TERRAIN ANALYSIS OF IROB LAND AND ITS RELEVANCE TO NATURAL RESOURCES MANAGEMENT, IROB, NORTHERN ETHIOPIA

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By

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Abstract

This study is about Irob land in northern Ethiopia. The geographical location is between 14°22′12.37″N, 39°28′58.13″E and 14°40′52.58″N, 39°59′04.39″E. Irob is also the name that stands for one ethnic minority that resides in Irob land.

Irob is the land of extreme topography and wide altitudinal range with very limited cultivable land. The altitude ranges from 150m to 3200m. The area coverage is estimated to 930sqkm and houses about 20000 people. Livestock was used to be the main socioeconomic base during early ages, yet with its decline in productivity a transformation to Agro-pasturalsim has taken place. The main challenge with this transformation was shortage of cultivable land which finally led the Irobs to come out with interesting land husbandry innovations like 'Daldal' and 'Setan-Maduwa' as a solution.

This paper is about digital terrain analysis of Irob land. The paper attempts to generate major terrain parameter groups like morphmetric, hydrological and climatic. Finally, the study attempts to relate the relevance and importance of the result to natural resources management in the region.

A contour generated Digital Elevation Model (DEM) was used as a main input to generate all the necessary terrain parameters. Data set obtained from Tigray regional planning bureau is the main input to this study. Script package developed for ILWIS 3.2 was used to automate those terrain parameters. Various DEM improvement steps were carried out before the use of it as an in put for farther analysis. A number of farther analysis and finishing steps were also carried out to optimize the extrapolation of the contained information in these generated sets of maps. All the most important steps and methods followed are attached as summarized using flowcharts.

In morphometric terrain analysis part a number of value maps such as slope, aspect, altitude and curvatures were generated. Most of these value maps were sliced and under gone a number of steps to come up with meaning full class maps, like slope class, altitude class, aspect class map.
A suitability map for potential resettlement and cultivation was computed using altitude and Slope class maps primarily. Similarly, maps on hydrological and Climatic terrain parameters were generated and analyzed. In hydrological terrain parameter maps information about Stream locations, ridges and erosion risk sites was visualized.

Climatic terrain parameters such as temperature index and slope irradiance maps were produced and analyzed. These maps contain information on the gradient and scale of variability in energy balance. As it was able to visualize temperature map has an inverse relationship to altitude, while Slope Irradiance / insolatoion map mainly varies with slope angle and aspect in relation to the sun angle and source of illumination.

Information, in the latter two categories of parameter maps, is indicative information (not real figure) and more of qualitative in nature. Thus, these maps are meant mainly for visual interpretation until they are quantified via field verification. But they are very helpful for hypothesis development and fieldwork planning for verification. After verification, it is possible to reinterpret to generate diverse information on microclimate, vegetation, hydrology, erosion and the likes.

Acknowledgement

My sincere gratitude goes to the Government of the Netherlands that covered my study cost through ITC with out which this study wouldn't be possible.

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ACRONYMS

DTA = Digital Terrain Analysis
DEM/DTM = Digital Elevation/Terrain Model/Modeling
PLANC = Plan Curvature
PRFILEC = Profile Curvature
CTI = Compound Topographic Index
SPI = Stream Power Index
STI = Sediment Transport Index
INRDA = Irob Nationality Rehabilitation and Development Association,
IRROB = Irob Relief and Rehabilitation Operation Brotherhood
ADCS = Adi-Grat Diocese Catholic Secretariat

1. INTRODUCTION

1.1. GENERAL

Terrain as physical environment that houses all biotic and abiotic resources, should be critically evaluated and placed under best fit land use type to maximize the profit from it with out jeopardizing its future productivity. Most of the biophysical processes in a given piece of land are highly influenced by the terrain nature of that land

"Reliable estimation of topographic parameters, which reflect terrain geometry, is necessary for geomorphologic, hydrological and ecological modeling. Because terrain controls fluxes of mass in the landscape." Helena Mitasova and Jaroslav Hofierka (1993).

"The relative magnitudes of many hydrological, geomorphologic, and biological processes active in the landscape are sensitive to topographic position." Moore et.al (1991) as cited by S.de Bruin and A.Stien (1997).

The interdependency of physical environment to the vegetation behavior is emphasized as follows. "Vegetation characteristics such as species composition total basal area, and growth habits have been correlated with gradient position defined by environmental scalars. These environmental scalars may include primary topographic attributes such as altitude, slope and aspect, or derived attributes such as radiation indices (Austin et al, 1993,1994). K.J Beven and I.D. Moore (1993). This is a big field of study known as phytogeomorphology as first coined by Howard and Mitchell (1985) (Ibid)
Irob land is the region of extremes where you can get the extremes of landforms, temperature, and altitude. This wide range of variations in environment led to diversification biophysical processes.

Hence, the study of terrain features that could influence most of all other biological and physical processes could help in knowing the environment better which could help in good planning too for sustainable use. For the reason such studies are lacking in the region, makes this paper a good contribution as a base line data for further studies.

1.2. DESCRIPTION OF THE STUDY AREA, IROB

1.2.1. PHYSICAL ENVIRONMENT

The study area, Irob land, is located in Tigray regional state, Northern Ethiopia directly bordered with Eritrea from most north and Northeastern part. The geographical location is between 14°22′12.37″N, 39°28′58.13″E and 14°40′52.58″N, 39°59′04.39″E.

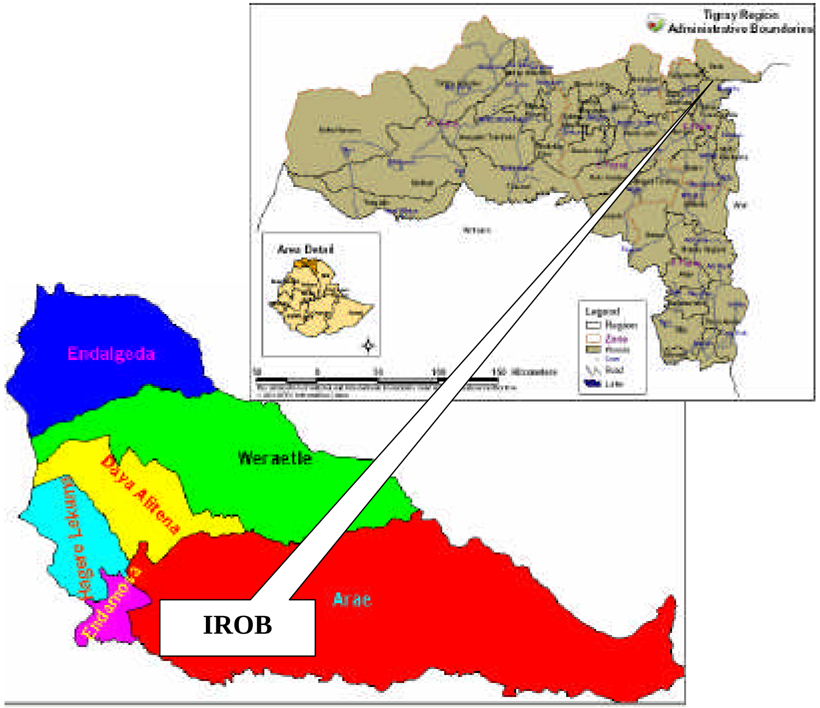


Figure 1:The study area (Ethiopia, Tigray, Erob)

The name Irob is also referred to the ethnic minority that lives in Irob land. Thus the name of the land is then emanating from the name of the inhabitants. Traditionally Irob land is divided into three big administrative regions/zones namely ***Buknite-Arae'***(Central Irob; the present 'Waraatele', 'Daya-Alitena', 'Agaralekoma' and 'Edamossa' hamlets) ***Adgadi-Arae*** (the present Edalgeda) & ***'Hassaballa'***(the present 'Arae').The population of Irob is estimated to 18000-20000 (1994 census data).

Irob has a wide altitude range of about 150m around 'Indelli valley' (near Red Sea) to 3200m around Mount 'Assimba' and 'Ayga' and extremely rugged topography. This factor of altitude has an over ruling influence on other climatic factors like temperature and rainfall which in turn collectively will affect the over all biophysical processes in the area. The range of variation in mean annual rainfall and temperature along the altitude range is: 250mm to 600mm and 25° to 15° respectively from lowland to high land. Bruno Strebel (1975). The area coverage of Irobland is estimated to 93000hactars

1.2.2. VEGETATION

Probably attributed to the variations in climatic and topographic features, the vegetation physiognomy and distribution of Irob has significance diversity and differs from the neighbouring Tigray regions much. The vegetation of Irob land is characterized by dominantly spineless flowering vegetation physiognomy, which makes different from the rest neighbouring regions where spiny Acacia vegetation, is abundant. Most of the floras in Irob are attracted by honeybee and could be one of the good reasons for the potential of honeybee farming

In some High lands of Irob like 'Silah', mountain chains of 'Assimba' and 'Ayga', it is still possible to see remnants of giant Junipers and Olea African trees. (Personal observation: Tesfay Ghebray, Tigray Agricultural Research Institute) as the underlying statement supports these variations could be accounted to major variations in climate of the region.

"The distribution of vegetation and solar radiation in small mountainous catchments in near Hokkaido, Japan are highly correlated (Takahashi 1976) and Austin et al (1993,1994) have shown that the distribution and zonation of Eucalypt species in South eastern Australia is related to altitude rain fall and annual radiation index." K.J Beven and I.D. Moore (1993

1.2.3. THE MAIN LIVELIHOOD SUPPORTING SECTORS AND MECHANISMS

In Irob livestock (cattle, Goat, Sheep) and honeybee farming were used to be the main economic sectors during early ages. Since last two centuries, the benefits from livestock start to decline mainly due to recurrent drought and degradation of grazing land, leading to transformation into agro-pastoralism with inventions of especial land husbandry innovations.

Honeybee farming is the other important livelihood-supporting sector. This environmentally friendly sector used to play significant role in the economy Irob people and is still prospective field to be considered due to its friendly nature to such a fragile landscape in Irob. "Irob area is known for its best quality honey product" Mengstu hail w/Gebriel (2003). The vigorously flowering vegetation type in Irob is ideal for apiculture.

Cactus Pear *(Opuntia ficus-indica)* is another important crop/plant I should mention for its significance in Irob lively hood support. The fruit is edible and constitutes a considerable share of every one's diet during summer (June-September). The leaves are also important as a feed for cattle. Opuntia has a very high drought resistance quality due to its succulent leaf nature to optimize water use efficiency. Cactus was introduced into Irob region in 1840s by one catholic priest in association with the introduction of Catholic religion and now it is abundant through out the eastern Tigray.

Another copping mechanism to the harsh livelihood in Erob community was temporary migration in search of job. Most of the Youth from Irob used to move out side the country and/or the region for some time. Saudi-Arabia used to be the country visited by most youth s of Erob since 1980s to 1990s. Almost one per family who doesn't attend school used to visit Saudi-Arabia for a year or longer due to its opportunity to obtain a well paid labour employment.

1.3. LIVELIHOOD TRANSFORMATION, INNOVATIONS, AND RESTTLEMENT

1.3.1. EARLY SETTLEMENT

The early settlement style of Irob population is a very scattered and the mainly concentrated in the mid high land to high land part of the region. Some considerably vast areas of lowland are not populated or if any very sparsely populated.

Even though it can't be concluded why so, Irob population has preferred to settle in the highlands during the early ages of settlement. From crop cultivation point of view the low lands are more potential mainly due to availability of fairly plain land. Some justifications can be drawn from the knowledge I have and some literature about the area.

The first the reason could be that, the livelihood of the early days of Irob population was more of livestock dominated type. Given this fact the habitability of highlands were then preferable for the demand for livestock is different from crop. Its moderate climate and water availability for themselves and their livestock could be one of the justifications for preference by then. The land was also unquestionably more productive those days especially for goat and sheep grazing which are the key live stock ownership components of Irob.

Secondly social values could also have some thing to do with the early settlement style. Mengistu Haile (2000) has mentioned that frequent ethnic/Tribal clashes and looting of cattle and property were common incidents during the early history of Irob. During the occurrence of such an accidents, the Irobs used to communicate using the only possible method relays calling from mountain to mountain peaks. The message can reach very village with in less than an hour and they gather to rescue the victimized village or person. This is known as 'Goron/Dero' (synonym to rescue mission). This factor may probably have some thing to do with the scattered high land settlement style.

The third factor is clearly most important that, there is no infrastructure like market and roads in the lowland region. The people use the neighbouring towns of zalambessa, Adigrat & Sanafe. The latter is the nearest as well as most used one but is a boundary town of Eritrea and hence not accessible any more since the recent war of the two countries. Which are all situated very far to the southwest side of the district and it takes about two days for round trip on foot with their pack animals even to the central town of Irob (Alitena). This was the only means of transportation used until the war broke in 1998.

Currently these highland parts of the region are at a state of degradation seeking for release of the land for restoration and especial land management.

1.3.2. THE TRANSFORMATION AND AGRICULTURAL INNOVATIONS

The suitability and capability of these highland regions finally deteriorated to the status of failure to support for the past traditional way of livelihood due to over exploitation for long decades. The benefits gained from livestock started to decline and a shift of livelihood towards mixed agriculture (agro-pasturalism started since 200 years ago. With this shift new form of agriculture, the topography of Irob

was quite a challenge for crop cultivation. Some reports like the report on drought assessment by the following organization estimates the cultivable land of Irob as 740hactares (Hans U. Spies, UN-EUE July11, 1994). The study by Dr. Bruno Sterbel also strengthens the shortage of land for cropping and serious degradation in his study of Erob in 1975 as follows:

"Irob land is a wild mountainous region with steep slopes strongly dissected by river valleys in the eastern escarpment of Tigrian plateau. Uncontrolled grazing, indiscriminate cutting of trees, cropping on steep slopes, and other unsuitable land use practices destroy the natural vegetation and promote the soil erosion there by constantly weakening the agricultural potential." Bruno strebel (1975)

Even though, it is quite true that, cultivable land is critical shortage in Irob region, the above figure that, estimates 740ha of arable land looks like representing central Erob('Bukniteearae') and not the whole Erob. If not, the figure for the whole Irob is expected to be bigger. This underestimation might be biased by two main factors. One the whole narrow valleys in Irob are under cultivation using especial innovations as will be explained later. This constitutes the largest portion of the cultivable land in central Irob region region. The fact that this is unusual it is difficult to account for may led to exemption. The second problem to the figure might come from lack of data from the unsettled and less accessible far-eastern and southeastern Erob low lands such as 'Sangade', 'Silah' (Dudub) and the whole 'Hassaballa' lowlands. These areas have considerable sites of potential cultivable land but often not surveyed due to their distance and lack of access roads and the same thing is expected to happen to this report too.

The people of Irob started to think about alternative options and innovations like 'Setan-Maduwa' and 'Daldal' were invented. Ann Waters-Bayer (1998). These days when one walks along the gorges up the catchment in Irob land, you find, a series of well-developed terraced farms under intensive management. It is amazing to be there than to describe with words.

'DALDAL' & 'SETAN MADUWA' INNOVATIONS

'Daldal' and 'Setan-Maduwa', Daldal' are special construction designs innovated by Irob farmers to capture silt and water from seasonal severe floods from hilly escarpments of Irob land. The rain behavior in Irob land is torrential and lasts for very short late afternoon hours. This results in severe silt washing from uplands resulting in deposition down the gullies where series of 'Daldal' structures are constructed readily to capture that silt and water taking an advantage of erosion. After few cycles of rainy days the structures are filled up with thick layers of sediment with considerable moisture depth. The filled sediment on rear side of these Daladil(pl) and Setan-Maduwa are mainly cultivated with maize soon after floods to establish themselves before that moisture escapes and maize is preferable crop to take an advantage of its deep rooting nature to capture the moisture from considerable depths in the silt layer. More over it has higher resistance to toppling/uprooting in case severe flooding occur compared to other common crops like barley and wheat in the area.

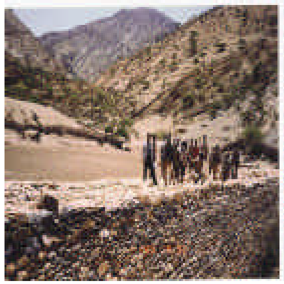


Figure- 2: 'Daldal' Innovations in Irob

Figure 3: Maize production on sediment filled 'Daldal'

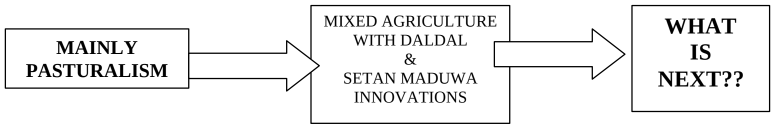
Figure 4: 'Assabol' dam site

Source: ***www.irrob.org***

This innovation is well discussed by Dr. A. Waters-Bayer on the article about Farmers' Innovations in east Africa. The underlying paragraph is a briefing about Setan-madwa from one of the innovators as taken from Ann Waters-Bayer (1998)

"Also Yohannes was frustrated to see so much water and silt pouring through the river beds of their arid rocky lands disappearing into the depths of the Dankil and Red sea. --- He thought of using the silt carried out by the river to build up land beside it, and using the river water to irrigate the land. ---At the first trial, he made a wall as he would make a house wall. But when the river flooded, powerful water ***lifted up*** *the stones and washed them away. --- Yohannes then came up with the idea if the water made the stones stand up right/lifted up, he would try to set the stones upright already before the water met them. --- After trial, he observed that the water roared over the top of the stones but didn't dislodge them. Yohannes had outwitted the river by using the force of its own water to push one stone against another and in effect tie them together through this pressure. This type of river side wall known locally as Setan-Maduwa (Devil's-tie), named after the complicated tie which is very difficult to open/untie, used to fasten the bag made of a goat skin to hold precious gifts for Irob bride" A. Waters-Bayer and Asfaha Zigta (1998).*

The above fact shows the strong attempts made by Irob farmers to maximize benefits from erosion. This period is a transformation from pure **pasturalism** to **mixed agriculture** type. These days due to serious changes in climate, this technology is also almost failing to continue supporting the society.



It became rare to get strong floods and regular summer rain since two decades. Summer rains used to start in mid June and stop late August. The amount was enough to generate floods that carry down the silt and water to fill these terraces in the valleys. Then immediately they were cultivated with maize and similar crops. This now became almost a tale since summer rains are not enough not regular both

1.3.3. NEED FOR DOMESTIC RESETTLEMT (VILLAGIZATION) WHAT NEXT??

Now comes the question what is the fate of Irob next! With the frequent threat of the drought it now became clear that rational rain fed agriculture isn't working in Irob. There is no farmer by now that can sustain his family with harvest from agriculture .The major period of the annual food is solely from aid.

The recent Ethio-Eritrean war aggravated this already staggering situation. The Irob land as one of the direct border district claimed by Eritrean government; was used to be one of the strongest fortresses locations for the recent war. As a result the population was displaced for the whole three years deserting every thing and suffered from all types of the under war zone tragedies. They lost all the properties they had and thus this people have to start from scratch again. They are victims of the long lasting post war crises. So the above question is thrilling the mind of every member of Irob yet with no appropriate answer.

Proposals like displacement to the western Tigray, like Humera low lands are on attempt. Yet this is not sound option to Irob people. Irob is small ethnic group (estimated to 20,000) confined in that region alone. The attempt to resettle them out side Irob land may cause so many crises including a threat to continue as ethnic group. It is like separating one big family. They know their land; the soil, the vegetation, the mountains and valleys. I also want to tell you that the, intended resettlement site, situated at about more than 600km across in western Tigray borders, is quite different and after all may be more harsh than Irob due to its extreme climatic conditions. This area borders southern Sudan and is have similar climate like some of the extremely hot dry lowlands of south Sudan. I personally know that the temperature rise beyond 40 degree celcious some seasons. Imagine people to be resettled there are from Asimba and Ayga areas where the altitude is 3000m 2800m respectively. The area is also devoid of any infrastructure so that demanding completely new establishment in physical infrastructure. To know the area by itself will need too much time, it is new environment that requires new innovations and new copping mechanism where the people are expected to start from scratch again. The agricultural innovations and experiences developed in Irob land can't ever be tried in Humera for they are for quite a different area. The area is also quite wild and full of challenges and risks like contagious disease such as malaria and restriction of movement due to armed lootings and theft. Therefore this plan may not really sound feasible and need is there to look for reconsideration. The only thing most possible at a moment is to evaluate potential resettlement sites in with in Irob like in the east and southeastern parts of it. Only domestic resettlement and villagization can be seen as best feasible and lasting solution.

Therefore this study will attempt to assess the potential suitable areas of the region for resettlement and development taking the topography (slope & Altitude) as a main factor. As already mentioned rain fed agriculture is not any more hope full in the region. Hence the point of irrigation should be focused also.

The Assabol irrigation project is an attempt to solve this particular problem. But I want to admit that this paper is only a mere start, since land evaluation needs diverse information on all relevant land resources and social aspects, which I can't get at a moment. The paper will only assess the physical terrain parameters like altitude slope may be very significant, in resources management and land suitability for a given purpose anywhere and especially in Irob for its extraordinary topography.

1.4. TERRAIN ANALYSIS AND ITS RELEVANCE TO NATURAL RESOURCES MANAGEMENT

Even though it is beyond the time limit to relate all aspects of this study with natural resources management, there is no doubt that terrain analysis information is meant mainly to serve for that purpose. Sufficient information on all the terrain parameters like morph metric, generic, hydrological, and climatic will strongly assist to understand many biophysical processes n the area and hence will help in better natural resources management. The following sections will briefly describe how the study could be relevant to the natural resources management and the social and physical conditions in Irob region.

The definition of natural resources is vague and variable both in sense and scope. Some writers describe it in a very broad and inclusive way including almost every thing like minerals, air water etc. others define it narrowly from their point of interest or view. Hence there is difficulty to understand and choose the best definition for natural resources and hence natural resources management. What so ever, how some one may define it, the two terms ***natural*** and ***resources*** are self explanatory that how broad and inclusive the phrase, natural resource is.

The problem with these various definitions is that often they try to separate those inseparable things. Let us look at two categories of natural resources as often may used to be categorized as; **physical** land resources (soil, water, air) and **biological** land resources (fauna and flora including human beings). It is really impossible to drop one /one group and talk about the other. They are all strongly interdependent and inseparable.

Specific to this study, it is all about terrain. Terrain, as a piece of land where all the above-mentioned resources dwell, it is a base or media where all the physical and biological processes take place. All the soil, water, air, fauna and flora exist on, in, or around are all considered when we talk about a piece of land. Terrain analysis is evaluation of the characteristics of piece of land under consideration and the secondary attributes like hydrology, vegetation, soil that may directly or indirectly influenced by the given terrain nature.

Let us assume, two pieces of land with different attributes one plain/flat land and the other steep slope. Take that they receive the same rain; due to tier differences in the slope (steepness, shape) the infiltration and retention capacity, the run off, the water logging conditions, will be quite different for the two different sites. It can be hypothesized that the flat plain may be more vulnerable to logging while the other one is more liable to erosion. This is just taking all the rest conditions constant, but that can't happen. Due to the very first difference in the physical nature of the two sites, all the rest conditions will be already different. The vegetation composition and growth habits in these two sites will be different. That may result in turn in different faunal composition in the two sites. The types of goods and services obtained from the two sites are different which will demand for different natural

resources management approach. Their role to the environmental and their requirement from the environment will be different for the flora and fauna of the two different sites. For instance the role of vegetation as in mitigating run off will be more relevant to the sloppy terrain than the flat one.

This will be achieved through its influence on interception, by enhancement of infiltration, improving the soil porosity/higher organic matter, as a physical barrier to slow flow velocity etc. These capacities are different for different flora/vegetation types hence, as a management aspect, selection of best species primarily for that role, and specification of special management approaches (e.g.: cut and carry methods, closure area methods of management will be better if the land is under grazing practices) to such sites will be a necessity. These different floral and faunal compositions will in turn again let the soils of the sites to differ. Because the up take and input as organic matter will vary accordingly. So it is clear that these three the soil, vegetation, and the water/ hydrological processes are cyclically interdependent and, and it is also possible to perceive that, the feature of a given piece of land is commanding these process.

Yet, the human beings in both sites will have the same niche which means we look for the same resources. How could it be? Different resource endowment, different land yet the same need, we need the two pieces of land to provide us with the same benefits! Management! Has key role to play here. Strong management to maximize the benefits and give similar services and goods can mitigate the shortcomings. So, the point in this analysis is that natural resources management is holistic and land is the base where every process is going on. Terrain information then will help in management of these processes. The following statement strengthens the idea.

"The stream power index (SPI), or its derivatives, could be used to identify places where soil conservation measures that reduce the erosive effects of the concentrated flow/surface run off, such as grassed waterways, should be installed (Moore and Nieber, 1989)" K.J. Bven and I.D. Moore (1993)

The approach to management should be holistic. All the disciplines should come to the same site with its whole holdings and act together considering the land as a base/house. Then, can they minimize the conflicting objectives and sustain optimum benefits from that piece of land. Because then we evaluated together, to know best fit options from the list and have decided on the basis to put that piece of land in the best fit land use type. This is meant to match the requirements of the specific **land use** and the **capability** of that **land** to provide that specific requirements. With out this evaluation sustainability can't be attained.

We are going to review some of the literatures to support the importance of DTA to natural resources management.

"With the development of digital terrain models capable of analyzing large sets of digital elevation, it is now possible both to quantify the detailed topography of landscape and to explore process based models in explaining map-able features." William E. Dietrich, et al 1993)

These days much valuable information can be analyzed from readily down loaded DTM with the help of GIS. Many of the subjectivity and hectic field surveys are significantly minimized with the help of satellite imageries.

"The DEM is the basic source of information for many aspects of landscape that are controlled by landforms and many algorisms have been written to derive new attributes from gridded DEMs." P.A Burrough et.al (2000). The writer elaborates the importance of DEM data as an input for computation many secondary derivatives that contain paramount information in various factors.

"Examples are the angle and aspect of Slopes, the rate of change of these expressed by profile and plan curvatures, the surface topology of run off and allied indices of wetness, distance to ridges or streams, and other surface properties such as seasonal variation of Incident solar radiation. Consequently, it is now possible to derive a wide range of landform data for every grid cell as a local function of its surroundings. More over each new attribute is derived in the same way at all locations to avoid biases (Ibid). For many other applications such as linking land attributes to land capability for land evaluation, the assessment of ecotopes for nature conservation, or for detailed mapping fro precision agriculture, it may be necessary to reduce the totality of spatial variation of all the individual landscapes to a limited set of locally optimal classes. These classes may be useful as a carrier of information about more general problems such as crop response to salinity, erosion or land slide hazards, or poor soil drainage." (Ibid)

Using DTA it is also possible to depict Slope isolation, Temperature and Wind map. More detailed information is present on Dozier, (1980), Dozier and Frew (1990) etc. To mention some of its importance let us see what Peter A. Burrough and Rachael A. McDonnell wrote.

"Note that it is a simple matter to integrate the daily or monthly estimates of irradiance for the whole season or year thereby to create a map that distinguishes sites in terms of the energy inputs for plant growth, home heating or rock weathering. Combing a classified map of warm and cold sites with a map of site wetness derived from the upstream elements enables maps of warm- wet, warm-dry, cold-wet, cold-dry to be made." Peter A. Burrough and Rachael A. McDonnell (1998)

Therefore this study is relevant to the region like Irob, where such a data is lacking and in the other hand where the developmental projects like INRDA (Irob Nationality Rehabilitation and Development Association, IRROB(Irob, Relief and Rehabilitation Operation Brotherhood), and ADCS (Adigrat Diocese of Catholic Secretariat) are demanding for such an information.

The 'Assabol' irrigation project, which is intended to irrigate the down catchment river banks in central Irob, and the far east situated 'Sangade', Silah' and parts in 'Hassabal/Arae' plain areas is of especial interest to this type of studies. The dam site is in 'Dawhan' area ('Assabol-gade'/'Kinkinti-boll'), near by the present administrative center of Irob. (Refer to figure-4)
Absence of similar information is one of the bottlenecks to the ongoing land management and developmental programs by ADCS/ADDA (Adigrat Diocese of Catholic Secretariat) projects. Irob is a small ethnic group of people, trying very hard to win harsh lively hood.

2. OBJECTIVES

To Map The Major Terrain Parameters from contour map
To associate with natural resources management
To assess potential resettlement area in the region

The major terrain parameters to be generated can be categorized as:

MORPHOMETRIC TERRAIN PARAMETERS
HYDROLOGICAL TERRAIN PARAMETERS
CLIMATIC TERRAIN PARAMETERS

3. METHODOLOGY& MATERIALS

3.1. DEFINITIONS OF SOME TERRAIN PARAMETRS

Definitions of most important terrain parameters used in this text are included below as a table. It is important to know them before going into the body of this document.

MORPHOMETRIC	DEFINITIONS
SLOPE	Rate of change of elevation, contains indicative information on steepness of terrain, overland and subsurface flow, etc (P.A. Burrough 1998)
ASPECT	The aspect data set describes the direction of maximum rate of change in the elevations between each cell and its eight neighbours. It can essentially be thought of as the slope direction. It is measured in positive integer degrees from 0 to 360, measured clockwise from north. Aspects of cells of zero-slope (flat areas) are assigned values of -1. Compass direction of steepness useful in analysing, irradiance, vegetation attributes, evapotranspiration etc (Ibid)
PLANC	The curvature perpendicular (plan curvature)/ to the gradient direction reflects the change in aspect angle and influences the divergence/convergence of the flow (accumulation potential in convergence location) Mitasova and Hofierka (1993). Rate of change of aspect (indicator of converging/ diverging flow)
PROFC	Profile Curvature (PROFILEC), the curvature in gradient direction reflects the change in sloe angle and hence the change of velocity of mass flowing down along the slope curve. (Ibid). Rate of change of slope P A. Burrough (1998), indicator of flow acceleration, zones of enhanced erosion (Ibid).
2. HYDROLOGICAL	
CTI	The Compound Topographic Index (CTI), commonly referred to as the Wetness Index, is a function of the upstream contributing area and the slope of the landscape. The CTI is calculated using the flow accumulation (FA) layer along with the slope as: CTI = ln (FA / tan (slope)) In areas of no slope, CTI value is obtained by substituting a slope of 0.001. This value is smaller than the smallest slope obtainable from a 1000 m data set with a 1 m vertical resolution. (The USGS - NASA Distributed Active Archive Centre URL: http://LPDAAC.usgs.gov/gtopo30/hydro/af_fa.asp Last Update: Monday, December 08, 2003)
SPI	Stream Power Index (SPI) characterizes the erosive power of the overland flow.

	Measure of the erosive power of over land flow (Ibid)
FLOW DIRECTION	The flow direction data set, like all of the other raster data sets, has been derived from the hydrologic ally correct DEM. It defines the direction of flow from each cell to its steepest down-slope neighbour. Values of flow direction vary from 1 to 255. Defined flow directions follow the convention adopted by ARC/INFO's flow direction implementation Cells with undefined direction of flow represent sinks and have flow directions that are simple combinations of its neighbours' flow direction values. (See ESRI documentation). Generation of basins and stream networks requires the flow direction data set. (Ibid)
FLOW ACCUMULATION	Developed from the flow direction layer, the flow accumulation data set defines the number of cells, which flow into each down slope cell. (Ibid)
CATCHMENT AREA	Number of cells/ area upstream of a given location under consideration.
STI	Sediment transport Index (STI) characterizes erosion and deposition process
3. CLIMATIC	
SIN	Slope isolation Index/ amount of solar energy received per unit area
TEMP	Temperature index map
DTM (DEM)	Digital Terrain Model (DTM) also known as Digital Elevation Models (DEM) Is a digital representation of earth's topography and is frequently used in hydrological, erosion and Engineering geological studies. Shrestha, (1998)
DTA	Digital Terrain Analysis (DTA) is the process quantitatively describing terrain is known as Digital Terrain Analysis (DTA) common synonymous are geomorphologic analysis, Land form parameterisation, Land surface analysis

3.2. MATERIALS USED

DATA SET

- Contour 50m intervals
- Rainfall point map
- Rivers
- District and Village boundary maps are available all from Tigray Regional Planning Bureau, GIS/RS Section.

SOFTWARES AND SCRIPTS

There are a number of Software packages to deal with Digital Terrain Analysis. Some of them are listed below:

- Topo-view; Arc View (Topo-view) for hydrologic modelling and solar isolation estimation
- Arc info (TOPOGRID in Arc info Module the ANUDEM interpolation) for hydrological parameters
- SAGA and DiGem Software (from Gottingen University, Germany), fully developed comprehensive packages for digital terrain analysis
- Set of digital terrain Analysis scripts developed for ILWIS 3.2 (Integrated Land and Water Information System)

The last one is taken as a main option in this study or the reason; it is more relevant to ILWIS 3.2 where I have better knowledge compared to the others and more relevant as a main software to ITC courses.

3.3. GENERAL INTRODUCTION

The approach of the study could be categorized in to three main sections:

- The DEM generation and quality improvement
- Generation of all terrain parameters
- Interpretation and finishing/result visualization

A package of script developed for terrain analysis Integrated Land and Water Information System) (ILWIS 3.2) is used for this study as mentioned above. This resource is used as lecture notes to ITC elective modules and is intended to serve as a basis for the development of especial module on terrain analysis. T. Hengl, S. Gruber and D. B Shrestha (2003)
Complete reference is available at http://www.itc.nl/pesonal/shrestha/DTA/

3.4. DEM GENERATION AND QUALITY IMPROVEMENT

Digital Elevation Model (DEM) was generated from 50m-interval contour segment map using linear contour interpolation technique. A pixel size of 10m is used based on various suggestions made by T. Hengl S.Gruber and D.B Shrestha (2003). Practical knowledge of the area, where abrupt changes in elevation per very short distance are quite common, was also considered not to generalize such phenomena. Based on recommendations by the same literature as mentioned above, various improvement measures are recommended on DTM and were carried out as suggested in three consecutive steps before use as an input for further Digital Terrain Analysis (DTA). These

TERRAIN ANALYSIS OF IROB LAND AND ITS RELEVANCE TO NATURAL RESOURCES MANAGEMENT, IROB, NORTHERN ETHIOPIA

improvements are: Detection and corrections for paddi-terraces (undefined areas enclosed by contours like ridge tops and narrow valley bottoms); an automated detection of medial axes script is used to come up with (DEM_L1). Detection of local outliers (gross error in data collection or in interpolation due to sampling quality an other script that combines the detection for such errors followed by kriging, is run to tackle this to come up with second level improved DTM (DEM_L2). Lastly, incorporation of streams and water bodies, using buffer map of the rivers/streams (rasterizing stream lines/drainage maps and then calculating the buffer distance from that), and then by re-interpolation of DEM_L2 is recommended and carried as required. This is the final product of DEM generation step, where DEM_L3, which is used for all forthcoming DTA, processes. Even after carrying out these attempts, it is quite common to come across some undefined pockets in DEM, and in further generated second order derivative like hydrological terrain parameters. Seriousness of the problem depends on the nature of the terrain (the more complex, the relief, more probable to find undefined facets), the quality of data (for contour, the more detailed, and smoother the contour lines the better) and the parameters being calculated (is worse in hydrological / other higher order derivatives). T.Hengl, S.Gruber and D.B Sherstha (2003). Similar problem in this study case was tackled using additional points using knowledge of the area and reasonable guess of values for elevation spots between consecutive contours. This approach is an acceptable means when field data is lacking. It is advisable to use a wise guess to edit point map from contour interpolated DEM and contour itself (ILWIS Users' Guide). Use the distance of consecutive contours with in which the undefined pockets are contained, wisely guess the elevation values for these pockets (Ibid). The whole process of DEM generation is summarized in flowchart. (Refer to Flowchart-1)

3.5. GENERATION OF THE MAJOR TERRAIN PARAMETERS

Most of the Morphmetric, Hydrological and Climatic Terrain Parameters were generated. The parameters were automated using the scripts from the same Source. For the reason this part is an ILIWIS internalised algorism with little manual intervention, it is not easy to describe and may not be necessary or too relevant to talk about the algorism. Hence it will be summarized using the flow charts for each of them. Yet, a considerable finishing and analysis processes were carried out after these automated results using various usual ILWIS expressions, which will be explained per each part in the forthcoming sections.

3.6. COMPUTATION OF MORPHOMETRIC TERRAIN PARAMETERS

The main Morphometric parameters computed in this study include: DEM, SLOPE, ASPECT, PLANC (plan curvature), PROFILEC (profile curvature) & MEANC (mean curvature) maps.
AS already mentioned earlier the script developed by T.Hengl, S.Gruber and D.B Sherstha (2003) was adapted just by substituting the values and parameters for input. This step is an immediate next step to DTM generation step above (DEM_L3). The DTM (for this case, DEM_L3AA) is one of the main inputs to this step. (The summarized steps are sketched in the flowchart-2 in the annex)

The Slope map, Aspect map and DEM maps were classified into logical classes. These are the inputs for interpretation and classification of areas under major altitude range/class (lowland, mid high land, highland), slope classes (steep, moderate, gentle) and aspect classes (east, southeast, south etc) respectively.

Further analyses were carried out from DTM and slope class maps to find out suitable areas for cropping mainly, based on its degree of plainness. Further analyses were also carried out to quantify the proportion of the suitable land in the lowland region. (The summarized steps are annexed in the flowchart-3)

3.7. HYDROLOGICAL TERRAIN PARAMETERS

Catchment area, streams, and ridges were automated from the same script package. In the other hand, Sediment Transport Index (STI), Stream Power Index (SPI) and compound Topographic Index / Wetness Index (CTI) are the other group of hydrological terrain parameters generated. The wetness index (CTI) of an area shows the potential moisture retention capability of the area while from combined information from STI & SPI it is possible to generate information on potential risk of erosion. “The stream power index (SPI), or its derivatives, could be used to identify places where soil conservation measures that reduce the erosive effects of the concentrated flow/surface run off, such as grassed waterways, should be installed.” (Moore and Nieber, 1989) in K.J. Beven and I.D. Moore (1993) (The summary is attached as flowchart-4)

3.8. CLIMATIC TERRAIN PARAMETERS

The main climatic parameters calculated straight forward from DTM are Slope Isolation, Temperature index map and Shadow map. These maps could give paramount information on microclimate of the area. The wind map script is not included in the package hence it wasn’t possible to generate wind map. The specifications for the script were adopted from T. Hengl (2003). The sun angle (Azimuth) is taken at 45º and the source of light is established, as it illuminating from 180º from south. This is the position of illumination source and it is a ‘standard cartographic position’ as it was suggested by the above literature. (Summarized steps please refer to flowchart-5)

4. RESULT ANALYSIS

4.1. MORPHOMETRIC TERRAIN PARAMETERS

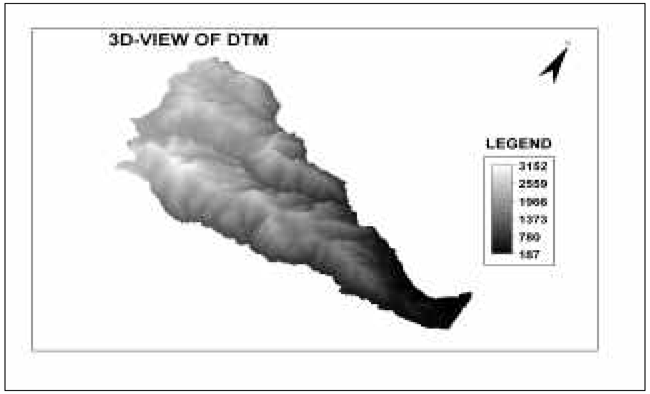
4.1.1. DTM 3D VIEW

A 3D-georefernce ‘SANGADE’ was created with the specification as below to serve as a base for 3D display of all maps in any need. The coordinate system ‘EROB’ was used to all maps and for this geo-reference too.

Viewing Angle	34.00	
Horizontal Rotation	30.00	
Vertical Rotation	45.00	
Distance	176855.15	
Scale Height	2.0	
Focal point	575647.435	1597473.766
View point	638175.173	1489172.547
View point height	127538.08	

Figure-5: 3D-View specification for DTM map

Using these specifications, the original DEM (DEM_L3AA) is displayed in 3D-View grey tone as below, so that to enhance the visualization. As it is observed from the 3D-view, the darker lower right parts of Irob are, the areas where we have lowlands. The whitish peaks in the upper left part of this map are the most mountainous part of Irob where locally some of the names are known as ‘Asimba’, ‘Araillo/Sabaata’, ‘Ayga’ and ‘Dambakomma’.



Map-1 3D-View of Irob DTM

These are the regions of quite high population density when compared to the unpopulated low lands in the right lower portion of the map such as ‘Hassaballa’ lowlands. This information is important because practically central Irob is most populated, but it is least suitable to cultivation compared to those east and southeast lying lowlands such as ‘Sangade-Silah’ (dudub), and ‘Hassaballa’ lowlands.

Key problem in these lowlands is shortage of water. 'Asabol' dam construction project under ADCS is mainly to solve this water shortage by supplying water for irrigation of these low lands.

4.1.2. ALTITUDE CLASS MAP

The altitude map (DTM) was sliced into altitude class map and the range is found to be from 186.90m to 3152m. The largest portion of the region lies in the mid high land region followed by the low land. For exact figures refer the underlying chart

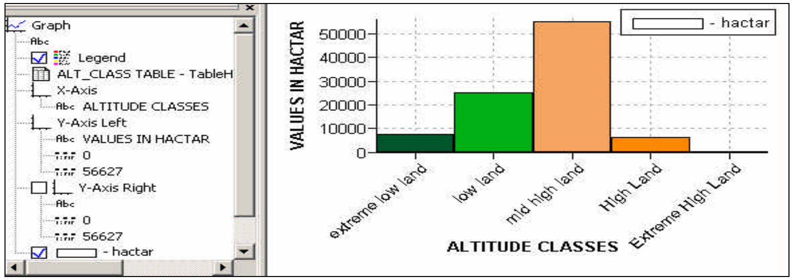
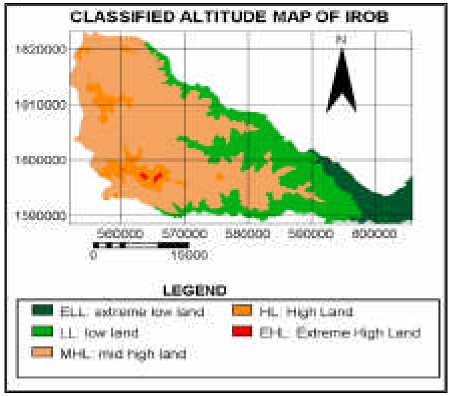


Chart-2: Graph showing area in hectare per slope class

Spatial locations of these altitude classes are presented on Map-2 below. As it can be visualized from this map, the extreme low land is located in the 'Hassaballa' hamlet/ 'Tabia' (smallest administrative zone) while the extreme high land is a peak of mount 'Assimba' in the central Irob.



Map-2 Altitude class map

4.1.3. SLOPE

The slope map was also classified based on the recommendation by ILWIS 3.2 Users' Guide. This guide suggests to use the ***minimum, mean ± 0.6*Standard deviation, mean ± 1.2*Standard deviation***, and the ***Maximum*** as the upper boundaries of classes as a criterion for classification. A compromise to this formula was made to accommodate the actual extreme terrain conditions of the study area to come up with logical slope classes. From the result, 37.15% of the region lies in the slope percentage >45° (Steep+ Extremely Steep). This particular figure shows the actual nature of most central Irob land. There is about 32.46% of area of the region in the slope range of 0°-12.5° which may taken as potential suitable area for cultivation from slope steepness perspective. The following chart quantifies the figures and map-3 in the annex-I is for visualization of the spatial information on slope classes.

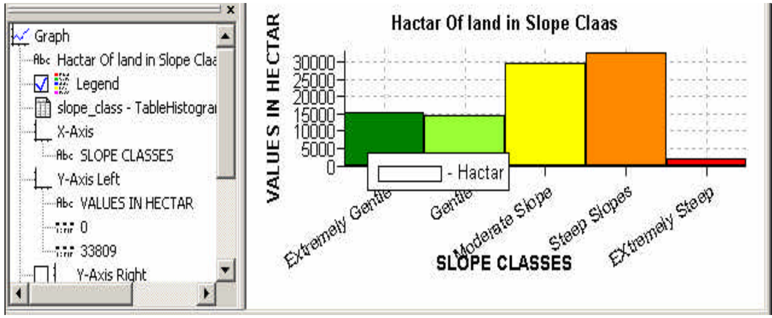


Chart-2: Graph showing area in hectare per slope class

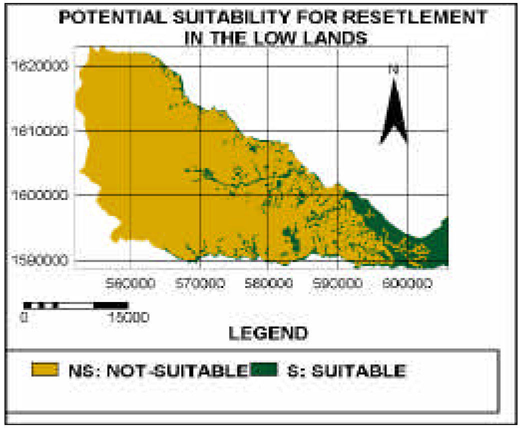
4.1.4. SUITABILITY FOR RESETTLEMENT AND AGRICULTURE ON SLOPE AND ALTITUDE BASIS

Given the rest conditions promising, the areas in the extremely gentle to gentle slope classes (<12.5º) can be recommended as potential settlement and cultivation zones. The patchy nature of these suitable areas could let them still less feasible for mechanisation possibilities. Hence this factor was taken into account to come up with final suitability map. The **average land holding** (0.25ha/hh) in Irob and the degree of **steepness** were used as a basis for determination of minimum hectare size. Further an inverse relationship was attempted between the sloppiness and farm size, hence the steeper slopes are expected less potential relative to the gentle farms. I.e., Area size>=0.50ha (2-hh) was taken for very gentle and >=1.50ha (6-hh) was considered for gentle slope regions.

From this map annexed at the end (Map-4, Annex-I), it was found about 40% (37258ha) of the region to be under the suitable class. This is just based on the slope steepness (the less sloppy it is, the higher the potential) but it is expected that most highland hilltops to be less productive due to long history of over utilization compared to the less populated and hence under utilized lowland regions.

Hence there is a need to check if really most of the plain land/suitable land is in the lower altitude regions or not, which then implies that these are potential resettlement locations for the reasons they are less populated. The computation was carried out and the outcome is depicted in the underlying map. The dark green areas in the lowland suitability map below shows that most of the low land areas are plain sites where potential resettlement and irrigated agriculture could be recommended.
This figure equals to 13% (12823ha) of the region, which is in the altitude range of <=1500m, in other word meant the Lowland region. Because of the fact that, most of the gullies in Irob land are

under cultivation using the 'Daldal' innovation techniques mentioned in the introductory section, these areas were included in the suitable class. (For the computation steps, fowchart-3)



Map-5 Lowland Suitability Map

This is significant figure in under Irob situation, where land shortage is critical as it was discussed in earlier as long as water problem is solved. The good news is that, Assabol-Dam project aims at solving this problem and is an encouraging start for such an opportunity.

4.1.5. ASPECT MAP

The aspect map was also classified into nine logical aspect classes based on the ILWIS guide (east, north, southeast--- etc). Taking into account the steepness of the slopes in the region, aspect (Slope face) could have important information on vegetation characteristics, insolation, wind and other related climatic biophysical characteristics.

"Vegetation diversity and biomass have been shown to be related to radiation input in United State". (Hutchins et al., 1976; Tajchman and Lacey, 1986) *in K.J Beven and I.D. Moore (1993).* Hutchins et al (1976) *found that slopes receiving greater amounts of solar radiation and higher temperatures and greater evaporative demand which was reflected in less dense tree stands and less well developed vegetation."(Ibid)*

In the other hand it is clear that, the amount of radiation received, is influenced by the aspect (slope face) especially in steep slopes in tropics, which makes this topic more relevant, to Irob topography where steeply sloppy escarpments are dominant feature of the terrain of the region. As it is indicated on the histogram in chart-3 and map-6 in the same annex, the eastward slopes, i.e. (east, southeast and northeast) altogether constitute more than half (57%) of the region.

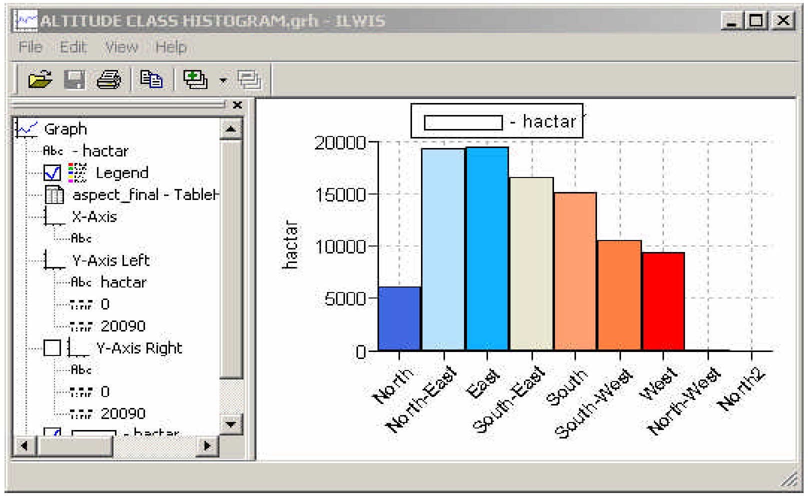


Chart-3 Graph showing the area size in hectare/aspect class

More over the Red sea is situated at about 65-75km towards east of Irobland. Given this proximity, it is worth mentioning that the aspect phenomenon may have many fold relevance to the prevailing climatic/weather situations as well as vegetation physiognomy of the region.

Practically the region is often under dry strong wind coming consistently from the Red Sea direction (East) most of the seasons. The main summer rain starts in the eastern portion of Irob and ascends to the higher mountains in the northwest. In general local variability in rainfall is very common in Irobland and often the east facing sloppy hills are favoured in summer rains. These big escarpments could also have undeniable aerographic effect to the west facing slopes. The other experience in Irob region is that the, vegetation type and physiognomy is different when the east and west faces of even the same escarpment are compared in steeper slopes. So these observations are worth calling for further studies in the region to analyse the actual interaction / relationship among aspect, climate, vegetation and Red sea location in Irobland.

4.2. ANALYSIS OF HYDROLOGICAL TERRAIN PARAMETERS

NB: Please refer the colored map overlay (Figure-5) and Map-7 together for explanation on hydrological terrain parameters part

The script for hydrological terrain parameters analysis was run to automate the catchment area from DTM (DEM_L3AA). The out puts of this algorism are qualitative and more of visual in nature.
As recommended by Burrough (1998), Low pass filters were applied to most of these out puts applied and to the catchment map to enhance the visualization.

4.2.1. ANALYSIS OF STREAMS AND RIDGES

One ambiguity in catchment map is that, when displayed alone in pseudo or grey, it looks like the streams are in the higher altitudes and ridges in depths. An over lay of catchment map (cyan), PLANC (grey), CTI (cyan), and DTM (pseudo), were used to solve this confusion. Different levels of transparency and background colour were used after trial of options to improve visualization. The colour gradient in DTM helps to indicate that the streams are located in the depressions unlike it appears, when the catchment map is displayed alone in linear pseudo or grey scale. Note in the DTM map, the higher the altitude the more reddish, as displayed in Pseudo, and where as the brighter/thicker the lines in catchment map, the higher the flow concentration potential locations for streams. The ***dark red*** line features along the higher altitude areas (here absorbed merely by the blue) stands for mountain **ridges** (dividing lines of watersheds).

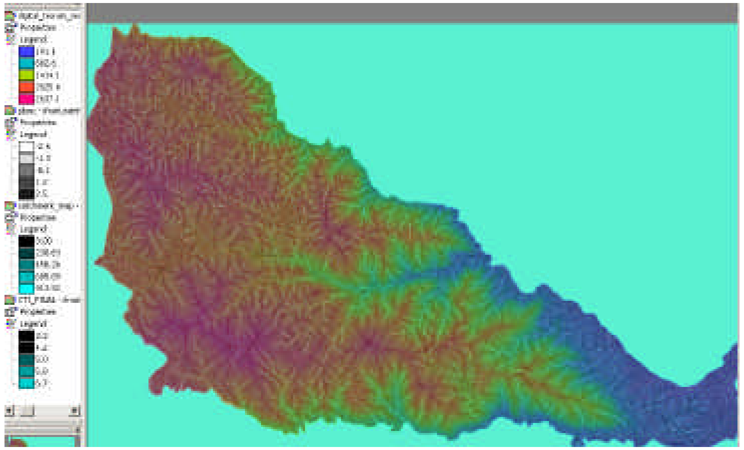
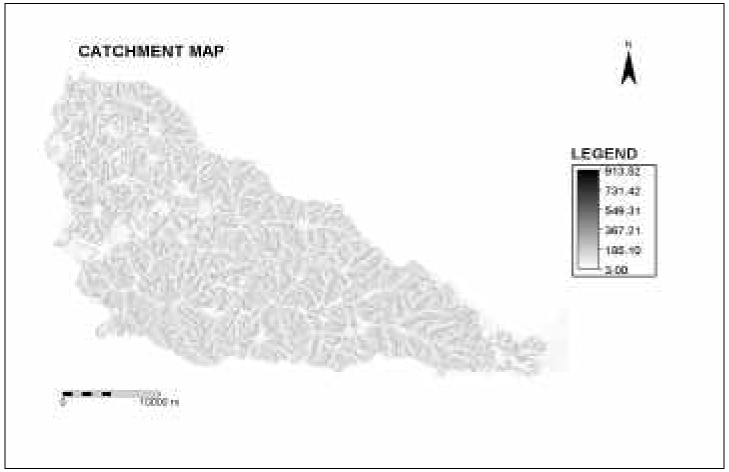


Figure-5 hydrological parameters overlay *(the same information as map-7 but for improved visualization)*

Inverse display in grey scale can also resolves this confusion some how. But here the reverse interpretation should be done, thus the darker lines in depressions represent the stream locations while the whitish stands for ridges. (See below in map-7)

The higher the values in the legend of this map means that these pixels (the darker ones) have bigger upstream area in the that drains into them, they are also in concave zones, showing that they are flow concentration zones and drain into fewer pixels due to their location in depressions. These characteristics are key features that are important for moisture retention and accumulation showing potential stream locations.



Map-7 Catchment map of Irob (inverse linear display)

4.2.2. CATCHMENT ZONES/FLOW CONCENTERATION SITES

Visualization of preliminary catchment zoning is also possible. The lightest lines in map-7 can be considered as watershed ***dividing lines*** where the upstream tributaries start while the darker lines represent the streams. The zone between these two main line features can be taken as specific catchment. The direction of flow of tributaries to the main river can be visualized observing the branching habits of dark lines (streams). As one ascends up in the catchment you get more and more branches, yet they become fade/thinner and vice versa when descends down. This can indicate the direction of flow sine the darker/thicker the line implies the higher the flow volume showing pixels lower in position in the catchment close to Main River and/or the main river itself.

As already mentioned above this value is influenced by many factors like, size of upstream area contributing to that pixel (catchment size), the steepness of the local slope (the steeper the slope the less potential the pixel to retain moisture), the shape of the slope (PLANC) and the easiness of the pixel to let water go out (out put). The later factor depends mainly on the shape of the area, and the number of directions to which that pixel drains. The information about this can be analysed from Plan Curvature maps, if the pixel is draining into many adjacent pixels, the less the moisture retaining capacity even if the input is higher. This information also gives awareness, that the pixels in the lower catchment positions are more potential flow accumulation centres, because they have to drain into fewer pixels, while in the other hand the higher chance of having bigger upstream area to drain into them.

Plan curvatures (PLANC) maps are good source of flow information. Convergence slope shapes (like valley bottoms) on PLANC map, has negative values and known as concave slope shapes. The opposite conditions are found on Ridges as explained by convex slope shapes with positive values. These are pixels, that don't have any upstream area draining into them (also known as watershed divide lines).

The caution with catchment map/streams is that it is often not easy to get continuously flowing lines with the increasing values as one descends down slope in the catchment. Due to the real nature of the terrain (presence of depressions/flow sink location), even with the best data, it is difficult to achieve this. The main source of interruption in flow lines are flow sinks, that can't be avoided totally. As a result there will be **discontinuities** and some times it is not always true to get the higher values always in the lower position.

The other observation is that, even though we expect higher values in the lower altitudes and valley bottoms, it is not so in **plain** areas. This is mainly attributed to the straightness of the slope (no concave shapes to collect water), which is very important in accumulation of flow. In addition in these straight slope conditions the pixels are potentially draining into all (eight) diagonal and down ward neighbouring pixels resulting in dissipation of the flow instead of accumulating. Hence streamlines are less visualized in plain parts of the lowlands.

4.2.3. SPI, STI, CTI, PLANC, AND PROFILEC

By combining information from SPI, STI, CTI, PLANC, and PROFILEC together with SLOPE factor, it is also possible to analyse areas of potential erosion risk. The first two indices (SPI&STI) give information about the **Erosive power of the over land flow** (attributed to the volume & velocity of the flow), and **erosive ness/vulnerability** (the inherent terrain topography) of the terrain itself respectively.

"Using CTI, it is also possible to predict potential landslide prone areas. Noting that higher CTI values meant areas of higher moisture index, which occur in convergent slope shapes/concave shapes, it was reported from field that, areas with higher CTI value (areas of topographic convergence) tend to be origins for landslides". (SINMAP USER'S MANUAL)

PLAN CURVATURE (PLANC)

PLANC is used to generate information on the slope shapes, which is important in put to generate and evaluate both the erosive ness of the terrain (via STI) and the erosive power of the flow (SPI) itself. The negative values in PLANC show concave shapes and hence concentration of flows and vice versa. The positive values are also used to indicate the potential ridge positions, which are the watershed, divide lines. This concentration affects the volume so that to enhance overland flow to result in higher capability to detach and transport material over the surface and hence erosion (higher SPI values). In the other hand the shape of the slope can also give information on the readiness/easiness of the material to be transported over the surface/terrain mainly due to the shape of the terrain. In convex to straight slopes the value of Sediment Transport Index (STI) is higher. showing the vulnerability of the terrain to erosion (erosive ness)

Generally one can see how significant this hydrological information can be for conservation and watershed management aspects. Through evaluation of these results can surely help in designing best conservation practices to control erosion. After all part of the USLE equation is derived from this component terrain analysis.

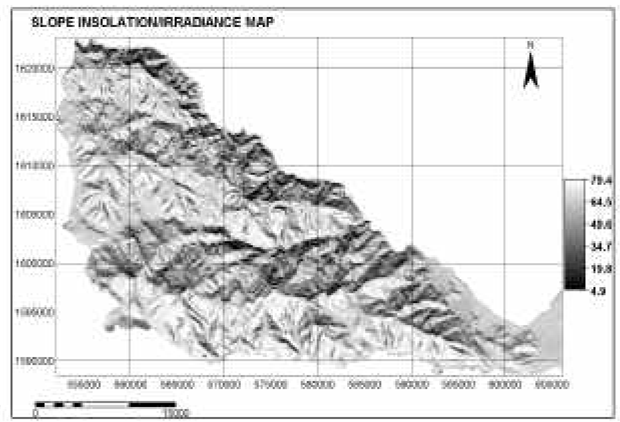
4.3. CLIMATIAC TERRAIN PARAMETERS

Elevation is highly correlated to climatic factors too. With reliable DTM data input and critical analysis of the out puts, important information can be inferred. With in depth analysis and field verification, the maps on climatic terrain parameters can give immense information on microclimate of the area. They will also assist in describing the vegetation characteristics and energy balance of the terrain.

"In many cases altitude is used as an indirect means of accounting for spatial variations in temperature and/or precipitation." (I.D moore, R. B. Grayson and A.R. Ladson). K.J. Beven and I.D. Moore (1993)

4.3.1. SLOPE INSOLATION / IRRADIANCE MAP

The slope insolation values vary mainly with slope face as it can be seen from the map, where as, the values for temperature are influenced mainly by the altitude.



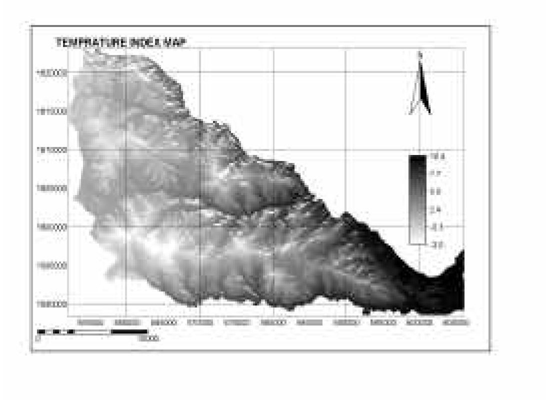
Map-8: Map of slope insolation / irradiance

Note this specific information is based on the specifications as described here and hence can vary with variation in those specifications. The sun angle is taken at 45º and the illumination source is oriented from 180º from south. Under this specifications steeper slopes facing towards or away to/from the source of illumination in the south-north direction are expected to be under the influence of **direct** (facing away) or casted (towards, steep narrow gorges) shadow during late day hours. The less values in the legend of map-8 and darker areas in the same map stands for such areas. These sites have values zero and appear completely dark in the SHADOW map, which isn't included here. As you can visualize from the above map the gentle to plain slopes have higher values of insolation index while steeper slopes and cleaves are dark showing less irradiance.

This is variable with the sun angle and orientation of illumination source, which may represent seasonal, and day hour variations in sun positions over the terrain. These factors then will be important in creating variability in energy input in steeper slopes like Irobland terrain coupled with aspect. Note then how relevant this information could be in vegetation types and characteristics as it highly varies with irradiance. Yet, it is worthy to mention that, this specific factor is less important to tropical countries compared to temperate regions where sun position is so variable in different seasons unlike in case of tropics.

4.3.2. TEMPRATURE INDEX MAP

The Temperature index map has almost inverse relationship with the altitude difference. Where the DTM values are maximal, you get minimum values for temperature. The map view below shows the temperature index map of Irob area. An INVERSE grey display option was taken for the reason of its visual clarity is by far higher than the linear grey scale. In this map the darker areas have higher values in the legend (Map-9) standing for higher in temperature indices. The negative values are those identified as zero on the SHADOW map and are the results of direct or casted shadow effect in cleaves and steepest slopes in relation to the sun angle and orientation.



Map-9: 3D-View of temperature index map

In general, the mountain peaks like ‘Ayga’ and ‘Assimba’ have got least values and Gorges like the big valley, (‘Zegazut-Gade’) and ‘Hassabala’ lowlands in the right lower parts of this map got highest values. The whitish spots are those areas with the negative values because of shadow effect.

5. CONCLUSIONS AND RECOMMENDATION

5.1. MORPHOMETRIC TERRAIN PARAMETERS

Topography in Irob land is extraordinarily complex. The altitude ranges around 150m to 3200m, which directly or indirectly will affect most climatic factors. These climatic factors are then the commanders of the overall biophysical process in a given environment.
From the result of this analysis, the major portion of Irob land is found to be in the steep slope (>45 degree) and in the altitude class of mid highland. This is also the region with long settlement history and over utilization. As a result, the current potential of the major portion of Irob land is expected to be degraded or at least very liable though field verification is necessary to be sure.

Therefore, research should be carried out to verify the automated outcomes of this paper with real ground truth on the physical environment of the region. It is also important to carry out a research so that to relate these terrain parameters with the biophysical processes. Based on that recommendation of most environmentally friendly livelihood mechanisms are needed to this peculiar environment if it should continue in life supporting.
The innovative land husbandry techniques in the region are excellent coping mechanisms where research and support from out side should continue to strengthen and sustain it.

It was possible from the slope and altitude map to show the presence of considerable plain land in the low land regions of Irob. The current figure doesn’t agree with the previous study/survey reports that have mentioned only 740ha as available cultivable land. Two issues should be assessed in this case, one the actual suitability assessment should be done in those areas depicted suitable in this paper with ground truth. Because in this paper, it was based mainly on slope steepness that the result was found, which is far than enough to conclude as land evaluation should include diverse factors that will determine the suitability of a piece of land for a given land use type.
Secondly the result of this paper shows the spatial locations of these potential suitable areas in the eastern Irob that are inaccessible; hence there is high expectation that the previous figures might have ignored these sites since they were mainly based on field survey unlike this paper.

5.2. HYDROLOGICAL

From hydrological terrain parameter analysis, the maps produced shows abundant stream locations. The quantification and identification of the real stream positions was not easier. Yet it was possible to visualize for visual perception, which could lay a path for planning for verification of actual potential ground locations for streams. The result can help for planning of watershed management in the region for the reason it shows preliminary catchment zones.

It was also possible to visualize, if not possible to quantify, the potential erosion risk sites. The STI, SPI and PLANC, and CTI are the key sources of information for this part.

5.3. CLIMATIC

Preliminary results in climatic terrain parameters show a relationship with slope face and altitude. Slope irradiance/insolation is mainly affected by the slope face in relation to the sun position (here 45 degree) where as temperature is mainly showed inverse relationship to altitude. In general the vast majority of the region has ample irradiance/energy input potential. The only exceptions are the extremely steep south/north facing slopes, which then may be laid under the direct or casted shadow influence.

The generated data from hydrological and climatic algorisms were not analysed to satisfactorily detail compared to morphometric terrain parameters. This is due to its difficulty in nature to quantify (very qualitative and visual) and the immature development of the script used, as well as its requirement for more time investment. Its level of development in ILWIS is also not as rich as that of morphometric terrain parameters. There are some recently developed Softwares like **DiGem**/**SAGA** and more updates in **ArcGIS**, which are specifically developed for terrain analysis. A further improvement with these recent updates is recommended before use. Further reifinment of the results with these software packages could for sure give better results in case of **hydrological** and **climatic** terrain analysis portion.

6. DISCUSSION

It was very difficult to get in depth so that to relate the whole analysis from natural resources management (NRM) point of view. This is mainly due to its wide range of out puts (too many parameters to be related), the need for thorough analysis to quantify most qualitative information, and the relevance of almost all results of the analysis to many aspects of natural resources management. Hence, here I will focus my discussion about the relevance of DTA information to NRM so that to bridge the gap in relating the topic to NRM. As usual, three terrain parameter categories can be considered, as **morphometric**, **hydrological** and **climatic** terrain parameters.

Morphometric terrain parameters are direct derivatives of digital terrain analysis (DTA) and they have two fold impacts on natural resources management. Information derived on morphometric terrain parameters like slope angle and slope shape can be utilized directly for evaluation of the terrain for various suitability analyses and conservation works. Slope characterization will also give very important information on the characteristics of flow/hydrological process, which are secondary derivatives of DTM. The slope steepness values will influence the velocity of flow so that to affect the erosive power of the flow. The shape information from PLANC will show where concave (concentration location and convex/divergence (ridge) locations are situated and hence the accumulation or dissipation of the flow. The information in flow volume meant information in erosive ness of the flow due to its volume as one of erosive factors. Thus the higher, the volume, concave shapes, the more power to transport sediment). Hence, slope analysis as one of most important morphometric parameter can render valuable information on erosion risks to help in designing best-fit conservation practices.

As secondary derivatives, from DTM, hydrological terrain parameters like SPI, STI, and CTI coupled with information from PLANC are sources of data on flow behavior and or surface hydrology. They contain information like the vulnerability of the terrain (STI), the erosive power of the flow (SPI & CTI). The higher the value in these three implies, the more potential erosion risk.

So again, hydrological terrain parameters are quite relevant sources of information for natural resources management planning.

Influenced by predominantly, the altitude and slope face, climatic terrain parameters are important indicators of energy balance over the terrain. This information can be generated from Slope Irradiance / insolation and temperature index maps. The information on energy input will indirectly help in analyzing the vegetation characteristics of the area. Hence, they are also of a paramount necessity to NRM. Lastly, I here recommend that all the information derived directly from digital analysis, should be verified in the field to make it reliable before usage for practical purposes.

The accuracy and precision of any digital terrain analyses analysis depends mainly on the quality of the **input data**, **analysis processes/methods**, the **soft ware** qualities, the **skills** and the complexity of **topography**, of the area itself.

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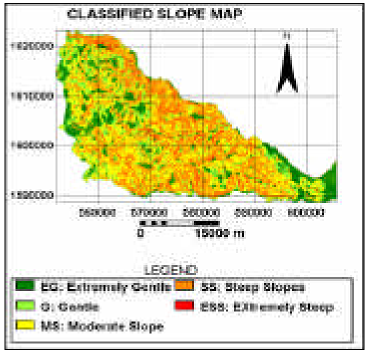
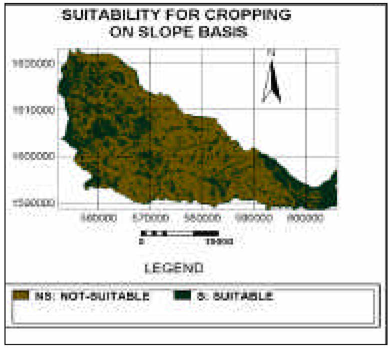
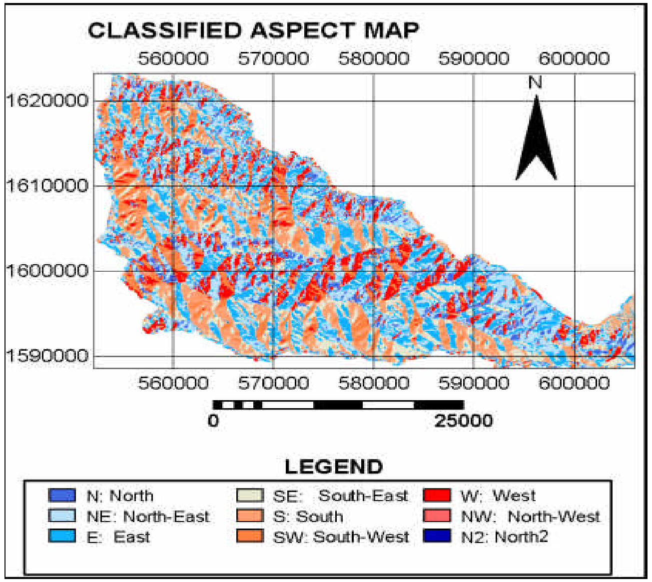
8. ANNEX-1 MAPS AND FIGURES



Map-3 Slope class map

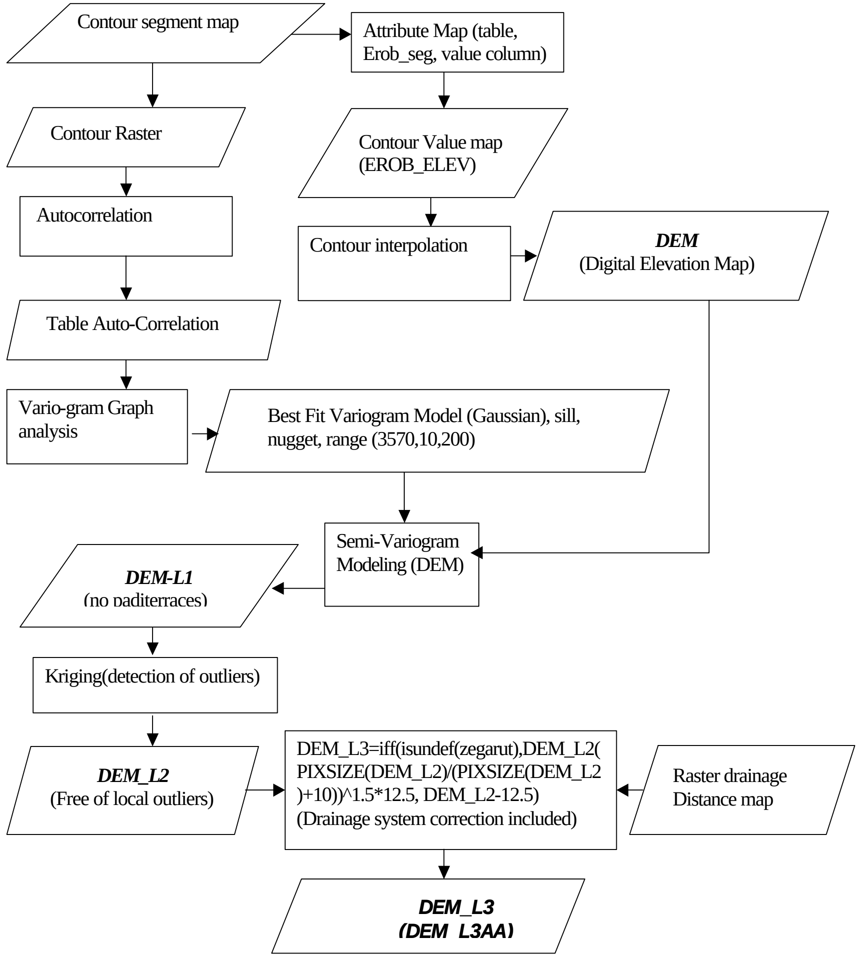


Map-4 Potential suitability for cropping

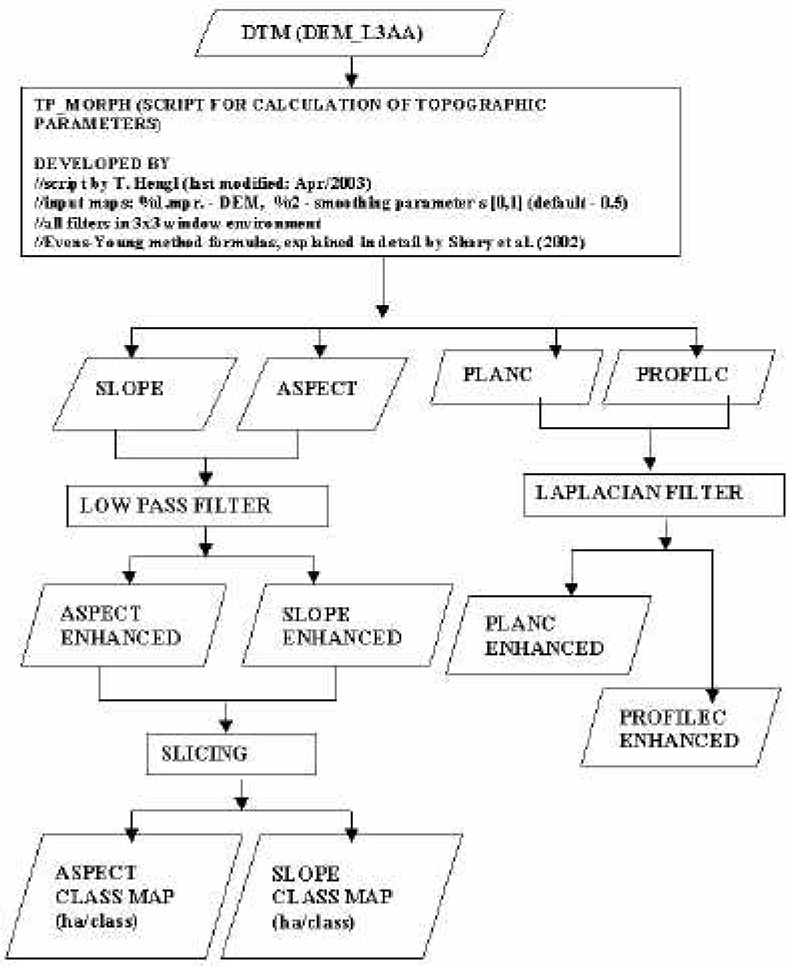


Map-6 Aspect class map

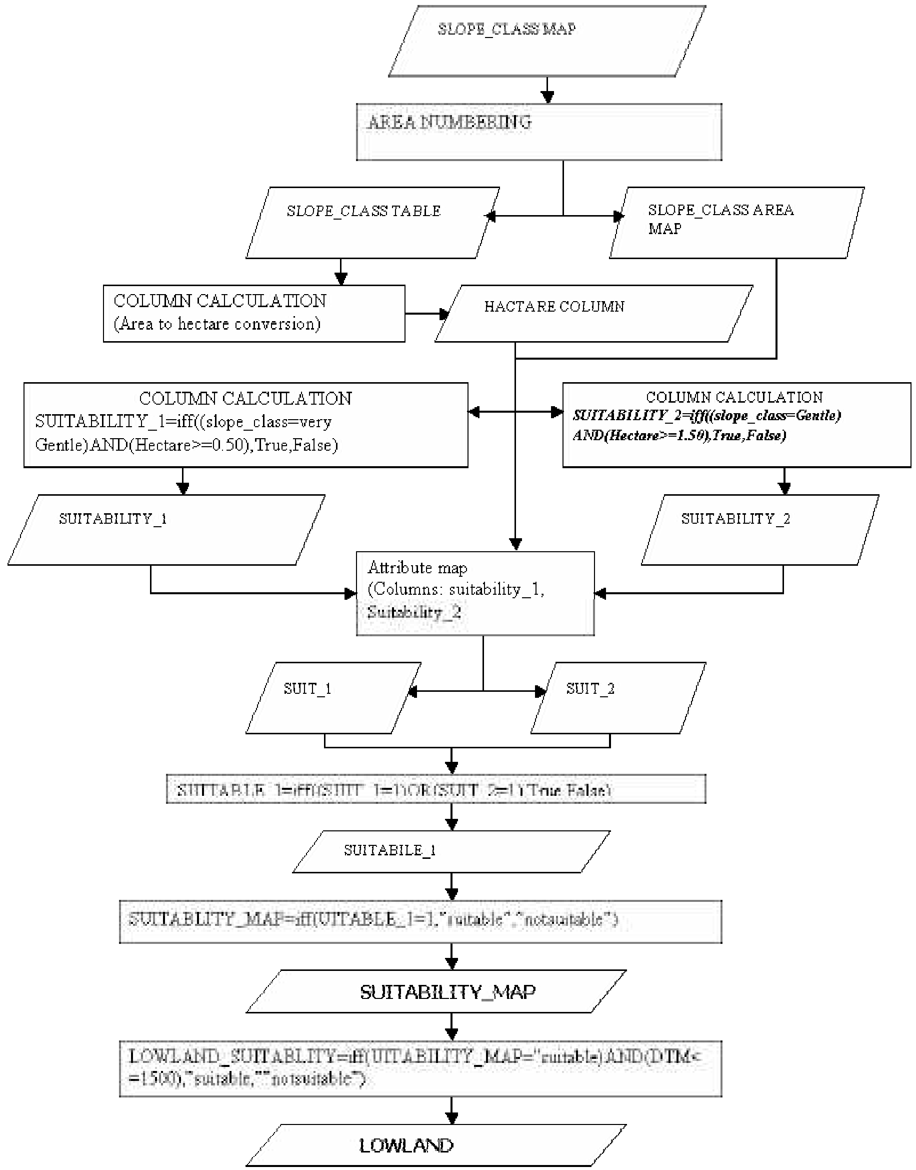
9. ANNEX-II FLOWCHARTS



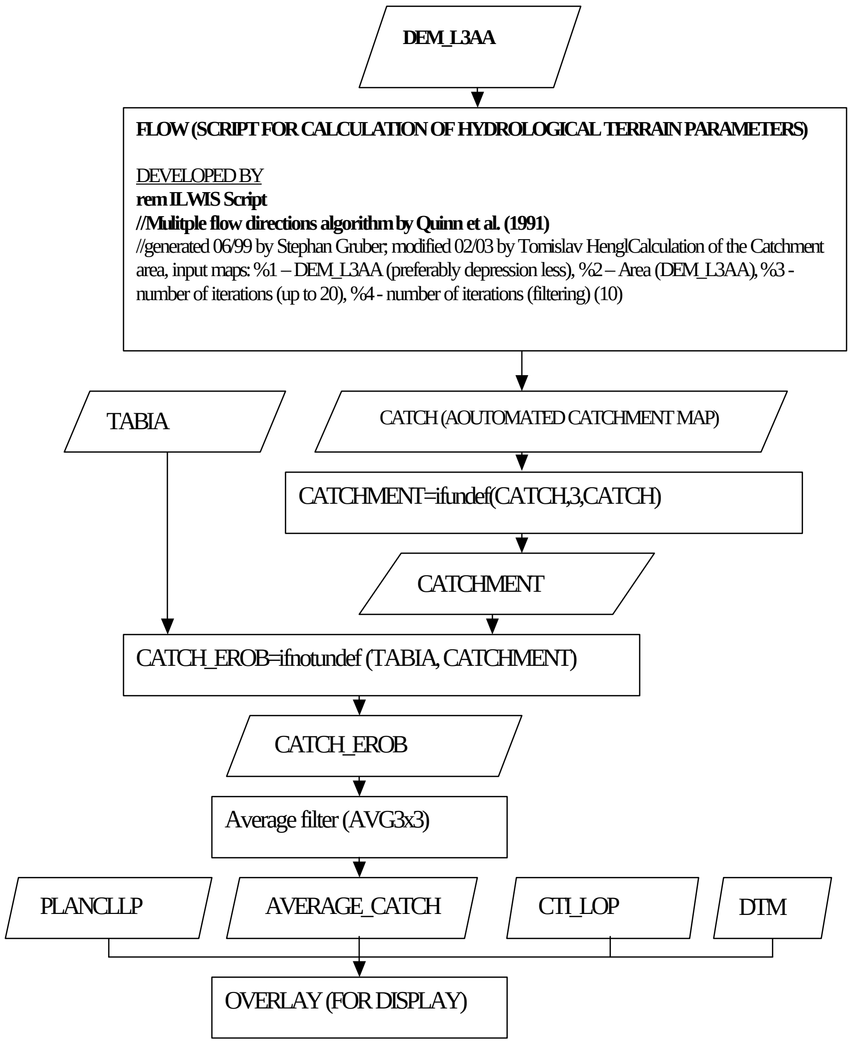
Flowchart-1: flowchart of DTM generation and quality improvement process



Flowchart-2: Generation of morph metric terrain parameters

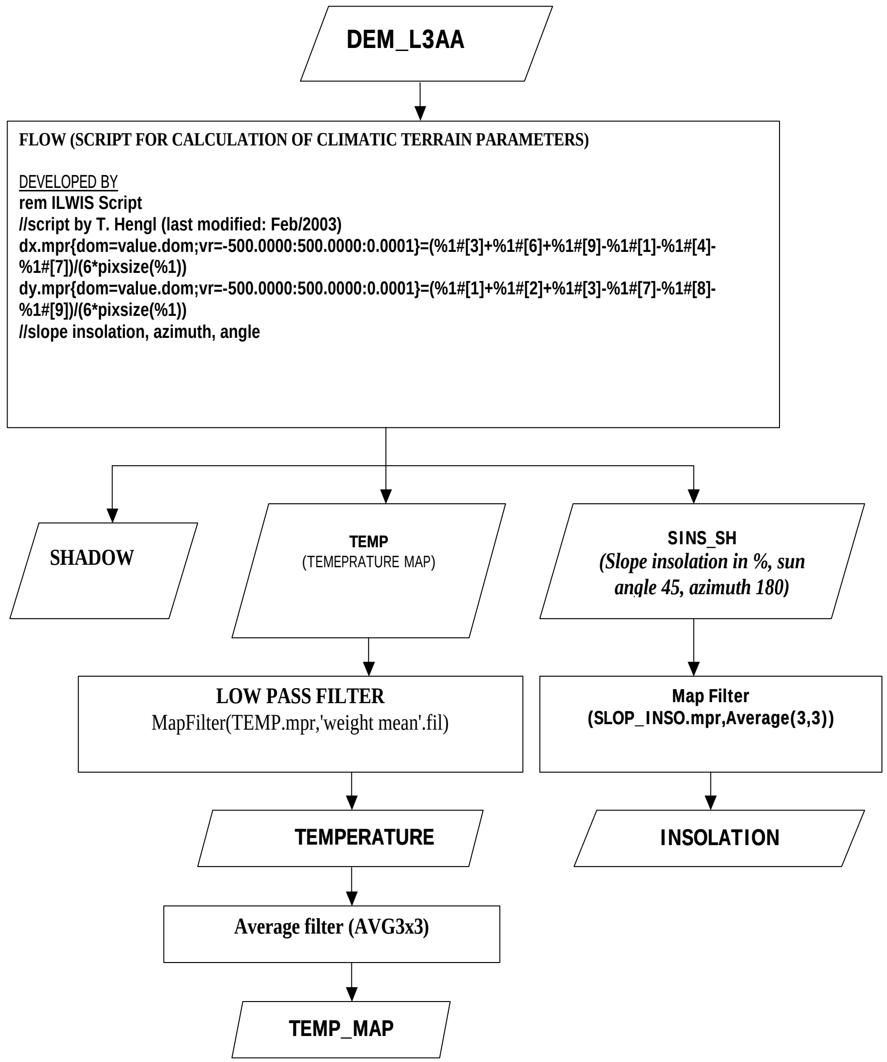


Flowchart-3 Suitability map calculation



Flowchart-4: calculation of Hydrological Terrain Parameters

TERRAIN ANALYSIS OF IROB LAND AND ITS RELEVANCE TO NATURAL RESOURCES MANAGEMENT, IROB, NORTHERN ETHIOPIA



Flowchart-5 Calculation of Climatic Terrain Parameters