfall hyetograph,
- substraction of losses to obtain rainfall excess,
- transformation of rainfall excess into direct runoff,
- addition of base flow to obtain total runoff.

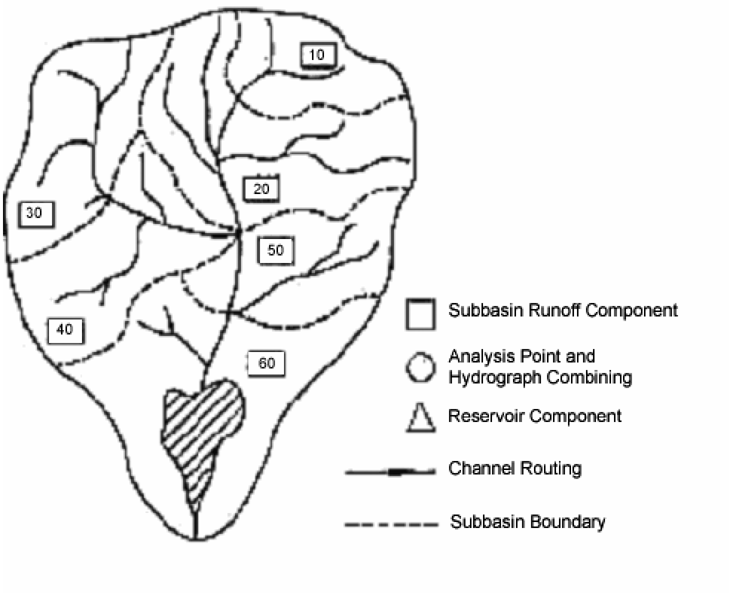

Figure 3: River Basin Simulation of the HEC-1 Model (after HOGGAN 1989).

In the model, precipitation which does not contribute to the runoff process is considered to be lost from the system as well as soil moisture or surface storage are not computed.River Routing is calculated with Muskingum Method, that is computing outflow from a reach using following equations:

$$QOUT = (CA - CB) * QIN + (1 - CA) * QOUT + CB * QIN \qquad (7)$$

$$CA = \frac{2 * \Delta t}{2 * AMSKK * (1 - X) + \Delta t} \qquad (8)$$

$$CB = \frac{\Delta t - 2 * AMSKK * X}{2 * AMSKK * (1 - X) + \Delta t} \qquad (9)$$

where: QIN: outflow to the routing reach
QOUT: outflow from the routing reach
CA / CB: assumed parameter to adjust X
AMSKK: travel time through the reach [hours]
X: Muskingum weighting factor ($0 \le X \le 0{,}5$)

The routing procedure has to be repeated for several times (designated as NSTPS), until:

$$\frac{1}{2 * (1 - X)} \le \frac{AMSKK}{NSTPS * \Delta t} \le \frac{1}{2X} \qquad (10)$$

4. STUDY SITE

Due to rifting processes along the African Rift Valley and to uplift processes at the plate edges along the fracture zones, continental divides occur along the ridges of the graben shoulders. In contrast, in the central part of the graben structure an endorheic drainage systems appears fed by tributaries from the eaves of the graben shoulder. Thus, east and west of the Rift Valley two large upland areas occur, draining via the River Nile into the Mediterranean in its western part, and to the east draining by various smaller tributaries through the Bale Mountains and Ogaden into the Indian Ocean. Between these two plateaus the Great Rift Valley is located, in which the Abaya-Chamo Basin is formed (Figure 1).

4.1 Location

The Gina River is a third order tributary of the Hare River and, thus, is tributary to Lake Abaya, a lake of the Rift Valley system in south Ethiopia. Consequently, Gina River catchment is a part of the Rift Valley Lake basin. It is located approximately 500 km south of Addis Ababa and about 25 km west of Lake Abaya (Figure 4).

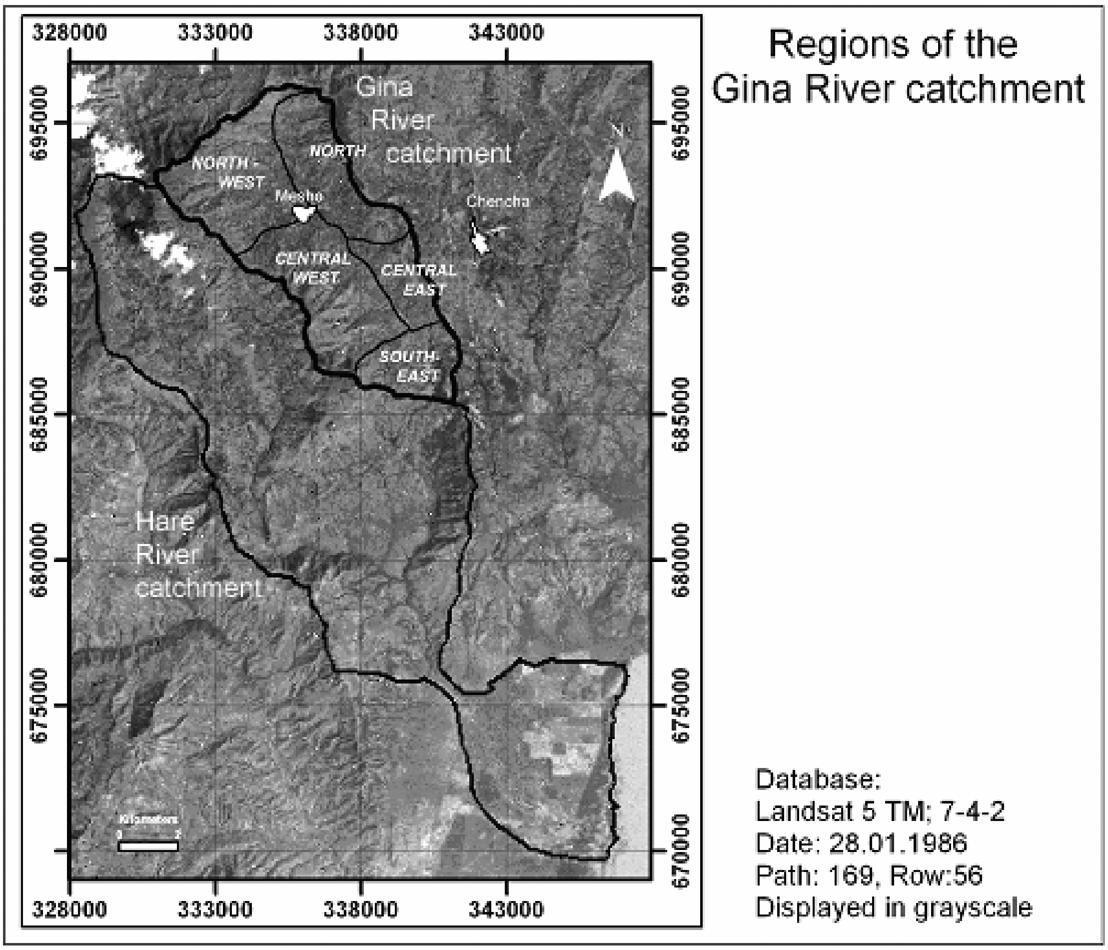

Figure 4: Regions of the Gina River catchment (map base: Landsat TM5 date: 28/01/1986).

4.2 Topography

The altitudes of the Gina River drainage basin range from 2400 m a.s.l up to 3200 m a.s.l. in its headwater areas. The elevation is a normal variable with fractions of altitudes between 2700 m a.s.l. and 2900 m a.s.l. (Figure 5).

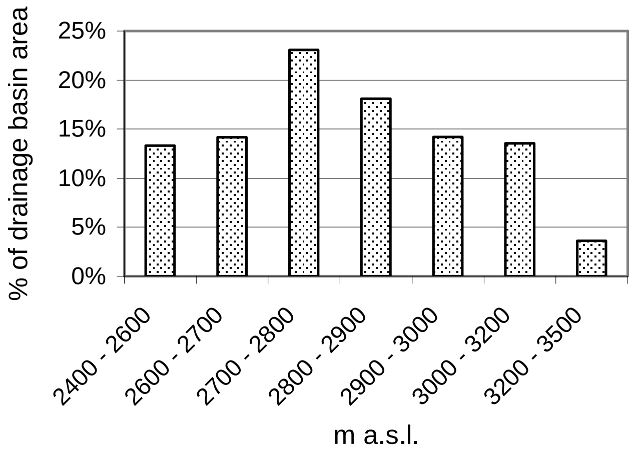

Figure 5: Distribution of elevation classes of Gina River catchment (data base: DEM 50x50 m² m cell size).

The Gina River catchment has a north-west – south-east alignment and shows some distinct morphological characteristics (Figure 4): East of the Gina River large homogenous morphological units occur showing a distinct differentiation into a northern and a southern part. The north-east is formed by steep ascents up to the divide and incised by v-shaped valleys, which run mostly perpendicularly to the Gina River. In contrast, the south-east decreases in elevation down to 2400 m a.s.l. and is gently sloped. The area west of the Gina River shows a more heterogenous character: north-west of the village Mesho the terrain ascends gently, while to the west the increase to the divide occurs with *Steep slopes* (>15°). Southwest of the village Mesho (central-west) the catchment area is again gently sloped and only along the v-shaped valleys of the Gina River and its tributaries strong ascends are formed.

4.2 Morphological units

Based on field survey and analysis of the digital elevation model (DEM 50) and its derivatives the Gina River catchment is subdiveded into six different morphological units (Figure 6).

The *Plains* are located predominantly in the south-east of the catchment and cover only a small area in its central part around the village Mesho. The *Plains* are characterised by a lack of significant changes in altitude corresponding to slopes less than 3°. Although these areas are not completely flat, they appear, due to their poor relief, distinctly different from the other morphological units defined for the Gina River catchment.

The *Undulating areas* show a complex hilly structure. Locally even slopes with inclinations up to 20° occur. Anyhow, steep inclining slopes are rare in the *Undulating areas* but are typical for the morphological units *Steep slopes* and *Mountain tops*.

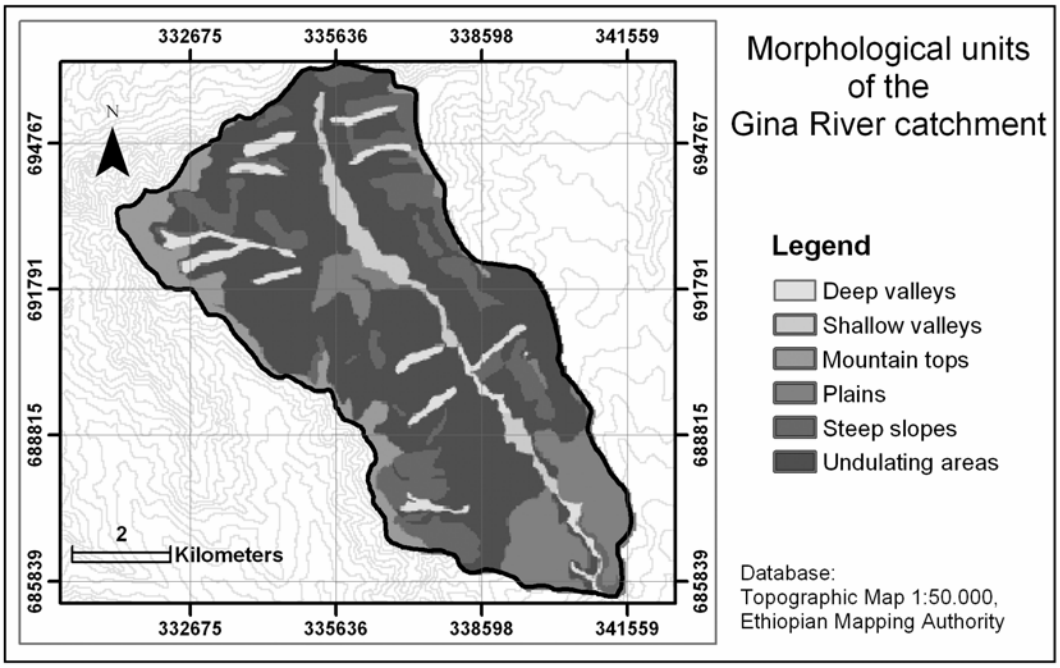

Figure 6: Morphological units of the Gina River catchment.

The morphological unit *Steep slopes* refers to the strong relief of the area. Unlike the *Undulating areas* the morphological unit *Steep slope* is quite homogeneous in shape. The morphological unit *Mountain tops* is defined due to its high elevation (above 3000 m a.s.l.), while morphometric parameters other than this are not considered. Inclination of slopes in the *Mountain tops* unit is mostly gentle to almost flat.

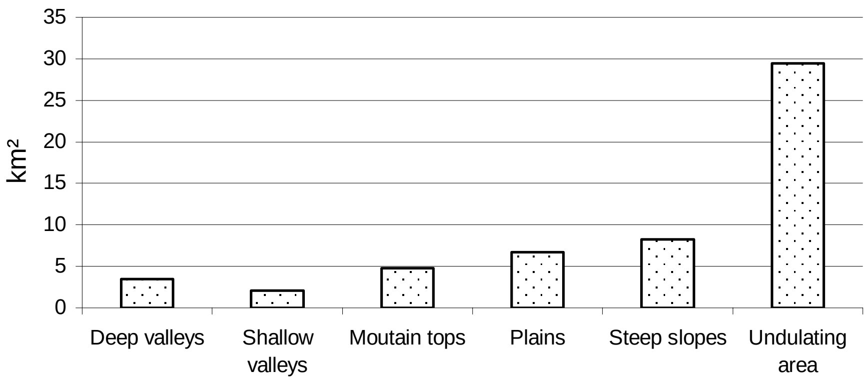

Figure 7: Absolute distribution of morphological units in the Gina River catchment.

The morphological unit *Deep valleys* can be characterised by channels with steep, perpendicular river banks; in general, the *Deep valleys* are flown through by perennial rivers. In contrast, the *Shallow valleys* show gently sloped river banks. The morphological unit *Undulating area* makes up the biggest part of the Gina River catchment, covering approximately 54 % of the drainage basin area (Figure 7). Thus, *Undulating areas* build the predominant morphological unit, covering most of the area between the Gina River course (*Shallow valley*) and the divide (*Mountain tops*). Only in the most southern parts of the drainage basin *Undulating areas* are lacking. Other morphological units than *Undulating areas* can be found uniformly distributed in the Gina River catchment. However, *Plains* (12.3 %) dominate the southern parts and the area around Mesho. *Mountain tops* (8.7 %) occur only in the highest regions of the catchment close to the headwater area. *Steep slope*s (15 %) frame the *Mountain tops*, and only in the north-western fringe *Undulating areas* adjoin the *Mountain tops*. *Deep valleys* (6.4 %) occur predominantly along the lower course of the Gina tributaries characterised by deeply incised, v-shaped valleys.

4.4 Climate

The Gina River drainage basin is located approximately 6°N the equator and shows due to its location in the transition zone between the Rift Valley floor and the Graben shoulder a strong hypsographical differentiation. Thus, the Gina River catchment affected by the seasonal migration of the Inner-Tropical Convergence Zone (ITCZ) causing a seasonality of rainfall. Throughout the year two rainy seasons are recorded: a short period of intermittent showers from March to April (*belg*) and a subsequent long rainy season from July to October (*krempt*) which occurs after a short interruption in May and June (TATO 1964). The remaining year is generally determined by dry conditions due to the impact of the north-east trade winds carrying dry air (two anticyclones from the Arabian Peninsula and Sudan).

Due to the hypsographical location of the Gina River catchment (altitudes between 2400 m a.s.l. to 3200 m a.s.l.) the annual average temperature totals 14° while the annual precipitation measured at the Chencha weather station (6°15’ N; 37°34’ E; 2680 m a.s.l.) averages c. 1350 mm.

4.5 Hydrology

Hydrological network in the catchment area of Lake Abaya

The water resources of Ethiopia are provided in lakes, rivers, streams and groundwater. The estimated annual surface runoff per year totals more than 110 billion m³, the groundwater about 2.6 billion m³ with 10^9 of the flow is transboundary. Only ten percent of the water of Ethiopia remains inside the country while most of it is drained to the River Nile (Table 9).

Table 9: Surface water distribution per capita per year (data from BEKELE 2001).

	1955	1990	2025	2050
Population y 10^3	20,418	47,423	126,886	194,203
Per Capita m^3	5,387	2,320	867	566

All over Ethiopia the average rural growth rate of population totals 2.23 %, while the population growth in the cities totals 4.11 % per year. To assess these differences in population growth, birth rates have to be considered as well as migration -loss and -profit. At least due to this tremendous population increase it is expected taht in near-future water resources run short.

The Abaya-Chamo basin is a sub-basin of the Rift Valley Lakes basin, entitled after its two major lakes (Figure 8). The major discharge systems of the basin are the rivers Gelana, Bilate, Gidabo, Hare, Baso, and Amesa, which are draining into Lake Abaya, while the rivers Kulfo, Sile, Argoba, Wezeka, and Sego are draining into Lake Chamo. The two lakes are hydrologically interconnected by a spillway, which is flooded ephemerally. Therefore, the basin is treated as one. The lake levels of Lake Abaya (1169 m a.s.l.) and Lake Chamo (1108 m a.s.l.) differ approximately 60 m.

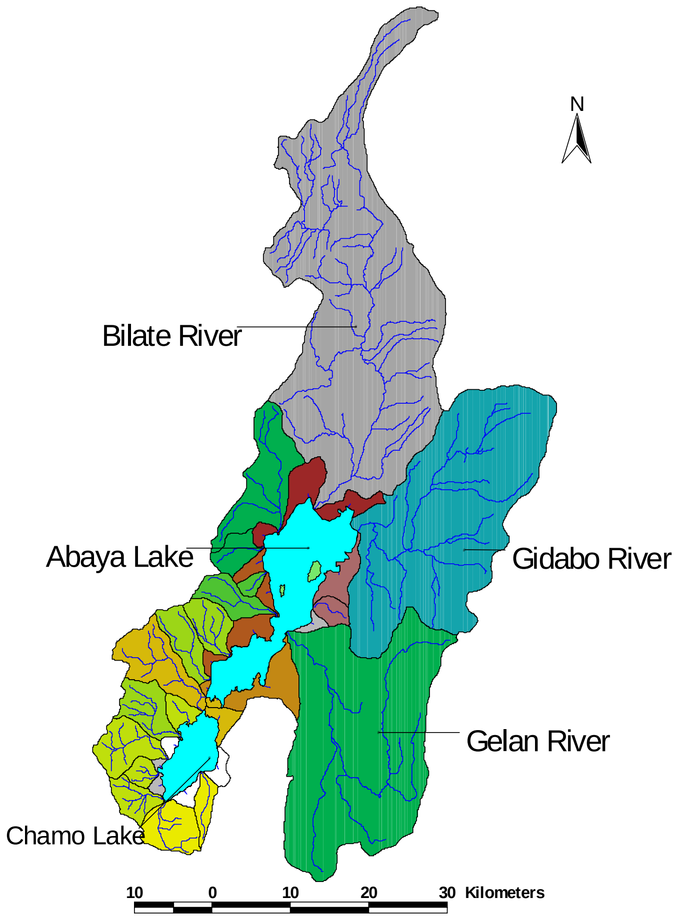

Figure 8: Abaya – Chamo basin map (copy from BEKELE 2001).

In the Abaya-Chamo basin the total relief varies between 3560 m a.s.l. and 1108 m a.s.l. In the eastern and northern part of the Lake Abaya drainage basin mainly large river systems occur, while the western side is drained by a multiply of small, stretched drainage basins. Lake Chamo is fed by several small rivers in the western and north-estern part of its drainage basin. Anyhow, from time to time the overflow of Lake Abaya also feeds Lake Chamo.

Hydrological Data Quality

In the Abaya-Chamo basin 22 stream gauge stations including lake water level observations exist. Some of the stations are currently out of order and the period of observations varies between the stations. Apart from some private gauging stations all hydrological stations are administrated by the Hydrological Department of the Ethiopian Ministry of Water Resources (MoWR). The quality of data from the different stations also varies as frequently single values in data series are missing. At some stations the survey of data takes place every day, while at others recording takes place only once a week or month. Gauged stream data are also susceptible to errors such as unaccounted stage-discharge curve modification due to aggradation, degradation and shifting of channel bed and channel bank, including also use of stage-discharge curve beyond the application limit (BEKELE, 2001).

4.6 Geology and Soils

The Gina River catchment is located on the graben flank of the East African Rift Valley. Paleozoic sediments and Late Tertiary volcanites predominate bedrock. Mineralogical composition of bedrock from the Gina River catchment shows quartz contents of 25-40%. Next to quartz anorthoclase, sanidine, and high albite occur as major and minor mineralogical components in the bedrocks of the drainage basin. Along the graben flank soil erosion processes are next to mass movements the predominant geomorphological processes. These processes cause an area wide pattern of soil sediments covering the saprolite with a sharp boundary. Thus, most of the soils in Gina River catchment are not developed in-situ. Also, in most locations there are no diagnostic horizons stating soil types. In-situ soil types, such as *Nitisols*, *Cambisols*, *Regosols* and *Fluvisols* occur only locally. Mineralogical analysis of soil profiles shows that clay minerals are the most important weathering product (Halloysite, Kaolinite), while the predominating *reddish* and *brownish* soil colours are due to the different contents of Hematite and Goethite (SCHWERTMANN 1989).

4.7 Vegetation

As a consequence of the long- lasting settlement and cultivation history of the area only a few natural plant societies occur today. Only the rather often growing bamboo (*Arundinaria gigantea ssp.)* and in some rare isolated valleys relic primary forests survived.

Most parts of the catchment area are used for agriculture, but also wide spread pasture lands can be found as well as scattered deciduous trees in forms of woodlands and grasslands close to the tributaries. Exceptionally, dense forests define the southern less elevated areas close to the Gina River. The crops cultivated predominantly within the catchment are barley, ensete, sorghum as well as certain vegetables.

4.8 Socio economy

Dorze people are the major ethnical group in the Gina River catchment. People‘s base for life is own needs economy. Cropping agricultural products such as barley, ensete, beans, sweet potatoes, sugar cane or sorghum, cattle-breeding (sheep, goats, zebus, donkeys and horses) and fuel wood collection are the main sources of income. Traditionally, Dorze people use terracing as an effective soil conservation measures to obtain productivity. Wide spread farm land is used in rotation with fallow land, which might be also used for grazing. Goods produced additional (meat, skins, dairy products, seeds, fuel wood) are sold at the market in Chencha or along the road to Arba Minch. Due to the lack of high quality roads in the catchment area and as a consequence of the lack of public transport systems, transport of goods takes place predominately by carrying by walkers.

There is only one road that opens up the Gina River catchment connecting Chencha and Mesho. As this ‘road’ is most likely a scooped dirt-track it is very susceptible to impacts of heavy rainfalls. The rest of the catchment is covered area-wide by a net of footpaths and trails. Families live in huts, so-called tukuls. The intact households consists of several tukuls, each having special purposes for family life, for storage and as stud for their domesticated animals.

5. RESULTS

Field investigation of the Gina River catchment included recording of various factors controlling and reflecting the capacity of the landscape. Special focus is pointed to indicators showing soil erosion damage and affecting soil erosion risk. Thus, in the following the defined different landscape units (Figure 4) will be featured by their natural and man-made characters. Soil erosion damages recorded are aligned to these landscape characters and in this way the most important factors entailing soil erosion risk are identified.

5.1 Landscape factors

Detailed information about the conditions of the research area is necessary to assess soil erosion risk and water balance. Therefore landscape factors of the Gina River catchment were recorded. They include physical and man induced factors. The physical factors comprise precipitation, morphological conditions and slope steepness, altitude and soil characters. The man induced factor considered in this study are land use and soil conservation measures.

5.1.1 Precipitation

Regression analysis for annual precipitation [mm] as a dependent variable from altitude shows the best results for a second order polynominal fit where 90 % of the annual rainfall can be explained by the elevation (Figure 11).

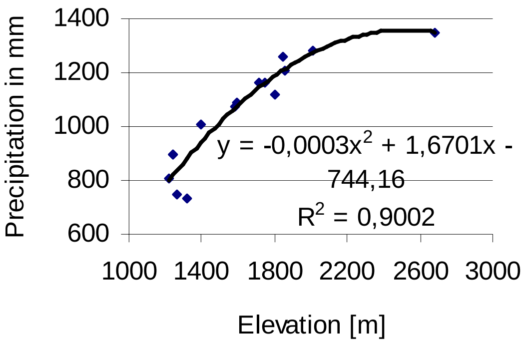

Figure 9: Correlation between altitude and annual precipitation for the meteorological stations in the Abaya – Chamo Basin.

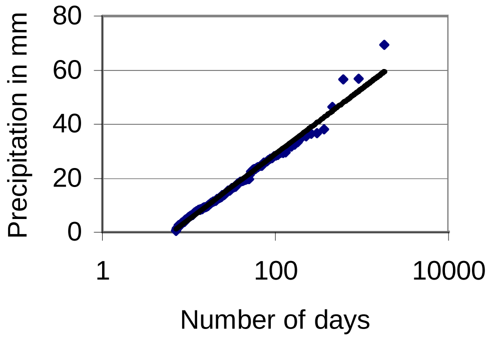

Figure 10: Recurrency interval of daily rainfall at Chencha weather station in 2001 and (at 2680 m a.s.l.).

Transferring the correlation analysis to the Gina River catchment area results in precipitation values range from 1530 mm/a in the lowland areas (about 2400 m a.s.l.) to 1580 mm/a (at 2780 m a.s.l.). *Mountain tops* show precipitation values around 1520 mm/a (about 3200 m a.s.l; Figure 9).

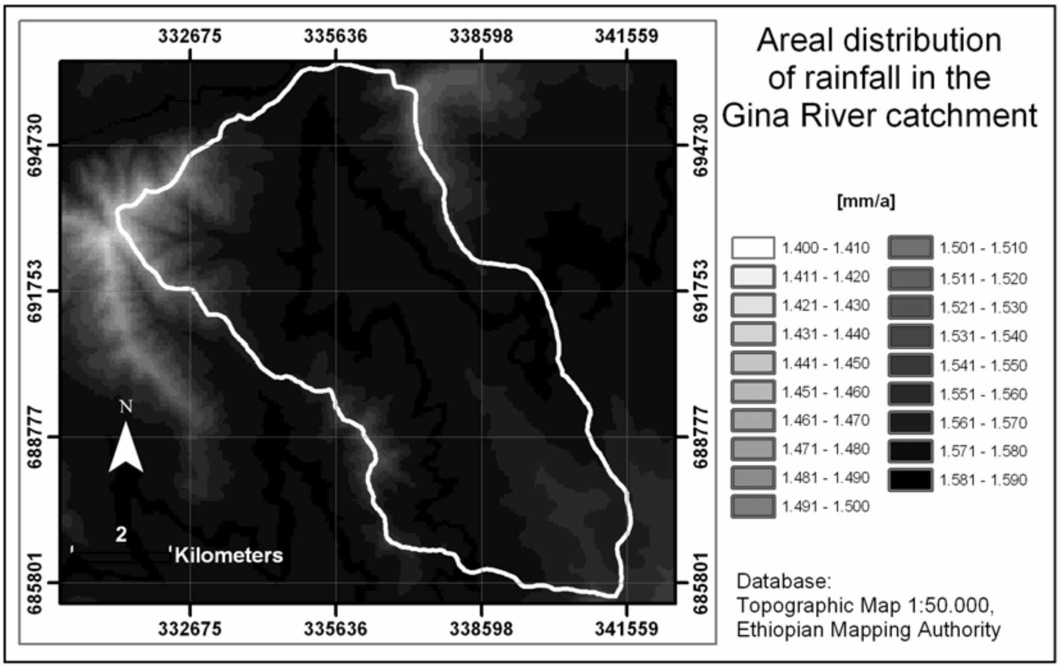

Figure 11: Areal distribution map of rainfall in the Gina catchment based on rainfall data from the Abaya – Chamo Basin (cf. Figure 9).

Describing the variability of rainfall a recurrence interval was calculated using daily rainfall data at the Chencha weather station for the period Jan. 2001 to Dec. 2002. The results of this magnitude-frequency analysis show that rainfall events of more than 50 mm per day have a recurrency interval of 1000 days, rainfall events of about 30 mm have a recurrency interval of 100 days and rainfall events of less than 10 mm per day have a recurrency interval of ten days (Figure 10).

5.1.2 Soils

The major aim of analysing the soil in the Gina River catchment is to obtain information on the infiltration capacity. A low infiltration capacity causes an increased surface runoff, which leads to higher transportation rates of the soil. The infiltration capacity is strongly correlated to the soil texture (RICHTER 1998).

Therefore, the soil texture is analysed by the ribbon method. Three categories of soil texture are differentiated for the Gina River catchment: *sandy loam* (category B), *clay loam* (category C) and *clay* (category D). *Clay loam* dominates (88 %) the other two soil categories *sandy loam* (5 %) and *clay* (7 %). *Sandy loam* occurs only along the Gina River course. *Clay* is located on the *Mountain tops* and on plots with eroded soil and without specific concentration in the Gina River catchment. The remaining part of the catchment area is covered with *clay loam* (Figure 12, 13).

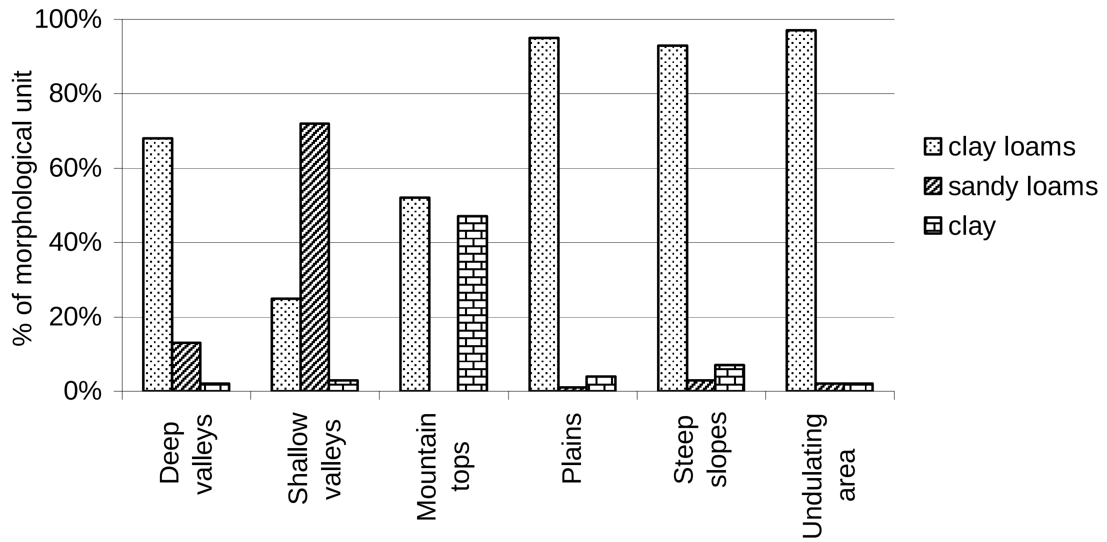

Figure 12: Soil group distribution in the morphological units.

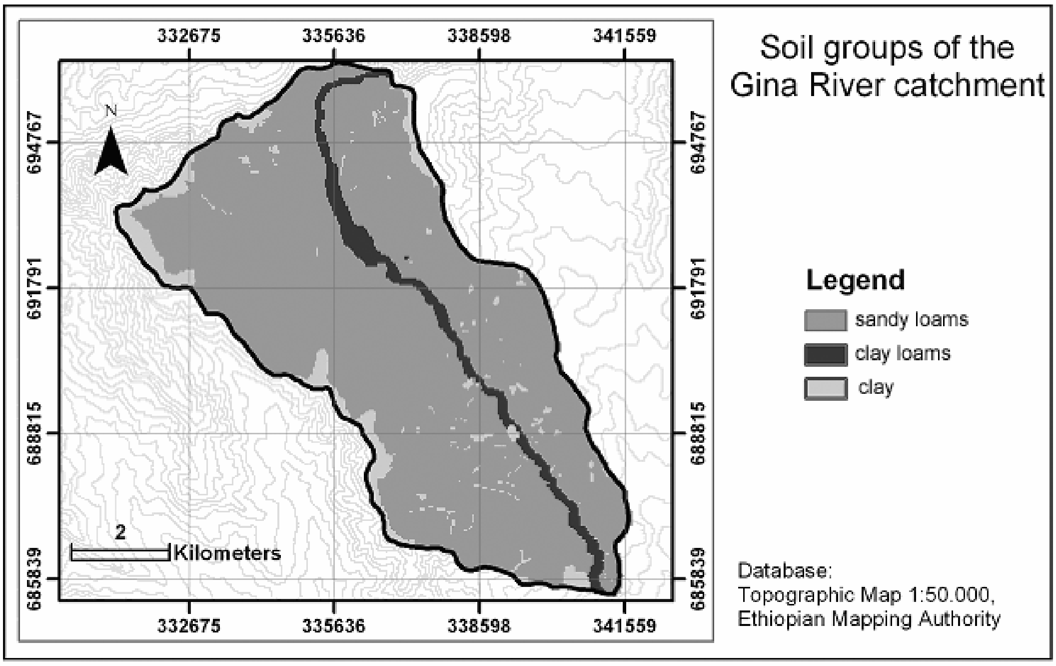

Figure 13: Soil texture differentiated after CN-soil groups in the Gina River catchment.

5.1.3 Land use

Land use of the Gina River catchment is predominantly determined by various forms of agriculture like cereal cropping and fallow land as well as ensete and legumes cultivation (Figure 14). Agriculturally used areas are area-wide recorded, excluding a strip along the western and northern divide (Figure 15). Along the course of the Gina River areas are only locally used by tillage. The highest fraction of the agricultural used area, primarily by cereal cropping and fallow land (23 %), occurs in the western part of the Gina River and in the central-eastern part. Mosaic cropping is also frequently practised (20 %), predominantly occurring in the

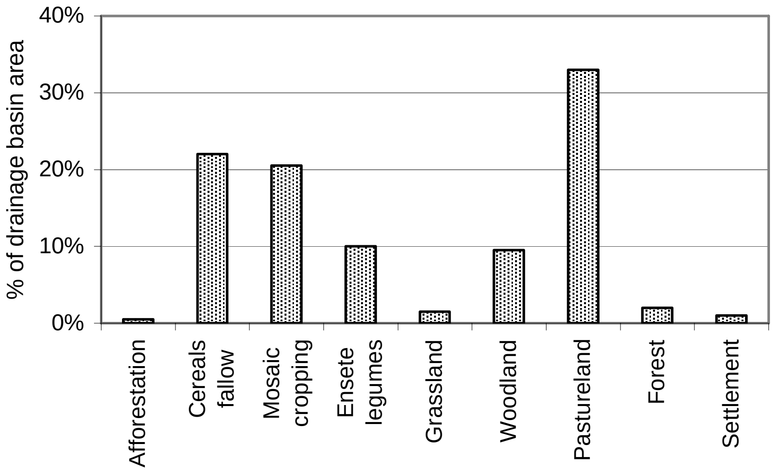

Figure 14: Percentage of land use in the Gina River catchment.

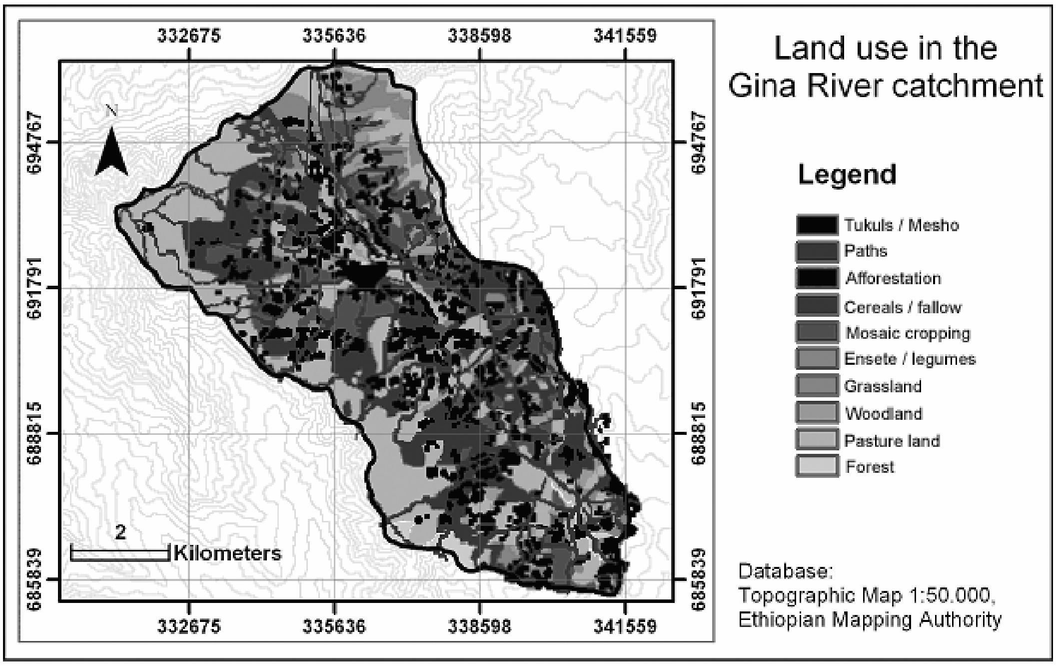

Figure 15: Land use in the Gina River catchment.

north and north-west as well as locally in the central parts of the Gina River catchment. Ensete and legumes are only cultivated to a lower extent (11 %). At all, cultivation of ensete and legumes has been recorded area-wide but mostly occurring locally in very restricted areas in the north, central-eastern and south-eastern part of the drainage basin. Next to the agricultural used areas pasture land covers 32.5 % of the Gina River catchment.

In the Gina River drainage basin the density of tukuls accounts 24 tukuls per km^2. However, the distribution of tukuls is not homogenous. Tillage areas hold a comparatively high density of tukuls (30 tukuls per km^2) (Figure 16). The highest tukul density is recorded in areas cultivated with ensete and legumes (37 tukuls per km^2). Above average density of tukuls occurs also in areas covered by woodland (31 tukuls per km^2). Areas used as pasture land show a distinct lower extent (11 tukuls per km^2).

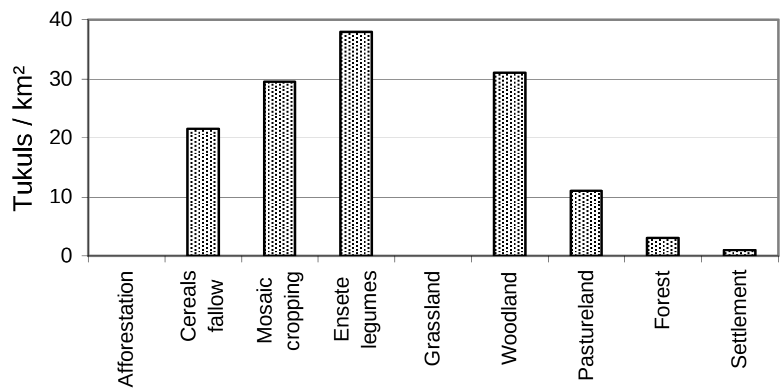

Figure 16: Tukuls per km² corresponding to land use areas.

Furthermore, a dense net of paths pervades the whole Gina River catchment. Correspon-ding to the occurrence of tukuls, most of the paths run through areas used for agricultural purposes. Next to this, paths are also recorded in areas classified as pastureland. This is mainly the case along the western divide.

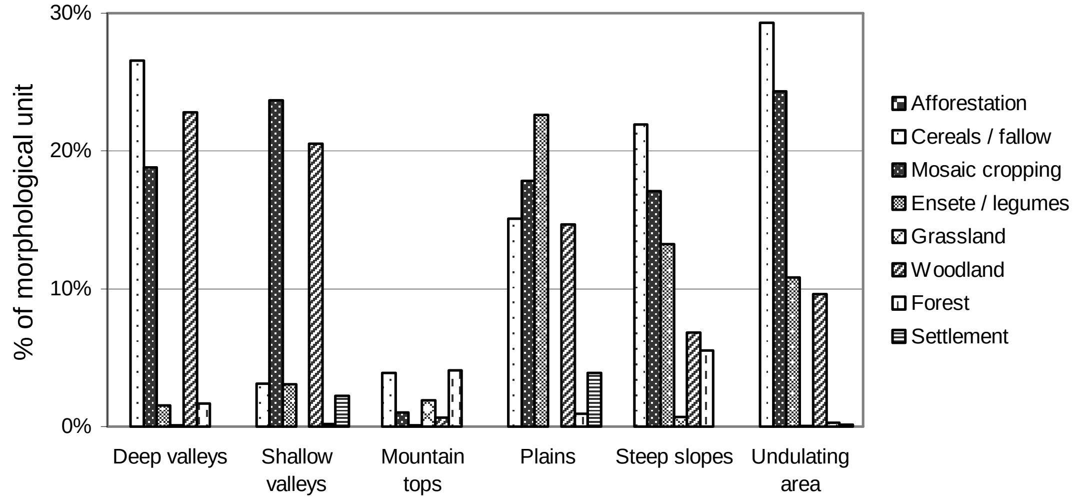

Figure 17: Relative distribution of different land use classes in the morphological units.

10 % of the Gina River catchment is covered by woodland. There woodlands can predominantly be found along the tributaries of the Gina River. Forest is remaining only in two parts along the southern divide and has a total coverage of 1.5 %. Grassland appears exclusively in the north of the drainage basin and covers an area of less than 1 %.

Regarding the assessment of soil erosion and soil erosion risk, the interrelation between land use and relief characters (summarised by the morphological units) is of interest. Agriculture predominates all morphological units except the *Mountain tops* and the *Shallow valley* units (Figure 18). In particular, the predominance of agricultural use is apparent in the *Undulating areas* unit determined by cereals cropping and fallow land. In contrast, in the *Mountain tops* and the *Shallow valleys* unit land is primarily used as pasture land (88 % and 46 %). Wherever agriculture predominates land use, it is adjoined by pasture lands, which cover up to 25 % of these areas.

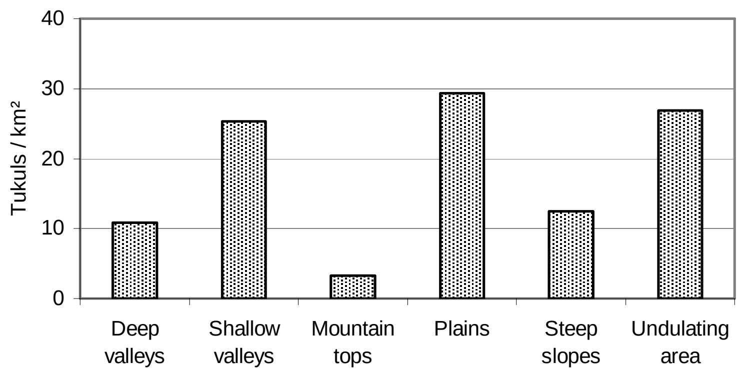

Figure 18: Tukuls per km² in each morphological unit.

Next to the predominant use by agriculture and pasture land, 23 % of the *Deep valley* areas are covered by woodland. Similarly, in the *Undulating areas* , *Shallow valley*s and *Plain*s unit a relatively high fraction of the area is covered by woodland. The remaining forest and grassland is almost exclusively located in the *Mountain tops* and the *Steep slope*s areas.

Furthermore, the density of tukuls differs between the morphological units (Figure 18). In the *Undulating area*s, *Shallow valley*s and *Plain*s units in average 27 tukuls per km^2 are recorded. In the morphological units *Steep slopes*, *Deep valley*s *and Mountain tops* the density of tukuls is much lower (9 tukuls per km^2 in average). Around the most tukuls fenced home gardens are laid out (Figure 19). Different crops are cultivated there, predominantly ensete and sugar cane.

Figure 19: Fenced in household consisting of different tukuls.

5.2 Present soil erosion damages and soil conservation measures

5.2.1 Soil erosion damages in the research area

Soil erosion damages occur in the entire Gina River catchment and, in general, are closely related to the defined morphological units. Most of the damages occur on the *Steep slopes* and in the *Undulating areas* (Figure 20). Few damages occur along the *Shallow valleys* and on the *Mountain tops*.

The correlation of the soil erosion damages' appearance and slope inclination of the respective location is proven. Most of the damages recorded are found at weakly to strongly sloped areas. In contrast, the frequency of soil erosion damages in gently sloped areas (classes 'no slope', 'very weakly sloped') are neglectably low. Next to this, soil erosion damages are lacking in areas with strong relief (Figure 21).

Rill erosion

Rill erosion (Figure 23) occurs all over the Gina River catchment. However, rill erosion is of monir importance in the *Shallow valleys*, the *Deep valleys* and the *Mountain tops* as only 7% of the overall occuring soil erosion damages by rill erosion are found in these

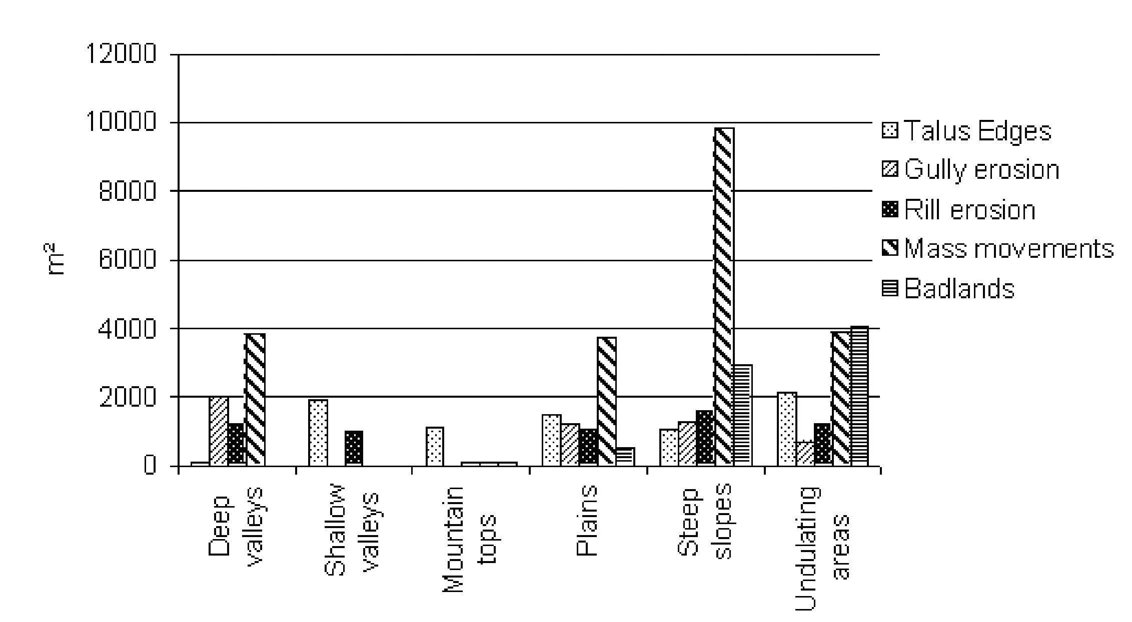

Figure 20: Absolute occurence of soil erosion damage per morphological unit [m²].

morphological units. 11 % of the damages by rill erosion can be found on the *Plains* 11 % of the damages by rill erosion can be found on the *Plains*, 21 % in the *Steep slopes.* The morphological unit *Undulating areas* is highly affected by damages due to rill erosion as here at least appear 60 % of the damges recorded.

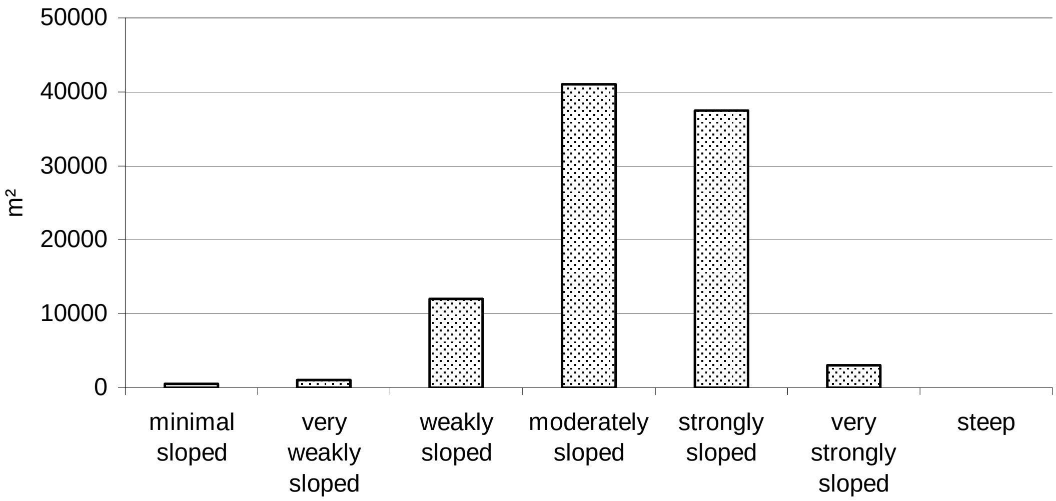

Figure 21: Distribution of soil erosion damages on diffrent inclined slopes.

However, weighting the occurance of the rill erosion damages to the respective shares of the morphologic units the *Steep slopes* (15 % of the catchment area) and the *Undulating areas* (54 % of the catchment area) are increasingly affected by rill erosion (Figure20). Remarkably, 38 % of inactive rills occurs in the morphological unit *Deep valleys* (Figure 22).

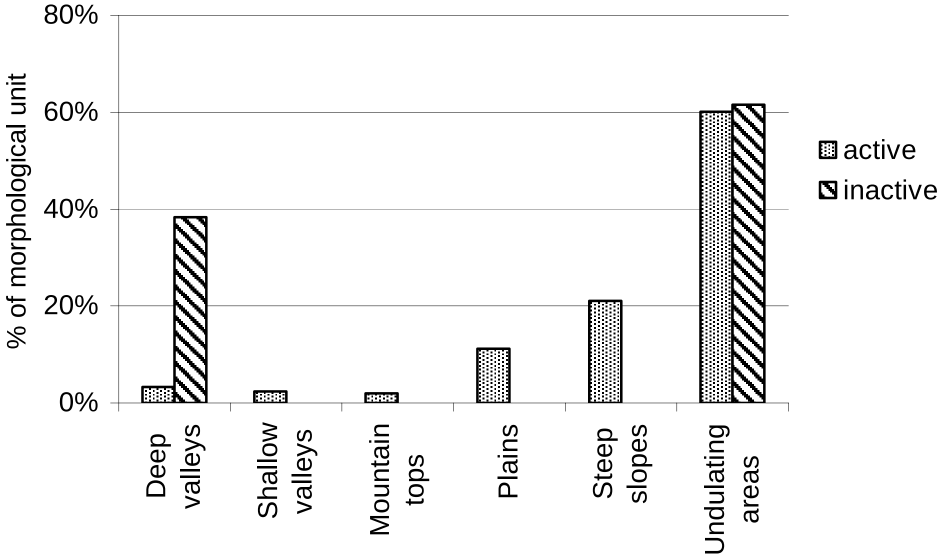

Figure 22: Distribution of rill erosion per morphological unit.

Talus edges

Talus edges (Figure 24) occur allover in the Gina River catchment. While the north and the central-east talus edges are lacking they occur area-wide in the south, central-west and north-west. Highest concentrations by talus edges occur in the southern part of the Gina River catchment. At all, more than 60 % of th edrainage basin area are affected by talus edges, and only in the morphological units *Deep valleys* and *Undulating areas* they are of minor imprtance (Figure 20).

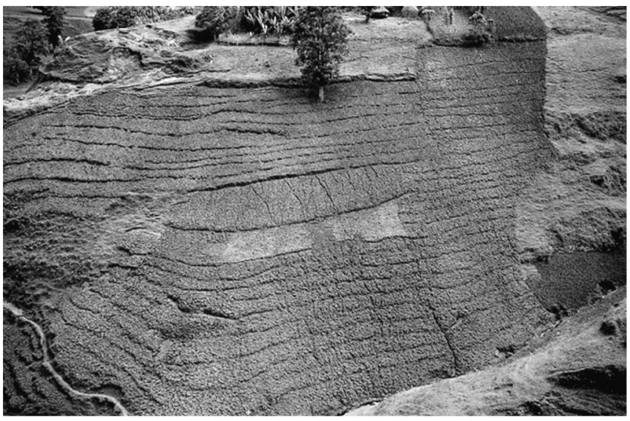

Figure 23: Soil erosion damage - Rill erosion on a cultivated slope.

Figure 24: Soil erosion damage – Talus edge along the road.

Mass movements

Except in the south-west mass movements are equally distributed all over the Gina River catchment. The major distribution of the mass movements is in *Steep slopes* and the *Undulating areas*. Only few mass movements can be found in *Deep valleys* and *Plains*. *Shallow valleys* and *Mountain tops* almost lack mass movements (Figure 20).

Sheet erosion

The majority of soil erosion damages by sheet erosion occurs in *Undulating areas* and *Steep slopes* in the northern region of the Gina River catchment. However, in the south-east of the drainage basin area is also affected by sheet erosion (Figure 20, 25).

Badlands

Badland areas occur widely spread throughout the Gina River catchment. The different badland areas are found predominantly in the south-east and central-east. Most of them are located in the *Undulating areas*. Neither in *Deep* nor *in Shallow valleys* badlands occur (Figure 20).

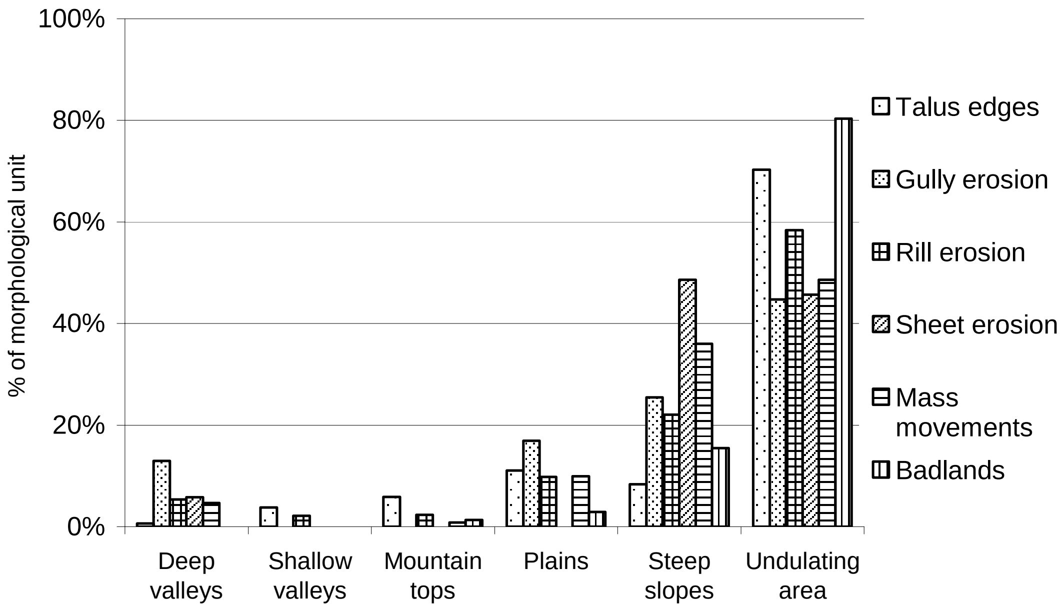

Figure 25: Relative distribution of soil erosion damage in the morphological units.

Relation between soil erosion damage and land use

An above average percentage of areas affected by sheet erosion occurs in areas used by Mosaic cropping and areas with cultivation of Ensete and legumes, but – interestingly - also in the woodlands (Figure 26). The other types of soil erosion damages do not differ in spatial distribution dependent on the different character of land use (agriculture, woodland, pasture land and forest).

5.2.2 Soil conservation measures

Terraced sites cover 7.8 % of the Gina drainage basin area, while sites with walls as conservation measures occur only in 0.1 % of the drainage basin area. Occurance of terraced sites and sites protected by walls show differences in the geographical distribution: Most terraces are found in the central-west, central-east and the north-west.

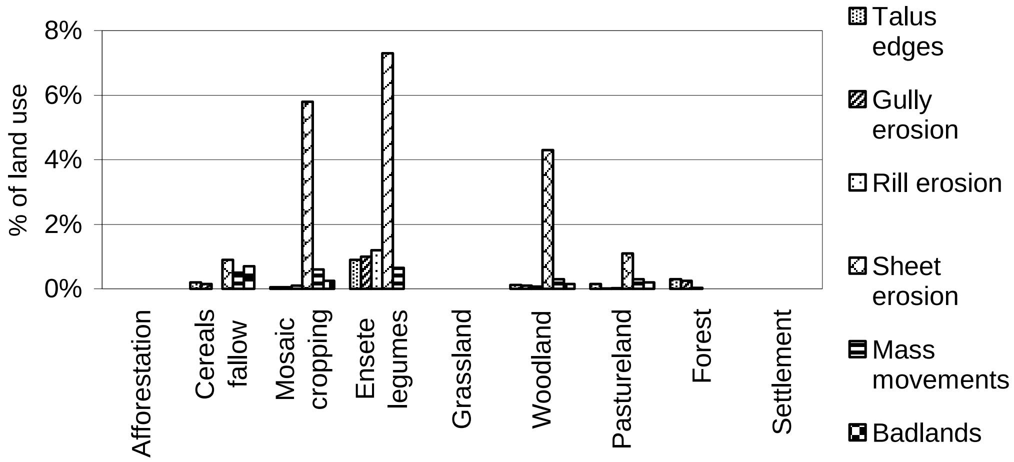

Figure 26: Proportion of each land use area affected by soil erosion damage.

Beyond this, the terraces in the central-east and north are in a bad condition; most of them, predominantly in the north are not well maintained (Figure 27).

Terraces occur in regions with slopes of 9-18 % as well as the walls. But the soil conservation measures incidence a decrease with growing and falling of slope, respectively. Consequently, on slopes of less than 2% and of more than 27 % conservation measures are only scattered distributed (Figure 28). In relation to the plot of each morphologic unit, terraces occur mainly in *Steep slopes*, followed by the *Undulating areas* and the *Deep valleys*. Also, there 4 % of *Plains* are covered by terraces. Besides, some walls are found in *Plains*. In *Shallow valleys* and *Mountain tops* only a small part of the terraces exist, less than 2 % of each morphologic unit (Figure 29).

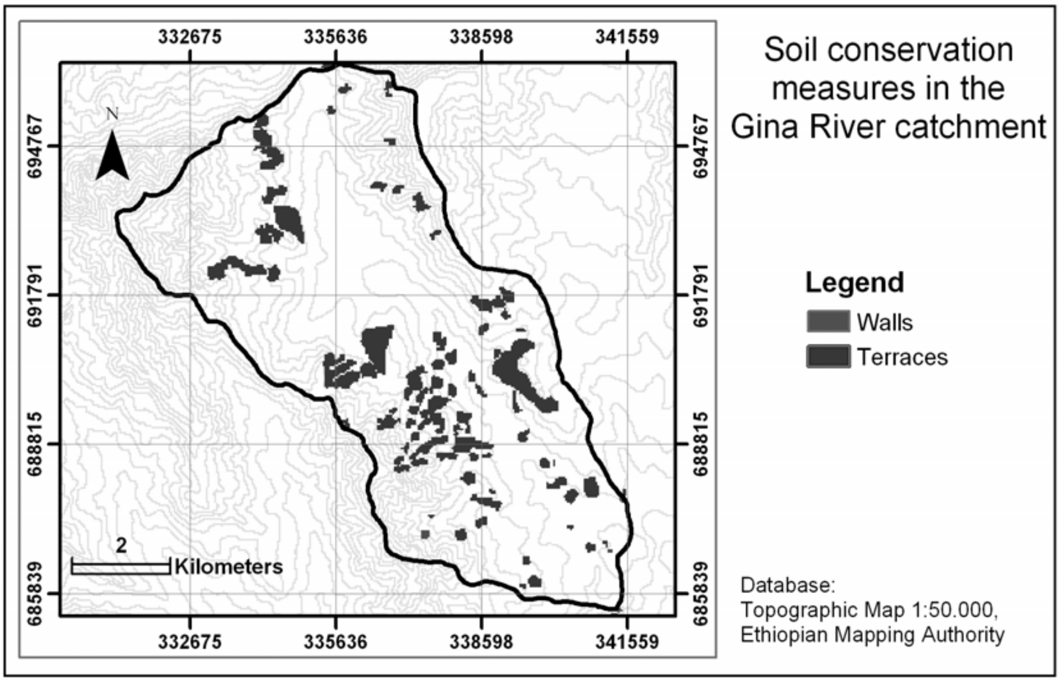

Figure 27: Soil conservation measures in the Gina River catchment.

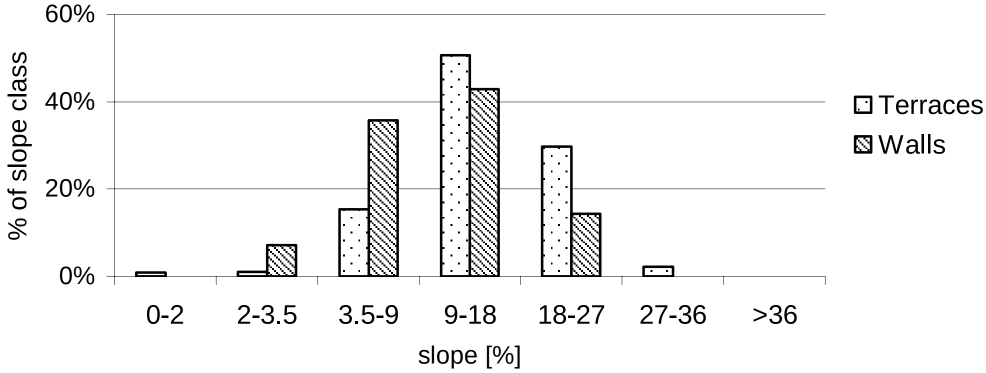

Figure 28: Distribution of slopes to conservation measures.

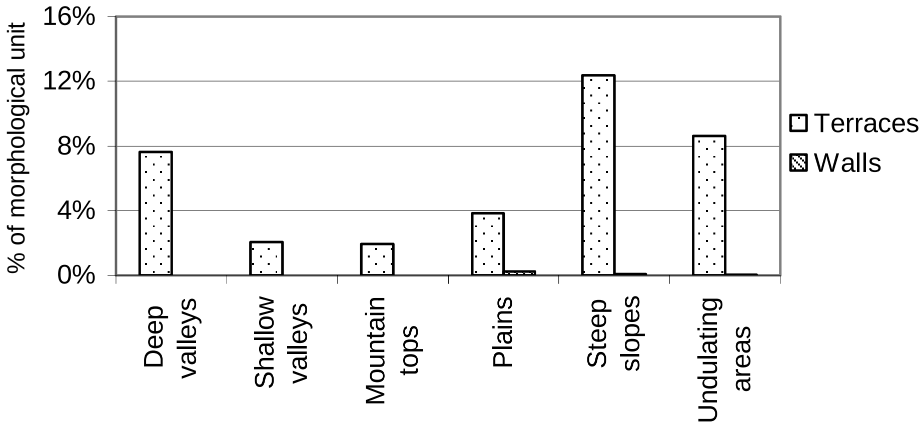

Figure 29: Distribution of conservation measures to morphological units.

5.3 Curve Numbers for the Gina River catchment

In the Gina River catchment terraced and straight row treatment are mapped as countered treatment lacks. Thus, all cultivated areas have been regarded as `straight rows`, except the ones that are assigned by terraces. All other areas, where soil is not cultivated are assigned as natural treatment. The land use mapped is transferred to the land use classification of the *Curve Number Method* except the classifications ‘afforestation’, ‘forest’ and ‘woodland’. They are merged to the CN classification ‘woodland/forest’.

Table 10: Average Curve Numbers in the sub-basins in the Gina River catchment.

Basin No	CN	Basin No	CN	Basin No	CN
1	78	7	82	13	80
2	80	8	82	14	79
3	80	9	82	15	82
4	80	10	80	16	80
5	81	11	79	17	80
6	81	12	81		

Table 11: Curve Number of the Gina river catchment.

Land Use (mapped)	Land Use Classification CN	Treatment or Practice	Hydrologic Condition	Hydrologic Soil Group B	C	D
Mosaic Cropping	Mosaic cropping	straight sow	---	76	84	88
		terraced	---	71	79	82
Cereals / fallow	Cereals	straight row	---	76	84	88
		terraced	---	71	79	82
Ensete / legumes	Ensete / legumes	straight row	---	75	83	87
		terraced	---	70	78	82
Pasture land	Pasture	natural	---	70	80	84
Grassland	Grassland	natural	good	58	71	78
Afforestation Forest Woodland	Woodland / forest	natural	---	60	73	80
Tukul / Mesho	Farmsteads	---	---	74	82	86
Paths	Roads	(dirt)	---	82	87	89
		(hard surface)	---			

The table 11 of the reclassified land use of the Gina River catchment afford possible curve numbers for the whole basin. As the Gina River catchment is divided into 17 sub-basins (chapter 5.4) only curve numbers for these sub-basins are determined. The curve numbers vary from 78 for basin 1 to 82 for sub-basins 7, 8, 9 and 15 (Table 10).

5.4 Rainfall-Runoff modeling

The model components of HEC-1 are based on simple mathematical relationships which are intend to represent individual meteorological, hydrologic and hydraulic processes which comprise the precipitation-runoff process (WOLTER 1996). A precipitation hyetograph is used as input for all calculations. It presents the average precipitation over the sub-basins.

Hare river catchment

The Hare River catchment has an average annual precipitation of approximately 1250 mm. It has two peaks, one between April and May, the other between September and October. As for the Hare and the Gina River catchment daily precipitations data are not available, data from Hossaina weather station are used for modelling. Hossaina is located in a comparable relief position 200 km north of the Hare River catchment in the Ethiopian Highland. The relief position of the Hossaina weather station is comparable to relief of the Hare River catchment. The average annual precipitation differs only +/- 80 mm, it is expected that also the distribution and amount of daily precipitation are comparable. (Table 12).

Table 12: Hare River Catchment: average monthly precipitation, 1980-1996 [mm/m²].

Jan.	Feb.	Mar	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
32	52	109	162	179	93	98	90	120	144	65	33

The average precipitation for the years 1980-1996 in the time period from April to May totals 341 mm, the respective average from September to October amounts 264 mm. The sum of rainfall in the first rainy season is therefore 77 % higher than in the second.

The average discharge for the years 1980-1996 of the Hare River in the time period from April to May only slightly differs from the September to October time period. From April to May it totals 8.25 m³/s, while from September to October it totals 8.68 m³/s. The discharge in September and October is more or less the same like in April and May, although the amount of precipitation is distinctly higher from April to May (Table 13).

Table 13: Hare River Catchment: Mean relationship between precipitation and discharge for the time period 1980-1996.

Ø runoff precipitation quotient (dry season)	Ø runoff-precipitation quotient (April-May)	Ø runoff-precipitation quotient (September-October)
0.36	0.23	0.37

The annual runoff-precipitation quotient for the time period from 1980-1996 totals 0.36, implying that 36 % of incoming precipitation are forming surface runoff. The runoff-precipitation quotient of the first rain season from April to May totals 0.23 (1980-1996), for the second rain season from September to October the runoff-precipitation quotient totals 0.37 (1980-1996).

Gina River Catchment

To accomplish runoff-precipitation modelling applying the HEC-1 tool the Gina River catchment is divided into 17 sub-basins. 10 Sub-basins are 1st order, 6 of the sub-basins are 2nd order and the whole Gina River catchment is 3rd order (Figure 30).

Table 14: Selective parameters of the sub-basins in the Gina River catchment.

Basin No	Composite CN	percentage of impervious area	Basin No	Composite CN	percentage of impervious area
1	78	14	10	80	35
2	80	24.5	11	79	22.7
3	80	9.2	12	81	20.7
4	80	11.6	13	80	18.7
5	81	9.9	14	79	25.4
6	81	25.7	15	82	32.6
7	82	7	16	80	29.5
8	82	26	17	80	31.7
9	82	14.6			

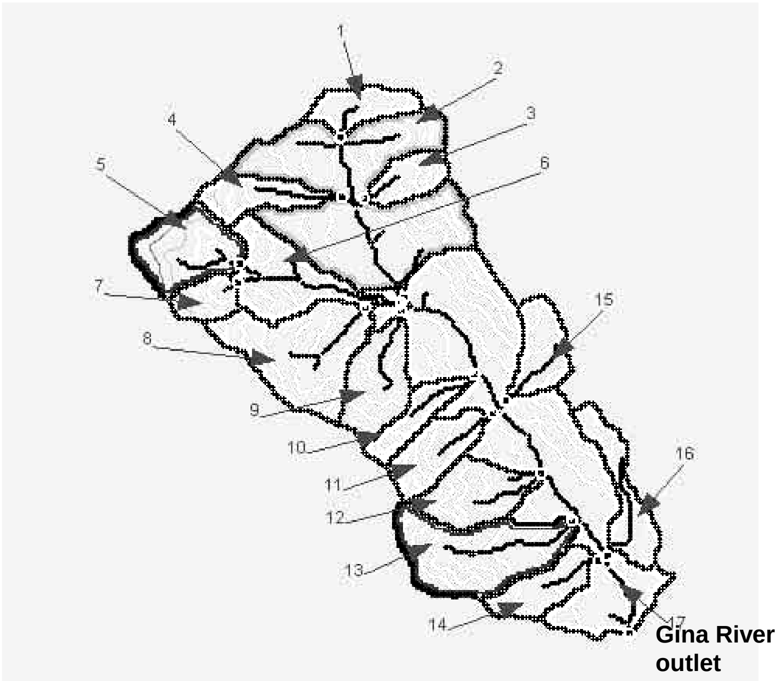

Figure 30: Distribution of sub-basins of the Gina River.

Table 14 also shows the percentage of the impervious areas in the drainage basin. These areas are composed predominantly by footpaths, settlements and roads.

After the simulation hydrographs for each sub-basin are generated. The hydrographs show the progression of the flood wave, whether the runoff is concentrated on a short period of time (Figure 31) or nearly constant through the whole period of rainfall.

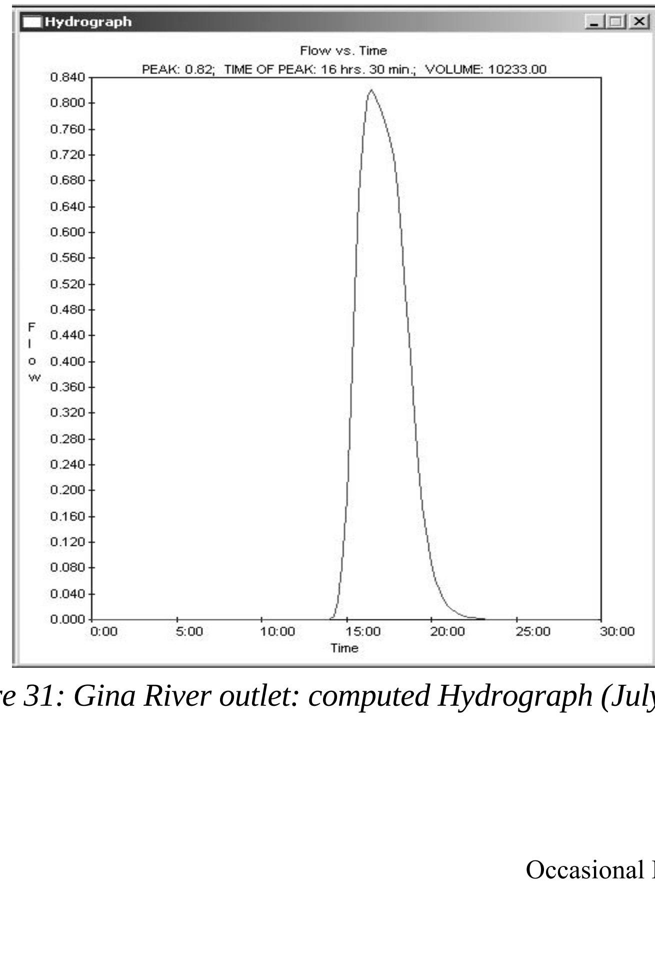

Figure 31: Gina River outlet: computed Hydrograph (July, 4th).

Modelling Examples

Table 15: Gina river sub-basins: July, 4th 2001, total precipitation: 0.8 mm.

Basin No	Drainage basin order	Peak [m³/s]	Time of Peak	Q [m³/s]	Total preci-pitation [m³]	Φ [%]	Slope [%]	Area [km²]	Main channel length [m]
1	1	0.03	16:00	144	1032	14.0	11.6	1.29	835
2	2	0.36	15:30	2144	10392	20.6	12.1	12.99	6562
3	1	0.02	15:30	82	920	9.0	19.6	1.15	906
4	1	0.03	15:45	135	1176	11.6	14.6	1.47	1831
5	2	0.04	15:45	197	1992	9.9	19.9	2.49	1416
6	2	0.32	15:30	1706	8360	20.4	12.0	10.45	5305
7	1	0.01	15:45	49	728	6.8	19.1	0.91	1572
8	2	0.17	15:30	866	3336	26.0	11.8	4.17	1970
9	1	0.04	17:30	262	1808	14.5	12.5	2.26	1909
10	1	0.05	16:45	332	952	34.9	14.1	1.19	1610
11	1	0.05	16:30	314	1384	22.7	18.2	1.73	1428
12	2	0.06	16:00	351	1704	20.7	16.4	2.13	1595
13	2	0.1	16:00	594	3176	18.7	15.6	3.97	2906
14	1	0.05	15:30	300	1192	25.2	9.7	1.49	1401
15	1	0.07	16:45	412	1264	32.6	11.8	1.58	1652
16	1	0.07	16:00	421	1432	29.4	6.5	1.79	2365
17	3	0.82	16:30	10233	42344	24.2	10.1	52.93	15273

Table 16: Gina river sub-basins: July, 18th 2001, total precipitation: 15.7 mm.

Basin No	Drainage basin order	Peak [m³/s]	Time of Peak	Q [m³/s]	Total preci-pitation [m³]	Φ [%]	Slope [%]	Area [km²]	Main channel length [m]
1	1	0.56	5:00	2872	20253	14.2	11.6	1.29	835
2	2	7.18	4:30	43386	203943	21.3	12.1	12.99	6562
3	1	0.38	4:30	1801	18055	10.0	19.6	1.15	906
4	1	0.53	4:45	2853	23079	12.4	14.6	1.47	1831
5	2	0.82	5:00	4372	39093	11.2	19.9	2.49	1416
6	2	6.71	4:30	35826	164065	21.8	12.0	10.45	5305
7	1	0.26	4:45	1289	14287	9.0	19.1	0.91	1572
8	2	3.61	4:30	18058	65469	27.6	11.8	4.17	1970
9	1	0.81	6:30	5835	35482	16.4	12.5	2.26	1909
10	1	1.02	6:00	6644	18683	35.6	14.1	1.19	1610
11	1	1.06	5:30	6273	27161	23.1	18.2	1.73	1428
12	2	1.29	5:15	7293	33441	21.8	16.4	2.13	1595
13	2	2.1	5:00	12092	62329	19.4	15.6	3.97	2906
14	1	1.06	4:30	6011	23393	25.7	9.7	1.49	1401
15	1	1.35	5:45	8451	24806	34.1	11.8	1.58	1652
16	1	1.32	5:00	8483	28103	30.2	6.5	1.79	2365
17	3	16.57	5:30	207964	831001	25.0	10.1	52.93	15273

Table 17: Gina river sub-basins: July, 24th 2001, total precipitation: 23.1 mm.

Basin No	Drainage basin order	Peak [m³/s]	Time of Peak	Q [m³/s]	Total precipitation [m³]	Φ [%]	Slope [%]	Area [km²]	Main channel length [m]
1	1	73	8:00	559882	29721	1883	11.6	1.29	835
2	2	643	7:45	5756962	299289	1923	12.1	12.99	6562
3	1	70	7:30	501183	26496	1891	19.6	1.15	906
4	1	79	7:45	643071	33868	1898	14.6	1.47	1831
5	2	136	8:00	1093712	57369	1906	19.9	2.49	1416
6	2	567	7:30	4678533	240768	1943	12.0	10.45	5305
7	1	53	7:45	401705	20966	1915	19.1	0.91	1572
8	2	254	7:30	1886994	96076	1964	11.8	4.17	1970
9	1	92	9:30	1006808	52070	1933	12.5	2.26	1909
10	1	55	9:00	539757	27417	1968	14.1	1.19	1610
11	1	84	8:30	767012	39859	1924	18.2	1.73	1428
12	2	112	8:15	950325	49075	1936	16.4	2.13	1595
13	2	201	8:00	1756140	91468	1919	15.6	3.97	2906
14	1	78	7:45	660742	34329	1924	9.7	1.49	1401
15	1	77	8:45	722211	36403	1983	11.8	1.58	1652
16	1	83	8:00	807372	41241	1957	6.5	1.79	2365
17	3	1241	10:00	23669873	1219507	1940	10.1	52.93	15273

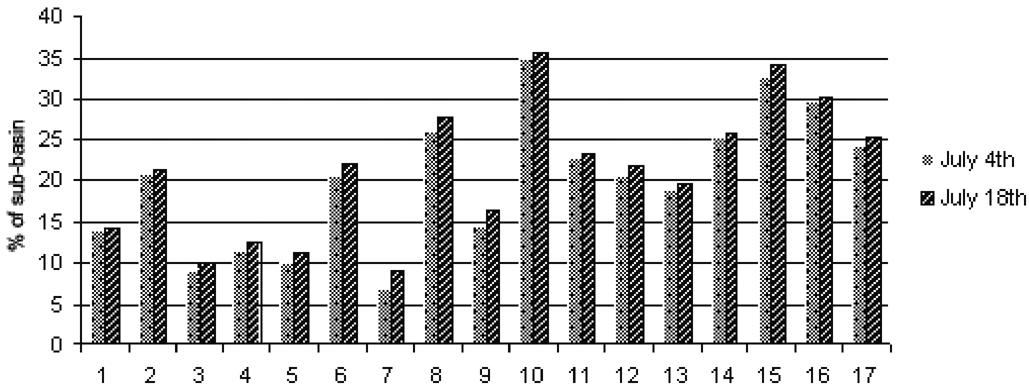

Figure 32: Gina river sub-basins: Runoff-precipitation quotient.

Table 17 shows inadequate results of the computed precipitation-runoff quotient. Although the assumed rainfall event of 23.1 mm is very similar the event of July 18th with 15.7 mm, the quotient raises to values more than 1900. These values are calculative impossible.

The computed runoff-precipitation quotient for an assumed area wide rainfall of 0.8 mm/h for the whole Gina River catchment varies from 6.8 to 34.9 for July 4th 2003within the 17 sub-basins. For an assumed rainfall of 15.7 mm/h for July 18th 2003 the runoff-precipitation quotient is only slightly changing from 9.0 to 35.6. Spatial variations of the runoff-precipitation quotient within the Gina River catchment are quite remarkable. In contrast to the variation between two different rainfall events (Figure 32).

The comparison of the runoff-precipitation quotient to the average slope of each sub-basin does not show any distinct trend. In general the runoff-precipitation quotient is decreasing at steeper slopes. But in some sub-basins, like in sub-basin 10 with an average slope of 14.1°, the runoff-precipitation quotient is much higher than in basins of smoother slopes. In contrast, the sub-basin 1 with an average slope of 11.6° the quotient is lower than in basins with steeper slopes (Figure 33).

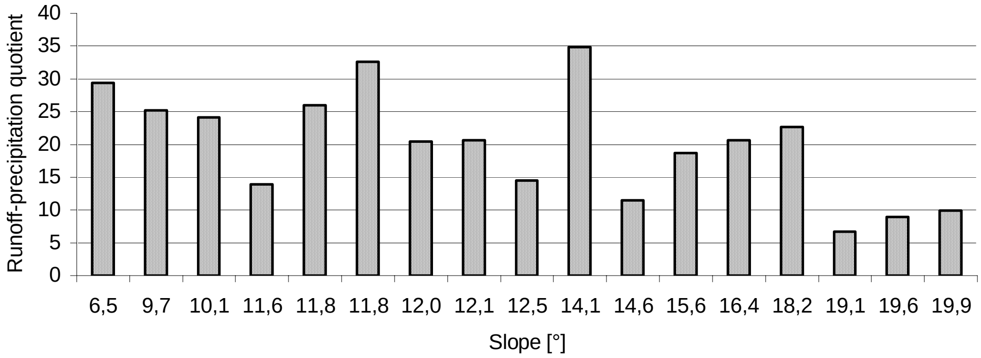

Figure 33: *HEC-1 computed runoff-precipitation quotients of Gina River catchment.*

6. DISCUSSION

6. 1 Landscape factors

6.1.1 Precipitation

During the rainy season wind directions in the Ethiopian highlands are generally west to north- west (GRIFFITHS 1972). Consequently, the mountains of the Abaya – Chamo Basin - and correspondingly, of the Gina catchment area - are exposed to the wind. Advection of water rich air masses along the graben flank cause increased preciptation in the highland areas compared to the lowland areas (NIEUWOLT 1977). This explains the distinct relation between elevation and precipitation since c. 80 % of the annual rainfall appear during the rainy season.

The effect of advection due to upslope lifting shows a significant difference between tropical and nontropical regions: while in nontropical regions the amounts of precipitation increase with elevation up to the highest areas of the mountains, in tropical regions the effect usually stops at a lower level which is determined by the regional conditions (normally at 1000 m to 1500 m) (NIEUWOLT 1977). In the Gina River catchment this point appears in 2780 m a.s.l.

The special characteristic of the tropics can be explained by two conditions, which are rare in other latitudes. First, in tropical air masses a frequent steep laps rate occurs, which tends to reduce the capacity of the air to retain vapour in the higher parts of the atmosphere. Secondly, the predominant vertical air movements are limiting the horizontal advection of moisture (NIEUWOLT 1977).

Due to the lack of data the behavior of the orographic rain effect in the Gina River catchment cannot be controlled. Yet the theoretical backround provides an informative base to support the polynomical precipitation –elevation- relationship given in the rainfall model (Chapter 5.1.1). However, poor availlability of precipitation data for elevations between 2000 m a.s.l. and 3000 m a.s.l. and the transfer of data from the Abaya – Chamo Basin to the Gina River catchement area are possible sources of error.

Next to this, the central Ethiopian highlands are characterised by a high precipitation variability. The lowest monthly variability can be noted in April and the highest in June (OSMAN 2001). Consequently, a significant amount of rain is falling in a low number of extreme precipitation events resulting in a high erosion capacity of the water. As the amount of rainfall basically increases by elevation, most of the runoff has a long runoff distance.

The recurrence analysis is a feasible approach to get an impression on rainfall variability but it does not provide data of high reliability. This problem is aggravated by the lack of continuous data series, which for the Abaya- Chamo basin since 1980 do not cover more than 24 months without data loss.

6.1.2 Land use

Rain fed agriculture predominates land use in almost all morphological units of the Gina River catchment. In contrast, agriculture in the Rift Valley is practised to a lower extent and cultivation takes mostly place in irrigated plantations. Apart from that, land use in the Gina River catchment is determined by pasture. This distribution of land use between highland (Gina River catchment) and lowland (Rift Valley) is due to the distinct availability of water as the determining factor (WESTPHAL 1995). The intensive use by agriculture in the highlands is especially apparent in the *Undulating areas*. This is benefited by the relatively smooth relief in this morphological unit as well as by a soil texture appropriate for cultivation. Thus, intensive cropping is possible (BEINEMPAKA et al. 1989).

Unlike the widely spread agricultural use in the Gina River catchment, land use in the two morphological units *Mountain tops* and *Shallow valleys*, is determined by pasture. Extensive pasture use in the *Mountain tops* corresponds to high altitudes and hypsographic change (adiabatic (lapse) rate) (HÄCKEL 1993). In contrast, extensive pasture use in the *Shallow valleys* is due to the phreatic surface close to the surface as the receiving water course is only shallow (WALTER 1993). Thus, in both areas environmental conditions are unfavourable for agriculture (HÖFS et al. 1993, WALTER 1993).

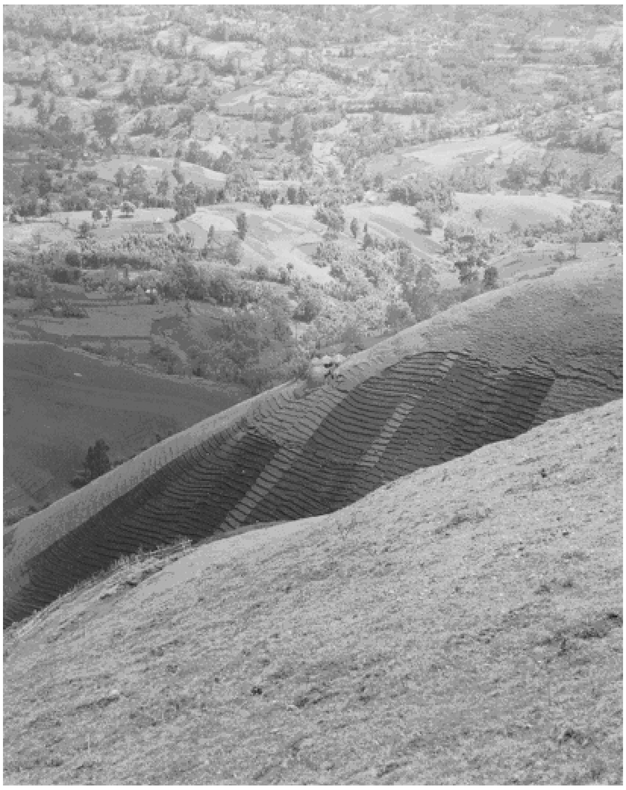

Figure 34: Cultivation of Steep slopes.

In the *Deep valley* areas Woodland occurs along the major draining courses as alluvial forests. Thus, woodlands are possibly the contractive remnants of the former area-wide existing woodlands and can still be found where there is difficult access to the area due to strong inclination of the slopes. In the *Shallow valley* and the *Plain* areas the patches of small woodlands are predominantly composed by bamboo, eucalyptus, yellowwood and junipers (MESFIN 1972). In these areas lumber and firewood are stockpiled. It is assumed that the density of these patches decreased during the last decades as it gets obvious by the overall occurring clear cutting sites with stubs (FEOLI et al. 2002; SANKHAYAN & HOFSTAD 2001).

Mesho is a central agglomeration of approximately 120-150 tukuls, located in the alluvial plain of the Gina River upper course. The settlement is fenced by palisades. Inside Mesho central place functions can be found such as a post office, several restaurants, a weekly market place and a school. The building of Mesho at the fringe of the *Plain* and the *Shallow valley* morphological units results from the local relief character: Flat or slightly rolling areas upside the Gina River flood zone stand for favourable living conditions with permanent water supply. Likewise, the high number of tukuls mostly besides cultivated fields in the *Undulating areas*, *Plain* and *Shallow valley* units can be attributed to the relief. In contrast, only few tukuls occur in the *Steep slopes* and *Deep valley* areas due to the strong inclination of slopes in both morphological units. In the *Mountain tops* unit settlement areas are rare, not likely due to the uncomfortable weather conditions (KULS & KEMPER 2000).

Thus, land use in the Gina River catchment corresponds in principal with the natural conditions of the drainage basin. Especially areas appropriate for cultivation and characterised by good living and settlement conditions are intensively used by man. Areas unsuitable cultivation mostly provide acreage for pasture management. However, also disadvantageous areas are influenced by humanimpact. On the one hand, this becomes apparent in the high proportion of area used agriculturally in *Steep slopes* and *Deep valley* units. Thus, construction of appropriate and adequate conservation measures especially in these areas are required. On the other hand, the insignificant fraction of remaining forest and grassland areas are located in the *Mountain tops* and the *Steep slopes* areas and remaining woodlands in the *Deep valley* areas. This can be contemplated as an indication for strong human impact which is confirmed by the declining proportion of woodlands in the *Shallow valley* and the *Plain* units. This dissemination of human activities is due to the high population pressure which can be perceived throughout Ethiopia (GREPPERUD 1996).

6.1.3 Soils

In the Gina River catchment area a high amount of sediments with sharp boundaries to saprolite or C-horizons indicate, that those soils did not develop in-situ. Soil sediment layers of several meters thickness point out long lasting processes of denudation- possibly due to soil erosion.

Chemical weathering with actual clay mineral formation characterises weathering and soil forming processes all over the Gina River catchment. Thus, *clay loam* (soil category C) is the predominant soil class in the drainage basin.

The soil category D (*clay*) usually occurs where in-situ soil development is not very mature. Those soils have considerable shrinking and swelling properties. They can be reported in *Undulating areas* with degraded soils, coinciding to the occurance of soil erosion damages such as rills, gullies and badlands. These soils have a medium infiltration capacity in the upper layer and a low infiltration capacity in the lower layer resulting in enhanced surface runoff. The distribution of the soil category B (*sandy loam*) around the Gina River can be attributed to alluvial deposits in the Gina River floodplain. The broad variety of soil texture (sand, silt, clay and gravel) along the river course is typical for fluvial sediments and coincides to the development of Fluvisols.

6.2 Soil erosion damages and Soil Conservation measures

6.2.1 Soil erosion damages

As stated in chapter 6.1.1 precipitation increases with altitude until the altitude of 2700 m a.s.l in the Gina River catchment. Providing this, *Mountain tops* do not receive the highest amount of rainfall. But still the amount of rainfall is considerable high in this morphological unit. However, despite of the high amount of precipitation the least soil erosion damages occur in this morphological unit next to the *Shallow valleys*. This is mainly due to the dense vegetation cover on the *Mountain tops*. The predominating meadow vegetation protects the soil from the splash effect of the raindrops, which, hence, cannot detach soil particles.

Intense root penetration of the upper soil horizon by grasses prevents the soil from erosion. Due to the estimated ground cover of 80 to 95 % the effects of precipitation are 10 times lower than on barely covered land (HUDSON 1995).

In the Gina River catchment only in areas affected by human impact soil erosion damages occur. In particular, ways and paths are due to the rare vegetation cover and the compacted underground areas where erosion forces can act effectively (AUERSWALD 1998; ROGERS 1991), enhanced by torrential rainfall events as the decisive part of the precipitation in terms of erosive forces.

The high intensity of sheet erosion damages at *Steep slopes* can be attributed to the morphology and land use, which is determined by agricultural purposes, in this morphological unit mostly cereal/ fallow. Due to the lack of permanent vegetative layer water does not infiltrate into the soil entirely, especially during torrential rainfall events, and drains off on the surface when the infiltration capacity is lower than the amount of precipitation. Additionally, the predominant soil texture *clay loam* enhance the erosion process as it is fine textured and, which favours the soil removal by water (AUERSWALD 1998).

Mass movements are very likely to occur on the *Steep slopes* as well. Above the impermeable loamy clayey saprolite water banks up, and cohesive forces between the soil particles weaken, resulting in a downward movement of the water saturated upper soil layer (solifluction; MATTHEß & RUMP-SCHENK, 1993; GERRARD 1990). This effect becomes enhanced by the approximately even depth of roots of the crops on these fields (AUERSWALD, 1998). A special type of solifluction is the cattle induced stepping of the slopes. On water saturated soils slow ascending cattle cause a contour parallel stepping of the slope resulting in a downward movement of the soil (AUERSWALD, 1998).

Problems detecting sheet erosion should be stated here. It is difficult to determine the degree of this type of soil erosion damage since minor soil erosion damages are hardly recognisable and difficult to map. Densely vegetated areas prevent the exact identification of those soil erosion damages and soil cultivation removes apparent damages (SCHMIDT 1979). Therefore the actual mapped soil erosion damages do not represent the actual amount and degree of sheet erosion.

Another important explanation for the occurrence of the soil erosion damages is unadapted agriculture. Periods of uncultivated fallow land and steep slopes are the main reasons for the damages, which show highest significance especially in the *Undulating areas*, where the population density is highest as well (Chapter 5.2.1). Here, the dense network of paths covers the intensively used areas with many small cultivated fields.

On *Plains* and in *Deep valleys* the reduced velocity power, of the running water results in a reduced erosion rate. Thus, the soil erosion damage is mainly affecting paths and small agglomerations of tukuls, because those are areas of high soil compaction. Along paths locally the development of gullies is initialised (HUDSON 1995).

6.2.2 Soil conservation measures

There is a close relationship between the occurrence of soil conservation measures, such as terraces and walls, and the distribution of land use. Most walls and terraces are constructed on slopes with an inclination of 9 - 18 % because here the largest proportion of agricultural activities is located. In steeper areas, however, a declining frequency of conservation measures is observed. The higher number of soil erosion damages led to the assumption that also a lot of protection measures had to be implemented at these areas. But also a less intensive agricultural practice might reduce the necessity for soil conservation measures.

Most terraces occur on *Steep slopes*, followed by *Undulating areas*. Here most of the area is used for agriculture and it is necessary to protect the soil from erosion. Due to the same reason the *Deep valleys* are covered widespread by terraces, as in this area agricultural use occurs also on slopes with strong inclination.

6.3 Curve Numbers for the Gina River catchment

The curve number is a correction factor to consider specific soil and land use characters for hydrologic modelling using black-box models such as HEC-I. Thus, the curve number has the character of a bulk parameter where input data have due to the necessities of the target a very generalising character. Referring to the case of the Gina River catchment only the soil hydrologic conditions (coupled to the mapped soil classes) and the land use vary within the catchment. 88 % of the soil texture recorded of the Gina River catchment is classified as sandy loam. Additionally, only few land use classes, based on the mapped data, lead to variations of the curve numbers. Accordingly, the curve numbers allow only an insufficient differentiation of the Gina River drainage basin and, thus, of explanation characterising the runoff potential of the land cover-soil complex.

6.3 Rainfall-Runoff modeling

6.3.1 Hare River catchment

Although the average precipitation in the Hare River catchment for the time period from April to May is higher than for the time period from September to October, the discharge of the Hare River is in opposite phase. The runoff-precipitation quotient reflects this result. Additionally the value of the runoff-precipitation quotient of the dry season is the same like for the time period from September to October, a time part of the rainy season.

Generation of surface runoff is directly correlated to the infiltration capacity of the soil. The results yield to the assumption that dry soil has a higher infiltration capacity than moist soil (SCHMIDT 1979). The time period before April is characterized by several dry month with very low precipitation. Contrarious, the time period before September is semi-arid to semi humid. On the other hand side tropical soils with high clay contend lead to seal surface immediately, causing high surface runoff. As cultivation of the Hare River catchment is very intensive surface runoff generation as saturated overland flow is of minor importance. Agriculture land is ploughed after or during the first rainfall events of the rainy season to increase infiltration capacity and prevent surface runoff. The climate in the time period in between the two rainy seasons does not desiccate the soil at all. Therefore, the soil moisture in the beginning and during the second rainy season is relatively high leading to increasing surface runoff. Due to the horizon depth plowed, the soil is saturated causing ‘Saturated Overland Flow’.

6.3.2 Gina River Catchment

Some results of the rainfall-runoff modeling presented by the runoff-precipitation quotient show plausible values. The variations of the data between the sub-basins give the impression that the runoff-precipitation quotients reflect overall characteristics for each sub-basin. Thus, it is obvious that the curve-numbers as a bulk parameter and the percentage of impervious area are insufficient to describe the complex character of a drainage basin with the target to compare water balance.

The runoff-precipitation quotient varies independent from the degree of the average slope of the sub-catchments. Also any correlation between the modeled runoff-precipitation quotient and the remaining variable input parameters except the percentage of impervious areas lack. Evidently the runoff-precipitation quotient is directly linked to the percentage of the impervious areas.

Anyhow, the results of the rainfall-runoff modeling using HEC-1 do not give any additional information on surface runoff generation. More over in some parts the rainfall-runoff modeling does not provide realistic results. At some days, e.g. the 24th of July, a peak discharge of more than 1200 m^3/s was computed. It is impossible that the output (discharge) is twenty times higher than the input (precipitation).

The overall insufficient modeling results of surface runoff generation do not allow any comparison to the distributed soil erosion risk estimation and, thus, also no calibration. At all, it need to be proven whether the HEC-1 modeling approach can be transferred to high relief catchments in tropical climates without any adaptation.

7. SOIL EROSION RISK ANALYSIS AND SCENARIOS

Various lumped and distributed models are available to evaluate soil erosion risk quantitatively (such as WEPP, USLE, EUROSEM, OPUS). Anyhow, these modelling approaches are developed for the Temperate Zones in Northern America and Europe, thus, they need to be aligned to the special conditions of the Gina River catchment which is located in the Suhumid Tropics.

At the present, there is no modelling approach available to allow a reliable estimation of soil erosion risk in the tropics. Thus, based on field investigation an individual approach to estimate soil erosion risk and to balance the factors causing soil erosion is proposed for the Gina River catchment. According to the quality of data available two approaches to estimate soil erosion risk are developed parallel and compared: The first one is based on the numerically scaled data and, thus, is semi-quantitative. The second one, in contrast, is based on qualitative weighting of the factors.

7.1 The semi-quantitative approach

To estimate soil erosion risk for the Gina River catchment in a semi-quantitative approach the factors considered are land use including paths and settlements, soil conservation measures and slope. Soil characters are not considered as intensity of field investigation of the Gina River catchment does not allow a significant differentiation in soil texture's spatial distribution . The factors selected are weighted qualitatively and put into erodibility categories which are combined in a soil erosion risk equation. A resulting map with 50 * 50 m² cell size shows the spatial differentiation of soil erosion risk in the Gina River catchment (Figure 37). The soil erosion risk categories are defined into five classes (1 = very low - 5 = very high). An quantitative of the erosion rate into t/ha/a as it is common in several modelling approaches (s. a.) is avoided due to the lack of data.

The area of soil exposed to the energy of raindrops is depending on the canopy cover, which, in turn, is dependent on the land use. Most of the soil erosion damages are located in areas intensive cultivated and used as pasture land (Figure 35). Agricultural used land has - especially in the beginning of the vegetation period - a very low canopy cover. Also after harvesting the soil is ploughed and bare, and, thus, the water can affect the soil easily. Soil's of pasture land is compacted by cattle tread. As the soil compaction diminishes the infiltration capacity it increases the surface runoff. Enlarged runoff is amplifying the soil erosion risk. From this process edges and rills result along paths in pasture land.

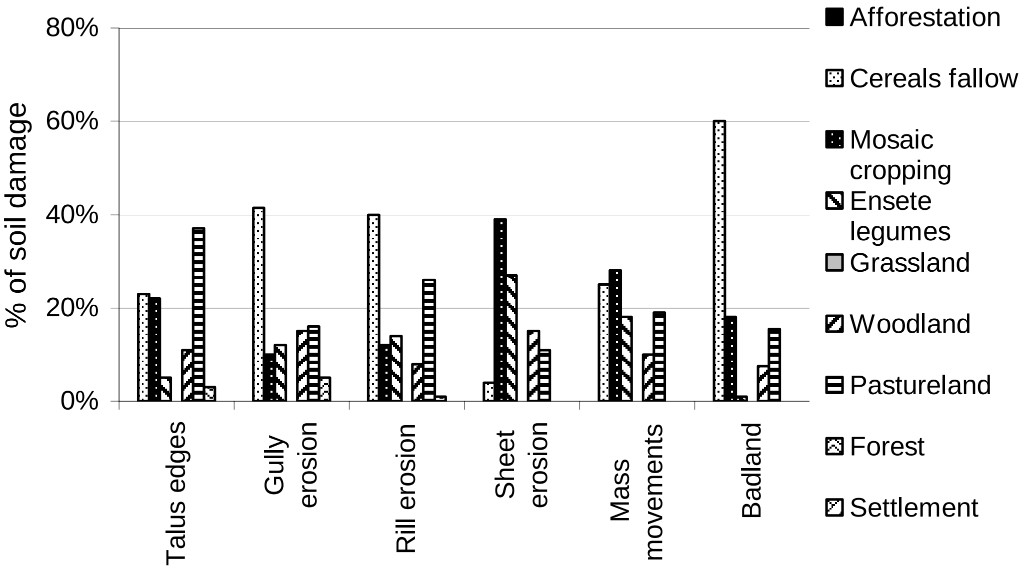

Figure 35: Distribution of the different soil erosion damages on land use areas.

Table 18: Allocated risk values for different land uses.

Land use	Soil erosion risk	Soil erosion risk value
Afforestation	medium	3
Cereals / fallow	very high	5
Mosaic cropping	high	4
Ensete / legumes	medium	3
Grassland	low	2
Woodland	low	2
Pastureland	medium	3
Forest	very low	1
Mesho (settlement)	very high	5

The different categories of land use are classified into five classes of soil erosion risk (Table 18). The population density is related to the density of tukuls, which totals approx. 24,3 tukuls/km² in the Gina River catchment. The soil-compaction is highest on housing plots and along the paths. Corresponding to the increasing population the agricultural use increases, too. Both factors, soil compaction as well as intensified land use, aggravate soil erosion risk. Thus, the plots of land with settlements respectively tukuls (weighted with *high soil erosion risk*-value = 4) and paths (weighted with *very high soil erosion risk*-value = 5) are integrated in the calculation of soil erosion risk.

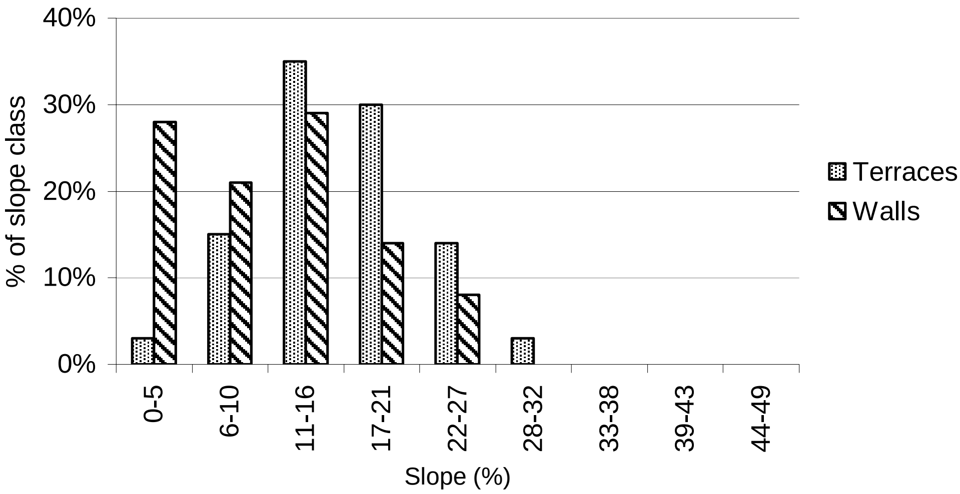

Figure 36: Distribution of soil conservation measures on slopes.

Next to the land use soil conservation measures are integrated into the soil erosion risk assessment, as soil conservation measures reduce velocity of surface runoff and support infiltration. Soil conservation measures occur predominantly on tilled slopes with moderate inclination (Figure 36). Steeper inclining slopes are also used for cultivation, but as here the portion of pasture land increases the amount of soil conservation measures decreases. Also in the slightly dipping areas, such as the *Plains,* soil conservation measures are found rarely. For the semi-quantitative estimation of the soil erosion risk levelling soil conservation measures like walls and terraces are merged and documented with the value 1 corresponding to its countervailing effect on surface runoff generation. The value 0 is reserved for the areas where soil conservation measures are lacking. Thus, these areas have no influence in the equation 12.

For the semi-quantitative estimation of the soil erosion risk the factor 'slope' gets classified in to eight classes (Table 19). The surface runoff is enhanced by steeper slopes increasing the soil erosion risk. Due to this the slope is identified as the most significant factor for soil erosion in this model. In consequence, slope inclination is integrated into equation 12 as multiplier of the soil erosion risks resulting from direct human impact.

Table 19: Applied classification of slope.

Slope [%]	Classes
< 1	1
1 – 2	2
2 – 3,5	3
3,5 – 9	4
9 – 13	5
13 – 27	6
27 – 58	7
> 58	8

Precipitation is due to its amount [mm] and its intensity [mm/min] one of the central factors generation surface runoff (HORTON-runoff, saturation overland flow; RICHTER 1998).

Data recorded at the meteorological stations into Abaya-Chamo-Basin only give information about the daily rainfall amount [mm] while data on rainfall intensity are lacking. Due to the lack of available detailed data the factor precipitation is not included in the model.

The classified datasets of land use, paths and tukuls are summed. By adding up terms factors they are treated as equal components. As soil conservation measures have an extenuating effect on surface runoff generation and, thus, on soil erosion processes, the value for soil conservation measures is subtracted. The combination of these terms reproducing influence of direct human impact on surface runoff generation becomes assessed by multiplication with the slope classes.

Semi-quantitative estimation of soil erosion risk:

$$SoilErosionRisk = \left[\left(LandUse + Tukuls + Paths\right) - SoilConservationMeasures\right] \times Slope \qquad (12)$$

The resulting soil erosion risk map of the Gina River catchment is differentiated into five soil erosion risk categories (Figure 37). Very low erosion risk is located predominantly in the *Shallow valleys* around Mesho, along the Gina river course, in some parts of the *Undulating areas* and in the south-west where some forests occur. The low soil erosion risk areas, in general, adjoin the very low soil erosion risk areas. The *Mountain top*s are characterised by medium soil erosion risk. High soil erosion risk areas predominantly occur at the base of the slopes due to the high amounts of runoff available and in the *Undulating areas* due to the intensive agricultural use. Very high soil erosion risk rates occur where *Steep slopes* are used by cereal cropping or as fallow land.

The soil erosion damages recorded by field investigation 70 % overlap with the areas accounted for high to very high soil erosion risk. This high degree of overlapping between soil erosion damages recorded by field-investigation and estimation of soil erosion risk by points out a high recall ratio of risk estimation. Anyhow, as congruence predominantly occurs in areas accounted for high soil erosion risk weighing of factors has to be challenged. Future improvement of the modelling approach shown in equation 12 as well should include the verification of the factor`s numerical scaling and classification as a revision of the algorithm applied.

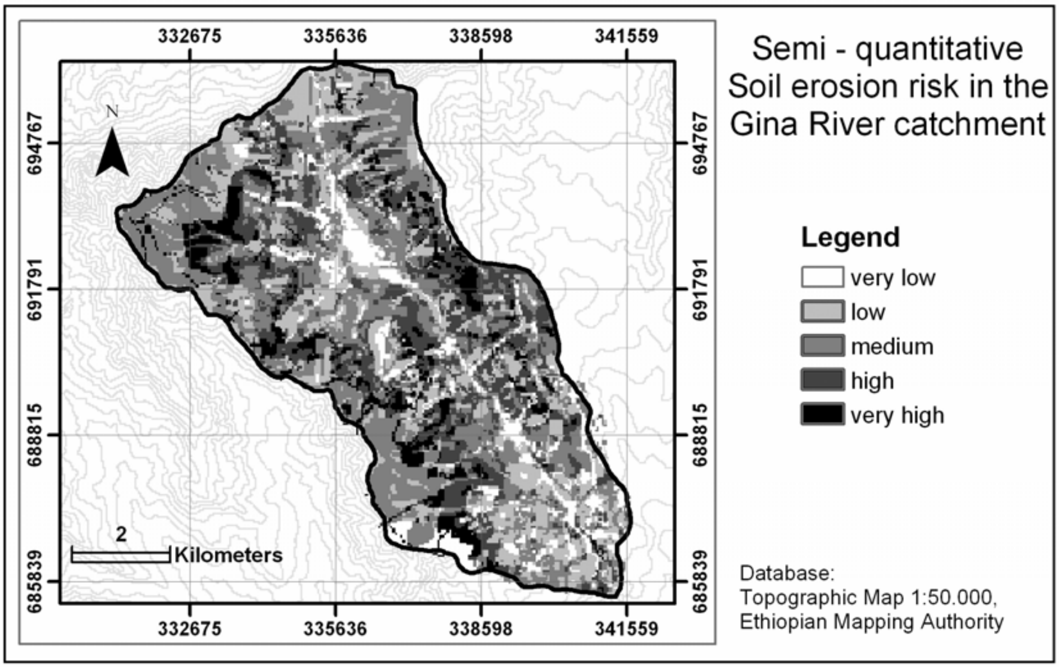

Figure 37: Semi-quantitative estimation of soil erosion risk in the Gina River catchment.

7.2 Qualitative approach

A multitude of models to estimate soil erosion risk is available. Most of them are conceived under lab-like conditions even when they are field grown. Most of these modelling approaches concentrate on a limited number of factors, mostly selected in subject to their physical attributes. Anyhow, due to the limited number of factors integrated, these modelling approaches can always reflect only a partial aspect of reality. Applying an holistic approach of soil erosion risk evaluation, not the single processes are accounted but landscape units, each characterised by a typical interaction of a multitude of processes. Attempting this qualitative approach factors contributing to soil erosion are classified into natural factors and factors induced by man. Natural factors considered are related to relief, soil and precipitation. Factors reflecting human impact are land use and soil conservation measures.

Based on the recorded soil erosion damages damage classes have been developed qualitatively in order to distinguish differently affected soil erosion damage areas. Five classes have been determined by the extents of soil erosion damages (Figure 38).

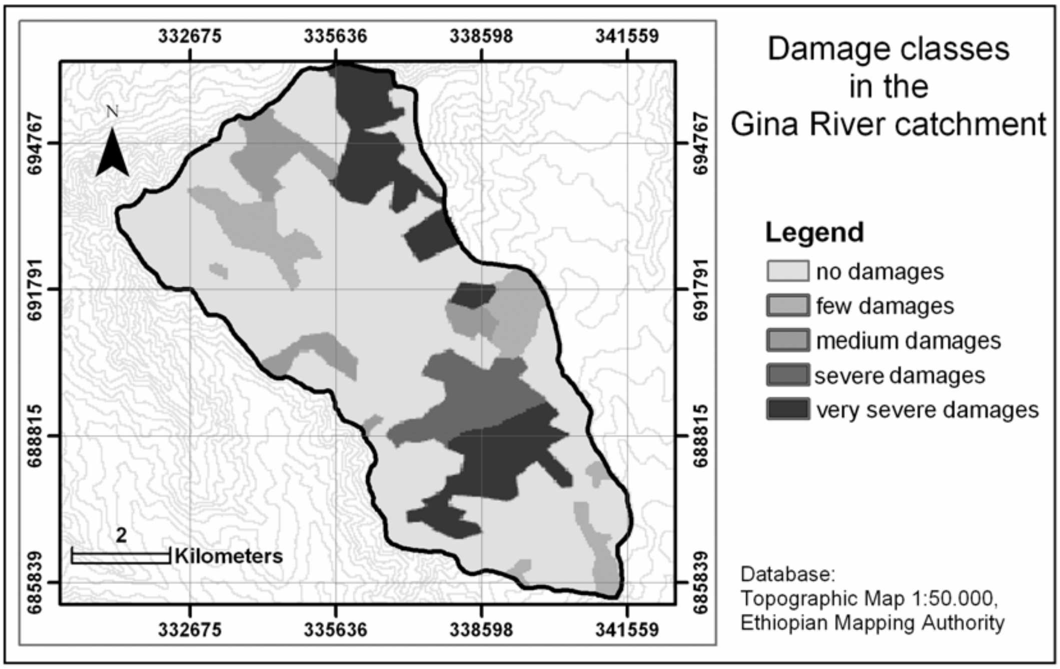

Figure 38: Damage classes in the Gina River catchment defined qualitatively.

As pointed out in the discussion of the soil erosion damages (chapter 6.2.1) their distribution can be explained predominantly by land use and relief. The distribution of torrential rainfall events, soil characters and soil conservation measures were not incorporated into the modelling approach for the assessment of the soil erosion risk. As data for torrential rainfall events are not available this factor is not integrated into the qualitative assessment. Since soils were recorded in order to appraise the curve

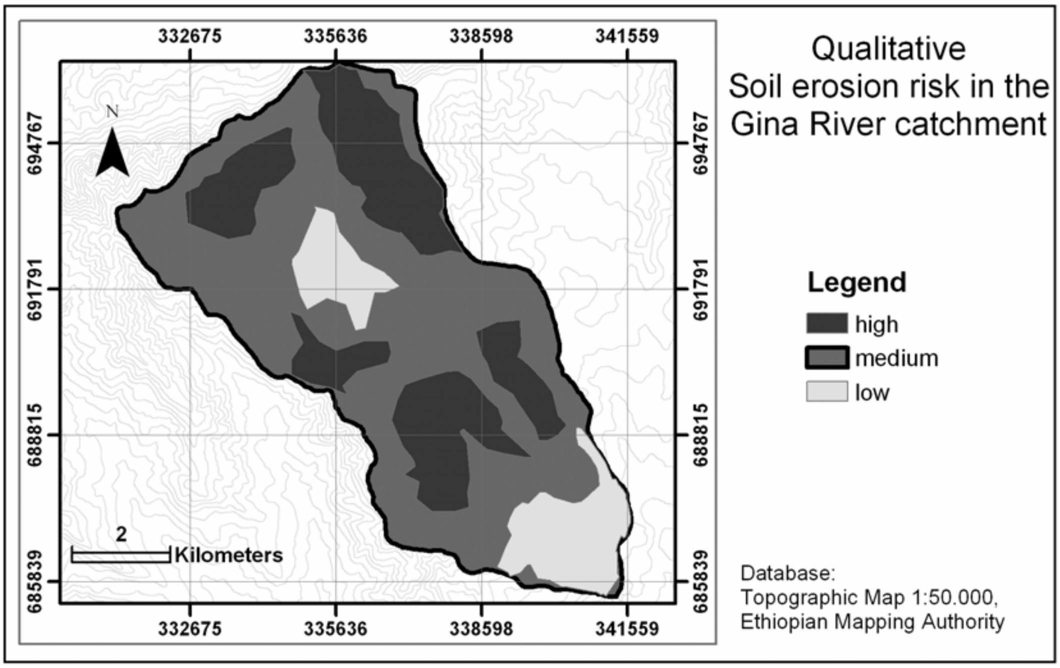

Figure 39: Present soil erosion risk in the Gina River catchment – qualitative.

numbers only, soil parameters other than required for the curve number method were not detected. Soil conservation measures occur only punctually so that this factor is not relevant for an area- wide estimation. As another aspect, the maintenance of the soil conservation measures, could not be recorded. The combination of both determining factors indicates soil erosion risk (Figure 39).

The pattern of the soil erosion damage class distribution is overlapping the areas of soil erosion risk with a similar behaviour in the Gina River catchment. The location of areas affected by severe and very severe damages are congruent with high erosion risk areas as well as areas of no and low soil erosion damages.

7.3 Comparison of qualitative and semi-quantitative modeling approaches to ettimate soil erosion risk

Two different approaches to estimate soil erosion risk in the Gina River catchment are introduced. (Figures 40 and 41). The qualitative approach compares impacts of different landscape factors by neglecting arithmetic methods, whereas in the semi-quantitative approach calculations are used to receive an overview of the soil erosion risk.

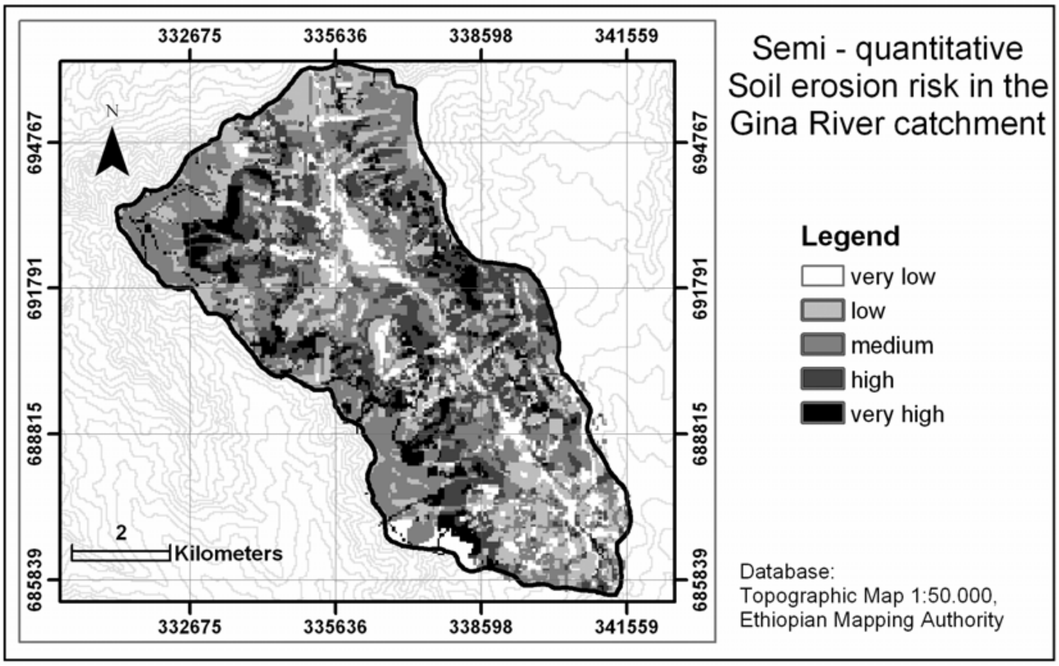

Figure 40: Semi-quantitative estimation of soil erosion risk in the Gina River catchment.

Two maps are resulting, both showing the soil erosion risk in the Gina River catchment (Figure 40 and 41). The qualitatively developed map is highly generalizing, whereas the map generated by applying the quantitave approach is characterised by a high spatial distribution. Both maps show high soil erosion risks for the north-east, parts of the north-west, the southern parts of central west as well as smaller parts in the very west of the Gina River catchment. Furthermore, areas of very low soil erosion risk occur in both approaches in corresponding areas. These correlations are very close in the weakly sloped areas around Mesho in the central regions and the south-east.

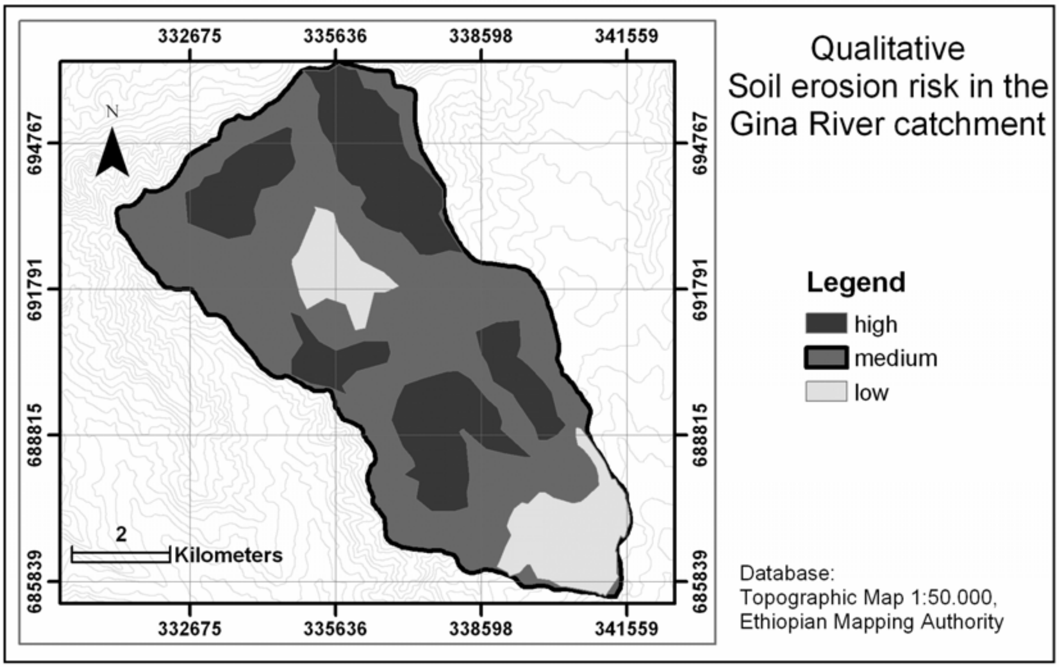

Figure 41: Qualitative estimation of soil erosion risk in the Gina River catchment.

Comparison of the two different modelling approaches shows the soil erosion risk assessment in both resulting map shows a similar pattern. The advantage of the quantitative approach is that it is possible to link a multiply factors with each other and analyse them more detailed.

7.4 Scenarios

Based on the assumption that in the Gina River catchment like in most areas of Ethiopia a doubling of population has to be expected until 2020, two different scenarios were developed to sketch the possible impact of such a demographic development on the environment. Scenarios include assumptions on changes in land use and soil conservation measures as well as on pattern and density of settlements, tracks and roads. Possible climate changes are not considered. Soil erosion risk in Gina River catchment under the conditions of a doubled population in 2020 is assessed by implementing these scenarios by applying the modelling approach introduced in equation 12**.**

7.4.1 Scenario 1

It is assumed that the increase in settlement density coinciding with a doubling in population takes place by a linear increase of tukuls. Due to the high density of the widely scattered tukuls also a dense network of tracks and roads will be developed (Figure 42).

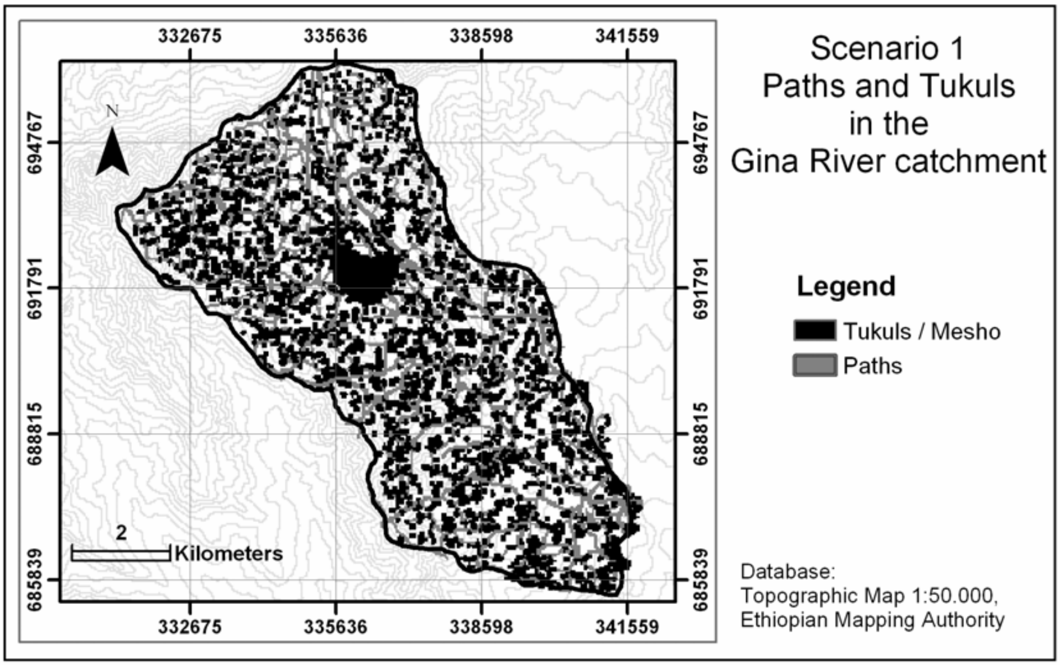

Figure 42: Scenario 1 – Distribution of paths and tukuls in the Gina River catchment in the year 2020.

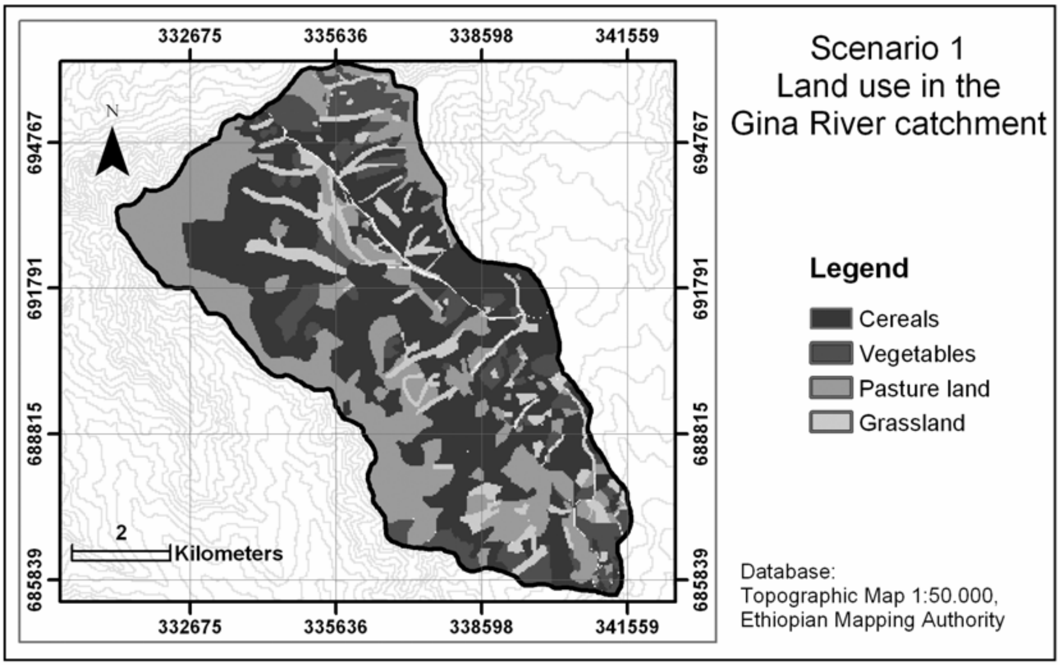

Figure 43: Scenario 1 –Land use pattern in the Gina River catchment in the year 2020.

Corresponding to the increased population an increased food supply is required. Hence, land use is intensified. As a consequence today pasture land will be used for tillage, while today still occurring woodland and forests will be cleared and used for pasture. As land will be rare afforestation measures will not be intended (Figure 43).

As distribution of settlements and corresponding infrastructure as well as changes in land use takes place without implementation of soil conservation will be lacking (Figure 44).

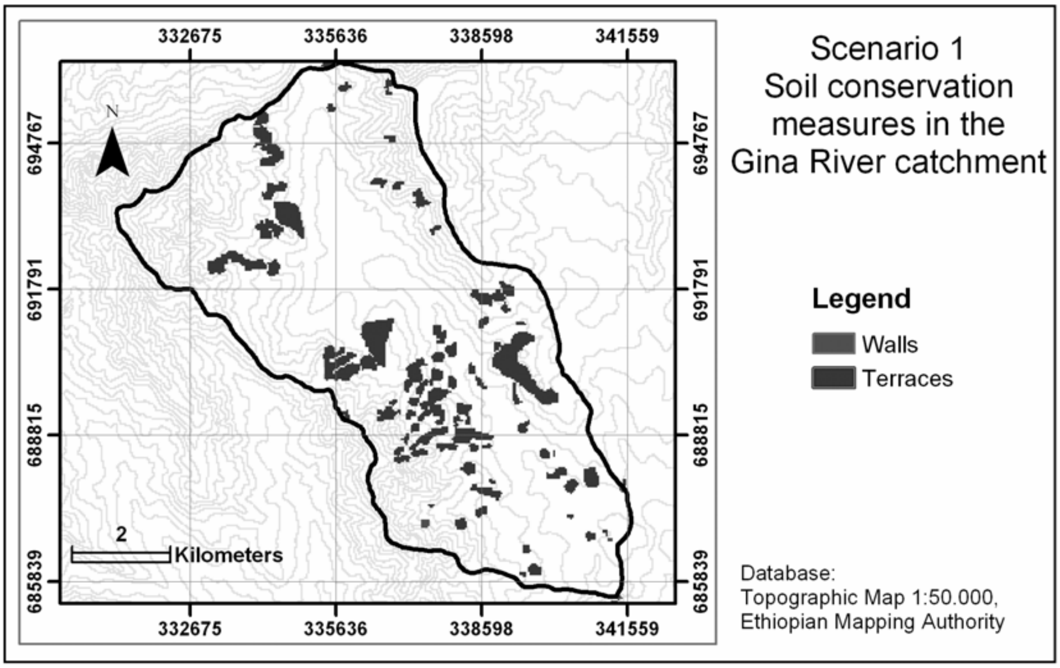

Figure 44: Scenario 1 – Soil conservation measures in the Gina River catchment in the Gina River catchment in the year 2020.

Implementing Scenario 1 into equation 12 soil erosion risk for the Gina River catchment is assessed (Figure 45). Comprising, it is shown that soil erosion risk will be distinctly increased allover the drainage basin area comparing to the present situation.

7.4.2 Scenario 2

Also the second scenario focuses a doubeling of population in the Gina River catchment until 2020. In contrast to the situation sketched in scenario 1 population will not widely be scattered in the drainage basin area but gets concentrated in central towns. Additionally to Mesho, four towns will exist while widely scattered tukuls do not occur anymore. Instead of numerous footpaths scattered all over the area bigger roads connect the towns and the agricultural used areas (Figure 46).

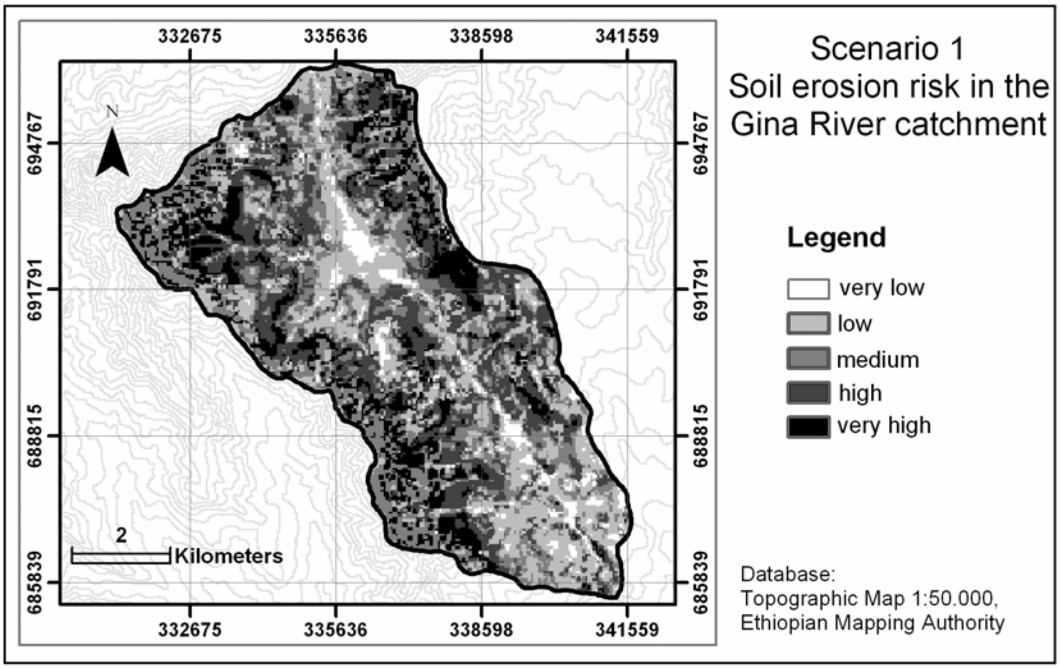

Figure 45: Scenario 1 – Semi-quantitative estimation of soil erosion risk in the Gina River catchment in the year 2020.

Regional planning tools will be implemented to guarantee a sustainable management of the limited resources soil and water. An important soil conservation measure implemented will be the reforestation of the high erosion risk areas like *Steep slopes* and *Deep valleys*. To avoid the hazard of soil erosion on the *Mountain tops* woody perennials will be combined with pasture (agroforestry).

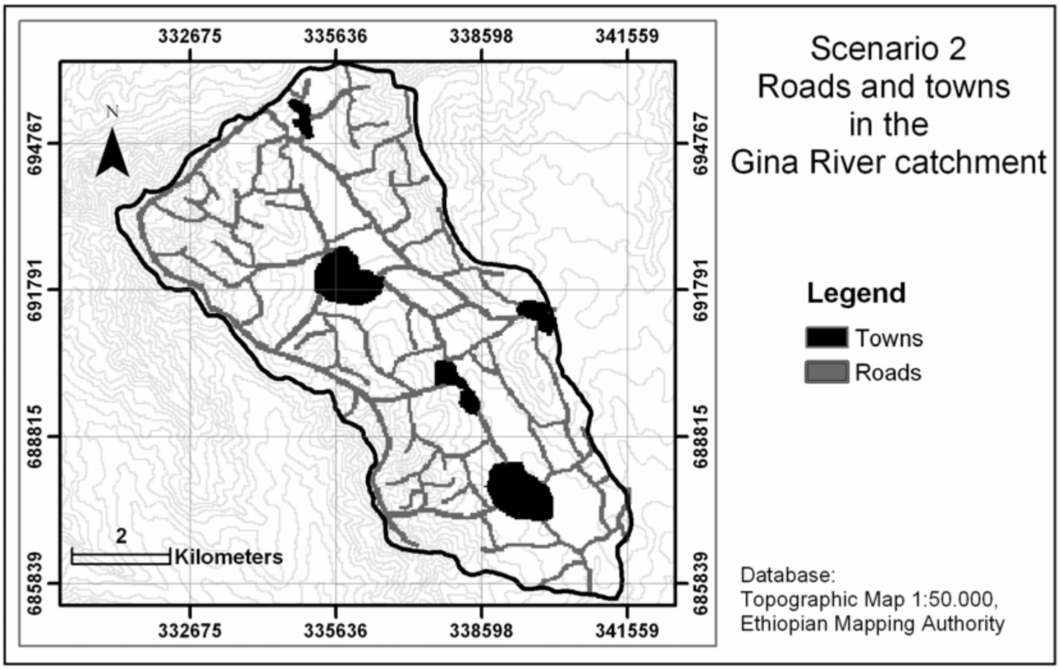

Figure 46: Scenario 2 – Roads and towns in the Gina River catchment in the year 2020.

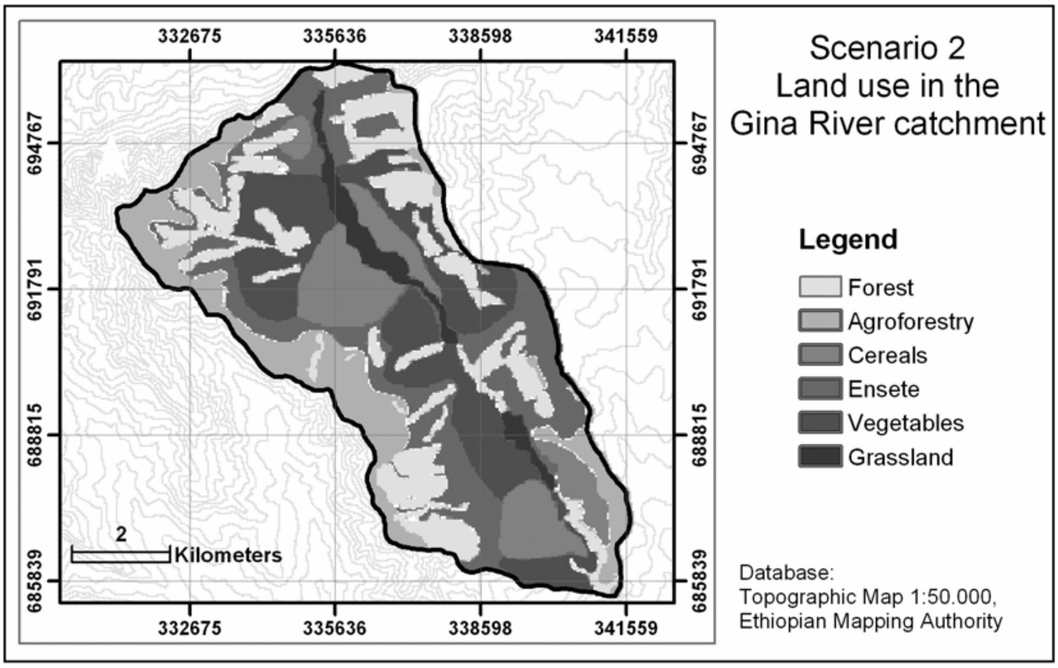

Figure 47: Scenario 2 -Land use in the Gina River catchment in the year 2020.

Solar collectors in the settlements will support the conservation of the forests. Natural grassland is protecting the Gina river from river bank erosion and will give space to flood events (Figure 47). Terraces implemented in all agriculturally used areas (Figure 48).

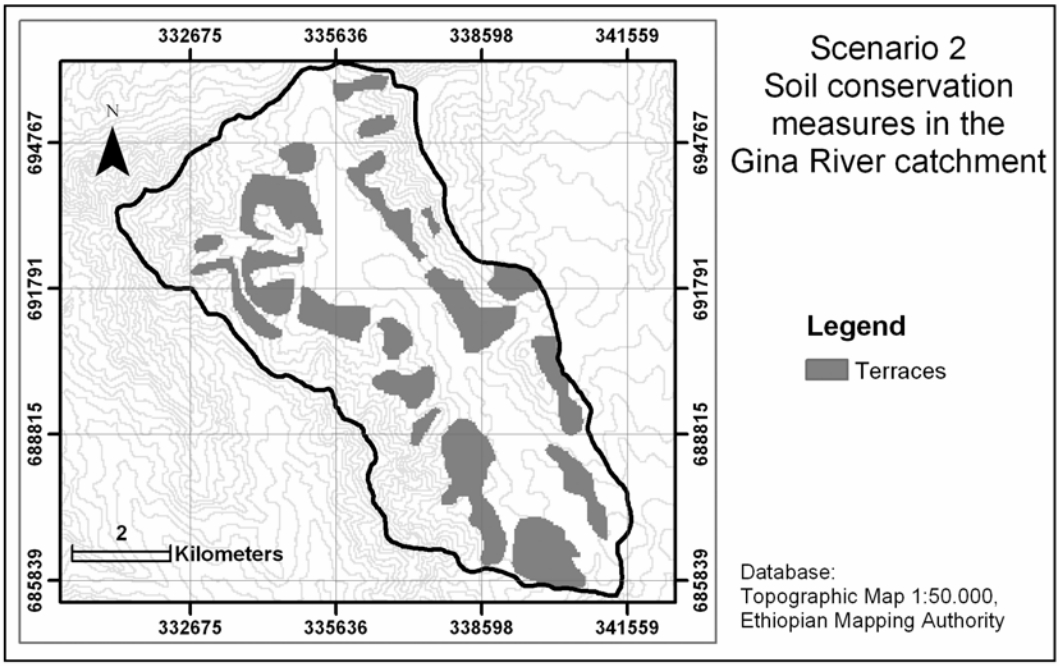

Figure 48: Scenario 2 – Soil conservation measures in the Gina River catchment in the year 2020.

The result of the scenario 2 implemented into the equation 12, shows a very low soil erosion risk for the Gina River catchment, instead of the scenario 1 and the present estimation of soil erosion risk for the Gina River catchment (Figure 52).

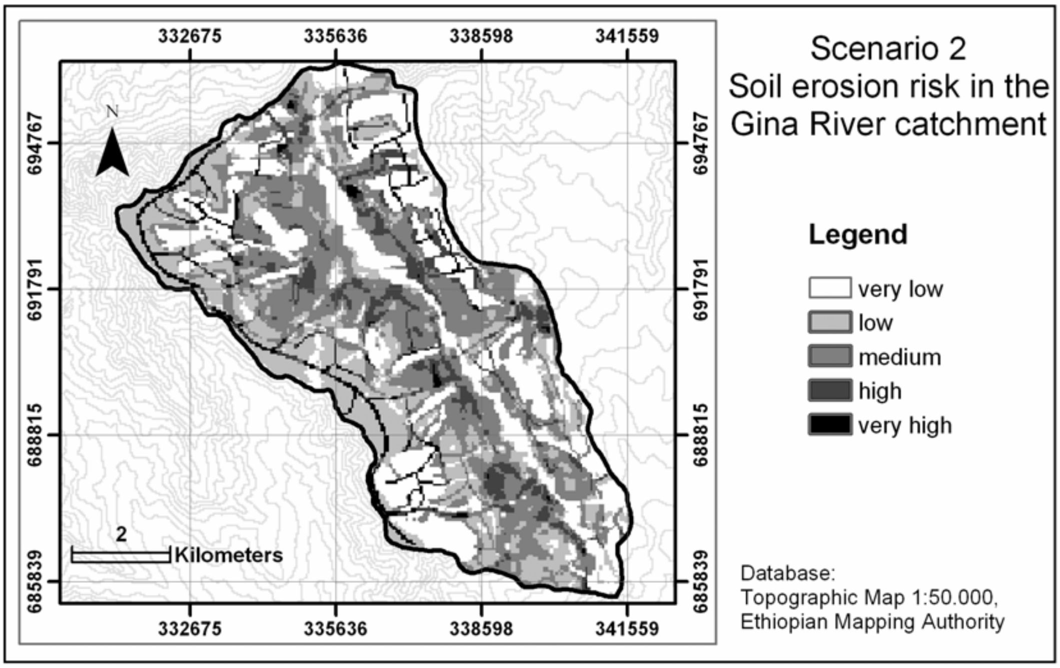

Figure 49: Scenario 2 – Semi-quantitative estimation of soil erosion risk in the Gina River catchment in the year 2020.

8 CONCLUSIONS

In the case study of the Gina River drainage basin present soil erosion damages and the processes influencing them were analysed and assessed. It is pointed out that due to the strong relief in the area inclination of slope is one of the major factors influencing erosion risk. Anyhow, due to the high population density human impact superposes the natural processes: causing positive feedback (strengthening) of soil erosion processes especially where surface runoff is increasing due to soil compaction (HORTON overland flow, saturation overland flow), causing negative feedback (diminishing) of soil erosion processes where flow velocity of surface runoff is reduced by soil conservation measures. As feasible modelling approaches to assess soil erosion risk in small tropical drainage basins are not available results of field investigation in the Gina River catchment were compiled and a modelling approach with limited regional transferability was created. A semi-quantitative and a qualitative approach were developed to predict soil erosion risk. The semi-quantitative modelling approach presented is based on numerically scaled characters of the Gina River catchment which are combined in a simple linear algorithm. In contrast, the qualitative modelling approach presented depends completely on the experience of the dealing persons. Both approaches were evaluated by comparison of the predicted soil erosion with the actual soil erosion damages. The results of the two approaches estimating soil erosion risk are more or less the same in both approaches. The intention to validate the approaches of soil erosion risk modelling by the integration of runoff-precipitation models as they are provided by civil engineering failed as it was not possible to adapt the necessities of the runoff-precipitation model (HEC-I) chosen and the limitations of the data sets available (discharge, precipitation).

In order to prevent land degradation and soil erosion under the conditions of a doubling of Ethiopian population within the next 20 years scenarios were developed and implemented into the modelling approaches which consider different options of future land use. Modelling results of these scenarios show impressively that soil erosion risk will increase disproportional when land use will develop without any control of regional planning (scenario 1), while under the influence of regional planning (scenario 2) soil erosion risk – and, thus, risk of land degradation – will be even less than under present population pressure. From these results it can be deduced that under the necessity of poverty reduction while the same time population is growing integration of regional planning into rural development strategies is essential.

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