6 Description of the Study Area

The *Bilate River* drains the northern watershed of the *Lake Abaya-Chamo Drainage Basin* and is located in the southern Ethiopian Rift Valley and partly in the Western Ethiopian Highlands. The watershed has a size of 5,412.5 km².

This chapter initially outlines the overall characteristics of the watershed, followed by a more detailed description of the differences in landscape characteristics by distinguishing the geomorphological units within the watershed. These have been identified by their distinct characteristics of geo-factors that are representative for each unit. Lastly, the eight test sites that have been selected within the watershed are described.

6.1 Bilate Watershed

In general, the landscape of the watershed is very heterogeneous, determined not only by physical factors, but also by human activities. The watershed stretches across different topographical zones. While sections of the watershed are located in the Ethiopian Highlands and display mountainous characteristics, other areas are part of the Rift Valley and thus, are almost flat or undulating.

In further context the terms '*Western Ethiopian Highlands*', '*Rift Valley*' and '*Valleys and Basin*' represent geomorphological units, which are defined and described in chapter 6.2.

6.1.1 Geology

Only limited amounts of information are available about the geology of the watershed itself, as no geological surveys have been conducted on a watershed scale. However, geological information published by FAO (1998) provides some overview over the area. While the northeast to southwest oriented graben zone is dominated by Oligocene to Miocene basalts in the *Rift Valley,* the *Western Ethiopian Highlands* are characterised by quaternary Rhyolites and Trachytes. *Lake Abaya*, which is in close proximity to the watershed, is typified by Holocene lake and swamp deposits (fig. 12). An ongoing geological survey conducted by the Ethiopian Ministry of Mines uses the geological map published by MOHR (1962) at a scale of 1:2,000,000 as their basis. It is clearly an issue of scale that makes the available information little useful and insufficient for the given research. Therefore, the geological map (MOHR, 1962) for the watershed can only be used as a rough approximation of bedrock characteristics on the ground. The maps of fracture patterns and volcanoes (fig. 13) highlight the major direction of scarps, but also show their heterogeneous occurrence within the watershed. There are two clusters of concentration: one in the north-western part of the watershed in the *Western Ethiopian Highlands*, and the other in the southern part, where the western graben shoulder of the *Rift Valley* is pronounced. The centre of the watershed is only insignificantly influenced by fractures. Here, the western graben shoulder descends smoothly into the *Rift Valley*. The right map of figure 13 also shows the existence of several volcanoes. These currently inactive volcanoes stand out noticeably in the landscape and are evidence of previous volcanic activity.

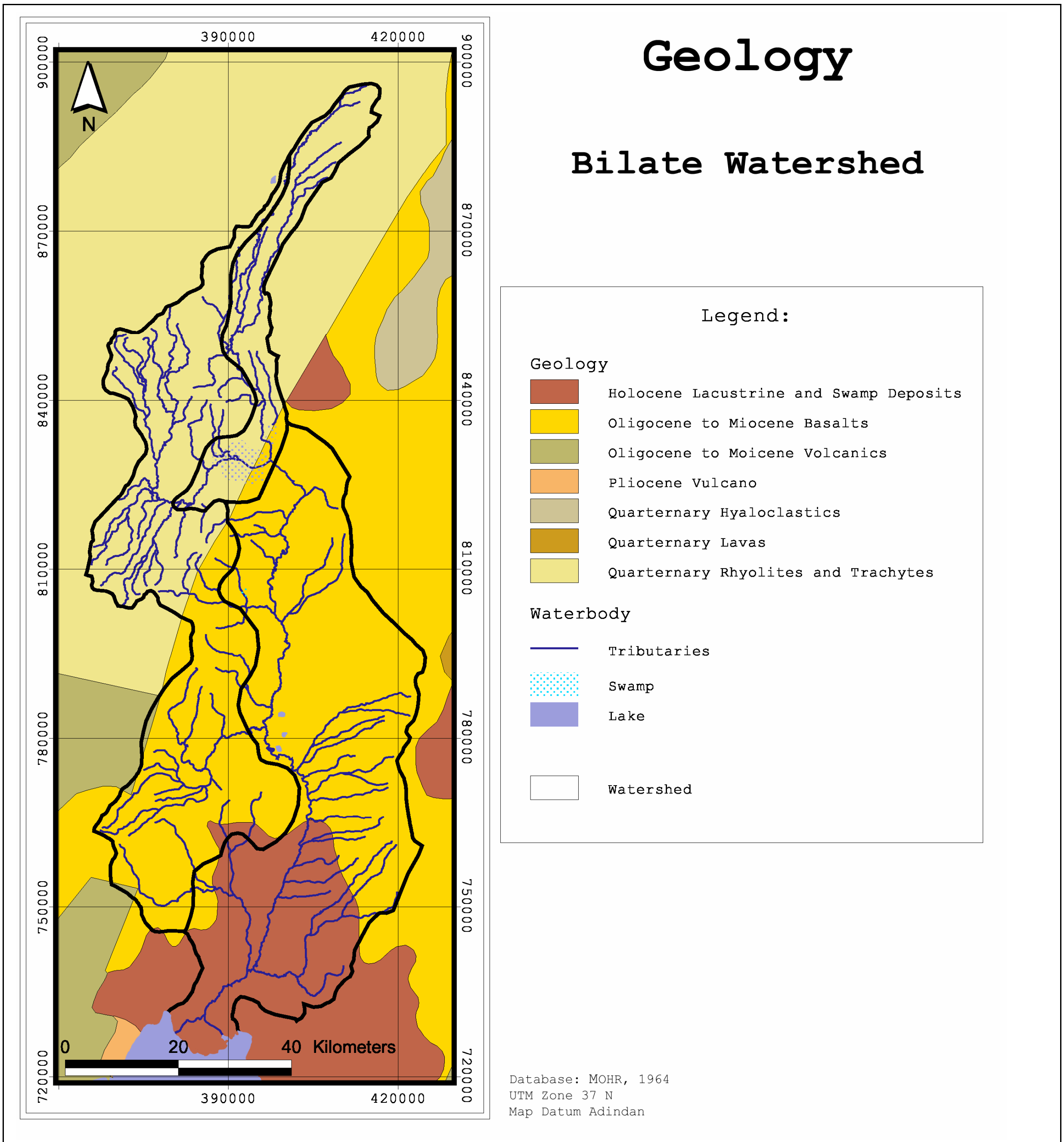

Fig. 12: Geology of the *Bilate* Watershed (source: FAO 1998)

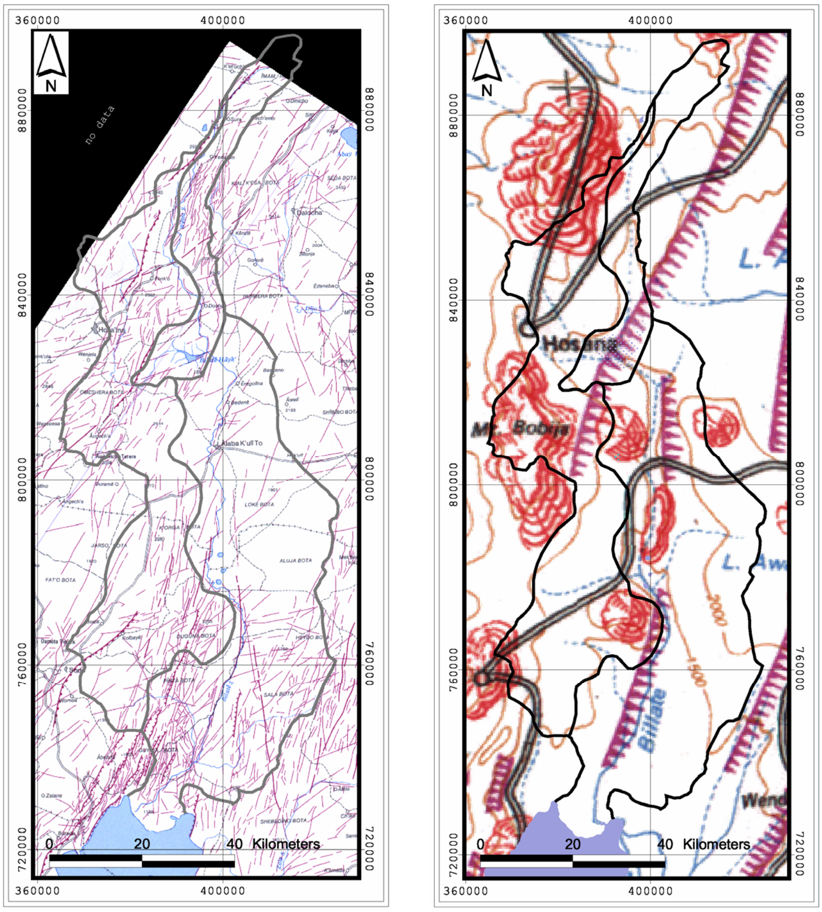

Fig. 13: Fracture Pattern and Volcanoes (modified after BEKELE, 1992)

6.1.2 Morphometry

The morphometry across the watershed is very distinct, which is due to the tectonic conditions in the *Rift Valley* in general. The digital elevation model and its derivatives reflect the topography of the watershed, as well as morphometric parameters such as slope, aspect, flow direction and accumulation and relief curvature. The altitude ranges from 1,188 m a.s.l. (altitude of *Lake Abaya*) to 3,443 m a.s.l. towards the northern realm of the watershed (fig. 14).

The relative relief (quotient of length [km] to height difference [m]) for the total length (254 km) of the *Bilate* is 0.11 (fig. 15), although the length profile of the river shows different relative relief sections. WEMMER (2004) shows that the relative relief of the *Bilate* can be separated into three parts:

- a relatively steep profile (relative relief: 0.29), which is separated into several convex partitions from the headwaters to approximately 61 km downstream,
- a convex profile from approximately 61 to 193 km (relative relief: 0.05), and
- a smooth and straight profile from 193 km to Lake Abaya (relative relief 0.04).

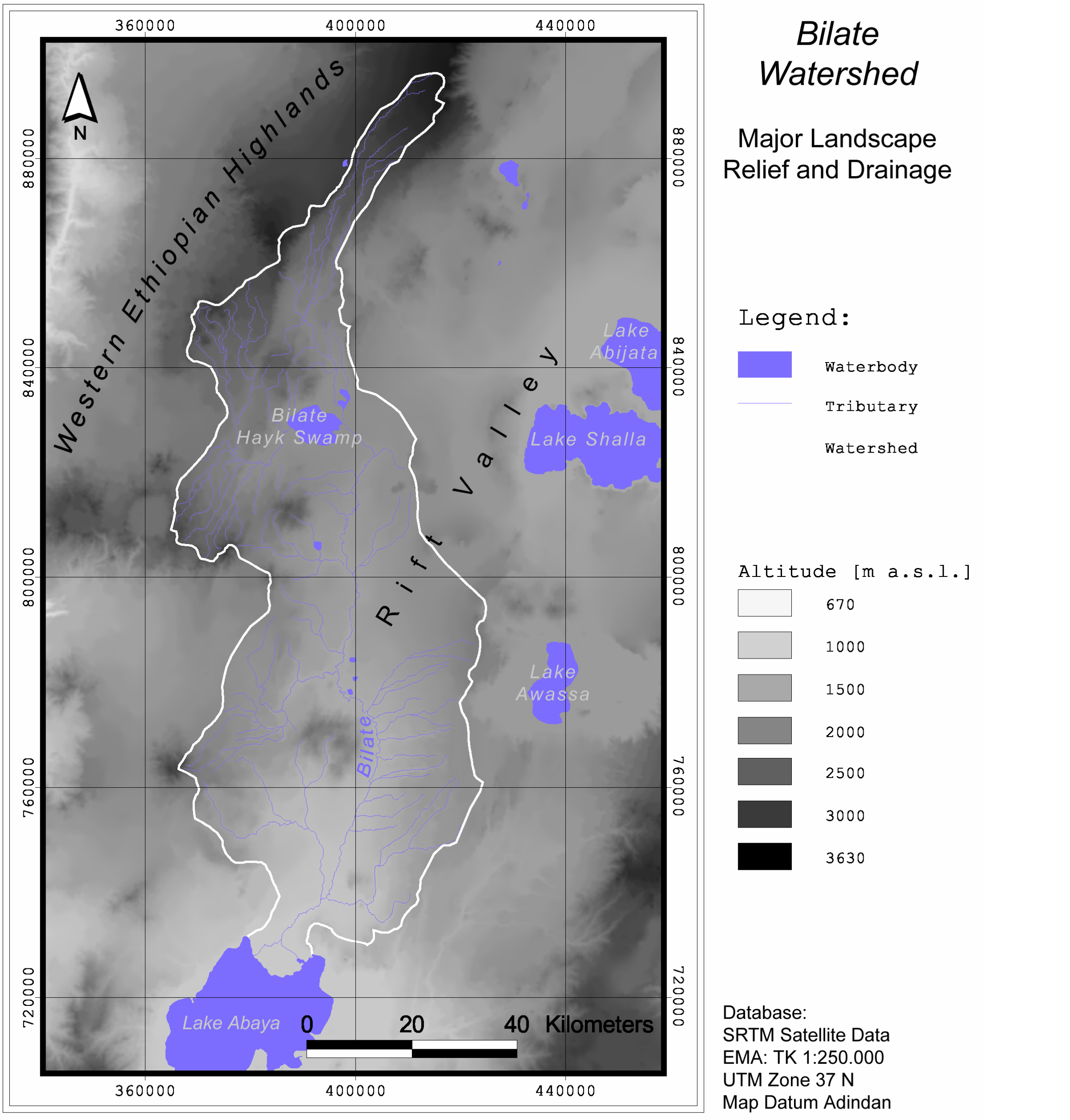

Fig. 14: *Bilate* Watershed: Relief and Drainage System

There is no indication that changes of relief curvature or slope are correlated to changes of geology or to the fracture pattern (WEMMER, 2004).

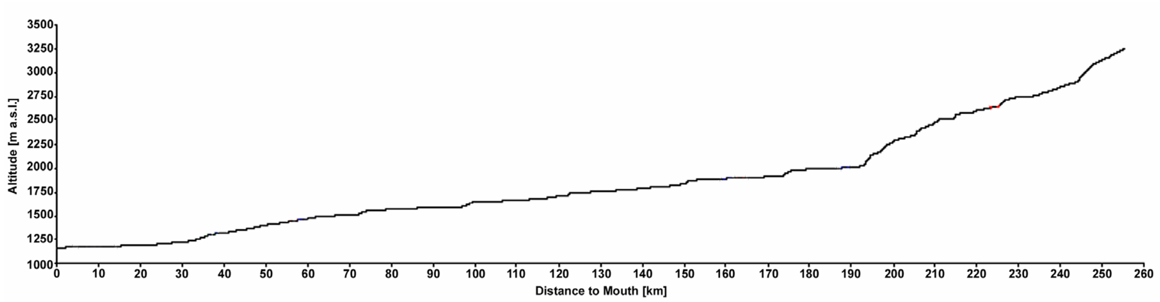

Fig. 15: Longitudinal Profile of the *Bilate River* (modified after WEMMER, 2004)

The watershed is characterised by a slightly skewed distribution of altitude levels (fig. 16). It is dominated by areas located in the undulating, almost flat *Rift Valley*, whereas mountainous areas (1,700 - 2,000 m a.s.l.) cover a smaller proportion of the watershed. The classification of slope values confirms that the majority of the watershed is located within the *Rift Valley* (1-3° gradient). In contrast, areas with steeper slopes are uncommon, and only occur in parts of the *Western Ethiopian Highlands*, the graben shoulder and on the volcanoes. These steep slopes are generally less than 200 m in length, whereas longer slopes are often linked with gradients of 3 to 12° (fig. 16).

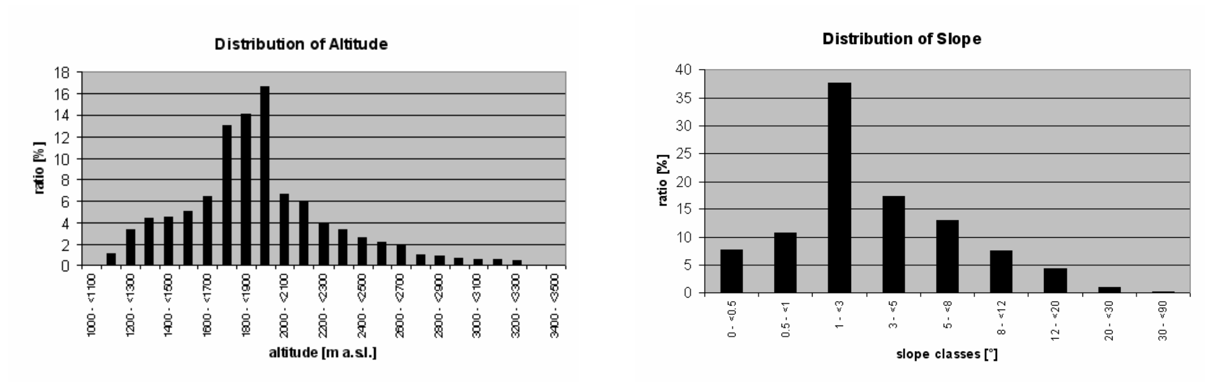

Fig. 16: Distribution of Altitude and Slope Classes

Flow accumulation shows the flatness of the *Bilate Hayk* (Amharic: hayk = English: lake / extended swamp) and the dominance of shorter slopes in its proximity. The length of the *Bilate* is illustrated by high flow accumulation values (fig. 17).

The complex curvature of the relief is normally distributed (fig. 17). However, in the transition zone from the *Western Ethiopian Highlands* to the *Rift Valley* smooth concave curvature is more frequent than strong profile-concave/plan-concave (cv/pcv) curvature. Strong convex curvatures generally dominate the base of the slopes in the *Western Ethiopian Highlands*. These are created by the slopes of short lengths and steep gradients. In addition, the *Bilate Hayk* has smooth cv/pcv relief elements, as shown in figure 17. Convex relief curvature (cx/pcx) can mainly be observed on the volcanoes and in the *Rift Valley* close to the tributaries. Here, the slopes are moderate to smooth with increasing gradients closer to the channels.

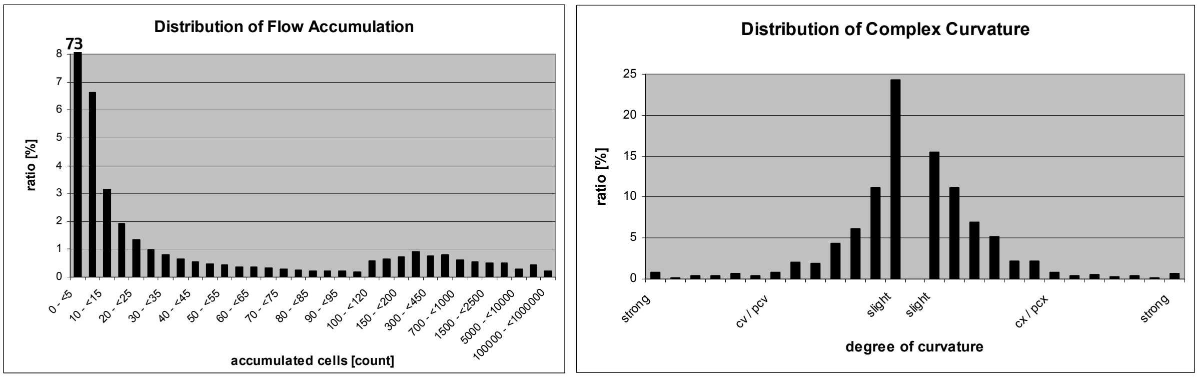

Fig. 17: Distribution of Flow Accumulation and Complex Curvature of the Watershed

6.1.3 Soil

The soil types within the watershed can only be roughly estimated, due to the inadequate scale of the available soil data (FAO, 1998; fig. 18). The occurrence of different soil types is related to geology, although the relief has a significant influence on the development of soil types in some areas. In the *Rift Valley*, three major soil types are present:

- Vitric Andosols dominate in the northern and central regions;
- Lithic Leptosols and eutric Vertisols occur primarily in the southern part; and
- Chromic Luvisols are present on most of the volcanoes in the watershed.

The exceptions are two volcanoes towards the eastern watershed boundary, which are dominated by mollic Andosols and luvic Phaeozems, respectively (though only at the volcano base). In the *Western Ethiopian Highlands*, chromic Luvisols also occur in association with humic Nitisols. Only towards the north, some areas of eutric Cambisols exist. While FAO identifies eutric Vertisols in the *Rift Valley*, these could not be confirmed during the field survey. In contrast, Fluvisols or Leptosols have been frequently encountered.

In general, most soil types could not be easily identified on the ground, as they usually occur in a mixture of different soil types and soil groups, are very young and therefore barely developed, or are sometimes covered by debris. Whether Vertisols are present depends strongly on relief position.

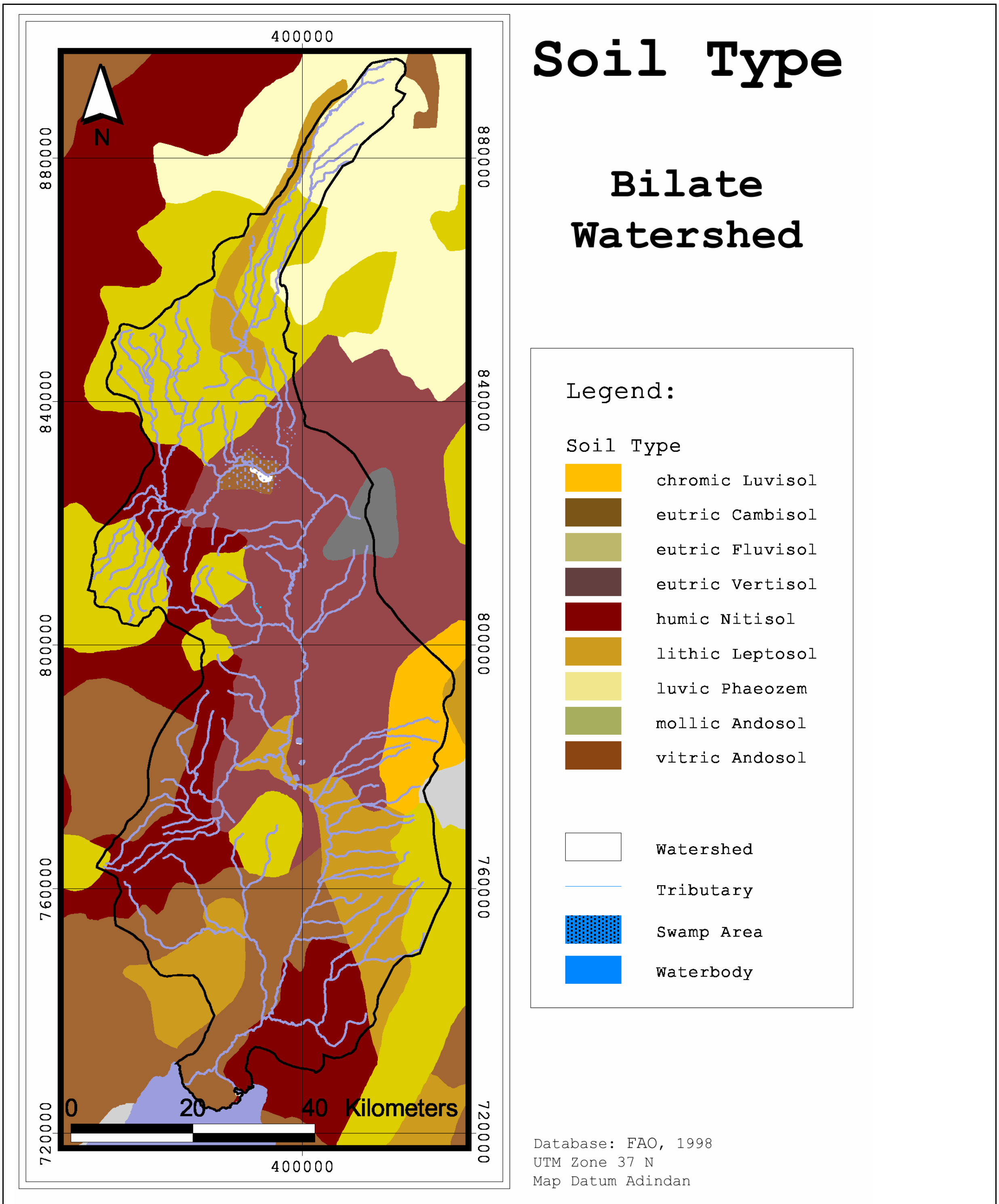

Fig. 18: Soil Types of the *Bilate* Watershed (source: FAO, 1998)

Vertisols were detected in a few accumulation zones in the *Western Ethiopian Highlands* and on some volcanoes, but were never found to be distributed over larger areas. The Andosols and Leptosols mapped by FAO (1998) in the *Rift Valley* are not easily identifiable on the ground either. Young soils are developing on multiple pyroclastic and strongly weathered layers which have been deposited on top of former soils (fig. 19). These young soils often have a very shallow depth of 30 to 50 cm.

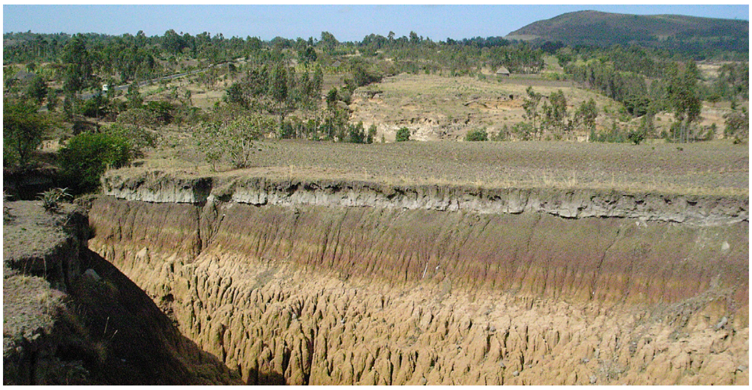

Fig. 19: Pyroclastic Layers in the Rift Valley

6.1.4 Climate

Fifteen meteorological stations monitor precipitation in the *Bilate* watershed. All of them are recording daily precipitation. In addition two stations are recording hourly precipitation.

Precipitation varies greatly across spatial as well as temporal scales. Due to the lack of data on the given scale, the spatial variability of precipitation across the watershed was modelled by interpolation from existing data; the approach is described in chapter 7.1.1.2.

Annual precipitation follows a bimodal distribution and the annual pattern is commonly distinguished as (LEGESSE ET AL., 2003):

- main rainy season (*Kirempt*) from June to September;
- dry season from October to February (*Bega*);
- small rainy season from March to May (*Belg*).

Rainfall is generally higher in the *Western Ethiopian Highlands* and on the volcanoes, than in the *Rift Valley*. However, there are no significant rainfall gradients across the watershed. Throughout the available record from 1970 to 1996 annual rainfall ranges from 830-1,500 mm in the *Rift Valley* (station *Alaba Kulito*) and from 850-1,630 mm in the *Western Ethiopian Highlands* (station *Hossaina*). In the unit *Valleys and Basin* precipitation is not recorded, but modelling the spatial precipitation indicates higher totals than in the *Western Ethiopian Highlands*. Precipitation patterns will be described for the study sites below and discussed in more detail in Chapter 8.1.1.

It was impossible to obtain temperature data from the National Meteorological Agency, Addis Ababa. Thus, temperature cannot be discussed in detail for the study sites.

However, some general estimates based on data obtained from Arba Minch University can be made. In contrast to precipitation patterns, temperature in the region is fairly constant throughout the year, with a maximum fluctuation of +/- 2° C. In the *Western Ethiopian Highlands*, annual temperatures average around 16° C to 17° C and are roughly three to four degrees centigrade lower than in the *Rift Valley*. Diurnal temperature variations are generally more significant (Arba Minch University Database, personal communication).

Evapotranspiration data are only available from a few meteorological stations in the Southern Ethiopian Rift Valley. BEKELE (2001) calculated potential evapotranspiration (PET) after THORNTHWAITE & MATHER (1957) for sub-watersheds of the *Abaya-Chamo Basin* and compared the results with measured potential evapotranspiration rates for selected meteorological stations. For the sub-watersheds that are located in the *Western Ethiopian Highlands*, the average annual PET is 700 mm, with a standard deviation (SD) of 15 mm/a. In the *Rift Valley,* annual PET ranges from 720 mm (SD = 21 mm/a) in the northern to 770 mm (SD = 26 mm/a) in the southern part of the watershed (BEKELE, 2001).

BEKELE (2001) determines an error of 50% between calculated and measured PET. Based on these results, PET rates for the watershed are estimated as ranging from 1,400 mm/a in the *Western Ethiopian Highlands* to 1,540 mm/a in the *Rift Valley*. However, BEKELE's approach has been criticized for not considering the influences of relief, altitude or vegetation patterns on evapotranspiration rates (THIEMANN & FÖRCH, 2005).

6.1.5 Land Use

Two main agricultural systems can be distinguished within the *Bilate* watershed. The land use system in the *Western Ethiopian Highlands* dominated by small-scale subsistence agriculture (fig. 20). The agricultural system integrates cereal and root crops in a fairly intensive manner. The main crops are teff (*Eragrostis tef)*, wheat and beans. Teff is a small grain that is used to produce the staple food *ingera*. In addition, farmers have intensive home gardens close to their *tukuls* (local synonym for houses), where they cultivate *enset* (*Ensete ventricosum* - "false banana"), as well as a range of vegetables. *Enset* is a perennial crop that is processed into a pulp; it serves as a staple food and has particular relevance in times of food scarcity. Fields are ploughed using the traditional Ethiopian plough *Maresha* (fig. 21).

Fig. 20: Small Scale Subsistence Farming in the *Western Ethiopian Highlands*

Fig. 21: Traditional Plough *Maresha*

On average, land holdings per household amount up to 1 hectare. However, land shortage, i.e. the lack of land to expand cultivation, is the main constraint faced by farmers in the region. Land in Ethiopia is owned by the state, while farmers have long-term leases (UNEP, 2005). The farming system also integrates livestock, mainly small stock. During the rainy season, the animals are kept in the proximity of the homesteads, as enough fodder is readily available. However, during the dry season, livestock are left to freely graze the harvested fields. Individual plots are often intersected with shrubs and trees, mainly *Eucalyptus*. Also, some *Eucalyptus* plantations exist. The wood is commonly used for house construction, as well as firewood. *Eucalyptus* leaves are collected as fuel for cooking.

In contrast to the relatively intensive land-use system of the *Western Ethiopian Highlands*, the *Rift Valley* has several different systems. The northern part, which is fairly flat, is used for large-scale maize farming. While a state farm operates commercially, the private farmers in this area also have larger fields. Due to the semi-arid climate of the *Rift Valley*, vegetation is generally less dense than in the highlands, and trees only grow in riparian areas. The exception is *Acacia spp,* which is well adapted to the prevailing environmental conditions. Towards the south, the communal lands are predominantly utilized by pastoralists for extensive livestock production, mainly cattle. Here, two state farms and a military base are located in close proximity to the *Bilate*. The farms are irrigated and mainly cultivate tobacco and maize. The far north of the watershed, due to its high altitude (> 2,800 m a.s.l.), is characterised by lush green perennial vegetation. Cultivation at this altitude is rarely practiced and most farmers keep livestock instead. However, due to the shortages of land in the more favourable zones, there is indication of expansion of cultivation into these higher altitudes.

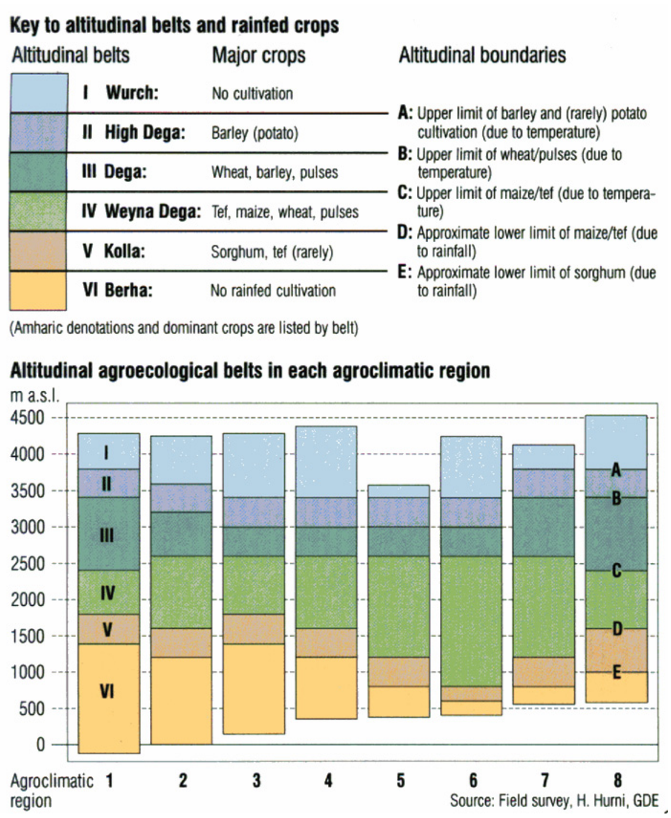

Fig. 22: Agro-climatic Regions of Ethiopia: Region of the *Bilate* *Watershed* = Region 5 'kolla' (source: HURNI, 1982)

The distribution of land-use systems is strongly linked to the prevailing climatic conditions, which in turn are determined by altitude (HURNI, 1982). Figure 22 shows the agro-climatic (agro-ecological) zones according to HURNI (1982). The watershed of the *Bilate* can be classified as *Kolla* and partially as *Weyna Dega*. According to this classification sorghum, teff, maize, wheat and pulses can be planted in most regions, while at altitudes above 2,500 m a.s.l. cultivable crops are only wheat, barley and pulses; beyond 3,000 m a.s.l. only barley can be grown (KULS, 1958; WESTPHAL, 1975; SCHULTZ, 2000). These land use patterns described in the literature have been confirmed by the observations made on the ground.

6.2 Geomorphological Units

Three geomorphological units have been identified within the *Bilate* watershed. This classification is based on the characteristic of relief morphometry and climatic conditions. The geomorphological units within the watershed are (fig. 23):

(1) *Western Ethiopian Highlands*
(2) *Valleys and Basin*
(3) *Rift Valley*

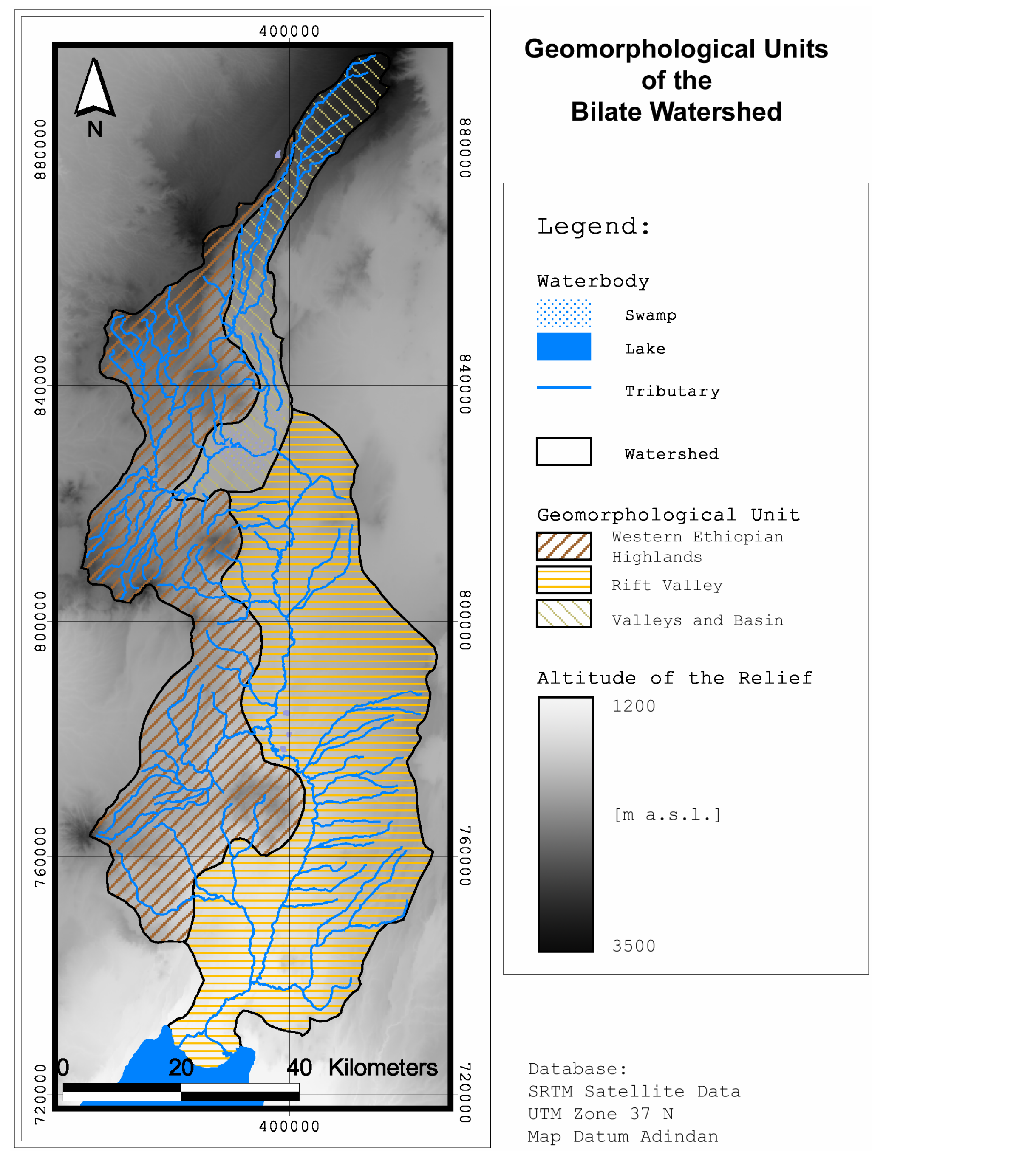

Fig. 23: Geomorphological Units of the Watershed

6.2.1 Western Ethiopian Highlands (WEH)

The relative relief position of the geomorphological units within the watershed, as well as their relief characteristics are determined by altitude differences (fig. 24). In the *Western Ethiopian Highlands* the altitude pattern is normally distributed; it exhibits very similar ratios and indicates a fairly homogenous relief character across the unit. The spatial distribution of slope classes reveals a similar pattern. The analysis of the relief complex curvature is presented as distributions of ½ standard deviations in figure 26.

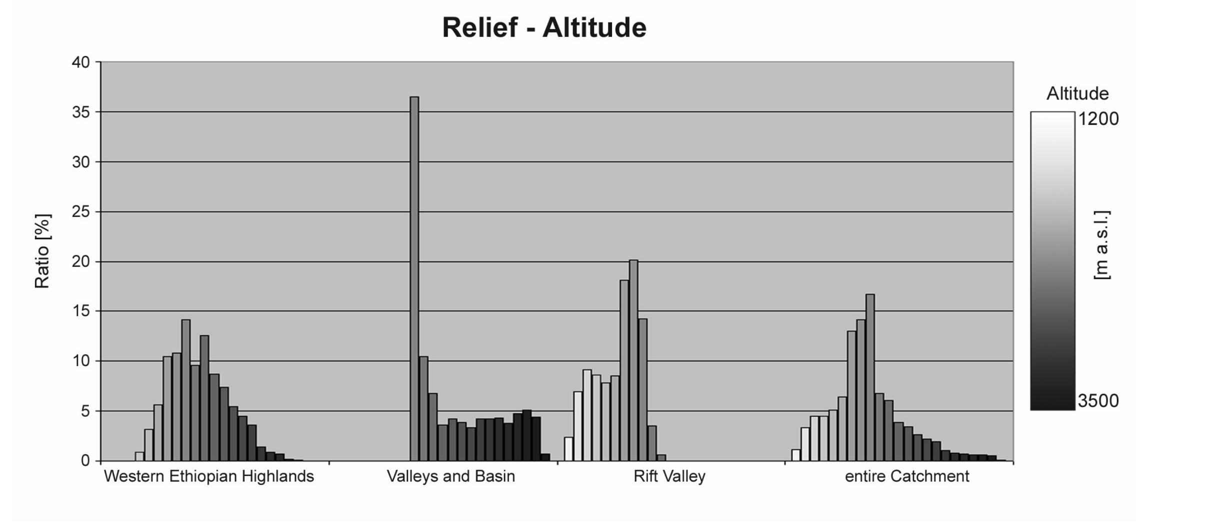

Fig. 24: Distribution of Altitude Classes within the Geomorphological Units

For the *Western Ethiopian Highlands* the complex curvature distribution shows a maximum for small degrees as well as a second small maximum for very high complex curvature degrees. In the *Western Ethiopian Highlands*, the values for highest flow accumulation ratios are not represented. This generally indicates the short channel lengths and the absence of the *Bilate* in this geomorphological unit.

6.2.2 Valleys and Basin (VB)

In the *Valleys and Basins*, the distribution of the altitude classes is extremely skewed. An outlier appears within the first altitude class that is occurring in this unit (fig. 24). This area has been identified as the *Bilate Hayk*, a large swamp area in the centre of the watershed. Additionally, steep slopes only have a minimal ratio, reflecting both the spatially dominant occurrence of the *Bilate Hayk* area and moderate relief characteristics. Slope classes are bimodally distributed with one maximum representing slope classes with 1-3° gradients and a second maximum of slopes steeper than 12° (fig. 25). Also the dominance of small curvature gradients reflects the unequal distribution of the relief characteristics in this geomorphological unit. In contrast to the other units, high curvature gradients are almost missing. The distribution of the flow accumulation (fig. 27) is also distinctly different than in the other geomorphological units. Here, the distribution is skewed towards small flow accumulation ratios, indicating the *Bilate Hayk*.

6.2.3 Rift Valley (RV)

The distribution of the altitude classes (fig. 24) is skewed towards smaller elevations in the *Rift Valley*. The distribution is bimodal, creating two homogenous areas:

altitude classes up to 1,400 m a.s.l. in the southern part of the watershed

altitude classes above 1,400 m a.s.l. in the central part of the watershed

The distribution of slope gradients in the *Rift Valley* reflects the undulating relief characteristic of this unit: the ratios of slope classes between 0-3° gradients are high, whereas higher values are less frequent (fig. 25).

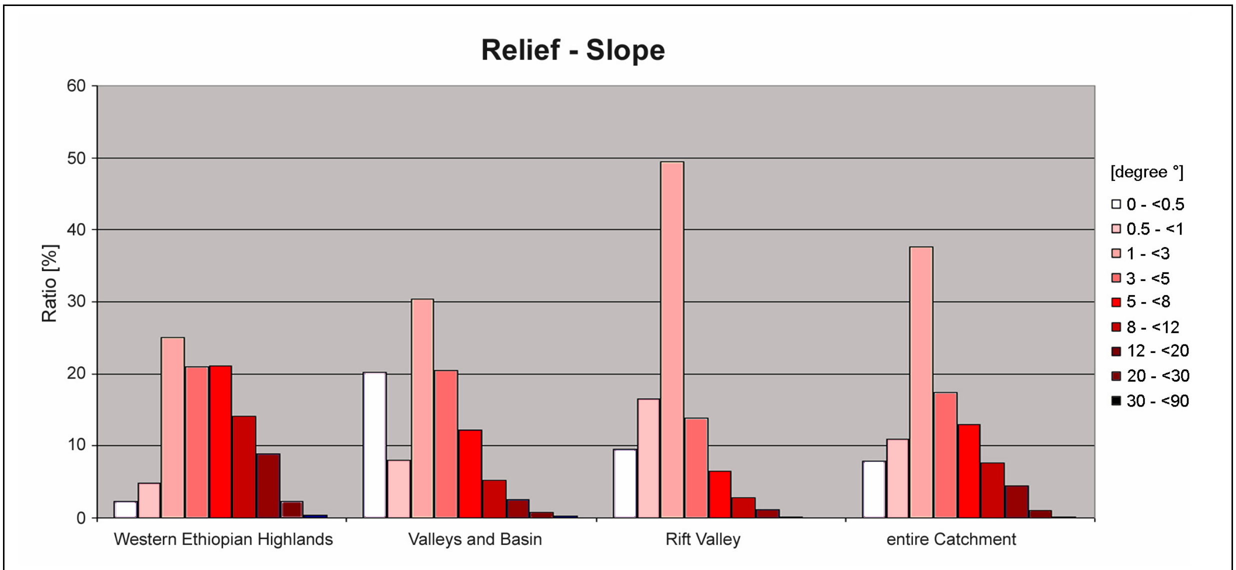

Fig. 25: Slope Classes within the Geomorphological Units

Similar relief characteristics illustrate the dominance of small complex curvature gradients, whereas high curvature gradients are almost missing. The ratios of concave / plan concave relief elements are higher than the convex / plan convex relief elements (fig. 26).

The flow accumulation is distributed as followed in the *Rift Valley*: The highest flow accumulation values coincide with the *Bilate River* and its tributaries. Overall, this analysis shows that channel lengths of the tributaries are much shorter than the length of the *Bilate* (fig. 27).

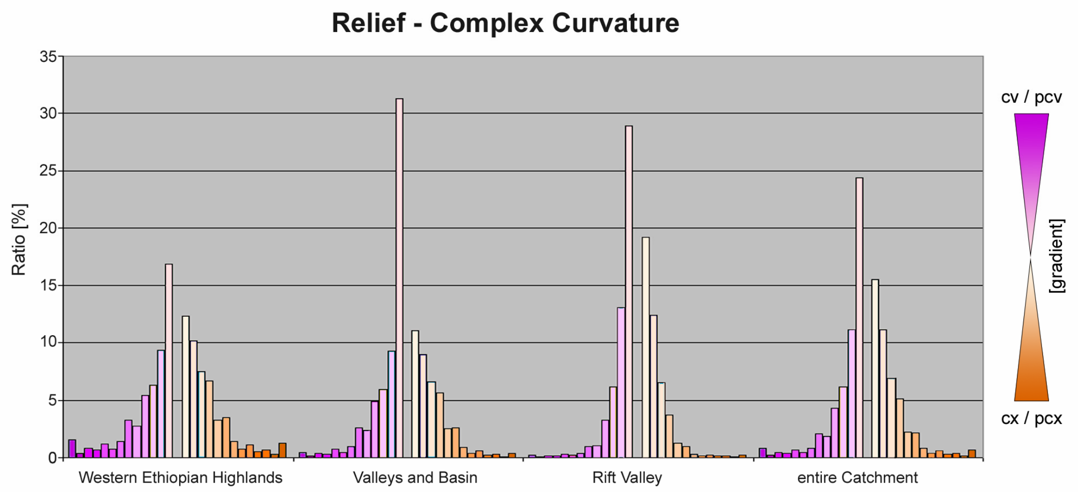

Fig. 26: Complex Curvature of the relief within the Geomorphological Units

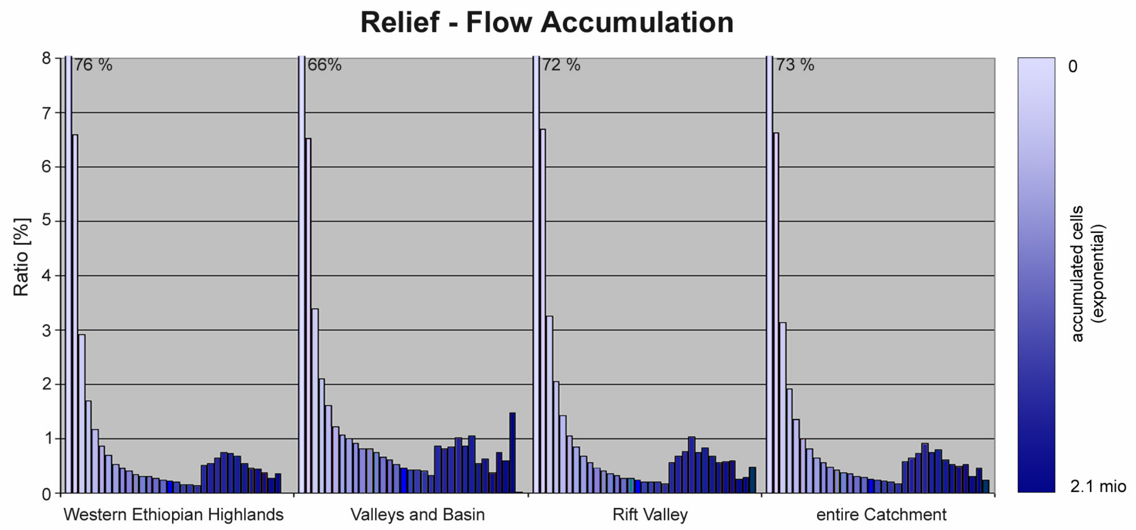

Fig. 27: Flow Accumulation within the Geomorphological Units

The analysis of variance of morphometry characteristics is based on data from a point raster (250 meter distance between each point) covering the entire watershed. Each point was assigned to a geomorphological unit. The differences between the units were detected by an analysis of variance combined with a Scheffé test. For significant differences, a $\alpha < 0.05$ was assumed. The analysis highlights the differences of morphometry between the geomorphological units.

Considering the distribution of the mean values of altitude and slope, not all geomorphological units are significantly different (tab. 7). However, the distribution of relief complex curvature shows only slight differences between the *Western Ethiopian Highlands* and the *Valleys and Basins* as well as between the *Valleys and Basin* and the *Rift Valley*. No differences could be determined between the *Rift Valley* and the *Western Ethiopian Highlands*.

The distribution of flow accumulation values shows no significant differences between all geomorphological units. Highest values are represented in the *Rift Valley* indicating the occurrence of the *Bilate River*. The *Western Ethiopian Highlands* show the smallest values and the smallest standard deviation, whereas in the *Valleys and Basin* the standard deviation and the mean are higher.

However, the values of the complex curvature and the flow accumulation show no significant differences, whereas their mean values strong differ.

Table 7: Analysis of Variance of Morphometry across Geomorphological Units

geomorphological unit	mean	n	standard deviation	significance of Scheffé test (α < 0.05)
altitude [m a.s.l.]				
Western Ethiopian Highlands	2064	346	318	WEH / VB 0.00
Valleys and Basin	2335	98	453	VB / RV 0.00
Rift Valley	1680	409	228	RV / WEH 0.00
slope [°]				
Western Ethiopian Highlands	5.98	338	4.42	WEH / RV 0.00
Valleys and Basin	3.84	98	3.20	VB / RV 0.08
Rift Valley	2.98	420	2.56	RV / WEH 0.00
complex curvature [plan curvature – profile curvature]				
Western Ethiopian Highlands	-0.0017	347	0.1577	WEH / VB 0.84
Valleys and Basin	-0.0099	98	0.0903	VB / RV 0.85
Rift Valley	-0.0022	420	0.0964	RV / WEH 0.99
flow accumulation [count of accumulation cells]				
Western Ethiopian Highlands	121.28	348	937.59	WEH / VB 0.99
Valleys and Basin	443.67	98	1983.88	VB / RV 0.68
Rift Valley	5131.90	420	69075.44	RV / WEH 0.35

The box-plots (fig. 28) clearly illustrate the differences of the mean values of altitude and slope characteristics across the geomorphological units. Based on complex curvature, the *Western Ethiopian Highlands* are not different from the *Rift Valley* and the *Valleys and Basin* in terms of their mean value. But the higher standard deviation of the complex curvature values of the *Western Ethiopian Highlands* indicates differences in the relief characteristics.

The flow accumulation distributions show no clear signal. Here, a high number of small accumulation values occur in all geomorphological units. This levels the difference, even though it occurs. Especially in the *Western Ethiopian Highlands*, only few areas of small flow accumulation are evident, indicating a very hilly relief character. This is accentuated by the distribution of the complex curvature values, which are also higher within the standard deviation and thus indicate a generally strong relief curvature character.

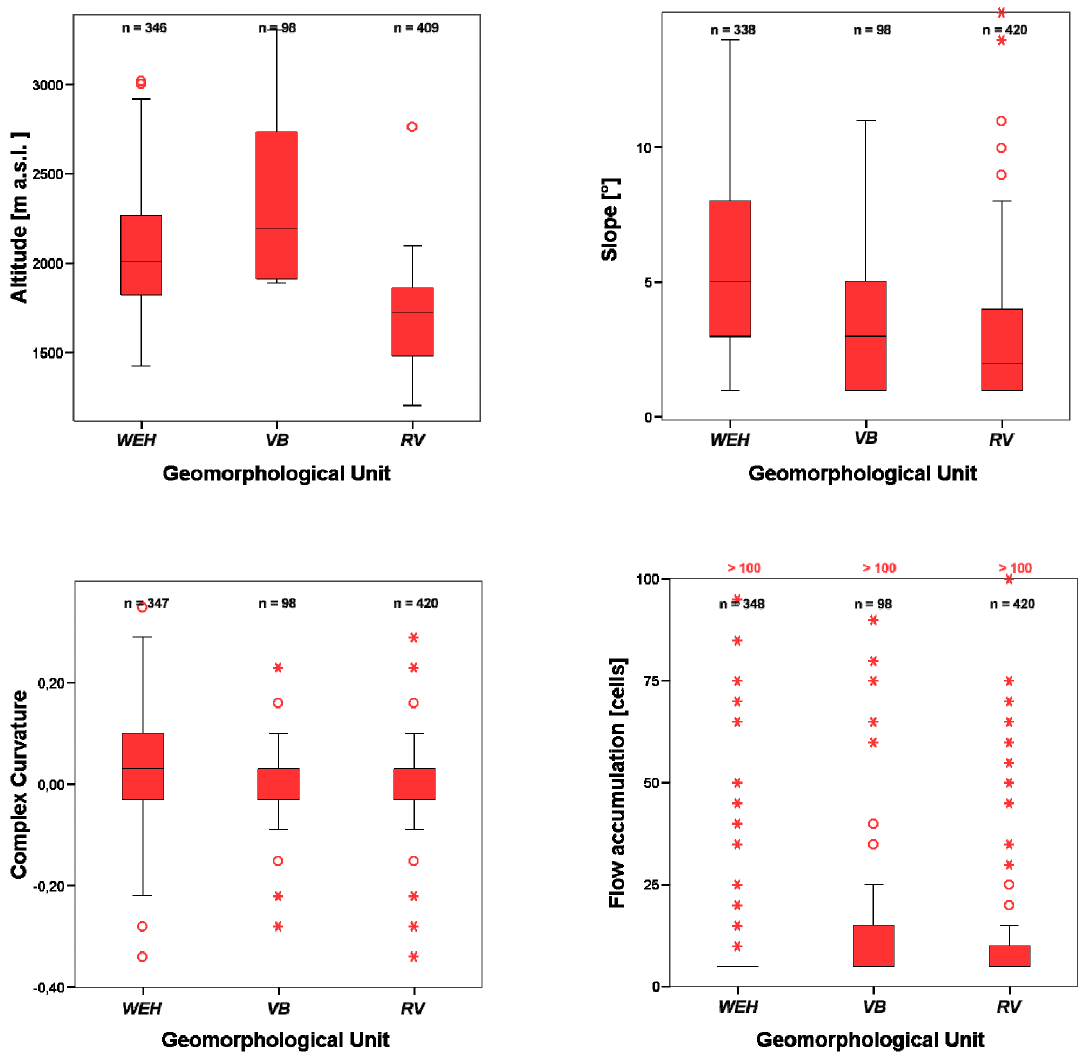

Fig. 28: Boxplots of Morphometry of Geomorphological Units

6.3 Study Sites

Eight test sites have been selected from the *Bilate* watershed and are discussed in detail below. They are distributed across two of the three geomorphological units or are situated in the transition zone between the two (tab. 8). The test sites are either study watersheds of small rivers or study areas representing landscape characteristics of interest (fig. 29).

There were no study sites selected in the *Valleys and Basin* due its inaccessibility, which would have made field work there too time intensive. However, it can be generally stated that this unit is severely degraded in local areas. Additionally, the transition zone to the *Western Ethiopian Highlands* shows severe erosion and soil erosion damages. These damages were not mapped conventionally on the ground, but their location has been recorded with GPS.

The following section describes the study sites in detail. In general, the described precipitation patterns have been interpolated from the available data to show the spatial variability across the study sites (chapter 7.7.1). None of the meteorological stations used for this analysis are located directly in the study sites. Temperature is not discussed in more detail, as data are not available on the sub-watershed scale; it has been generally covered above.

Table 8: Allocation of Study Sites – Geomorphological Units

Western Ethiopian Highlands (WEH)	*Rift Valley (RV)*	*Transition zone Western Ethiopian Highlands - Rift Valley (WEH/RV)*
Ana (chapter 6.3.1)	*Bedesa (chapter 6.3.5)*	*Sedebo (chapter 6.3.7)*
Doyancho (chapter 6.3.2)	*Dimtu (chapter 6.3.6)*	*Agega (chapter 6.3.8)*
Hage (chapter 6.3.3)		
Ofi (chapter 6.3.4)		

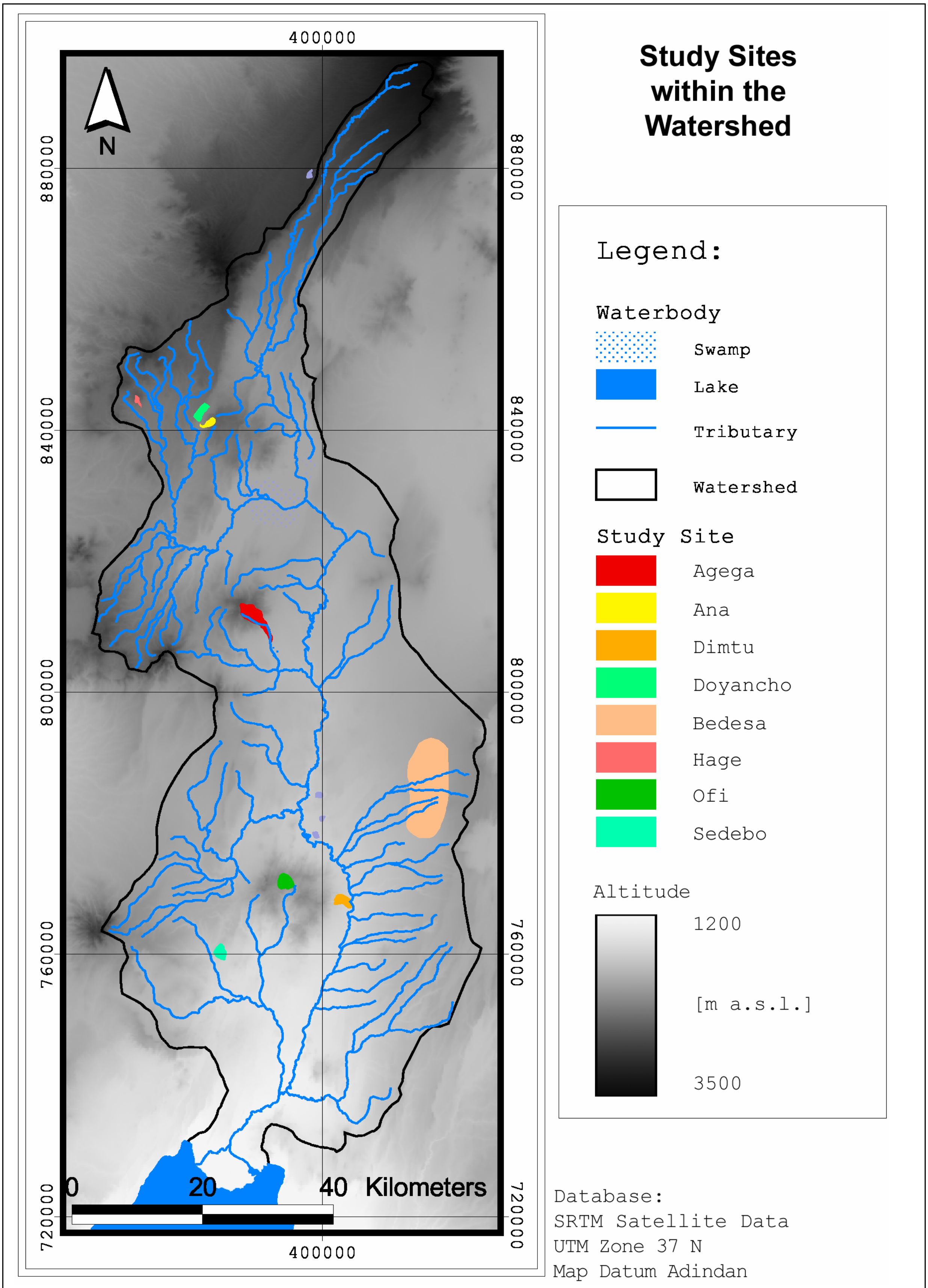

Fig. 29: Study Sites within the *Bilate* watershed

6.3.1 Ana

The study watershed *Ana* (fig. 30) is located in the *Western Ethiopian Highlands* in the north-eastern part of the watershed of the *Bilate River*. It has an area of approximately 1.8 km² and varies in altitude from 2,220 m a.s.l. to 2,550 m a.s.l. (relative relief: 0.14).

The landscape is characterised by moderate to steep slopes, which alternate with almost flat areas at the alluvium and the headwater areas. Soil types differ corresponding to the relief characteristic. The dominant soil type is a chromic Luvisol, but in areas of alluvial infill chromic Cambisol is present. Bedrock is formed by highly weathered quaternary Rhyolites and Trachytes (FAO, 1998).

The watershed is very typical for the *Western Ethiopian Highlands*. Settlements are generally located in the relatively flat headwater areas or in proximity to tributaries or roads. Footpaths are randomly but permanently utilised.

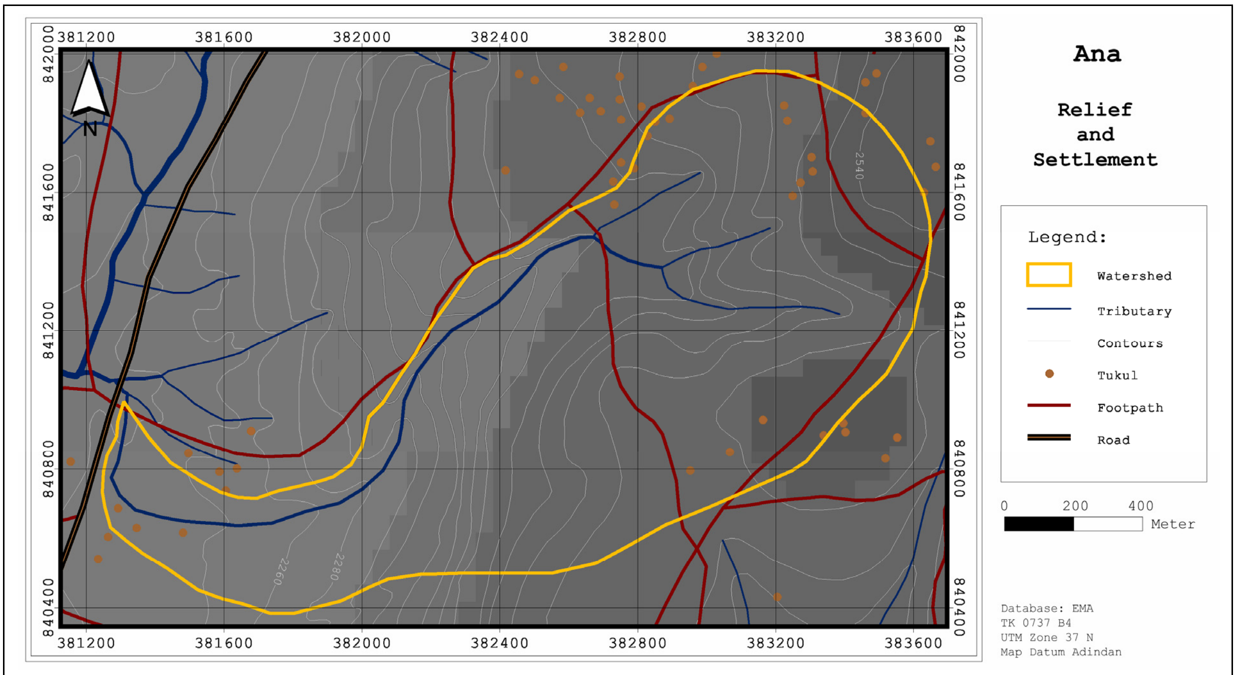

Fig. 30: Ana Study Site: Relief and Settlement

Moreover, the entire area is under cultivation, only very steep slopes in the southern part are not cultivated. A closed area with terraces and reforestation has been established here. Vegetation cover is relatively dense in closed areas and in proximity to the v-shaped channels. Erosion and soil erosion features were only identified on cultivated land. Around settlements no erosion forms exist, except on footpaths due to migration of humans and livestock (fig. 31). In general, the small numbers of cattle are kept confined in the grasslands close to the *tukuls*.

Fig. 31: Captured Surface Runoff

Erosion forms that have developed more recently include two badland areas, several gully systems, tillage edges and rills that occur area-wide. The development of the badlands and the gully systems is dominantly associated with the appearance of Eucalyptus trees on steep slopes and the random development of footpaths. In contrast, rills and tillage edges are a result of farming and develop not only on steep slopes but occur at all gradients in different frequencies. The rills are mostly tributaries to gullies and to the main channel or they end in the fields where they develop small fans. Often the rills can only be detected indirectly by the occurrence of the corresponding fans (i.e. off-site damages).

The average annual precipitation is ranging from 1,326 mm in the valley to 1,447 mm in the headwater areas. The bimodal distribution of the annual precipitation displays the two peaks in March (~180 mm/month) and in July/August (~220 mm/month). Data from the meteorological station *Hossaina*, which is located approximately 10 km from the site, show an average annual precipitation of 1,208 mm for the time period from 1970 to 1996, with a minimum of 852 mm in 1981 and a maximum of 1,732 mm in 1985. The standard deviation is 222 mm/a. However, the daily precipitation variability is higher than the monthly variability. For instance, the highest amount of 63 mm has been measured on April 12th 1993, whereas the average is ranging between 3 and 9 mm/d for April (NMA).

6.3.2 Doyancho

The study area *Doyancho* (fig. 32) is approximately three km long and one km wide. The major slope direction is perpendicular to the length of the area. The site is located in the *Western Ethiopian Highlands* at the opposite side of the valley of where the study site *Ana* is situated. The altitude ranges from 2,200 m a.s.l. to 2,400 m a.s.l. (relative relief: 0.17), the soil type is a chromic Luvisol and bedrock formed by highly weathered quaternary Rhyolites and Trachytes (FAO, 1998).

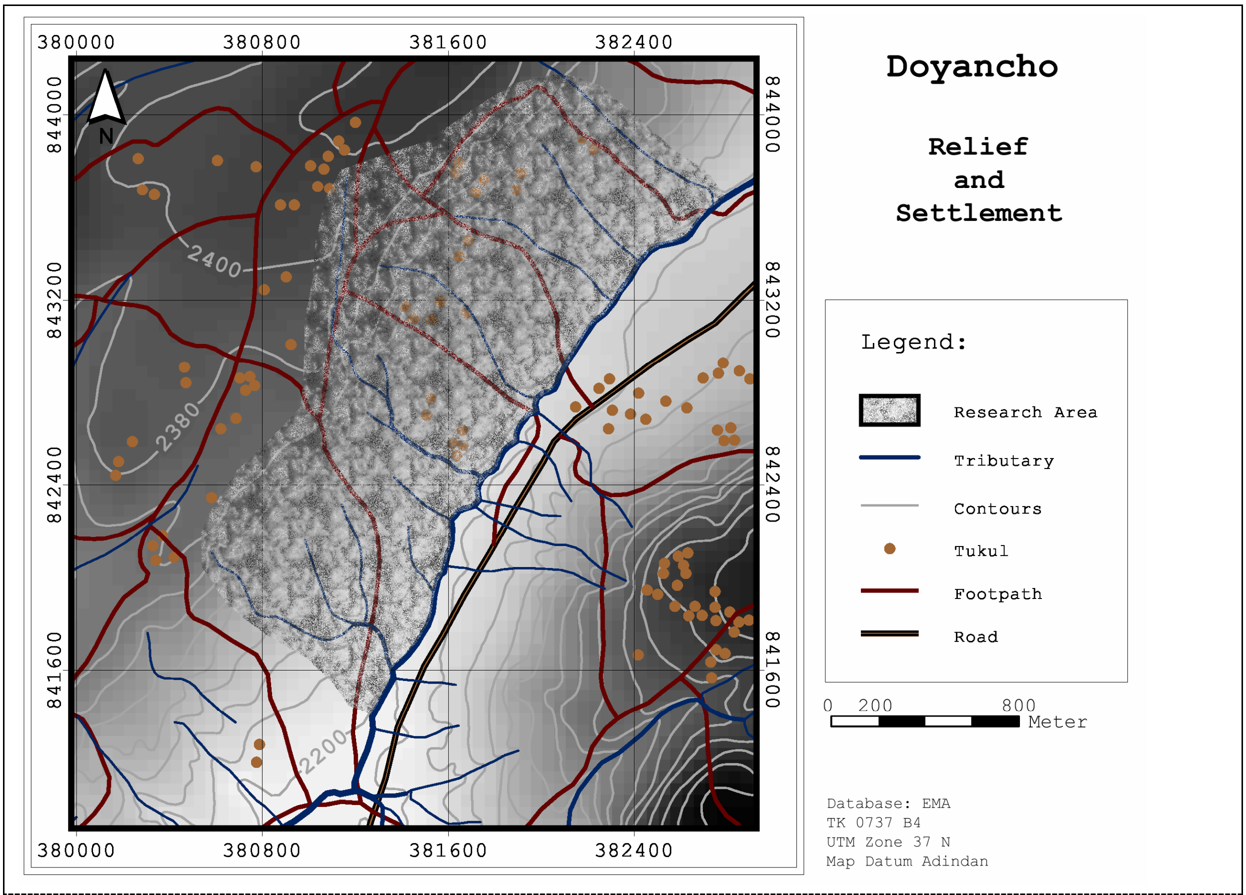

Fig. 32: *Doyancho* Study Site: Relief and Settlement

The upper part of the area is densely settled, with the most settlement starting some 15 years ago due to increasing population pressure (appendix 14.1, interview 5). The area is under intensive agricultural use: *ensete*, maize, wheat and beans are the predominant crops. Erosion forms in the settled areas could not be detected because of very dense vegetation cover. Badlands are developed only on steep slopes, which are planted with eucalyptus trees. These badlands either stop in the concave profile just below the steep slopes or proceed into gully systems which are tributary to the river *Doyancho*. Overall, huge linear erosion processes dominate this area. Less *tukuls* exist in the lower part of the study area, which is used for farming wheat and beans.

Fig. 33: Landslide on Steep Slope

Fig. 34: Badland Areas

In addition to some detected rills, a few gullies and badland areas and many tillage edges occur. These have heights between 20 and 100 cm. Figure 33 shows a small earth slide on a steep slope on cultivated land. Topsoil has been eroded to a maximum depth of approximately 20 cm. Moreover, all detected rills have the same maximum depth. Gullies are locally restricted and in contrast, the badland areas cover an extremely large area. One badland area has an extent of more than 1 km length, 300 m width and 60 m depth (fig. 34). Tributaries of the river *Doyancho* generally have v-shaped character. They show very high vegetation cover, no or little bank erosion or recent incision.

Precipitation is similar to that in the study area *Ana.*

6.3.3 Hage

The watershed of the tributary *Hage* (fig. 35) is approximately 0.75 km² in size. It is located in the *Western Ethiopian Highlands* at an altitude between 2,360 m a.s.l. and 2,640 m a.s.l. (relative relief: 0.13). The channel it not a direct tributary to the *Bilate River* as it develops a huge and widespread fan on a plane. Rather, it is draining into another tributary of the *Bilate*. Bedrock here is quaternary Rhyolite or Trachyte, on which, according to FAO, a chromic Luvisol should be developed (FAO, 1996). However, field survey identifies the development of Nitisols.

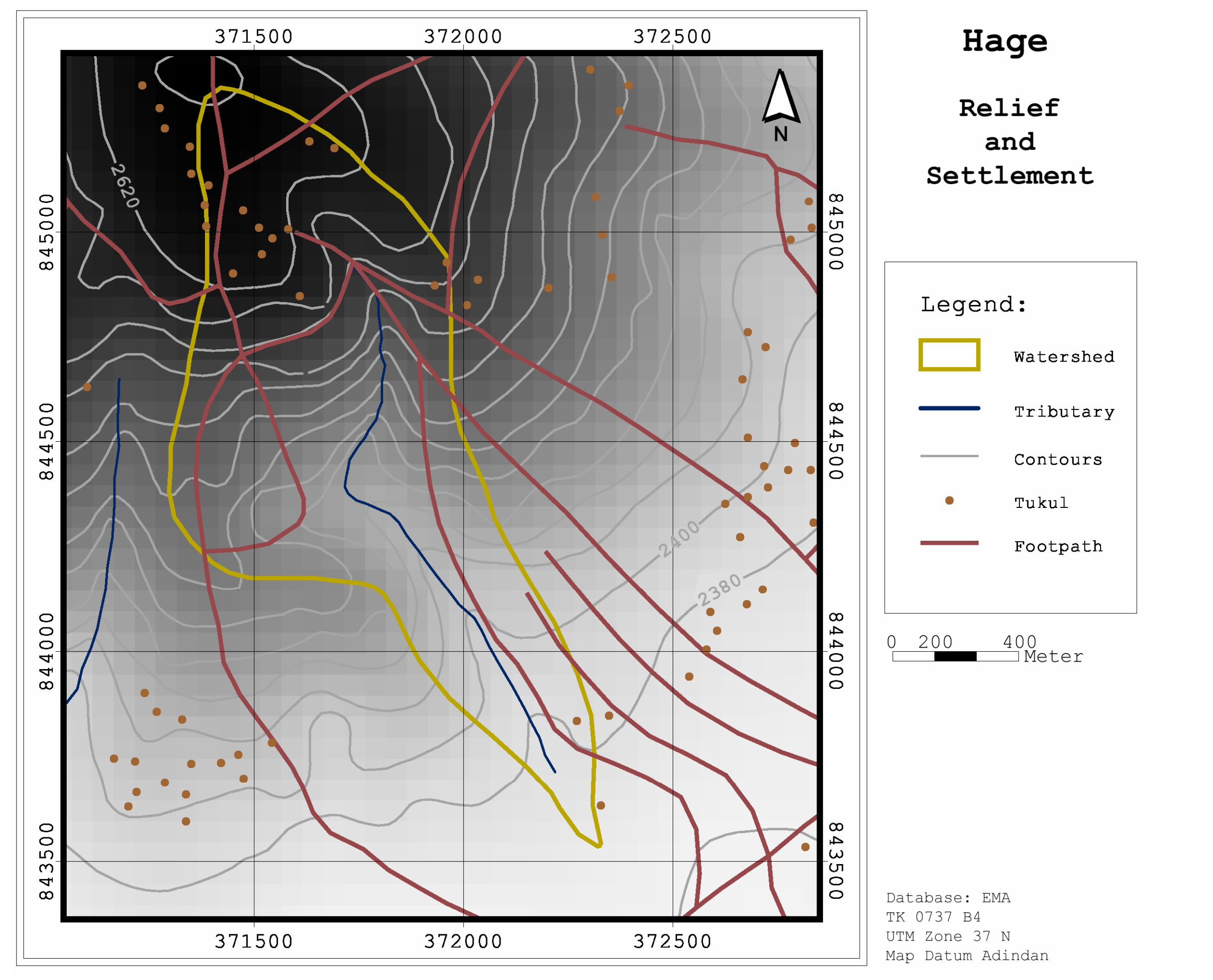

Fig. 35: *Hage* Study Site: Relief and Settlement

The area is densely settled in the headwater areas and on the fan. Intensive cultivation – even on very steep slopes – is dominating: wheat, barley and beans are planted throughout the area and *ensete* grows in the immediate vicinity of the *tukuls* (fig. 36).

Linear erosion forms generally do not exist; only short active rills have been detected in addition to some inactive long rills. These inactive rills have u-shaped cross-sections. In the headwater area close to *Hage* Mountain, badlands are developed on locations where *Eucalyptus* trees are planted. The valleys are all v-shaped but show only few or no soil erosion forms.

In contrast, tillage edges can be found across the watershed, which have different heights between 30 and 100 cm. In addition, changes in profile curvature of the relief shows small landslides. One farmer mentioned that sometimes heavy rainfall causes small landslides (fig. 37; appendix 14.1, interview 1).

Fig. 36: Contour Ploughing

Fig. 37: Landslide on Steep Slope

Soil conservation measures, such as terracing do not exist, but contour farming is common. The basin of the major valley is filled with colluvial sediments. It builds an aquifer with a spring downhill, which is used for local water supply.

The average annual precipitation is approximately 1,385 mm in the plains and 1,543 mm/a in the headwater area. The average monthly variation, computed for 1970-1996, shows a minimum in November with 12 mm and two maxima in May (~170 mm) and August (~260 mm). The standard deviation of the annual precipitation total is 220 mm/a at the meteorological station *Hossaina*, which is located in 10 km distance.

6.3.4 Ofi

The watershed *Ofi* is located on an individual volcano in the southern part of the *Rift Valley* but is actually part of the geomorphological unit *Western Ethiopian Highlands*. The altitude ranges from 2,075 m a.s.l. in the centre to 2,170 and 2,150 m a.s.l. in the south and north, respectively (relative relief to the north: 0.09). *Ofi* is a very small watershed which covers only 0.9 km² and has no distinctly developed drainage system or outlet (fig. 38). In the centre of the watershed three sinkholes exist with depths of more than 20 m. All surface water drains into these sinkholes and disappears into the bedrock. FAO identifies the bedrock as fissured basalt, but the field survey shows that multiple layers of basalt and ash occur at different depths (fig. 39). A chromic Luvisol developed on top of the bedrock (FAO, 1998).

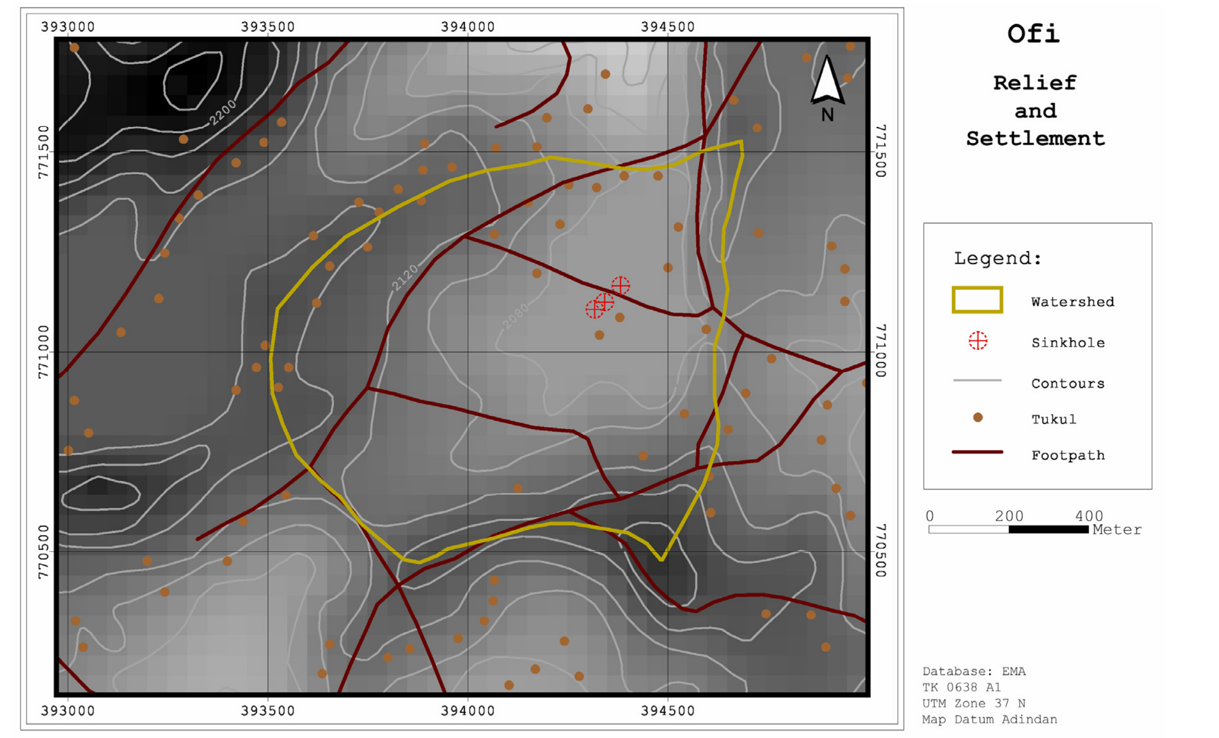

Fig. 38: *Ofi* Study Site: Relief and Settlement

The watershed is densely settled, due to its suitability for cultivation. In contrast to the other study areas the farmers here employ some measures for soil conservation and water harvesting (fig. 40). The small numbers of livestock are kept confined in the grasslands close to the *tukuls*. The damages from erosion and soil erosion exist all over the watershed area, but are only severe on agricultural fields. Most damages are ephemeral rills or small channels, except one small permanent drainage channel that displays the shape and characteristic of a developing gully.

Fig. 39: Ash Layer at Study Site *Ofi*

Fig. 40: Water Harvesting on Fields

Precipitation on this volcano varies strongly throughout the year. The distribution of the computed average monthly precipitation in the centre of the watershed (1970-1996) is bimodal: minima are in November and December (30 / 32 mm) and maxima in May and August (167 / 186 mm). Precipitation is slightly higher at higher elevations. The average annual precipitation is 1,367 mm.

6.3.5 Bedesa

In the *Rift Valley* an area in proximity to a state farm has been selected to assess erosion and soil erosion forms. The study area *Bedesa* (fig. 41) is located east of Lake *Awassa* at the base of a volcano. The extent of the study area is approximately 80 km² and is dominantly characterised by the large fields of a state farm.

Little elevation differences from 1,860 m a.s.l. to 1,990 m a.s.l. are characteristic of the relief (relative relief: 0.02) and profile relief curvature is straight. An exception is the base of the volcano, where profile curvature is concave. Bedrock is Oligocene to Miocene fissured basalt. FAO defines the soil type either as vitric or mollic Andosol. With the soil types, the A-horizon only has a depth of several decimetres, whereas the C-horizon, at some locations, is more than 4 metres deep.

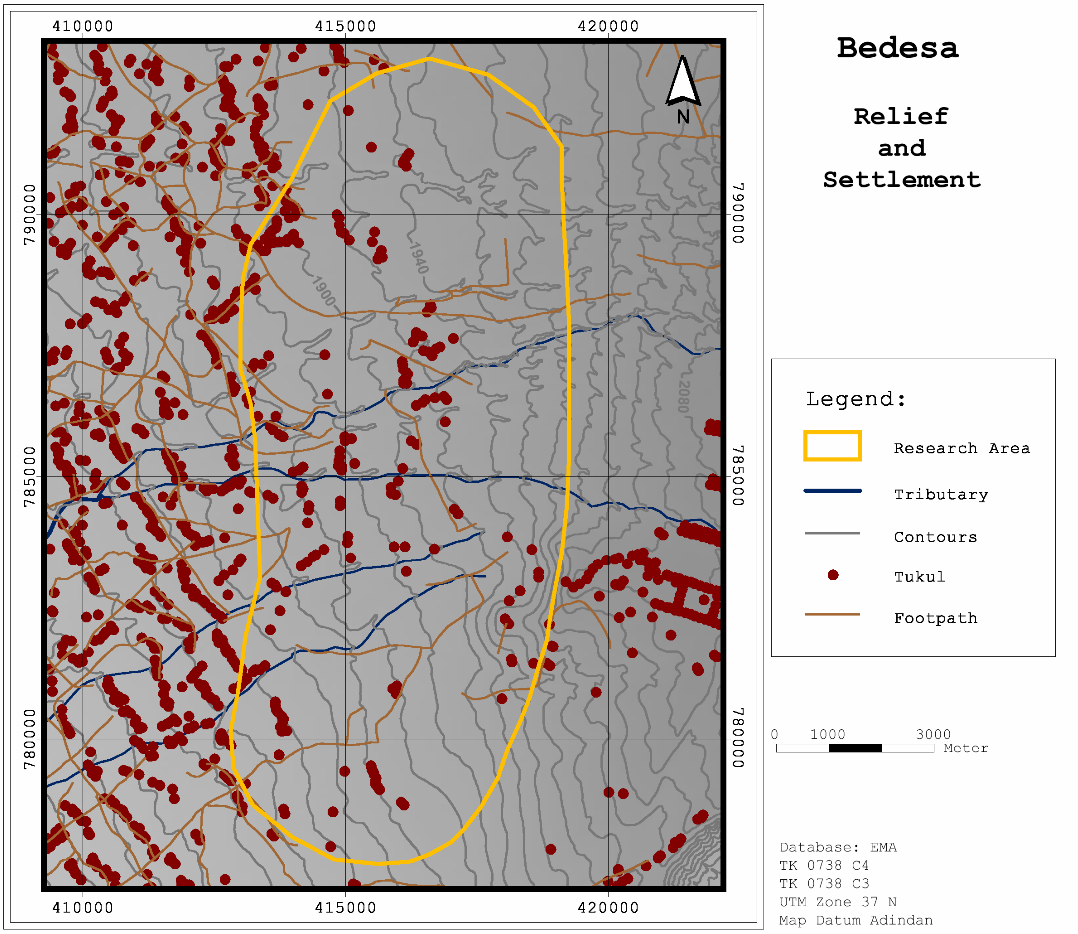

Fig. 41: *Bedesa* Study Site: Relief and Settlement

The area is sparsely settled due to the large extent of the fields within the state farm. In the western part settlement is higher while field sizes are smaller. Small-scale farming is predominant here. Within the study area, only few erosion forms of either scale could be recorded. Some gullies occur, but normally they do not advance beyond the field margins (fig. 42). In the valleys of the tributaries only few small erosion forms have been detected. Whether ephemeral gullies or rill exist is not clear, as mechanical cultivation is levelling out all erosion forms.

Fig. 42: Gully on Grassland within the State Farm

Fig. 43: Wind Erosion on Ploughed Fields

Area wide wind erosion was observed (fig. 43), but will be neglected in this study. Where small-scale farming is practiced only little erosion forms occur. The entire research site can therefore be defined as an area without notable soil erosion.

Precipitation in *Bedesa* varies only little. As no meteorological station is located in the proximity, only computed precipitation data can be shown. The average annual precipitation, computed for 1970-1996, is 1,160 mm. Spatial variations are less than 10 mm/month, whereas a specific distribution could not be determined. The monthly variability is ranging from ~25 mm in November and December to ~150 mm in May and August.

6.3.6 Dimtu

The study site *Dimtu* (fig. 44) is located in the transition zone of an individual volcano (*WEH*) towards the *Rift Valley*. Here, not a defined watershed but an area with typical erosion processes has been selected. Bedrock in the entire area is fissured basalt, on which a vitric Andosol is developed in the eastern part and a lithic Leptosol closer to the *Bilate* (FAO, 1998). The area covers altitudes from 1,500 m a.s.l. to 1,550 m a.s.l. (relative relief: 0.03) and is relatively flat on macro-scale. On a meso-scale, several scarps arise where bank erosion occurs. In some areas barren degraded and weathered bedrock outcrop (fig. 45). The scarps at the realm of the barren degraded land have maximum heights of 4 meters measured at several locations. Highly weathered bedrock is also eroding. This erosion form extends more than 30 km upstream on both sides of the *Bilate* and stops where the transition zone from the *Western Ethiopian Highlands* to the *Rift Valley* is less abrupt.

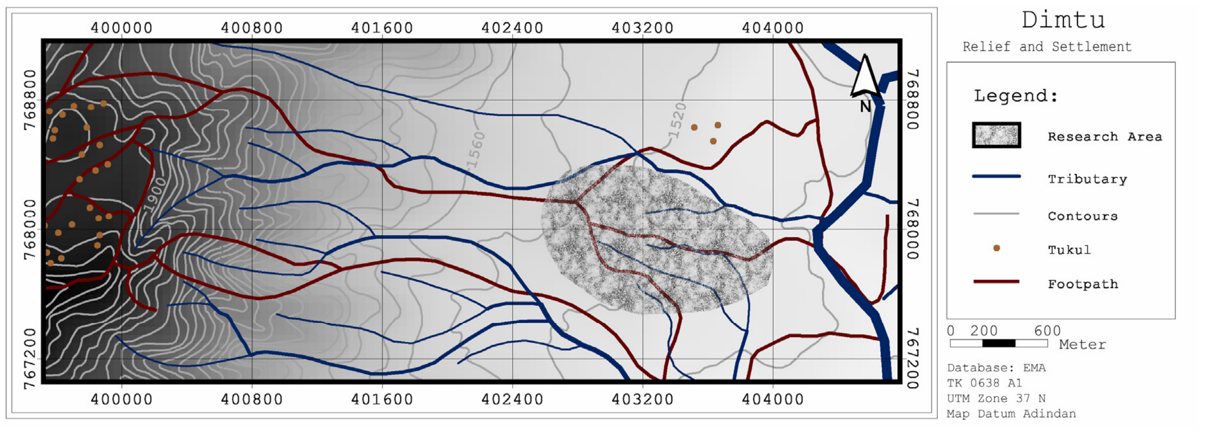

Fig. 44: Dimtu Study Site: Relief and Settlement

The population density, in general, is very low in this study area, and thus, actual impacts by movement of men and livestock are minor. Land use, i.e. cultivation, was much more intensive in the past (appendix 14.1, interview 2), but is now, due to severe soil degradation, limited to extensive grazing practices.

Fig. 45: Severe Erosion and Soil Erosion Damages

Average annual precipitation, as recorded at the meteorological station *Dimtu* in two kilometre distance, is 956 mm with a standard deviation of 215 mm/a (n=27). This highlights the extreme precipitation variability of the area. Monthly precipitation variability is even higher – while no rainfall was recorded for March 1973, March 1970 experienced 304 mm. The standard deviations of the monthly precipitation sums range from 18 mm in December and 78 mm in March (NMA).

6.3.7 Sedebo

The study watershed *Sedebo* (fig. 46) is located in the transition zone from the *Western Ethiopian Highlands* towards the *Rift Valley*. The watershed covers an area of 3.5 km². It includes two channel systems and varies in altitude from 1,500 m a.s.l. to 1,700 m a.s.l. (relative relief: 0.05). According to FAO the soil type eutric Vertisol should occur here, but the field survey could not verify this information. Except in the accumulation areas in the south, Nitisols occur throughout the watershed. The soil type in the south could not be determined, as accumulation material covers the soil. The bedrock is fissured Oligozene to Miozene basalt (FAO, 1998).

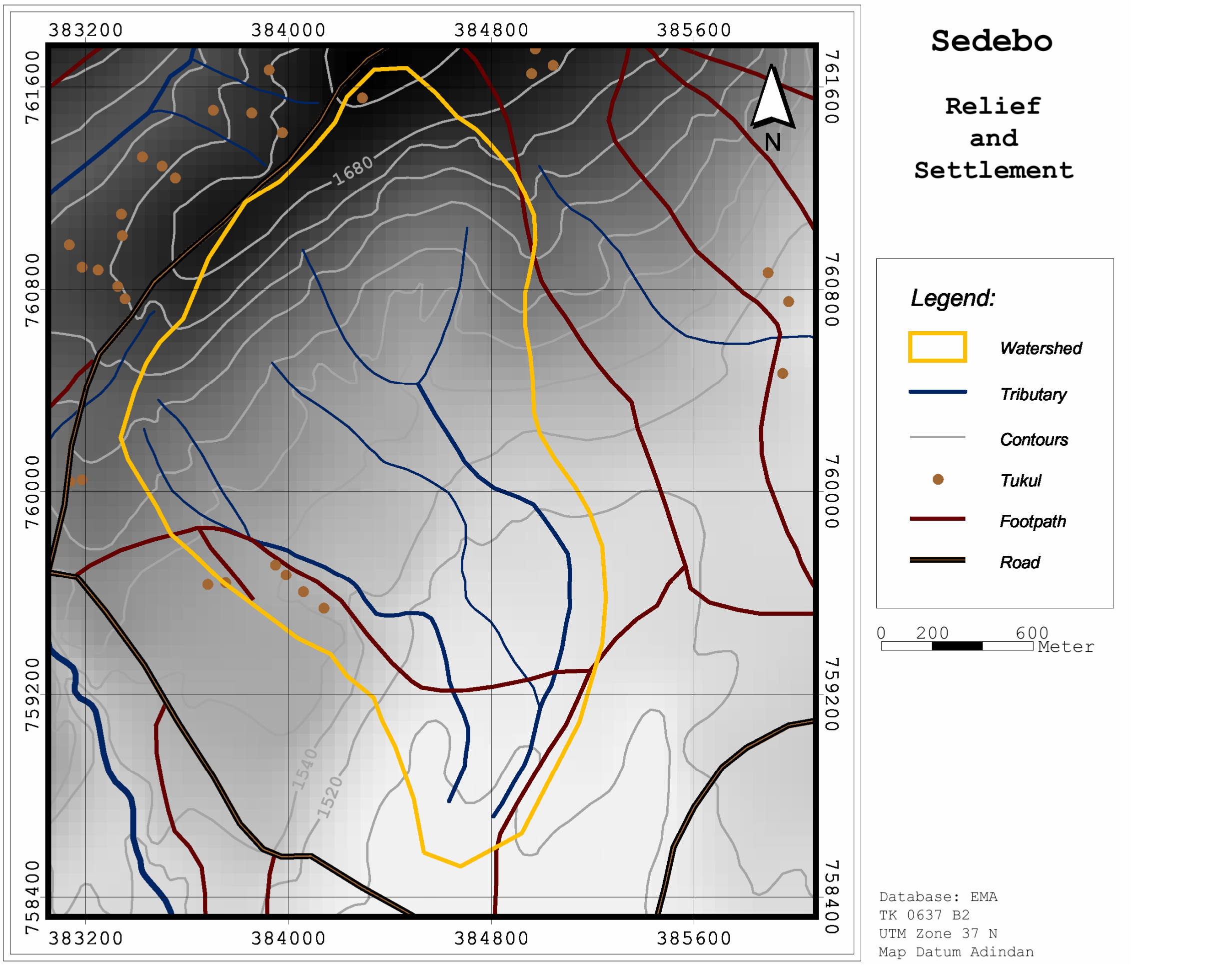

Fig. 46: *Sedebo* Study Site: Relief and Settlement

80% of the study area had been badlands in former times, but is now closed for agriculture and grazing. Therefore, only some settlements exist and agriculture is rare. However, until today the damages from erosion and soil erosion are severe. Huge gully systems are draining the area and form widespread fans in the southern part. Very dense vegetation occurs next to badlands but does not cover the badlands itself. Here, the soil is washed out completely. The gullies are deeply incised into the soil and further into the underlying old s1ediments or highly weathered Saprolite (fig. 47).

Fig. 47: Badlands and Total Soil Loss

Fig. 48: Sedimentation in a Channel and on the Alluvium

These deep and intensive erosion damages cause high sedimentation of the eroded material within the channels and on the alluvium (fig. 48). In the centre of the watershed several badlands form one huge barren degraded area with some islands of vegetation in between. Here, also Saprolite outcrops.

The average monthly precipitation data recorded at the meteorological station *Bedessa*, which is only 3 km in distance, show a bimodal distribution throughout the year. For the time period 1970-1996 the average monthly precipitation shows its minimum in December (17 mm) and one maximum in May (147 mm) and another in July (152 mm). The standard variation for the same time period is ranging between 18 mm/month for December and 80 mm/month in August (n[month]=27). The variation of the annual precipitation totals throughout the time period is also quite high. The minimum has been 800 mm/a in 1974, whereas the maximum in 1979 reaches 1870 mm/a. Here the standard deviation is 260 mm/a.

6.3.8 Agega

The study watershed *Agega* is located in the transition zone from a volcano of the *Western Ethiopian Highlands* to the *Rift Valley* (fig. 49). It is representative of the processes of erosion and soil erosion and its forms that occur throughout similar relief positions. The watershed has an extent of approximately 11.3 km², ranging from 1,780 m a.s.l. to 2,630 m a.s.l. (relative relief: 0.09). The major channel in *Agega* originates in the highland areas within the watershed and drains into the valley of the *Bilate*. However, this channel is not a direct tributary of the *Bilate*.

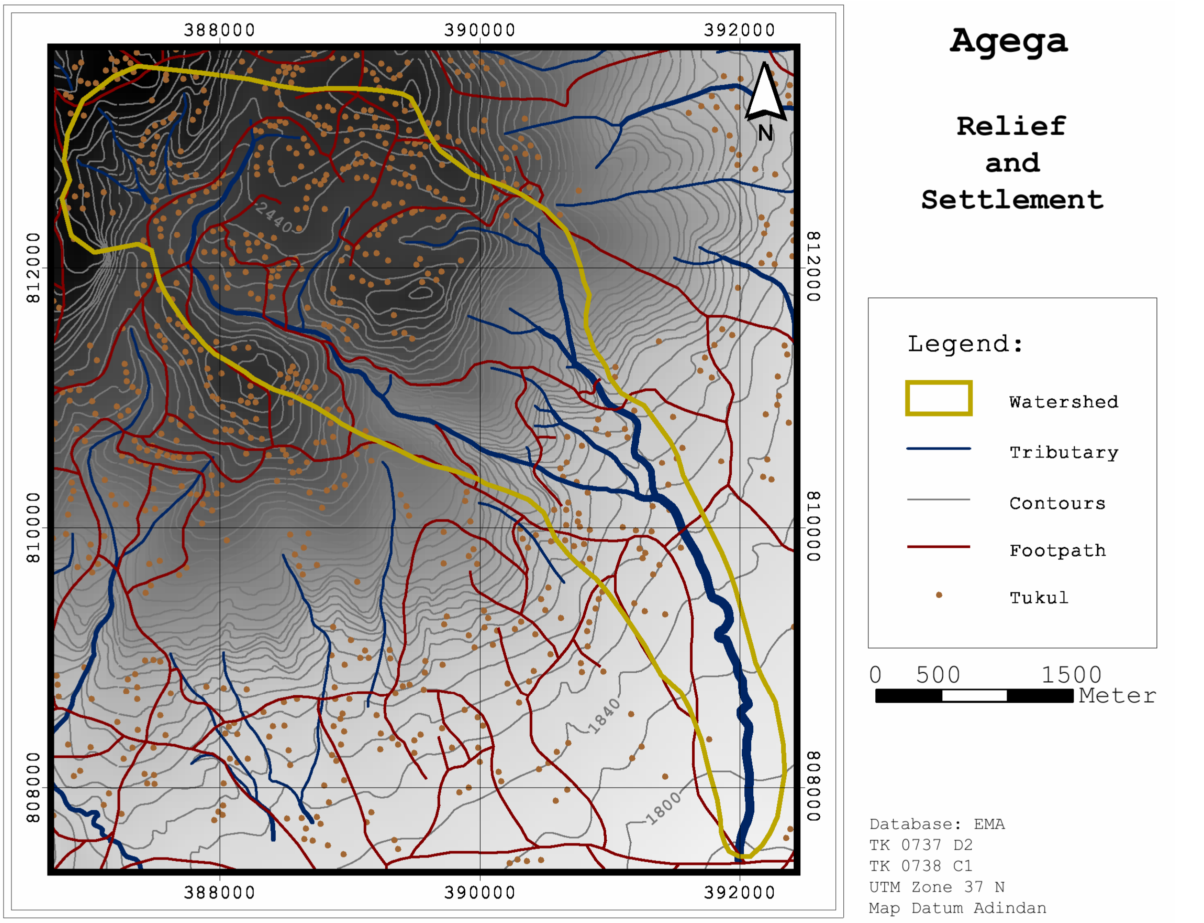

Fig. 49: *Agega* Study Site: Relief and Settlement

The landscape of *Agega* consists of three distinct types: the headwater areas are characterised by moderate slopes, which are incised by several small tributaries. Several plateaus are embedded in headwater areas; the steep slopes from the headwater to the alluvium also include some small flat areas. The alluvium itself is almost flat and a distinct drainage system does not occur. However, the main channel is deeply incised into the alluvium forming a u-shaped channel bed.

According to the FAO soil map two soil types are present at *Agega*. First, chromic Luvisols dominate the headwater area and the steep slopes, whereas, second, vitric Andosols occur in the alluvium. The underlying bedrock in both cases is fissured basalt (FAO, 1998). Although FAO soil map is presented at the scale 1:1,000,000 the different soil types could be confirmed in the field.

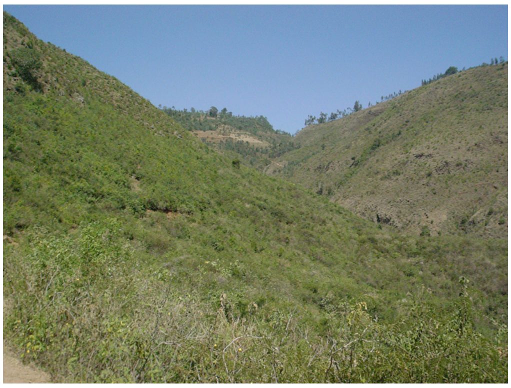

Fig. 50: Closed Area on a Steep Slope

Fig. 51: Colluvium and Alluvium

The headwaters of *Agega* are utilized for intensive farming. Further downstream, the steep slopes towards the alluvium are closed for public use (fig. 50). Farming, as well as grazing is prohibited, as large badlands had developed some 15 years ago (appendix 14.1, interview 3). The badlands have largely recovered under the closure and only small erosion forms are visible. On the small even areas that intersperse the steep slopes, settlements and cultivation are common and soil erosion processes have been detected there. The alluvium in the lower area is characterised by smooth slopes and relief curvature gradients (fig. 51). This area is settled and used for agriculture, mainly intensive maize and teff cultivation.

Soil erosion occurs in the form of rills across the study site, while gullies appear adjacent to footpaths. U-shaped channels are affected by bank erosion. The rills generally do not develop into channels but form small fans. They always occur in plan convex relief elements, even at very small curvature and slope gradients. The gullies end in fans and are not tributary to the larger channels.

The closest meteorological station to *Agega* is *Alaba Kulito*, located approximately 7 km from the study site at an altitude of ~1,780 m a.s.l. In *Agega*, average annual precipitation ranges from 1,116 mm in the lowlands to 1,575 mm in the headwaters. Average monthly precipitation, recorded at *Alaba Kulito* (1970-1996), follows a bimodal distribution. The precipitation maxima occur in May (132 mm) and from July to September (127 / 152 / 124 mm) respectively. December is the month with the lowest precipitation (19 mm). The standard deviation of the average monthly precipitation is always greater than 40 mm/month and thus, highlights the high intra-annual (i.e. seasonal) variability of precipitation in the area. The inter-annual variability (1970-1996) is also high, varying from 651 mm (1974) to 1,508 mm (1987), whereas the standard deviation is 204 mm/a (NMA).