Impact of current and alternative land use scenarios on soil erosion in Eastern Tigray: A catchment scale study

Working Paper
2003-08

M.E. Mosugu

Policies for Sustainable Land Management in the Ethiopian Highlands

IFPRI-WUR project *Policies for Sustainable Land management in the Ethiopian Highlands*

Land degradation problems--including soil nutrient depletion, soil erosion, deforestation and other concerns--are severe in the Ethiopian highlands. These problems are contributing to low and declining agricultural productivity, poverty and food insecurity. The proximate causes of these problems are relatively well known. Underlying these proximate causes are many more fundamental causes. These more fundamental causes are affected by many aspects of government policy. Assessing the impact of different causal factors and identifying effective policy strategies to improve land management is a critical research challenge that has not yet been solved. In part, this is due to the complexity of factors influencing the problem. "One-size-fits-all" policy or program approaches are unlikely to be broadly successful. There is thus a general need and desire for more effective targeting of policy strategies towards specific regions and groups, although this depends on improved information about the potential impacts of alternative strategies.

The long-term goal, immediate purpose and specific objectives of the project are as follows:

Long-Term Goal:
To contribute to improved land management in the Ethiopian highlands, in order to increase agricultural productivity, reduce poverty and ensure sustainable use of natural resources.

Immediate Purpose:
To help policy makers in Ethiopia identify and assess strategies, including technology development policies, to achieve that goal.

Specific Objectives:

- To identify the key factors influencing land management in the Ethiopian highlands and their implications for agricultural productivity, sustainability and poverty;
- To identify and assess policy, institutional and technological strategies to promote more productive, sustainable, and poverty reducing land management;
- To strengthen the capacity of collaborators in the Ethiopian highlands to develop and implement such strategies, based upon policy research; and
- To increase awareness of the underlying causes of land degradation problems in the Ethiopian highlands and promising strategies for solving the problems.

The research takes place in Tigray, Northern Ethiopia. The project started in January 2001 and will continue until December 2003.

The WUR component of the project is funded by the Dutch Ministry of Foreign Affairs, Cultural Cooperation, Education and Research Department, Research and Communication Division (WW132171), Wageningen University (RESPONSE programme) and the Netherlands Ministry of Agriculture, Nature Management and Fisheries (North-South Programme). Their support is gratefully acknowledged.

More information can be found at the project web site:
www.sls.wau.nl/oe/pimea

The Participants

The WUR component of the project is co-ordinated by the **Development Economics Group** of **Wageningen University**. Next to overall project management, the DEG is responsible for bio-economic modelling and backstopping of research activities.

For more information and ordering of working papers contact:
Dr. G. Kruseman
Tel : +31 (0) 317 484668
Fax: +31 (0) 317 484037
Gideon.Kruseman@wur.nl

The **Trade and Development Group** of the **Agricultural Economics Research Institute** (LEI) is responsible analysis of current and alternative agricultural activities, using the NUTMON methodology.

For more information:
G. Meijerink
Tel : +31 (0)70 3358243
Fax: +31 (0)70 3615624
G.W.Meijerink@wur.nl

Plant Research International (PRI) is responsible for analysis of potential activities, using TCGs, and the analysis of the dynamics of natural resources.

For more information:
Dr. H.Hengsdijk
Tel : +31 (0) 317 475913
Fax: +31 (0) 317 418094
h.hengsdijk@wur.nl

ALTERRA is responsible for the spatial aspects of sustainable land management and the scaling-up of biophysical processes, using the LISEM model.

For more information:
Dr. M.E. Mosugu
Tel : +31 (0)317 474648
Fax: +31 (0)317 419000
m.e.mosugu@wur.nl

In Ethiopia the local partner is **Mekelle University**. MU is responsible for facilitation of PhD and other research conducted within the framework of the project.

For more information:
Dereje Aberra
Derejeaa@yahoo.com

The other project partner is the **International Food Policy Research Institute**. IFPRI is primarily responsible for the marketing analysis.

For more information:
Dr. J.Pender
j.pender@CGIAR.ORG

M.E. Mosugu

Impact of current and alternative land use scenarios on soil erosion in Eastern Tigray: A catchment scale study

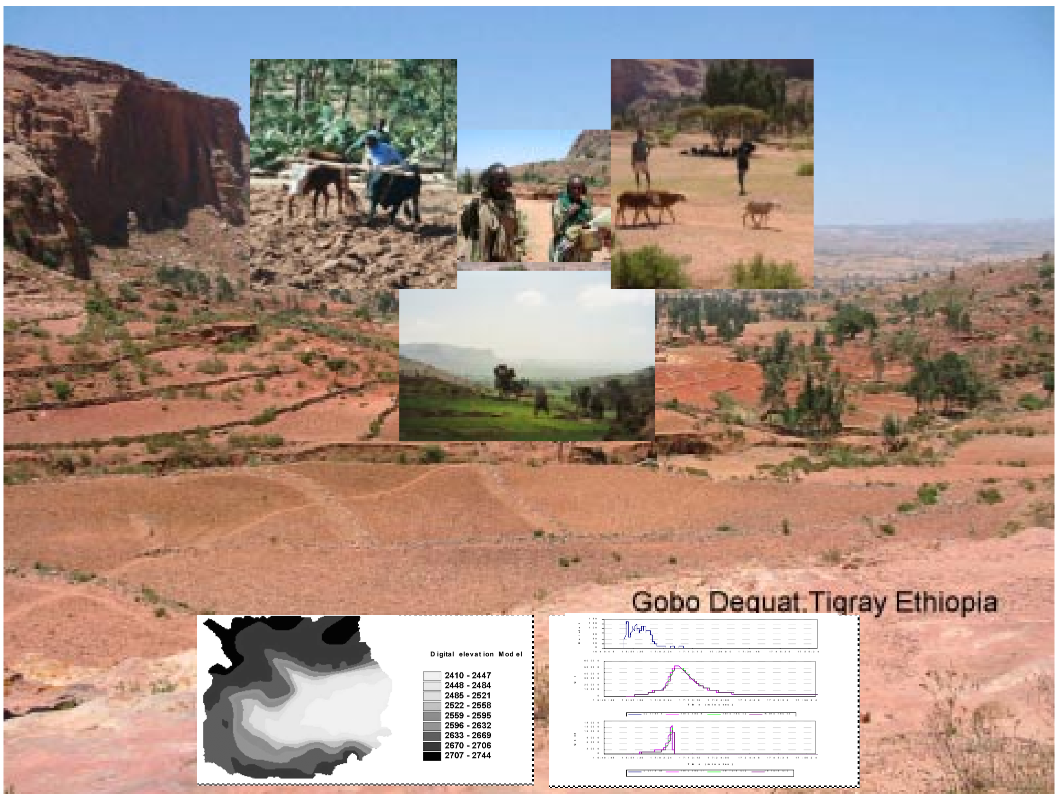
List of *Policies for Sustainable Land Management in the Ethiopian Highlands* working papers:

2002-01	Kruseman, G., J.Pender, G.Tesfay and B.Gebremedhin *Village stratification for policy analysis: multiple development domains in the Ethiopian Highlands.*
2002-02	Kinfe Abraha Weldemichael *Public and private labour investments and institutions for soil and water conservation in Tigray, Northern Ethiopia.*
2002-03	Boetekees, S. *Rural credit and soil and water conservation: a case study in Tigray, Northern Ethiopia.*
2002-04	Kruseman, G., R.Ruben, G. Tesfay *Diversity and Development Domains in the Ethiopian Highlands*
2002-05	Meijerink, G.W. *Alternative cropping practices in Ethiopia: A literature review*
2002-06	Meijerink, G.W. *Rural livelihoods and soil conservation in Eastern Tigray. A Rapid Diagnostic Appraisal Report for Gobo Deguat and Teghane*
2003-07	Mulder, H. *A qualitative and quantitative assessment of soil nutrient management in Tigray*
2003-08	Mosugu, M.E. *Impact of current and alternative land use scenarios on soil erosion in Eastern Tigray: A catchment scale study*

PIMEA WORKING PAPER 2003-08

Impact of current and alternative land use scenarios on soil erosion in Eastern Tigray: A catchment scale study

M.E. Mosugu



Wageningen, July 2003

List of figures

List of tables

1 Introduction

Land degradation problems are severe in the Ethiopian highlands. An assessment of the magnitude and direction of their impacts remain an unsolved research challenge, which may be attributed in part to spatial and temporal variability in the causal factors. To meet this challenge, more appropriate policy strategies and more effective targeting of these strategies towards specific regions and groups based on improved information and tools are required. The PIMEA project targets the generation of such information and tools, with the aim to help policy makers in Ethiopia to (i) identify and assess strategies, including technology development policies, that contribute to improved land management in the Ethiopian highlands and to (ii) alleviate the impacts of land degradation such as decreasing agricultural produtivity, resource depletion and poverty.

Soil erosion has been identified as one of the major causes of land degradation in Ethiopian highlands. Although earlier estimates are now considered to overstate the rate of soil erosion in the region, it is generally accepted that soil erosion in the area is critical (Bojo and Cassel, 1995 refd. By: Chisholm N. 1998. Community based natural resource management in Tigray, Northern Ethiopia. The World Bank/WBI's CBNRM Initiative, case report. At http://srdis.ciesin.org/cases/ethiopia-005.html). It is identified as one of the major forms of land degradation in eastern Tigray, where it is described as severe and attributable to a combination of unsustainable land management practices: continued cultivation of poor soils, lack of or low application of agricultural input and unfavourable environmental conditions: low and erratic rainfall, steep slopes and inherently poor soils.

Soil erosion in the Ethiopia highlands has resulted in the complete loss of surface soil and, in some parts, the subsoil, from sloping lands, leaving stones and bare rocks. This makes cultivation of old farmlands impossible in many parts of the region, forcing farmers to constantly cultivate new and more marginal areas. Such unsustainable use of the land result in further intensification of the problems of deforestation, over-cultivation and nutrient mining (Stoorvogel and Smaling 1990, Esser et al., 2002). This current trend of land use in turn results in further erosion and therefore highlight the need for alternative land use practices that are able to meet the needs of the population for subsistence while reducing degrading impacts of land use such as soil erosion on the land.

Many studies have highlighted the economics and adoption of land management practices by farmers in Tigray. However, less is known about the quantitative assessment of the impacts of these practices on land degradation. More quantitative information of the biophysical impact of current land use and impact of the proposed alternatives on soil is required. These are considered as necessary inputs for identifying more sustainable land use alternatives for the region. This study therefore aims to provide a quantitative assessment of the impact of current land use and three scenarios of reforestation in a case study catchment in eastern Tigray. The study is based on the use of a hydrological and soil erosion model, LISEM (De Roo et al., 1996a, 1996b).

2 Study area

2.1 Location and *physiography*

The study was carried out in a selected catchment in eastern Tigray, Northern Ethiopia. Eastern Tigray has a land area of ~8,800 sq km. and a population of ~600,000 (Chisholm, N., 1998). The region is characterised by mountainous and hilly topography with steep slopes. Degree of vegetation cover in the region is low, implying low supply of organic litter to the soil. Like in parts of central Tigray, where soils are shallow in most areas, with low fertility, high run-off, and low infiltration capacity (Mitiku, 1996), the soils of Eastern Tigray are also low in organic matter content and fragile. The region is characterised by extremely dry conditions, with characteristic low annual rainfall, which can be erratic and torrential. Severe poverty, largely attributable to the harsh environmental conditions is also experienced in parts of the region. The combination of these factors contribute significantly to the severe problem of soil erosion observed in region.

A study catchment was selected to reflect the bio-physical and socio-economic characteristics of eastern Tigray (figure 1a) in Northern Ethiopia (figure 1b). The catchment, with a total land area of ~369 ha, is located in the Kushet Gobo Deguat (13°40' N, 39°25'E) in the Tabia Debre Bizen of Wereda Hawzen (figure 1c). Gobo Deguat is located in a valley in between two plateaus, with a cave connecting two watersheds at each side of the plateau. The catchment consists of a hillland-plateau-valley landscape, with elevation ranging between 2400 m 2750 m asl (figure 2) and general slope ranging from 0 to >60%.

Figure 1 Regional location of study area

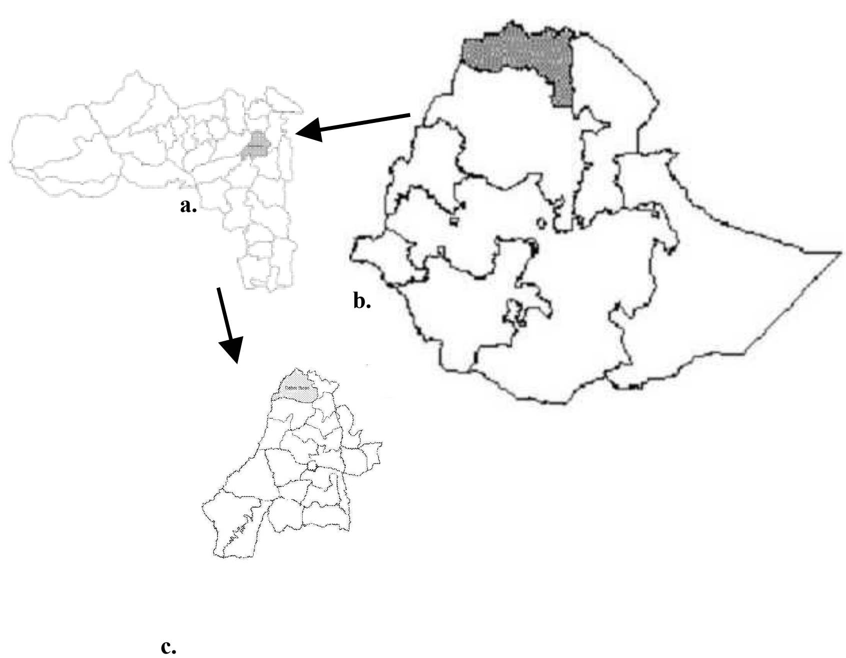
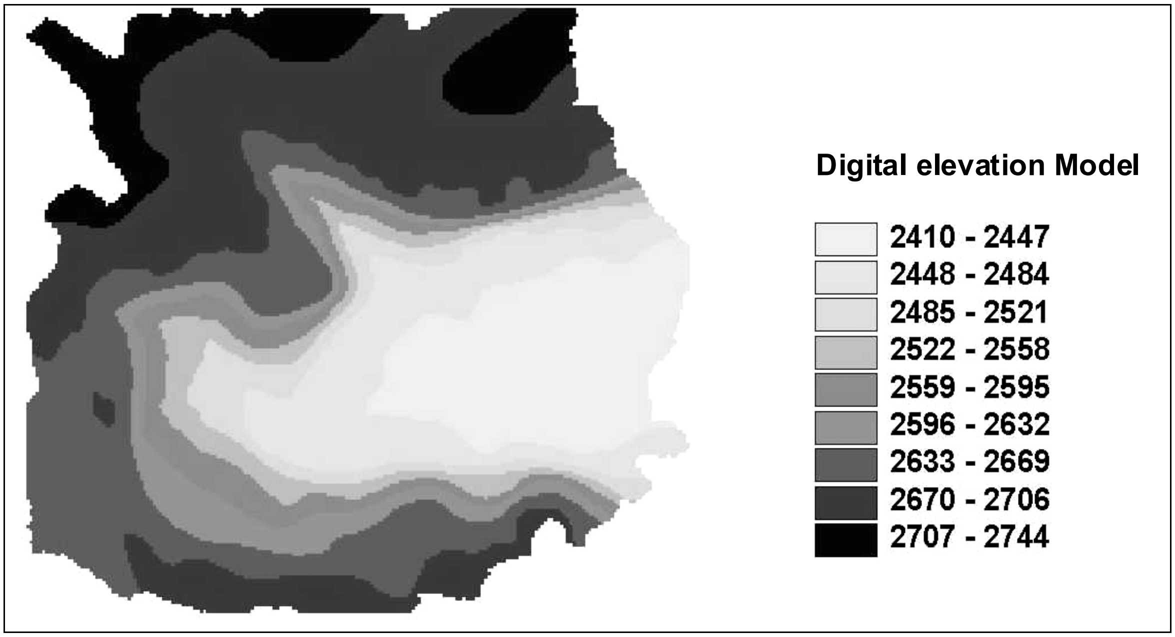


Figure 2 Digital elevation model of study study catchment in Gobo Deguat



2.2 Soil

The main soil types found in the catchment are Leptosols and Cambisols (figure 3). These constitute ~54% and 21% of the soil coverage respectively, while ~11% and 14% of the catchment is covered by vertic soils and rock outcrop respectively. The soils are predominantly sandy and stony, reflecting the predominating lithology of the area, which is sandstone, and are low in soil organic matter content. Surface soil layers are either absent or thin in some parts, reflecting the influence of slope and erosibility of the soils. Percent distribution of each soil type and their location with respect to general slope in the catchment is shown in table 1. Physical and chemical characteristics of the soils are summarised in table 2.

Figure 3 Soil map of the study area

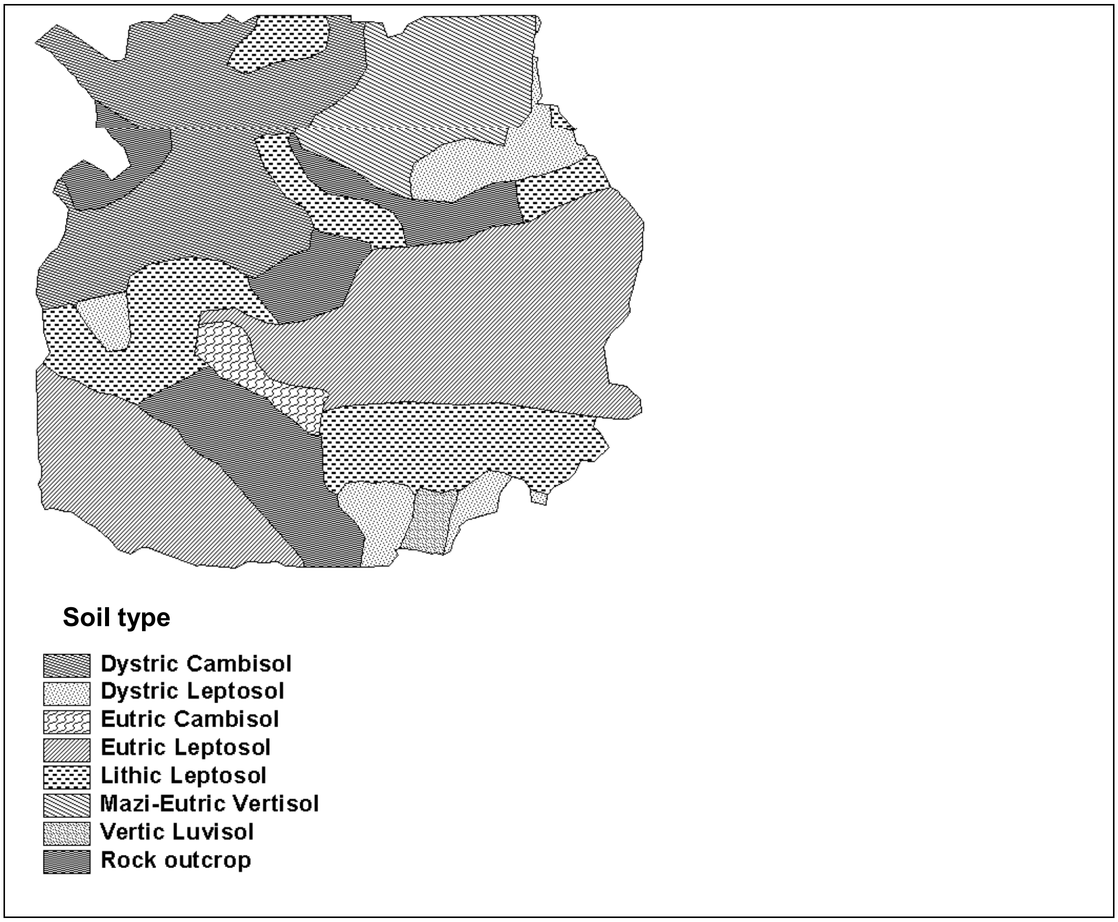


Table 1 Percentage distribution of soil types in the study area

Soil type	Distribution %	General slope
Dystric Cambisol	18.95	0-2
Dystric Leptosol	6.52	0-2
Eutric Cambisol	1.81	0-3
Eutric Leptosol	29.74	0-50
Lithic Leptosol	17.76	0-60
Mazi-Eutric Vertisol	10.76	0-2
Vertic Luvisol	0.86	0-2
rock outcrop	*13.60*	*>60*

Table 2 Physical and chemical properties of the soils of the study area

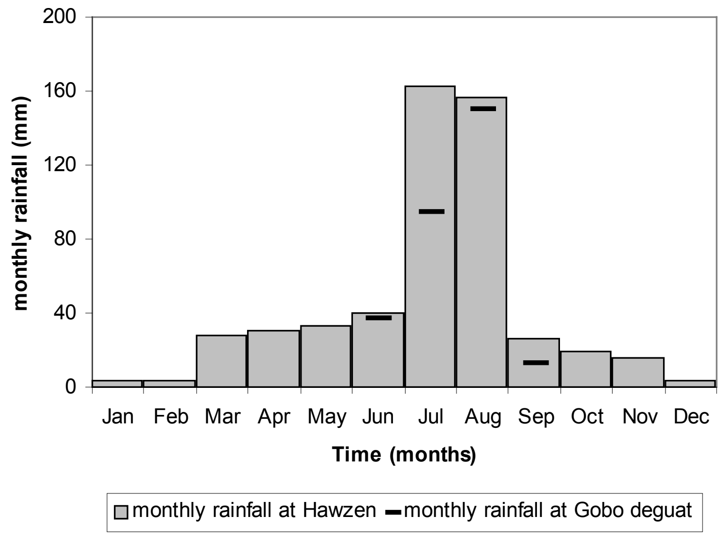
Soil properties	Soil units						
	Dystric Cambisol *(*Humer)*	Dystric Leptosol *(Rekik Keyahtah Hutsa)*	Eutric Cambisol *(Makelay Hutsa)*	Eutric Leptosol *(Keyahtah Hutsa + Rekik Bakhel + Bitami Regid Hutsa)*	Lithic Leptosol *(Bitami Rekik Keyahtah + Bitami Rekik Humer + Rekik Humer)*	Mazi-Eutric Vertisol *(Walka)*	Vertic Luvisol *(Rgid Keyahtah Hutsa)*
Physical properties and hydraulic properties							
Sand (%)	68.4	-[a]	92.4	75.4 – 80.4	68.4	54.4	55.4
Silt (%)	26.7	-	3.7	11.7 – 15.7	26.7	16.7	27.7
Clay (%)	4.9	-	3.9	4.90 – 8.90	4.9	28.9	16.9
Thetas[b] ($cm^3 cm^3$)	0.69	-	0.41	0.42 – 0.62	0.69	0.80	0.81
Ksat (cm per day)	74.79	-	69.65	23.20 – 74.15	74.79	71.98	16.35
Textural class[c]	SL	SL	S	LS, SL	SL, SCL	SCL	SL
Chemical properties							
Organic matter (%)	1.8	-	0.43	0.31 – 1.46	1.80	2.05	0.40
N (g per kg soil)	0.75	-	0.63	0.64 – 0.70	0.75	0.78	1.03
Exch. K (meq. per 100g soil)	0.27	-	0.07	0.09 – 0.18	0.27	0.13	0.11
PH (in H_2O)	7.07	-	7.0	6.99 – 7.67	7.07	7.18	6.50

[a] -, no data
[b] Thetas, saturation moisture content
[c] SL, sandy loam; S, sand; LS, loamy sand; SCL, sandy clay loam
* Local soil names in italics

2.3 Rainfall

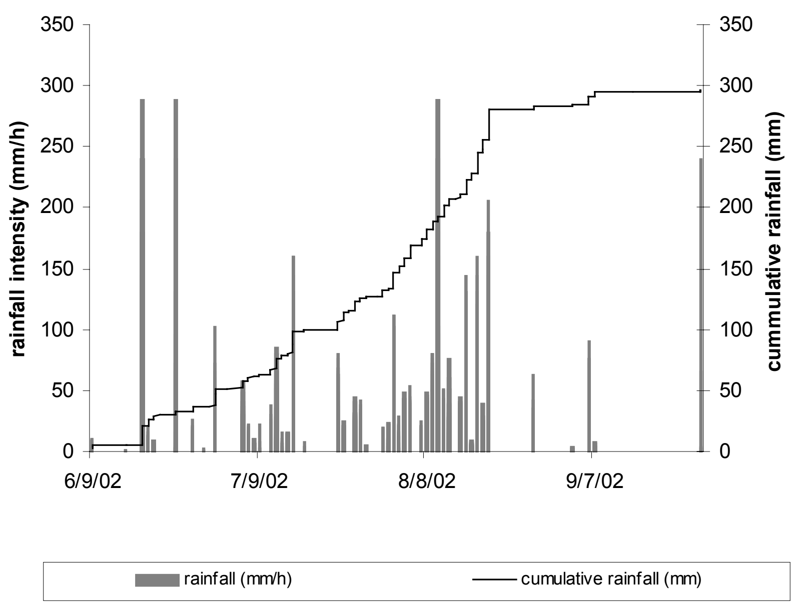
Rainfall in Tigray is concentrated into two seasons: the *Belg* (March to May) and the *Meher* (July to September). Average annual rainfall data at levels below the Wereda level in the region is scarce. Annual data for a period of 17 years is available for the Hawzen meteorological station, located ~20 km from the study area. This data, rainfalkl data measured in Gobo Deguat in 2002, are used as basis for describing the rainfall pattern in Gobo Deguat. The data for Hawzen shows rainfall is characterised by large annual variability, with annual values rainging 342 mm and 707 mm, with a mean of ~517mm in the wereda. The data also shows that most of the rainfall is received in the months of the *Meher*, mainly in July and August. Similarly measured rainfall data in the *Meher* of 2002 in Gobo Deguat shows July and August to be the wettest months of the season. However, total monthly rainfall during this season in Gobo Deguat was lower than the long term average values for the same season in Hawzen (figure 4). The long term (17 years) average rainfall during the *Meher* in the Hawzen is 386 mm, while a total of ~296 mm of rainfall was received during this season in Gobo Deguat in 2002. Intensities of the *Meher* (2002) rains in Gobo Deguat ranged between 0 and 288 mm/h (figure 5). A study by Hunting (1976, cited in Nyssen et al, 2001)) in part of Tigray shows that 77% of total rain rain volume falls with an intensity of >25 mm/h. Later study Nyssen et al (2001) in a less arid part of Tigray observed 88% rain with intensity of <30 mm/h, with 3-5% of the rains falling with intensities ranging between 60 and 208 mm/h. Although soil erosion occurs in response to small rain events, most erosion will take place during large rainfall events. Two major rainfall events with relatively high maximum intensities, which occured during the *Meher* of 2002 were therefore selected for simulation.

Figure 4 Average monthly rainfall at Hawzen for a period of 17 years



Source: Hawzen meteorological station
Stripes: Monthly rainfall at Gobo Deguat during the *Meher* 2002.

Figure 5 Intensity and cumulative rainfall in Gobo Deguat (*Meher 2002)*



2.4 Land use

The current land use distribution in Gobo Deguat (figure 6) shows that agriculture is a major activity in the catchment, with cultivated land occupying ~32% of the land area (table 3). Ploughing is considered an important factor by the farmers in Gobo Deguat. It is regarded by some as a means of increasing soil fertility (Meijerink, 2002b). As in many parts of Tigray, cultivation in Gobo Deguat is largely based on traditional practices, which is characterised by the use of ox-drawn ploughs, the *maresha*. It involves the use of wooden ploughs with wedge-shaped metal ploughs and the use of animal (oxen) traction (Goe, 1999 cited in Nyssen et al., 2000a; Meijerink, 2002b). These ploughs are suited to the different bio-physical conditions, such as different stone cover and slope conditions, and therefore allows the cultivation of unsuitable lands.

Figure 6 Curret land use distribution in the study area

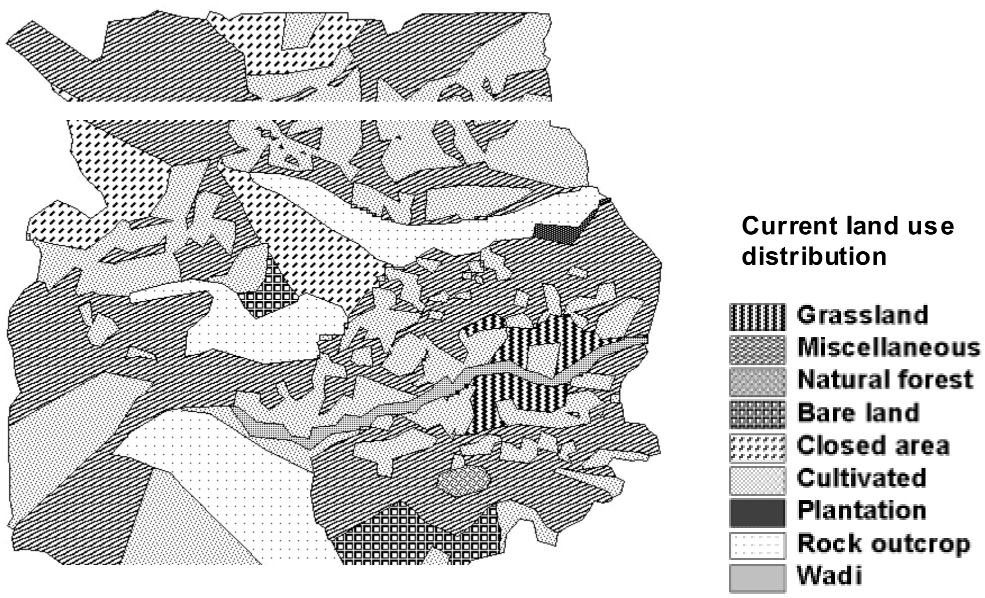


Table 3 Summary description and percentage distribution of current land use in Gobo Deguat *(based on field observations, 2002)*

Land use type	Description	Distibution (%)
grassland	Pasture land designated mainly for grazing; part of the land unit sometimes designated as closed area during the growing season.	2.3
miscellaneous	No specific defined use	39.6
natural forest	Land under natural tree vegetation	0.4
bare land	bare land	3.6
closed area	Land protected against cattle to allow natural regeneration of the vegetation	7.8
cultivated	Cultivated land of varying fertility, sown mainly to wheat and / or barley and to beans in relatively small part. Irrigation and construction of terraces is done in some of the fields during the growing season	31.7
plantation	Planted forest. Main tree species being Eucalyptus	0.3
wadi	Main drainage (gully channel) in the catchmnt	1.6
**rock outcrop*	*Bare rock*	*12.9*

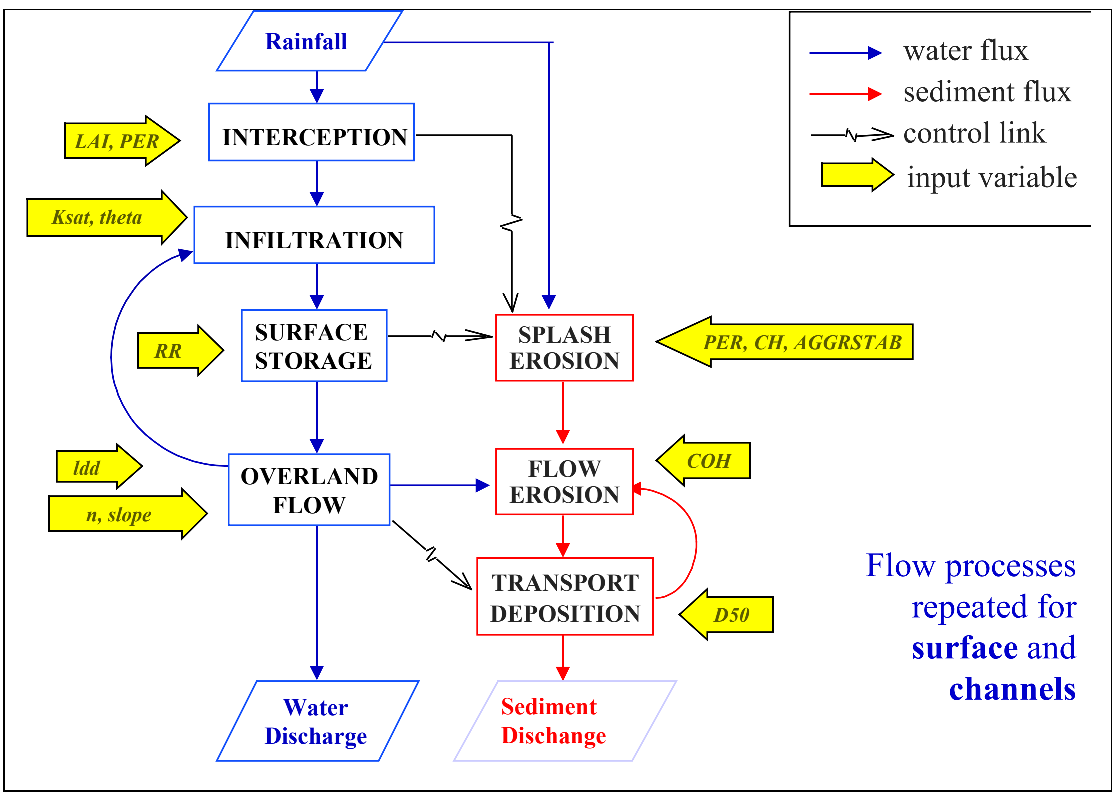
Plouhing is carried out mainly in May and August in the catchment, before the start of the *Meher* and more than half way through the season. This implies that the soils are loose and more susceptible to erosion at the onset of the rainy season and also before the end of the season. Given the observed links between cultivation and soil erosion (Nyssen et al., 2000a), the observed soil erosion in Gobo Deguat may be partly attributed to the continued use of the traditional method of land preparation based on the use of the traditional ploughs. Soil loss under the current land use and proposed scenarios of alternative land use based on reforestation in the catchment are assessed below, using the LISEM model.

3 Limburg Soil Erosion Model

The Limburg Soil Erosion Model, LISEM is a physically based hydrological and soil erosion model. The model incorporates a number of processes, many of which are highly influenced by land management. Processes incorporated in the model include rainfall, interception, surface storage in micro depressions, infiltration, vertical movement of water in the soil, overland flow, channel flow, detachment by rainfall and through fall, detachment by overland flow and transport capacity. The model is therefore able to simulate the effects of land use and soil conservation measures on hydrology and erosion and can thus be used for land use planning and conservation purposes.

The model is integrated in a Geographical Information System (GIS), which allows a more representative incorporation of spatial variability in topography in simulating the fluxes of soil and water in a catchment. It also facilitates faster and more detailed simulation of large catchments. This incorporation also provides a good opportunity for visualising the static hydrological properties of a catchment (e.g. drainage area, drainage direction) and dynamic hydrological properties (e.g. runoff, soil erosion / deposition corresponding to a storm event). The general structure of LISEM is shown in (figure 7).

Figure 7 Simplified flow chart of the LISEM soil erosion model *(De Roo et al., 1996a, 1996b)*



3.1 LISEM Input data

Being a distributed model, LISEM requires spatial input data in form of maps. A few parameters are also required as single constants for the model. There is a range of simulation options, which allows the user to specify processes to be simulated; for example there are 5 infiltration options in LISEM, each requiring specified infiltration-related maps. The input data requirement therefore varies, depending on user defined simulation options. The 2-layer Green and Ampt infiltration option is used in this study. A minimum of 24 input maps are required for LISEM. Most of these maps can be derived from 4 base maps:

- digital elevation model (DEM),
- land use
- soil type and
- impermeable areas such as tarred roads, if applicable.

Spatial input maps required for LISEM can be grouped into six categories for the modelling of hydrology and erosion (table 4). These include maps describing the physiography, vegetation, soil surface, infiltration, erosion / deposition and channels in the catchment.

Table 4 Summary of LISEM input maps defining the biophysical characteristics of a catchment

Input maps	Contents	Unit	Range
Catchment	local drain direction *(ldd)*		1 - 9
	catchment boundaries *(area)*		1
	area covered by raingauges *(id)*		1-n (= # of raingauges)
	slope gradient (sine of slope) *(grad)*	-	must be > 0
	location of catchment outlet and suboutlets *(outlet)*		0-3
Vegetation	leaf Leaf Area Index *(lai)*	-	0 - 12
	fraction of soil covered by vegetation *(per)*	-	0 - 1
	vegetation height *(ch)*	meters	0 - 30
Soil surface	manning's n *(n)*	-	0.001 - 10
	random Roughness *(rr)*	cm	0.05 – 20
	fraction covered with stones *(stonefrc)*	-	0 – 1
	fraction covered with a crust *(crustfrc)*	-	0 – 1
	width of impermeable roads *(roadwidt)*	meters	0 - cellsize
Infiltration (Green and Ampt 1&2)	saturated hydraulic conductivity *(ksat1 & 2)*	mm/hr	0 – 1000
	saturated volumetric soil moisture content *(thetas1 & 2)*	-	0 – 1
	initial volumetric soil moisture content *(thetai1 & 2)*	-	0 – 1
	soil water tension at the wetting front *(psi1 & 2)*	cm	0 – 1000
	soil depth *(soildep 1 & 2)*	mm	0 - 1000
Erosion deposition related	aggregate stability *(aggrstab)*	-	0.00001 – 200; -1
	cohesion of bare soil *(coh)*	kPa	COH+COHADD >= 0.196
	additional cohesion by roots *(addcoh)*	kPa	COH+COHADD >= 0.196
	d50 value of the soil *(d50)*	µm	Recommended: 25 - 300
Channels	local drainage direction of channel network *(lddchan)*		1-9
	gradient *(changrad)*	-	0.0001 – 10 6
	manning's n for channel *(chanman)*	-	– 0.6
	cohesion of the channel bed *(chancoh)*	kPa	>0.196
	width of channel *(chanwidt)*	meter	0 - cell width
	channel cross section shape *(chanside)*	-	0 – 10

1 and 2 refer to upper and lower layers of the soil profile (0-15cm and >15 layers respectively)

3.2 LISEM output data

The output data generated by LISEM includes total values of water balance variables as well as erosion, deposition and soil loss. The model produces erosion and deposition maps expressed as tonnes/ha and time series output maps at regular time intervals or at user specified time steps. Depending on the simulation options selected time series output maps that can be produced by LISEM are listed in table 5.

Table 5 Time series output maps from LISEM

Time series output map	Unit
Runoff as discharge	l/s
Runoff as unit discharge	l/s/m
Water height at the surface	mm
Runoff height	mm
Concentration of suspended sediment	g/l
Erosion	ton/ha
Deposition	ton/ha
Nutrients in suspension	kg
Nutrients in solution	kg

4 Scenario description

Four scenarios of land use in Gobo Deguat were simulated (figure 8). These include the current land use scenario and three proposed scenarios of reforestation in the catchment as described in the following sections.

4.1 Current land use scenario

The current land use scenario (figure 8a) is based on the land use distribution in the catchment during the *Meher* of 2002. Main land use types in the catchment are identified as grassland, miscellaneous, natural forest, bare land, closed area, cultivated and forest plantation. Cultivation is one of the main land use types under the current land use (see section 2.4). A description of the land use types and their percent areal distribution in the catchment is shown in table 3.

4.2 Alternative land use scenario

Tree planting is regarded as one of the alternative technologies for sustainable land management in Ethiopia (Meijerink, 2002a). Tree covers are known to offer ecological benefits, including protection of land from erosion (Elevitch, C and Wilkinson, K. The overstory no.7). In addition, tree covers provide many goods and services. Reforestation is therefore identified as a technology with a potential to rehabilitate soils and provide many goods and services in resource constrained areas such as Eastern Tigray, where there is a serious need for soil protection, bio-mass shortage reduction and increase in off-farm income.

Some cultivated lands under current land use in Gobo Deguat are located on sloping parts of the catchment. Accelerated soil erosion, which results from the cultivation of sloping lands can be controlled through the conversion of such lands to more suitable uses. Increased reforestation, characterised by the conversion of cultivated land and land classified as miscellanous on varying slopes to tree plantation forest is therefore considered as a promising alternative in Gobo Deguat for reducing soil loss in the catchment to a significantly lower level than that under the current land use scenario (figures 8b, 8c and 8d). A summary description of the alternative land use scenarios with respect to slope restrictions is given in table 6.

The defined alternative land use scenarios are characterised by increase in forest cover from 0.3% under current land use to 2.2%, 43.1% and 71.5% under reforest1, reforest2 and reforest3 respectively. Correspondingly, areal extent of cultivated and miscellaneous land units in the catchment decreased respectively from 31.7% and 39.6 under the current land use scenario to 0% under reforest3 (figure 9).

Figure 8 Current (a) and alternative land use scenarios (b: reforest1; c: reforest2 and d: reforest3) in Gobo Deguat

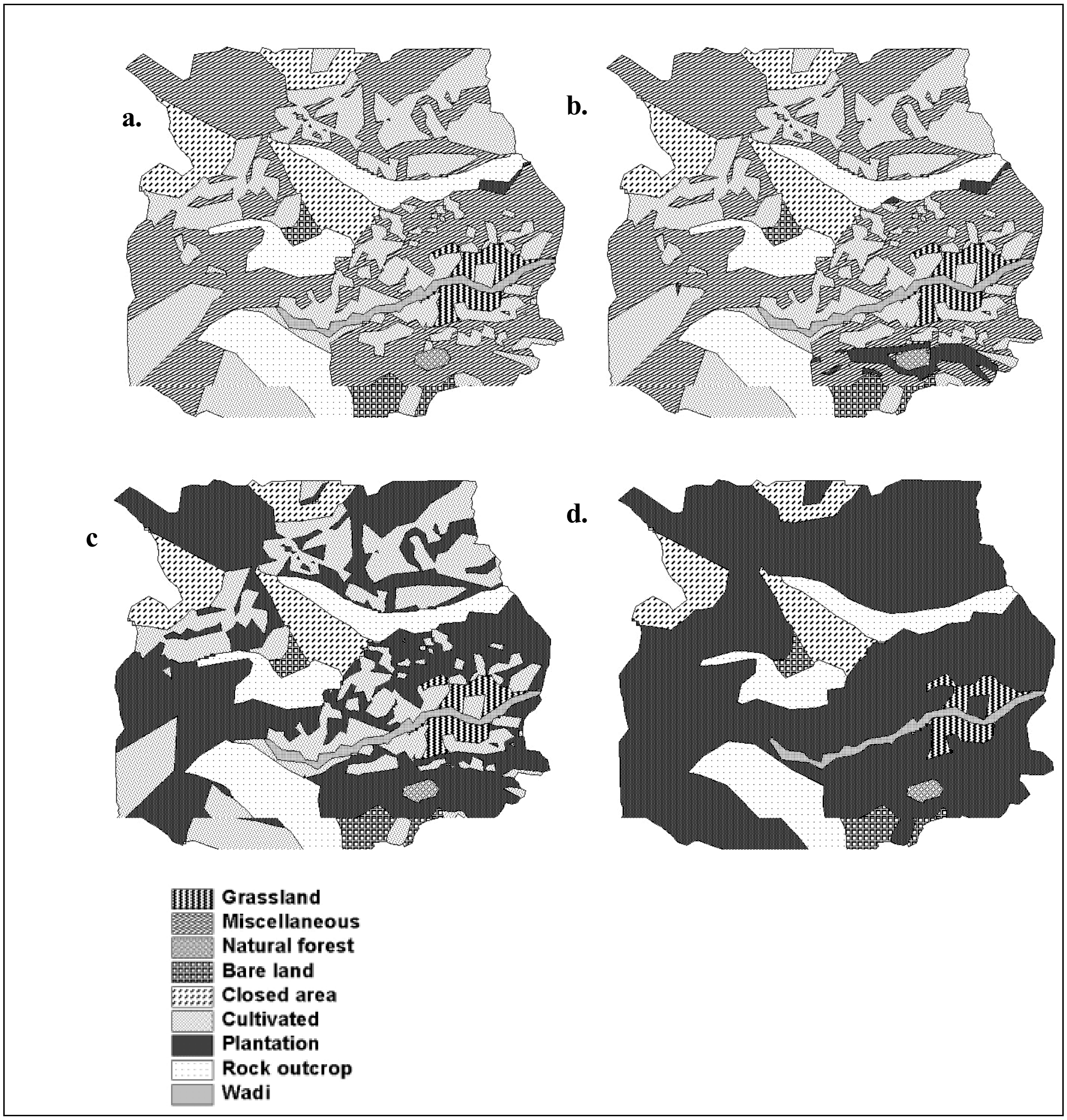
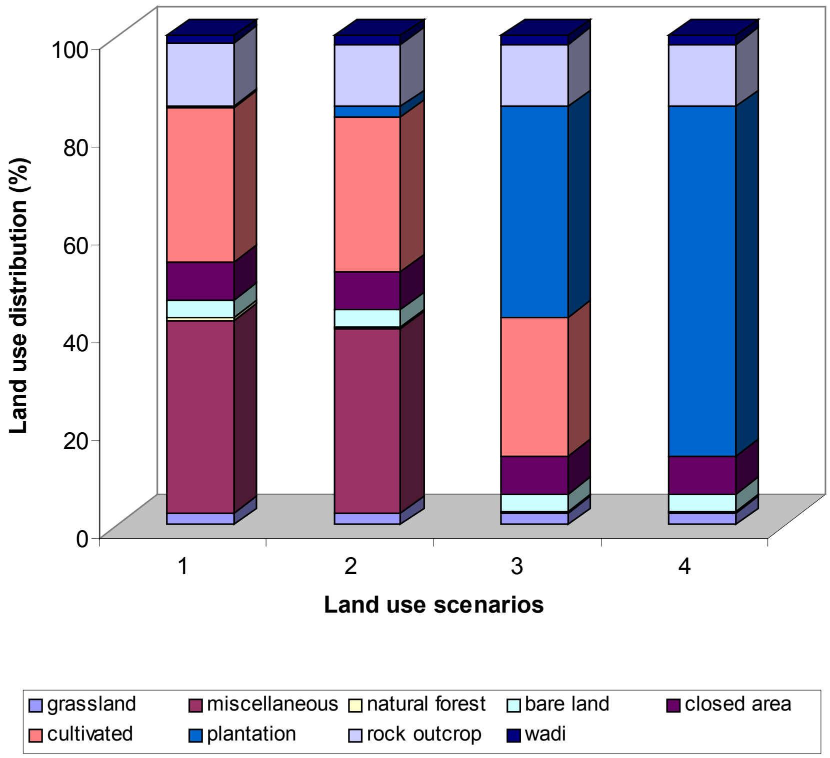


Table 6. Summary description of alternative land use scenarios with respect to slope restrictions

Land use scenario	Description
1. current land use	Land use as at rainy season of 2002 *(figure 8a)*
2. reforest1	miscellaneous and cultivated land on slopes >10 converted to forest plantation *(figure 8b)*
3. reforest2	All miscellaneous land in the catchment, plus all cultivated land on slopes > 3 converted to forest plantation *(figure 8c)*
4. reforesrt3	All land miscellaneous and cultivated land, irrespective of slope, converted to forest plantation *(figure 8d)*

Figure 9 Land use distribution under current land use: stack1 and alternative land use (reforest1: stack2) reforest2: stack3 and reforest3: stack4 scenarios in Gobo Deguat



5 Simulation of soil erosion in the catchment

5.1 Spatial input maps and parameters defining catchment characteristics, vegetation, soil surface and infiltration

The relative effects of the defined land use scenarios on soil erosion were examined using the same parameter values for a given land use unit in all scenarios. The main difference between the scenarios is therefore the areal extent of the land use units.

An intensive measurement campaign to collect input data for the model was carried out from June to September 2002 in Gobo Deguat. Data describing soil and plant characteristics were measured in 10 selected fields. The fields were selected based on the main land use types identified in the field. The catchment was also instrumented for measuring rainfall intensity data and for the continous measurement of water level during this season. In addition, manual measurements of rainfall and sediment concentration in runoff were carried out. However, the continous measurement of water level was unsuccessful. It was also not possible to measure some of the required soil hydraulic parameters for these fields during the field campaign. The parameter sets and related spatial input maps that were used in the simulations are therefore based on a combination of data measured as part of this project (measurements during the rainy season of 2002 and during the MU soil and topographic survey activities in 2002) as well as data from secondary sources (published sources e.g. Rawls et al., 1983; Chow et al., 1988; Mehari, Y., 1996; Scurlock et al., 2001; the Hydraulic propoerties Calculator (http://www.bsyse.wsu.edu/saxton/soilwater/).

5.2 Spatial input maps defining physiographic characteristics of the catchment

The input maps and parameters defining the physiographic characteristics of Gobo Deguat catchment (table 4) were derived from a DEM of the catchment (figure 2), which was derived from a topographic map of the catchment provided by the GIS department of MU.

5.3 Input maps and parameters defining other biophysical characteristcs of the catchment

Parameters defining vegetation, soil surface, erosion and deposition parameters in the catchment are shown in table 7. The 2-layer Green and Ampt infiltration option is used in this study. Infiltration parameters for the catchment based on the Green and Ampt infiltration model are shown in table 8. Corresponding spatial input maps were prepared based on these parameters for the catchment.

Table 7 Input parameters defining vegetation, soil surface and some erosion and deposition characteristics in Gobo Deguat

Landuse	Model input parameters							
	ch	per	lai	rr	ag	coh	n	stonefrac
	(m)	*(m^2/m^2)*	*(m^2/m^2)*	*(cm)*	-	*(kpa)*	-	-
grassland	0.067	0.65	0.3	0.55	2.94	9.8	0.014	0.03
Miscellaneous	0.68	0.50	0.41	0.45	0.61	9.0	0.010	0.35
natural forest	7.3	0.65	0.61	0.55	3.23	9.8	0.014	0.35
bare land	0.0	0.0	0.0	0.55	0.1	9.0	0.009	0.09
closed area	7.3	0.40	0.41	0.60	3.23	9.8	0.014	0.80
cultivated	0.023	0.003	0.21	0.53	1.10	6.4	0.014	0.22
plantation	10.83	0.75	1.56	0.36	3.23	9.8	0.014	0.35
rock outcrop	*0.0*	*0.0*	*0.0*	*0.45*	*3.55*	*10.78*	*0.010*	*0.90*
wadi	0.025	0.2	0.21	0.60	2.0	9.5	0.014	0.35

ch: plant height; per: plant cover; lai: leaf area index; rr: random roughness of the soil surface; ag: aggregate stability; coh: cohesion of bare soil; n: manning's n; stonefrac: % stone fraction.

Table 8 Input parameters defining infiltration characteristics in Gobo Deguat

Soil type	Model input parameters							
	Ksat1	Ksat2	Thetas1	Thetas2	Thetai1	Thetai2	Psi1	Psi2
	(mm/h)	*(mm/h)*	*(cm^3/cm^3)*	*(cm^3/cm^3)*	*(cm^3/cm^3)*	*(cm^3/cm^3)*	*(cm)*	*(cm)*
Dystric Cambisol	10.9	1.5	0.37	0.23	0.11	0.15	11.01	21.85
Dystric Leptosol	0.15	0.1	0.37	0.23	0.11	0.15	11.01	0.0
Eutric Cambisol	29.9	1.5	0.34	0.21	0.07	0.12	11.01	21.85
Eutric Leptosol	1.5	29.9	0.36	0.21	0.09	0.13	21.85	21.85
Lithic Leptosol	10.9	1.5	0.37	0.22	0.11	0.15	11.01	21.85
Mazi-Eutric Vertisol	1.5	0.6	0.48	0.25	0.10	0.14	21.85	23.9
Vertic Luvisol	10.9	0.3	0.45	0.53	0.11	0.15	11.01	31.36
Rock outcrop	*0.1*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*

ksat: saturated hydraulic conductivity; thetas: saturated columetric soilmoisture content; thetai: initial volumetric soil moisture content; psi: soil water tension at the wetting front; 1 and 2: Ist and second soil layers with lower boundaries at 20 and 80cm depths respectively.

To allow for comparison, all scenarios are simulated using a single rainfall event. To compare losses under rainfall of different magnitudes, soil loss under all land use scenarios was also examined under a second rainfall event of a smaller magnitude but higher maximum intensity (table 9). These rainfall events were selected from a number of events that took place in July and August of the rainy season of 2002. It is assumed that the intensity of the rainstorms for which the modelling was done is uniform for the catchment.

Table 9 Amount and maximum intensity of rainfall events that were selected for simulation

	rain1507	rain1908
Total rainfall *(mm)*	32.6	21.7
Measured maximum intensity *(mm/hr)*	120	160

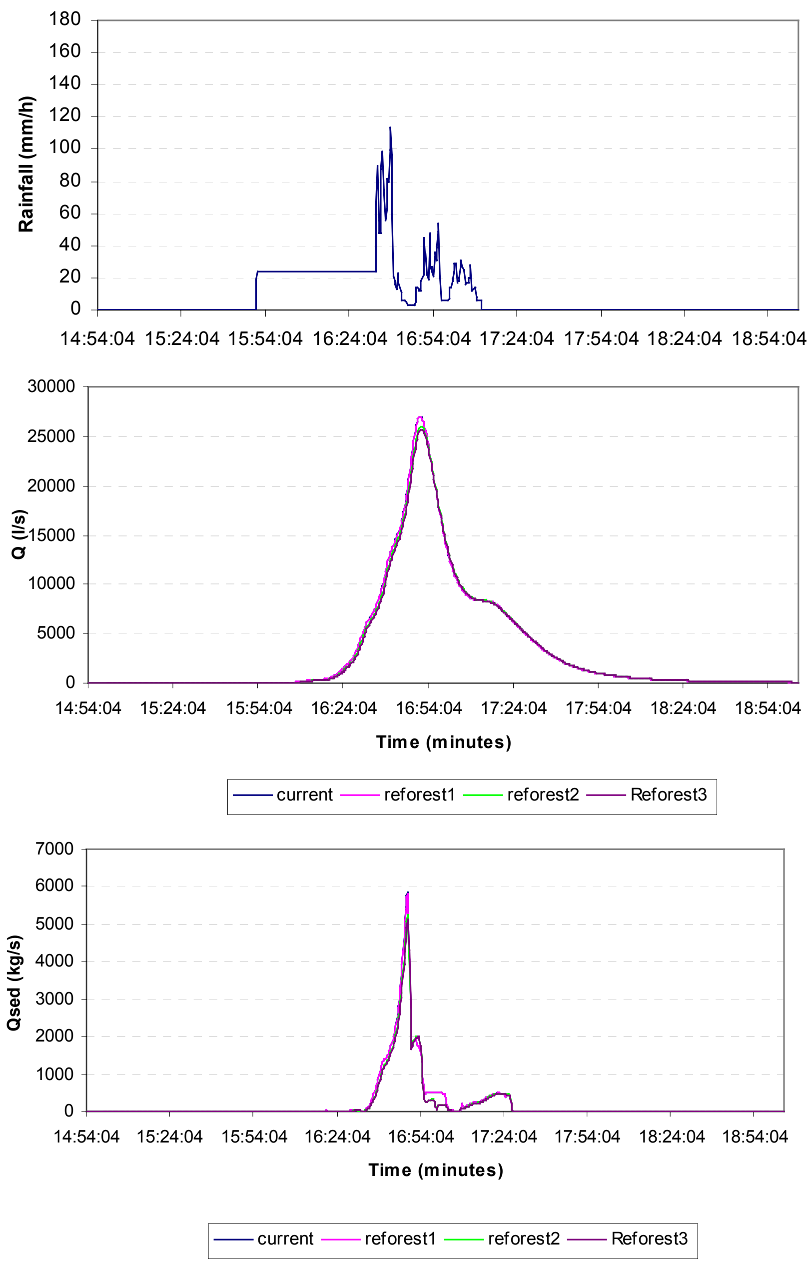
6 Results

Results of modelled water and sediment discharge under the specified land use scenarios in the catchment are presented below for two rainfall events.

6.1 Water and sediment discharge in response to a rain event in July (rain1507)

Time series output of modelled water and sediment discharge in for the four land use scenarios in response to rain1507 is presented in figure 10. This show higher water and sediment discharge under current land use than under the scenarios of reforestation.

Figure 10 Modelled water and sediment discharge for four land use scenarios in response to a rainfall event in July 2002 in Gobo Deguat



Total values of the water discharge and soil loss under the four land use scenarios is summarised in table 10. This shows a decrease in total and peak discharge values from 49527 m3 and 26981 l/s under the current land use scenario to 48009 m3 and 25701 l/s under scenario reforest3. Correpondingly, total and average soil loss from the catchment decreased from 3106 tons and 8426 kg/ha under current land use to 2665 tons and 7222 kg/ha under reforest3.

Table 10 Summary of water discharge and soil loss under four land use scenarios in response to a rainfall event in July 2002 in Gobo Deguat

Landuse scenarios	**Total discharge** ***(m^3)***	**Peak discharge** ***(l/s)***	**Total infiltration** ***(mm)***	**Total soil loss** ***(ton)***	**Average soil loss** ***(kg/ha)***
Current landuse	49527	26981	18.9	3106.4	8425.9
reforest1	49488	26955	18.9	3094.4	8393.4
reforest2	48623	25983	18.9	2727.3	7397.6
reforest3	48009	25701	18.8	2664.8	7228.2

Catchment area: 368.7 ha
Total rainfall: 32.6 mm

6.2 Water and sediment discharge in response to a rain event in August (rain1908)

Time series output of water and sediment discharge in response to the second rainfall event (rain1908) are shown in figure 11. Water discharge and soil loss was also higher under the current land use scenario than under the scenarios or reforestation in response to this rain event. Total discharge and peak discharge decreased from 44374 m3 and 53576 l/s under current land use to 42678 m3 and 50432 l/s land use scenario reforest3 (table 11). Correspondingly, total and average soil loss from the catchment decreased from 3003 tons and 8146 kg/ha under current land use to 2573 tons and 6980 kg/ha under reforest3. Similarly, average soil loss decreased from 8146 kg/ha under current land use to 6980 kg/ha under reforest4 (table 11).

Figure 11 Modelled water and sediment discharge for four land use scenarios in response to a rainfall event in August 2002 in Gobo Deguat

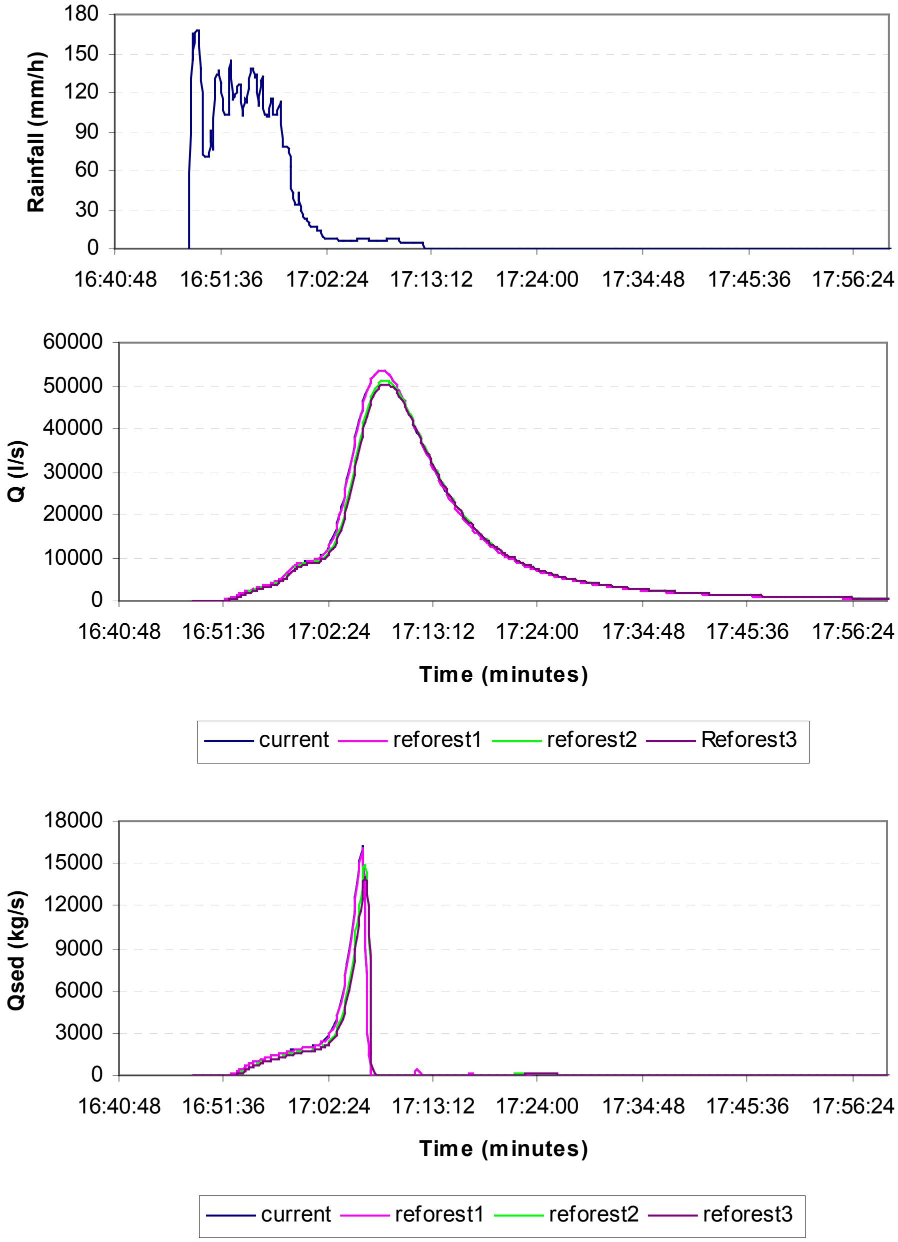


Table 11 Summary of water discharge and soil loss under four land use scenarios in response to a rainfall event in August 2002 in Gobo Deguat

Landuse scenarios	Total discharge *(m^3)*	Peak discharge *(l/s)*	Total infiltration *(mm)*	Total soil loss *(ton)*	Average soil loss *(kg/ha)*
current	44374.2	53572.9	9.4	3003.3	8146.3
reforest1	44317.3	53539.4	9.4	2978.2	8078.1
reforest2	43291	51287.2	9.5	2720.5	7379.3
reforest3	42678.3	50432	9.4	2573.3	6980

Catchment area: 368.7 ha
Total rainfall: 21.7 mm

7 Discussion

Soil loss is associated with rainfall and hence expected to occur mainly during the rainy season. Most of the rains are received in the *Meher*, mainly in the months June, July and August. Based on this and the failure of the *Belg* rains in 2002, the cumulative rainfall of 295.6 mm, which was measured in the catchment during the *Meher* of 2002 (June to september) could be regarded as the total rainfall total for that year. The two simulated rain events (rain1507 and rain 1908) account for ~11% and ~7% of this total rainfall respectively. Corresponding average soil loss in response to the two rainfall events range from ~8.4 t/ha under land use current land use to ~7.2 t/ha under reforest3 and from ~8.1 t/ha under current land use to ~6.9 t/ha under reforest3.

Estimated soil erosion ranging from 17-35 t/ha/yr have been reported for the Ethiopian highlands, including Tigray (table 12). Considering these estimates, the model results for Gobo Deguat, which is in response to a single rainfall event, indicates a high rate of soil loss in the catchment. The rate of soil loss for the catchemnt exceeds the tolerable annual rate of 6 t/ha/year estimated for Ethiopia (Bati and Fiedler, 1995) and are only slightly lower than the annual rate of 10 t/ha/yr estimated for the Ethiopian highlands (Hurni, 1985; Hellden, 1987; Mwendera, 1997).

Table 12 Estimated rates of soil erosion in Ethiopian Highlands (*source: Bati and Fiedler, 1995*)

Study Area	Estimated soil erosion (t/ha/year)	Year	Author
Highlands	20-35	1962, 1986	Fournier; EHRS
Tigray	17-33	1977	Virgo/Munro

The results also show a decrease in and soil loss following a change from the current land use to reforest3 in the catchment. However, significant decrease is obtained only with >40% increase in forest cover (table 13). Such increase in forest cover in the catchment requires a significant decrease in cultivated land. Given the known ecological advantages of reforestation, which includes soil erosion control, the decrease of <15% soil loss shown by model results for the catchment appears to be insignificant.

Table 13 Percentage decrease in average soil loss with increasing areal extent of tree cover in Gobo Deguat, using the current land use scenario as base scenario

Alternative Land use scenarios	forest cover %	decrease in soil loss %	
		Rain1507	Rain1908
reforest1	2.2	0.4	0.8
reforest2	43.1	12.2	9.4
reforest3	71.5	14.2	14.3

The extent of cultivable land in Gobo Deguat is already limited by the rugged terrain and large extent of rock outcrops and bare land. Large 'take-over' of land by forest plantation such as proposed for alternative land use scenario reforest3 in the catchment is only possible at the expense of part or all of the cultivated land, thus increasing the need for alternative sources of income. A probable justification for such 'land-take' may therefore be the use of tree species, such as the Eucalpytus species. The use of native tree species may be constrained by uncertain and inadequate seed supply for planting needs. Studies have shown that prevailing circumstances, in terms of number of seed sources or success of germination and recruitment, in natural forests are insufficient to produce enough seedlings for sustained development and regeneration of native forests (e.g. Tewolde-Berhan et al., 2002).

The planting of Eucalyptus trees on farmlands is resctricted by potential environmental externalities associated with the tree species, which include its ability to out-compete crops and other vegetation for water and nutrients. However the species is described as a fast-growing and resilient tree species, which performs better than most indigenous tree species, with a potential to improve rural livelihood through the provision of products that can raise farm incomes, reduce poverty, increase food security and diversify smallholder-farming systems in less favoured areas of Tigray (Jagger and Pender, 2003). Adoption of the reforestation alternative based on Eucalytpus trees, combined with with development of access to markets to facilitate sale of the forest products is therefore considered suitable under bio-physical and socio-eonomic conditions represented by Gobo Deguat catchment.

8 Summary

Keywords: Tigray, catchment, Meher, alternative land use scenario, plantation forest, Eucalyptus tree species

This report presents the catchment scale assessment of the impact of land use on soil loss in Eastern Tigray as a part of the project Policies for Sustainable Land Management in the Ethiopian Highlands (PIMEA). The PIMEA project is a collaborative project of The International food Policy Research Institute (IFPRI), U.S.A., Wageningen University and Research Centre (WUR), The Netherlands, The International Livestock Research Institute (ILRI), Ethiopia and Mekelle University (MU), Ethiopia. The project is supported by the Dutch Ministry of Foreign Affairs (DGIS), The Netherlands. The long term goal of the PIMEA project is to contribute to improved land management in the Ethiopian highlands, in order to increase agricultural productivity, reduce poverty and ensure sustainable use of natural resources.

The soils of eastern Tigray are characterised by low productivity and severe land degradation attributed to many causes, principal among which is soil erosion. The rugged terrain, coupled with poverty, significantly limit resource availability for agricultural production in many parts of the region. Crop production is therefore characterised by practices that are regarded as unsustainable and thus compound the problems of land degradation. These highlight a strong need for sustained effort to promote land use practices that offer better soil protection, while providing supplementary sources of income in the region. Reforestation is identified as a technology with the potential to rehanilitate soils and provide many goods and services in resource constrained areas. Reforestation is therefore identified as a possible viable alternative land use for the Eastern Tigray region in this study, which examines the impact of different land use scenarios on soil erosion in a selected catchment in eastern Tigray. Specifically, the study examines soil loss under prevailing land use (current land use scenario) and three alternative land use scenarios based on reforestation (reforest1, reforest2 and reforest3) at a scale above plot level. The study is carried out in a selected catchment, that is identified as representative of bio-physical and socio-economic conditions in eastern Tigray.

A modelling methodology is adopted in the study, based on the application of a physically based hydrology and soil erosion model LISEM. The model allows the quantitative assessment of the impact of land use scenarios on the soil and water dynamics at catchment scale. Activities carried out in the study include: i. collection of input data / parameters to characterise the selected catchment and to prepare the input data to characterise the selected catchment, ii. Preparation of spatial input maps for the model; iii. definition of alternative land use scenarios for the catchment; iv. simulation of water discharge and soil loss in the catchment and v. analysis and description of model results.

The relative impact of the different land use scenarios on soil loss are examined by simulating soil loss under all scenarios in response to a single rainfall event. In addition, the impact of rainfall magnitude on soil loss is assessed by comparing simulation results for two rainfall events of different magnitudes.

Model results show average soil loss in the catchment ranging from 7.2 tons/ha under to 8.4 tons/ha. Compared to the tolerable rates of soil erosion, which is estimated at 6 t/ha/year for Ethiopia (Bati and Fiedler, 1995) and at ~10 t/ha/yr for the Ethiopian highlands, depending on slope gradient and land use type (Hurni, 1985; Hellden, 1987; Mwendera, 1997), this study appears to indicate a high rate of soil loss in Gobo Deguat. The rate of soil loss is higher under current land use scenario than under the scenarios of reforestation. Average soil loss of 8.4 tons/ha, 8.3 tons/ha, 7.4 tons/ha and 7.2 tons/ha occurred under land use scenarios current, reforest1, reforest2 and reforest3 in response to one of the rainfall events. However the difference in soil loss between current land use and the reforestation scenarios in response to the rainfall events correspond to <15% decrease in soil loss in the catchment, despite the large increase in plantation forest cover under two of the scenarios of reforestation.

Given the known ecological advantages of reforestation, which includes soil erosion control, the decrease in soil loss shown by model results for the catchment appears to be insignificant. Furthermore, the large 'take-over' of land by forest plantation in the catchment as required under some of the reforestation scenarios is only possible at the expense of part or all of the cultivated land. The extent of cultivable land in Gobo Deguat is already limited by the rugged terrain and large extent of rock outcrops and bare land. However, the service and production functions of Eucalyptus trees are high. A probable justification for such land-take in Gobo Deguat may therefore be the use of Eucalyptus species in such an intensive reforestation, coupled with development of access to market to facilitate the sale of the forest products.

Many studies focus on the economics and adoption of land management practices by farmers in Tigray. However, less is known about the quantitative assessment of the impacts of these practices on land degradation. This study has provided a quantitative assessment of the impact of current land use and three scenarios of alternative land use involving reforestation in a case study catchment in eastern Tigray based on the use of a hydrological and soil erosion model, LISEM. This approach is regarded as useful for judging the relative performance of proposed land use alternatives and therefore provide useful information for different stakeholders in the use and management of land in the region.

9 Conclusion

The study shows that current land use, accounts for more soil erosion than proposed alternative land use based on increased tree cover in the catchment. However, the decrease in soil erosion associated with increased tree cover is considered as relatively low. It is noted that measured and estimated soil and plant parameters defining the different land use and soil types in this study are mainly based on current conditions in the catchment, which indicate poor bio-physical conditions even in land units that are under tree cover. This observation may explain model results for the catchment, which shows with only ~15% reduction in soil loss in response to >40% increase in tree cover in the catchment. Such increased tree cover in the catchment is only possible at the expense of other land, including cultivated land, which is already under much pressure. It is therefore considered that tree species such as Eucalyptus, which are known to have high service and production functions be used, which are adapted to local conditions and are already known to the local community be adopted. This should be coupled with development of access to markets in order to facilitate sale of products forest products. This should increase the benefits of increased tree cover above the ~15% decrease in soil erosion.

Bio-physical and socio-economic factors, through a complex of interactions, determine the land use options that are available to a community at a given time. Environmental problems such as the severe soil erosion observed in the Ethiopian highlands, which are associated with land use, are thus characterised by a web of bio-physical and socio-economic relationships. Assessments of the impact of land use on soil erosion therefore need to be done at appropriate scales, within which the causes and effects of these relationships are adequately expressed. This study shows that the catchment approach provides an adequate scale of assessment for such purpose. It has been possible to provide quantitative information on the impact of current and alternative land use scenarios defined based on driving biophysical and socio-economic conditions in a catchemnt in Eastern Tigray.

References

Bati G. A. & H. J. Fielder (1995). Soil degradation in the Ethiopian highlands. *Arch. Für Nat. – Lands.* -, **33**, 243-253

Chisholm N. (1998). Community based natural resource management in Tigray, Northern Ethiopia. The World Bank/WBI's CBNRM Initiative, case report. At http://srdis.ciesin.org/cases/ethiopia-005.html)

Chow, Ven Te, D.R. Maidment and L.W. Mays. 1988. Applied Hydrology. McGraw-Hill. Chpt. 4.

De Roo A.P.J., Wesseling C.G. and Ritsema, C.J. (1996a). LISEM: a single event physically-based hydrologic and soil erosion model for drainage basins. I: Theory, Imput and Output. Hydr. Processes, 10, 1107-1117

De Roo A.P.J., Offermans, R.J.E. & Cremers, N.H.D.T. (1996b). LISEM: a single event physically-based hydrologic and soil erosion model for drainage basins. II: Sensitivity analysis, validation and application. Hydr. Processes 10: 1119-1126.

Elevitch, C & Wilkinson, K. Agroforestry: A way of farming that can work for everyone. In: The Overstory #7, Agroforestry ejournal http://agroforestry.net/overstory/overstory7.html.

Esser K, Vågen T-G; Tilahun Y & Mitiku H (2002). Soil conservation in Tigray, Ethiopia. Noragric Report No. 5. February 2002. 21pp Esser et al., 2002

Hellden, U. (1987). An assessment of woody biomass, community forests, land use and soil erosion in Ethiopia. Lund studies in Geography, Ser. C. General, Mathematical and Regional Geography. No. 14. Lund University Press, Sweden.

Hurni, H., (1985). Soil conservation manual for Ethiopia: a field manual for conservation implementation. Soil Conservation Research Project, Addis Ababa.

Hunting, (1976). Tigrai Rural Development Study, Annex 2: water resources, Volume 1: Hydrology and surface water. Hemel Hempstead (g.b.), Hunting Technical Services Ltd. 213p.

Jagger, P.& J. Pender (2003). The Role of Trees for Sustainable Management of less-favoured lands: the case of eucalyptus in Ethiopia. Forest Policy and Economics, 5, pp83-95

Mehari Yohannes,. CO-SEART feasibility study report, 1996

Mitiku, H. (1996). Soil resources Central Tigray: a case study of selected farms in 7 weredas. In: A.O. Øyhus & G. Gebru (eds), Rural explorattory studies in the central zone of Tigray, Northern Ethiopia. Proceeding of a workshop, pp 19.33. Noragric, Addis Ababa, Ethiopia.

Meijerink, G.W. (2002a). Alternative cropping practices in Ethiopia: A literature review. Policies for Sustainable Land Management in the Ethiopian Highlands. *Working paper 2002-05*. 21pp.

Meijerink, G.W. (2002b). Rural livelihoods and soil conservation in Eastern Tigray – A Rapid Diagnostic Appraisal Report for Gobo Deguat and Teghane. *Working Paper 2002-06*.

Mwendera E.J. & Mohamed Saleem, M.A. (1997). Hydrologic response to cattle grazing in the Ethiopian Highlands. *Agriculture, Ecosystems and Environment*, vol **64**, 33-41

Nyssen, J., J. Poessen, H. Mitiku, J. Moeyersons, J. Deckers. (2000a). Tillage erosion with soil conservation structures in the Ethiopian highlands. Soil and Tillage Research 57. pp.115-127.

Nyssen, J., Peosen, J., Vandenreyken, H., Moeyersons, J., Deckers, J., Mitiku, H. & Salles, C. (2001). Saptial variability of rain and its erosivity in a tropical mountain catchment, Tigray, Northern Ethiopia. Submitted to: Proceedings of the

second International Conferennce on Tropical Climatology, Meteorology and Hydrology. Brusses 12-14 dec. 2001.
Rawls, W.J., D.L. Brakensiek and N. Miller. 1983. Green-Ampt infiltration parameters from soils data, J. Hydraul. Div., Am. Soc. Civ. Eng., vol. 109, no. 1, pp. 62-70.
Scurlock, J.M.O., Asner, G.P & S.T. Gower (2001). Worldwide Historical Estimates of leaf Area Index, 1932-2000. ORNL/TM-2001/268, 23pp.
Stoorvogel, J. J., and E. M. A. Smaling. 1990. Assessment of soil nutrient depletion in sub-Saharan Africa: 1983-2000. Report 28. Wageningen, The Netherlands: Winand Staring Centre for Integrated Land, Soil and Water Research.
Tewolde-Berhan S., Mitlöhner, R., Muys B. & Mitiku, H. (2002). Comparison of vegetation development of closed areas and ancient forest in Tigray, Ethiopia. *Submitted*. Proceedings, Conference on International Agricultural Research for Development. Deutscher Tropentag 2002. Witzenhausen, October 9-11, 2002.
The Hydraulic Properties Calculator: (http://www.bsyse.wsu.edu/saxton/soilwater/)