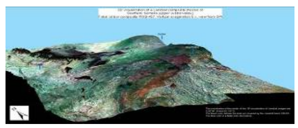
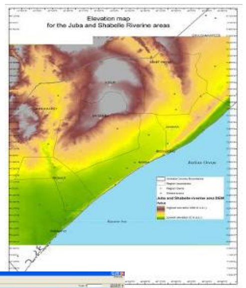
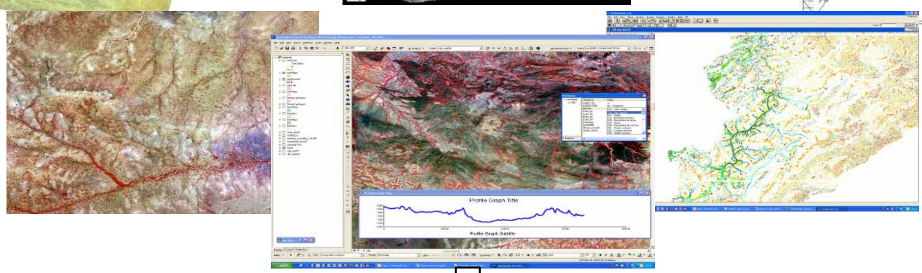
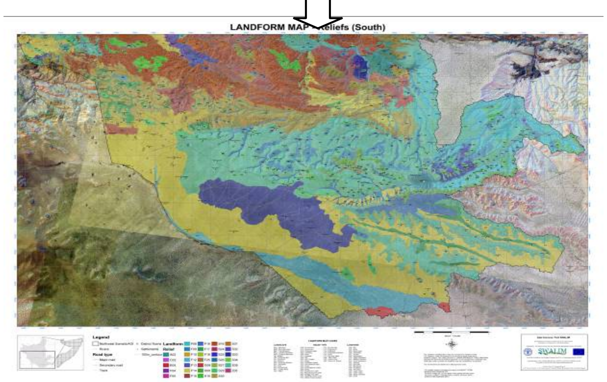
Landform of Selected Study Areas in Somaliland and Southern Somalia

Integrated Landform Mapping Approach at semi-detailed scale using Remote Sensing and GIS techniques









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List of acronyms

AOI – Area of Interest
DTA – Digital Terrain Analysis
DEM – Digital Elevation Model
FAO – Food and Agriculture Organization
FS – Field Survey
GIS – Geographical Information System
RS – Remote Sensing
SRTM – Shuttle Radar Topography Mission
SILHMA – Somalia Integrated Hierarchical Landform Mapping Approach
VImI – Visual Image Interpretation

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INTRODUCTION

The present exercise is an output of Activity 2.B.8 of the FAO - SWALIM Project.

The main focus is on Landform mapping of two Areas of Interest (AOI) in Somalia, using Remote Sensing and GIS. The two AOI are located in the north-west and the south of Somalia, respectively. In the north-west AOI it was possible to carry out two months of fieldwork, but this was, and has not, been possible for the southern AOI. Methodology developed during the exercise will allow incorporation of collected field data in the southern AOI as and when general logistic and security conditions permit it.

The aim was the production of new datasets on the physical environment of the two AOI, as part of a Natural Resource Inventory and as one of the contributing layers for a land evaluation exercise.

The present exercise was been carried out at a semi-detailed scale of 1:50 000 to 1:100.000, and currently constitutes the most recent, detailed and consistent dataset over large portions of the Somali territory.

Existing previous datasets about landforms of Somalia are two early FAO products: FAO SOTER (Global and national soils and terrain digital database, 1995), and FAO Africover. Both have quite different characteristics (aim, scale, methods, and year). FAO-SOTER used a scale of 1:1 000 000, aimed at defining Soil and Terrain through an hierarchical landform classification ordered in two levels (1st and 2nd). FAO-Africover used a scale of 1:350 000 for its landform map (while its landcover dataset had a scale of 1:200 000), aimed at mapping landcover while adopting the same classification criteria of FAO-SOTER for landforms.

Land suitability assessments at a semi-detailed scale in two AOI was one of the main aims of the SWALIM Project; hence a landform map had to be produced as a basis for that activity and also as the main input to soil survey activities.

A hierarchical system of landform classification (geopedologic approach) was selected, with three orders that integrate purely morphological (SOTER approach and geomorphometry) and morphogenetic attributes.

The results are of two different types: a main outcome, and several sub products. The main outcome is a new landform dataset (maps and GIS layers) for the selected AOI, aimed at natural resources inventory with a close focus on soil map production.

The sub products are: 1) a new legend; 2) a digital system for the input of polygon attributes adopting the *ad hoc* legend; 3) a set of digital semi-automatic landform classifications; 4) a digital mask for the input of field forms; 5) the present report describing the overall process of landform mapping.

In this report the conceptual background, data and methodology, as well as results and recommendations are presented.

1.1 CONCEPTUAL BACKGROUND

Geomorphology, or the interdisciplinary and systematic study of landforms and their landscapes as well as the earth surface processes that create and change them, is a factor in soil formation (Gerrard 1992; Brady & Well 2002; Schaetzl & Andersons 2005), which is why it also plays a very important role in natural resource inventory and land evaluation.

We considered it important to combine qualitative and quantitative approaches in order to generate a proper landform map that would take into account the morphographic, morphometric, morphogenetic and morphochronologic attributes of the land surface. To achieve this, we used all available spatial layers starting from topographic maps, satellite images and extracting topographic parameters from a DEM (parameterization).

In geomorphology, unlike in geology or soil science, there is no unequivocal standard for mapping land features, or terminology to do this. Different types of maps, depending on the aims, materials and scale of the work to be done, have been developed.

There are essentially four alternative methods of terrain classification in which geomorphology plays a central role: 1) Landform mapping, terrain classification or land system surveys; 2) morphological mapping; 3) geomorphological mapping *sensu stricto*; and 4) the parametric/morphometric approach.

In this study, instead of a pure or applied geomorphological map, the aim was to develop a landform map. The primary purpose of a landform map is to show, at an appropriate scale and in an intelligible way, the distribution of landforms and to characterise the processes that sculpture landforms and modify materials.

The concept of landform mapping or terrain classification has been developing since the early 1960s, following easier access to aerial photography. It arises from the concept that all landscapes can be divided into smaller units.

As stated by Ollier (1978) "most [of the landscape] will be made up of a number of repeated landforms, and the landforms in turn will consist of assemblages of still smaller landscape units such as ridge tops, mid-slopes, valley floor, etc. They [geomorphologists] can built up an inventory of landscapes and landforms in the form of maps, diagrams and descriptive material. Furthermore, if the units of the landscape brought out by these techniques have a high correlation with economic aspect of land or land use, then the inventory of terrain information will be a potentially useful tool."

At the time that Ollier wrote the above, few field experiences had been developed among which the Australian ones were the most extensive in use. Users were attempting to develop terrain or land classification using a variety of different terms for identifying land units, but most adopted the principle of an hierarchical landscape classification. Some of these included ITC classification; CSIRO (Australian) land research and regional survey classifications; MEXE (Military Engineering Experimental Establishment) developed at Oxford and applied in the field in Uganda, Kenya and Swaziland; USSR methods (Solentsev, 1962) considering the landscape as an ecological unit, and focusing also on geochemical landscape characterisation. A brief summary of these different systems is given in Table 1.

Table 1: Comparison between different methods of terrain or landform mapping adopted by different schools

Level	Main characteristics	Scales	Physiographic classification	ITC Terrain classification	Oxford MEXE	CSIRO Geomech. Div.	CSIRO Land Research and Reg. Surv.	DOS	Soviet System	Geopedologic Approach (Zinck, 1988)
Geomorphological province	**Highly generalised**. genesis, climate and lithology are most important. Display a small range of surface form and properties expressive of a lithological unit or a close lithological association of comparable geomorphic evolution.	**<1:250 k**	Physiographic province	Terrain province	Land region	Terrain province	Complex land system	Land region/ province	Landscape	Landscape
Main geomorphological unit	**Moderately generalised**. relief, lithology and genesis are the main criteria for the classification. Display a recurrent pattern of relief genetically linked to terrain component.	**>1:250 k**	Main physiographic unit	Terrain system (pattern)	Land system	Terrain pattern	Land system	Land system	Mestnosti (and Urochischa)	Relief type (& lithology)
Geomorphological unit	**None, or minor generalization in area classes**. Detail may be generalised. Relief, lithology and genesis are the main classification criteria. Reasonably homogeneous and fairly distinct from surrounding terrains.	**>1:50 k**	Detailed physiographic unit	Terrain unit	Land facet	Terrain unit	Land unit	Land facet	Urochischa	
Geomorphological detail	**No generalization in area classes**. No or minor generalization in details. Relief is most important classification criterion. Basically uniform in land form, lithology, soil, vegetation and processes.	**>1:10 k**	Physiographic element	Terrain component	Land element	Terrain component	-	-	Facies	Landform

Over the past decade, many landform mapping exercises have been carried out using the automatic parameterization of DEMs, an exercise also known as geomorphometry. Geomorphometry includes derivation of primary and secondary topographic attributes from DEMs, and automatic (both unsupervised and supervised) landform classification techniques. Results are promising, but as they are based only on quantitative approaches, some very important thematic (qualitative attributes) aspects are frequently omitted.

Other problems may arise from using a purely geomorphometric approach. In the case of identification of landforms being applied to soil and land evaluation at a semi-detailed scale (as in the SWALIM studies), it is important to also define morphogenetic differences between landforms. This involves identifying the different agents contributing to current landforms, because the same morphogenetic processes also affect soil types and distribution. In many cases, basic landforms that can be clearly identified by means of geomorphometry (plains, valley, ridges, peaks, saddles, etc.) can result from different morphogenetic processes. These are called convergent landforms, where two or more morphogenetic processes have led to the construction of the same land feature/s.

This means that different soil-forming environments can be identified as only one, if using a purely geomorphometric approach or digital terrain analysis. As an example, a plain can result from many different morphogenetic factors that have influenced its soil formation in different ways. A plain can be the result of a river wandering in its alluvial plain, or it can be derived from wave erosion on a coastal plain, or it can be the final result of a complete karstic process of erosion. All of the above processes give rise to different soil types, which could also result from the horizontal attitude of the underlying bedrock.

In the same way, a hill can be a result of blocks being uplifted by faulting, or of prolonged denudational morphogenetic processes acting on a slope, influenced by rock structure. With a purely digital terrain analysis we can easily identify the landscape morphology (that is, identify the geometric shapes of the topography in a 3D reference space) but not the factors that formed them.

A modern approach to landform mapping should also consider the information obtainable from DEM analysis, both in terms of primary derived products and more complex digital terrain classification.

It is our strong belief that comprehensive mapping of landform for land evaluation purposes should take into consideration:

- Morphometry - analysis of the geometry of land surface features;
- Morphogenesis - analysis of the genetic factors of land surface features;
- Morphochronology - analysis of the time factor in the creation of land surface features;
- Morphodynamic - analysis of the levels of activity of different features (active, inactive or quiescent).

The above, therefore, are the reasons why these studies decided to combine the morphological/morphometric approach with the morphogenetic one.

Land systems mapping has already proved to be a very efficient method for rapid classification of extensive land areas and has been widely used in land resource assessment projects around the world. It has been widely adopted by the FAO for land evaluation exercises.

Among hierarchical landform classification systems, a new approach is that of Zinck (1988) called the Geopedologic approach (GP approach).

Following Zinck (1988) and Farshad (2001), geomorphology contributes to two activities within the complex processes of soil survey, namely soil mapping (classification and location) and soil formation (soil-forming factors). In both cases, geomorphological processes and environments influence formation, types and position of soils. Geomorphic processes also indicate the time factor (morphochronology), through which degrees of soil development are estimated.

Basically, incorporating geomorphology into the various steps of a soil survey operation will add useful information.

Different methods of using geomorphology for soil survey have been applied, a few examples of which are given here (Zinck, 1988):

- Terrain analysis (ITC approach explained in van Zuidam, 1985);
- Physiographic approach of CIAF-ITC (in Colombia), and of CSIRO (Australia);
- Land-type approach (ITC Soil Division approach, started under Buringh, further developed under Vink, Bennema and Goosen);
- SOTER legend (FAO, 1993), developed at ISRIC, Wageningen, The Netherlands (under directorship of Sombroek). This is a universal legend for world soils and a terrain digital database, to be used at a scale of 1:1 000 000.

These and many other approaches aim mainly at establishing mapping legends adapted to local or regional conditions, and in general a solid structure is lacking. This problem arises from the fact that geomorphology does not yet enjoy a taxonomically structured land-form classification, unlike the disciplines of botany, geology and soil science.

From a RS and GIS perspective, with the aid of a field survey it is quite possible to define morphometry and morphogenesis at scales between 1:100.000 to 1:50.000, while morphochronology and morphodynamics require more intensive field surveys at a more detailed working scale.

The GP approach (Zinck, 1988; Farshad, 2001), following hierarchical and taxonomic soil classifications, defines at least six different categorical levels of land classification (moving from the biggest to the smaller):

6- Geostructure (order)
5- Morphogenetic environment (suborder)
4- Landscape (group)
3- Relief/moulding (subgroup)
2- Lithology/facies (family)
1- Landform (subfamily)

6 - Geostructure is defined as: large continental portion characterised by a specific geological structure.

Possible ***Taxa*** are:

- Cordillera: a system of young mountain ranges
- Shield: a relatively stable continental block
- Geosyncline: a large sedimentary basin

5 - Morphogenetic environment is defined as: broad type of biophysical medium.

Possible ***Taxa*** (on the basis of various environments) are:

- Structural : controlled by internal geodynamics;
- Depositional (carried by water, ice, wind);
- Erosional (denudational);
- Dissolutional (e.g. karst);
- \- Residual (e.g. inselberg)
- Mixed (e.g. structural, dissected by erosion)

4 – Landscape is defined as: large portion of land characterised either by a repetition of similar relief-types or an association of dissimilar types.

Possible ***Taxa*** are:

- Valley
- Plain
- Peneplain
- Plateau
- Piedmont
- Hilland
- Mountain

It should be borne in mind that in some cases the concept of landscape is quite ambiguous, for instance, when talking about valleys. There are many different definitions of valley, according to the different points of view from which they are studied.

3 - Relief-type/Molding are defined as: *Relief-type*: geoform determined by a given combination of topography and geological structure (e.g. cuesta type of relief); *Molding*: geoform determined by specific morphoclimatic conditions or morphogenetic processes (e.g. glacis, fan, terrace, delta).

Possible ***Taxa*** are:

Structural	Erosional	Depositional	Dissolutional	Residual
Depression Mesa Cuesta Creston Hogback Bar Flatiron Escarpment Graben Horst Anticline etc.	Depression Vale Canyon Glacis Mesa Hill Crest etc.	Depression Swale Floodplain Flat Terrace Mesa etc.	Depression Dome Tower Hill Polje Canyon Dry vale etc.	Planation surface Dome Inselberg Tors etc.

2 – Lithology is defined as: the petrographic nature of hard rock and facies of the soft cover formations.

Possible ***Taxa*** are:

- -Rock classes
- -Material facies, such as glacial, periglacial, alluvial, colluvial, littoral or coastal, mass movement, volcanic, mixed, anthropic, etc.

1 – Landform is defined as: the generic concept for the lowest level of the proposed hierarchical system. Landform = topographic form + geomorphic position + geochronologic unit = soil formation frame.

Possible ***Taxa*** are: summit, shoulder, overflow basin. Landforms are grouped into four general categories, with sub-categories:

A) Controlled by geological structure:
   1. Structural
   2. Volcanic
   3. Karstic

B) Controlled mainly by morphogenetic agents:
   1. Nival, glacial and preglacial
   2. Aeolian
   3. Alluvial and colluvial
   4. Lacustrine
   5. Gravity and mass movement
   6. Coastal

C) Banal geoforms (dissected hills and ridges)

D) Fluvial landforms and depositional systems

1.2 Somalia Integrated Hierarchical Landform Mapping Approach - SIHLMA

In the present exercise we started from the GP approach, then integrated and modified it. Firstly, the main difference lay in the fact that, instead of aiming at creating a soil map using aerial photography, the objective was to create a landform map using satellite imagery. The types of spatial and spectral information that can be extracted from aerial photography or a satellite image are quite different, even though they may be complementary. Furthermore, we integrated the visual image interpretation with Digital Terrain Analysis, giving rise to a integrated landform mapping.

This approach has been called the Somalia Integrated Hierarchical Landform Mapping Approach (SIHLMA). It retains the hierarchical structure of the GP approach (with modifications explained in the following paragraphs), as satellite images and digital terrain classification were used at scales of 1:100 000 and 1:50 000. The morphogenetic factor was introduced in the GP approach and is clearly included in the code of the resulting relief type and landform. The reason why, is because the resulting outcomes have been purely Landform maps without any soil data. These results can thus be used for a broader spectrum of activities such as soil mapping, identification of flooded areas, abandoned river traces, etc.

The choice of landscape, relief, and landform classes were made while considering the arid and semiarid environment of Somalia, and thus certain morphogenetic environments and processes such as glacial or periglacial or nival ones, were omitted.

Of the original six GP levels, four were retained, viz. 4 (Landscape), 3 (Relief), 2 (Lithology) and 1 (Landform). As can be seen from Table 2 below, 3 (Relief type/Molding) was renamed “Relief” .

Following a detailed literature review, the following definitions for the four main terms of Landscape, Relief, Lithology and Landform were adopted following the geopedological hierarchy.

Table 2: Definitions of the terms Landscape, Relief, Lithology and Landform

Term	Definition
Landscape	Large portion of land characterised either by a repetition of similar patterns or an association of dissimilar one. It is mainly determined by endogenic forces such as orogenesis & volcanism. It maintains lithological and tectonic uniformity. Examples: Valley; Plain; Peneplain; Plateau; Piedmont; Hilland and Mountain. In some cases is quite difficult to determine a boundary of this type of land subdivision. Average linear magnitude is of 10^1-10^2 km.
Relief	Represents a morphology of Earth’s surface determined by a given combination of topography and geological structure (e.g. cuesta relief-type), and hence also determined by specific morphoclimatic conditions or morphogenetic processes (e.g. glacis, fan, terrace, delta). Average linear magnitude is of 10^0-10^2 km.
Lithology	The macroscopic physical characteristics of rocks, subdivided into the three main genetic classes (sedimentary, igneous and metamorphic) and into many sub-classes. It is derived directly from existing geological maps integrated through image interpretation.
Landform	The smallest unit considered here. Corresponds to the Pedogenetic environment, regarded as the sum of topographic form, geomorphic position & geochronology unit. In most cases is a further subdivision of Relief. Dominated by exogenous processes. Average linear dimension is 10^0-10^{-1} km

Due to cartographic rules the slightly different SIHLMA classification and legend structure was adopted, represented by the following diagram:

Landscape
Relief
Landform
Lithology 01
Lithology 02
Lithology 03
Lithology 04

The repetition of four Lithology classes was necessary because, in many cases, it was possible to recognise at least four different lithologies within a single relief or landform polygon. The rule was adopted that the lithology occupying the biggest surface inside the same polygon, was ranked 1st, the one occupying the second biggest surface was ranked 2nd and so on up to the 4th level, i.e. the least representative lithology in terms of outcropping surfaces.

The lower Landform level is not always present in the maps of the northern AOI and never in the southern AOI, where mapping has been performed at a scale of 1:100 000. This is due to the fact that from a spatial point of view the Landform is the smallest element recognisable through image analysis and it has only been possible to identify it where high contrast in relief and/or the image were present, and an appropriate scale adopted.

In practice, from the point of view of GIS as will be explained in the GIS Interim Report L01, inside the landform layer attribute table there is a Userlabel field where the code list has been concatenated, separated by strokes, such as in this example:

Landscape code/Relief code/Landform code/Lithology 01/Lithology 02/Lithology 03/Lithology 04

The process of defining every single class of landscape, relief, lithology and landform has followed two consequent steps: 1) firstly, all possible classes of landscape, relief, lithology and landform were defined, taking into consideration the arid and semiarid environment of Somalia and its geological and geomorphological evolution context; and 2) during the landform mapping exercise focus was more on the two Areas of Interest (AOI), where the number of classes to be used in the final map legend was refined and significantly reduced. This was done while keeping in mind that the landform mapping could be extended to the entire Somali territory, and the desire was to leave a tool that could be used in the future.

Here the complete list of Landscape, Relief, Lithology and Landform classes that were defined at the beginning of the exercise, are presented. Appendix 1 is a detailed explanation (both written and graphic) of each class. The actual list of classes adopted for the two AOI and printed in the Landform maps, is presented in Chapter 5.

The Landscape level is subdivided into 21 classes, listed together with their codes in the following table and with the corresponding GP class. Each Landscape class has a code consisting of three letters, the first of which is upper case. The first two letters reflect the general class (Mountain, Hilland, Piedmont, Plateau, Peneplain, Plain, Valley) while the last, third letter gives a more detailed classification of the landscape.

Table 3: Landscapes codes and corresponding GP codes

Landscape code	Landscape classes	Corresponding GP code
Mou	Mountain	Mountain
MoB	Block Mountain	
MoF	Fold Mountain	
MoV	Volcanic Mountain	
MoR	Residual Mountain	
Hil	Hilland	Hilland
HiD	Dissected Hilland	
HiC	Coastal Dune	
HiB	Domed Basement Hilland	
Pie	Piedmont	Piedmont
Pta	Plateau	Plateau
PtD	Dissected Plateau	
PtV	Volcanic plateaus/shield	
Pen	Peneplain	Peneplain
Pln	Plain	Plain
PlA	Alluvial Plain	
PlK	Karst plain	
PlC	Coastal Plain	
PlD	Dissected /Incised plain	
Vay	Valley	Valley
VaL	Lateral Valley	

Each landscape can consist of a number of reliefs and landforms, characterised by different lithologies.

The Relief level is subdivided into nine morphogenetic processes, each of them characterised by a first, uppercase letter that also forms the first capital letter in the code of relief classes.

Table 4: Morphogenetic environments related to the different Relief groups

Morphogenetic processes for RELIEF	Morphogenetic process related to relief
S	Structural
V	Volcanic
K	Karstic
E	Aeolian
F	Fluvial – Alluvial
L	Lacustrine
G	Gravitative
C	Coastal
A	Antrophic

Every morphogenetic process can give rise to different Relief classes, as listed in the following tables:

Table 5: Detailed list of all Relief classes used in the image interpretation exercise, representing relief classes that can theoretically be present in Somalia

RELIEF Code	RELIEF Classes	Morphogenetic process
S01	Anaclinal (obsequent) valley	Structural
S02	Cataclinal (consequent) valley	
S03	Orthoclinal (subsequent) valley	
S04	Chevron	
S05	Combe	
S06	Creston	
S07	Creston of overturned flank	
S08	Escarpment	
S09	Fault escarpment	
S10	Faultline escarpment	
S11	Tilted fault-block	
S12	Graben	
S13	Horst	
S14	Klippen	
S15	Depression	
S16	Dissected ridge	
S17	Anticline	
S18	Syncline	
S19	Flatiron	
S20	Excavated anticline	
S21	Truncated anticline	
S22	Hanging syncline	
S23	Tor	
S24	Inselberg	
S25	Cuesta	
S26	Mesa	
S27	Hogback	
S28	Bar	

S29	Hill	
S30	Hill Complex	
S31	Ridge	
S32	Planation surface	
S33	Denudational slope	
S34	Slope	
S35	Denudational surface	
S36	Plain, of structural origin	

RELIEF Code	RELIEF Classes	Morphogenetic process
V01	Strato volcano	Volcanic
V02	Cumulo volcano	
V03	Shield volcano	
V04	Cone	
V05	Ash cone	
V06	Spatter cone	
V07	Ash mantle	
V08	Sill	
V09	Dyke	
V10	Longitudinal dyke	
V11	Annular dyke (ring dyke)	
V12	Hogback Dyke	
V13	Neck	
V14	Escarpment	
V15	Volcanic plug	
V16	Volcano scarp	
V17	Crater	
V18	Depression	
V19	Caldera	
V20	Block (lava)	
V21	Ropy (Pahoehoe) lava	
V22	Fluvio-volcanic flow	
V23	Lava flow	
V24	Maar	

RELIEF Code	RELIEF Classes	Morphogenetic process
K01	Conical karst (dome)	Karstic
K02	Hill (hum)	
K03	Tower karst	
K04	Intergrown sinkhole (uvala)	
K05	Polje (karstic plain)	
K06	Blind vale	
K07	Dry vale	
K08	Canyon	
K09	Labyrinth karst	

RELIEF Code	RELIEF Classes	Morphogenetic process
E01	Deflation basin (blow-out)	Aeolian
E02	Rocky deflation surface	
E03	Stony deflation surface	
E04	Yardang	
E05	Playa	
E06	Pan	

RELIEF Code	RELIEF Classes	Morphogenetic process
F01	Alluvial fan	Fluvial and Alluvial
F02	Colluvial fan	
F03	Anastomizing river plain	
F04	Braided river plain	
F05	Meandering river plain	
F06	Straight river plain	
F07	Meandering belt	
F08	Badland (complex gully)	
F09	Gully/Rill erosion surface	
F10	Sheet erosion surface	
F11	Trace of palaeoriver	
F12	Alluvial plain	
F13	Depression	
F14	Pediment	
F15	Dissected pediment	
F16	Delta	
F17	Flat floor valley	
F18	River plain	
F19	Flood plain	
F20	Terraced surface	
F21	Upper Pediment	
F22	Lower Pediment	
F23	Old meandering river plain	
F24	Confined meandering plain	
F25	River incision	

RELIEF Code	RELIEF Classes	Morphogenetic process
L01	Lacustrine terraces	Lacustrine
L02	Lake basin	

RELIEF Code	RELIEF Classes	Morphogenetic process
G01	Fall landslide	Gravitative
G02	Flow landslide	
G03	Slide landslide	
G04	Soil creep surface	
G05	Solifluction surface	
G06	Talus cone	
G07	Talus fan	
G08	Talus slope	

RELIEF Code	RELIEF Classes	Morphogenetic process
C01	Cliff	Coastal
C02	Coastal plain	
C03	Sandy coast	
C04	Foredune	
C05	Stabilized dune	
C06	Mobile dune	

RELIEF Code	RELIEF Classes	Morphogenetic process
A01	Dam	

A02	Town, Industrial districts
A03	Quarry, mines
A04	Terrace

The final Relief classes adopted in the two AOI are presented in Chapter 5.

The **Lithology** level represents the hard rocks or the facies of the soft cover formations (mostly of quaternary age; alluvial, colluvial aeolian, etc.). Often lithology can be inferred from aerial photographs or satellite images, at the level of rock classification such as sedimentary or igneous rocks. To distinguish between metamorphic and sedimentary rocks, or to make a distinction between different types of any of the above mentioned rock types is not always an easy task in image interpretation. Lithology is normally deduced from a geological map, which may in some cases be unavailable. If lithology is unknown and cannot be inferred from interpretation of aerial photographs, then a question mark is entered in this column to indicate that it needs to be checked and completed in the field. The legend for Lithology is subdivided into three main petrogenetic classes: sedimentary, igneous and metamorphic, all of which contain many different subtypes of rocks. The list is consistent for the Somali environment and is based on the only geological maps published for the country. The Africover structure is used, reflecting the work of Soter regarding rock classification. A new field has been added, relating to the original code used in the Geological maps.

Table 6: Lithogenetic environments and related rocks (from Africover)

Igneous rock	**Sedimentary rock**	**Metamorphic rock**
Granite	Unconsolidated clastic sedimentary rock	Contact metamorphic rock
Granodiorite	Clay	Hornfels
Quartz diorite	Silt	Spotted slate
Syenite	Sand	Skarn
Monzonite	Gravel	Cataclastic metamorphic rock
Diorite	Loess	Cataclastic breccia
Gabbro	Loam	Mylonite
Foidic plutonic rock	Colluvium	Regional-metamorphic rock
Ultramafic plutonic rock	Shells	Slate
Igneous hypabyssal rock	Consolidated clastic siliceous sedimentary rock	Schist
Aplite	Mudstone	Gneiss
Pegmatite	Siltstone	Migmatite
Porphyry	Shale	Granulite
Dolerite/diabase	Quartzarenite	Eclogite
Igneous volcanic rock	Lithic arenite	Quartzite
Rhyolite	Feldspathic arenite/arkose	Marble
Dacite	Greywacke	Serpentinite
Trachyte	Conglomerate	Other Metamorphic rock
Latite	Breccia	
Andesite	Calcareous rock	
Basalt	Marl	
Phonolite	Calcilutite	
Tephrite	Calcarenite	
Pyroclastic rock	Calcirudite	
Ash	Algal/reefal limestone	
Lapilli	Travertine	
Scoria	Tufa	
Tuff	Dolomite	
Ignimbrite	Evaporite	
Lahar	Gypsum	
Agglomerate	Halite	
Other Igneous rock	Organic rock	
	Peat	

Lignite Coal Tar Residual rock Laterite Bauxite Kaolin Other Sedimentary rock

The **Landform** level is further subdivided into nine morphogenetic processes, each characterised by its first letter (in capitals) that are entered into the code of relief classes as the first capital, or uppercase letter. In addition, a field labelled X characterises the general position along a slope, and is not related to a specific morphogenetic agent.

Table 7: Morphogenetic environments related to the different Landform groups

Morphogenetic processes for LANDSCAPE	Morphogenetic process related to Landscape
S	Structural
V	Volcanic
K	Karstic
E	Aeolian
F	Fluvial – Alluvial
L	Lacustrine
G	Gravitative
C	Coastal
A	Antrophic
X	Slope position

Every morphogenetic process can give rise to different **Landform classes**, as listed in the following tables:

Table 8: detailed list of all the Landform classes set up before starting of the image interpretation exercise. They represent the possible relief classes that, from a theoretical point of view, can be present in Somalia

LANDFORM Code	LANDFORM Classes	Morphogenetic process
S01	Scarp	Structural
S02	Fault escarpment facet	
S03	Structural surface	
S04	Lithologic surface	

LANDFORM Code	LANDFORM Classes	Morphogenetic process
V01	Planeze	Volcanic

LANDFORM Code	LANDFORM Classes	Morphogenetic process
K01	Lapies	Karstic
K02	Shallow hole (ponor)	
K03	Sinkhole (doline)	

LANDFORM Code	LANDFORM Classes	Morphogenetic process
E01	Aeolian levee	Aeolian
E02	Generalised sand mantle	
E03	Loess mantle	
E04	Nebka	

E05	Barkhane dune	
E06	Parabolic dune	
E07	Longitudinal dune	
E08	Transversal dune	
E09	Star shaped dune	
E10	Pyramidal dune	
E11	Reticulate dune	

LANDFORM Code	**LANDFORM Classes**	**Morphogenetic process**
F01	Ablation surface	Fluvial - Alluvial
F02	Rill	
F03	Gully	
F04	Point bar complex	
F05	River levee	
F06	Floodplain	
F07	Terrace	
F08	Terrace scarp	
F09	Depression	
F10	Backswamp	
F11	Ox bow lake	
F12	Infilled channel	
F13	Colluvial fan	
F14	Upper Pediment	
F15	Middle Pediment	
F16	Lower Pediment	

LANDFORM Code	**LANDFORM Classes**	**Morphogenetic process**
L01	Lake shore	Lacustrine
L02	Lacustrine terrace	

LANDFORM Code	**LANDFORM Classes**	**Morphogenetic process**
G01	Head	Gravitative
G02	Main body	
G03	Footslope	
G04	Toe	

LANDFORM Code	**LANDFORM Classes**	**Morphogenetic process**
C01	Backshore	Coastal
C02	Foreshore	
C03	Beach rock	
C04	Coastal lagoon	
C05	Beach	
C06	Coastal dunes	

LANDFORM Code	**LANDFORM Classes**	**Morphogenetic process**
A01	Hydrographic Canal	Antrophic
A02	Roads, rail, tracks	
A03	Coastal protection system	

LANDFORM Code	**LANDFORM Classes**	**Morphogenetic process**
X01	Summit	Slope position
X02	Shoulder	

X03	Backslope	
X04	Footslope	
X05	Toe slope	
X06	Upper slope	
X07	Lower slope	
X08	Slope Complex	
X09	Crest	

1.3 DTA analysis and parameters

Digital Terrain Analysis (DTA) can be defined as the analysis of Digital Elevation Models (DEM) using software applications, in order to extract physical parameters. The usefulness of DTA lies in three main factors:

1) it allows the quick extraction of many parameters that previously required very time-consuming exercises, based only on topographic maps;
2) it implies the use of modern, mostly remote-sensed and updated, sources of Digital Elevation/Terrain Model;
3) it allows a consistent and objective parameterization of large areas of the earth's surface, providing inputs for further analysis and modelling.

The purposes of terrain analysis include visualization, data preparation e.g. hydrological, geomorphological, and biological applications. An example of visualization is a shaded relief map, which gives a more realistic impression of map elevations. An example of a geomorphological application is the identification of landform elements (peaks, ridges, valleys, etc.), or the calculation of soil wetness indices, or prediction of landslides. An example of a hydrological application is a hydrological simulation model, which converts a time series of rainfall (mm/day) into a time series of river discharge (m^3/s, averaged over a day). An example of a biological application is as a predictor of locations where a rare species may exist in a study area.

Almost all software performing DTA use a grid-based elevation source, which allows consistent elaborations and exporting of the results as a grid that can be displayed on most the commercial and free GIS and image analysis software.

The Earth's topographic surface can be depicted as a mathematical differential curve, and it is possible to derive 1st, 2^{nd} and 3rd .orders when applying the derivates.

Slope, aspect, plan and profile curvature are also referred to as primary topographic attributes; these are usually computed using directional derivatives of a topographic surface, either by using second-order finite difference schemes or by fitting a bivariate interpolation function to the DEM and then computing the derivatives of the function (Wilson & Gallant, 2000; Moore *et al*, 1993). Secondary attributes are computed using two or more primary attributes and offer the ability to describe pattern as function of process (Hugget & Cheesman, 2001).

A gridded surface is supposed to be mathematically continuous and in principle it is possible to obtain mathematical derivates at any location. In practice, because the surface has been discretized, derivates are approximated either by computing differences within a square filter or by fitting a polynomial to the data within the filter.

The parameters extracted from DEM and used in our analysis are:

- Slope, aspect, shaded relief, plan curvature, profile curvature, landform classification (LandSerf, TAS, TPI).
- Slope and aspect (ArcGIS 9.0).
- Shaded relief (derived following the procedure outlined by Sijmons *et al*, 2005).

The digitally-derived products that have been created and used during the integrated landform mapping are: elevation, slope, aspect, plan and profile curvature, landform classification and wetness index. A brief discussion of each is given here:

Slope and **Aspect** correspond to the 1st derivative of the topographic surface.
Plan and **profile curvature** correspond to the 2nd derivative of the topographic surface.
Landform classification and **wetness index** are complex topographic attributes.

Slope represents the maximum rate of elevation change between adjacent cells of the raster, or is a measurement of how steep the ground surface is.

From a GIS point of view, DEMs do not have continuous curves that define topography. They store a matrix of cells of given dimension (30x30 m, or a square of 900 m² in this case) where each cell contains the average elevation value for that area.

The slope is usually expressed in integer degrees of slope between 0 and 90, or in percentages ranging from 0 to very high values (infinite).

How **Slope calculation** works - slope identifies the rate of change in elevation values from each cell to its eight neighbors in the 3x3 kernel.

The best algorithm that is used to calculate slope, among the many available, is:

rise_run = SQRT(SQR(dz/dx)+SQR(dz/dy)) or $\frac{dz}{dxy} = \sqrt{\left(\frac{\delta z}{\delta x}\right)^2 + \left(\frac{\delta z}{\delta y}\right)^2}$

degree_slope = ATAN(rise_run) * 57.29578

where the deltas are calculated using a 3x3 roving window.

Usually slope is displayed with a colour scale, becoming more intense toward the highest values. A common colour scheme is: red for the highest slope angles, yellow for intermediate and green for the lowest ones.

Calculating slope in a GIS has many applications. Some of the most useful are studying water flow, flooding, erosion, travel costs, suitable habitat, velocity of runoff, soil-water content and land capability classes.

Aspect represents the direction of the slope, counted clockwise from the north.

Aspect – Aspect can be thought as the direction of slopes or as the compass direction to which every single slope facet (or matrix cell) faces. Some authors call it Exposure. It describes the direction of the rate of change in elevations between each cell and its eight neighbours. That is, if you were standing on a hillside and looking down the slope, the direction you were facing would be the aspect of the slope.

Aspect is measured in positive integer degrees from 0 to 360, clockwise from north. Aspect of cells of zero slope (flat areas) are assigned values of -1. This is one of the most important items for topographical analysis as, together with elevation and slope, it contributes to determination of water flow direction across a surface (flow direction).

Applications of the aspect function are, *inter alia*:

- studying insolation and temperature, correlating these to vegetation types, soil characteristics, moisture, and visibility;
- calculating the solar illumination for each location in a region as part of a study to determine diversity of life at each site;
- identifying areas of flat land suitable for emergency aircraft landing strip/s.

Plan or Planform Curvature describes whether a theoretical flow of water flowing along a slope accelerates or decelerates at each location. In other words, it indicates where water is running faster or slower in its downslope path.

From a mathematical point of view, it corresponds to the second derivative of the curvature. It corresponds to the orthogonal component to the profile curvature. For an exhaustive description of the mathematical formula, see Wood (1999).

Topographically, it corresponds to the direction in which gravitational processes are minimized. It is a measure of the curvature along the contour lines, differentiating straight parts along an horizontal profile from ones with maximum curvature, on the xy (or horizontal) plan.

From a GIS point of view, when the horizontal plane is straight, the plan curvature or convexity, will have the lowest negative values; when the horizontal plane shows the highest curvature it will have the highest positive values. Usually it is displayed with a colour ramp, the highest values of curvature shown as red and the lowest as blue (equating with flat regions where water can accumulate).

Profile curvature describes whether a theoretical flow of water along a slope will converge towards a location, or diverge away from it. In other words it gives an indication of where water flows concentrate along a slope.

From a mathematical point of view it corresponds to the second derivative of the curvature. It corresponds to the orthogonal component to the plan curvature. For an exhaustive description of the mathematical formula, see Wood (1999).

Topographically, it corresponds to the direction where gravitational processes are maximized. It is a measure of curvature across the contour lines, or across a topographical profile. It differentiates the straight tracts of a topographical profile to the ones with maximum curvature, on the z (or vertical) plan.

From a GIS point of view, when the vertical profile is flat, the profile curvature will have the highest positive values, while when the vertical plane shows the highest curvature it will have the lowest negative, values. Usually it is displayed with a colour ramp.

Landform classification

Landform classification has been calculated using three different software packages: LandSerf, Terrain Analysis System (TAS, Lindsay, 2005) and Topographic Position Index (TPI, Jenness Enterprise, 2005). These three different packages were used to derive an automated landform classification, adopting slightly different methodologies and algorithms for deriving landform components in Table 9 (below).

Table 9: Landform automated classification classes adopted through use of three different software packages

Landform components	Software
Planar region Peak Ridges Passes Channel Pit	**LandSerf** (surface feature classification;Wood, 1999)
Valley Lower slope Flat slope Middle slope Upper slope Ridge	**TPI** (slope position index, using 6 classes; Weiss, 2001)
Canyons, Deeply incised streams Midslope drainages, shallow valleys Upland drainages, headwaters U-shaped valleys Plains small Open slopes Upper slopes, Mesas Local ridges, Hills in valleys Midslope ridges, Small hills in plains Mountain tops, High ridges	**TPI** (landform classification, using 10 classes; Weiss, 2001)
Convergent footslope Divergent footslope Convergent shoulder Divergent shoulder Convergent backslope Divergent backslope Level	**TAS** (Landform classification; Pennock *et al*, 1998)

Each package operates on the basis of thresholds and shapes, on which basis landform classification is performed. These two parameters can vary from software to software, with different degrees of customisation (for a more detailed explanation, see Annex 5).

For both AOI, SRTM-DEM 90 m was used. It has a horizontal spatial resolution of 90x90 m and an absolute vertical accuracy of 16 meters (and a relative one of 6 meters) (Falorni *et al*, 2005).

1.4 Visual Image Interpretation

Visual Image Interpretation is a well-established discipline, described in great detail in many books and manuals. It is not the aim of this report to illustrate the principles of image and photo interpretation, but a few basic principles are explained and readers are then referred to the basic bibliography for more detail.

Image interpretation differs from photointerpretation: satellite images are not photographs, but discontinuous matrices of digital numbers derived by scanning the earth’s surface with a scanner that is sensitive only to specific electromagnetic wavelengths (the spectra). Aerial photographs by contrast are a representation of radiance reflecting back from the earth’s surface.

The great advantage of interpreting satellite, or digital, images instead of aerial photographs lies in the fact that the former can hold a multispectral set of information, allowing the display to incorporate different bands of the electromagnetic spectrum, using false colours. This process allows wave intervals, or bands, displayed in false colour composite, to be seen by the human eye. Using this technique it is possible to identify and analyze more details than with panchromatic images.

The interpretation process is a subjective activity that is performed taking into consideration the technical characteristics of the images and the experience and skills of the interpreter.

In this study we adopted the use of digital image interpretation with all images georeferenced and displayed using GIS software on computer monitors. In this way it was much easier to enhance image quality, allowing interpreters to extract the highest amount of information in the most precise way possible.

1.5 Field survey methodology

The field survey methodology is explained in detail in the Field Survey Manual (Project Report L01). A few considerations are explained here.

As in the case of landform legend and classification, in landform field survey there are any widely used standards.

In this study, the landform field sample points were meant to be at the same locations as the landcover sample boxes, in addition to the soil sample locations and any other appropriate points decided on by the surveyors. The selection of new field sample points was done according to the expertise of the field surveyors and should be representative of a given landform class.

General criteria to follow when selecting *en route* panoramic viewpoints for photography, in that stops should be located at points from where it is possible to make panoramic as well as local observations and measurements.

For this reason, a dual-purpose type observation and form were conceived: one for general observations (panoramic view of surrounding landforms); and one for specific observations (detailed observation and site measurements). The data collection form used is found in the Field Survey Manual.

1.6 Integration of digital terrain analysis, visual image interpretation and field survey

As already explained in the previous paragraphs, the SIHLMA methodology adopted for this exercise integrates classic image interpretation with digital terrain analysis, verified by field data.

The process aimed at producing a land form map as quickly and reliably as possible. The maps produced in this way will be useful as:

- a base for soil mapping (which is why the SIHLMA starts from the GP approach);
- a base for a land unit mapping classification (hierarchical structure and morphometric parameterization);
- a base for further hydrological investigations: flooding area extent, palaeo-river and ephemeral river identification, etc (visual image interpretation).

The integration of the three methods aims at producing an objective but comprehensive map that can take into consideration, and map, morphometric topographic attributes together with morphogenetic environments. The former helps in identifying geometrical limits between different parts of the topographic surface, and the latter helps in attributing genetic significance to previously identified surfaces. These processes, that have their roots in photointerpretation, were greatly assisted by the use of topographic profiles along selected transects.

2 STUDY AREAS

2.1 Location and delineation

The study areas, or Areas of Interest (AOI), are located in the north-western and southern parts of the country respectively (Figure 1). They differ from geological and geomorphological points of view.

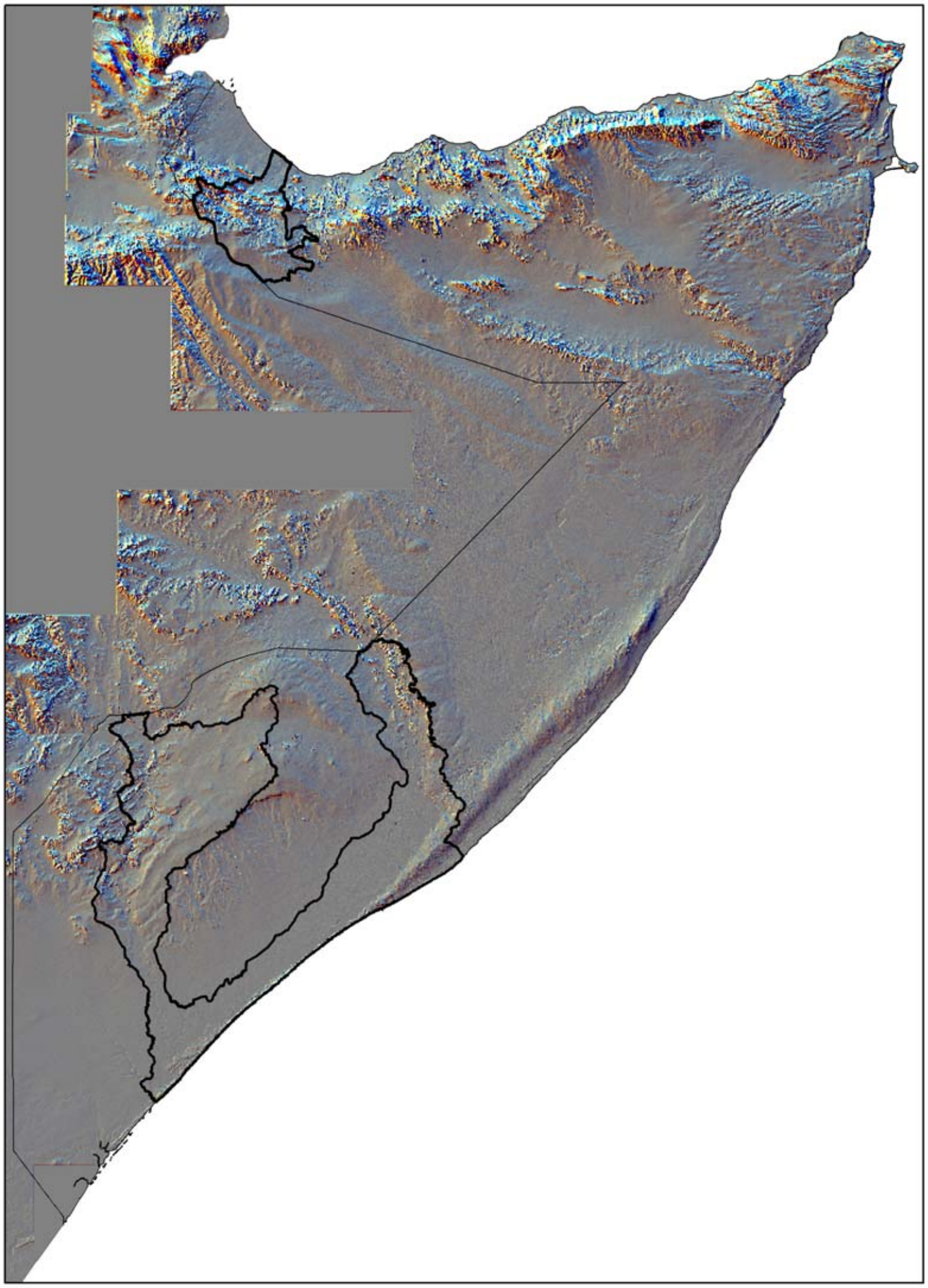

Figure 1: The two Areas of Interest: north-western Somalia and southern Somalia

The boundaries of the two areas of interest were delineating considering the existing available datasets on the Somalia territory. In particular the following data were been evaluated:

1. NASA 90 meters SRTM-DEM;
2. FAO Africover Landform;
3. FAO SWALIM Phase I Landcover;
4. Available satellite imageries.

Delineation took into account the following areas:

- watershed limits extracted from NASA's SRTM-DEM;
- alluvial plains (code L11ap) and floodplains (both L11wa and L11we) extracted from the Africover Landform ;
- agricultural areas extracted from Landcover prepared during SWALIM Phase I for the south, and identification of agricultural areas from available Landsat imagery for the north.

After combining the above layers, morphological criteria guided selection of area shape. The Dur-Dur and Gebiley watershed in the north was selected in this way, adding a small area extending outside of the watershed, due to the presence of agricultural schemes.

In the southern AOI the watershed of the Juba and Shabelle Rivers was considered, as they can be subdivided into many sub-watersheds. The following specifications were adopted for delineating the AOI;

- the eastern boundary of the AOI corresponds to the Shabelle main watershed limit;
- the southern boundary corresponds to the coastline;
- the western boundary corresponds to the Juba main watershed limit, not including a tributary entering from Kenya;
- the northern boundary corresponds to the Somalia/Ethiopia border;
- the central, empty, part of the AOI has been excluded following the eastern main watershed limits of the Juba, and the limits of the alluvial plain defined by the FAO-Africover layer.
- If an important agricultural area was found to be outside of watershed limits but in proximity to it, then it was included.

2.2 Available information

Very little information is present in the literature about landforms of the Somali territory. Most available information concerns only parts of Somalia (Pallister, 1963; Daniels, 1965; Coltorti & Mussi, 1987; Abdirahim *et al*, 1994; Sommavilla *et al*, 1994, Carbone & Accordi, 2000) only one of which (Perissotto, 1978) included a nationwide, albeit general, description of the area's geomorphological characteristics. Very useful information about the landscapes and landforms of Somalia, at a nation-wide scale are provided by the technical report of the FAO Africover Project (at a scale of 1:300 000)(Rosati, 1999) and some other information can be extracted from the FAO Soter datasets (at a scale of 1:1 500 000)(FAO, 1998). Further information is available on geology: one 1:1 500 000 geological map for the whole country, with other geological maps at different scales covering smaller areas (Daban Basin, part of Puntland, Bay and Bakol Region), while the central regions and the north-western ones have no detailed geological information.

Available geological literature is scanty. There is no general geological description of the Somalia territory, but there are geological analyses of specific areas and subjects (e.g. Abbate *et al*. Ed, 1994; Ali Kassim *et al*., 2002; Clift *et al*., 2002; Fantozzi & Ali Kassim, 2002). The "Geological map of Somalia" at a scale of 1:1.500 000 (Abbate *et al*., 1994) is the only nationwide and most recent document on the geology of the entire country.

2.3 General features of the Northern Area of Interest (NAOI)

2.3.1 Climate

The region lies at the extremity of the sub-Saharan semi-arid zone commonly referred to as the Sahel, which traverses the continent from Senegal to Somalia.

The climate of the study area is hot, dry desert in the coastal plain (Lughaya and northern part of Baki districts) and arid in Borama and surroundings. Semi-arid conditions prevail at higher altitudes of the Al Mountains and south of Gebiley. Mean annual rainfall ranges from below 200 mm in the coastal areas of Lughaya, to 500 – 600 mm in the east of Borama and surroundings. The rest of the study area has a mean annual rainfall of 300 – 500 mm (see Figure 4).

The study area lies entirely between the two subtropical anticyclone belts. The main weather pattern is controlled by the seasonal monsoon winds, and rainfall in the area is consequently bimodal (see Figure 2). The northeast monsoon brings the primary *Gu* rains between March and June. The *Gu* is followed by a hot dry period called *Xagaa* (June/July). Short rains locally known as *Deyr* also occur between August and October followed by cool long dry *Jilaal* period between November-February.

Figure 3 illustrates how temperature decreases with increasing altitude. In the higher altitudes of the Al Mountains and plateau areas, temperatures vary considerably through the seasons, with a mean annual temperature of 20-24°C, while the coastal region has mean annual temperatures of 28-32°C.

Relative humidity of the highlands is mostly around 40%, except during rainy periods when it increases to 80%. High temperatures in the coastal areas combine with a high relative humidity of more than 70% to create an exceedingly hot, humid environment.

The major winds in the study area occur during the *Xagaa* dry season, particularly (June to July) and in *Jilaal* (December to February) every year when the weather is hot. Hot, calm weather occurs between the monsoons (part or whole of April and part or the whole of September). Generally, in the northwest the winds are strongest during the southwest monsoon. Weaker winds generally occur during April-May and October-November. Average wind speeds vary from 8 - 10 m/s, but during a large part of the year, strong winds of up to 17 m/s occur, causing frequent dust-devils all over the coastal plains and plateaus.

The study area is subject to high potential evapotranspiration (PET), with an annual average between 2000 and 3000 mm. Annual rainfall is very far below the potential evapotranspiration and a large water deficit exists during most of the year, throughout the region. This rainfall condition is not always sufficient for successful crop production (Figure 2).

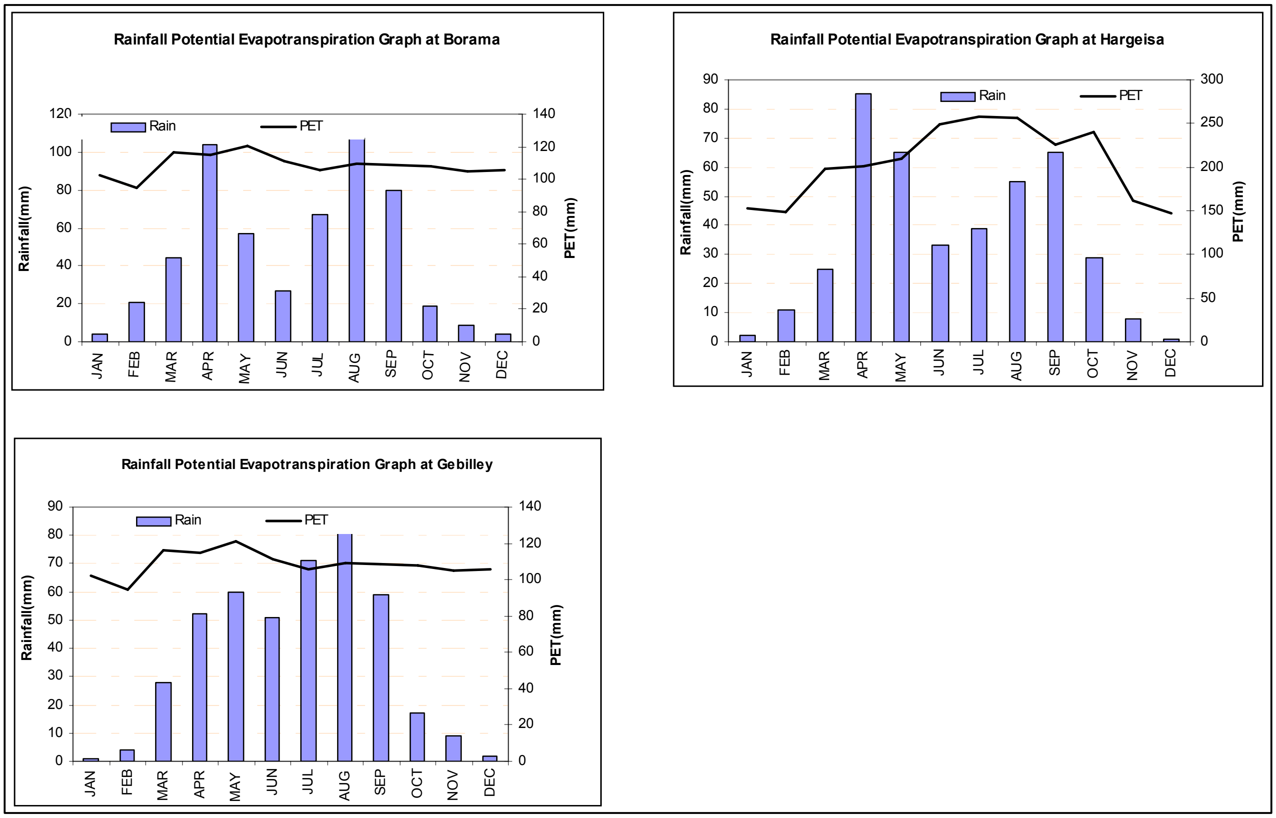

Figure 2: Rainfall and Potential Evapotranspiration

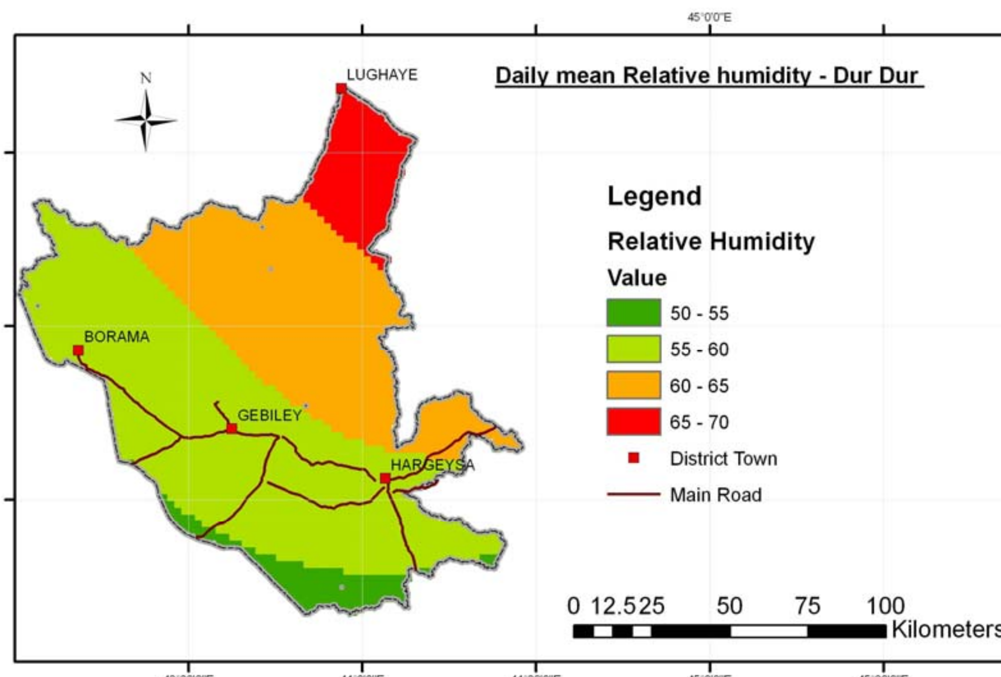

Figure 3: Relative Humidity of the Study Area

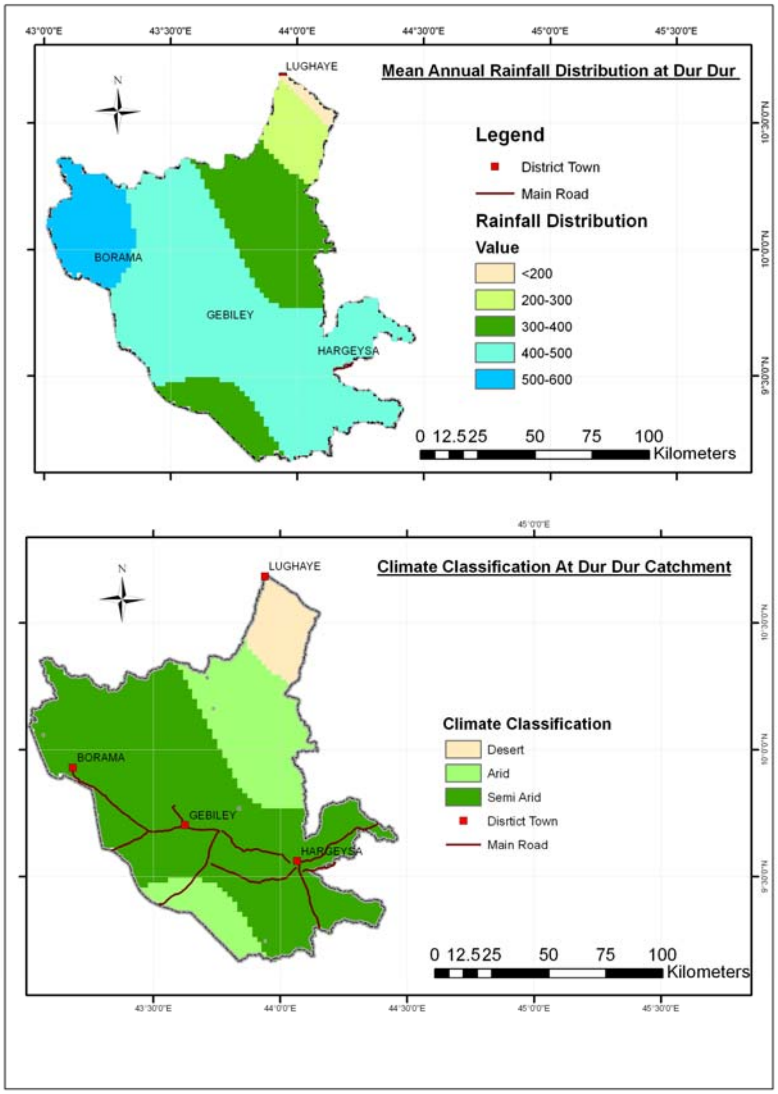

Figure 4: Rainfall distribution and climate classification of the study area

2.3.2 Geology/Lithology

The study area is covered by rocks dating from Pre-Cambrian to Recent, comprising sedimentary, igneous and metamorphic rocks. The tectonic arrangement of rock outcroppings in the region is complex and severely affected by many different systems of faults and fractures, mainly oriented parallel to the coast (i.e. WNW-ESE).

From the geological point of view in the northern AOI is possible to find sedimentary, igneous, and metamorphic rocks. Most sedimentary rocks are limestones and sandstones, igneous consist mostly of basalts and rhyolites, and metamorphic rocks show a range of different rocks such as marbles, gneiss, micaschists, gabbros, quartzite and migmatites. Along the coast some sands and quaternary alluvial deposits form the greater part of the outcropping lithologies.

The basement complex covers an extensive area of the Al Mountains around Borama and Baki districts. In other parts of the region, it is covered by Jurassic limestone and Miocene bio-limestone, Pleistocene basalts and Recent alluvial and aeolian deposits. Igneous rocks consist mostly of basalts and rhyolites, and metamorphic rocks include a wide range of schists, ortogneiss, quartzite, migmatites, marble, calcosilicate and paragneiss, intruded by granite, diorite and gabbro.

Pleistocene basalt outcrops and other volcanic rock outcrops occur dispersed along the northern escarpment and coastal plain.

2.3.3 Landform and Soils

Geomorphologically, the study area can be divided into the following landscapes: Plateau (both dissected and normal), Mountainous and Hilland, Piedmonts and the Coastal Plain. There are three main ephemeral river systems (Togga Durdur, Togga Biji and Togga Waheen) that drain from the plateau, traversing the mountain range in the direction of the Red Sea and from the southern side of the same mountain to the southern highlands respectively.

According to the bibliography, the northern AOI is characterised by the following land features:

1. A narrow coastal plain, washed by the waters of the Gulf of Aden which is fairly depressed in relation to the mountain range at its rear;
2. A mountain range, oriented almost E-W, parallel to the coast, with a very rugged topography that rises up from the coastal plain to the country’s highest peak (2,407 m, outside of the AOI);
3. Highlands and plateaus, southward of the mountain range, consisting of gently undulating or almost flat terrains dipping toward the south-east, cut by several wadis and with wide alluvial plains.

In the northern AOI there are a number of ephemeral rivers (locally called *togga*, *tug* or *wadi* - Faillace, 1986) which contain water only during the rainy season. Drainage follows the general relief from the almost E-W mountain range to the northern Gulf of Aden coast, and also from the same mountain range to the inner south-facing highlands. They give rise to deep gorges in the inner part of the mountain range.

According to the Sogreah soil survey report (Sogreah, 1983), soil distribution patterns closely follow the geomorphology of the region. On the high plateau, soils were mapped as predominantly deep and heavy textured Vertisols. The Mountainous and Hilland areas were mapped as rocky or covered by shallow Entisols and some Aridisols. The soils in the Piedmont areas were classed as Entisols and Aridisols. A big portion of the region is covered by Rocky soils that were mapped as a separate non soil class.

2.3.4 Land cover

The land cover of the study area consists mostly of natural vegetation, including Open Shrubs, Wooded vegetation and Open to Closed Herbaceous formations. Other cover types include Urban and Associated Areas (Settlement/Towns and Airport), Bare Areas (Bare Soils and Sandy areas) and Natural Waterbodies.

The vegetation in the study area is mainly savannah consisting of woody species such as *Acacia nubica*, *A. tortilis*, *A. bussei*, *A. senegal*, *Aloe* spp., *Croton gilletti*, *Hypoestes hildebrandtii*, *Acalypha fruticosa*, *Grewia tenax* and *Balanites aegyptiaca.* Herbaceous species include *Cenchrus ciliaris*, *Cynodon dactylon*, *Sporobolus marginatus*, *Tragus racemosus and Aristida adscensionis*. Other vegetation types include Open Shrubs and Open Trees. Closed trees are not common. More details on the vegetation of the area can be found in FAO-SWALIM Technical Report No. L-03.

2.3.5 Land Use

The main land use in the study area is extensive grazing (pastoralism). Other land uses include rainfed agriculture, irrigated orchards along alluvial plains, and wood collection.

Rainfed agriculture is found in what is considered as the sorghum belt of Somaliland, practiced in combination with pastoralism and wood collection. This class of land use is the economic basis of households in the study area.

Cultivation of irrigated orchards is a cash-oriented activity in the area, involving the growing of fruit trees such as citrus, guava, papaya and mango. Supplementary water for irrigating the crops is obtained from wells, dams and other water bodies.

Wood collection for charcoal production is very frequent, occurring in all well-treed areas. Preferred tree species are *Acacia bussei*, *A. nilotica* and *A. etbaica*. Interventions to help introduce sustainable sources of cooking energy are important and urgent.

Most of the area is used for extensive grazing, or pastoralism. Goats and sheep are grazed mostly on sloping areas, whereas cattle and camels are grazed in flatter areas. Sedentary pastoralism around homesteads is a common practice. Hay harvesting from enclosures supports this land use, as harvested hay can be used in the dry season. However, hay harvesting may be a source of conflict as enclosures are not generally welcomed. Hay production requires further research to establish its levels of sustainability without being a cause of conflict in the study area.

Urban centres offer a good market for farm produce, but due to poor access roads are inaccessible to most farmers. The urban centres are also points of high demand for charcoal.

2.3.6 Population

The study area constitutes the districts of Dila, Gebiley, Faraweyne and Allaybaday and parts of the districts of Hargeisa, Borama, Baki and Lughaya. The size of this study area is effectively a little more than one third of the total area of Awdal and Waqooyi Galbeed Regions. According to Somalia UNDP 2005 (Table 10), the estimated population for Hargeisa by mid-2005 was 560.028, making it the second largest town in Somalia. Borama had a population of 215.616 and Gebiley 79.564. These three are the main towns in the study area.

Table 10: Regions, districts, and their populations (Somalia UNDP 2005, draft version)

		District	**Estimated population**		
Zone	**Region**	**(* Regional capital)**	**2005 (Mid-year)**		
			Total	**Urban**	***Non-urban***
North-west			**1,828,739**	**819,989**	**1,008,750**
	Awdal		**305,455**	**110,942**	**194,513**
		Borama *	215,616	82,921	132,695
		Baki	25,500	8,577	16,923
		Lughaya	36,104	14,010	22,094
		Zeylac	28,235	5,434	22,801
	Woqooyi Galbeed		**700,345**	**490,432**	**209,913**
		Hargeisa *	560,028	422,515	137,513
		Berbera	60,753	42,070	18,683
		Gebiley	79,564	25,847	53,717

2.4 Southern Area of Interest (SAOI)

2.4.1 Location and delineation

The Southern AOI lies between 41°53' and 46°09' east of the Prime Meridian; and between 0°16' south of the Equator and 5°04' north of the Equator. It extends for almost 88 000 square kilometres (8 793 596 hectares) covering the whole Juba River watershed, in its Somali tract, and the greater part of the Shabelle River watershed in Somalia.

The most important cities found in the area are: Luuq, Garbahaarrey, Baardheere, Bu'aale, Jilib, Jamaame and Kismaayo, in the Juba valley; and Ferfer, Beledweyne, Buulobarde, Mahadday Weym, Jawhar, Balcad, Muqdisho, Afgooye, Marka, Baraawe, and Haaway in the Shabelle valley.

This AOI encloses the Somali side of the basins of the Juba and Shabelle rivers, the upper parts of the basins lying in Ethiopia. The delineation of the boundary of the study area can be found in section 3.1.

2.4.2 Climate

The climate of river basin areas of southern Somalia is tropical arid to dry, sub humid and is influenced by the north-easterly and south-easterly air flows of the Intertropical Convergence Zone (ITCZ). North-easterly and south-easterly air masses meet in the Intertropical Front (ITF) and raise air upwards to produce rain. The annual movement of the ITCZ from north to south across Africa and back gives rise to four different seasons in Somalia, comprising two distinguishable rainy seasons alternating with two marked dry seasons, as follows:

- *Gu*: April to June, the main rainy season for all over the country
- *Xagaa*: July to September, littoral showers, but dry and cool in the hinterland
- *Deyr*: October to December, second rainy season for all over the country
- *Jilaal*: January to March, longer dry season for all over the country

Rainfall in the study area is erratic, with a bimodal pattern except in the southern riverine areas close to the coast where some showers may occur even during the *Xagaa*. (see Figure 5). Rainfall varies considerably over the study area, with the *Gu* delivering about 60% of total mean annual rainfall. Total mean annual rainfall ranges from 200 - 400 mm in areas bordering Ethiopia in Hiiraan, Gedo and Bakool regions and 400 - 500 mm in the central Bay and northern part of Middle and Lower Shabelle Regions. High rainfall areas receiving more than 600 mm occur in the Middle Juba region, around Jilib in the southern riverine areas. Rainfall is characterised by intense, short rainstorms. The study area has a high inter-annual rainfall variation and is subject to recurrent drought every 3-4 years, and more severe dry periods every 7-9 years.

Air temperatures are influenced by altitude and by the strength of seasonal winds. In the first dry season (*Xagaa*) days are often cool and cloudy all over the region, with light showers in areas close to the coast. In the second dry season (*Jilaal*) days are hot, or very hot and dry. However, the hottest period coincides with the months of March and April.

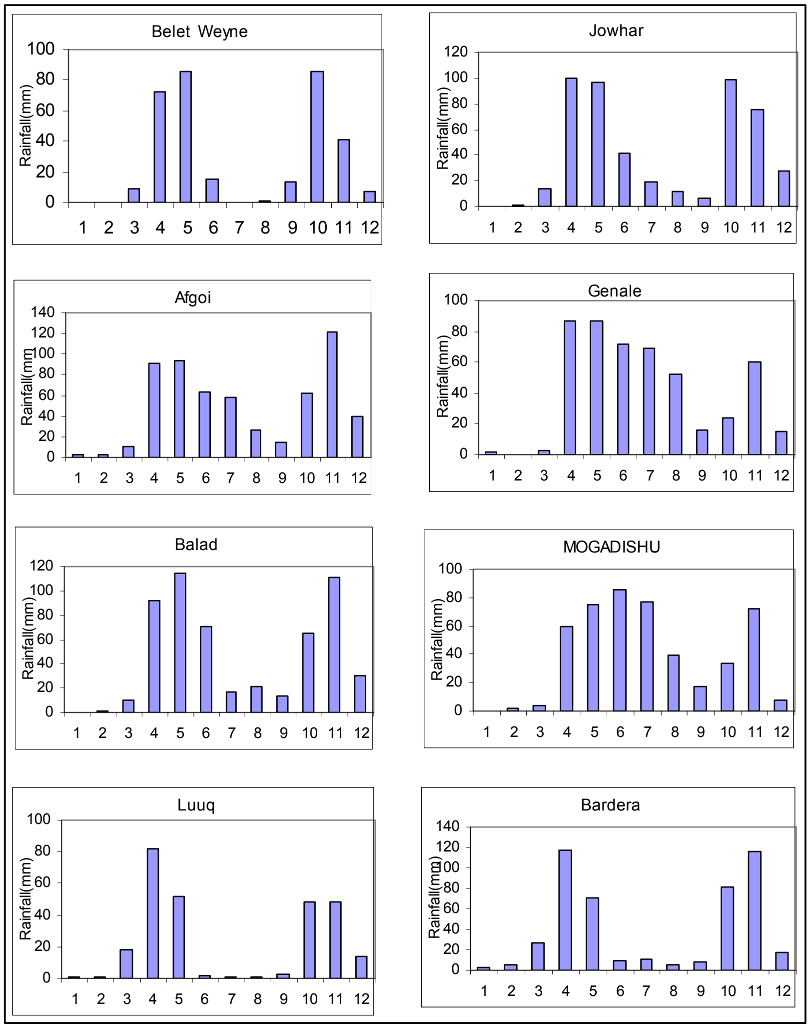

Figure 5: Mean monthly rainfall patterns in the study area (1963-2001)

Temperatures vary with the seasons, with the mean annual temperature ranging from 23°-30°C, with a maximum temperature of 41°C in March (Baardheere) and a minimum temperature of 24°C in July. In areas near the major rivers the relative humidity is high, ranging from about 70-80%, but further inland away from the rivers the air is much drier. Relative humidity is higher in the coastal areas, where it usually exceeds 87%. Normally, the high relative humidity is compounded by higher temperatures.

The major winds are in response to the north and south seasonal movement of the Intertropical Convergence Zone, and in particular the Intertropical front. In the study area the winds persistently blow from the northeast during *Jilaal* (December to February), when the weather is hot or very hot, and from the southwest during *Xagaa*, (June to August), when the weather is cool and cloudy.

The weather is hot and calm between the monsoons (part or whole of April and part or whole of September). In the *Jilaal* periods, prevailing winds are strong and blow in heavy dust storms from the Arabian Peninsula. Weaker winds generally occur during the inter-monsoonal periods of April/May and October/November. The average wind speed varies between 2-6m per second.

Evapotranspiration is consistently high throughout the study area. The highest potential evapotranspiration occurs in the northern areas of Gedo, Bakool and Hiraan regions, where it exceeds > 2 000 mm/yr; the rest of the area it is between 1 500 – 2 000 mm/yr. Annual rainfall (P) is everywhere far below potential evapotranspiration (PET) and there is a significant moisture deficit for most of the year.

Three broad climatic zones may be recognised, characterised by differences in patters of rainfall:

- The coastal zone - with significant amount of rain occurring from July -August (*Hagi* rains) that lengthen the *Gu* season.
- The semi-arid zone – with two strongly defined rainy seasons and an additional light rainy season that may occur during July-August.
- The arid zone – with a lower annual rainfall and a dry period between July-August. The monsoon winds are the most important factor affecting the climate and the timing of the rainy periods. The south-west monsoon winds prevail during June, July and August. The north-east monsoon winds prevail during December, January and February.

2.4.3 Geology

The southern AOI is characterised by the outcropping of the metamorphic basement complex, made up of migmatites and granites. Sedimentary rocks such as limestones, sandstones, gypsiferous limestones and sandstone are present, and a huge and wide coastal sand dune system. Basaltic flows are present in the northwest part of the AOI. From a tectonic point of view, this AOI is characterised by a fault system parallel to the coast, in the alluvial part of the AOI and by a system of northwest-southeast oriented faults in the metamorphic basement complex.

Some late Tertiary fluvio-lagunal deposits occur on the Lower Juba plain and part of the southern Shabelle, consisting of clay, sandy clay, sand, silt and gravel. Recent fluvial deposits are common alongside two major rivers, the Juba and the Shabelle, consisting of sand, gravel, clay and sandy clay. Other Recent alluvial deposits occur in small valleys in Gedo and Bakool Regions and in the Buur area, and consist of gravelly sand or red sandy loam materials. A wide coastal dune system occurs along the coast.

2.4.4 Landform / Soils

The southern AOI is characterised by the following land features, according to the bibliography:

1. the two main river valleys (Jubba and Shabelle Rivers) that traverse the generally level, undulating morphology of the area;
2. hilly topography in the middle of the AOI cut by wadis, and gently undulating wide plains toward the coast;
3. a coastal dune complex, known as the Merka red dunes which fringes the coast from beyond the Kenyan border, separating the narrow coastal belt from the Uebi Shebeli alluvial plain (Carbone & Accordi, 2000).

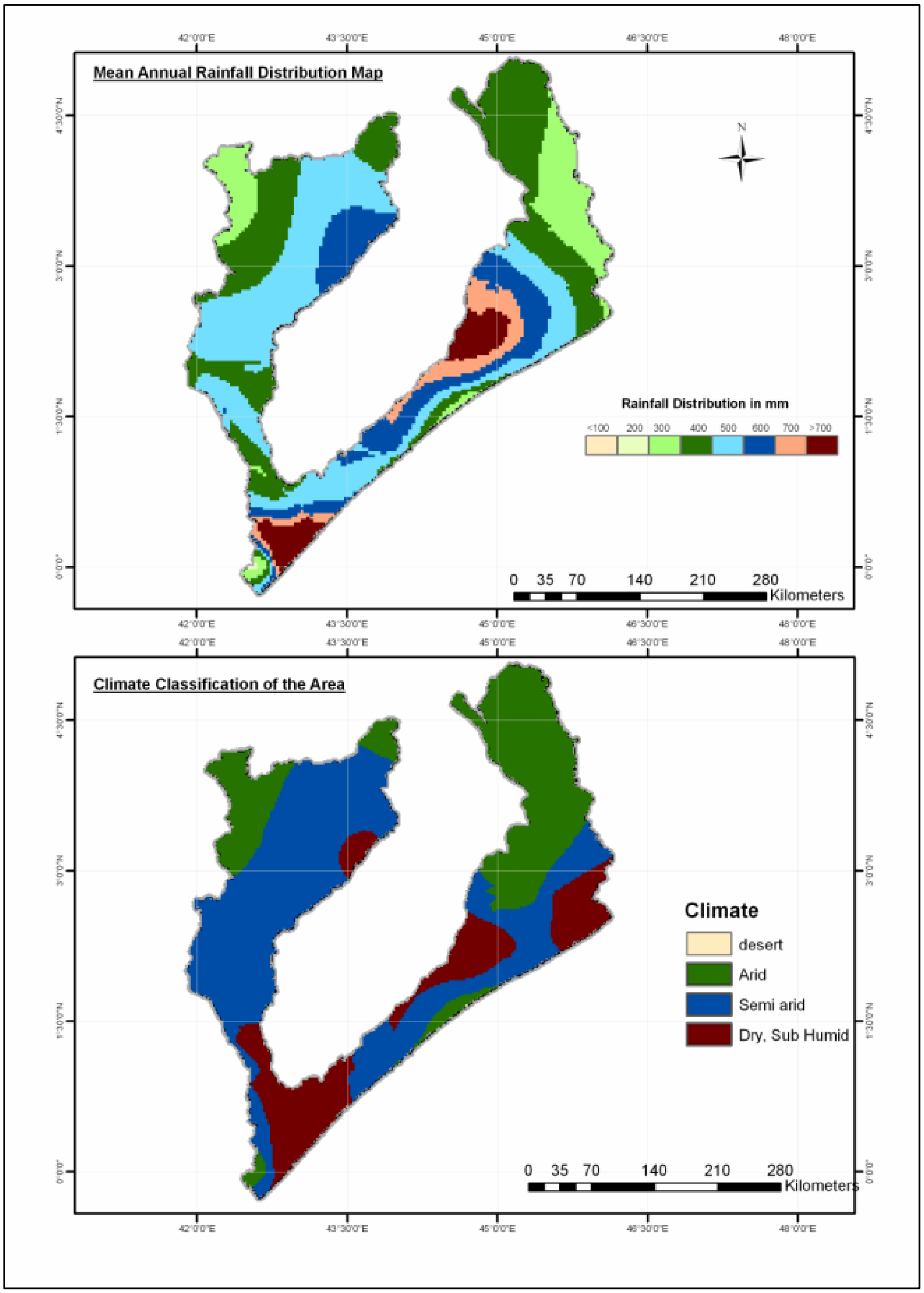

Figure 6: Mean annual rainfall distribution map and climate of study area

The southern AOI is dominated by the presence of the distal portion of the two main perennial rivers of the Horn of Africa, flowing from the highlands of Ethiopia toward the Indian Ocean: the Jubba River (700 km of which in within Somalia, out of its 2 000 km total length) and the Shabelle River (1 560 km of which is within Somalia, out of its almost 1 800 km of total length). The Jubba flows into the Indian Ocean almost at Kismaayo city, while the Shabelle impounds itself a few kilometres before reaching the lower tract of the Jubba.

Because of the predominance of alluvium, many soils comprise layers of deposited materials which, because of the semi-arid climate, have been little-affected by normal soil-forming processes. Despite their variability, most soils share the characteristics of heavy texture and low permeability, with a tendency to poor drainage.

2.4.5 Land Cover

Land cover in the study area consists mainly of natural vegetation. Other cover types include Crop fields (both rainfed and irrigated), Urban and Associated Areas (Settlement/Towns and Airport), Dunes and Bare lands and Natural Water bodies. The natural vegetation consists of forest, bush lands and grasslands. Woody and herbaceous species include *Acacia bussei*, *A. etbaica*, *A. nilotica*, *A. tortilis*, *A. senegal*, *Chrysopogon auchieri* var. *quinqueplumis*, *Suaeda fruticosa* and *Salsola foetida*.

2.4.6 Land Use

Land use in the study area consists mainly of grazing and wood collection for fuel and building. Rangelands in the Juba and Shabelle catchments support livestock such as goats, sheep, cattle and camels. Livestock ownership is private, but grazing lands are communal, making it very difficult to regulate range use. Rangelands are utilised by herders using transhumance strategies (Shaie, 1977). Land cover associated with this land use includes forest, bushlands and grasslands (GTZ, 1990).

Farmers in these two river valleys are sedentary, practicing animal husbandry in conjunction with crop production. They tend to keep lactating cattle, a few sheep and goats near their homes, while non-lactating animals are herded further away, in the manner of herding nomadic stock. However, rainfed and irrigation farmers keep relatively small numbers of livestock, mainly cattle and small ruminants.

Animal feed is primarily from natural vegetation and crop residues, while dry season watering of animals is from rivers. Crop residues provide forage for non-browsers such as cattle and sheep. Several wars provide water in the wet season and also serve as alternative water sources to rivers. Groundwater is also an important source of water for livestock, other sources including hand-dug wells, swamps, creeks and boreholes.

Other land uses include rainfed agriculture, which includes agriculture that is entirely dependent upon rainfall. Crops under this category of land use include sorghum, millet, maize, groundnuts, cowpeas, mung beans, cassava and other minor crops, and are grown twice a year in the Gu and Deyr seasons.

Small-scale irrigated fields are also found along the Shabelle and Juba river valleys, growing maize, sesame, fruit trees and vegetables while large-scale plantations include sugar cane, bananas, guava, lemon, mango and papaya.

Flood recession cultivation in desheks (natural depressions) on the Juba River floodplain is common, crops including sesame, maize and vegetables. Major crops in the *desheks* are maize, sesame, tobacco, beans, peas and vegetables, watermelon and (rarely) groundnuts. Cropping is either single or mixed.

3 MATERIALS AND METHODS

The materials and methods utilised in this exercise are described following the subdivision of the three integrated methodologies that were adopted: materials for the Digital Terrain Analysis (DTA), Visual Image Interpretation (VImI) and the Field Survey (FS). A flowchart of the methodology followed and the software used, are presented. The conceptual background for this methodology is explained in Chapter 2.

3.1 Materials for the Digital Terrain Analysis (DTA)

The DTA started with the acquisition of a Digital Elevation Model (DEM). In this case the DEM was the public release of 90 m resolution data produced by NASA's Shuttle Radar Topography Mission (NASA-SRTM). Many different sources of DEM are now available, but the only consistent dataset for Somalia remains that freely distributed by NASA–SRTM. This dataset is the result of a collaborative effort between the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA – previously know as NIMA), with participation of the German and Italian Space Agencies. The SRTM instrument consisted of the Spaceborne Imaging Radar-C (SIR-C) hardware set modified with a Space Station-derived mast and additional antennae, to form an interferometer with a 60 m long baseline. A description of the SRTM mission can be found in Farr & Kobrick (2000). SRTM was the primary payload on the STS-99 mission of the Space Shuttle Endeavour, which launched February 11, 2000 and flew for 11 days. The target consisted of all land between 56°S and 60° N, or almost exactly 80% of the earth's total surface.

The data have been refined at NASA's Jet Propulsion Laboratory (JPL) obtaining a seamless dataset with 30 m resolution that is only freely available for the area of the United States of America. For areas outside the USA, only the 90 m DEM is freely available.

Three software packages were used for DTA analysis, apart from ArcGIS, all of which are freely available through the internet:

- LandSerf, for landform classification
- TAS, Terrain Analysis Software, for Landform classification
- TPI, Topographic Position Index, for Landform classification and slope position index.

Many different software packages for digital terrain classification are available, both gratis and at cost. After a detailed analysis of those available, three were chosen, apart form the ArcGIS package. They are: TAS (Terrain Analysis System), TPI (Topographic Position Index) and LandSerf.

Terrain Analysis System (TAS) was developed by J.B. Lindsay (2005), to whom we refer for this explanation: "TAS is designed to meet the research needs of government and academic scientists while being simple enough in operation to be used for student instruction. TAS is a stand-alone GIS that possesses much of the spatial analysis functionality typically found in GIS packages. However, it is also capable of advanced modelling of catchment processes. Analysis in TAS is organized into five broad categories: pre-processing, image processing, statistical analysis, GIS analysis, and terrain analysis".

Common tasks for which TAS has been applied include landform classification, watershed extraction, basin morphometric analysis, stream network extraction and analysis, and wetland delineation.

TAS can classify landforms based on the Pennock *et al*. (1987) scheme, but the relative landscape position subprograms (Table I) and fuzzy membership facilities (Table II) are also useful for developing custom landform classifications. The landform classification classes are: Covergent footslope; Divergent footslope; Convergent shoulder; Divergent shoulder; Covergent backslope; Divergent backslope; Level.

The *Topographic Position Index* (TPI) is an extension to be run under ESRI ArcView. It was created by J. Jenness (2005), to whom we refer for a description;

"TPI is based on a poster presented at the 2001 ESRI International User Conference describing the concept of Topographic Position Index (TPI) and how it could be calculated (Weiss 2001; see also Guisan *et al*. 1999 and Jones *et al*. 2000). Using the TPI at different scales, plus slope, users can classify the landscape into both slope position (i.e. ridge top, valley bottom, mid-slope, etc.) and landform category (i.e. steep narrow canyons, gentle valleys, plains, open slopes, mesas, etc.).

The algorithms are clever and fairly simple. The TPI is the basis of the classification system and is simply the difference between a cell elevation value and the average elevation of the neighbourhood around that cell. Positive values mean the cell is higher than its surroundings while negative values mean it is lower.

The degree to which it is higher or lower, plus the slope of the cell, can be used to classify the cell into slope position. If it is significantly higher than the surrounding neighborhood, then it is likely to be at or near the top of a hill or ridge. Significantly low values suggest the cell is at or near the bottom of a valley. TPI values near zero could mean either a flat area or a mid-slope area, so the cell slope can be used to distinguish the two.

TPI is naturally very scale-dependent. The same point at the crest of a mountain range might be considered a ridgetop to a highway construction crew or a flat plain to a mouse. The classifications produced by this extension depend entirely on the scale you use to analyze the landscape".

LandSerf is a Java-based standalone software developed by J. Wood (2005) of City University, London (see also http://www.landserf.org/). "LandSerf is a freely available Geographical Information System (GIS) for the visualisation and analysis of surfaces. Applications include visualisation of landscapes; geomorphological analysis; gaming development; GIS file conversion; map output; archaeological mapping and analysis; surface modelling and many others.

It runs on any platform that supports the Java Runtime Environment (Windows, MacOSX, Unix, Linux etc.). The surface feature classification function is the one we used for our purposes. The result of Surface features detection is a classification of a surface into 6 categories - pits, channels, passes, ridges peaks and planar regions. Two parameters have to be set for performing this function: the slope tolerance value determines how steep the surface can be while still being classified as part of a pit, pass or peak feature - larger values of this parameter tend to increase the number of point features detected; the curvature tolerance value determines how convex/concave ('sharp') a feature must be before it can be considered part of any feature - curvature is recorded as a dimensionless ratio, with typical tolerance values ranging from 0.1 to 0.5, larger values tend to increase the proportion of the surface classified as planar, leaving only the sharpest features identified.

Apart from these two parameters other two must be set up. The window (or kernel) size is set as the number of cells along one side, so a value of 3 gives 3x3=9 cells, 4 gives 16 cells, etc. The value must be odd and less than the size of the smallest side of the raster. In addition, a distance decay exponent can be set that determines how important cells nearer the centre of the window are in comparison with those towards the edge. A value of 0 gives equal importance to all cells, a value of 1, inverse linear distance decay, and a value of 2, inverse squared distance decay. Negative and non-integer values are also permitted".

3.2 Materials for the visual image interpretation

The software used was mainly the ArcGIS package, that allows the integration and overlapping of many layers, allowing also setting up transparencies of each layer and thus the possibility of having a truly integrated view and analysis of all the different data layers.

Three main datasets were used for the visual image interpretation:

1. Satellite images;
2. Existing maps and datasets;
3. Grey literature.

For satellite imagery, the main data sources were Landsat 7 ETM+, Aster, Ikonos and QuickBird (See Annex 5).

Existing maps and datasets included 1:100 000 topographic maps from the 1970s (revised in the early 1990s), geological maps, some at a semi-detailed scale (1:200 000 and 1:250 000) and one at a national scale (1:1 500 000), datasets on landform from SOTER (scale 1:1 000 000), and Africover (1:300 000) (See Annex 5).

In the following tables the two AOI are considered separately and a list of all materials used is presented.

3.3 Materials for the FS

The field survey was thus far conducted only for the north-western part of the country. The same materials prepared and used for the north will be appropriate for use in the future south Somalia field survey. A more detailed description of field materials and methods is given in the Field Survey Report and Field Survey Manual (Interim Report Li-03 and Project Report L-01). Five main datasets/tools have been used and/or produced for the field survey:

1. Preliminary map, printed on A0 format paper, with legend;
2. Field forms, paper based;
3. Laminated tables with legends for the codes adopted for the maps;
4. Field tools;
5. Glossaries and bibliography.

The preliminary maps were printed in colour on A0 format paper in sets of two sheets at a scale of 1:130 000, the number of copies equivalent to the number of surveyors, plus two spare copies. Five sets of landform maps were printed. In addition to this, three geological maps were draped over a hillshade background and given to field surveyors.

The field forms were created and edited starting from the few existing bibliographic references, and are included in Annex 3. Form structure and content are detailed in the Field Survey Manual (Project Report L-01).

Glossaries were provided to the field surveyors in order to assist landform investigation and form completion. A detailed description of field tools is included in the Land Theme Activities Report (Interim Report Li-02).

The glossaries related to landforms and lithology (see Annexes 1 and 2); with regard to the bibliography, certain references were extracted and provided to the field surveyors.

3.4 Methodology

The methodology follows the integration scheme (Chapter 2.5). In the following two diagrams a general and a detailed flow chart of the methodology is illustrated.

In the general methodology flow-chart (Figure 7), three stages are highlighted: Stage 1 refers to the preliminary preparation of data and software and of unverified maps for the North and South AOI; Stage 2 refers to the proper field survey, conducted as a joint mission with international and Somali national experts; Stage 3 refers to two different parts: one for the northern AOI, where the finalization of the field verified maps has been performed in the second half of 2006, and one for the Southern AOI where data has been implemented by further digital terrain analysis, and field verification has been performed in March 2007.

In the detailed flow-chart (Figure 8) a description of the software used is presented as a flow chart.

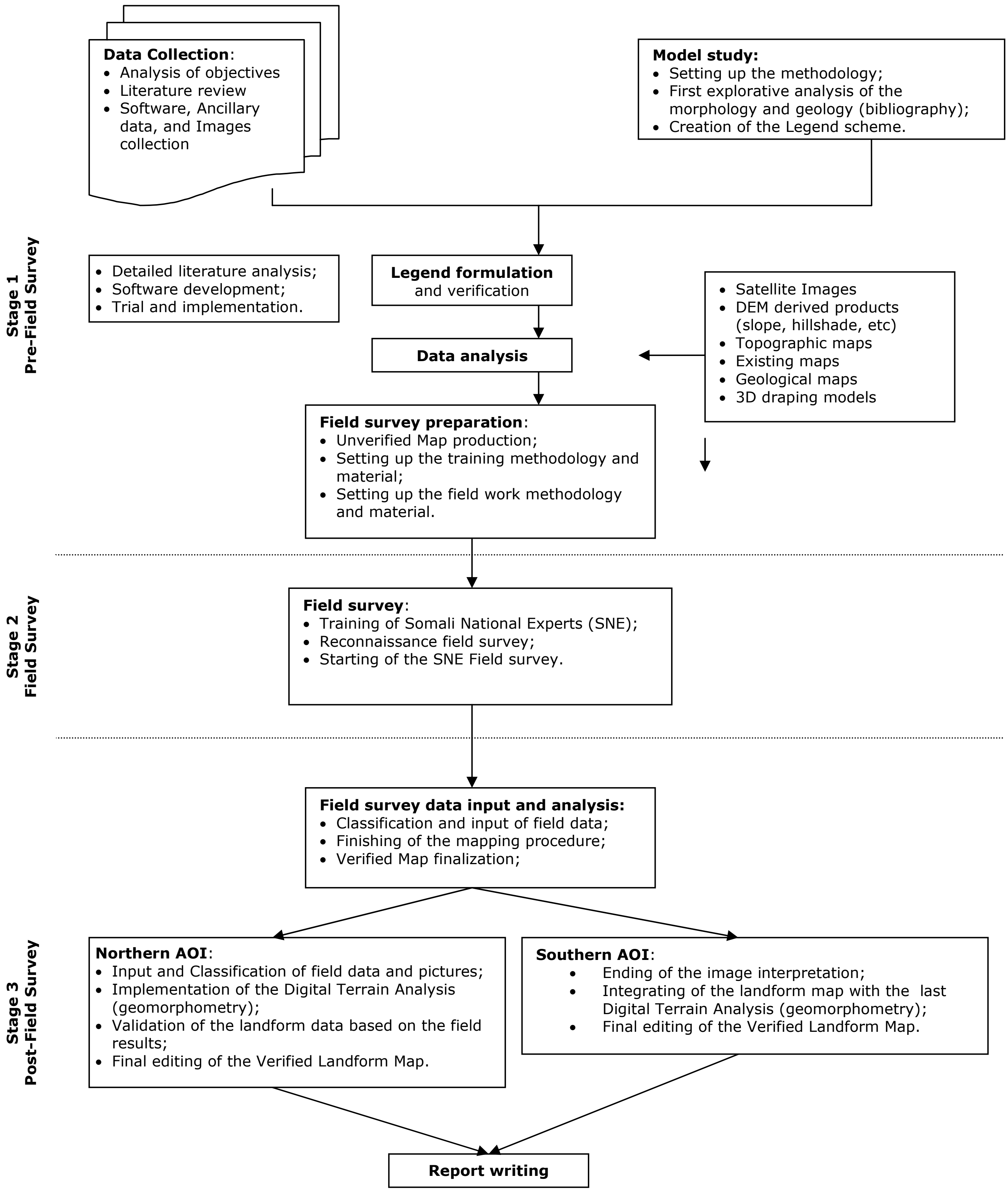

Figure 7: Flow chart showing general methodology followed during the landform mapping process

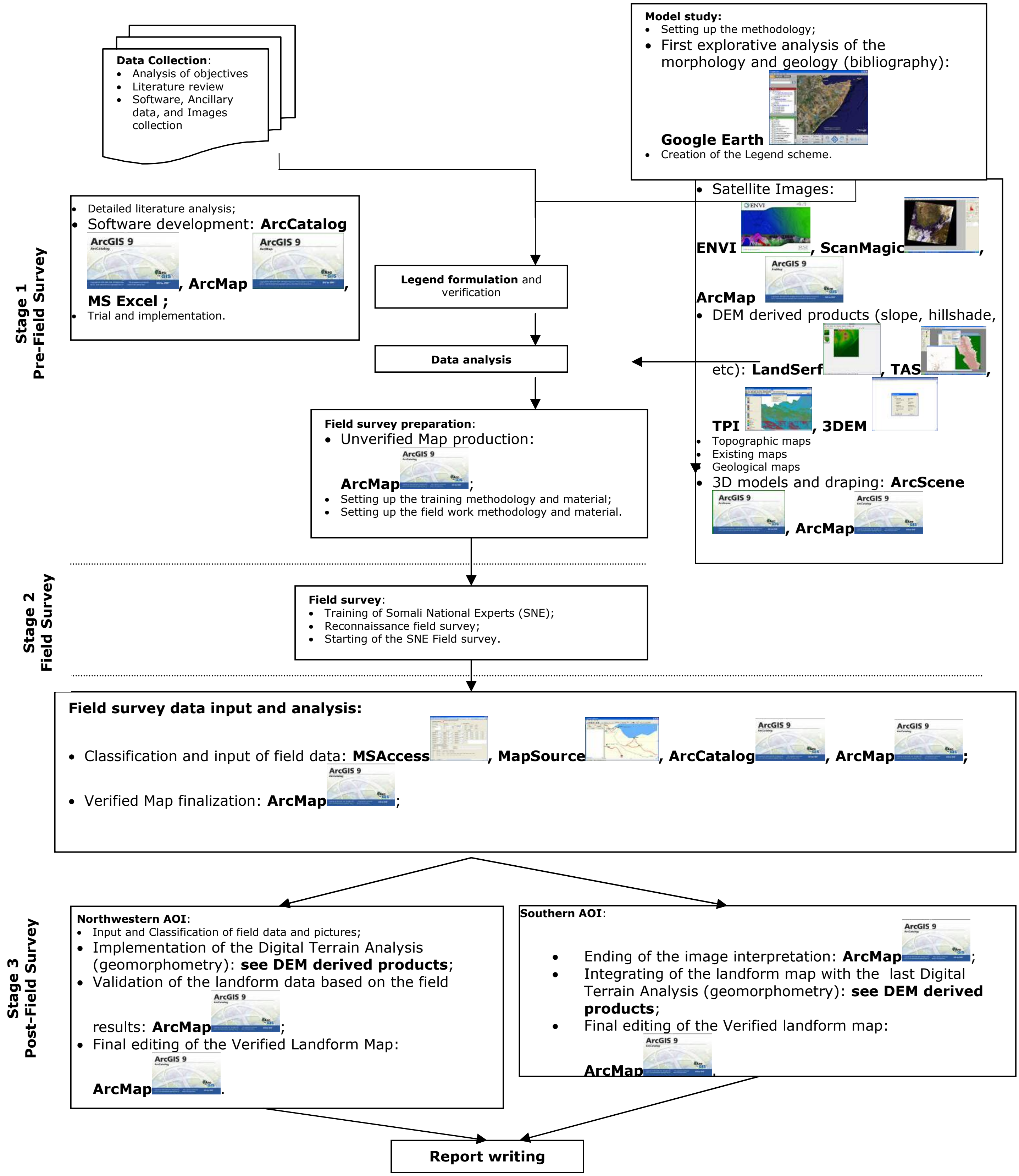

Figure 8: Flow chart showing software used during the landform mapping process

4 RESULTS

The results of the present exercise are described. They consist of different outputs for the two AOI, and of methodological general results, regardless of the geography of the area. This is why in this chapter three paragraphs account for the different results:

- The first for the North, field verified, AOI, with Landscape/Relief/Landform description;
- The second for the South, field verified AOI, with Landscape/Relief description;
- The third for the general achievements and outputs, with a description of the new landform legend developed under GIS environment, the geological conversion table, the vectoralisation of the national geological map.

In the two chapters dealing with the two AOI a synthesis of the analytical investigation of the Landform and Lithology is presented. Morphology is described first, then lithology, then landforms, and finally a characterisation of the AOI is attempted.

4.1 Landforms of the Northern AOI

The northern AOI extends for almost 13 000 km² (1 293 700 hectares) covering most part of the Dur-Dur catchment. The most important city is Hargeisa, located in the south-eastern part of the AOI.

4.1.1 Morphology

The northern AOI covers an area extending from the flat coastal plain up to some of the highest mountain peaks in Somalia (Figure 9), with elevations ranging from 0 m-1 854 m asl (Figure 10). The highest elevation is located in the western part of the AOI surrounding the city of Borama. The elevation classes increase in height parallel to the coastline for the first 1 000 meters, whereafter they follow a different pattern.

Looking at the elevation patterns, it is possible to define two areas: one from the coastline up to the 1000 m contour in which changes in elevation are smooth and follow a regular gradient; another area extends from the 1 000 contour up to the highest elevation, where gradient are irregular and more influenced by geological structures, as it will be seen later.

The slope map (Figure 11) clearly shows the presence of the steeper mountains that occupy most of the north-western and central sectors of the AOI. The mountains demonstrate a general NW-SE alignment that can be grouped into three main parallel blocks, moving from the coast toward the interiors.

According to slope patterns noted, it is possible to define four main areas: a coastal sector close to the coast and extending for almost 50 km landward, where the general slope is < 8% (3,6°); a central-western sector where values of the slope are on average > 8% (3,6°) and frequently higher than 50% (22,5°); a south-western sector where the terrain is almost flat with slope values between 0-4% (0-almost 2°); and a south-eastern sector where average slope values are still quite low, below 16% (7,2°) but showing a peculiar pattern defined by the presence of wide valleys.

The aspect of the slopes within the AOI shows a pattern that follow the four sectors defined for the slope (Figure 12): a coastal sector with a general aspect toward the north; a central-western sector where the aspect is facing alternatively toward the north-east and south-west, following the paths of narrow valleys and ridges; a south-western sector where the general aspect faces towards the south; and a south-eastern sector where slopes face both the south and the north-west.

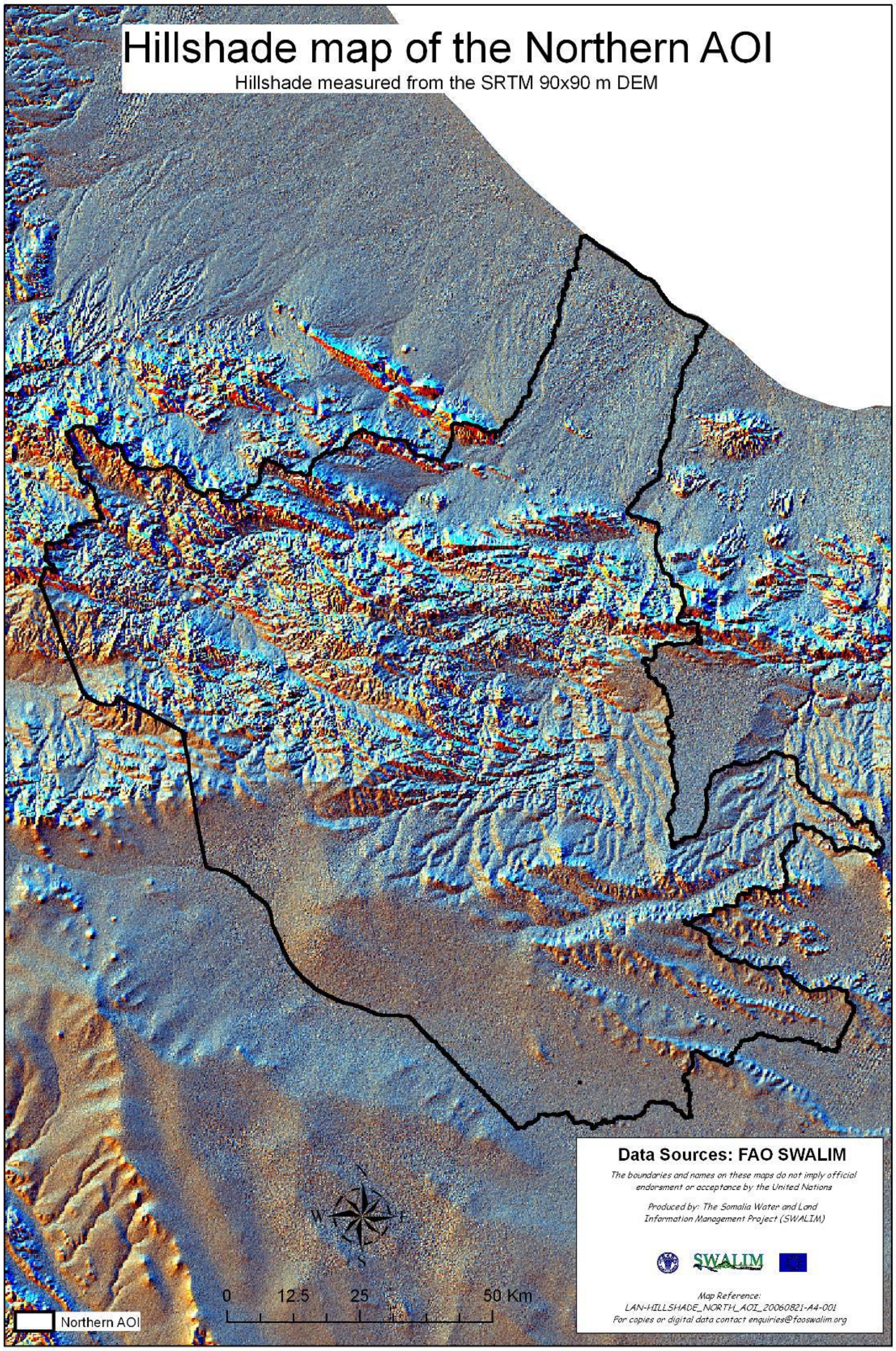

Figure 9: Hillshade (shaded relief) of the northern AOI

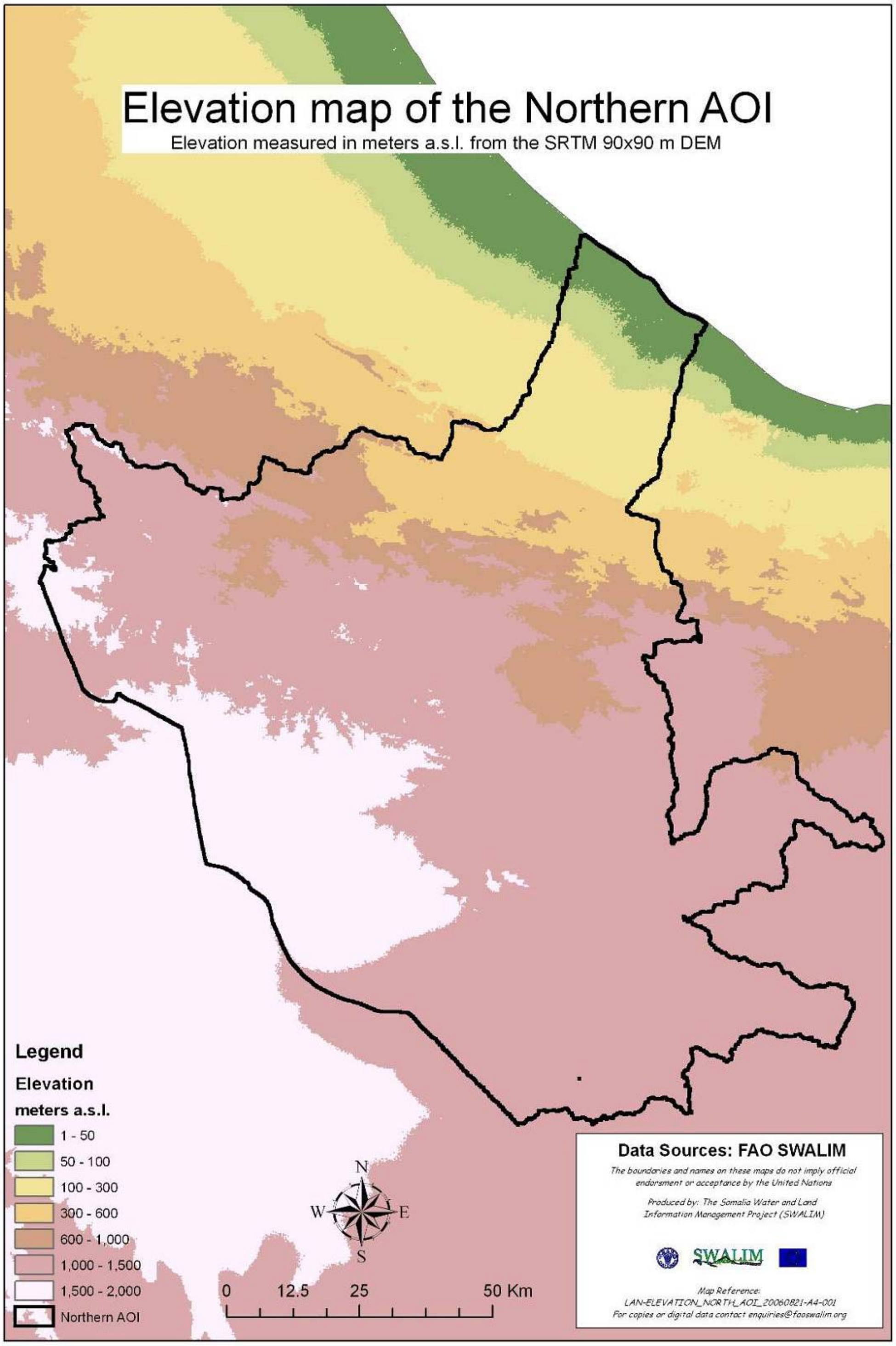

Figure 10: Elevation map of the northern AOI

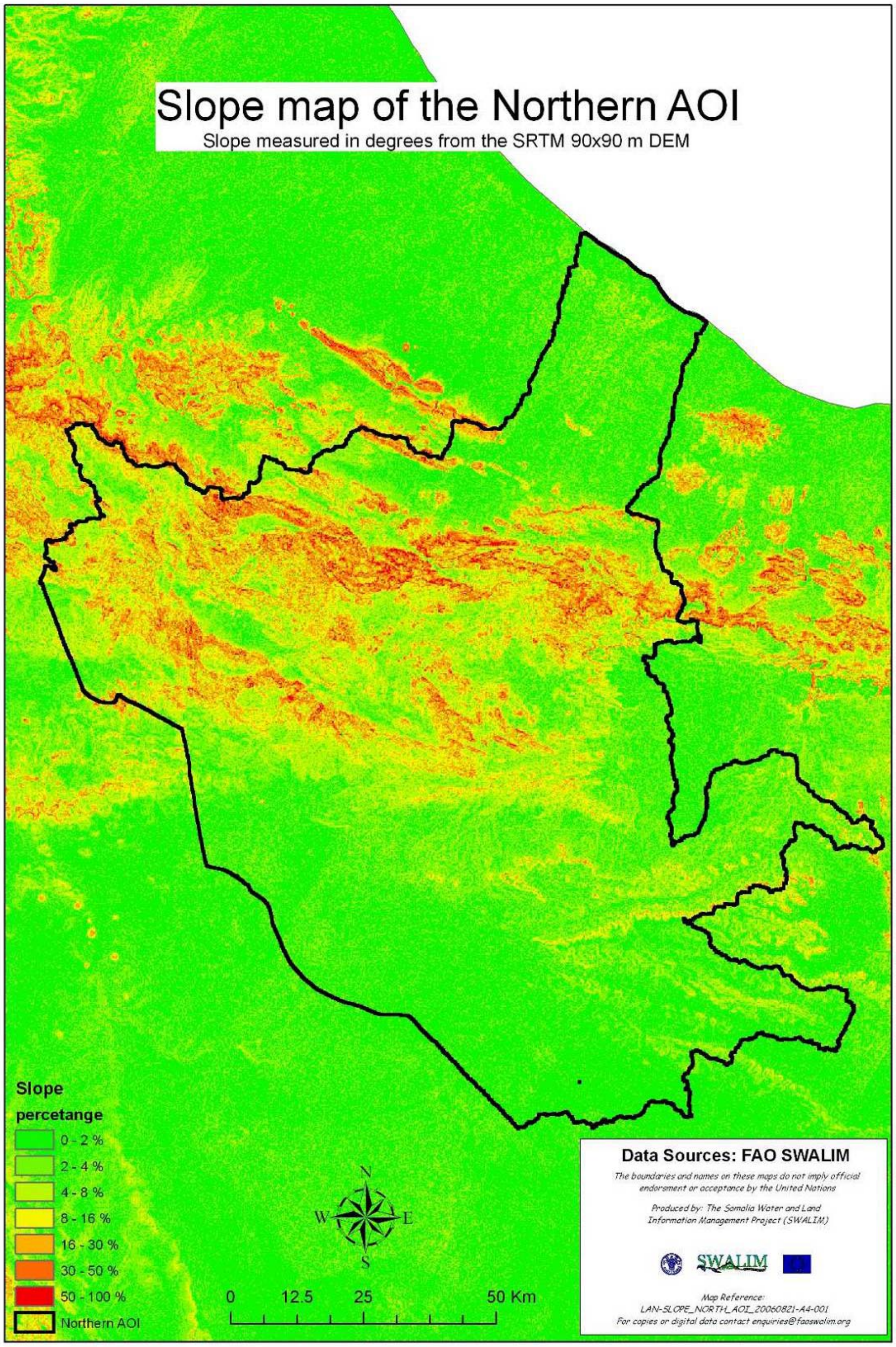

Figure 11: Slope map of the northern AOI

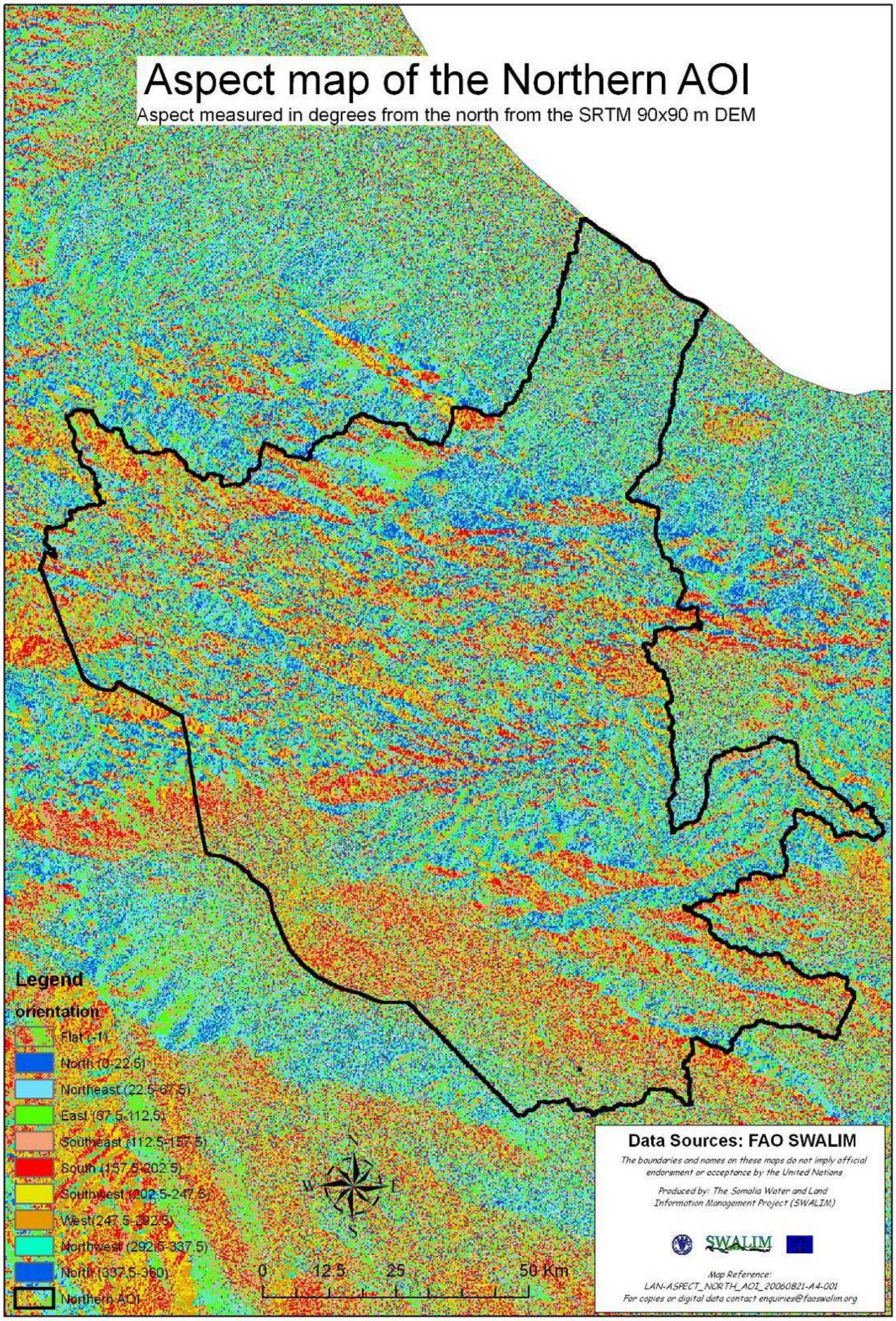

Figure 12: Aspect map of the northern AOI

4.1.2 Lithology

The Northern AOI is characterised by the presence of sedimentary, igneous and metamorphic rocks. Analysis of the field survey forms and descriptions indicates that the majority of differences between rock types and their condition (in terms of fracturation) follow the general topographical pattern. The Lithological map (Figure 13) clearly shows the distribution of sedimentary, igneous and metamorphic rocks.

The *south-eastern* and *northern* sectors are characterised by outcroppings of sedimentary rocks, mainly sandstone and limestone and unconsolidated fluvial, alluvial and colluvial deposits, respectively. Rocks formations are generally flat-topped, which also is reflected in landform arrangements in this area. Where outcrops consist of less cohesive rocks, intense water erosion, both gully and sheet, affect the area. In the coastal area, where all water flowing from the interior mountains accumulates, there is a very dense, albeit ephemeral, hydrographic network.

The *central* and *western* sectors consist of mainly igneous and metamorphic rocks. These are extremely fracturated by a complex system of faults and fractures resulting in both the macro- and meso-scale as conjugated plans of fractures. Furthermore, erosive water processes have cut deep gorges inside the mountainous area.

4.1.3 Landform

1 028 polygons were mapped in the northern AOI, accounting for six general Landscape groups (Hillands, Mountains, Piedmonts, Plains, Plateaus and Valleys; Figure 14) and 15 different Landscape types (Figs. 15, 5.1-8 and Table 11), 31 different Relief types (Figs. 5.1-9, 5.1-10 and Table 11), and 19 different Landform types mapped only for certain portion of the AOI where it was possible to distinguish them on satellite imagery (Figs. 91, 5.1-12 and Table 11). In the following table the completed legend for the northern AOI is presented.

Table 11: Final legend scheme, including all the three hierarchical levels, for the northern AOI

Landscape		**Relief**		**Landform**	
Code	*Description*	*Code*	*Description*	*Code*	*Description*
HiD	Dissected Hilland	A02	Town, Industrial district	F02	Rill
Hil	Hilland			F03	Gully
		C03	Sandy Coast	F05	River levee
MoB	Block Mountain			F06	Floodplain
MoF	Fault Mountain	E05	Playa	F07	Alluvial Terrace
MoR	Residual Mountain			F09	Depression
Mou	Mountain	F04	Braided river plain	F14	Upper pediment
MoV	Volcanic Mountain	F05	Meandering river plain	F15	Middle pediment
		F08	Badland (complex gully)	F16	Lower pediment
Pie	Piedmont	F09	Gully/Rill erosion surface		
		F10	Sheet erosion surface	X01	Summit of the slope
PlA	Alluvial Plain	F12	Alluvial plain	X02	Shoulder of the slope
PlC	Coastal Plain	F13	Depression	X03	Backslope
PlD	Dissected Plain	F14	Pediment	X04	Footslope
Pln	Plain	F15	Dissected pediment	X05	Toe-slope
		F16	Delta	X06	Upper Slope
Pta	Plateau	F17	Flat floor valley	X07	Lower slope
PtD	Dissected Plateau	F18	River plain	X08	Slope complex
		F25	River incision	X09	Crest
Vay	Valley				
		G08	Talus slope		
		S08	Escarpment		
		S15	Depression (structural)		
		S16	Dissected ridge		
		S24	Inselberg		
		S25	Cuesta		
		S26	Mesa		
		S27	Hogback		
		S29	Hill		
		S30	Hill complex		
		S31	Ridge		
		S32	Planation surface		
		S33	Denudational slope		
		S34	Slope		
		S35	Denudational surface		

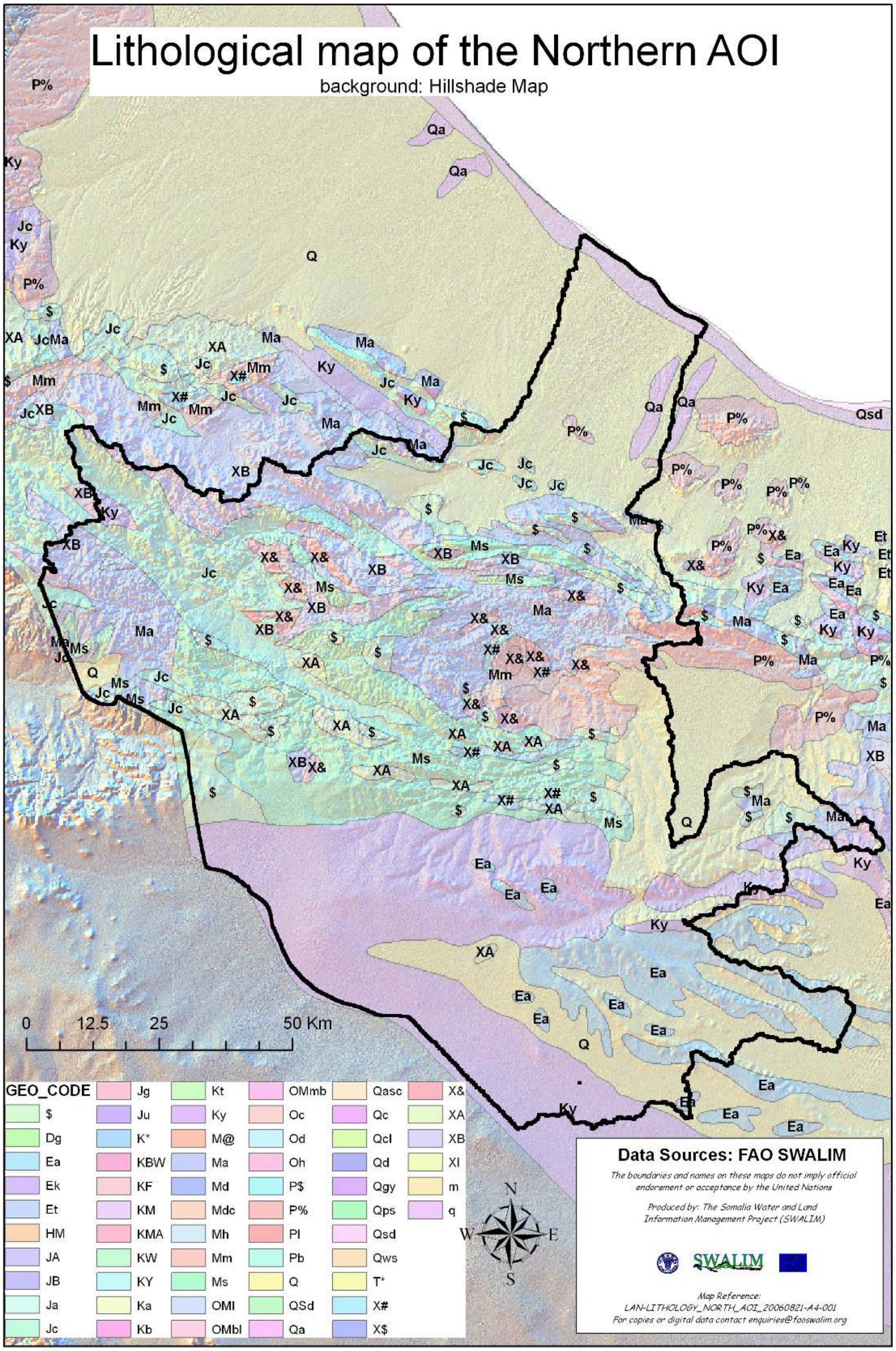

Figure 13: Lithological map of the northern AOI, using the base map of Abbate *et al*., 1994 (for classes refer to Annex 2)

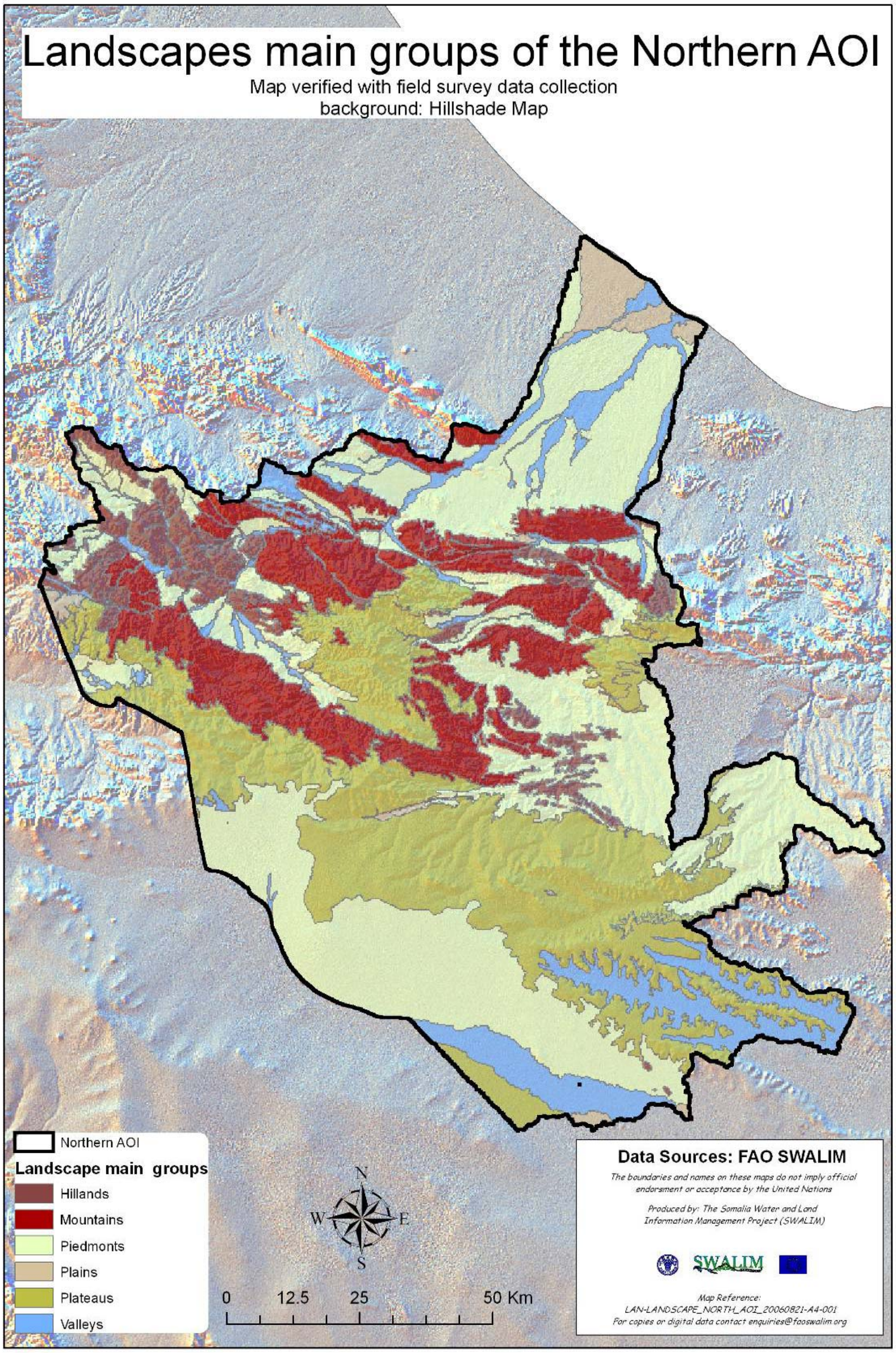

Figure 14: Main Landscape groups of the northern AOI

This map (Figure 14) represents the highest level of the hierarchy Landscape/Relief/Landform. It groups the major physiographic land elements, and illustrates where to expect very sloped terrain (mountains), Moderately sloping lands

(Hilland) Sloping land (Piedmonts), very gently sloping land (Plateau) and almost flat land (Plains and Valleys).

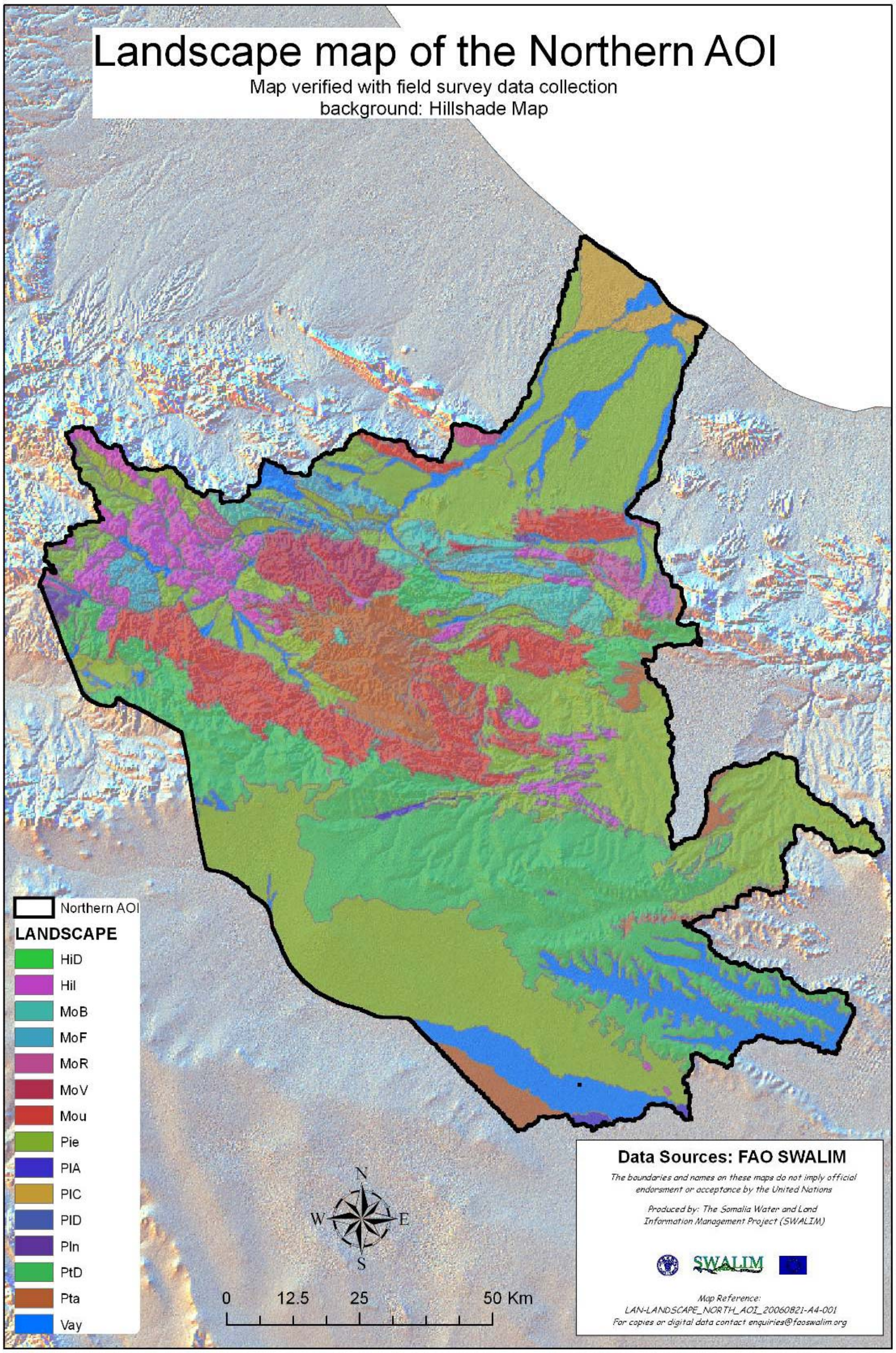

Figure 15: Landscape types of the northern AOI

Figure 15 represents all the different types of Landscapes and their geographical location. From Table 12 and Figs. 5.1-8 it is evident that the piedmont landscape type occupies the greatest surface, followed by Dissected Plateaus and Valleys, respectively.

Table 12: Distribution of Landscape types and their specific areas (in km^2)

Landscape code	Landscape description	Km^2
HiD	Dissected Hilland	0.34
Hil	Hilland	666.02
MoB	Block Mountain	308.47
MoF	Fault Mountain	225.34
MoR	Residual Mountain	119.72
Mou	Mountain	1152.51
MoV	Volcanic Mountain	304.51
Pie	Piedmont	4869.58
PlA	Alluvial Plain	42.29
PlC	Coastal Plain	205.77
PlD	Dissected Plain	1.07
Pln	Plain	32.41
Pta	Plateau	734.66
PtD	Dissected Plateau	2996.93
Vay	Valley	1279.47
Total		12939.08

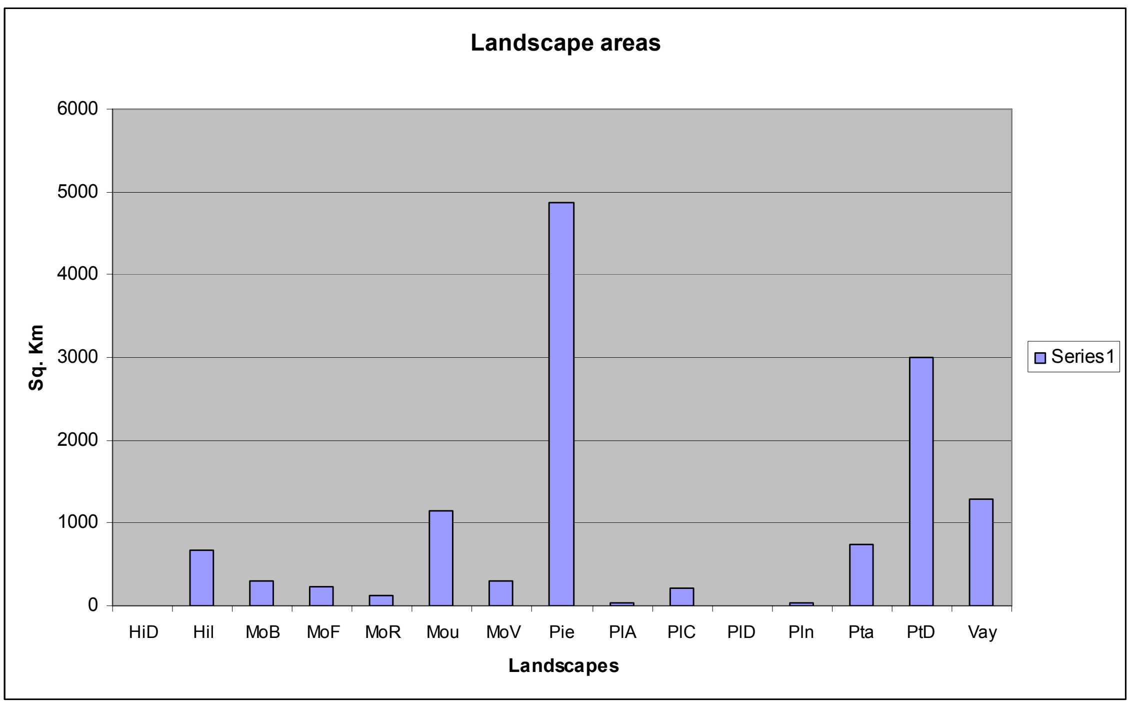

Figure 16: Chart showing Landscape types vs. Area (km²)

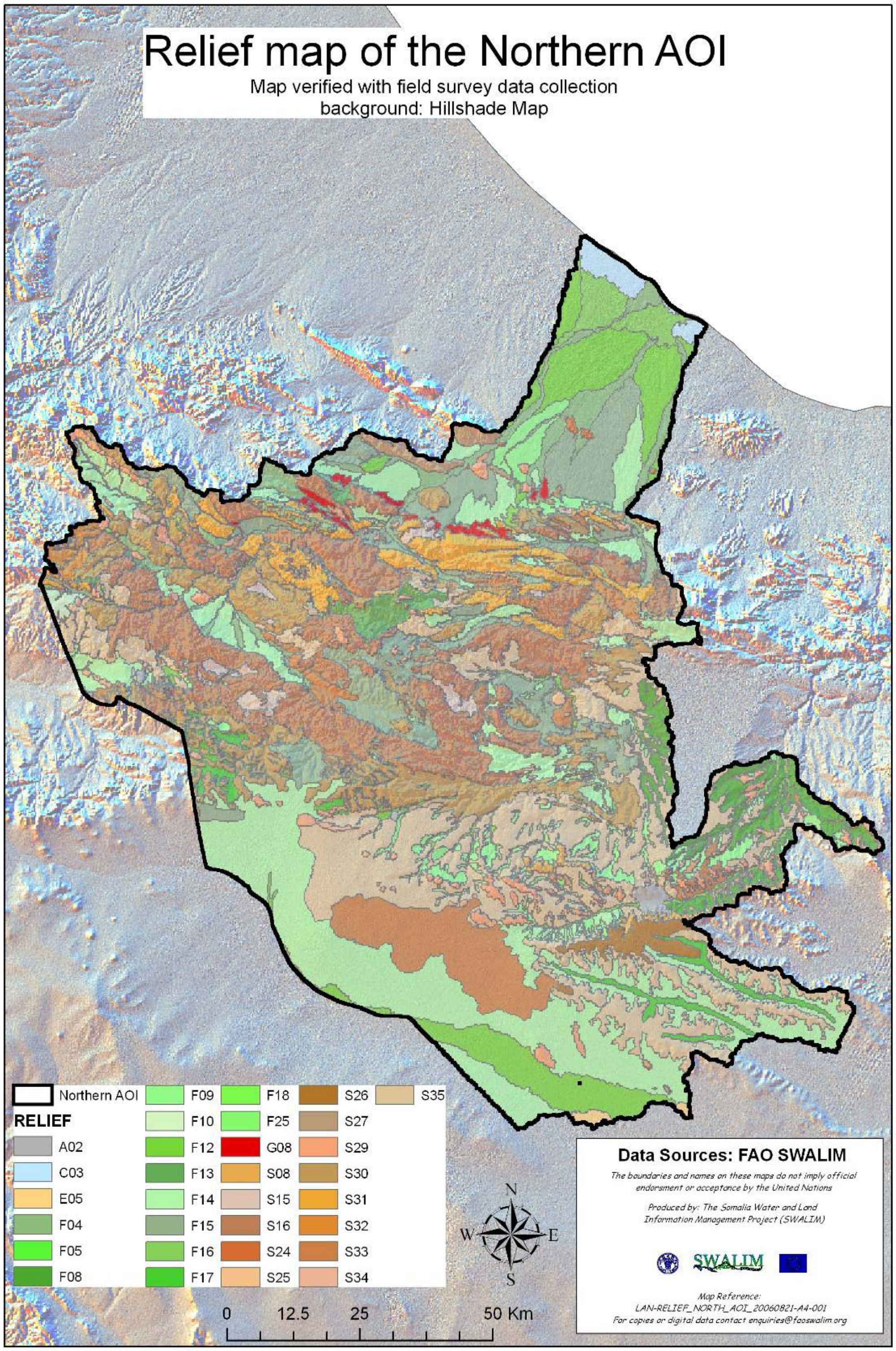

Figure 17: Relief types of the northern AOI

Figure 17 illustrates the different types and location of relief in the northern AOI. From Table 13 and Figure 17 it is evident that Fluvial (F14) and Structural (S35 and S16) reliefs are the most representative. They are in good agreement with the prevalence of

Valley and Piedmont landscapes. Many denudational surfaces (S36) are areas acted upon by sheet and linear water erosion, giving rise to significant soil loss.

Table 13: Distribution of Relief types and their specific areas (in km2)

Relief codes	Relief descriptions	Km^2
A02	Town, Industrial district	41.20
C03	Sandy Coast	88.91
E05	Playa	25.47
F04	Braided river plain	544.41
F05	Meandering river plain	2.86
F08	Badland (complex gully)	351.33
F09	Gully/Rill erosion surface	413.59
F10	Sheet erosion surface	31.41
F12	Alluvial plain	830.10
F13	Depression	121.88
F14	Pediment	2352.27
F15	Dissected pediment	933.05
F16	Delta	139.90
F17	Flat floor valley	205.44
F18	River plain	14.24
F25	River incision	7.44
G08	Talus slope	73.68
S08	Escarpment	90.56
S15	Depression (structural)	106.23
S16	Dissected ridge	1581.89
S24	Inselberg	12.16
S25	Cuesta	5.74
S26	Mesa	103.12
S27	Hogback	75.29
S29	Hill	347.86
S30	Hill complex	1197.12
S31	Ridge	509.50
S32	Planation surface	49.52
S33	Denudational slope	661.02
S34	Slope	27.80
S35	Denudational surface	1992.94
Total		12939.08

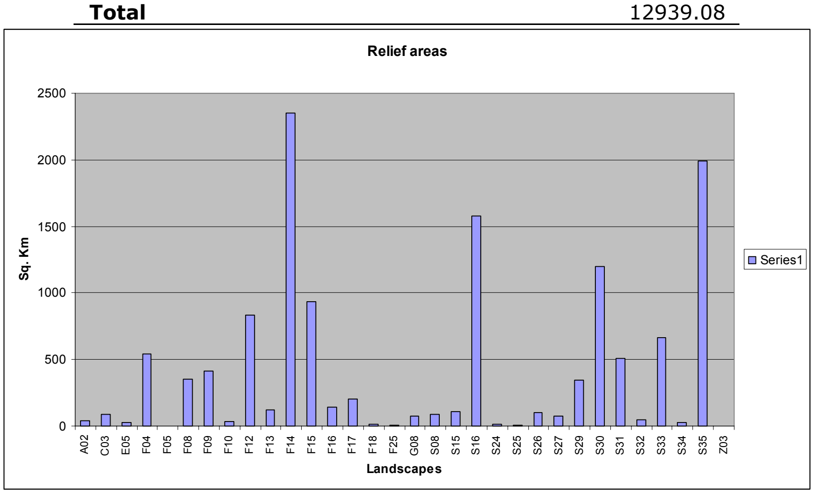

Figure 18: Chart showing Relief types vs. Area (km^2)

LANDFORM MAP

Table 14: Distribution of Landform types and their specific areas (km^2)

Landform codes	Landform descriptions	Km²
F02	Rill	9.36
F03	Gully	7.75
F05	River levee	0.22
F06	Floodplain	217.97
F07	Alluvial Terrace	11.91
F09	Depression	3.19
F14	Upper pediment	349.83
F15	Middle pediment	304.24
F16	Lower pediment	42.33
X01	Summit of the slope	115.54
X02	Shoulder of the slope	23.70
X03	Backslope	559.53
X04	Footslope	307.95
X05	Toe-slope	219.24
X06	Upper Slope	307.33
X07	Lower slope	475.08
X08	Slope complex	1179.08
X09	Crest	51.19

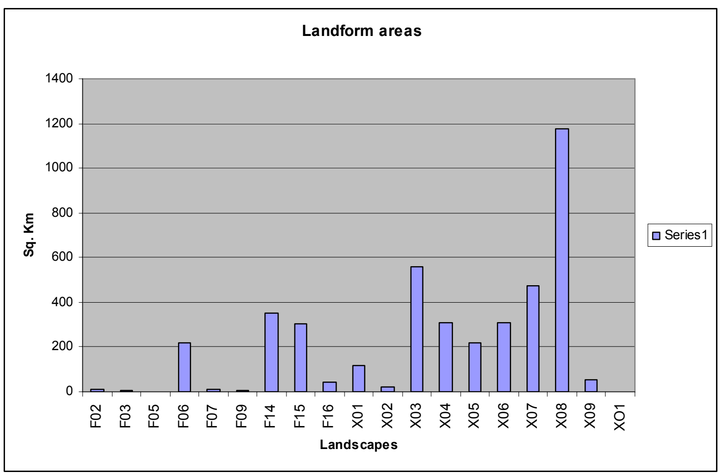

Figure 19: Chart showing Landform types vs. Area (km^2)

A brief description of each landscape, with its characteristic reliefs and landforms, is given below.

Valley (Vay) landscapes are characterised by flat-lying surfaces of the valley floors, only. They do not include valley sides, that are here considered part of Hillands or Mountains or other landscapes. Valley floors slopes are generally between 0-4% up to a maximum of 8% (4 degrees). They generally consist of alluvial sediments and are drained by *toggas* (*wadis*) that, in the northern AOI, receive water only during the rainy seasons. They can have very different planar shapes, but many contain meandering or braided rivers: the former is more common in the inner part of the mountain chain, while the latter is much more common on the wide coastal piedmont and also on the plateaus and dissected plateaus. Within the valleys, the most common reliefs are Braided river plain

(75%) followed by Pediments (9%) and by Alluvial plains (4%). Some isolated hills are present (3%), where valleys are wide.

Piedmont (Pie) landscapes are characterised by a sloping surface at the foot of more elevated landscapes such as plateaus, hills or mountains. They can also represent an area of gentle slopes and low relief flanking an upland area. Within Piedmonts there can also be assemblages of planar alluvial surfaces flanking an area of mountains or rocky desert uplands. They are generally gently to moderate sloping lands connecting steeper with flatter zones. In the northern AOI they are widespread in the junction zone between the mountain front and the coastline. Here, a gently-sloping piedmont hosts an intricate network of braided rivers carrying all the sediments derived from erosion of the mountains inland. These braided rivers channels can carry sediments the size of boulders of over a metre in diameter during the heaviest rains. They are also present in the southern part of the AOI, where they connect the higher dissected hillands with the lower Shabelle valley (in its higher Ethiopian course). Within the Piedmont landscapes the most common reliefs are the Hills (20%) followed by Pediments and Gully/Rill erosion surfaces (both 14%) and by Denudational surfaces and Dissected pediments (both 9%). These figures account for the presence of numerous isolated hills within the gently to moderately sloping Piedmonts, and also for the presence of relatively wide surfaces where erosional processes are shaping these portion of land, causing great soil loss, and loss of productivity.

Plateau (Pta and PtD) landscapes are characterised by the two different landscape types of Plateaus and Dissected plateaus, the difference only being in the absence or very low frequency of river incisions in the former type and a quite high number of linear incisions (mainly fluvial) in the latter. Plateaus are extensive, flat or almost flat surfaces found in upland regions. They are considerably elevated above the adjacent country and limited by an abruptly descending scarp on at least one side. They can also be bounded by piedmonts or other gently sloping land features. Plateaus can be of volcanic origin, but uplands with level summits can be found in sedimentary and metamorphic formations as well. In the northern AOI, plateaus are often composed of sedimentary, horizontally bedding rocks, mainly sandstones and limestone of different origins. In the case of plateau it is possible to find Denudational slopes (36%) and Hills (29%), while in the case of Dissected Plateaus fluvial relief also occurs, as expected, with Gully/Rill surfaces (29%) together with Hills (29%) and Flat floor valleys (13%) with denudational surfaces (13%). The three biggest towns of the northern AOI are located within Dissected Plateaus, the city of Hargeisa being very close to a Plateau escarpment.

Hilland (Hil and HiD) landscapes are characterised by strong relief rising straight from a plain or surrounding area, usually not exceeding a relief intensity of about 300 m. They form prominences smaller than a mountain and, like a mountain, can be isolated (see relief type Hill) or in complexes (see relief type Hill complex). They have uneven summit heights generally not concordant, separated by a rather dense hydrographic network. In the northern AOI the Hilland landscape is populated in its greater part with structural reliefs pertaining to Hill (S30, with 28%, and S29 with 19%) and Ridge (S31, with 22%, and S16 with 10%). As already noted, hill features can be found at many different scales as defined in relation to surrounding land features.

Mountain (Mou, MoB, MoF, MoV, and MoR) landscapes are characterised by an elevated, rugged, deeply dissected land portion, characterised by significant relative height in relation to lower-lying surrounding areas and by important internal dissection with the presence of high relief intensity. They cause localised disruptions to climate, drainage, soils, plants and animals, being characterised by high elevations (up to thousands of m asl) and high relief intensity (some hundreds of m). Mountains can be isolated features or arranged in systems. Successions of mountains (mountain ranges or mountain systems) are generally closely related in position, direction and geologic features. According to the main genetic (endogenetic) process, they can be dominated by the presence of evident fault systems (MoF), isolated blocks (MoB) or volcanic features (MoV), or they can be the result of weathering processes on ancient rocks, giving rise to residual mountains (MoR). In the northern AOI they dominate the central sector and a series of different reliefs are present, the majority represented by structural ones. The most frequent reliefs are Ridge (S31, with a frequency between 16-55%), and dissected ridges (S16, with a frequency between 16-61%) in all the different types of Mountains. Another very well-represented relief is that of Depressions (S15, with frequency of 2-10%) and Hill complex (S30, with frequency of 4-9%).

A collection of maps showing parameters derived from DTA (Digital Terrain Analysis) as used in the interpretation process for the northern AOI, is presented in Annex 6. Their significance has been already discussed in Chapter 2.

Field survey observations and the image interpretation exercise are discussed below.

There is a consistent correlation between landforms and lithology, as can be expected. In particular, the presence of two very different rocks types (sedimentary, near Hargeisa, and metamorphic, from Gebiley to Borama) is reflected by differences between the landforms. The landforms underlain by sedimentary rocks show a sharper morphology, with slopes covered by angular debris. Their slopes are of a general regular slope angle, in most of the cases between 30-40°. South of Hargeisa (on the main plateau area) they show a more rounded morphology and a lower profile. Along the Hargeisa-Berbera road (north of the main plateau) they are of the mesa type, made up of horizontal strata with a flat harder strata on top that give rise to a so called "cap rock". Their slopes are stonier than those south of Hargeisa.

Landforms underlain by metamorphic and igneous rocks (granite), show a smoother profile than those underlain by sedimentary ones. Their slopes show a more irregular shape, characterised by big boulders and blocks and a highly fractured pattern on their sides. They show a more general uniformity of landforms compared to sedimentary ones. Quite often there is the presence of sedimentary outcrops and landforms in between a general metamorphic landscape.

The AOI is characterised by several *toggas* (or *wadis*), the majority of which are quite wide alluvial plains and extended floodplains. Their banks are very high and most show a thick alluvial mattress made up of sand, silt, gravel and boulders. In many cases the dimension of the boulders in the *togga* beds are larger than one meter. All these signs show highly effective erosional processes underway in *toggas* when they are in flow (mainly bank erosion on the outer sides of the meanders).

Most agriculture is located on top of alluvial terrains and/or alluvial terraces. These are also affected by intense erosive phenomena such as gully and rill erosion.

In the plateau areas the soils are developed only in the depressions/valleys while the flanks of the hills are characterised by very high stoniness. Here agriculture is found on the flat lands, even if affected by intense gully and rill erosion.

The rest of the landforms (mainly hills and mountains) show very limited soil development and, as a consequence, very little agriculture. In these landforms there is a strong pastoralist presence that also extends into agricultural areas (agro-pastoralists). It is thus possible to distinguish the distribution of different socio-economic activities on the basis of landform distribution.

4.2 Landforms of the Southern AOI

The Southern AOI extends for almost 88 000 km² (8 793 596 ha) covering the whole Jubba River watershed in its Somali tract, and the great majority of the Shabelle River watershed in Somalia.

The most important cities are: Luuq, Garbahaarrey, Baardheere, Bu'aale, Jilib, Jamaame and Kismaayo, in the Jubba valley; and Ferfer, Beledweyne, Buulobarde, Mahadday Weym, Jawhar, Balcad, Muqdisho, Afgooye, Marka, Baraawe and Haaway in the Shabelle valley.

4.2.1 Morphology

The Southern AOI covers an area extending from the huge coastal dunes, parallel to the coast up to the border with Ethiopia, excluding sloping land extending from the Bay region down to the Lower Shabelle region. The main physiographic elements are represented by the two valleys of the Jubba and Shabelle and the wide alluvial plain of the lower tract of the Shabelle River (Figure 20). Elevation ranges between 0-980 m asl (Figure 21).

According to patterns of elevation, it is possible to define three sectors (Figure 21): the first is represented by the interval 0-50 m contour that extends into the Jubba alluvial plain, northward from the Jubba mouth, and also eastwards along the Shabelle alluvial plain; it is also present in a narrow strip coastal strip north of Muqdisho. The second sector is defined by the contours between 50-300 m, that occupies the two valleys of the Jubba and Shabelle and also characterises the coastal dunes (which reach a maximum elevation of almost 300 m asl.); the third is defined by contours between 300-1000 m, from the upper part of the Jubba river valley up to the highest elevation in the middle distance between the Jubba and Shabelle rivers.

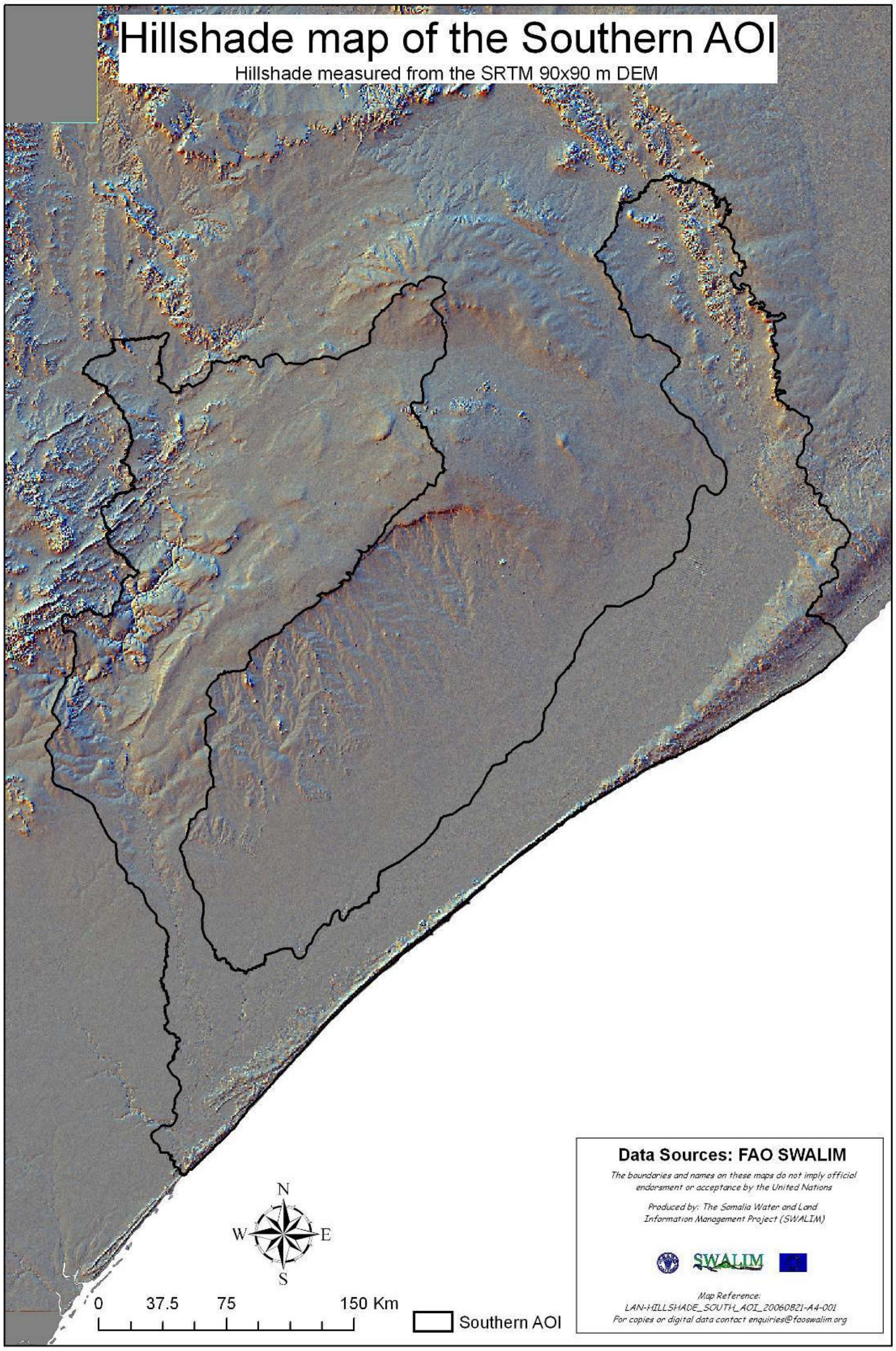

Figure 20: Hillshade (shaded relief) of the southern AOI

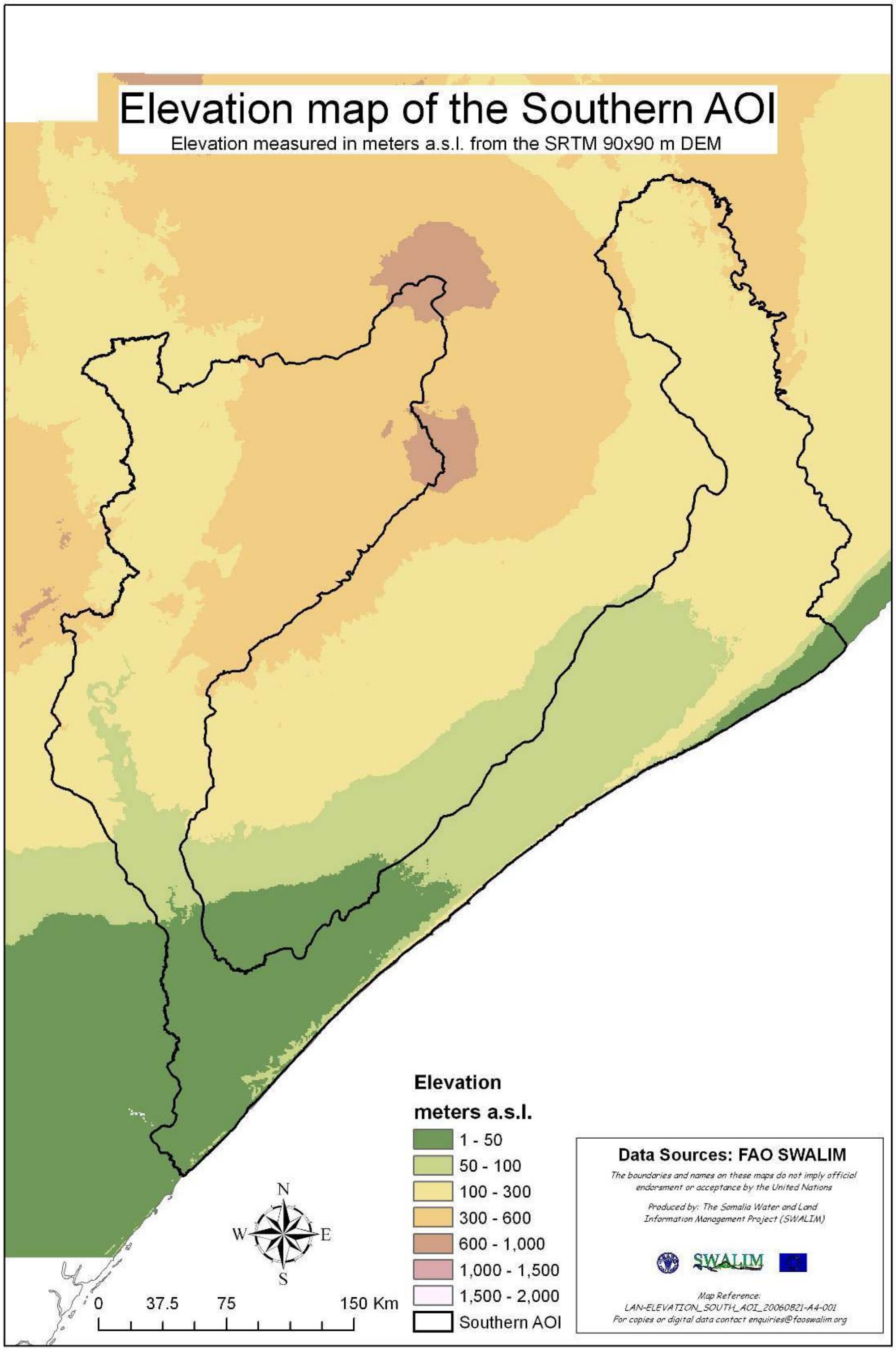

Figure 21: Elevation map of the southern AOI

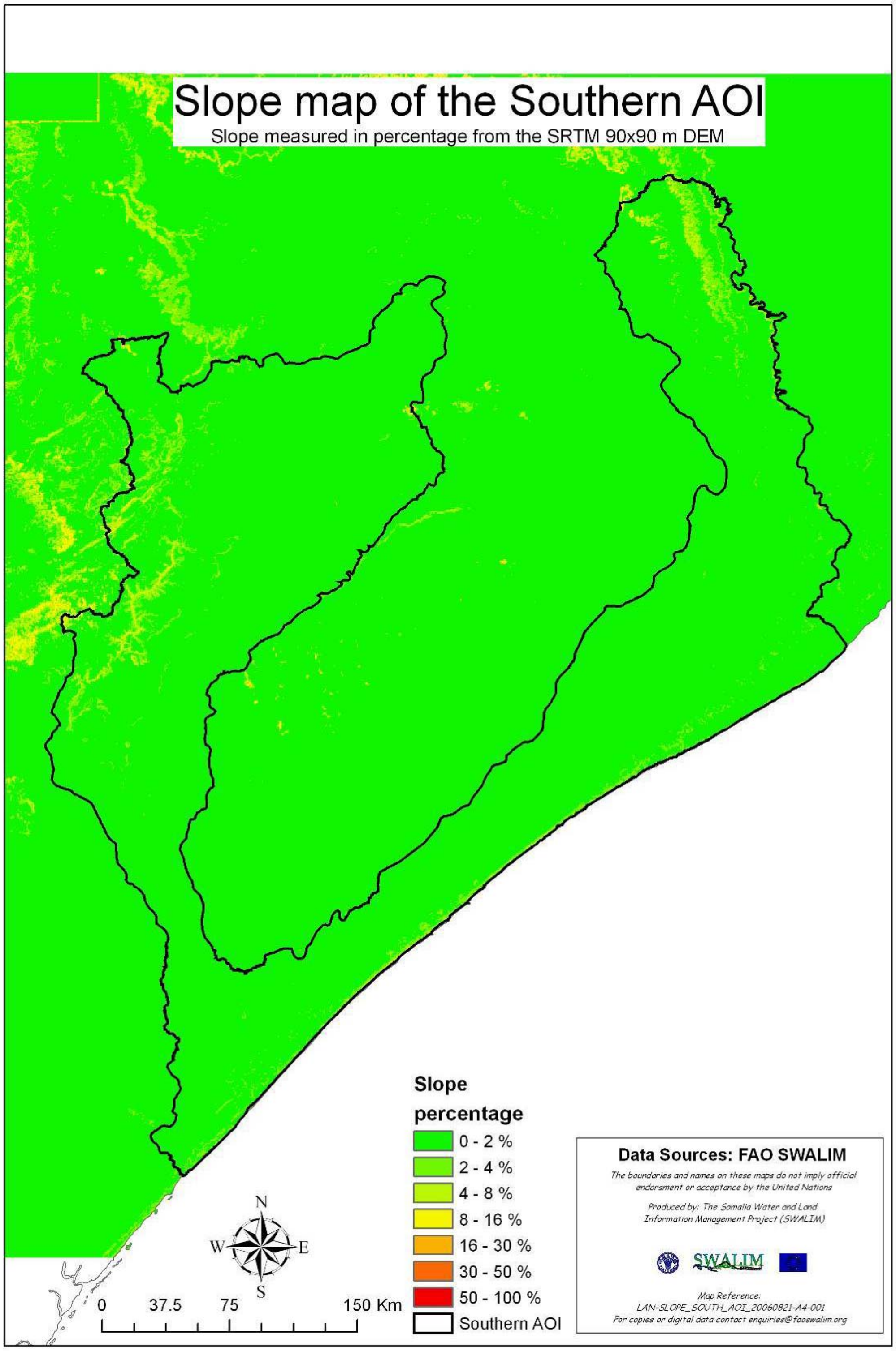

Figure 22: Slope map of the southern AOI

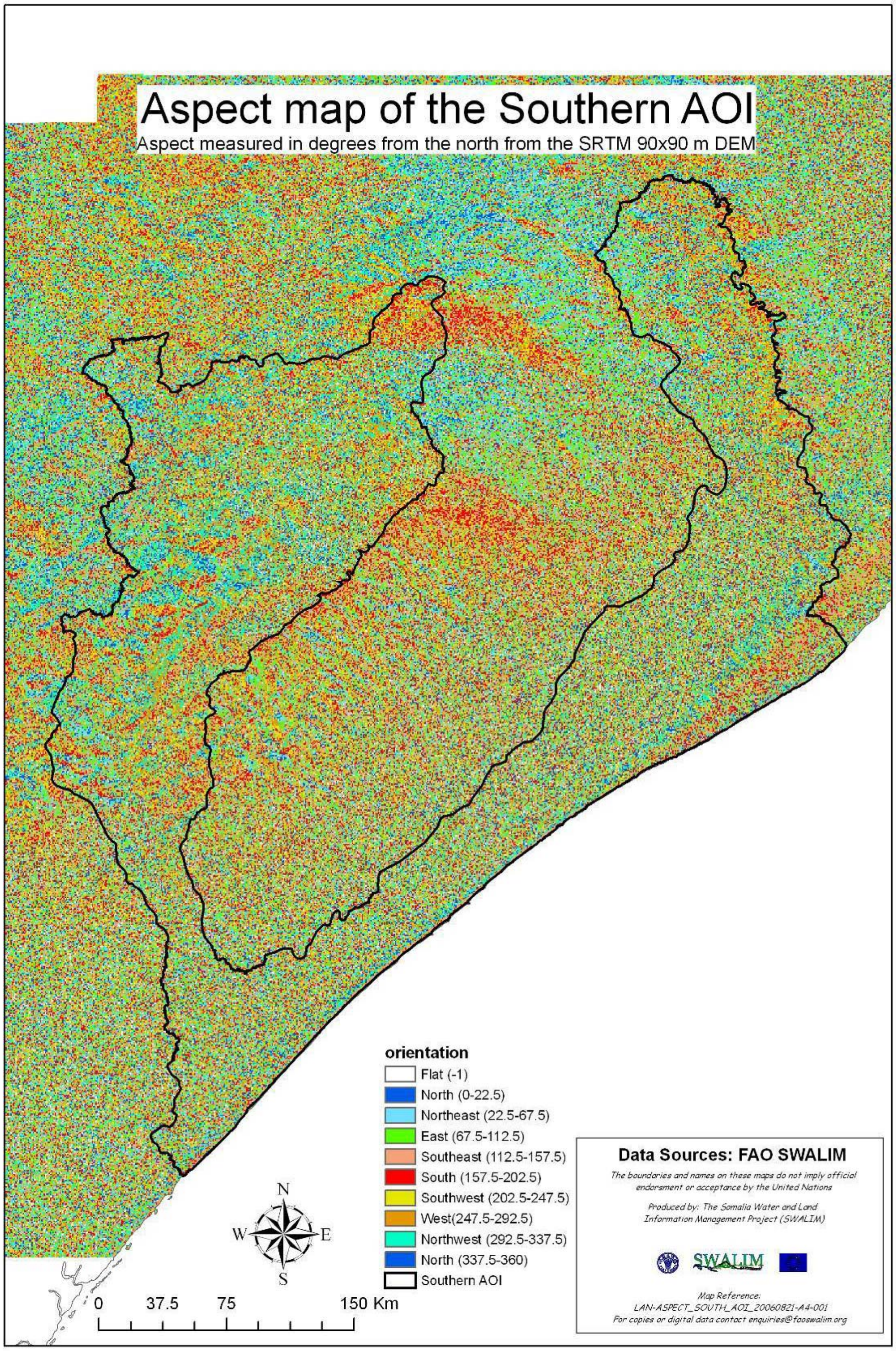

Figure 23: Aspect map of the southern AOI

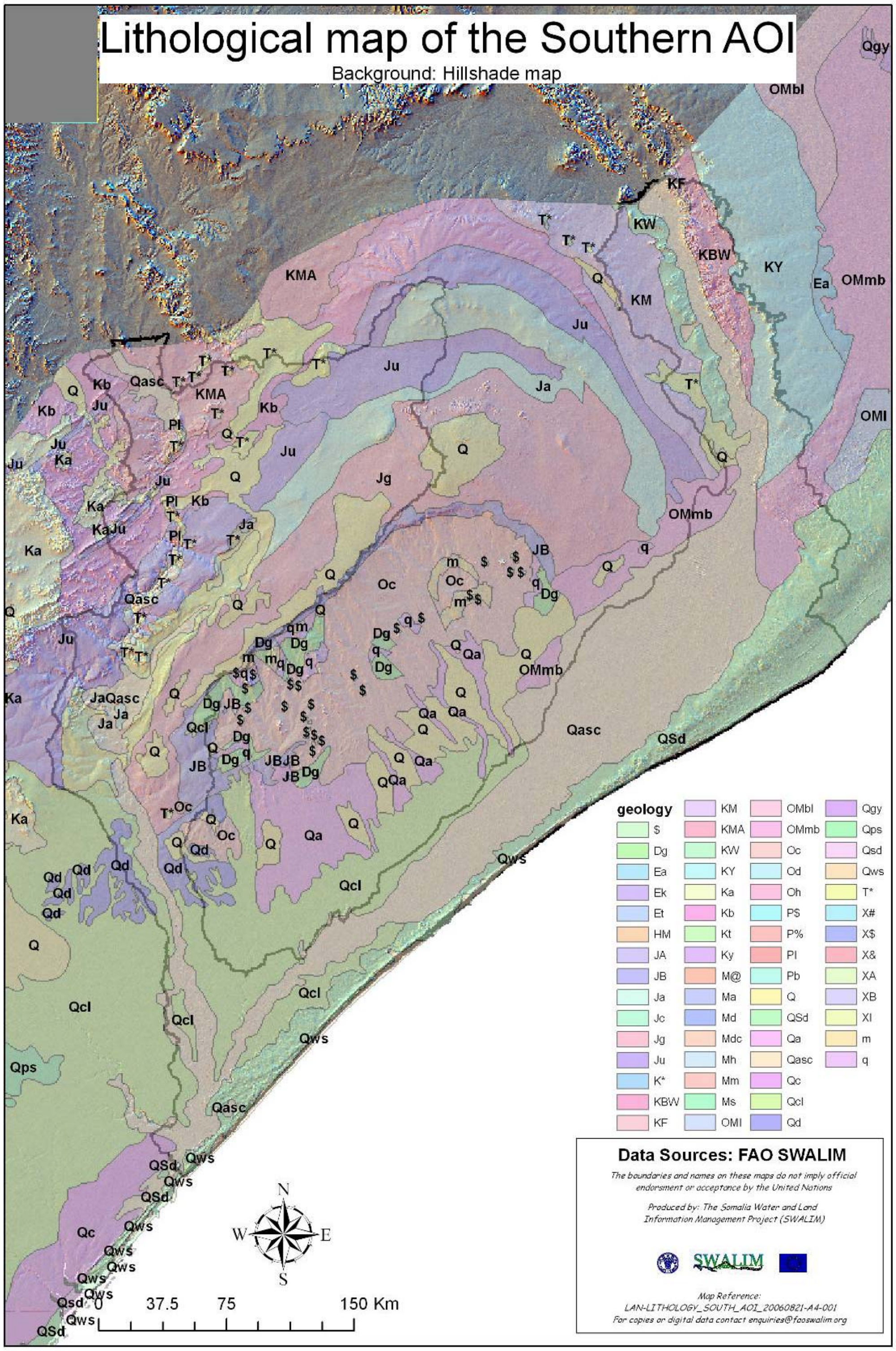

Figure 24: Lithological map of the southern AOI, derived from Abbate *et al.*, 1994. (See Annex 2 for codes)

The slope map (Figure 22) shows values that are, for the great majority less than 8%. The gradient pattern is almost flat everywhere, except for two areas: one in the Jubba river valley and one in the Shabelle river valley. In the former the higher slope values are located in a tract where the Jubba River flows in a confined rocky tract, while the latter area is located in close proximity to the steep right-hand side of the higher Shabelle River tract.

The aspect map (Figure 23) reflects the general trend of elevation and slope, showing the great majority of the area to be flat or almost flat.

According to the aspect pattern it is possible to identify two slopes, one facing the northern sector and one the southern, just north of Muqdisho. The upper part of the two river valleys show aspects that are generally facing the western and the eastern sectors, in accordance with the valley directions. In the Jubba valley sector of the AOI, a more complex aspect occurs.

4.2.2 Lithology

The Southern AOI is characterised by the presence of sedimentary, metamorphic and igneous rocks (Figure 24). The northeast-southwest oriented alluvial plain of the lower Shabelle is dominated by the presence of unconsolidated Quaternary sediments and the sandy sediments of the coastal dunes. The almost north-south upper Shabelle valley is dominated by gypsiferous formations, both sandstone and limestone. These lithological formations account also for the high salinity of waters flowing from the upper Shabelle River valley. The almost north-south Jubba River valley is characterised by the presence of sedimentary rocks (mainly clays and sand) for the first 250 km from the river mouth, while from there up to the border with Ethiopia rocks forming the valley sides are mainly old sedimentary limestones and sandstone with some young basaltic flows on top of hills. The hardness of the sedimentary sequence accounts also for the fact that the river valley in this tract are confined. The area separating the two upper river valleys is made up of metamorphic rocks (basement complex) with a domed geometry.

4.2.3 Landform

The Southern AOI incorporates 805 mapped polygons. Within these, five main Landscape groups have been identified (Hilland, Piedmont, Plain, Plateau and Valleys), 12 different Landscape classes, and 42 Reliefs. No landforms were mapped here due to the scale of the work. In the following table all legend entries used for mapping of the southern AOI are listed (Table 15).

Table 15: Final legend scheme, including the two hierarchical levels, for the southern AOI

Landscape		**Relief**	
Code	*Description*	*Code*	*Description*
HiB	Domed Basement Hilland	A02	Town, Industrial district
HiC	Coastal Dune		
HiD	Dissected hilland	C02	Coastal plain
Hil	Hilland	C03	Sandy coast
		C04	Foredune
Pie	Piedmont	C05	Stabilized dune
		C06	Mobile dune
PlA	Alluvial Plain		
PlC	Coastal Plain	E05	Playa
Pln	Plain	E06	Pan
Pta	Plateau	F01	Alluvial fan
		F03	Anastomizing river plain
VaC	Confined valley	F04	Braided river plain
VaL	Lateral valley	F05	Meandering river plain
Vay	Valley	F09	Gully/Rill erosion surface

	F10	Sheet erosion surface
	F11	Trace of palaeoriver
	F12	Alluvial plain
	F13	Depression
	F14	Pediment
	F15	Dissected pediment
	F16	Delta
	F18	River plain
	F19	Flood plain
	F20	Terraced surface
	F21	Upper pediment
	F22	Lower pediment
	F23	Old meandering river plain
	F25	River incision
	G08	Talus slope
	L02	Lake basin
	S08	Escarpment
	S15	Depression (structural)
	S24	Inselberg
	S25	Cuesta
	S26	Mesa
	S29	Hill
	S30	Hill complex
	S31	Ridge
	S32	Planation surface
	S33	Denudational slope
	S34	Slope
	S35	Denudational surface
	S36	Plain

Figure 25 shows the highest level of generalization of the Landscape/Relief. It groups together the major physiographic elements identified during the mapping procedure. This map has been verified by field survey in March 2007. The scale of the original mapping is 1:100 000.

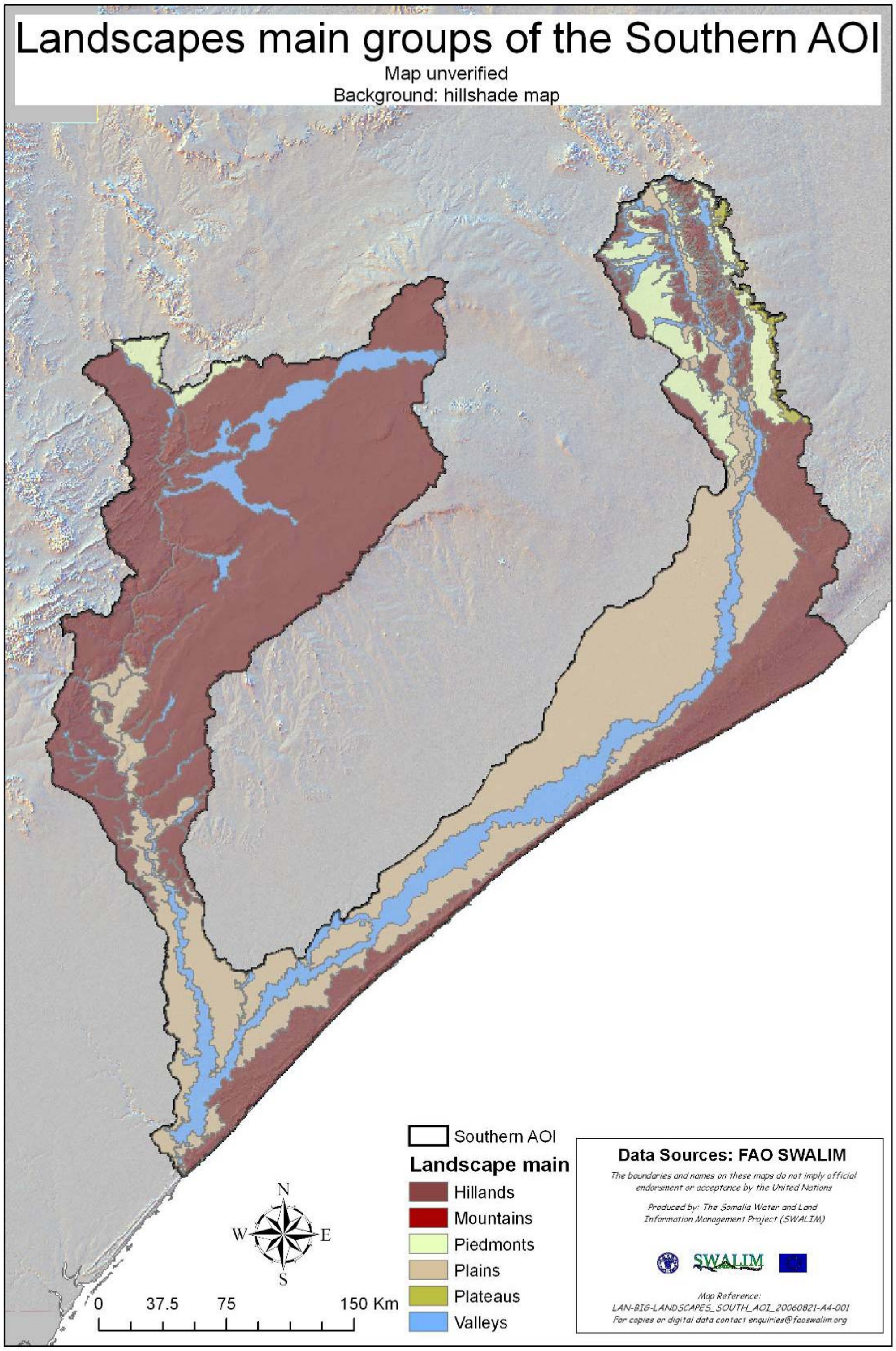

Figure 25: Main Landscape groups of the southern AOI

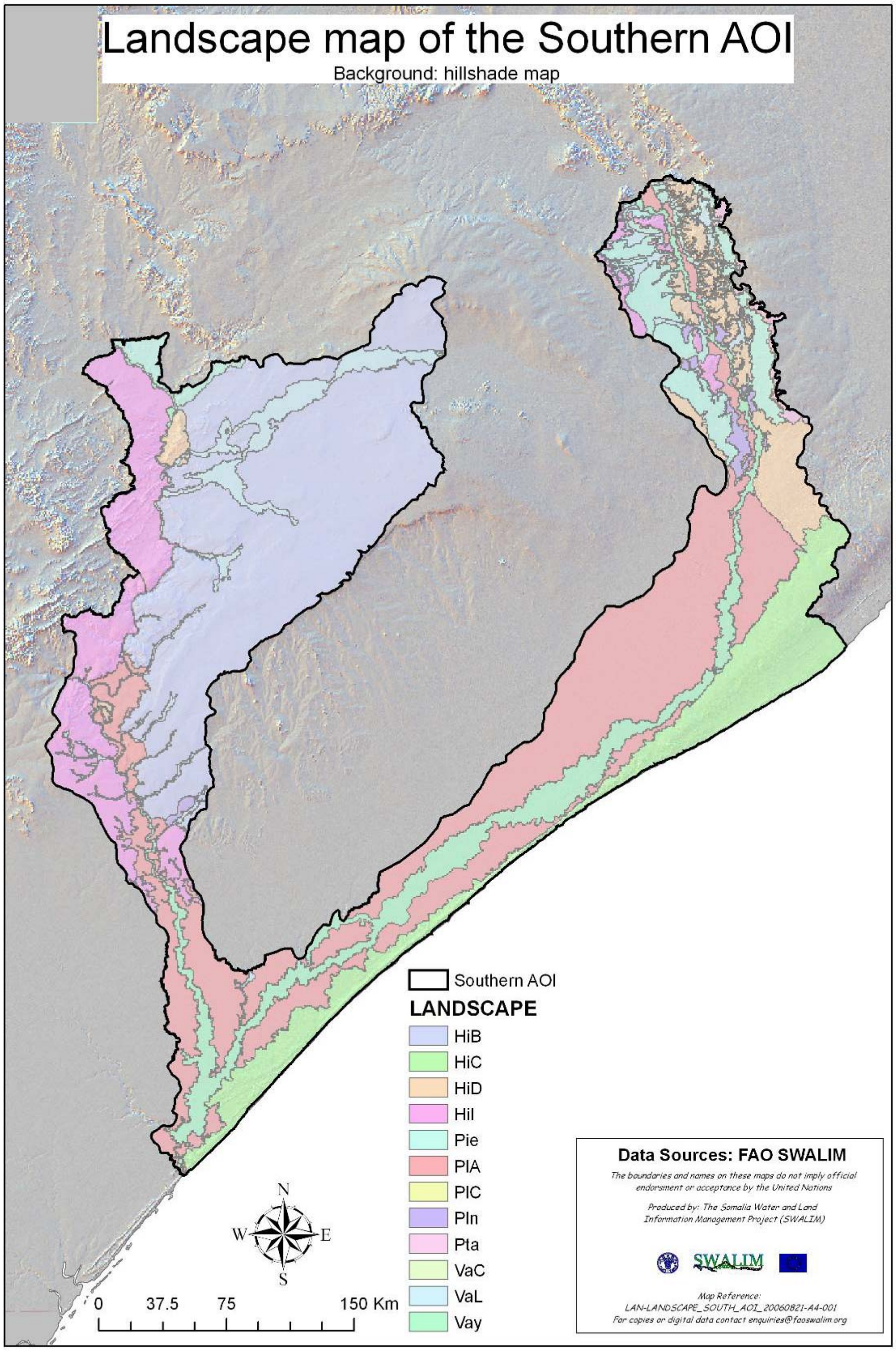

Figure 26: Landscape types of the southern AOI

In Figure 26 all mapped Landscape classes are represented. A new class (HiB, for Domed basement Hilland) was introduced here due to a metamorphic basement complex outcropping in between the two upper river valleys that has a domed shape (not included in the AOI), truncated on the south by a steeper slope that descends to the lower Shabelle alluvial plain.

From the following table (Table 16) and Figure 27 it is evident that the most-represented Landscape in the southern AOI is the HiB (Domed basement Hilland). This new Landscape has been defined as the arcuated domed topography located in between the two upper parts of the river valleys. It is the place where the metamorphic basement complex outcrops, and it has a domed or bulged morphology abruptly interrupted only by a steeper slope degrading to the south as far as the Shabelle River lower alluvial plain. The Hilland Landscape accounts for the great majority of the landscapes in the southern AOI.

Table 16: Distribution of Landscape classes and their areas (km²)

Landscape code	Landscape classes	Area (km²)
HiB	Domed Basement Hilland	25,117.34
HiC	Coastal Dune	9,323.40
HiD	Dissected hilland	4,410.08
Hil	Hilland	9,021.84
Pie	Piedmont	4,666.06
PlA	Alluvial Plain	22,957.76
PlC	Coastal Plain	32.79
Pln	Plain	698.24
Pta	Plateau	575.78
VaC	Confined valley	113.12
VaL	Lateral valley	4,020.09
Vay	Valley	6,986.53
Total		87,923.03

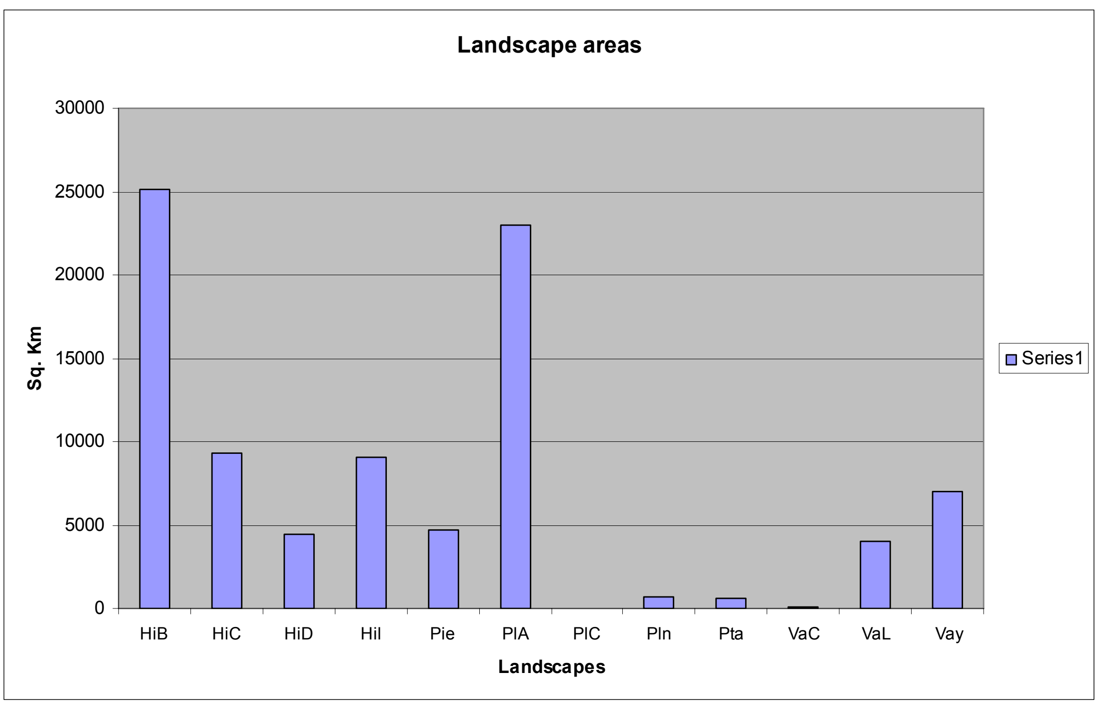

Figure 27: Chart showing Landscape types vs. Area (km^2)

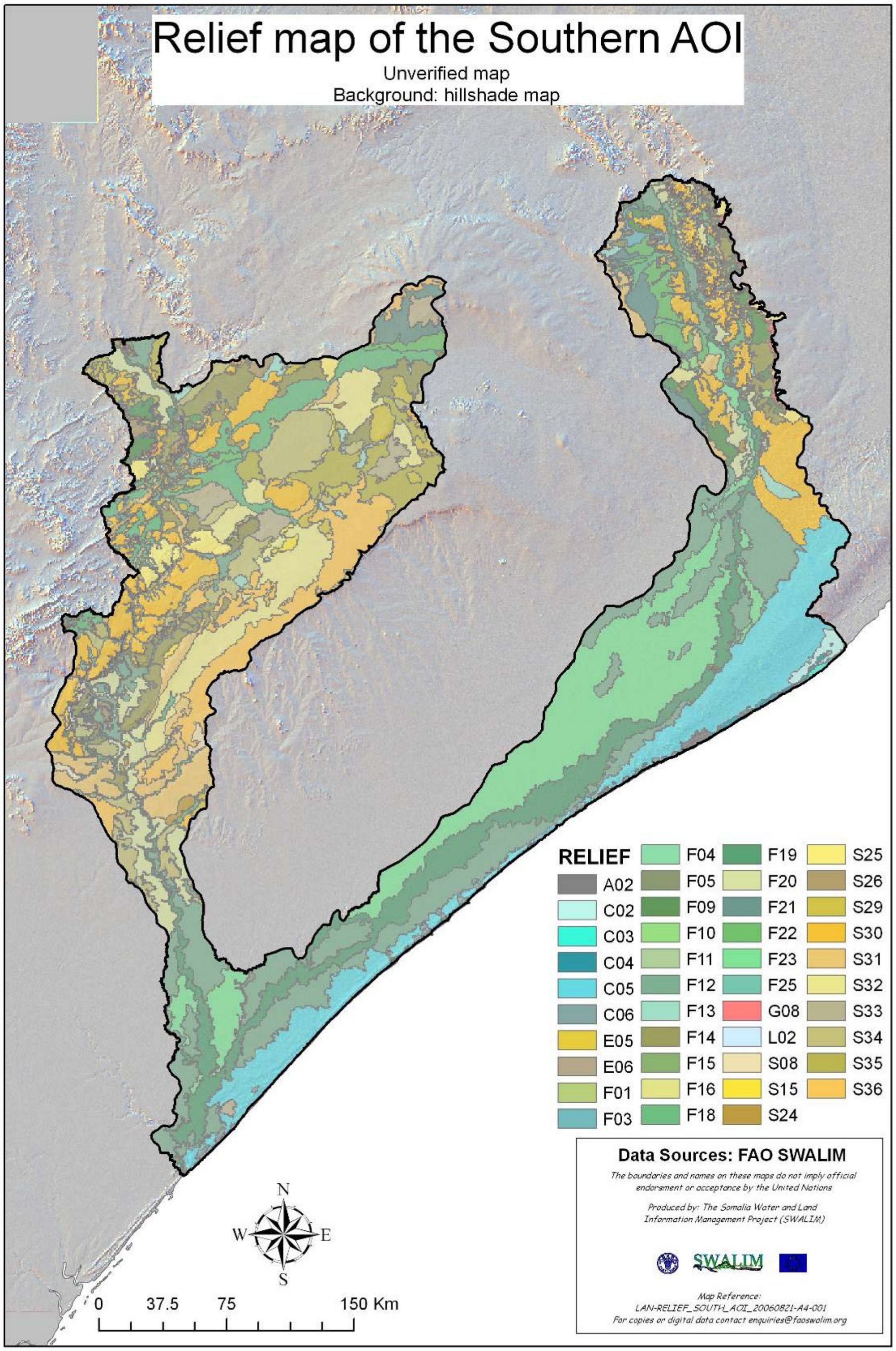

Figure 28: Relief types of the southern AOI

The Relief map (Figure 28) shows the distribution of all 42 Relief classes inside the southern AOI. Looking at Table 17 and Figure 29 it is evident that the predominant Relief types (in terms of area) are F12 (Alluvial plain), F23 (old meandering plain), S30 (Hill complex), and C05 (Stabilized dune).

They are in good agreement with the predominance of Hilland and Plains in these AOI, at the Landscape level.

Table 17: Distribution of Relief classes and their areas (km²)

Relief code	Relief description	Area (km^2)
A02	Town, Industrial district	92.51
C02	Coastal plain	296.25
C03	Sandy coast	206.00
C04	Foredune	162.75
C05	Stabilized dune	8,084.65
C06	Mobile dune	451.57
E05	Playa	49.15
E06	Pan	1.15
F01	Alluvial fan	86.41
F03	Anastomizing river plain	149.29
F04	Braided river plain	9.80
F05	Meandering river plain	37.76
F09	Gully/Rill erosion surface	1,528.41
F10	Sheet erosion surface	94.64
F11	Trace of palaeoriver	0.80
F12	Alluvial plain	11,801.58
F13	Depression	580.06
F14	Pediment	4,161.04
F15	Dissected pediment	23.64
F16	Delta	2.54
F18	River plain	4,167.15
F19	Flood plain	6,948.21
F20	Terraced surface	2,905.42
F21	Upper pediment	1,382.13
F22	Lower pediment	1,256.66
F23	Old meandering river plain	10,351.80
F25	River incision	181.68
G08	Talus slope	529.14
L02	Lake basin	39.89
S08	Escarpment	274.09
S15	Depression (structural)	222.90
S24	Inselberg	351.31
S25	Cuesta	1,187.20
S26	Mesa	354.83
S29	Hill	1,447.46
S30	Hill complex	8,448.08
S31	Ridge	3,546.36
S32	Planation surface	4,348.49
S33	Denudational slope	1,274.61
S34	Slope	4,259.40
S35	Denudational surface	2,552.00
S36	Plain	4,074.21
Total		87,923.03

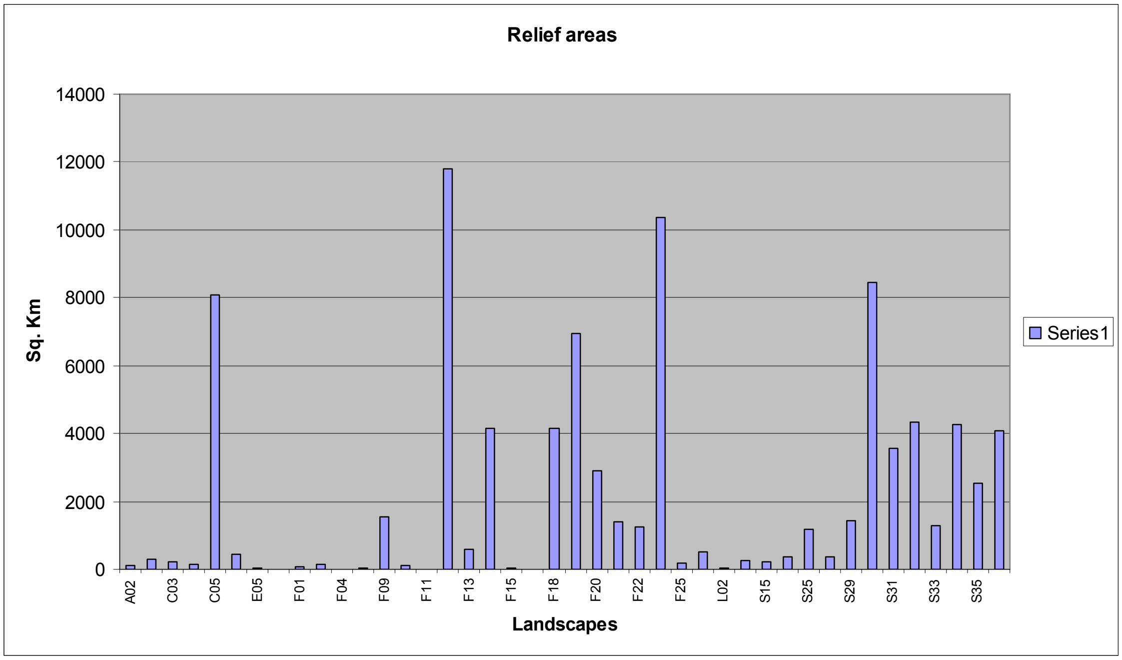

Figure 29: Chart showing Relief types vs. Area (km^2)

A brief description and characterisation of each landscape and the most representative reliefs found in the southern AOI are given.

Valleys landscapes are defined as per the northern AOI. In the southern AOI they include: Valley, Lateral valley, and Confined valley. The Valleys themselves are made up of alluvial deposits in the great majority of their area (97% sand, silt, and gravels) and are mainly floodplains (97%). Lateral valleys extend much further on the flanks of the main valleys and this is also reflected in the outcropping lithology that consists almost 50% of limestones and 23% of alluvial deposits. In Lateral valleys the most common relief is River Plain (82%). The last type, the Confined valley, is characterised by the presence of very steep rocky walls with the floor made up of quaternary unconsolidated deposits (100%). Within this landscape the only relief found is Confined valley (100%).

Plateau landscapes are made up of 55% by cuestas and 45% by talus slopes. The lithology that forms the plateaus are 100% sandstone of the Yessoma Sandstone formation.

Piedmonts have been found mainly on the upper Shabelle river valley flanks, and they are formed 22% by Gully and Rill erosion surfaces and by Lower and Upper pediment surfaces (18% and 11%, respectively). The lithology of Piedmonts are mainly sedimentary rocks: the main gypsum formation (26%), limestones (19%) and sandstone (18%).

The **Plains** (Plain, Alluvial Plain, and Coastal Plain) are the second-most important landscape of the southern AOI, after the Hilland. They dominate the lower Shabelle River valley and they are also present along the coast. They have been separated into three landscape classes. A characteristic of the Alluvial plain (the great majority of all the Plain landscapes) is the presence of meandering rivers with many cut-offs and oxbow lakes, too small for mapping. Wide Alluvial plains (48%) and the so-called Old meandering plains (45%) are the prevalent relief classes on the Alluvial Plains landscape. Several Flood plains have also been identified (66%) on the Plain landscape, where there are also some Inselbergs (19%) but more in the upper parts of the valleys, where one may find plains on top of the bordering hills. On the coastal plains the only relief is contributed by Sandy coast, which sometimes passes laterally to the mobile dunes (within the Hilland landscape).

The **Hillands** are the great majority of landscapes found in the south. They form in almost all cases much-smoothed, gently sloping hills with elevations between 300-600 m. They consist of four landscape types: Hilland, Domed Basement Hilland, Dissected Hilland and Coastal Dune. Coastal dune has been included in the Hilland landscape as it reaches elevations of 300 m or more, and is a long, wide dune system running for more than 1 000 km along almost the entire Indian ocean coastline of Somalia. The Domed Basement Hilland is the Landscape found between the two river valleys, formed as a consequence of the bulging and emplacement of the basement complex. They reach the highest elevation of the entire AOI (more than 900 m) and consist of a metamorphic rocks core covered by sedimentary ones. In the AOI there is very little outcropping of metamorphic rocks.

Within the Hilland landscape the majority of relief is represented by Hill Complex (24%), followed by Ridges and Slopes (both with 15%). The rocks underlying the Hilland landscape are Limestones (25%), Marls and Limestone (16%) with Gypsum formations (15%) only on the Shabelle river side.

Within the Dissected Hilland the most representative reliefs consist of Hill complexes (72%) with a few others such as pediments, talus slope, and planation surfaces at the top of the hilland.

In the Coastal dune landscape only six reliefs are found, the great majority of which are Stabilized dune (87%), the rest represented by Coastal plain (3%) and some mobile dunes, foredune and Town (the city of Muqdisho).

Within the Domed Basement Hilland the great majority of the area is defined as Hilland landscapes. Here the most diffuse reliefs are Planation surfaces (16%), Plains (15%) and Pediments (11%). The most representative lithologies are Limestones (60% Jurassic) plus a certain amount of Quaternary deposits (17%).

As for the northern AOI a collection of maps showing parameters derived from DTA (Digital Terrain Analysis) as used in the interpretation process for the northern AOI, is presented in Annex 6. Their significance has been already discussed in Chapter 2.

Field survey observation showed a consistent correlation between the mapped landform units and the ones in the field, especially along the upper part of the Juba valley. However the absence, in the flat alluvial plain, of panoramic points that could have allowed a broader panoramic view and interpretation of the landscape represented a small limitation in field verification.

4.3 General Results

The specific landform results for the two AOI have been described in the previous pages. Here we wish to briefly account for the other types of results not specifically related to the two AOI, achieved during the present exercise:

1. a new legend;
2. a digital system for the input of the attributes of polygons, adopting the new legend;
3. a set of digital semi-automatic landform classification;
4. a digital mask for the input of field forms;
5. vectorization of the geological map of Somalia;
6. the present report describing the overall process of landform mapping.

1) The legend system adopted for the landform mapping is conceptually new, even if it has its roots in the GP approach and considers also the FAO standard. As already explained in Chapter 2, this legend system takes into account the integrated use of satellite images, topographic and other thematic maps, DEM and their derived products, and 3D visualization, for identifying and mapping the landforms of Somalia with the greatest precision. The structure is hierarchical, adopting three levels of increasing detail plus the lithological layer. The aim of the present legend is to produce a landform map suitable for soil mapping and identification of the main geomorphological hazards (erosion and flooding). For this purpose it adopts both morphometric, and visual interpretation criteria, taking into account also morphogenetic processes. This legend can be used as it is for the whole country. The complete legend is here summarised in Table 18. In Annex 1 it is also possible to find a complete glossary of the Landscapes, Reliefs and Landform adopted. If required it can be also adapted for other bio-morphoclimatic environments.

Table 18: Complete legend adopted for both the northern and southern AOI

LANDSCAPE			RELIEF			LANDFORM		
N.	*Code*	*Description*	*N.*	*Code*	*Description*	*N.*	*Code*	*Description*
1	HiD	Dissected Hilland	*1*	A02	Town, Industrial district	*1*	F02	Rill
2	Hil	Hilland				*2*	F03	Gully
3	HiB	Domed Basement Hilland	*2*	C02	Coastal plain	*3*	F05	River levee
4	HiC	Coastal Dune	*3*	C03	Sandy coast	*4*	F06	Floodplain
			4	C04	Foredune	*5*	F07	Alluvial Terrace
5	MoB	Block Mountain	*5*	C05	Stabilized dune	*6*	F09	Depression
6	MoF	Fault Mountain	*6*	C06	Mobile dune	*7*	F14	Upper pediment
7	MoR	Residual Mountain				*8*	F15	Middle pediment
8	Mou	Mountain	*7*	E05	Playa	*9*	F16	Lower pediment
9	MoV	Volcanic Mountain	*8*	E06	Pan			
						10	X01	Summit of the slope
10	Pie	Piedmont	*9*	F01	Alluvial fan	*11*	X02	Shoulder of the slope
			10	F03	Anastomizing river plain	*12*	X03	Backslope
11	PlA	Alluvial Plain	*11*	F04	Braided river plain	*13*	X04	Footslope
12	PlC	Coastal Plain	*12*	F05	Meandering river plain	*14*	X05	Toe-slope
13	PlD	Dissected Plain	*13*	F08	Badland (complex gully)	*15*	X06	Upper Slope
14	Pln	Plain	*14*	F09	Gully/Rill erosion surface	*16*	X07	Lower slope
			15	F10	Sheet erosion surface	*17*	X08	Slope complex
15	Pta	Plateau	*16*	F11	Trace of palaeoriver	*18*	X09	Crest
16	PtD	Dissected Plateau	*17*	F12	Alluvial plain			
			18	F13	Depression			
17	Vay	Valley	*19*	F14	Pediment			
18	VaC	Confined valley	*20*	F15	Dissected pediment			
19	VaL	Lateral valley	*21*	F16	Delta			

22	F17	Flat floor valley
23	F18	River plain
24	F19	Flood plain
25	F20	Terraced surface
26	F21	Upper pediment
27	F22	Lower pediment
28	F23	Old meandering river plain
29	F25	River incision
30	G08	Talus slope
31	L02	Lake basin
32	S08	Escarpment
33	S15	Depression (structural)
34	S16	Dissected ridge
35	S24	Inselberg
36	S25	Cuesta
37	S26	Mesa
38	S27	Hogback
39	S29	Hill
40	S30	Hill complex
41	S31	Ridge
42	S32	Planation surface
43	S33	Denudational slope
44	S34	Slope
45	S35	Denudational surface
46	S36	Plain

2) To avoid errors in entering landscape/relief/lithology/landform codes into the attribute table of the shapefiles, a script was implemented (dll file) that runs under ESRI ArcGIS and creates a geodatabase with fixed values (domains). With this script it is possible to have a drop-down menu from which to select a desired code. This prevents erroneous entering of codes and increases reliability and quality of entered data. The system adopted is explained in the following figure 30.

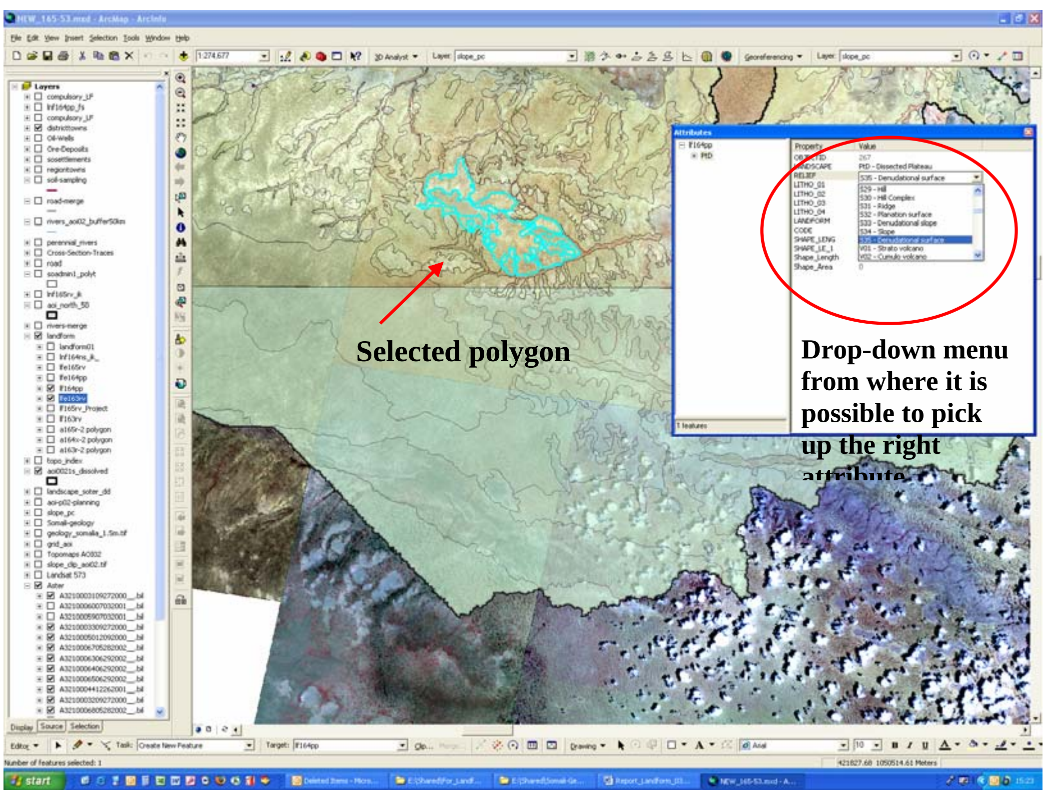

Figure 30: Example of the drop-down menu from which codes for Landscape, Relief, Lithology or Landform can be selected, thereby avoiding possible typing mistakes

3) A set of DTA-derived products were created for the two AOI which have been used during the landform mapping process, all of which are available for further investigation. They have been described in Chapters 5.1 and 5.2 and they are also annexed (see Annex 5 for a full list of the Landform automatic classification and Chapter 2 for an explanation of the conceptual background).

4) The input of the completed field forms (see Annex 3, and Field Manual for an explanation of the field forms) was done using the MS Access database. In order to speed up the input process and to avoid errors in the input itself, a mask was created for data entry. This mask (Figure 31) has some dropdown menus that assist an operator in entering correct values. It also allows entry of notes and comments of field surveyors. After having entered the data, from the same database it was possible to create a point shapefile with which to visualize and analyze the field datasets.

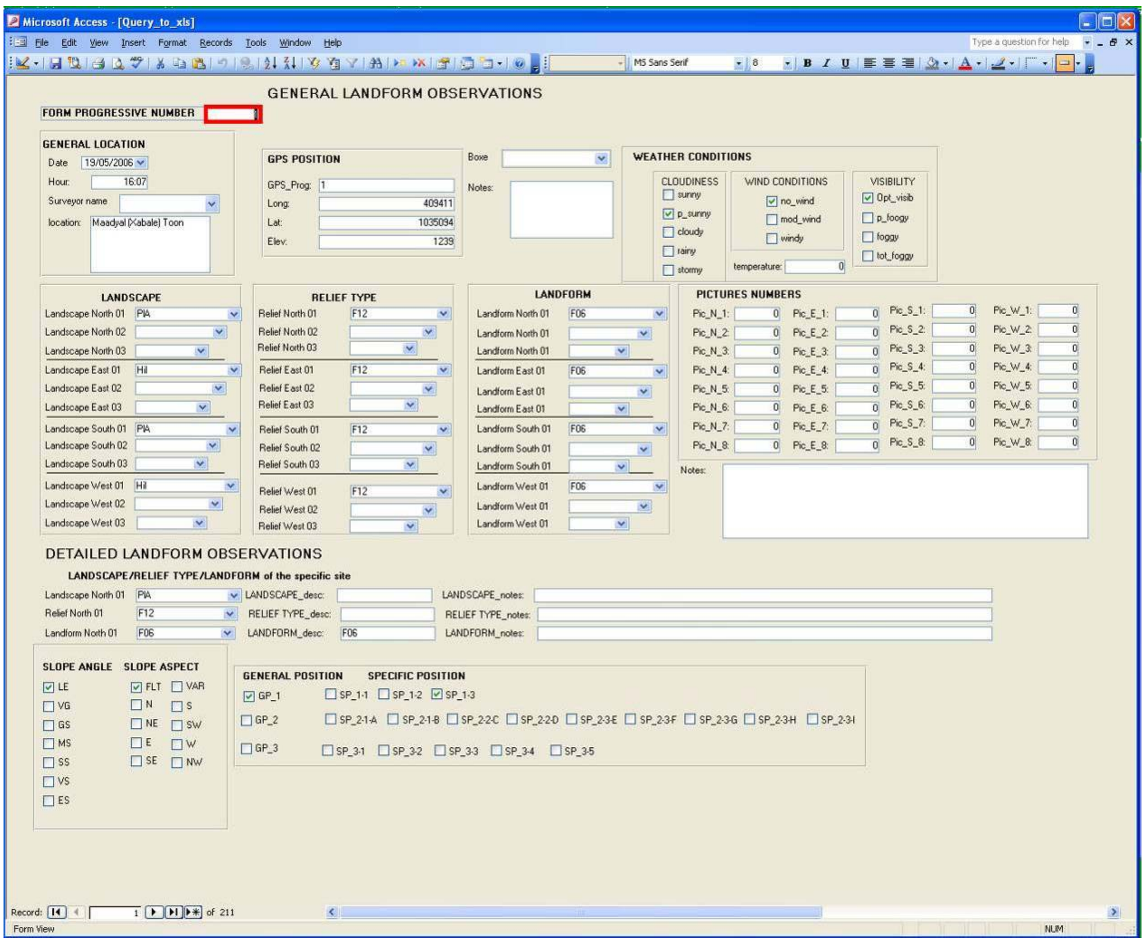

Figure 31: Example of the MS Access mask used for the field data entry

5) Together with the water theme of SWALIM Project, the Geological Map of Somalia has been georeferenced and vectorized in order to be able to use vector shapefiles

in the landform mapping processes as well as to enable its use elsewhere in the country. It is also a base for soil mapping. Vectorization included oil wells, faults, ore deposits and traces of profiles. It is available on the server of the SWALIM Project. A conversion table between the geological codes used in the two semi-detailed maps of the Bay and Bakool area and the one covering the whole country was set up., which is used for labelling the codes in the lithological fields of the attribute tables (Table 19)

Table 19: Conversions between the Bay and Bakool Region Geological map and the Geological Map of Somalia

Bay and Bakool geological maps	Geological map of Somalia	NOTES
Q	Q	
Qc	-	To be added
Tα	Pβ	To be changed
Pl	Pl	
ToF	-	To be added
Ka	Ka	
KGm	KMa	To be changed
KGb	Kg	To be changed
Ju	Ju	
Ja	Ja	
JBg	Jg	To be changed
JBb	JB	To be changed
γ	Γ	
m	M	
q	Q	
Dg	Dg	
Oc	Oc	

5 CONCLUSIONS AND RECOMMENDATIONS

This report, together with the GIS database, is a significant step in understanding and describing the landforms of Somalia. It will be an input to soil mapping and land evaluation, as is a starting point in the definition of Land Mapping Units.

It is also a product that can be used directly in possible further studies on natural hazards, as well as on resources of the two AOI.

The production of the two landform maps raised some scientific and technical questions that the report has tried to answer. During the elaboration some important points arose that are summarised here as recommendations for any further mapping of landforms in the Somali territory.

Firstly, security and logistics allowed to verify only a limited part of the southern landform data. It is thus recommended to perform a wider field verification especially in the upper Shabelle valley, as soon as improved field conditions will allow it. Nevertheless, the map presented here has been produced according to the highest possible levels of precision, given the data and methodology adopted.

Secondly, it is suggested that the landform be used as a base for the identification and characterisation of the Land mapping Units. The hierarchical structure and the aims of the mapping processes allow the land evaluator to automatically extract the highest hierarchical land units represented by the Landscape classes. Having seen the importance of water resources, it is suggested that the landscape classes, some of the fluvial reliefs and specifically the F02, F04, F05, F12, F16, F17, F18, F19, F25 that identify the river plains and deltas, be overlaid and analysed.

Thirdly, if further investigation on the two AOI is needed, it is recommended that erosion, water resources and natural hazards are focussed upon.

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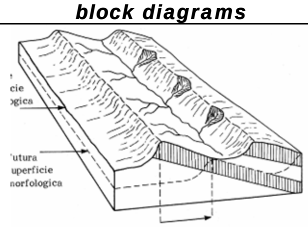
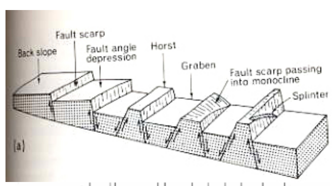
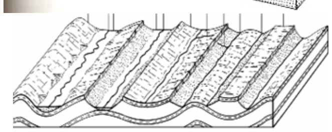
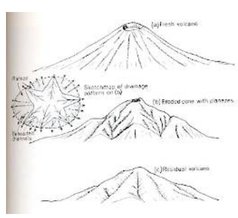
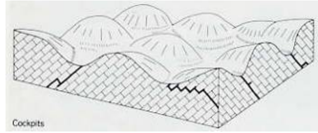
ANNEXES

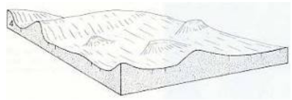
Annex 1: Landform Glossary

This glossary is intended as a guide to landscape/relief/landform terminology adopted in the present document. Where possible, a sketch has been inserted to help visualise the land feature. The glossary follows the same hierarchical levels of the legend. It presents a definition only for the landscape/relief/landform actually used in the legend.

LANDSCAPE (first order land surface feature)

Code	***Description***	***Example from drawings or block diagrams***	**Definition**
Mou	Mountain		A feature of the earth's surface that rises high above the base and has generally steep slopes and relatively small summit area. Mountains can be isolated features or arranged in systems. Successions of mountains (mountain ranges or mountain system) are generally closely related in position, direction and geologic features. They are an elevated, rugged, deeply dissected land portion characterised by important relative height in relation to lower-lying surrounding areas and by important internal dissection with high relief intensity. They result in localised disruptions to climate, drainage, soils, plants and animals. They can reach thousand of m asl) and have high relief intensity (some hundreds of m).
MoB	Block Mountain		A mountain whose origin is mainly related to tectonic **faulting**, specifically vertical faulting. The resulting main landforms are long and well preserved escarpments, long straight features, fault lines or fault valleys, great relief intensity.
MoF	Fold Mountain		A mountain whose origin is mainly related to tectonic **folding**. The resulting main landforms are anticline and syncline valleys with usually gentle flanks and the development of flat irons, antecedent river valleys, long and well preserved escarpments and fault lines or fault valleys.
MoV	Volcanic Mountain		A mountain whose origin is mainly related to **volcanic** activity. The resulting main landforms are cones or cone shaped relief, or remnants of same. A generally high, intense degradation takes place on the slopes of young volcanoes. A characteristic centrifugal drainage pattern develops on top of it.
MoR	Residual Mountain		The remains of a bigger mountain relief, diminished due to chemical actions of dissolution and disgregation of rocks. They are usually found in arid climates where the weathering of rocks is stronger than at middle latitudes. They are strongly influenced by the nature of the underlying rock.
Hil	Hilland		A land surface feature characterised by strong relief rises straight from the plain or surrounding areas, usually not exceeding a relief intensity of 300 m. It is a prominence smaller than a mountain and like a mountain can be isolated (see the relief type Hill), or in complexes (see the relief type Hill complex). It has uneven summit heights, generally not concordant, separated by a rather dense hydrographic network.

HiD — **Dissected Hilland**



A hilland that has undergone a deeply fluvial incision leaving a more rough topography than gently undulating hilland.

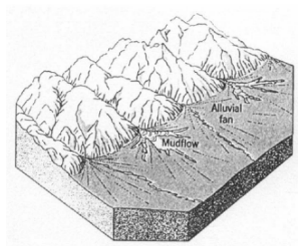
HiC — **Coastal Dune**

A system of dunes that rims the coastline and can reach considerable elevation (exceeding 400 m asl). They can be dunes stabilised by vegetation or by mobile dunes experiencing wind erosion.

HiB — **Domed basement Hilland**

This term identifies a domed topography that is due to the bulging of sedimentary rocks, overlying the metamorphic basement complex of Proterozoic age. These hills are smoothed with gently slopes, but can also be truncated with steep sides.

Pie — **Piedmont**

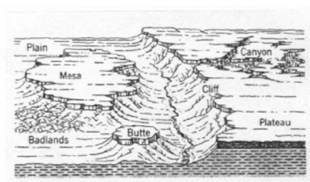


Thin streamlike mudflows commonly issue from canyon mouths in arid regions, spreading out upon the piedmont alluvial fan slopes.

Any sloping surface lying or formed at the foot of more elevated landscapes, such as plateaus, hills or mountains.

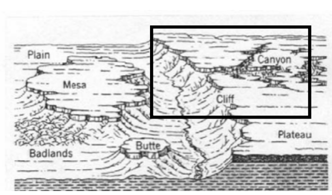
Also an area of gentle slopes and low relief flanking an upland area. The term is commonly applied to assemblages of planar alluvial surfaces flanking an area of mountains or rocky desert uplands.

Pta — **Plateau**



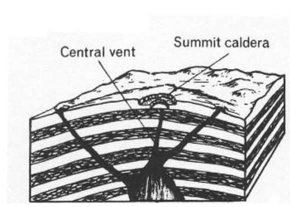
An extensive, flat or almost flat surface found in the upland region, considerably elevated above adjacent country and limited by an abrupt descent scarp on at least one side. Plateaus can be of volcanic origin, but upland plateaus with level summits can be found in sedimentary and metamorphic formations. Plateaus are often but not always horizontally-bedded and vary in size from sub-continental features such as the Deccan plateau (India) to small mesas in the American south-west. Volcanic plateaus are formed by successive layers of very fluid basic lava eruptions from a large number of linear or fissure vents in earth's crust. Successive eruptions spread very mobile basaltic lava out over preceding flows. Eventually, lava may be 100s of m thick, completely covering the original landscape. Vertical jointing in basalt causes plateau edges to be very abrupt, and where rivers have dissected the plateau, valleys tend to be steep-sided gorges. Strictly linked with the plateau, is the term *steps fault platform*, a term used to indicate a broad landform with an irregular feature produced by step faulting.

PtD — **Dissected Plateau**



A plateau that has undergone a deeply (fluvial) incision leaving a rougher topography than the almost flat plateau. Proper valleys and hills can develop as a consequence of dissection.

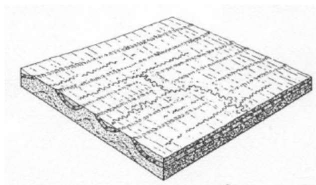
PtV — **Volcanic plateaus/ shield**



A hill or mountain formed by the eruption of molten rock from a central opening or vents in the crust. Lava edifices are built by successive lava flows. The size and the shape of shield is mainly determined by the nature of the material erupted. Lava viscosity of depends on % of silica (20-60% is acid rock e.g. rhyolite- extremely viscous and immobile. < 20 % SiO_2 e.g. trachyte - fairly viscous, unable to flow far before solidifying and basalt - very fluid and mobile). Free-flowing basalt in large quantities can build up a broad shield volcano, flowing for long distances before solidifying. The basalt volcano generally is a large, flat-area topped convex feature of basic lava with gently sloping sides and is usually low in height, relative to a large basal diameter.

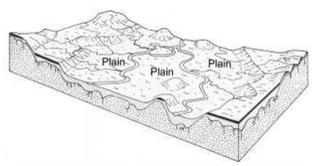
Some of these shields present residual landforms called *calderas*, large rounded depressions resulting from destruction of the upper part of a volcano in a violent eruption. Calderas are also due to subsidence. Major eruptions, by reducing the magma supply, leave a huge chasm beneath a volcano. The weight of the overlying cone becomes too great, faults develop, and it collapses into the chasm. Many calderas probably result from both explosions and subsidence. Slopes can be deeply dissected by radial valleys. Erosion develops first on the upper slopes, and in the early stages of dissection triangular facets of the original volcano, called *planezes*, may remain on the lower slopes. Eventually these are also destroyed.

Pen Peneplain



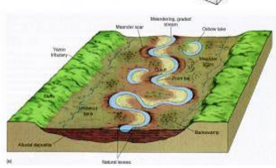
Gently undulating land area, characterised by pervasive repetition of rounded or elongated low hills with summits of similar height, separated by a dense, reticular hydrographic network. Form either by dissection of a former plain or plateau, or by down-wasting and flattening of an originally rugged land surface.

Pln Plain



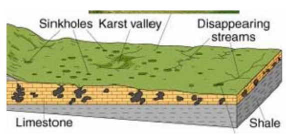
An extensive, generally broad tract of land, flat or gently sloping, unconfined, low-lying with low relief intensity (1-10 m altitude difference) and gentle slopes (generally <3%). Can occur around bases of many mountain/hill ranges, along main river valleys or along coastlines.

PlA Alluvial Plain



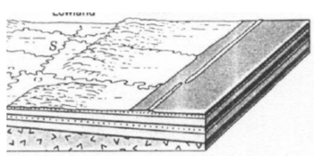
Plains derived from fluvial activity and characterised by the extensive presence of alluvial deposits. Usually the drainage network on them is not very well developed. They have very low slopes and are some 100s – 1 000s meters wide.

PlK Karst plain



Plains derived mainly from chemical dissolution of limestones and salty (gypsiferous) rocks under specific climatic conditions. Tend to have no surficial drainage and punctuated by other karstic features such as doline, polje, etc.

PlC Coastal Plain

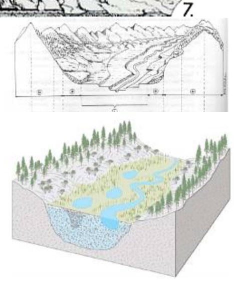


Plains generated by activity of ocean or sea movements: they can be both erosional (erosion of a rocky coast to give rise to a flat rocky platform, erosion of a dune system to give rise to an almost flat sandy surface, etc) and depositional (accumulation of sand or gravel).

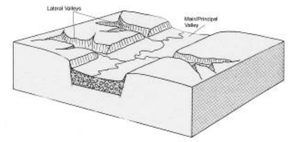
PlD Dissected /Incised plain

Gently-sloping land marked by intense erosive cutting with a well-developed drainage network.

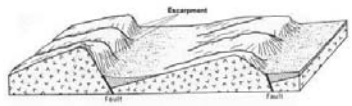
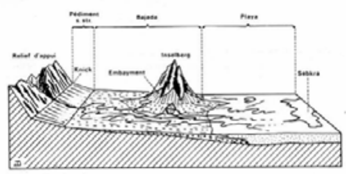
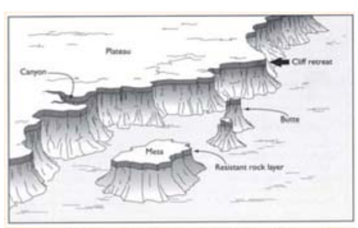
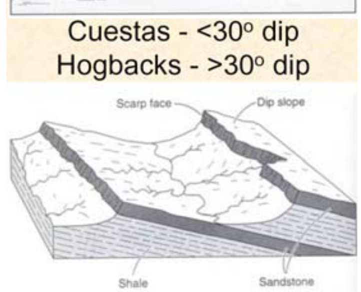
Vay Valley

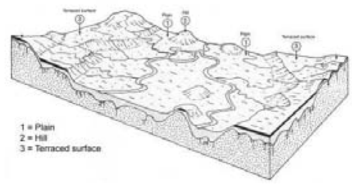
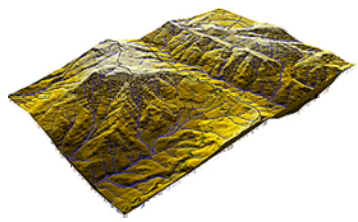
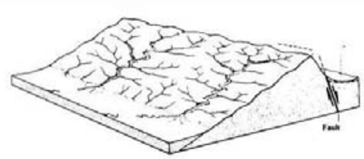
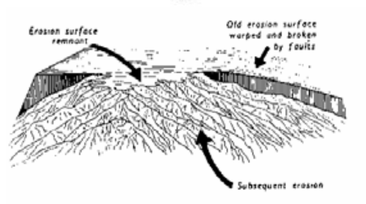
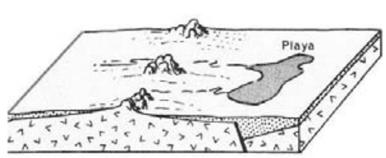


Elongated, flat land intercalated between two bordering, higher relief zones (e.g. piedmont, plateaus, hill or mountain). Main origin can be linked with fluvial/erosion activities but the weathering actions are also an important factor in its development. Include only flat valley floors.

VaL	Lateral Valley		A tributary fluvial valley to the main one. Usually it has a sharp junction (with an angle close to 90°) with the main valley.
VaC	Confined Valley		A valley with very steep, rocky, close walls delimiting its course. The floor is generally flat and it is usually occupied by a perennial river.

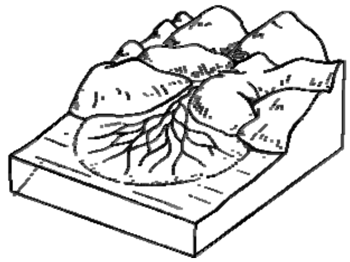
RELIEF TYPE (second order land surface feature)

Code	Description		Definition
S08	Escarpment		A fault scarp (or escarpment) is a steep, exposed slope where the land falls from a higher to lower level. Escarpments can be caused by vertical displacement of the earth's surface along fault lines. Some are more defined, while others are less evident especially if weathering and vigorous erosion processes have taken place on softer rocks. They form a linear, extensive straight, or sinuous steep slope.
S15	Depression		An elongated trough or depression bounded by inward facing fault scarps along faults. These depressions can vary in width. Generally, the bottom is characterised by a flat or almost flat terrain.
S16	Dissected ridge		An elongated, narrow, steep-sided elevation of the earth's surface. Its crest and slopes are cut by running waters in channels. Contains a number of slope faces and peaks.
S24	Inselberg		Inselberg is a word of German origin, meaning 'island mountain'. It is a steep-sided residual hill, knob or mountain, generally rocky and bare, rising abruptly from an extensive low-level land erosion surface. Some are surrounded at their base by gentle rock pediments. They vary in shape and size; some being only small hills less than 100 m high while others can reach much higher altitudes.
S25	Cuesta		A ridge that possesses both scarp and dip slopes (see Figure 6 for Hogback).
S26	Mesa		A steep-sided plateau of rock, in horizontally bedded rocks surrounded by a plain.
S27	Hogback		A long ridge of rock dipping steeply on both sides that is the exposure of a stratum of hard rock which has been tilted until the originally horizontal beds are almost vertical.

S29	Hill		An isolated, well-defined relief with gently undulated summit and gently inclined to precipitous slopes. Their drainage network varies from fixed, shallow erosional stream channels to very widely spaced. There is continuously active erosion by wash and creep on their slopes and, in some cases, active erosion by landslides. Their relief intensity is usually not greater than 300 m.
S30	Hill Complex		A complex of adjoining hills, as defined above.
S31	Ridge		An elongated, narrow, steep-sided elevation of the earth's surface. It has a single crest, which may have a more or less constant elevation, or may contain a number of peaks.
S32	Planation surface		A term commonly used to describe a flattish plain resulting from erosion. Usually is a very gently sloping surface that can be incised by rivers or fractures.
S33	Denudational slope		A slope on which there is clear evidence of erosional processes by active, channelised running waters or on which there is evidence for mass wasting processes (landslides, creep, etc).
S34	Slope		The flank of a mountain, hill, hill complex, ridge, etc on which it is not possible to recognise any of the detailed features here adopted. Slope and relief intensity can vary greatly.
S35	Denudational surface		An almost flat surface on which there are clear evidence for erosional processes through active channelisation by running waters on which there is evidence for mass wasting processes (landslides, creep, etc).
S36	Plain		A flat surface the origin of which is influenced by the presence of almost horizontal layered rocks or by the action of a tectonic element. A plain (structural) is different from a alluvial plain, because the latter is mainly formed by the action of rivers avulsion.
E05	Playa		A closed depression in a dryland area that is periodically inundated by surface water. The term is also used to refer solely to the salt flat that may occupy such a depression. Terms such as pan, *chott*, and *kavir* are used for the same features.
E06	Pan		A closed dryland depression that many hold an ephemeral shallow water body or which may have been occupied by a lake under past positive water balance

conditions. The term is widely used in southern Africa and is equivalent to playa and deflation basin elsewhere, though pans do not exceed 10^1 - 10^4 m in diameter.

F01 Alluvial fan

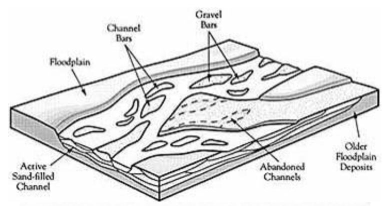


Depositional land feature whose surface forms a segment of a cone that radiates downslope from a point where the stream leaves the source area. The plan view of a cone-shaped deposit is broadly fan-shaped with the contours bowing downslope.

F03 Anatomizing (anastomosing) river plain

A category of fine grained, low energy anabranching rivers. They have a distinctive alluvial architecture consisting of arenaceous channels and argillaceous overbank deposits and are sometimes associated with coal and liquid hydrocarbon.

F04 Braided river plain

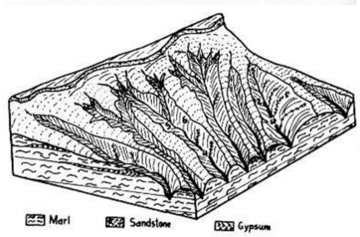


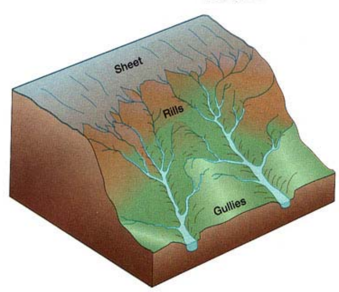
A plain traversed by a river which passes through a number of interlaced branches that divide and rejoin.

F05 Meandering river plain

A plain where a sinuous winding river flows.

F09 Gully/Rill erosion surface



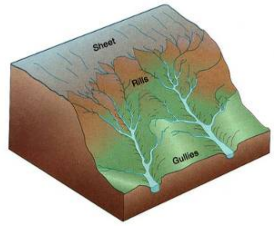


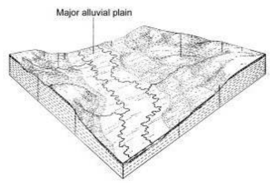
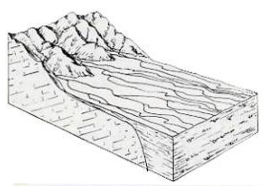
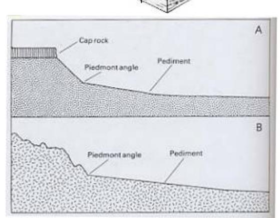
Gully are steep sided trench or channel often deep (several meters), that is cut into poorly consolidated bedrock, weathered sediment or soil. A gully is deeper and longer than a rill..

Rills are very small ephemeral channels that often form in sub-parallel sets on sloping agricultural land in response to intense run-off events. They are also common on steep and unprotected surfaces like road and other earthen embankments. Rill dimensions lie in the range of cm-dm for both width and depth but rill length may reach hundreds of meters.

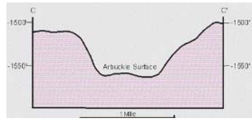
F10 Sheet erosion surface

A surface affected by stripping of soil material from a relatively broad area such as a field or hillside to a uniform depth and without the incision of discrete channels as large as gullies.



F11	Trace of palaeoriver		A feature of the land detectable mainly by means of aerial photography or remote sensing where it is possible to recognise the presence of an old river trace, actually filled up with sediments and covered by vegetation. In most cases it has different porosity from surrounding sediments and these allow to clearly identify it on remote sensed images.
F12	Alluvial plain		A fan-shaped deposit formed by a stream either where it issues from a narrow mountain valley onto a plain or broad valley, or where a tributary stream joins a main stream. Its surface forms a segment of a cone that radiates downslope from the point where the stream leaves the source areas. The coalescing of many alluvial fans forms a depositional piedmont commonly called *bajada*.
F13	Depression		A depression originating from fluvial incision/erosion where the fluvial erosion-transport-sedimentation is the main morphogenetic process.
F14	Pediment	 	A term that has changed its meaning since its first usage (1880) and is now defined as follows: a smooth plan-concave upward erosion surface, typically sloping down from the foot of a highland area and graded to either a local or more general base level. It is an element of the piedmont belt, which may include depositional elements, such as fans and playas. The pediment excludes such depositional components although an alluvial cover is frequently present. It is broadly synonymous with the French term *glacis*. Coalescent pediments form a pediplains.
F15	Dissected pediment		A pediment cut by numerous fluvial incisions (sometimes very deep) or by fracture/fault planes that give rise to a dissected pediment topography.
F16	Delta		Accumulation of river-derived sediment deposited at the coast when a stream enters a receiving body of water, which may be an ocean, lagoon, estuary or lake. Deltas result from the interaction of fluvial and marine forces. Development of delta involves the progradation of the river mouths and delta shorelines producing a sub aerial deltaic plain surmounting delta front deposits which have accumulated to seaward.

F17 Flat floor valley

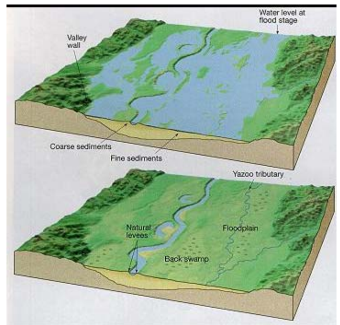


A small valley, usually at the upper part of catchments and normally, but not always, without a permanent drainage whose floor is flat or almost flat lying. It is normally occupied by crops. Its downslope limit is given by an abrupt change in slope.

F18 River plain

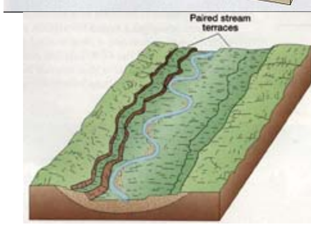
An alluvial plain where the river that formed the deposits is not anymore acting, or it has migrated in another part of the plain.

F19 Flood plain



A relatively flat alluvial landform, constructed largely by the flow regime of the present river and subject to flooding, Commonly flood plains flank a clearly defined river channel, but some occur in valleys without channels, while others form downstream of channels. A flood plain shows strongly affinity to the river that has formed it. With changes in flow regime, rivers may incise, leaving abandoned floodplains as river terraces.

F20 Terraced surface



A nearly flat surface formed at the river level but now above the river, separated at least by an eroded slope. Terraces may be rock-floored or alluvial.

F21 Upper Pediment

The upper part of a Pediment (see F14)

F22 Lower Pediment

The lower part of a Pediment (see F14)

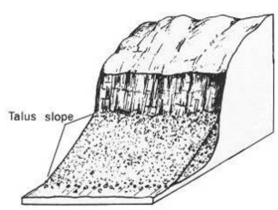
F23 Old meandering river plain

A plain where there is a trace of a river or stream which no longer conveys discharge and is no longer part of the contemporary fluvial system.

F24 River incision

An incision in alluvial sediments or rocks, operated by the action of running surficial waters

G08 Talus slope

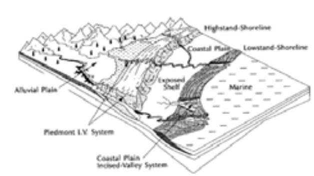


An accumulation of mostly angular clasts which lies at an angle of around 36° beneath an exposed free face or cliff. The prime cause of deposition is rock fall, but other processes, such as debris flow, may contribute to their development. The largest clasts occur at the base of the slope.

L02 Lake basin

A body of water contained within continental boundaries.

C02 Coastal plain



A small plain that faces the coastline and is built of sand transported by the action of the waves

C03 Sandy coast

Or beaches, are accumulations of sediment deposited by waves and longshore current in the shore zone.

C04 Foredune

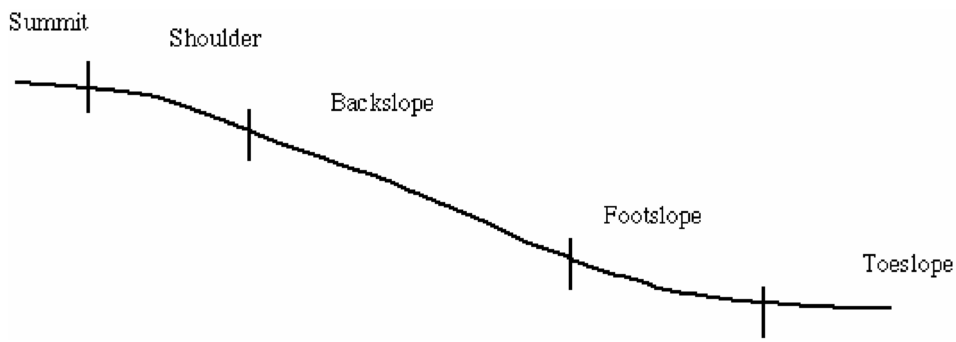
A distinctive coastal dune with geometry controlled by wind, nearshore processes, sand and vegetation. Characteristic morphology of mature foredunes are near-continuous ridge

			with a an erosion scarp windwards and dune grass cover on the crest and lee slope.
C05	Stabilized dune		Stabilized dunes are sand dunes where the morphogenetic action of the wind is stopped and the vegetation has had the possibility to colonize the dune stabilizing with its roots the sand.
C06	Mobile dune		Dunes where the wind action is still the dominant morphogenetic process and the vegetation is not able to fix the sand grains. In this kind of dunes the production of sediment mobilized by the wind is very high and they can be dispersed many kilometres away.
A02	Town, ind. District		An area occupied by buildings for residential or production purposes,. usually with roads and might have a railway passing through it. It has to be clearly visible from satellite imagery.

LANDFORM (third order land surface feature - glossary for the northern area)

Code	Description	Definition
F02	Rill	A small ephemeral channel that often forms in sub-parallel sets on sloping agricultural land in response to intense run-off events. They are also common on steep unprotected surfaces like roads and other earthen embankments. A rill's dimensions lie in the range cm-dm for both width and depth, but rill length may reach hundreds of m.
F03	Gully	A steep-sided trench or channel, often deep (several m), cut into poorly consolidated bedrock, weathered sediment or soil. The agent of gullying is ephemeral flow of running water. A gully is deeper and longer than a rill.
F05	River levee	A broad, long-crested ridge running alongside a floodplain stream or intertidal inlet composed generally of coarse sand to silt sediments deposited by floodwaters as they overtop channel banks.
F06	Floodplain	Relatively flat alluvial landform, constructed generally by the flow regime of the present river and subject to flooding. Commonly floodplains flank a clearly defined river channel, but some occur in valleys without channels, while others form downstream of channels.
F07	Terrace	Former flood plain on which erosion and aggradation by channelled and over-bank stream is inactive or barely active because deepening or enlargement of the stream has lowered the level of flooding. The elevation of terraces on the active flood plain can vary from few meters to hundreds. There can be paired and unpaired fluvial terraces along the main river/alluvial plain.
F09	Depression	A surface of land that is lowered below the surroundings, mainly through fluvial erosion. It is normally of sub-circular or elliptical shape and maintain a well-developed drainage network. It can be assimilated within a small catchments basin.
F14	Upper Pediment	The upper part of a pediment. It is easily recognizable by the presence of an abrupt change in slope between the lower middle part of a pediment.
F15	Middle Pediment	The middle part of a pediment. It is easily recognizable by the presence of an abrupt change in slope between the upslope upper pediment and the downslope lower part of a pediment.
F16	Lower Pediment	The lower part of a pediment. It is easily recognizable by the presence of an abrupt change in slope between the upslope middle part of a pediment.
X01	Summit	Refer to figure at the base of the page
X02	Shoulder	Refer to figure at the base of the page
X03	Backslope	Refer to figure at the base of the page
X04	Footslope	Refer to figure at the base of the page
X05	Toe-slope	Refer to figure at the base of the page
X06	Upper slope	The upper part of a slope, marked by a clear change in slope angle along the slope. It is used when it not possible to distinguish all the five distinctions of a slope.
X07	Lower slope	The lower part of a slope, marked by a clear change in slope angle along the slope. It is used when it not possible to distinguish all the five distinctions of a slope.

X08	Slope Complex	A slope in its different parts that is not possible to distinguish in any of the previous two systems (five different tracts or even two tracts)
X09	Crest	The uppermost part of a relief, ridge, hill showing a long and sometimes sharp shape. It can also be almost flat lying but always its length dimension is bigger than its width one.



Annex 2: Lithology Glossary

Lithology groups and types (adapted from SOTER, ISRIC, 2005)

Major class	Main Group Code	Main Group Description	Rock Type Code	Rock Type Description	Definition
IGNEOUS ROCK (I)					
	IA	Acid	***IA1***	granite	A coarse-grained intrusive igneous rock with at least 65% silica. Quartz, plagioclase feldspar and potassium feldspar make up most of the rock and give it a fairly light colour. Granite has more potassium feldspar than plagioclase feldspar. Usually with biotite, but also may have hornblende
			IA3	Syenite	Intrusive equivalent of trachyte. It usually contains the following minerals: orthoclase, microcline, a small amount of plagioclase, one or more mafic minerals (esp. hornblende) and little to no quartz. With an increase in quartz content it grades into granite.
			IA4	rhyolite, dacite	Extrusive rock typically porphyritic and commonly it exhibits flow texture, with phenocrystals of quartz and alkali feldspar in a glassy to cryptocrystalline groundmass. It is an extrusive equivalent of granite (rhyolite). A fine grained extrusive rock with the same general composition as andesite but having a less calcic plagioclase and more quartz (dacite).
			II2	diorite, diorite-syenite	Intrusive igneous rock made of plagioclase feldspar and amphibole and/or pyroxene. Similar to gabbro only not as so dark, and containing less iron and magnesium.
	IB	Basic	***IB1***	gabbro	A dark, coarse-grained intrusive igneous rock. Gabbro is made of calcium-rich plagioclase, with amphibole and/or pyroxene, and is chemically equivalent to basalt.
			IB2	basalt	A dark, fine-grained, extrusive (volcanic) igneous rock with low silica content (40% to 50%), but rich in iron, magnesium and calcium. Generally occurs in lava flows, but also as dikes. Basalt makes up most of the ocean floor and is the most abundant volcanic rock in the Earth's crust.
			IB3	dolerite/diabase	A dark, fine-grained igneous rock, consisting mainly of dark pyroxene surrounding light feldspar crystals
	IP	Pyroclastic	**IP1**	tuff, tuffite	A term for all consolidated pyroclastic rocks (tuff) that can contain also detrital material (tuffite).
			IP2	volcanic scoria/breccia	Very bubbly (vesicular) basalt or andesite. Both scoria and pumice develop their bubbly textures when escaping gas is trapped as lava solidifies. Scoria is more dense and darker than pumice.
			IP3	volcanic ash	
			IP4	ignimbrite	The rock formed by the widespread deposition and consolidation of ash flows and *nuees ardentes*.
METAMORPHIC (M)					
	MA	Acid	**MA1**	quartzite rock	Hard, somewhat glassy-looking rock made up almost entirely of quartz.

				Metamorphosed quartz sandstone and chert are quartzites
		MA2	gneiss, migmatite, granulite	A coarse-grained, foliated metamorphic rock that commonly has alternating bands of light and dark-coloured minerals (gneiss). "Mixed rock". A metamorphic rock that forms in one of two ways. The metamorphic rock may be heated enough to partially melt, but not completely. The molten minerals resolidify within the metamorphic rock, producing a rock that incorporates both metamorphic and igneous features. Migmatites can also form when metamorphic rock experiences multiple injections of igneous rock that solidify to form a network of cross-cutting dikes (migmatite).
		MA3	slate, phyllite (pelitic rocks)	A compact fine grained metamorphic rock that possesses slaty cleavage and hence can be split into slabs and thin plates. Most slates was formed from shale.
		MA4	schist	Metamorphic rock usually derived from fine-grained sedimentary rock such as shale. Individual minerals in schist have grown during metamorphism so that they are easily visible to the naked eye. Schists are named for their mineral constituents. For example, mica schist is conspicuously rich in mica such as biotite or muscovite.
	MB	Basic	**MB**	basic metamorphic	
			MB1	slate, phyllite (pelitic rocks)	A very fine-grained, foliated metamorphic rock generally derived from shale or fine-grained sandstone. Phyllites are usually black or dark grey; the foliation is commonly crinkled or wavy. Differs from less recrystallized slate by its sheen, which is produced by barely visible flakes of muscovite (mica).
			MB2	(green)schist	A schistose metamorphic rock whose green colour is due to the presence of chlorite, epidote or actinolite
			MB3	gneiss rich in ferro-magnesium minerals	
			MB4	metamorphic limestone (marble)	A metamorphic rock of made of calcium carbonate. Marble forms from limestone by metamorphic recrystallization
			MB5	amphibolite	A rock made up mostly amphibole and plagioclase feldspar. Although the name amphibolite usually refers to a type of metamorphic rock, an igneous rock composed dominantly of amphibole can be called an amphibolite too.
			MB6	eclogite	A granular rock composed essentially of garnet and sodic pyroxene. Rutile, kyanite and quartz are typically present.
	MU	Ultrabasic	**MU1**	serpentinite, greenstone	A metamorphic rock derived from basalt or chemically equivalent rock such as gabbro. Greenstones contain sodium-rich plagioclase feldspar, chlorite, and epidote, as well as quartz. The chlorite and epidote make greenstones green
SEDIMENTARY (S)					

	SC	Clastic	**SC1**	conglomerate, breccia (consolidated)	A sedimentary rock made of rounded rock fragments, such as pebbles, cobbles, and boulders, in a finer-grained matrix. To call the rock a conglomerate, some of the constituent pebbles must be at least 2 mm (about 1/13 of an inch) across (conglomerate). Rock made up of angular fragments of other rocks held together by mineral cement or a fine-grained matrix. **Volcanic breccia** is made of volcanic rock fragments, generally blown from a volcano or eroded from it. **Fault breccia** is made by breaking and grinding rocks along a fault.(breccias)
			SC2	sandstone, greywacke, arkose	Sedimentary rock made mostly of sand-sized grains.
			SC3	siltstone, mudstone, claystone	A very fine-grained sedimentary rock formed from mud (mudstone)
			SC4	shale	Sedimentary rock derived from mud. Commonly finely laminated (bedded). Particles in shale are commonly clay minerals mixed with tiny grains of quartz eroded from pre-existing rocks. **Shaley** means like shale or having some shale component, as in shaley sandstone.
	SO	organic	**SO1**	limestone, other carbonate rock	A sedimentary rock made mostly of the mineral calcite (calcium carbonate). Limestone is usually formed from shells of once-living organisms or other organic processes, but may also form by inorganic precipitation. A magnesium-rich carbonate sedimentary rock. Also, a magnesium-rich carbonate mineral ($CaMgCO^3$) (dolomite)
			SO2	marl and other mixtures	Unconsolidated earthy deposits consisting chiefly of an intimate mixture of clay and calcium carbonate, usually including shell fragments and sometimes glauconite.
	SE	evaporites	**SE1**	anhydrite, gypsum	*It is the commonest sulfate mineral and is frequently associated with halite and anhydrite in evaporites, forming thick, extensive beds*
			SE2	halite	It is native salt rock (NaCl) occurring in massive, granular, compact or cubic crystalline forms.
Unconsolidated rocks (U)	**US**	sedimentary	**US1**	unconsolidated undifferentiated sediments	
	UR	weathered residuum	***UR1***	bauxite, laterite	A grey, yellow or reddish-brown rock composed of a mixture of various aluminium oxides and hydroxides, along with free silica, silt, iron hydroxides and clay minerals. If it is highly aluminous it is called laterite.
	UF	fluvial	***UF1***	sand and gravel	A detrital particle smaller than a granule and larger than a silt grain, having a diameter in the range of 1/16 to 2 mm (sand). If larger than 2 mm is gravel.
			UF2	clay, silt and loam	A detrital mineral particle of any composition having a diameter less than 1/256 (clay) or between 1/16 to 1/256 (silt) or a soil composed of a mixture of clay, silt, sand and organic matter (loam)
	UL	lacustrine	**UL1**	sand	*A detrital particle smaller than a granule and larger than a silt grain, having a diameter in the range of 1/16*

				to 2 mm.
		UL2	silt and clay	Loose particles of rock or mineral (sediment) that range in size from 0.002-0.0625 mm in diameter. Silt is finer than sand, but coarser than clay.
UM	marine and estuarine	**UM1**	gravel	A detrital particle having a diameter larger than 2 mm.
		UM2	sand	
		UM3	clay and silt	
UC	colluvial	**UC1**	colluvial	
		UC2	slope	
		UC3	lahar	
UE	aeolian	**UE1**	sand	
UA	anthropogenic	**UA1**	redeposited natural material	
		UA2	industrial/artisanal deposits	
UU	unspecified	**UU1**	clay	
		UU2	loam and silt	
		UU3	sand	
		UU4	gravely sand	All sedimentary particles larger than two mm are called gravel. Gravel is subdivided into pebbles, cobbles, and boulders.
		UU5	gravel, broken rock, blocks	
		UU6	other: ……………………… ……….	

Table a: Correlations between codes used in the legend of Abbate *et al*. (1994), the main lithologic description for each rock formation, the lithogenetic environment of each rock formation and the Africover lithology codes.

Code	Lithologic description	Rock type	Africover corresponding codes
Q	Sand, Silt, Gravel, Colluvium	Sedimentary	M213, M212, M214, M217
Qa	Sand, Gravel	Sedimentary	M213, M214
Qasc	Silty clay, Sand, Gravel	Sedimentary	M273, M213, M214
Qc	Caliche	Sedimentary	
Qc	Algal/Reefal Limestone, Calcarenite	Sedimentary	M235, M233
Qcl	Clay, Sand	Sedimentary	M211, M213
Qd	Sand	Sedimentary	M213
Qps	Quartz sand	Sedimentary	M272
Qsd	Sand	Sedimentary	M213
Qws	Sand	Sedimentary	M213
Pb	Alluvial Fanglomerate, Sandstone	Sedimentary	M267, M264
Pl	Conglomerates, Sands, Shale	Sedimentary	M228, M213, M223
ToF	siltic and sandy shales of lacustrine environment	Sedimentary	
Pbeta	Basalt, Rhyolite	Sedimentary	M136, M131
Talfa	Basalt flows, tuffs and sills	Igneous	
Mb	Algal/reefal Limestone	Sedimentary	M235
Md	Algal/reefal Limestone	Sedimentary	M235
Mdc	Conglomerate, Sand	Sedimentary	M228, M213
Ms	Marl, Clay, Sandstone, Gypsum, Limestone, Conglomerates	Sedimentary	M231, M211, M264, M241, M265, M22
Od	Siltstone, Sandstone, Conglomerate, Gypsum, Marl	Sedimentary	M222, M264, M228, M241, M231
Ogy	Gypsum, Clay	Sedimentary	M241, M211
Oh	Marly Limestone, Limestone, Calcarenite, Sandstone	Sedimentary	M276, M265, M233, M264
OMbl	Limestone, Marl	Sedimentary	M265, M231
OMI	Limestone, Sandstone, Siltstone	Sedimentary	M265, M264, M222
OMmb	Gypsiferous sand, Sandy clay, Limestone	Sedimentary	M274, M275, M265
Et	Anhydrites, Gypsum, Dolomite, Cherty	Sedimentary	M268, M241, M238,

	Limestone, Shale		M269, M223
Ek	Limestone, Marl	Sedimentary	M265, M231
Ea	Algal/reefal Limestone, Marl, Chert	Sedimentary	M235, M231, M270
Ka	Sandstone	Sedimentary	M264
Kb	Algal/reefal Limestone, Limestone, Calcarenite, Sandstone	Sedimentary	M235, M265, M233, M264
KBW	Algal/reefal Limestone, Sandstone	Sedimentary	M265, M264
KF	Gypsum, Sand, Marl	Sedimentary	M241, M213, M231
KM	Gypsum, Shale, Dolomite, Limestone, Marl	Sedimentary	M241, M223, M238, M265, M231
KMA	Gypsum, Shale, Dolomite, Limestone, Sandstone	Sedimentary	M241, M223, M238, M265, M264
Kt	Algal/reefal Limestone, Marl, Sandstone, Conglomerate	Sedimentary	M235, M231, M264, M228
KW	Algal/reefal Limestone, Marl	Sedimentary	M235, M231
Ky	Quartzarenite, Siltstone	Sedimentary	M224, M222
JA	Limestone, Marl, Dolostone, Sandstone, Clay, Gypsum	Sedimentary	M265, M231, M271, M264, M211, M2
Ja	Marl, Marly Limestone, Limestone, Sandstone	Sedimentary	M231, M276, M265, M264
JB	Calcarenite, Limestone, Limestone, Marl, Calcarenite, Quart	Sedimentary	M233, M265, M265, M231, M233, M22
Jc	Algal/reefal Limestone, Marl, Shale	Sedimentary	M235, M231, M223
Jg	Limestone, Dolomitic limestone, Calcarenite	Sedimentary	M265, M277, M233
Ju	Limestone, Calcarenite, Sandstone	Sedimentary	M265, M233, M264
gamma	Granite	Igneous	M111
XA	Mepelite, Metavolcanites	Metamorphic	M345, M346
Xl	Cataclastic metamorphic rock, Marble	Metamorphic	M320, M338
XM	Cataclastic metamorphic rock, Metabasalt	Metamorphic	M320, M344
Xgamma	Gabbro	Igneous	M117
Xsigma	Syenite	Igneous	M114
m	Marble	Metamorphic	M338
q	Quartzite	Metamorphic	M337
Dg	Para Gneiss, Migmatite	Metamorphic	M333b, M334
Oc	Migmatite, Para Gneiss, Anphibolites (Felsen), Quartzite	Metamorphic	M334, M333b, M342, M337
Mm	Marble	Metamorphic	M338
Ma	Biotite, Anphibolites (Felsen)	Metamorphic	M341, M332
Ms	Schist, Gneiss	Metamorphic	M332, M333
Mmiu	Migmatite, Anphibolites, Marbles	Metamorphic	M334, M340, M338
xbeta	Migmatite, Para Gneiss	Metamorphic	M334, M333b
Ta	Basalt, Tuff, Silt	Igneous/Sediment	M136, M144, M212

A tentative correlation between lithologic units and their technical characteristics, derived exclusively from the bibliography (Selby, 1993), is given in the following table. It attempts to give average values for Density (Tonn/m^3), Modulus of elasticity (GPa), Shear modulus (GPa), Poisson's ratio, and, in the second table, Unit weight (saturated and dry)(KN/m^3), Friction angle (degrees), and Cohesion (kPa), for the cohesive materials. The values have to be considered as average values derived from the bibliography. Nevertheless, they can be used in many different considerations on rock and soil geology.

Table b: Density, modulus of elasticity, shear modulus and Poisson's ratio for some rocks identified in the AOI (from Selby, 1993).

Rock type	Density (Tonn/m^3)	Modulus of Elasticity (E) (GPa)	Shear modulus (G) (GPa)	Poisson's ratio (v)
Basalt	2.6-2.8	45-100	10-30	0.28
Conglomerate	2.5-2.7	20-30	6-20	0.1-0.29
Diorite	2.7	35-80	15-25	0.1-0.28
Dolomite	2.4-2.7	50-80	20-30	0.2-0.4
Gabbro	3.0	55-90	20-40	0.2-0.38
Gneiss	2.7-2.8	55	-	0.21
Granite	2.64	35-70	15-50	0.21-0.28
Limestone	2.3-2.7	26-63	3-30	0.2-0.23
Marble	2.7	17-100	17-30	0.1-0.28
Quartzite	2.5-2.8	50-70	1-40	0.1-0.4
Salt	2.2	28	-	0.3
Sandstone	2.2-2.5	10-70	1-40	0.1-0.45
Schist	2.4-2.8	20-60	8-25	0.1-0.3
Shale	1.8-2.5	20-50	1-15	0.1-0.3
Siltstone	2.0-2.7	20-40	1-22	0.1-0.4
Aluminium	2.7	73	49	0.34
Steel	7.8	210	135	0.29

Table c: Unit weight, friction angle and cohesion for cohesive and cohesionless materials found in the AOI (from Selby, 1993).

Cohesionless material		Unit weight (saturated/dry) (kN/m^3)	Friction angle degrees
Sand			
	Loose sand, uniform grain size	19/14	28-34
	Dense sand, uniform grain size	21/17	32/40
	Loose sand, mixed grain size	20/16	34-40
	Dense sand, mixed grain size	21/18	38-46
Gravel			
	Gravel, uniform grain size	22/20	34-37
	Sand and gravel, mixed grain size	19/17	48-45
Compacted broken rock			
	Basalt	22/17	40-50
	Granite	20/17	45-50
	Limestone	19/16	35-40
	Sandstone	17/13	35-45
	Shale	20/16	30-35

Cohesive Material		Unit weight (saturated/dry)	Friction angle	Cohesion (kPa)

		(kN/m^3)	**degrees**	
Clay				
	Very soft organic clay	14/6	12-16	10-30
	Soft, slightly organic clay	16/10	22-27	20-50
Rock				
	Hard igneous rocks: granite, basalt	25/30	35-45	35,000-55,000
	Metamorphic rocks: quartzite, gneiss	25/28	30-40	20,000-40,000
	Hard sedimentary rocks: limestone, dolomite, sandstone	23/28	35-45	10,000-30,000
	Soft sedimentary rocks: sandstone, coal, chalk, shale	17/23	25-35	1,000-20,000

Annex 3: Field Forms

LANDFORMS

Form Progressive Number:
____

DESCRIPTION OF THE TERRAINS

VALIDATION of the LANDFORM MAP

DATE OF DESCRIPTION: …………………………..	GPS COORDINATES
HOUR OF DESCRIPTION:………………..a.m./p.m.	X (longitude Est):
SURVEYOR's Names: ……………………………….	……………..……………………………
…………………………………………………………..	Y (latitude North):
LOCATION: …………………………………………...	……………………………………………..
…………………………………………………………..	Elevation (m a.s.l.): ……………………
…………………………………………………………..	
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…………………………………………………………..	

WEATHER CONDITIONS:

CLOUDINESS	WIND CONDITIONS	VISIBILITY	TEMPERATURE
☐ Sunny	☐ No wind	☐ Optimal visibility	°C:…...............
☐ Partly cloudy	☐ Moderate wind speed	☐ Partly foggy	
☐ Cloudy	☐ Windy	☐ Foggy	
☐ Rainy	☐	☐ Totally foggy	
☐ Stormy			

Notes:……….
…….

SKETCH DRAWING OF THE SITE SURROUNDINGS (always put the directions N, E, S, W)

LANDSCAPE

CODE	DESCRIPTION	NORTH	EAST	SOUTH	WEST
		☐	☐	☐	☐
		☐	☐	☐	☐
		☐	☐	☐	☐
		☐	☐	☐	☐

RELIEF TYPE

CODE	DESCRIPTION	NORTH	EAST	SOUTH	WEST
		☐	☐	☐	☐
		☐	☐	☐	☐
		☐	☐	☐	☐
		☐	☐	☐	☐

LANDFORM

CODE	DESCRIPTION	NORTH	EAST	SOUTH	WEST
		☐	☐	☐	☐
		☐	☐	☐	☐
		☐	☐	☐	☐
		☐	☐	☐	☐

PICTURES

Numbers:……………………………………………………………………………………….

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Notes:………………………………………………………………………………………

ANNOTATIONS:

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LANDFORM CHARACTERISATION OF THE LAND COVER FIELD BOX SAMPLE

LANDSCAPE/RELIEF TYPE/LANDFORM of the LAND COVER FIELD BOX SAMPLE
(with reference to Form 6A, to be estimated using the topographic map. Check the altitude of the upper and lower contour lines and write the average value):

LANDSCAPE

CODE	DESCRIPTION	Annotation

RELIEF TYPE

CODE	DESCRIPTION	Annotation

LANDFORM

CODE	DESCRIPTION	Annotation

SLOPE ANGLE, To be measured carefully with the gradiometer (choose **ONE** of the following classes):

	Value	Description	Code
□	0-2%	Level	LE
□	2-4%	Very gently sloping	VG
□	4-8%	Sloping	GS
□	8-16%	Moderately sloping	MS

	Value	Description	Code
□	16-30%	Strongly sloping	SS
□	30-50%	Very steep	VS
□	>50%	Extremely steep	ES

SLOPE LENGTH (choose **ONE** of the following classes)**:**

To be estimated visually. Evaluate the distance from the site to both the upper and lower limit of the topographic shape where you are. The limit is where the slope changes its slope angle. In practice you have to find how far are: 1) the top of the slope upward; 2) the foot of the slope downward)

	Value	Description	Code
□	<15 m	very short	VSH
□	15-50m	short	SHO
□	50-250m	moderately long	MLO

	Value	Description	Code
□	250-500m	long	LON
□	>500m	very long	VLO

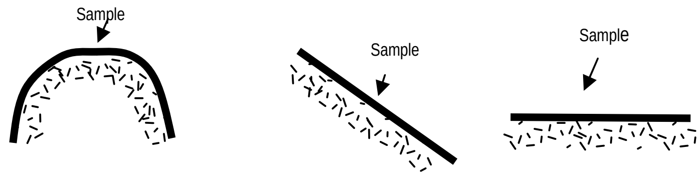
SLOPE ASPECT, To be calculated with the compass (choose **ONE** of the following classes. North is 0°)**:**

	Value	Description	Code
□	--	Flat or almost flat	FLT
□	--	Variable	VAR
□	338° - 22°	North facing	N
□	23° - 67°	North-East facing	NE
□	68° - 112°	East facing	E

	Value	Description	Code
□	113° - 157°	South-East facing	SE
□	158° - 202°	South facing	S
□	203° - 247°	South-West facing	SW
□	248° - 292°	West facing	W
□	293° - 337°	North-West facing	NW

GENERAL POSITION:

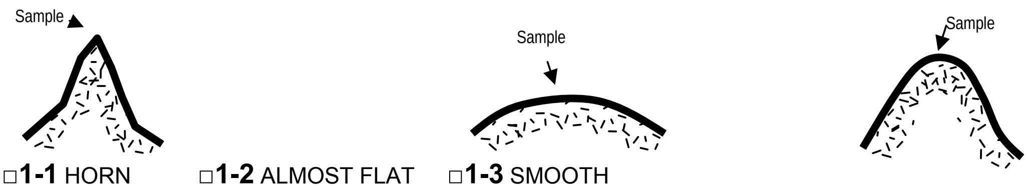
Looking at the scheme below, choose **ONE** of the three following main positions in respect to the slope:



□**1** - on TOP of a relief □**2** - on a SLOPE □**3** - on a PLAIN

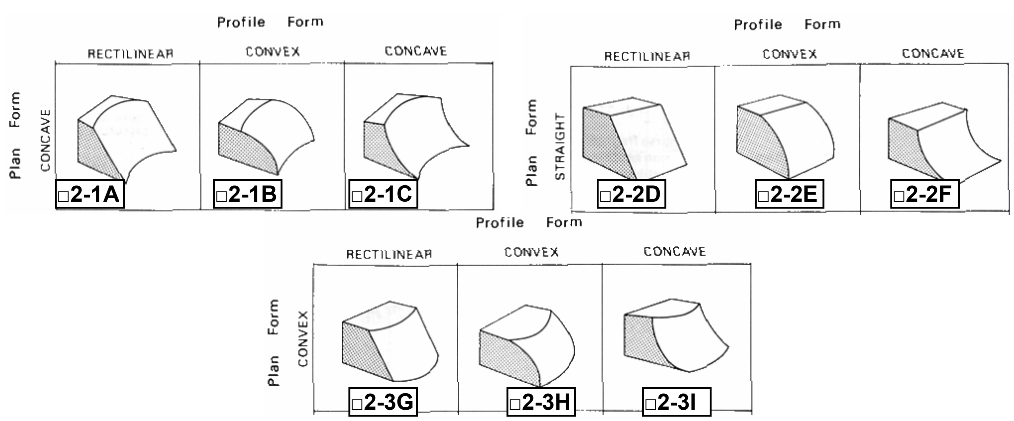
SPECIFIC POSITION:

If in "General Position" **you have chosen 1** (TOP of a relief) then distinguish between the following "TOP OF RELIEF" SUBTYPES, looking at the scheme below choose **ONE** of the three following options:

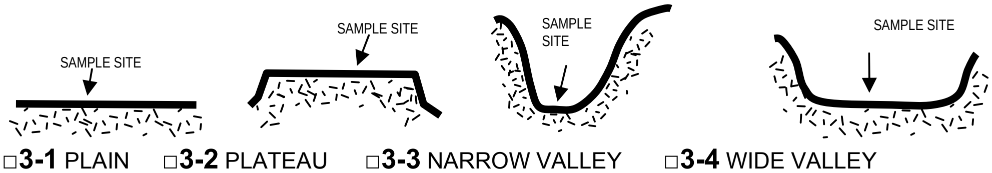


□**1-1** HORN □**1-2** ALMOST FLAT □**1-3** SMOOTH

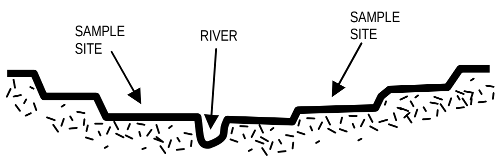
If in "General Position" **you have chosen 2** (SLOPE) then distinguish between the following "SLOPE" SUBTYPES, looking at the scheme below choose **ONE** of the six following options:



If in "General Position" **you have chosen** 3 (PLAIN) then distinguish between the following "PLAIN" SUBTYPES, looking at the scheme below choose **ONE** of the six following options:



□**3-1** PLAIN □**3-2** PLATEAU □**3-3** NARROW VALLEY □**3-4** WIDE VALLEY



□ **3-5** TERRACED SYSTEM VALLEY

Annex 4: Metadata of the satellite images and topographic maps

NORTHERN AOI

Table a: Satellite images used for visual image interpretation of the northern AOI

Satellite	Path and row / code	Date (year month day)	Colour composite	Pixel resolution (meters)
Landsat 7 ETM+				
	165_53	2001 04 07	573	28.5
			432	28.5
			457	28.5
	165_54	2001 09 14	573	28.5
			432	28.5
			457	28.5
	166_53	2000 05 13	573	28.5
			432	28.5
			457	28.5
Aster				
	A3210003109272000	2000 09 27	432	15
	A3210006007032001	2001 07 03	432	15
	A3210005907032001	2001 07 03	432	15
	A3210003309272000	2000 09 27	432	15
	A3210005012092000	2000 12 09	432	15
	A3210006705282002	2002 05 28	432	15
	A3210006306292002	2002 06 29	432	15
	A3210006406292002	2002 06 29	432	15
	A3210006506292002	2002 06 29	432	15
	A3210004412262001	2001 12 26	432	15
	A3210003209272000	2000 09 27	432	15
	A3210006805282002	2002 05 28	432	15
	A3210007205122002	2002 05 12	432	15
	A3210009501282005	2005 01 28	432	15
	A3210003009302001	2001 09 30	432	15
	A3210007305122002	2002 05 12	432	15
	A3210009302282002	2002 02 28	432	15
QuickBird	Q-34-114036_01-07142003-pan	2003 07 14	panchromatic	0.6

Table b: Topographic maps (1:100.000) used for landform mapping of the northern AOI

Topographic map	Date edition/revision	Number/code	Scale	Scanning resolution (dpi)
Defense Mapping Agency – USA	1970/1990	Nc-38-40	1:100,000	72
	1970/1990	Nc-38-51	1:100,000	72
	1970/1990	Nc-38-52	1:100,000	72
	1970/1990	Nc-38-53	1:100,000	72
	1970/1990	Nc-38-63	1:100,000	72
	1970/1990	Nc-38-64	1:100,000	72
	1970/1990	Nc-38-65	1:100,000	72
	1970/1990	Nc-38-75	1:100,000	72
	1970/1990	Nc-38-76	1:100,000	72
	1970/1990	Nc-38-77	1:100,000	72
	1970/1990	Nc-38-87	1:100,000	72
	1970/1990	Nc-38-88	1:100,000	72
	1970/1990	Nc-38-89	1:100,000	72
	1970/1990	Nc-38-100	1:100,000	72
	1970/1990	Nc-38-101	1:100,000	72

Table c: Geological map used for landform mapping of the northern AOI

Author/s	**Title**	**Year**	**Scale**	**Scanning resolution (dpi)**
Abbate E., Sagri M. & Sassi F.P. (editors)	Geological map of Somalia – Warqadda cilmiga dhulka ee Soomaaliya	1994	1:1,500,000	72

SOUTHERN AOI

Table d: Satellite images used for visual image interpretation of the southern AOI

Satellite	Path and row / code	Date (year month day)	Colour composite	Pixel resolution (meters)
Landsat 7 ETM+				
	163_57	2002 01 06	547	28.5
			432	28.5
			742	28.5
	163_58	2002 01 06	547	28.5
			432	28.5
			742	28.5
	163_59	2000 02 02	547	28.5
			432	28.5
			742	28.5
	164_56	1999 11 21	547	28.5
			432	28.5
			742	28.5
	164_57	2000 03 28	547	28.5
			432	28.5
			742	28.5
	164_58	2002 04 03	547	28.5
			432	28.5
			742	28.5
	164_59	2003 03 21	547	28.5
			432	28.5
			742	28.5
	164_60	2001 02 27	547	28.5
			432	28.5
			742	28.5
	164_57	2001 11 17	547	28.5
			432	28.5
			742	28.5
	164_58	2000 01 15	547	28.5
			432	28.5
			742	28.5
	164_59	2000 01 15	547	28.5
			432	28.5
			742	28.5
	164_60	2001 11 17	547	28.5
			432	28.5
			742	28.5
Aster				
	A3210000711272004	2004 11 27	432	15
	A3210001510162001	2001 10 16	432	15
	A3210001610162001	2001 10 16	432	15
	A3210001910022001	2001 10 02	432	15
	A3210002010022001	2001 10 02	432	15
	A3210002110022001	2001 10 02	432	15
	A3210002210022001	2001 10 02	432	15
	A3210002310022001	2001 10 02	432	15
	A3210003808062001	2001 08 06	432	15
	A3210004612092003	2003 12 09	432	15
	A3210004712092000	2000 12 09	432	15
	A3210005112062002	2002 12 06	432	15
	A3210005212062002	2002 12 06	432	15
	A3210005312062002	2002 12 06	432	15
	A3210005412062002	2002 12 06	432	15
	A3210007403232004	2004 03 23	432	15
	A3210007503232004	2004 03 23	432	15
	A3210007603232004	2004 03 23	432	15
	A3210007703232004	2004 03 23	432	15
	A3210007803232004	2004 03 23	432	15
	A3210007903232004	2004 03 23	432	15
	A3210008403042002	2002 03 04	432	15
	A3210008503042002	2002 03 04	432	15
	A3210008603042002	2002 03 04	432	15
	A3210009901032001	2001 01 03	432	15

	A3210010001032001	2001 01 03	432	15
	A3210010101032001	2001 01 03	432	15
	A3210010201032001	2001 01 03	432	15
	A3210011101032001	2001 01 03	432	15
	A3210011202232006	2006 02 23	432	15
	A3210011302232006	2006 02 23	432	15
	A3210011402232006	2006 02 23	432	15
	A3210011502232006	2006 02 23	432	15
	A3210011602232006	2006 02 23	432	15
	A3210011702252006	2006 02 25	432	15
	A3210011802252006	2006 02 25	432	15
	A3210011902252006	2006 02 25	432	15
	A3210012003192005	2005 03 19	432	15
	A3210012110022001	2001 10 02	432	15
	A3210012210022001	2001 10 02	432	15
	A3210012310022001	2001 10 02	432	15
	A3210012411302005	2005 11 30	432	15
	A3210012512022000	2000 12 02	432	15
	A3210012612022000	2000 12 02	432	15
	A3210012712022000	2000 12 02	432	15
	A3210012812022000	2000 12 02	432	15
Ikonos				
	I-01-135561-01022003-p4	2003 01 02	Pancromatic	1.0
	I-02-135568-01022003-p4	2003 01 02	Pancromatic	1.0
	I-02-135568-01132003-p4	2003 01 13	Pancromatic	1.0
	I-03-135570-09282003-p4	2003 09 28	Pancromatic	1.0
	I-04-135573-04022003-p4	2003 04 02	Pancromatic	1.0
	I-05-135574-01022003-p4	2003 01 02	Pancromatic	1.0
	I-06-135576-01032003-p4	2003 01 03	Pancromatic	1.0
	I-07-135579-01302003-p4	2003 01 30	Pancromatic	1.0
	I-08-135581-01032003-p4	2003 01 03	Pancromatic	1.0
	I-09-135582-01032003-p4	2003 01 03	Pancromatic	1.0
	I-10-135584-01032003-p4	2003 01 03	Pancromatic	1.0
	I-11-136073-02022004-p4	2004 02 02	Pancromatic	1.0
	I-12-135586-12202002-p4	2002 12 20	Pancromatic	1.0
	I-13-135587-12202002-p4	2002 12 20	Pancromatic	1.0
	I-14-135973-12202002-p4	2002 12 20	Pancromatic	1.0
	I-15-135590-09092003-p4	2003 09 09	Pancromatic	1.0
	I-16-135763-09092003-p4	2003 09 09	Pancromatic	1.0
	I-17-135592-09032003-p4	2003 09 03	Pancromatic	1.0
	I-18-135599-09092003-p4	2003 09 09	Pancromatic	1.0
	I-19-135600-09182003-p4	2003 09 18	Pancromatic	1.0
	I-20-135601-12032004-p4	2004 12 03	Pancromatic	1.0
	I-21-135602-09032003-p4	2003 09 03	Pancromatic	1.0
	I-22-135603-08272003-p4	2003 08 27	Pancromatic	1.0
	I-23-135604-08272003-p4	2003 08 27	Pancromatic	1.0
	I-24-135605-03152003-p4	2003 03 15	Pancromatic	1.0
	I-25-135606-11072002-p4	2002 11 07	Pancromatic	1.0
	I-26-135607-05062003-p4	2003 05 06	Pancromatic	1.0
	I-27-135608-09172003-p4	2003 09 17	Pancromatic	1.0
	I-28-136077-02022002-p4	2002 02 02	Pancromatic	1.0
	I-29-135610-11252002-p4	2002 11 25	Pancromatic	1.0
	I-30-136075-02022004-p4	2004 02 02	Pancromatic	1.0
	I-31-135614-07112002-p4	2002 07 11	Pancromatic	1.0
	I-32-135616-04022003-p4	2003 04 02	Pancromatic	1.0
	I-33-135617-02042003-p4	2003 02 04	Pancromatic	1.0
	I-36-140079-05252002-p_	2002 05 25	Pancromatic	1.0
	I-37-140080-02152002-p4	2002 02 15	Pancromatic	1.0
	I-38-140088-12202003-p4	2003 12 20	Pancromatic	1.0
	I-40-140089-03232003-p_	2003 03 23	Pancromatic	1.0
	I-41-140090-12312003-p4	2003 12 31	Pancromatic	1.0
	I-42-140091-03182003-p4	2003 03 18	Pancromatic	1.0
	I-43-140093-01302003-p4	2003 01 30	Pancromatic	1.0
	I-44-140095-07192002-p4	2002 07 19	Pancromatic	1.0
	I-44-140095-08132002-p4	2002 08 13	Pancromatic	1.0
	I-45-140097-05172002-p4	2002 05 17	Pancromatic	1.0
	I-46-140099-03052002-p_	2002 03 05	Pancromatic	1.0
	I-46-140099-03282000-p4	2000 03 28	Pancromatic	1.0

Table e: Topographic maps (1:100 000) used for landform mapping of the southern AOI

Topographic mapping Agency	Date edition/revision	Number/code	Scale	Scanning resolution (dpi)
Defense Mapping Agency - USA	1970/1990	Sa-38-02	1:100,000	72
	1970/1990	Sa-38-01	1:100,000	72
	1970/1990	Nb-38-140	1:100,000	72
	1970/1990	Nb-38-139	1:100,000	72
	1970/1990	Nb-38-138	1:100,000	72
	1970/1990	Nb-38-136	1:100,000	72
	1970/1990	Nb-38-135	1:100,000	72
	1970/1990	Nb-38-134	1:100,000	72
	1970/1990	Nb-38-133	1:100,000	72
	1970/1990	Nb-38-128	1:100,000	72
	1970/1990	Nb-38-127	1:100,000	72
	1970/1990	Nb-38-126	1:100,000	72
	1970/1990	Nb-38-124	1:100,000	72
	1970/1990	Nb-38-116	1:100,000	72
	1970/1990	Nb-38-115	1:100,000	72
	1970/1990	Nb-38-114	1:100,000	72
	1970/1990	Nb-38-112	1:100,000	72
	1970/1990	Nb-38-103	1:100,000	72
	1970/1990	Na-38-99	1:100,000	72
	1970/1990	Na-38-98	1:100,000	72
	1970/1990	Na-38-97	1:100,000	72
	1970/1990	Na-38-90	1:100,000	72
	1970/1990	Na-38-89	1:100,000	72
	1970/1990	Na-38-88	1:100,000	72
	1970/1990	Na-38-86	1:100,000	72
	1970/1990	Na-38-85	1:100,000	72
	1970/1990	Na-38-8	1:100,000	72
	1970/1990	Na-38-79	1:100,000	72
	1970/1990	Na-38-78	1:100,000	72
	1970/1990	Na-38-77	1:100,000	72
	1970/1990	Na-38-74	1:100,000	72
	1970/1990	Na-38-73	1:100,000	72
	1970/1990	Na-38-7	1:100,000	72
	1970/1990	Na-38-68	1:100,000	72
	1970/1990	Na-38-67	1:100,000	72
	1970/1990	Na-38-66	1:100,000	72
	1970/1990	Na-38-65	1:100,000	72
	1970/1990	Na-38-62	1:100,000	72
	1970/1990	Na-38-61	1:100,000	72
	1970/1990	Na-38-57	1:100,000	72
	1970/1990	Na-38-56	1:100,000	72
	1970/1990	Na-38-55	1:100,000	72
	1970/1990	Na-38-54	1:100,000	72
	1970/1990	Na-38-51	1:100,000	72
	1970/1990	Na-38-50	1:100,000	72
	1970/1990	Na-38-49	1:100,000	72
	1970/1990	Na-38-45	1:100,000	72
	1970/1990	Na-38-44	1:100,000	72
	1970/1990	Na-38-43	1:100,000	72
	1970/1990	Na-38-42	1:100,000	72
	1970/1990	Na-38-40	1:100,000	72
	1970/1990	Na-38-39	1:100,000	72
	1970/1990	Na-38-38	1:100,000	72
	1970/1990	Na-38-37	1:100,000	72
	1970/1990	Na-38-33	1:100,000	72
	1970/1990	Na-38-32	1:100,000	72
	1970/1990	Na-38-31	1:100,000	72
	1970/1990	Na-38-28	1:100,000	72
	1970/1990	Na-38-27	1:100,000	72
	1970/1990	Na-38-26	1:100,000	72
	1970/1990	Na-38-25	1:100,000	72
	1970/1990	Na-38-20	1:100,000	72
	1970/1990	Na-38-19	1:100,000	72
	1970/1990	Na-38-16	1:100,000	72
	1970/1990	Na-38-15	1:100,000	72
	1970/1990	Na-38-14	1:100,000	72

	1970/1990	Na-38-135	1:100,000	72
	1970/1990	Na-38-134	1:100,000	72
	1970/1990	Na-38-13	1:100,000	72
	1970/1990	Na-38-124	1:100,000	72
	1970/1990	Na-38-123	1:100,000	72
	1970/1990	Na-38-122	1:100,000	72
	1970/1990	Na-38-112	1:100,000	72
	1970/1990	Na-38-111	1:100,000	72
	1970/1990	Na-38-110	1:100,000	72
	1970/1990	Na-38-101	1:100,000	72
	1970/1990	Na-38-100	1:100,000	72
	1970/1990	Na-38-04	1:100,000	72
	1970/1990	Na-38-03	1:100,000	72
	1970/1990	Na-38-02	1:100,000	72
	1970/1990	Na-38-01	1:100,000	72
	1970/1990	Na-37-84	1:100,000	72
	1970/1990	Na-37-72	1:100,000	72
	1970/1990	Na-37-60	1:100,000	72
	1970/1990	Na-37-48	1:100,000	72

Table f: Geological maps at different scales, used for landform mapping of the southern AOI

Author/s	Title	Scale	Year	Scanning resolution (dpi)
Abbate E., Sagri M. & Sassi F.P. (editors)	Geological map of Somalia – Warqadda cilmiga dhulka ee Soomaaliya	1:1,500,00	1994	600
Abdirahman, H.M., Abdirahim, M.M., Ali Kassim, M., Bakos, F., Carmignani, L., Conti, P., Fantozzi, P.L., Sassi, P.F.	Geological map of the Bay Region (Southern Somalia)	1:250,000	1994	600
Ali Kassim, M., Carmignani, L., Fantozzi, P.L., Conti, P.	Geological map of the Gedo and Bakool Region (Southern Somalia)	1:250,000	1994	600

Regarding the grey literature, many reports and internal document were consulted. Most of them were relevant to the southern part of the country (Jubba and Shabelle river basins) while only very broad scale landform references were found for the north-western part of the country.

Table g: List of grey literature used for preliminary landform analysis of both northern and southern AOI.

Report title	Date	Author/Editor	Publisher
Agricultural and Water Surveys for Somalia; Volume III - Landforms and Soils	1966	FAO	FAO
Landform mapping using satellite remote sensing data, Somalia	1999	Rosati, I.	FAO
Hydrogeology and water quality of Northern Somalia	1986	Faillace, C. & Faillace, E.R.	GTZ
Hydrogeology and water quality of Central Somalia	1986	Faillace, C. & Faillace, E.R.	GTZ
Hydrogeology and water quality of Southern Somalia	1986	Faillace, C. & Faillace, E.R.	GTZ
Water resources, engineering, soils and agriculture	1969		Hunting Technical Services Ltd; Sir M. Macdonald & Partners, Consulting Engineers
The Horn of Africa 1925	1925	Dardano, A.	UNDOS
Soil of East Africa - Users Guide	1997	FAO	FAO
Report on geological work carried out in connection with the proposed subsurface dam; Hargeisa: October 1954- May 1955	1955	Hunt, J.,A.	Somali Democratic Republic
Comprehensive groundwater development project interim report	1985	Louise Berger Int'l inc; Roscoe Moss Inc	Water Development Agency, Somali Democratic Republic
Report on geological exploratory boreholes and test wells in the N-W region of Somali Democratic Republic	1983	Chinese Well Drilling Team (China National Complete Plant Export Corporation)	China National Complete Plant Export Corporation
Somalia geophysical survey report	2003	Cooperazione Italiana	Cooperazione Italiana
General survey of the Somaliland protectorate 1944-1950	1952	Hunt, J. A.;	E.P.S Shirley
Somalia environmental CD		UNDP	UNDP
Water resources assessment, water supply, planning and rehabilitation surveys; Hydrological and geophysical surveys; Gedo region Somalia January/February 2002	2002	Gajsek, C.	International Committee of the Red Cross/Crescent
Project for the water control and management of the Shebelle River	1969	Hunting Technical Services Ltd., Land Use and Agricultural Consultants; Sir M. Macdonald & Partners, Consulting Engineers	FAO
North-West Region Agricultural Development Project. Feasibility Study and Technical Assistance	1982	Sogreah Consulting Engineers	Sogreah
Surface and underground water resources of Shabelle river	1964	Faillace, C.	Somali Republic, Ministry of Public Works & Communication
Brief description of major drainage basins affecting Somalia with reference to surface water resources	1989	Kameer , D.	UNDP
Rainfall, environment and water resource development in Somaliland and the Sahel	1999	Print, C.	Imperial College, University of London
Shabelle river valley	1990	Ministry of	Ministry of Agriculture,

		Agriculture, Republic of Somali (Somali Republic)	Republic of Somali (Somali Republic)
A Natural Resources Monitoring and Evaluation System for Somalia; Can remote sensing play a role?	1997	Amuyunzu, C	IUCN-The World Conservation Union - Eastern African Regional Office
Jowhar sugar estate: Drainage and reclamation study	1978	Mott MacDonald Group	Mott MacDonald Group

Annex 5: Digital Terrain Analysis products for the two AOI

The values of parameters adopted in our classification using LandSerf, TPI and SPI software packages are explained here. TAS does not require the setting of thresholds. Thresholds definition was decided after several trials executed separately for the northern and southern area of interest. The two areas differ significantly in morphology which created the need to find different thresholds. At the end of an intensive trial period we had determined the following values.

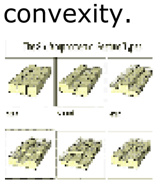
Threshold values for the different software, used in the two different AOI

AOI	Software	Parameter	Threshold values
Northern Area			
	LandSerf		
		Window size:	11 pixels (990 m)
		Distance decay:	1 pixel
	TPI & SPI		
		Neighborhood type:	*circle*
		Units:	*meters*
		Radius:	*300 meters*
Southern Area			
	LandSerf		
		Window size:	9 pixels (270 m)
		Distance decay:	3 pixel
	TPI & SPI		
		Neighborhood type:	*circle*
		Units:	*meters*
		Radius:	*800 m*

LandSerf software includes a detailed and useful helpfile with links to the theory behind the classification performed. Jo Wood's webpage incorporates an extract from his PhD thesis (Wood, 1996) where the landform classification is explained in detail:

"One of the overall aims of this study has been is to develop a set of tools that describe the general geomorphometry of a surface. On the whole, this is quite distinct from the process of identifying specific geomorphometric features such as cirques or floodplains. There are however, a number of surface features that may be used both in the specific and general geomorphometric identification process. These features can be thought of as *morphometric* features rather than *geomorphometric* in that they are characteristic of any surface".

The most widely used set of morphometric characteristics, is the subdivision of all points on a surface into one of *pits*, *peaks*, *channels*, *ridges*, *passes* and *planes* (see Figure below). The names of these features suggest a geomorphological interpretation, but they may be unambiguously described in terms of rates of change of three orthogonal components (see Table below). Note that the components *x* and *y* are not necessarily parallel to the axes of the DEM, but are in the direction of maximum and minimum profile convexity.



* The six categories of morphometric feature illustrated by the relationship between a central DEM cell and its eight neighbors.

Morphometric Features described by second derivatives.

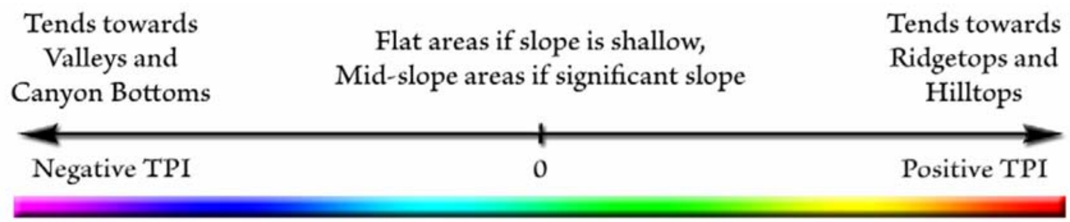
Feature name	Derivative expression	Description
Peak	$\frac{\partial^2 z}{\partial x^2} > 0, \quad \frac{\partial^2 z}{\partial y^2} > 0$	Point that lies on a local convexity in all directions (all neighbors lower).
Ridge	$\frac{\partial^2 z}{\partial x^2} > 0, \quad \frac{\partial^2 z}{\partial y^2} = 0$	Point that lies on a local convexity that is orthogonal to a line with no convexity/concavity.
Pass	$\frac{\partial^2 z}{\partial x^2} > 0, \quad \frac{\partial^2 z}{\partial y^2} < 0$	Point that lies on a local convexity that is orthogonal to a local concavity.
Plane	$\frac{\partial^2 z}{\partial x^2} = 0, \quad \frac{\partial^2 z}{\partial y^2} = 0$	Points that do not lie on any surface concavity or convexity.
Channel	$\frac{\partial^2 z}{\partial x^2} < 0, \quad \frac{\partial^2 z}{\partial y^2} = 0$	Point that lies in a local concavity that is orthogonal to a line with no concavity/convexity.
Pit	$\frac{\partial^2 z}{\partial x^2} < 0, \quad \frac{\partial^2 z}{\partial y^2} < 0$	Point that lies in a local concavity in all directions (all neighbors higher).

The identification of these features forms the basis of the techniques described in this chapter for describing DEM characteristics. The first two sections describe how the features themselves may be identified. The third section extends the technique to extract multi-scale behaviour. The final section concentrates on the hydrological implications of the layout of these morphometric features. It is worth noting at this stage that this classification produces point-based categories (pits, passes, and peaks), two line-based categories (channels and ridges) and one area-based category (planes)" (Wood, 1996).

The same degree of detail is offered by Jenness (2005) on the TPI extension running under ArcView software (http://www.jennessent.com/arcview/tpi.htm). where he offers a clear explanation of the TPI and SPI classification: "Andrew Weiss presented a very interesting and useful poster at the 2001 ESRI International User Conference describing the concept of Topographic Position Index (TPI) and how it could be calculated (Weiss 2001; see also Guisan *et al*. 1999 and Jones *et al*. 2000). Using this TPI at different scales, plus slope, users can classify the landscape into both slope position (i.e. ridge top, valley bottom, mid-slope, etc.) and landform category (i.e. steep narrow canyons, gentle valleys, plains, open slopes, mesas, etc.).

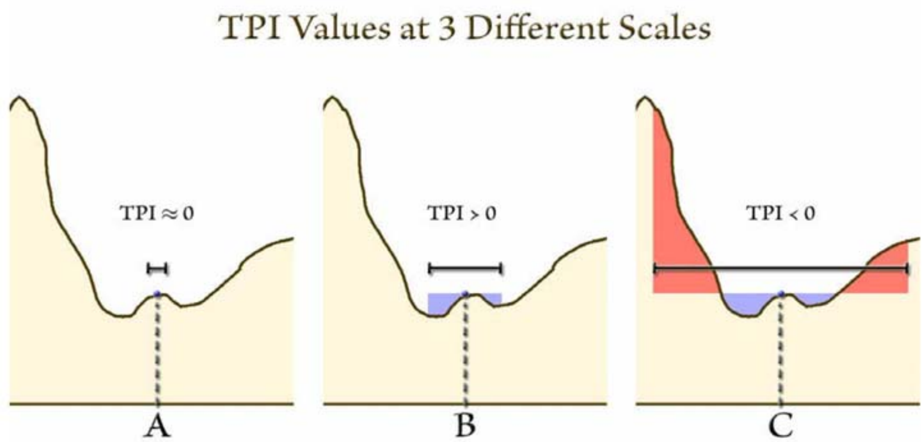
The algorithms are clever and fairly simple. The TPI is the basis of the classification system and is simply the difference between a cell elevation value and the average elevation of the neighborhood around that cell. Positive values mean the cell is higher than its surroundings while negative values mean it is lower.

The degree to which it is higher or lower, plus the slope of the cell, can be used to classify the cell into slope position. If it is significantly higher than the surrounding neighborhood, then it is likely to be at or near the top of a hill or ridge. Significantly low values suggest the cell is at or near the bottom of a valley. TPI values near zero could mean either a flat area or a mid-slope area, so the cell slope can be used to distinguish the two.



Scales and Neighborhoods: TPI is naturally very scale-dependent. The same point at the crest of a mountain range might be considered a ridgetop to a highway construction crew or a flat plain to a mouse. The classifications produced by this extension depend entirely on the scale you use to analyze the landscape.

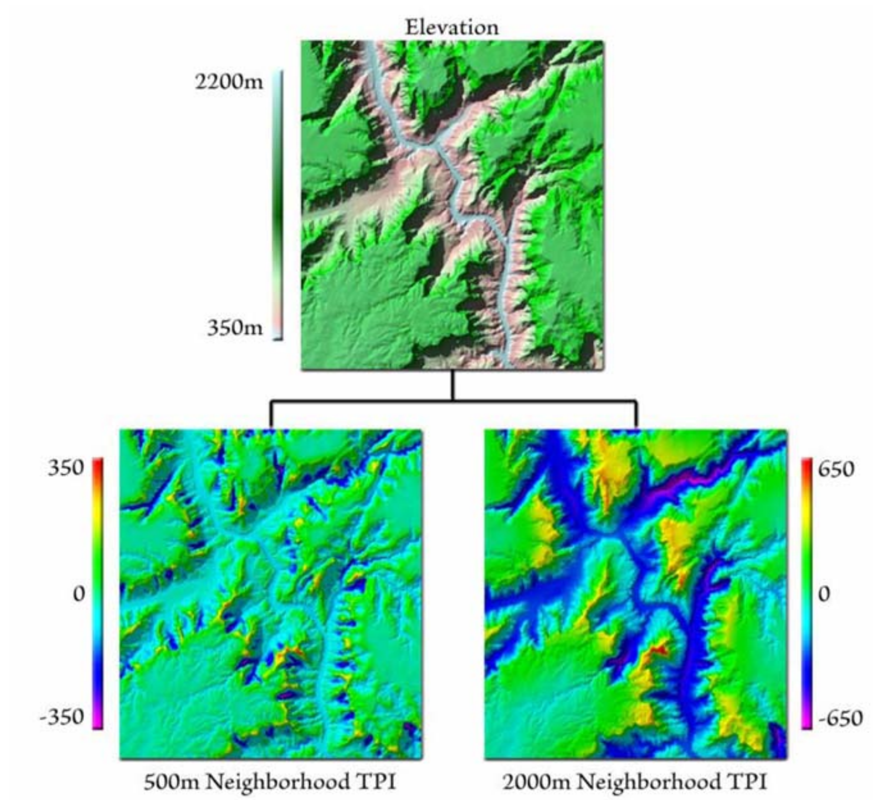
For example, in the illustration below, TPI is calculated for the same point on the landscape using three different scales. In each case, the point is located on top of a small hill set inside a larger valley. In Case A, the scale is small enough that the point is at about the same elevation as the entire analysis region so the TPI value would be approximately 0. In Case B, the analysis region is big enough to encompass the entire small hill, and the point is consequently much higher than its neighbors and has a correspondingly high TPI value. In Case C, the neighborhood includes the hills on either side of the valley, and therefore the point is lower than its neighbors and has a negative TPI value.



Users should consider carefully what scale is most relevant for the phenomenon being analyzed. If you are interested in topographic habitat characteristics of large, wide-ranging animals, you would likely define your landscape classifications in terms of large, distinctive topographic features. Cougars, for example, are likely to be much more influenced by a nearby ridgeline hundreds of feet high than by minor ripples and bumps on the landscape immediately surrounding them. Furthermore, a point on top of a small hill at the bottom of a canyon may be classified as a canyon bottom at one scale, or a hilltop at a different scale. Both are accurate and valid classifications, and the user must be responsible for knowing what scale is reasonable for their analysis.

Scale is determined by the neighborhood used in the analysis. The TPI values reflect the difference between the elevation in a particular cell and the average elevation of the cells around that cell. The neighborhood defines what cells are considered to be “around” that cell.

In the illustration below, TPI values were calculated using two different neighborhoods. The left example used a circular neighborhood with a 500 m radius, meaning that the TPI value for each cell reflected the difference between the elevation of that cell and the average elevation of all cells within 500 m of that cell. This neighborhood did a good job of identifying extreme values in the side drainages of the canyon. The example on the right used a circular neighborhood with a 2 000 m radius and did a much better job of highlighting the overall canyon system.



These examples used circular neighborhoods, but other options are available. Weiss' examples used annular (ring- or doughnut-shaped) neighborhoods where only cells within a specified distance range are considered. Some researchers use rectangular neighborhoods, although in most cases circular or annular neighborhoods are more reasonable.

Wedge-shaped neighborhoods are useful for restricting your analysis to a particular direction. Weiss' poster discusses some ideas for future research in which he plans to compare directional TPI values in order to distinguish saddles from flat areas, ridges from hilltops and valleys from local depressions, as well as identify the general aspect of landforms.

For sophisticated neighborhood delineation, you can also define exactly which local cells should be considered as a neighborhood. These are referred to as "irregular" neighborhoods in ESRI software, and this extension provides a means for designing these specific custom neighborhoods.

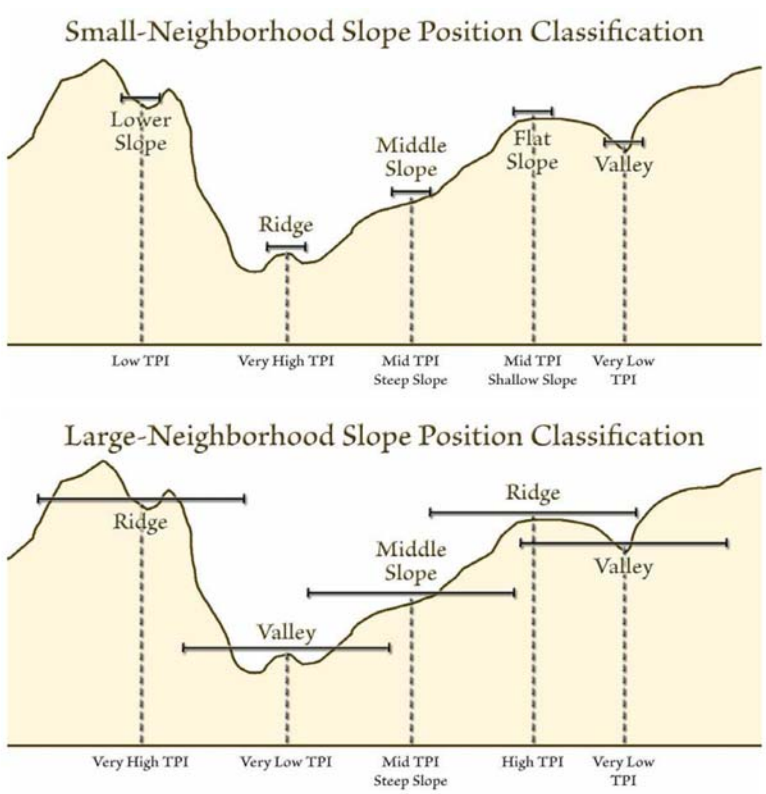
Classifying by Slope Position: TPI values can easily be classified into slope position classes based on how extreme they are and by the slope at each point. There are a couple of strategies you can take to do this.

The easiest way is simply to set threshold values for the TPI grids themselves (or for standardized TPI grids; see p. 122). TPI values above a certain threshold might be classified as ridgetops or hilltops, while TPI values below a threshold might be classified as valley bottoms or depressions. TPI values near 0 could be classified as flat plains (if the slope is near 0) or as mid-slope areas (if the slope is above a certain threshold).

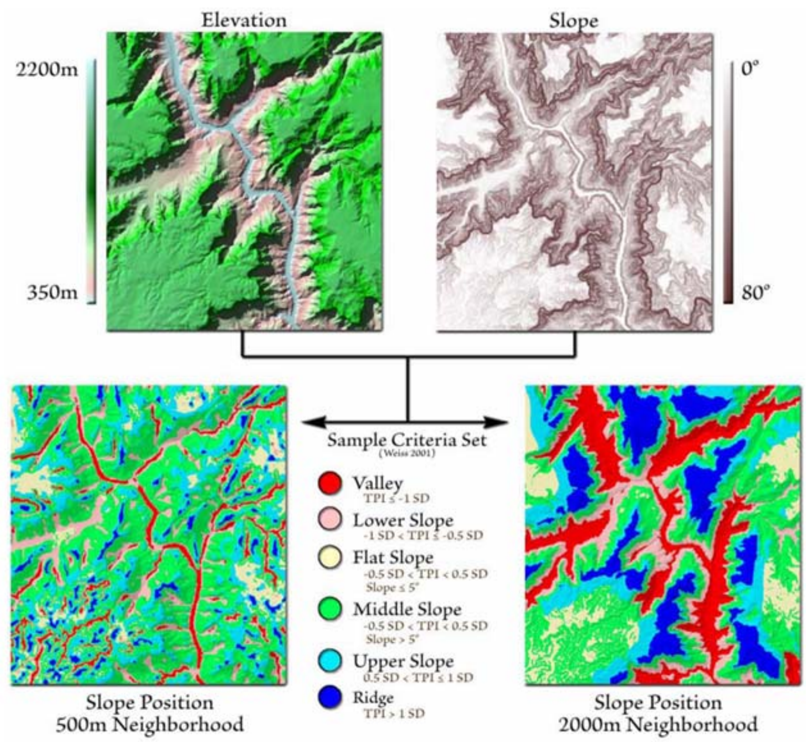
Dickson and Beier (in review) use this method in a study of the influences of topography on cougar movement.

A somewhat more sophisticated method, illustrated by Weiss in his poster, is to define threshold TPI values in terms of standard deviations from the elevation, which therefore take into account the variability of elevation values within that neighborhood. This means that grid cells with identical TPI values may be classified differently in different areas, depending on the variability in their respective neighborhoods. This method may or may not be useful in your analysis. You would use this method if you felt that cells with high neighborhood elevation variability should have to meet a higher TPI threshold in order to be classified into some category.

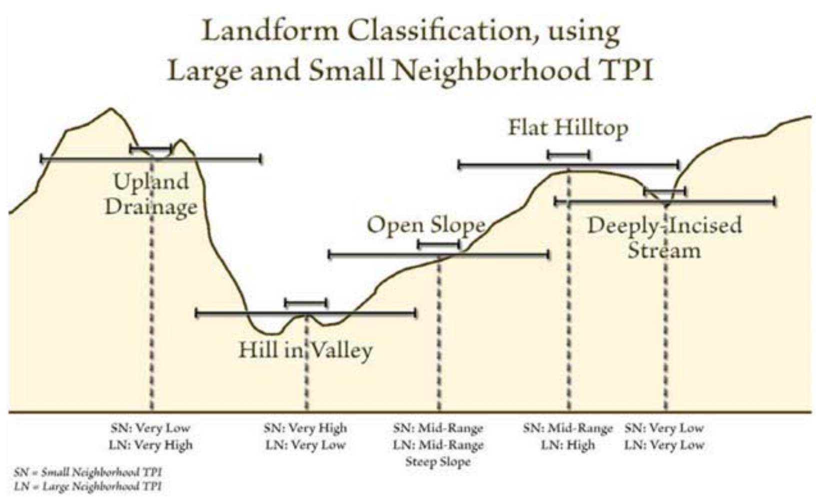
As with TPI values in general, neighborhood size is also a critical component of the Slope Position classification process. Small neighborhoods capture small and local hills and valleys while large neighborhoods capture larger-scale features.



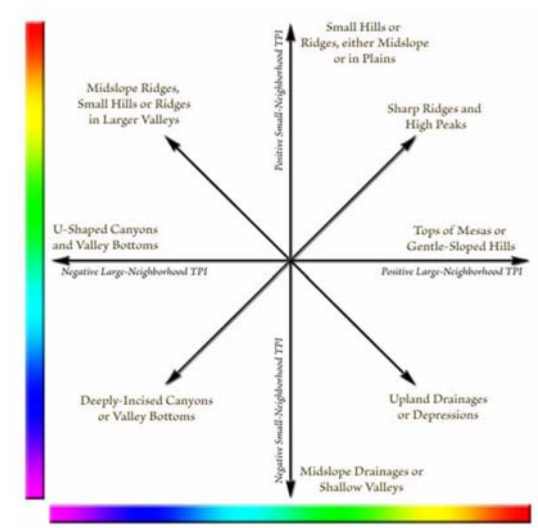
TPI values near 0 mean only that the elevation is close to the mean elevation of the neighborhood cells, and this could happen if that cell is in a flat area or if it is mid-slope somewhere. An easy way to distinguish between these two possibilities is to check the slope at that point. If the slope is near 0, then the point is probably on a flat area. A high slope value implies that the point is mid-slope somewhere. In his poster, Weiss demonstrates one possible classification process using both TPI and slope to generate a six-category Slope Position grid.



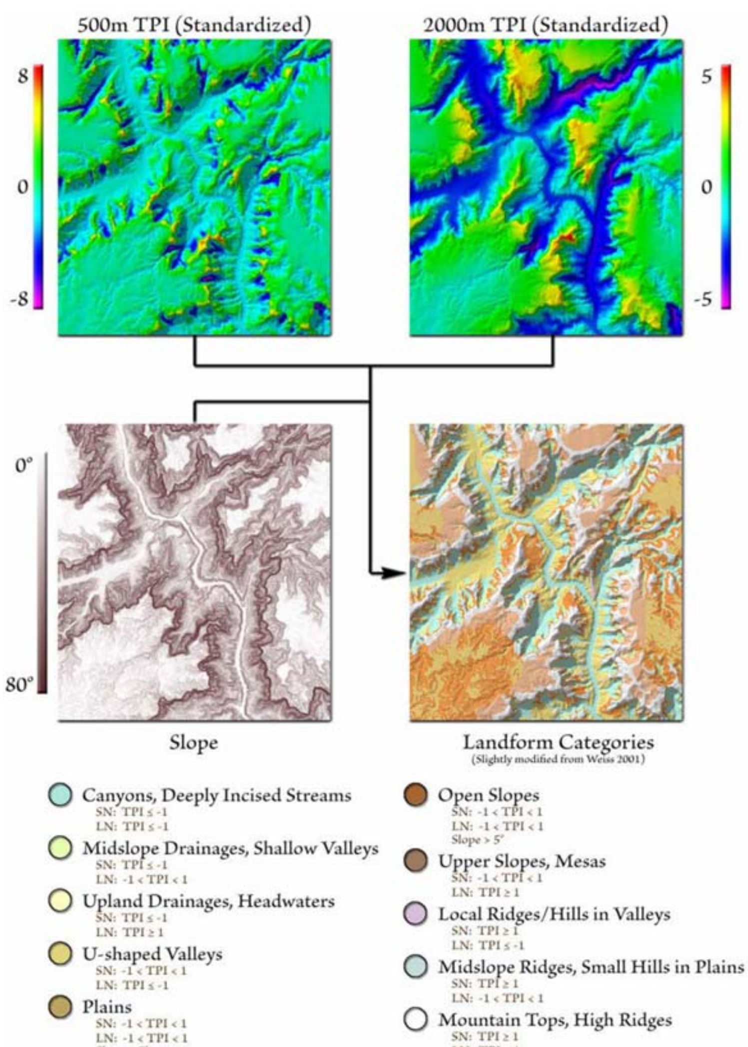
Classifying by Landform Category: Landform category can be determined by classifying the landscape using two TPI grids at different scales. The combination of TPI values from different scales suggest various landform types.



For example, a high TPI value in a small neighborhood, combined with a low TPI value in a large neighborhood, would be classified as a local ridge or hill in a larger valley, while a low small-neighborhood TPI plus a high large-neighborhood TPI would be classified as an upland drainage or depression.



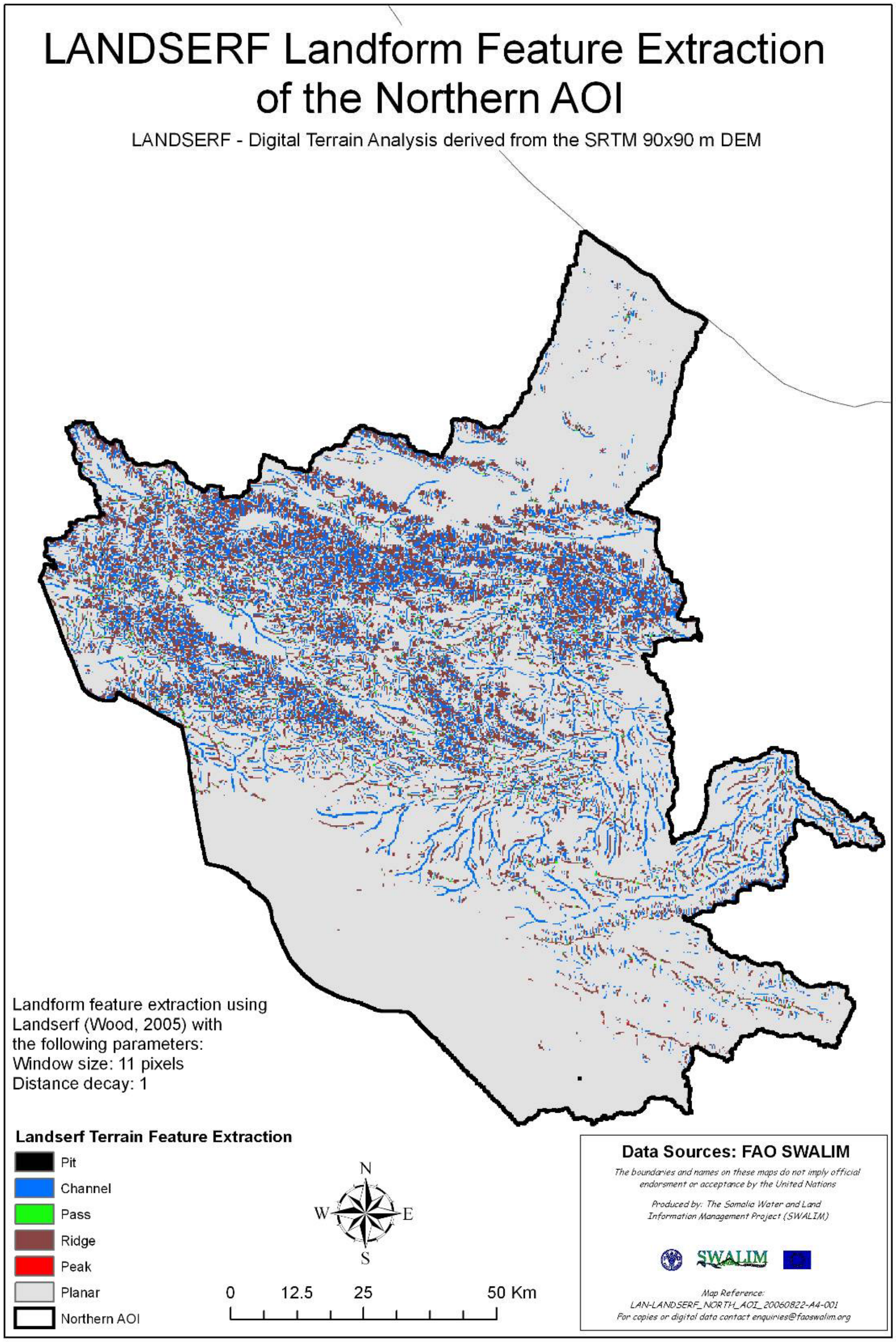
Weiss' poster provides examples demonstrating how two TPI grids and a slope grid can be used to identify canyons, mid-slope drainages, U-shaped valleys, plains, open slopes, upper slopes, mesas, mid-slope ridges and mountain tops.

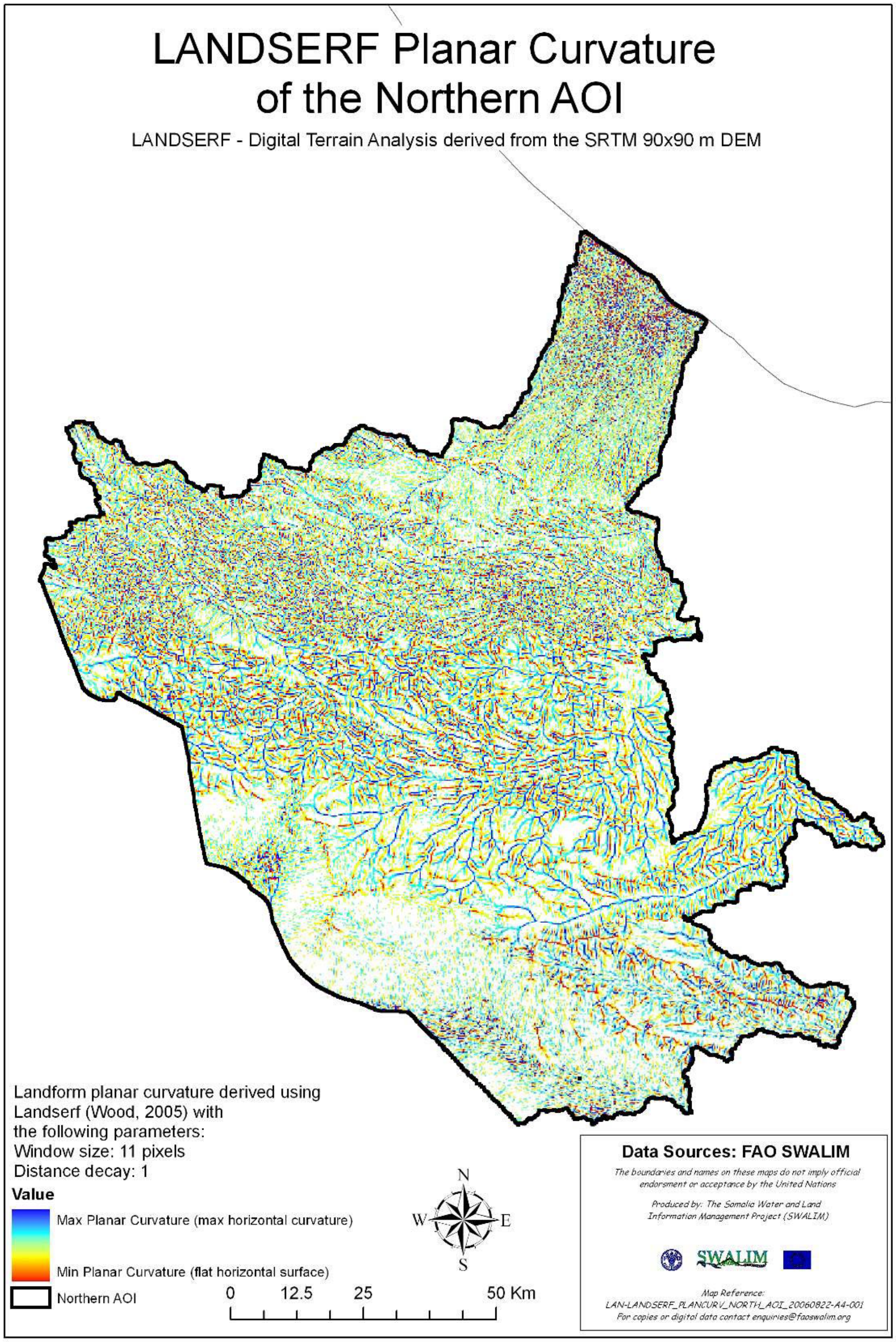


The last software used was TAS (Terrain Analysis Software) which is a stand-alone GIS application used specifically for geomorphological and hydrological applications of DEMs. Its potential lies in the fact that it allow the user to choose among the most-recognised algorithms published in the scientific literature to extract morphometric DEM parameters.

"TAS is designed to meet the research needs of environmental modellers and managers, while being simple enough to use in the classroom. Some geographic information systems (GIS) possess some of the capabilities required by hydrologists, geomorphologists, and other environmental researchers; however, these programs are usually prohibitively expensive. In addition, very few programs compile the number of functions available in TAS in one stand-alone package. Often, such programs rely on other GISs for visualization and standard spatial analysis. TAS can display both raster and vector types of geographic data, and possesses many of the standard spatial analysis function that the environmental modeller requires. The graphical user interface is designed with ease of use in mind. As such, TAS is ideal for lab exercises in introductory to advanced level courses in physical geography, geomorphology, hydrology, environmental science, and watershed management" (Lindsay, 2005).
http://www.jennessent.com/downloads/TPI_Documentation_online.pdf

Northern AOI




LANDSERF Planar Curvature
of the Northern AOI
LANDSERF - Digital Terrain Analysis derived from the SRTM 90x90 m DEM
Landform planar curvature derived using
Landserf (Wood, 2005) with
the following parameters:
Window size: 11 pixels
Distance decay: 1
Value
Max Planar Curvature (max horizontal curvature)
Min Planar Curvature (flat horizontal surface)
Northern AOI
N
W
E
S
0
12.5
25
50 Km
Data Sources: FAO SWALIM
The boundaries and names on these maps do not imply official endorsment or acceptance by the United Nations
Produced by: The Somalia Water and Land Information Management Project (SWALIM)
SWALIM
Map Reference:
LAN-LANDSERF_PLANCURV_NORTH_AOI_20060822-A4-001
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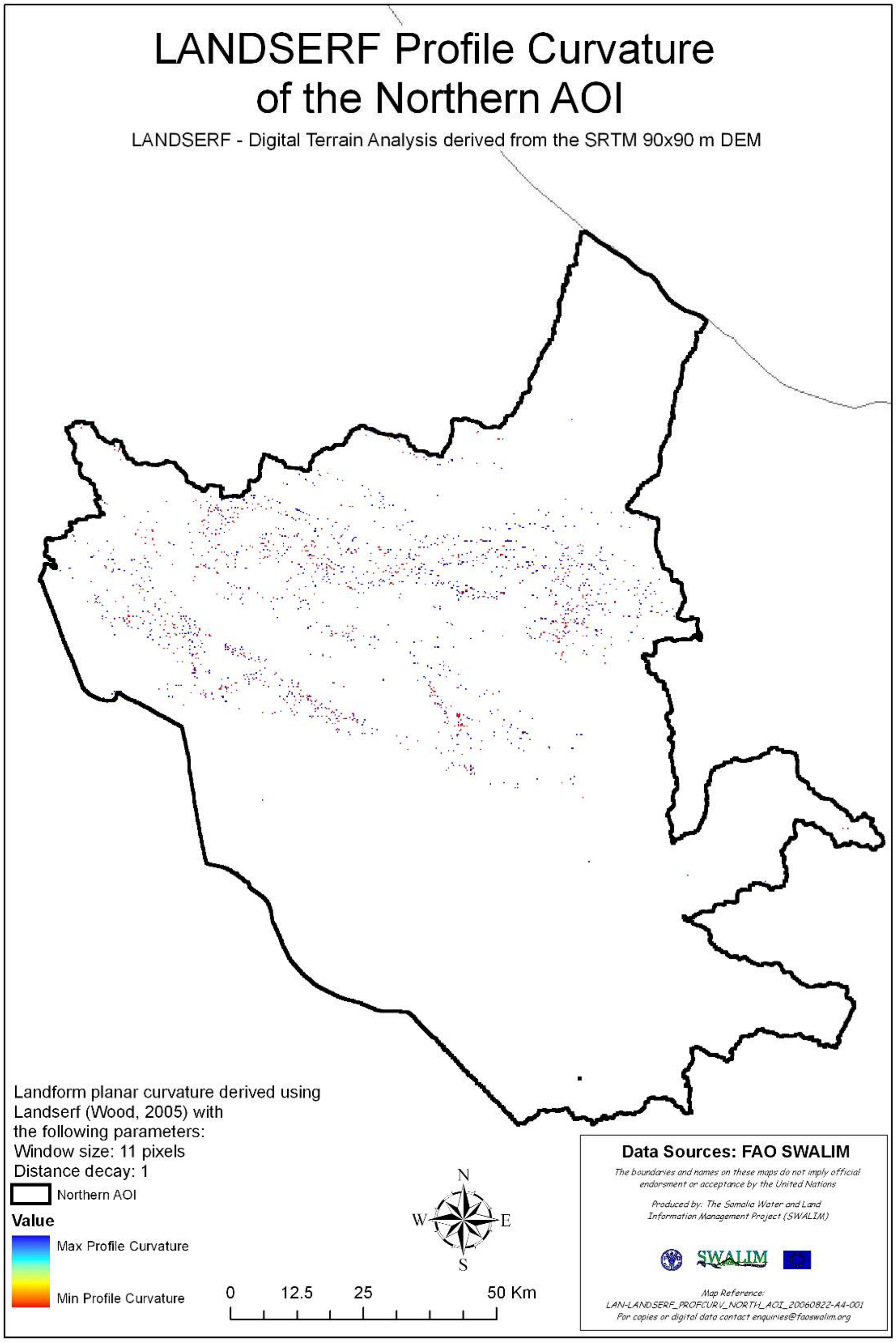
LANDSERF Profile Curvature
of the Northern AOI
LANDSERF - Digital Terrain Analysis derived from the SRTM 90x90 m DEM
Landform planar curvature derived using
Landserf (Wood, 2005) with
the following parameters:
Window size: 11 pixels
Distance decay: 1
Northern AOI
Value
Max Profile Curvature
Min Profile Curvature
N
W
E
S
0
12.5
25
50 Km
Data Sources: FAO SWALIM
The boundaries and names on these maps do not imply official
endorsment or acceptance by the United Nations
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SWALIM
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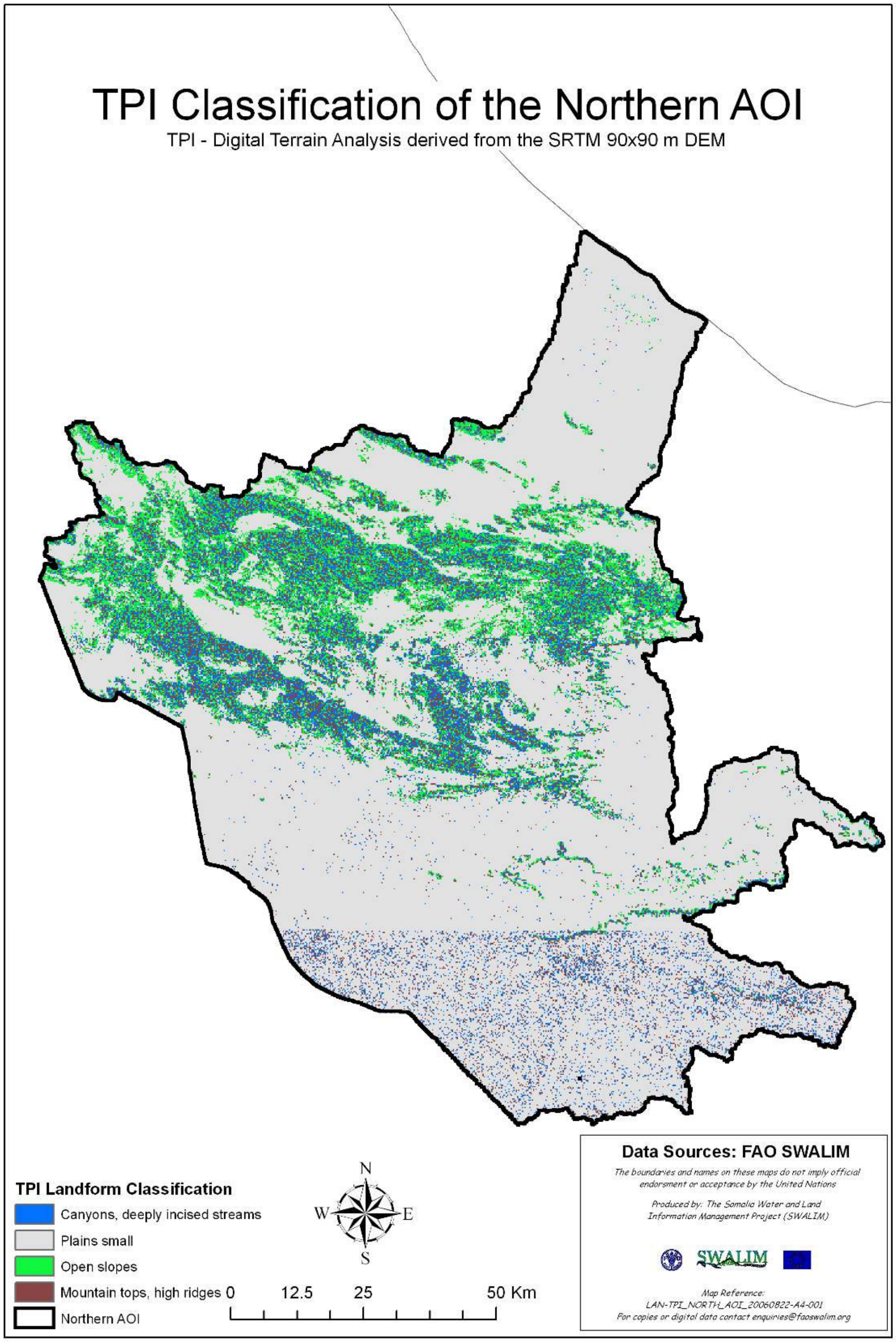
TPI Classification of the Northern AOI
TPI - Digital Terrain Analysis derived from the SRTM 90x90 m DEM
TPI Landform Classification
Canyons, deeply incised streams
Plains small
Open slopes
Mountain tops, high ridges
Northern AOI
N
S
W
E
0
12.5
25
50 Km
Data Sources: FAO SWALIM
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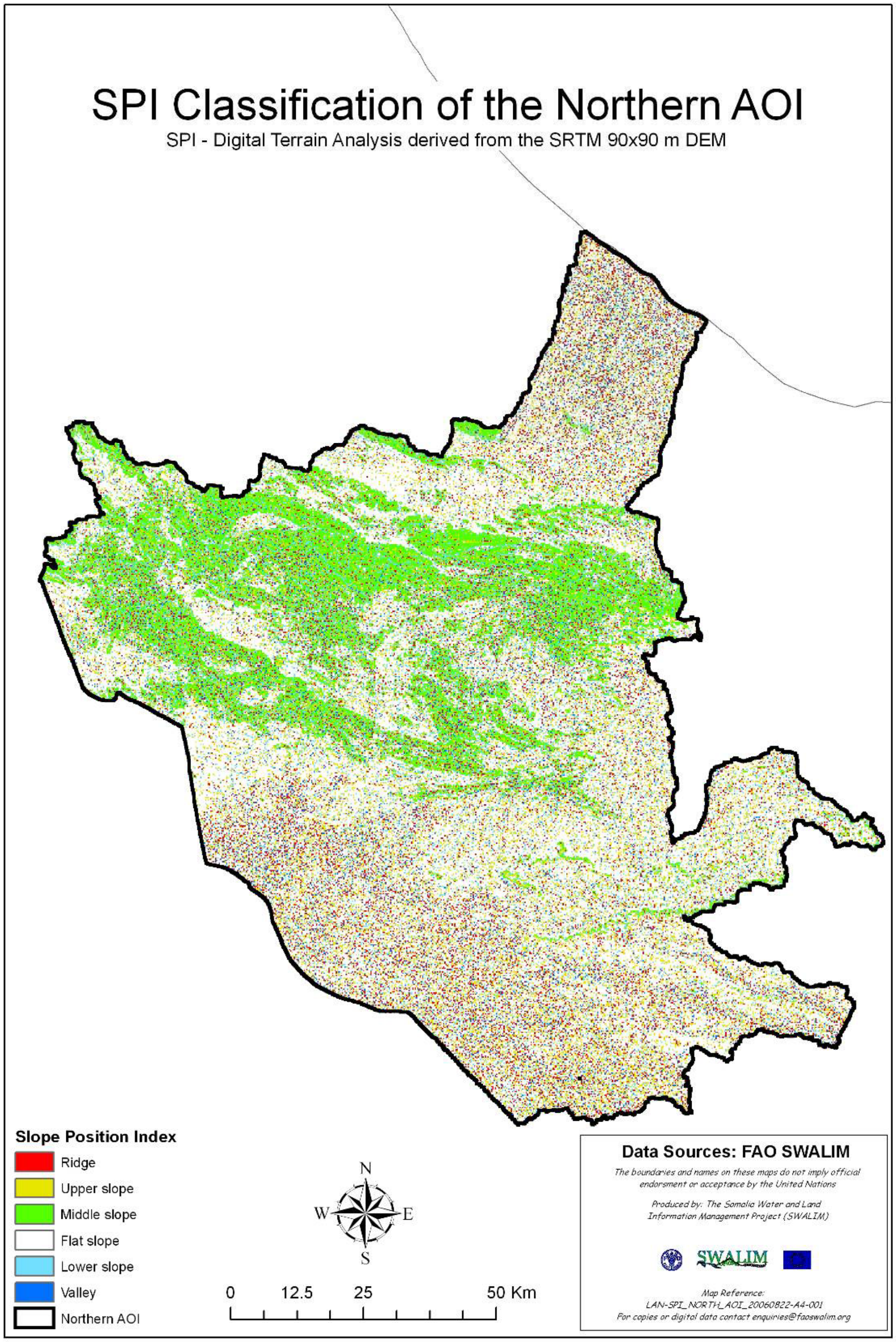
SPI Classification of the Northern AOI
SPI - Digital Terrain Analysis derived from the SRTM 90x90 m DEM
Slope Position Index
Ridge
Upper slope
Middle slope
Flat slope
Lower slope
Valley
Northern AOI
N
W
E
S
0
12.5
25
50 Km
Data Sources: FAO SWALIM
The boundaries and names on these maps do not imply official endorsment or acceptance by the United Nations
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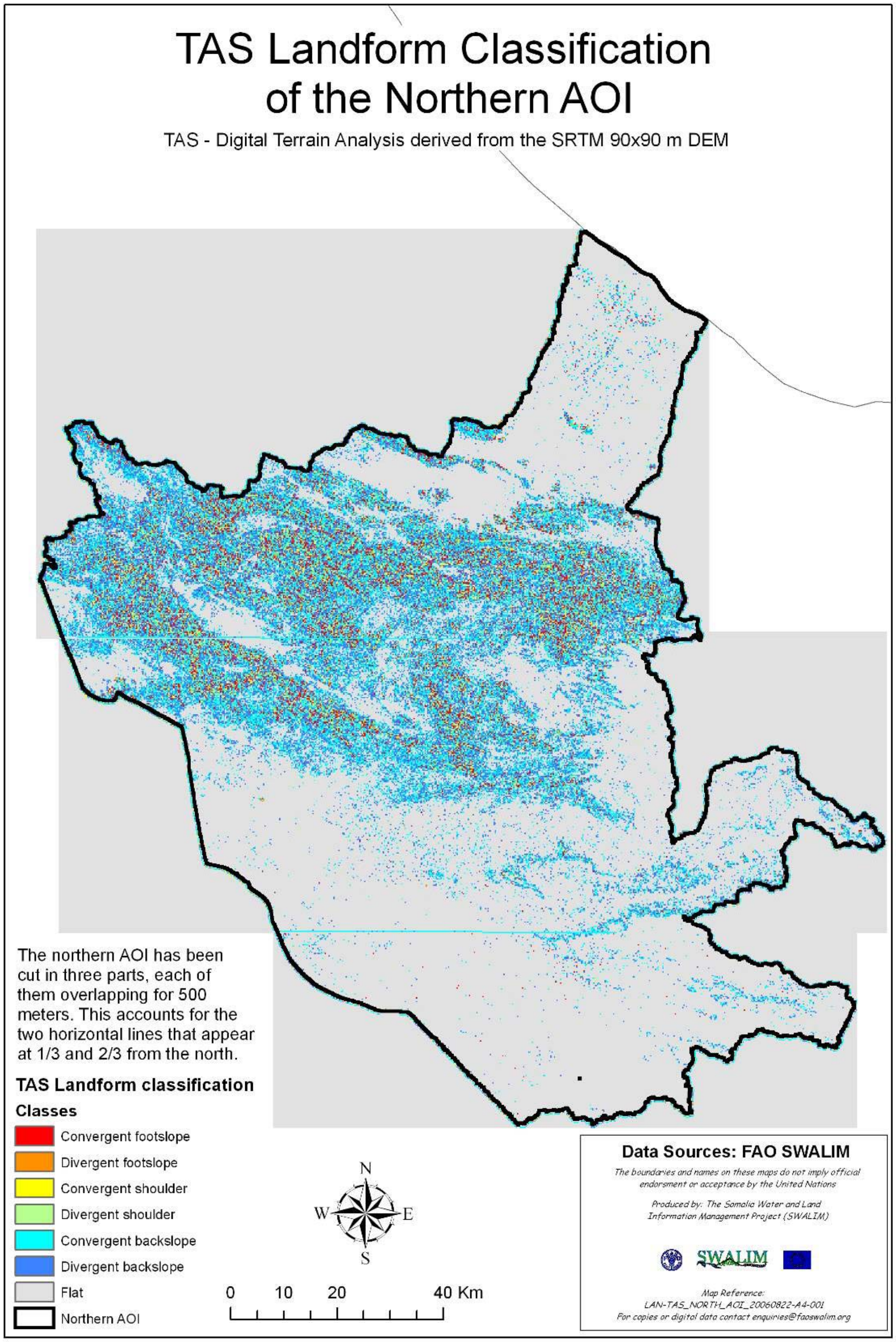
TAS Landform Classification
of the Northern AOI
TAS - Digital Terrain Analysis derived from the SRTM 90x90 m DEM
The northern AOI has been cut in three parts, each of them overlapping for 500 meters. This accounts for the two horizontal lines that appear at 1/3 and 2/3 from the north.
TAS Landform classification
Classes
Convergent footslope
Divergent footslope
Convergent shoulder
Divergent shoulder
Convergent backslope
Divergent backslope
Flat
Northern AOI
N
W
E
S
0
10
20
40 Km
Data Sources: FAO SWALIM
The boundaries and names on these maps do not imply official endorsment or acceptance by the United Nations
Produced by: The Somalia Water and Land Information Management Project (SWALIM)
Map Reference:
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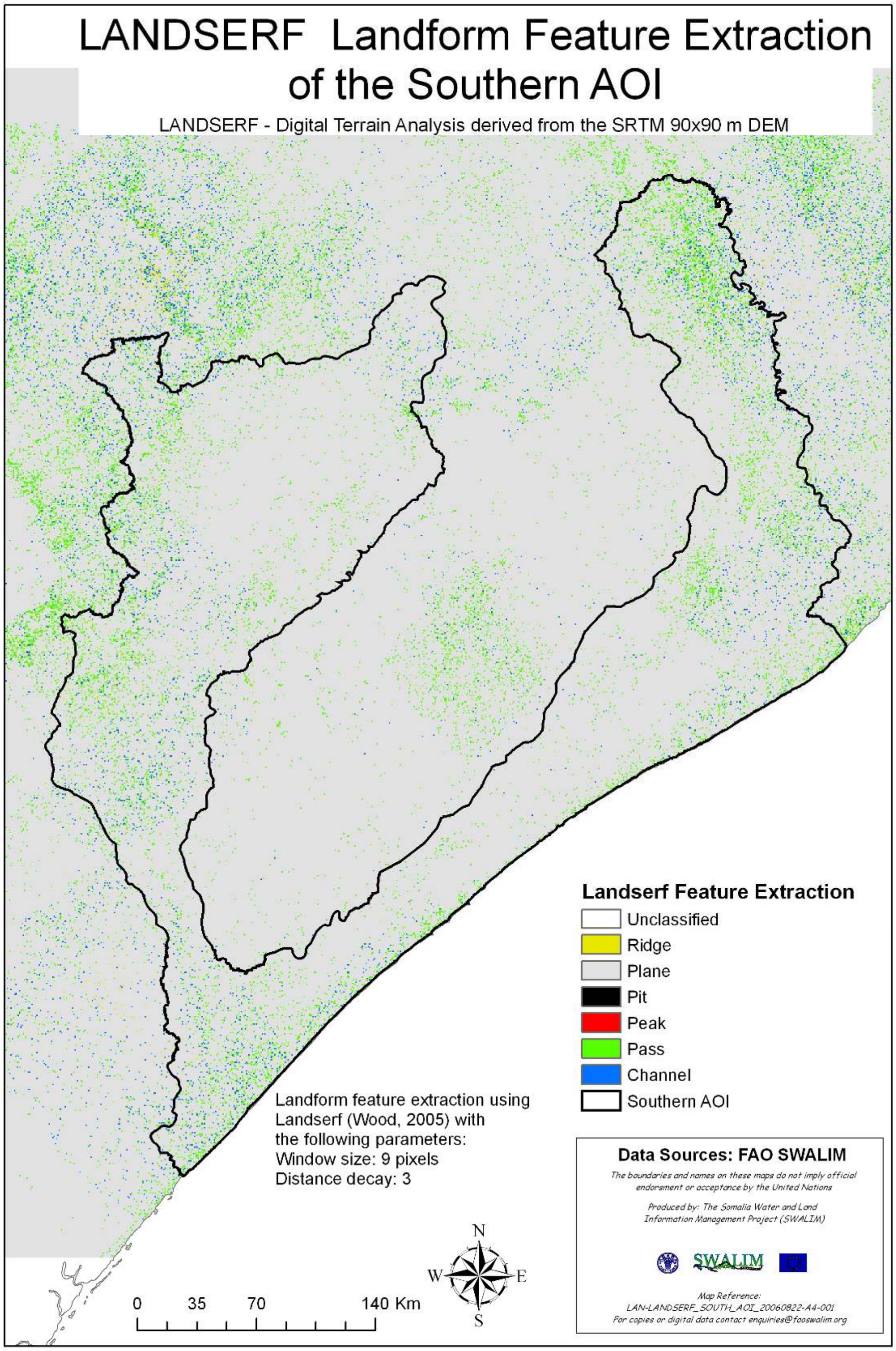
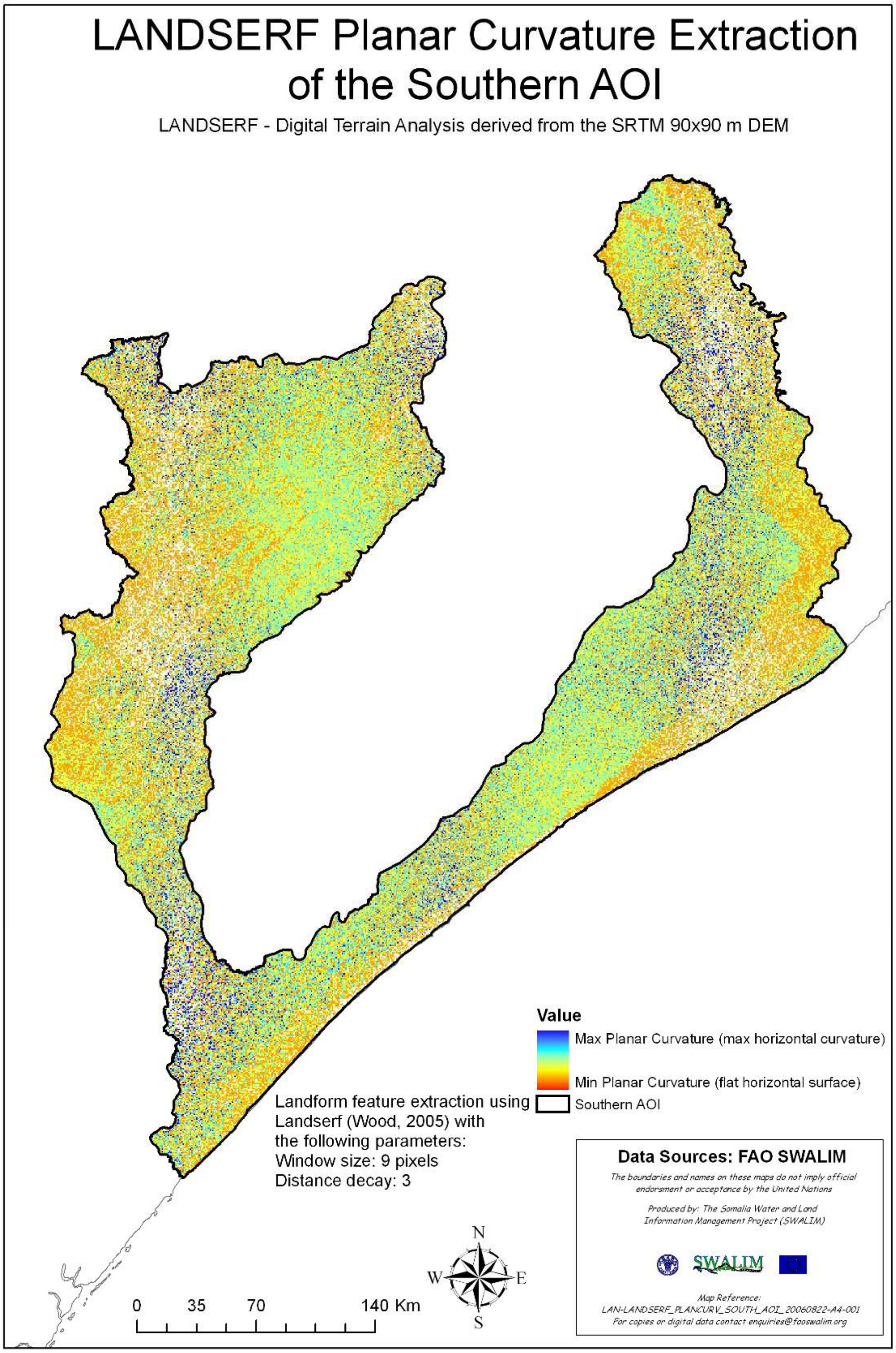
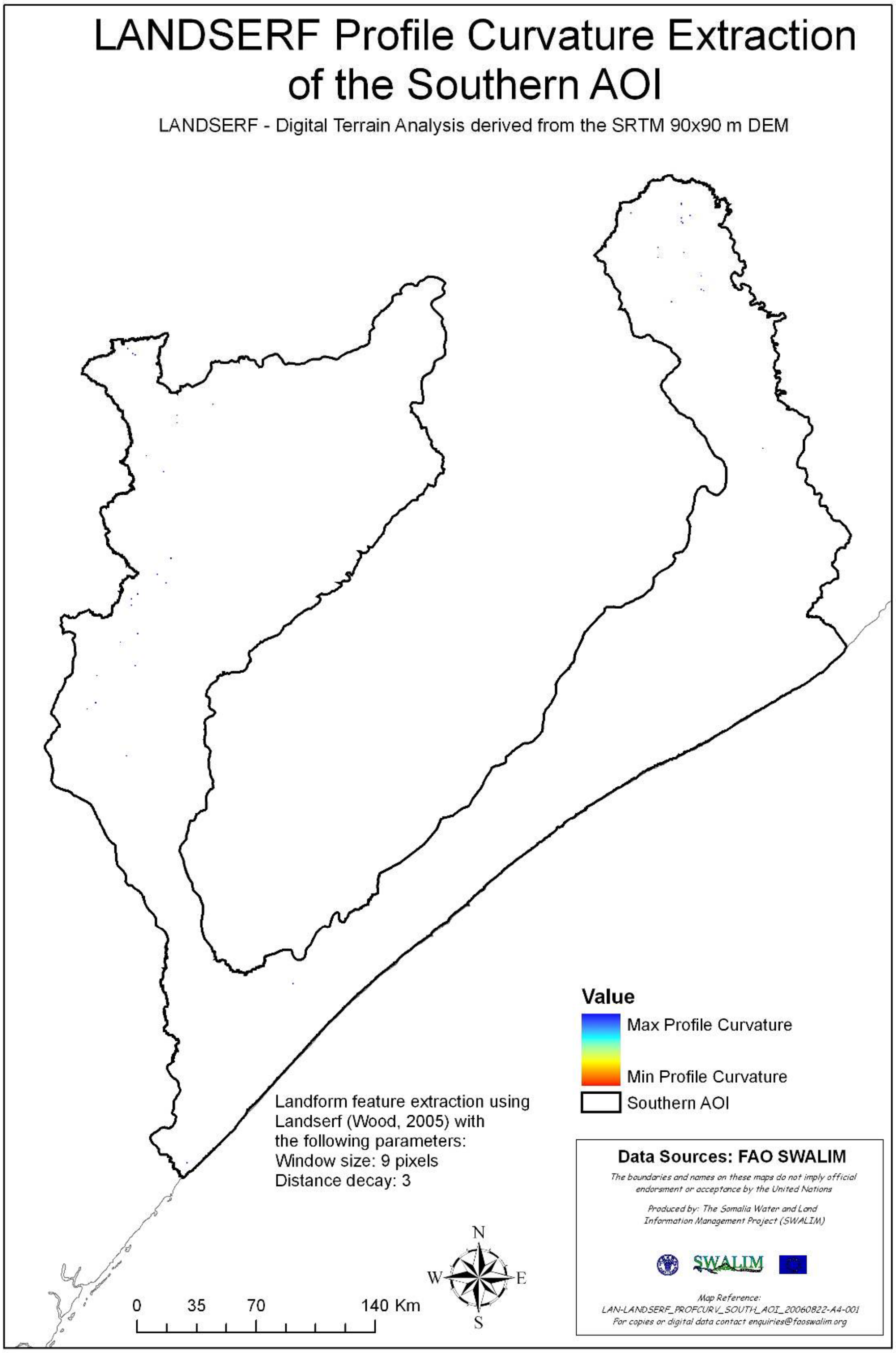
Southern AOI




LANDSERF Planar Curvature Extraction of the Southern AOI
LANDSERF - Digital Terrain Analysis derived from the SRTM 90x90 m DEM
Value
Max Planar Curvature (max horizontal curvature)
Min Planar Curvature (flat horizontal surface)
Southern AOI
Landform feature extraction using Landserf (Wood, 2005) with the following parameters:
Window size: 9 pixels
Distance decay: 3
Data Sources: FAO SWALIM
The boundaries and names on these maps do not imply official endorsment or acceptance by the United Nations
Produced by: The Somalia Water and Land Information Management Project (SWALIM)
SWALIM
Map Reference:
LAN-LANDSERF_PLANCURV_SOUTH_AOI_20060822-A4-001
For copies or digital data contact enquiries@faoswalim.org
N
W
E
S
0
35
70
140 Km


LANDSERF Profile Curvature Extraction of the Southern AOI
LANDSERF - Digital Terrain Analysis derived from the SRTM 90x90 m DEM
Value
Max Profile Curvature
Min Profile Curvature
Southern AOI
Landform feature extraction using Landserf (Wood, 2005) with the following parameters:
Window size: 9 pixels
Distance decay: 3
Data Sources: FAO SWALIM
The boundaries and names on these maps do not imply official endorsment or acceptance by the United Nations
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SWALIM
Map Reference:
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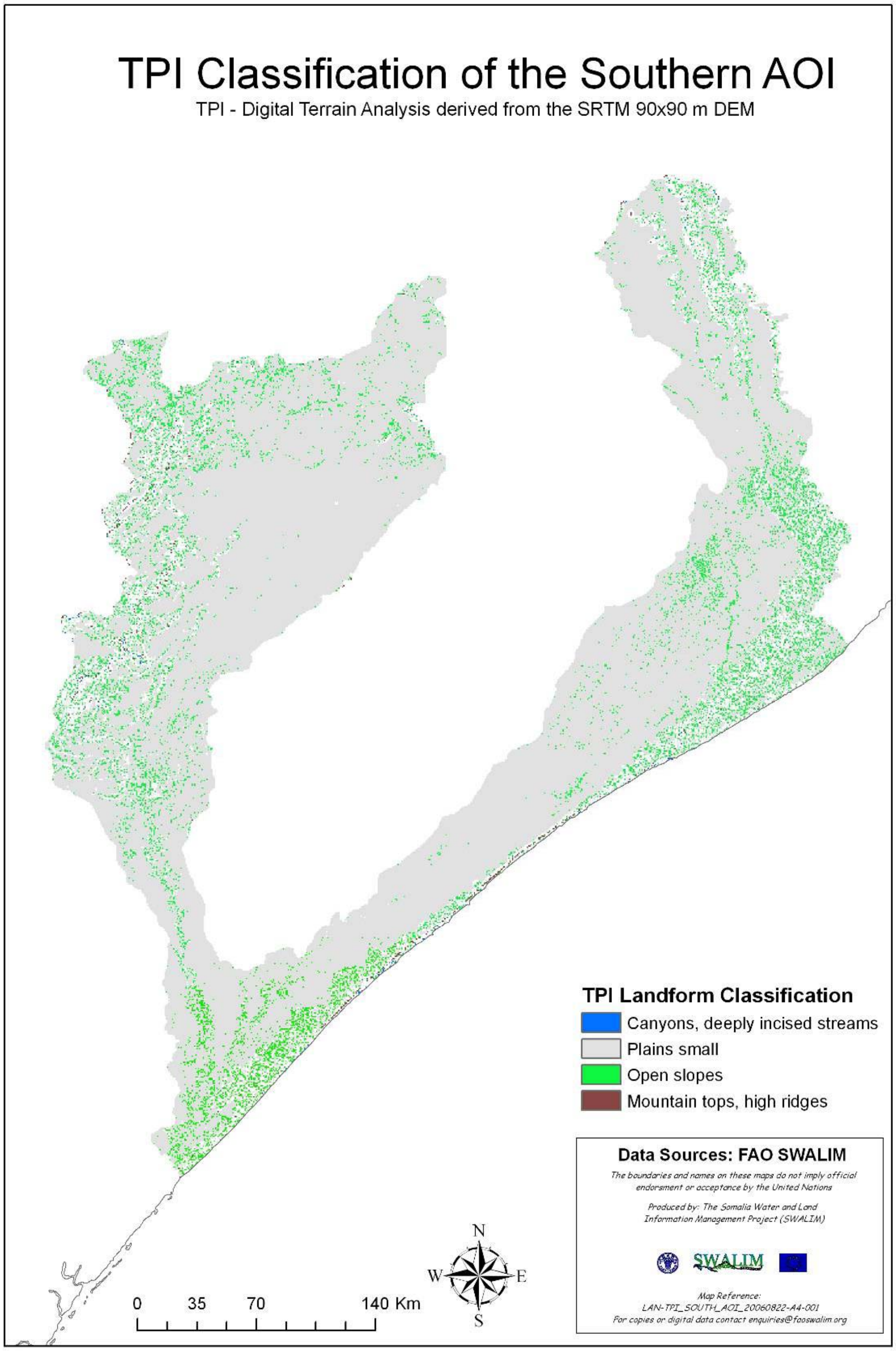
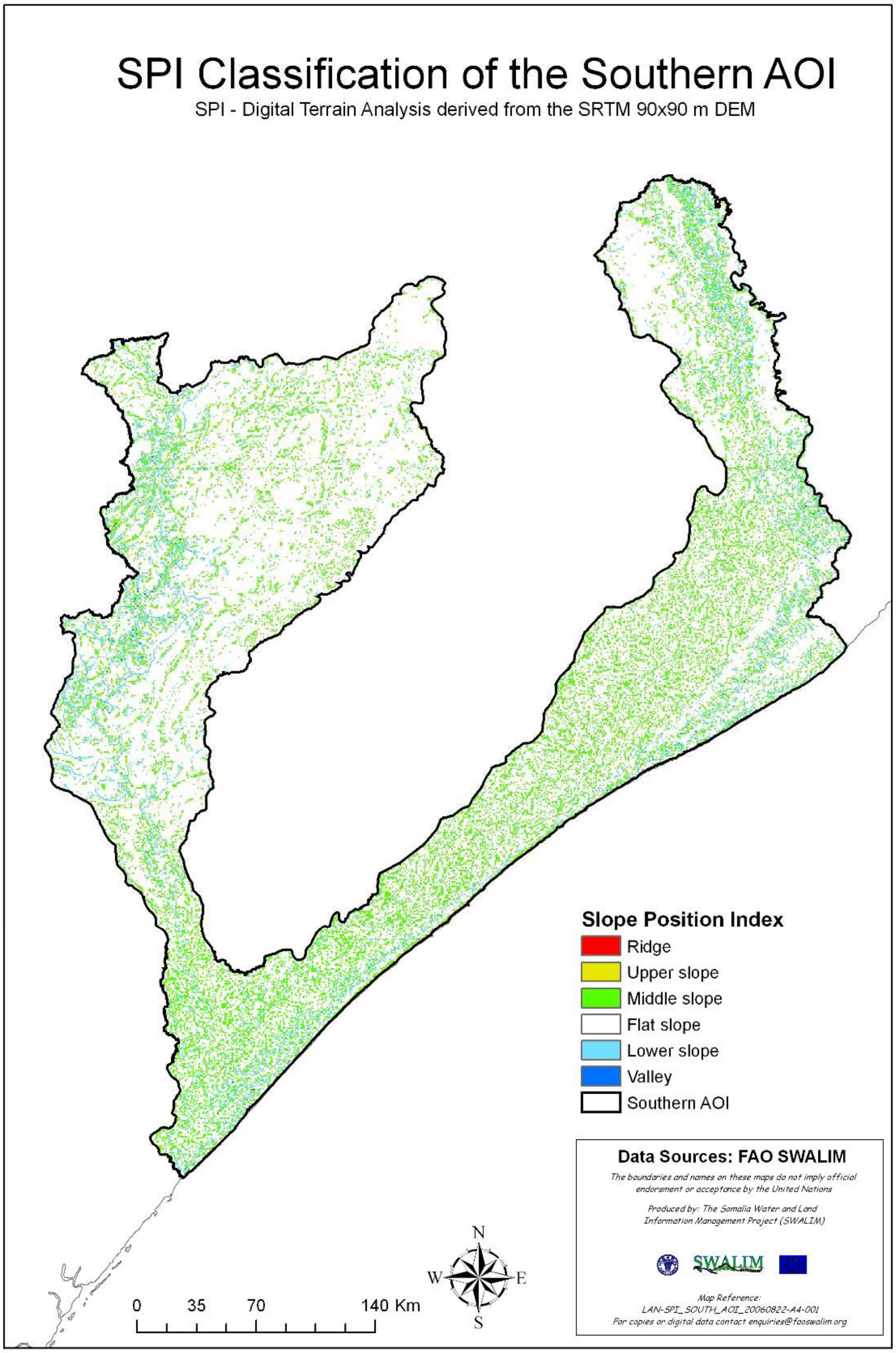
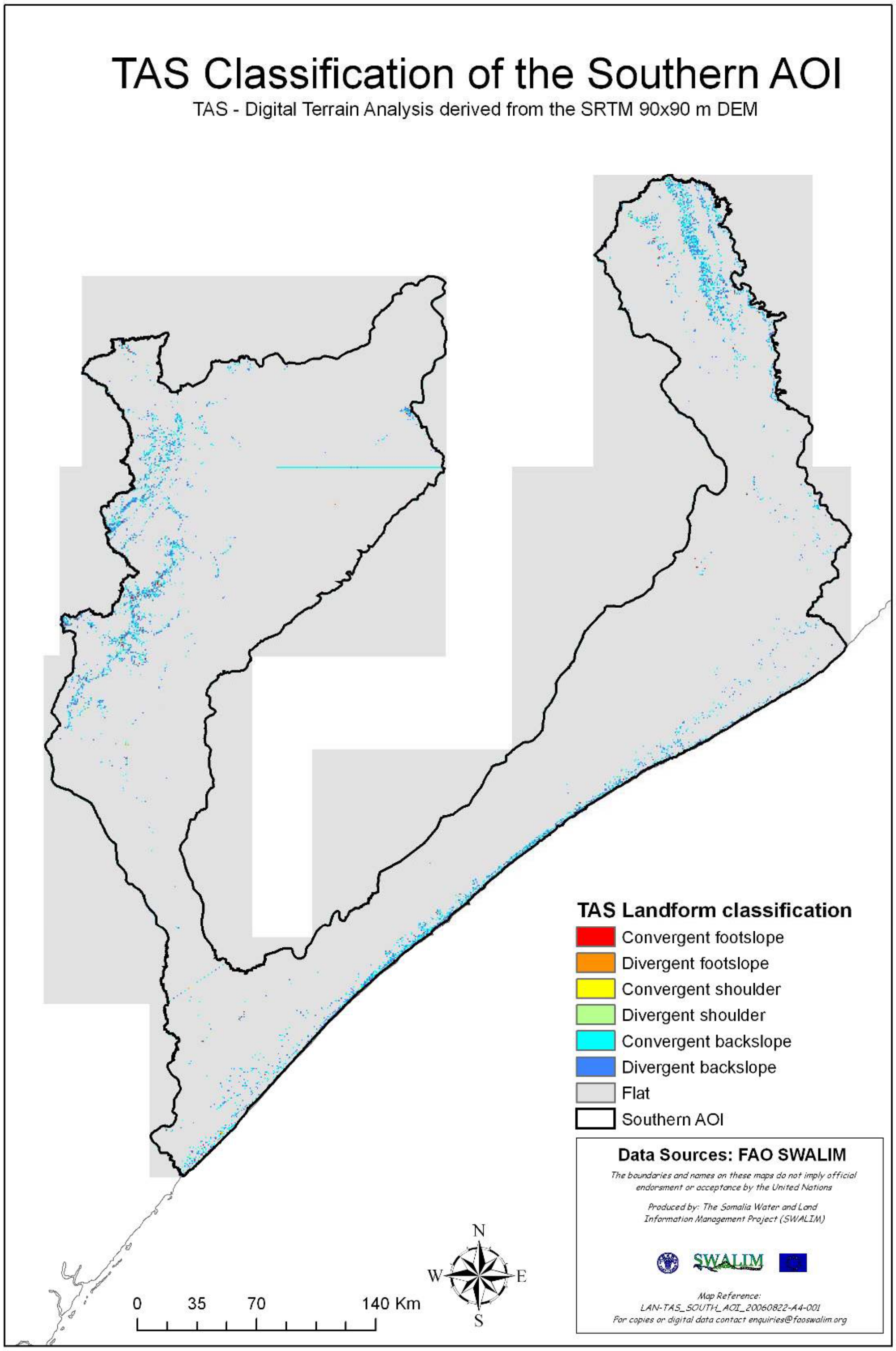
N
W
E
S
0
35
70
140 Km


TPI Classification of the Southern AOI
TPI - Digital Terrain Analysis derived from the SRTM 90x90 m DEM
TPI Landform Classification
Canyons, deeply incised streams
Plains small
Open slopes
Mountain tops, high ridges
Data Sources: FAO SWALIM
The boundaries and names on these maps do not imply official endorsment or acceptance by the United Nations
Produced by: The Somalia Water and Land Information Management Project (SWALIM)
SWALIM
Map Reference:
LAN-TPI_SOUTH_AOI_20060822-A4-001
For copies or digital data contact enquiries@faoswalim.org
N
W
E
S
0
35
70
140 Km


SPI Classification of the Southern AOI
SPI - Digital Terrain Analysis derived from the SRTM 90x90 m DEM
Slope Position Index
Ridge
Upper slope
Middle slope
Flat slope
Lower slope
Valley
Southern AOI
Data Sources: FAO SWALIM
The boundaries and names on these maps do not imply official endorsment or acceptance by the United Nations
Produced by: The Somalia Water and Land Information Management Project (SWALIM)
SWALIM
Map Reference:
LAN-SPI_SOUTH_AOI_20060822-A4-001
For copies or digital data contact enquiries@faoswalim.org
N
W
E
S
0
35
70
140 Km


TAS Classification of the Southern AOI
TAS - Digital Terrain Analysis derived from the SRTM 90x90 m DEM
TAS Landform classification
Convergent footslope
Divergent footslope
Convergent shoulder
Divergent shoulder
Convergent backslope
Divergent backslope
Flat
Southern AOI
Data Sources: FAO SWALIM
The boundaries and names on these maps do not imply official endorsment or acceptance by the United Nations
Produced by: The Somalia Water and Land Information Management Project (SWALIM)
SWALIM
Map Reference:
LAN-TAS_SOUTH_AOI_20060822-A4-001
For copies or digital data contact enquiries@faoswalim.org
N
W
E
S
0
35
70
140 Km

Annex 6: Fieldwork Pictures

LANDFORMS

Picture 1: North-East of Hargeisa: panoramic view of the mesas, extending from the main plateau (GPS point 017).

Picture 2: North-East of Hargeisa (road Hargeisa-Berbera): panoramic view northwards from top of mesa. Note pond in middle of the picture (GPS point 017).

Picture 3: North-east of Hargeisa: two isolated mesas emerging from the denudational surface

Picture 4: South of Borama: granite inselbergs emerging from the denudational surface.

Picture 5: North of Borama, toward Bown: sedimentary ridges (foreground) and very stony surface with shrubs.

Picture 6: East of Borama: Ridges of metamorphic rocks emerging from the valley. Stony surface close to the road, vegetated surface far from the road.

Picture 7: Between Borama and Bown: IFAD water reservoir with livestock and people collecting water (see Annex 6). Sedimentary ridges in the background.

Picture 8: From Bown to Borama: wide, flat-floored valley surrounded by metamorphic ridges

Picture 9: Between Borama and Gebiley: *togga* with boulders in its bed and strong bank erosion on its sides (landslides, mainly toppling, are visible in the near right *togga* walls).

Picture 10: Between Borama and Gebiley: dry *togga* crossing. Note high percentage of big boulders in the *togga* bed, testifying to high water energy during the rains. This picture was taken during the rainy season.

Picture 11: Between Gebiley and Hargeisa: water in a *togga* due to an isolated, contemporaneous rainy event in the upper catchment. Note the sunny conditions at the *togga* crossing point.

LITHOLOGIES

Picture 12: North-east of Hargeisa: a block of limestone with chert. Note the desert varnishing on the chert and fracturation of the black

Picture 13: South of Hargeisa: big nodule of chert within limestone. Note the effect of weathering and fracturation on the chert nodule

Picture 14: North of Hargeisa: sandstone parent material of soils in this area. The sandstone is highly weathered and very poorly cohesive. It contains some calcium carbonate nodules

Picture 15: North of Borama: outcrop of schist (metamorphic rock composed of micas and/or amphibole) highly fracturated and easily erodable (note debris at base)

Picture 16: North-East of Borama: alluvial deposits exposed in a natural profile along a *togga* side. Note different sizes of the blocks and boulders and the fairly thick soil cover on top. All have been eroded by fluvial activity

Picture 17: Jurassic Limestones outcrop north of Borama: effect of weathering (chemical and physical degradation) on the limestone surface, combined with a high degree of fracturation in angular blocks.

Picture 18: East of Borama: results of chemical weathering and fracturation on the calcium carbonate-rich sandstone of this area. Note deep action of weathering on more erodable calcareous (grey) veins. All calcium carbonate so dissolved was found in soils surrounding this outcrop

Picture 19: North of Borama: metamorphic rocks (migmatites and granitoids) with very high fracturation and degradation on the side of a mountainous *togga.*