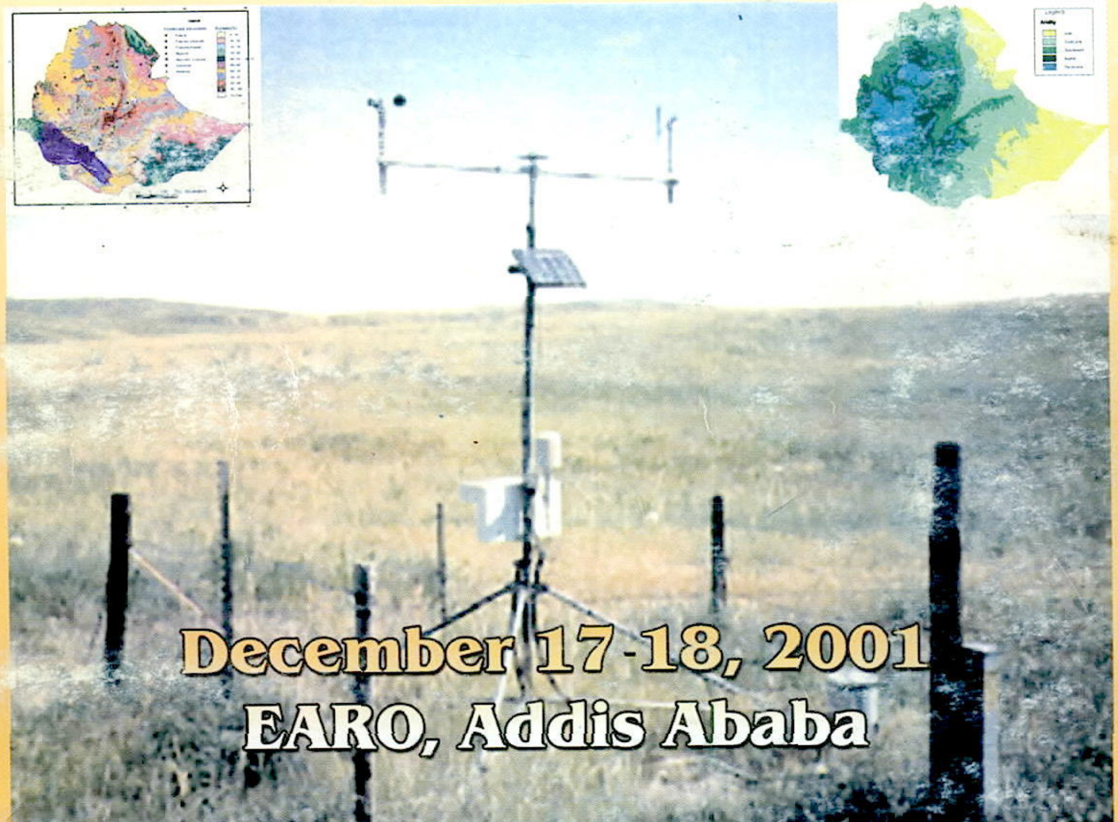
PROCEEDINGS OF THE NATIONAL SENSITIZATION WORKSHOP ON AGROMETEOROLOGY AND GIS



ETHIOPIAN AGRICULTURAL RESEARCH ORGANIZATION

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PROCEEDINGS OF
The National Sensitization Workshop on AGROMETEOROLOGY and GIS, December 17 -18,2001
EARO, Addis Abeba

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- GIS and Remote Sensing concepts and application;
- Topics related to climate change and desertification.

Therefore, 23 different research papers will be presented in the two days workshops. The paper presenters include stakeholders in agrometeorology and GIS with in EARO, Government organizations and NGOs. We expect some 200 participants from federal and regional research centers, government and non-government organizations.

With this brief introductory remark I would like to invite Ato Yiorgalem Abate, the Deputy Director General for administration to open the workshop officially.

OPENING ADDRESS

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Dear invited guests,
Dear colleagues,
Ladies and gentlemen

I feel honored for being invited to open this national sensitization workshop on Agrometeorology and GIS.

Ladies and gentlemen,

The Ethiopian economy is agrarian with the engagement of 85% of its population in agriculture. Agriculture accounts for about 45% of the gross domestic product (GDP) and 90% of the national export earnings. However, the sector is exposed to the effects of weather and climate. Failure of rains or recurrence dry spells during the growing season causes production reduction, which in turn leads to food shortage. Though food shortage arising from adverse weather conditions is not new in this country, its magnitude has increased in recent years.

On the other hand, the agroclimatic resources of the country are not well studied. Less attention was given to study these resource in the agricultural research system. This is mainly because there is a wide tendency to consider climate as a constraints instead of considering it as a resource. Because of this fact most agricultural research studies did not consider climate in their studies.

Agrometeorological service in the then IAR, started in 1965 with the establishment of a meteorological station at Melka Werer Research Center. Gradually, the number of different classes of agrometeorological stations increased and reached 35. Later on the Melkassa Research Center has been co-coordinating the service within IAR. Among the achievements made by the center archiving of a climatological data series and offering different services to researchers are the major ones. Research achievements are limited due to shortage of trained humanpower and limited research facilities. Generally, the then IAR gave very little attention to agrometeorological studies. Many of the research activities carried out had been under different research programs. Currently, new research activities of the program are separated from some other programs to stand by themselves. More over, the EARO management has given due attention to the subject matter and already established units to coordinate Agrometeorology, GIS and Biometrics and a joint national research program to coordinate these three disciplines. Hence, EARO is the first national institution to initiate agrometeorology and GIS research program. This program has the following five projects:

- Agroclimatic characterization
- Weather –crop/livestock/soil and water/forest production system
- Agroclimatic modeling and forecasting
- GIS and Remote Sensing
- Biometrics

To strengthen this program successive training programs for researchers and agrometeorological observes are being carried out. We have conducted in last July and August training workshop for agrometeorological observers in cooperation with the National Meteorological Services Agency, which I would like to thank for providing us with the resource person and facilities and playing active role in the aforementioned training.

Ladies and gentle men
Dear workshop participants,

We have signed memorandum of understanding with NMSA to conduct joint research activity on agrometeorology. Though, we do not have joint research projects with NMSA currently, the Agency is providing our researchers with meteorological data free of charge. Moreover, it is also sending us ten-day weather assessments along with the weather forecast on regular basis. EARO is playing an important role in the national committee for climate change. Therefore, this type of cooperation should expand and cover research collaboration.

Dear colleagues

To achieve its objectives, EARO has organized itself into five directorates, two technical departments and five national research programs. Moreover, it has taken several important steps to upgrade and modernize the management of the research system in the country. This includes the development of research programs and projects, good linkage with regional research centers, higher learning institutes, extension system and others. In addition it decentralized and created incentive mechanism to enhance the management system to increase the efficiency and effectiveness of the research system in the country.

EARO would like to work together with other stakeholders not only in areas of Agrometeorology and GIS but also in areas of crops, livestock, forestry, soils, water, socio-economics, extension and other fields of interest for which EARO is mandated. Therefore, I would like to use this opportunity to call other stakeholders to work with us.

Finally I would like to congratulate the Agrometeorology, GIS and biometrics research program staff for organizing such an important sensitization workshop.

I declare that the workshop is officially opened.

THE HISTORY AND ROLE OF METEOROLOGY IN ETHIOPIA

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Abstract

All living things in one-way or the other could not escape from the impact of weather and climate. Hence, meteorology should be given due attention in order to take advance measure to minimize the impacts of hazardous weather and climatic conditions. In this aspect, the basis that was laid by the government to create an institution which can shoulder this responsibility must have been formulated. Hence, the National Meteorological Service Agency (NMSA) was established under the proclamation No.201 of 1980.

INTRODUCTION

Meteorology is the science that deals with atmosphere. It studies the weather and climate phenomenon of the present and of the future. Moreover, it plays the greater role in assisting the exploitation of almost all of the natural resources. Hence, it is one of the rapidly growing fields of the science of today.

All living things in one-way or the other could not escape from the impact of weather and climate. The negative impact of weather and climate such as drought, flood, tropical cyclones, etc. has a devastative economic and social outcomes, while the favorable situation of the weather and climate would play a greater role in the better economic and social return.

Therefore, when hazardable weather and climatic condition is anticipated, meteorology would be in place to give early warning to the authorities concerned and to the direct beneficiaries as to take advance measure to secure the life and property of the people. This has been experienced by the NMSA whenever hazardous conditions, such as untimely rains were expected during the dry season by the heading tropical cyclones that hit the Gulf of Aden and the heavy rains that cause flood and the drought that frequently occur over the agriculturally productive high lands of the country. Hence, meteorology should be given due attention in order to take advance measure or to minimize the impact of hazardous weather and climate conditions, and to plan the economic and social aspect of a country.

The science of meteorology became vivid and important with the emergence of aviation technology particularly in the third world. This situation was also true in Ethiopia. When the Ethiopian Civil Aviation Administration (CAA) started its services in 1951, the meteorological department was opened to backup aviation.

However, with the growing demand by both the public and various economic sectors, the National Meteorological Services Agency must have come into existence with the main objectives:-

1. To render meteorological services,
2. To control air pollution and maintain the natural balance of the air and
3. To discharge better, Ethiopia international obligation regarding meteorological activities.

It becomes vivid that at any time and places, meteorological services constitute the driving force behind the development of disaster prevention, agriculture, transport, recreation and tourism, electrical utilities and energy, media and general public, construction, environment, health and water resource. Hence, this paper does not only try to look in to the Agency's background, but also tries to give some birds-eye view on few relevant subject matter.

The Atmosphere and its Composition

The major gaseous composition

Meteorology as mentioned earlier the science that studies the atmosphere. The earth is surrounded by a gaseous envelope known as atmosphere. The atmosphere is composed of various gaseous, of which the major ones are Nitrogen 78%, Oxygen 21%, Argon 0.93% and Carbon Dioxide 0.03% by volume. In addition, there are minute quantities of such gaseous as neon, helium, methane, krypton, hydrogen, nitrous oxide, xenon, etc. Nitrogen and oxygen make about 99% of the air but are generally passive in most meteorological processes. By contrast, some of the minor constituents of the atmosphere produce important atmospheric effects despite their small concentrations, which again are of serious concern to meteorologists. In addition to the dry air, there is a variable amount of water vapour, ranging up to several percent. This can change its state to become solid or liquid.

Atmospheric ozone

Ozone is just nothing but three atoms of oxygen that exist in the atmosphere. It is formed by the photons (small parcels of energy that comes from partly electromagnetic radiation and partly from ultraviolet radiation) The process of making ozone, Hence, occurs by colliding the oxygen (O_2) atoms with the single molecules of the third particle (M). Then Ozone (O_3) may be formed.

$O_2 + O + M \Rightarrow O_3 + M$,

The Ozone molecule is heavier than oxygen molecules. They, therefore, tend to sink in the atmosphere and many accumulate at altitude between about 15 and 35 km. In this region the ozone molecules are largely protected from the ultraviolet radiation to the sun. Actually it is the ozone that protects us from the ultraviolet rays.

Water vapor in the atmosphere

Water vapor is always present in the atmosphere, but in varying amounts. It first enters the atmosphere from the surface of the earth by the process of evaporation and transpiration. Later it changes to the liquid or solid state and finally returns to the earth's surface as drizzle, rain, snow, hail, dew or frost. On the average, the concentration of water vapour decreases with altitude.

Carbon Dioxide

Carbon Dioxide enters the atmosphere by such processes as human and animal breathing, and the decay and burning of materials containing Carbon. Volcanic activity is also a source of Carbon Dioxide. Carbon Dioxide is removed from the atmosphere by plant life. Carbon Dioxide provides the Carbon required for the growth of the plants. Parts of plants are then eaten by man or by animals, and so the Carbon in living things is derived from the Carbon Dioxide of the air.

The concentration of Carbon Dioxide in the lower atmosphere is affected by changes in the temperature of the oceans, in which Carbon Dioxide is released into the air. The human interference, however, has a serious and negative impact on this gaseous. The depleting of ozone by super sonic flight, gives rise to the escaping ultra violet. Similarly deforestation process interrupts the hydrological cycle whereas combustion and industrial smokes increase the concentration of Carbon Dioxide in the atmosphere, Which in return increases the temperature of the atmosphere.

The Vertical Divisions of the Atmosphere

Many methods have been developed for studying the physical conditions of the atmosphere. These have been made possible with such technological development as earth satellites, rockets, sonds, etc. As a result of these studies, a great deal of information has become available about the atmosphere as a whole. However, in studying the atmosphere, it is often useful to distinguish various vertical divisions of the atmosphere, which are of meteorological significance. The classification of the atmosphere based on temperature, distinguishes four divisions:- the troposphere, stratosphere, mesosphere and thermosphere.

The following figure (Figure 1) would enlighten us with the concept of the vertical divisions of the atmosphere.

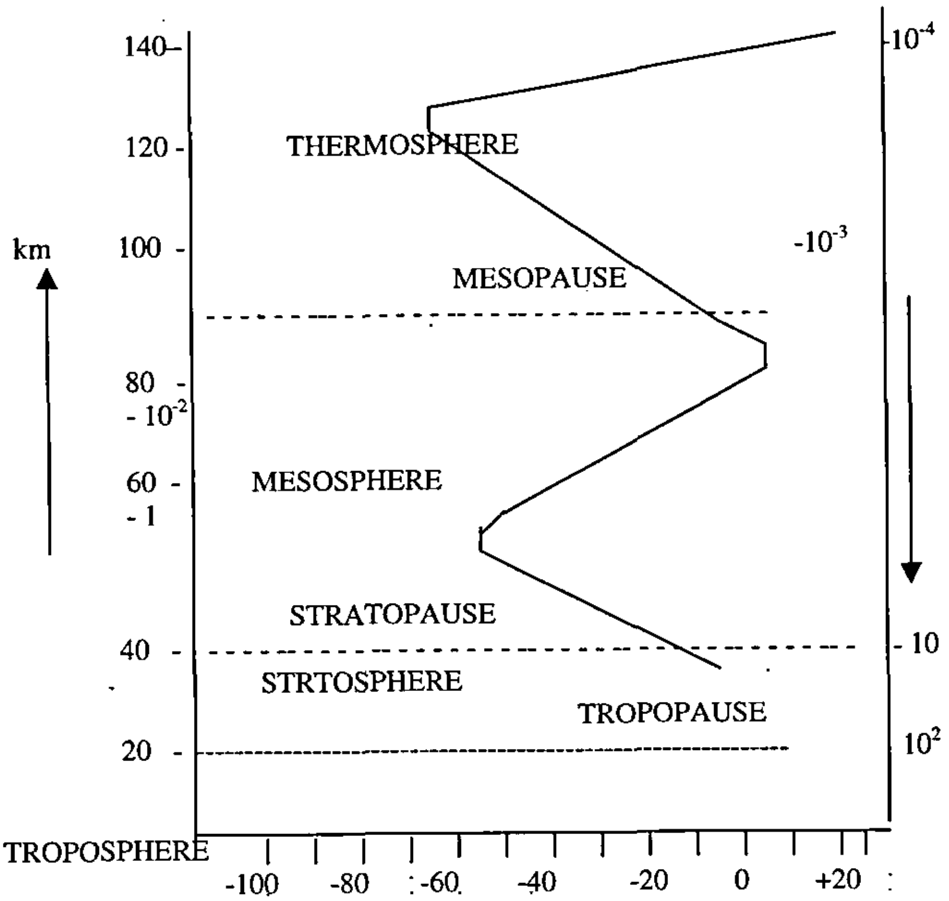

Figure1. The vertical divisions of the atmosphere

The lower part of the atmosphere, the troposphere is the region where our interest lies to study in depth. The troposphere contains the greater part of the mass of the atmosphere. The moving weather systems and their associated cloud systems are almost entirely confined to this region. In this region, the temperature and the density of the air decreases and the wind speed increase with height. It is in this region where a lot of atmospheric gases are concentrated and whereby a lot of atmospheric activities take place. The top of this layer is called the tropopause where temperatures cease to decrease with height. The height of this layer varies with latitude. In the tropics, it is as high as 18 kms whereas in the higher latitude doesn't go beyond 8 kms.

The remaining three spheres indicated in the figure need not be discussed for the consumption of this workshop as they are not our area of interest.

The emergence of the Ethiopian meteorological services and the role of meteorology in the national economy

History tells us that meteorological services made their debut in Ethiopia in the early fifties to satisfy the growing demands in the fields of Aviation. Countries can not dispense today without meteorological services. This is precisely why the expansion of meteorological facilities is being given an important place in every country. Greater attention is given on the role of National Meteorological Services in monitoring, understanding and predication of weather and climate so that the humankind is adequately prepared to face the challenges related to weather and climate now and into the future.

- Having this in mind, the need for meteorological information grew with time by various economic sectors, there came a challenge as to how to fulfill this demand by the then a department under the CAA. By doing this, several attempts were made to open the door for the users. Ultimately, it was believed by the government that the information generated by Meteorological Services would highly assist the different economic sectors and as a result the Ethiopian National Meteorological Services Agency established in 1981 under the decree No.201/81.

The National economy of Ethiopia comprises of the agricultural, industrial and service sectors. Each of these economic sectors shares something in common in the process of its development. This common denominator is the resource from the atmosphere which can be quantified in terms of measures capable of describing the behavioral aspects of the atmosphere.

The science of meteorology, thanks to the technological advances achieved in the field itself and other related categories, has made it possible to survey the biosphere and the lithosphere for a better understanding of their behavioral aspects. Such a surveillance of the atmosphere and the uppermost layers of the earth can contribute a lot to crop monitoring, facilitating industrial processing and planning aspects of the various economic sectors. This is a clear manifestation of the role that meteorology can play vis-à-vis the close relationships that exist between atmospheric behaviors and every aspect of human engagements. As a result of such close relationships, it has been possible to increase efficiency in agricultural production dramatically, which in turn has a positive role in facilitating the supply of industrial input such as raw material.

When it comes to the planning aspect, a set of meteorological data for a specified period of time is crucial both in feasibility studies and operational aspects. Hence, site selection for agricultural or industrial projects can better be carried out through conducive atmospheric manifestations for sustainable economic development. Hydrological services can benefit a lot from meteorological services as the two are bonded through water cycle dynamics. Hence, locating industrial plants, potable water distribution for both rural and urban dwellers, assessing the water (both surface and sub-surface) requirements of irrigation projects, etc., all have something to exploit from meteorological service rendering activities.

It could be possible to extend the argument further. However, the aim of this paper is to portray the role of meteorology in promoting the day-to-day activities of the major economic sectors.

Meteorological Services Provided by the NMSA

A glimpse at the historical development of provision of meteorological services in Ethiopia takes on both national and international dimensions. At the very beginning of the service rendering activities of the National Meteorological Services Agency, meeting the needs of the air transport service sector was high on the agenda. As a result of this, due emphasis had been given to facilitate domestic and international airports with conventional meteorological instruments installed at the so-called synoptic meteorological stations. Meteorological data colleted from these stations, though mainly manual, contributed a lot towards coping with fulfilling Ethiopia's requirement for global data exchange which is the prime objective of the International Civil Aviation Organization (ICAO) apart from the domestic aspect. Hence, it has become possible to achieve safe, efficient and economic air navigations with adequate aeronautical information as input proper. Of course, this has been the case since the beginning both in Civil and Army Aviation.

Following diversifications in the socio-economic formation the role of meteorological services has exhibited a tremendous leap in response. Nearly every piece of meteorological information has turned out to play a vital role from planning to operational phases of various sectors of the economy. By way of mitigating such prevalent issues, the NMSA has embarked on the following main service rendering activities:

1. Meteorological stations network expansion,
2. Increasing meteorological data acquisition, archiving and retrieval efficiencies,
3. Enhancing consultation service through appropriate human resource development,
4. Carrying out forecasting service to satisfy the needs of users,
5. Discharging international obligations of the country as far as fulfilling World Meteorological Organization and ICAO provisions for watching the atmosphere and dissemination of meteorological data,
6. Ensuring appropriate policy formulation with regard to safeguarding the environment from aggravated air pollution, and
7. Expanding capacity building of the NMSA with a view to promote Regional Meteorological Services.

Rules and regulations through appropriate policy formulations govern the above stated meteorological services. Hence, users from any economic, social and cultural sectors are welcome to enjoy the various meteorological services rendered by the NMSA as per policy provision. However, our Agency has limitations in serving users that emanate from lack of meteorological instruments and accessories thereof due to escalating prices of the former which may unfortunately turn out to be unbearable as a result of insufficient resource allocation. Anyhow, such failures could be tackled accordingly to bring about more and more success.

The technical facilities that the NMSA use in its day-to-day activities

Despite the poor economic situation of the country, the NMSA has acquired the basic or the most needy facilities for its major activities. This, however, does not mean the Agency is in its fullest capacity to determine and forecast all the weather activities over the country. In this regard, even the developed world with its fullest and advanced facilities, did not attain the best results allover. Nevertheless, the national Meteorological Services Agency of Ethiopia is at least in a better position as compared to most of the African countries both in its input and out put. The number of meteorological stations is close to seven hundred among which the number of principal station is about one hundred twenty. They provide all meteorological parameters which are mainly used for Agriculturalists, early warning and all other economic sectors.

The NMSA has the following facilities to execute its day- to-day activities:-

- As mentioned earlier, with the acquisition of conventional meteorological instruments, the NMSA has established about 670 different classes of meteorological stations all over the country. Although the vast number of these stations send their data both to regional offices and to the center on ten daily or monthly basis, while the principal ones are supposed to send daily to the respective offices for operational work. The stations exchange their respective data by trans-receiver single side band (SSB) radios and telephones as well, while from the rest we receive by mails monthly.
- The radio sonde or the upper air observations are carried out at two stations Addis-Ababa and Negele. The radio sonde works by sensor meteorological instruments having loaded transmitting radio attached to a one kilogram balloon. The radio transmits temperature, wind direction and speed, and humidity to the ground receiving station measured by each sensor. The information collected by the upper air stations are one of the best tools for making meteorological forecasts for a given parts of the country.
- Meteorological Data Dissemination (MDD) or The Weather satellite reception for global, regional and country level is one of the best component of the facilities that NMSA possess at its disposal. It facilitates a conducive condition for making a satisfactory forecast by avialing actual and prognostic meteorological information from Europe. This system provides information not only in coded and decoded forms, but also actual and prognostic charts in the final form.
- The invent of internet has contributed a lot to meteorological services on the globe. This vital system backs our services to a greater extent. It provides meteorological information that would fill the gap missed by MDD or ourselves both in actual or prognostic meteorological information.
- Computers are the key and basic necessity for all kinds of meteorological activities at all levels of its services. Starting from data entry, all the way up to computation, analysis and interpretation the use and application of computers is of greater importance to meteorological science. They will also serve the Agency in near future as a communication media via microwave link with our regional meteorological offices.

CONCLUSION AND RECOMMENDATIONS

Although the meteorological science is infant as compared to most of the other natural sciences, the growth and development in the field has become tremendous since the last two to three decades. Having known the uses and values of meteorology, the efforts being paid by the scientists towards research and development allover the globe is also immense. However, with the crippling economy and limited resources, we are very much behind in the advancement of the field. We need to work very hard in doing to arrive at what the other end of the world is achieving. The NMSA would still need to strengthen the capacity building to fulfill the alarming demand from the various sectors of the economy.

In addition to this, as the handful population of the nation fully depend on agriculture, time now has come to work together with the agricultural community at large. Joint research works with EARO scientists have to be carried out in order to improve the agricultural production based on crop-weather relations. Once again, both EARO and NMSA have to work hard on the strengthening of information exchange and expansion of stations network as the interdependency is very high.

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HISTORY AND THE NEED FOR INSTITUTIONALIZING AGROMETEOROLOGICAL RESEARCH IN ETHIOPIAN AGRICULTURAL RESEARCH SYSTEM: CURRENT STATUS, SCOPE AND GAP ANALYSIS

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Abstract

Agriculture is the springboard for the whole range of economic developments in Ethiopia. However, farming systems are as diverse as agroecology. These carry both opportunities and disadvantags to the farming community. The diversity of natural resources (climate, crops, livestock, vegetation and soil types) entails the existence of the *enormous potential of agricultural development in this country. On the extreme side, farming takes place almost entirely under the full-blown impacts of climatic variability.*

The climatic factors like temperature, solar radiation, wind speed and relative humidity enhances evapo-transpiration (concurred with agricultural drought, shortage of watering points and feeds availability for livestock and diminished species composition of vegetation of a given agro-ecology). Diseases and pest incidence is also strongly associated with localized climatic variability.

While this is the objective reality, in the past, no significant attempts have been made to integrate the quantitative climatic /weather information into technology generation and transfer efforts, at least, in order to account for the prevailing low agricultural productivity due to these climatic variables.

Here, agrometeorology as a science that harnesses the knowledge and experience of meteorology into agriculture is every thing; it binds information from various and constraints into one comprehensive expression and determines whether these can be managed through agricultural research. In this case, agrometeorology being replete with knowledge and experience can play greater role in addressing the multi-faceted research problems associated with low agricultural and ecological productivity. Therefore,,, its institutionalization in the agricultural research system is more than justified.

In this context, the historical development, past achievements, scope and gap analysis in Agrometeorology research program of EARO is reported herein. Currently EARO has about 33 agrometeorological stations of vary standards, across a range of agro-ecologies, as well as, massive climatic data. It has also been grown up to a full fledged national program including other two related projects (Biometrics and Geographic Information System).

In this paper, possible recommendations, as derived from the framework of the entire report are presented, so that agrometeorology may establish its momentum in the research system and gradually becomes the day-to-day component of research activities in EARO.

INTRODUCTION

Agriculture is the springboard for the whole range of economic development in Ethiopia. However, farming systems are as diverse as agroecologies. These carry both opportunities and disadvantages to the farming community. The diversity of natural resources (climate, crops, livestock, vegetation and soil types) entails the existence of the enormous potential of agricultural development in this country. On the extreme side, farming takes place almost entirely under the full-blown impacts of climatic variability.

The climatic factors equally important : like temperature, solar radiation, wind speed, relative humidity and evapo-transpiration influence crop production, watering points and feeds availability for livestock and species composition of vegetation of a given agro-ecology. Diseases and pest incidences are also strongly associated with localized climatic variability.

The cyclic and the broad seasonal characteristics of the Ethiopian climate, with the alternating dry and wet seasons, are determined largely by the annual movements across the country of the equatorial low pressure zones and the seasonal movement of the Inter-Tropical Convergence Zone (ITCZ). These two cause the convergence of moist winds of southwesterly origin. During November to February (when northeasterly wind persists), long periods of dry winds are experienced, with little or no cloud and low relative humidity. Between March and June, the convergence of the moist south easterly winds originating from the Indian Ocean with weakening north easterly air stream causes heavy rain to occur over many places, such as Bale highlands, Negele Borena and southern Tigray of Ethiopia. The rains during this season are light shower and less reliable (highly variable). The main rains come in July to October, when, due to the position of ITCZ, moisture-laden winds from the south Atlantic and Indian oceans converge over the highlands of the country (NMSA, 1999). In fact, this could be modified by local factors, such as mountains, altitude, exposure/ slope and distance from the seacoast.

Irregularly, the combined effect of El Nino(EN)- the warming of waters of the eastern pacific of Ecuador, Peru and Northern Chili and Southern Oscillation (SO), together known as ENSO events is believed to be the major cause for Ethiopia's frequent drought, along with sea surface temperature(SST) anomalies in the Southern Atlantic and Indian Oceans (Haile, 1988). According to Glantz *et al* (1991), there is strong association between ENSO and droughts in Ethiopia due to an atmospheric tele-connection of the seemingly disconnected weather anomalies. This means that, the oceanic and atmospheric processes in another parts of the world significantly influences Ethiopian climate. These negatively affect rainfall distribution in Ethiopia by displacing and weakening the rain producing air masses.

To understand these cyclic and abnormal climatic patterns and plan effective agricultural research projects, agrometeorology as an applied atmospheric science is very essential. Agrometeorology helps to undertake detail research on this predicaments, generate scientific information from diverse sources and give a unified and quantitative picture of the environment in which research and development works are being undertaken. This integrated information helps agronomists, physiologist, breeders, pathologists, entomologists, extension workers and farmers take informed decisions in their respective core business. It was with this gross notion that institutionalizing Agrometeorology Service in the former IAR has gone back to the age of the institute itself. All along the way, establishing new weather observatory stations have almost been concurred the establishment of any new research center. These days due to the fact that the Ethiopian government has attached greater importance to agriculture-led industrial development, and for there is no other economic sector as agriculture that is sensitive to the climatic and immediate weather changes, greater stress than hitherto has been given to agrometeorology research in EARO. Accordingly, agrometeorology now has already grown up to the full-fledged national program level, including its own two and other two sister projects, vis., Geographic Information (GIS) and Biometrics. That is historical turning point and a welcome realization!

The overall objectives of agrometeorology, Biometrics and GIS are:-

1. To maintain/upgrade existing agrometeorological stations and establish new ones in a representative research centers and agroecologies.
2. To establish strong agrometeorological databases of biophysical resources: climate, crop, soil, livestock and vegetation through application of climatic, biometrics and GIS knowledge and experience.
3. To promote improved research methodology and undertaking localized weather sensitive and priority problems- focused research activities.
4. To predict annual agricultural production potential, rainfall, drought, erosion, diseases, pests and yield losses(early warning system).
5. To contribute to the natural resources conservation centered research efforts of EARO.

The objective of this paper is, Therefore,,, to summarize and report on history, achievements and progresses made in the past; and assess the scope (potential) and the gaps to be closed with major emphasis on agrometeorology research and service of Ethiopian agricultural research system.

A. History And Current Status of Agrometeorology In Ethiopian Agricultural Research System

The service was first established at Werer and Jimma research centers in 1965 and 1968 respectively (Girma Mamo, 1995), the time when even the NMSA was not set up to its current organizational level. Since then, the mission of establishing stations across a range of geographic regions and research centers representing various agroecologies has been gradually accomplished, in collaboration with NMSA. Currently, EARO has 33 agrometeorological stations of varying standards. The generated massive climatic data have many interesting and flexible features of potential utility in that most are registered five times a day (at 0600, 0900, 1200, 1500 and 1800 hours), as well as in terms of completeness, representativenes for their vicinity and length of record period. These data can be used in some critical analysis and interpretation in relation to crops, livestock, soil and vegetation management. Since 1980, Melkassa Agricultural research Center (MARC) has been played a coordination role for IAR's agrometeorological stations network. Most of the observatory stations have been established and upgraded only after the coordination responsibility was vested in MARC, as well as, standardizing data recording and archiving for uniform data processing and summary reports generation has been possible. This has also ensured data security and integrity, although it still exists in hard copies.

Utility scope of the existing climatic data

EARO has limited capacity in terms of agrometeorological research resources (including standard meteorology stations, observers and professionals), as well as, massive climatic data. The potential advantages embodied in the existing meteorology facilities and data could be manifold, that it can take us certain distances in research. The following paragraphs present some uses of the existing meteorological data.

1. To model and map agroclimatic regions in broad terms and identify the agroclimatic analogues (efficient and inefficient farming zones), for possible research and extension interventions, such as correct timing of agricultural operations and take full advantage of weather and climate conditions.
2. To make environmental screening, develop and extend areas for agriculture purpose, for instance, wheat production beyond its traditional belts (Jeffrey *et.al.*, 2001).
3. To undertake confidence limits and probability analysis for instance of receiving a given amount of solar energy and rainfall and foretell with some degree of accuracy of the forthcoming rainy season for that climatic regime and also make site similarity analysis (Manning, 1950; Belay Simane 1990: Hailu Regassa *et. al.*, 1987). For instance, given information on the amount of water required for germination and establishment, the probability distribution of successful planting dates of crops can be computed.
4. To analyze historical climatic data in conjunction with GIS technologies (prediction of rainfall, drought, crops phenological stages and yield in a more enhanced mode even for locations where meteorology stations not established (Jeffrey *et.al.* 2001).
5. To quantify the runoff yields of watersheds for water harvesting and assess the erosion hazard of a given environment.

6. To develop regression models for the data collected from the standard meteorology stations and the ones obtained from field level experiments (yield, disease and pest prevalence and their control measures), based on which, knowledge gaps could be identified and appropriate research interventions planed.

General gaps: Macro level

Considering it's relatively longer age and the parallel momentum it should have attained in the research system, it may be surprising why agrometeorology couldn't organize itself up to that expectation. The major problem among many others is, institutional constraints (imprecise vision, goals and objectives) and *professional constraints (biases among research personnel and shortage of* effective research resources). At the utmost, some interested individuals (Table-1) have carried out climatic analyses of all past seasons for which records exist and used them in making a single fixed "best bet" recommendations such as 'optimum date of planting', 'plant population' and 'fertilizer levels', diseases and pest control measures. While these broad information have assisted in formulating and targeting technology packages to a given locations; however, such data sets are of limited significance, since the response of biological resources to physical (climate, weather and soil) resources is not so simple as to be defined by such descriptive statistics alone. Moreover, such techniques make simple assumptions, i.e., all what rains is considered as effective rainfall, be it trace or excess in amount. However, since losses from evaporation, deep percolation, seepage and surface run-off are inevitable, such information serve only up to a limited extent. In such cases, the problems apparently come after the analysis and interpretation, when data needs to be interpreted with the location specific climatic and farming system perspectives, where simple treatment difference may not be enough to adopt improved technologies.

Table 1. Some of the published works in agrometeorological research

No	Title	Refernces,published works
1	Agroclimatic analysis to assess crop production potentials in Ethiopia	Belay Simane, (1990), ICRISAT, India
2	Agroclimatic potentials of the arid & semi arid zones of Ethiopia	Engda Mersha,(1994) 1st national workshop on dryland farming research in Ethiopia
3	Agroclimatic analysis for sustainable development and agricultural planning over Ethiopia	Engida Mersha,(1992), WMO/UNDP Project Eth/86/021
4	A desertification convention based classification of moisture zones of Ethiopia	Engida Mersha,(2000) EJNR. 2(1):1-9
5	Identification of Appropriate flowering and fruit setting periods of arebica coffee in relation to probability analysis of precipitation occurrence at Melko	Gibramu Temesgen and Yakob Edjamo (1997) SEBIL, Vol,8, CSSE,
6	Forecasting of yield of selected Arabica coffee- using multiple regression model	Gibramu Temesgen, (1996) SEBIL, Vol,7, CSSE
7	Probability analysis of microclimatic variables and impact of some biological environments on sorghum varietal response to selection	Girma Mamo (1995), SEBIL, Vol,6, CSSE,
8	Long term mean data summary of all stations	Hailu Adnew(unpublished works)
9	Agroclimatic data analysis of selected locations in deep black clay soils(Vertisol) regions of Ethiopia	Hailu Regassa, *et., al.*(1987) ICRISAT, India
10	An Agroclimatological characterization of bread wheat production areas in Ethiopia	Jeffrey W.White, *et.al* (2001). Mexico, D.F. CIMMYT
11	Climate classification of Ethiopia	Lemma Gonfa,(1996), Meteorological Report, Series No 3
12	Relation of weather variables to crop disease outbreak	Mengistu Huluka, (1989), 21st NCIC
13	Towards a comprehensive agroecological zonation of Ethiopia	Mengistu Negash, (1988), 20th NCIC
14	Relation between weather and outbreak of insect pests	MOA, (1989), 21st NCIC
15	Climatic and Agroclimatic Resources of Ethiopia	NMSA (1996) Meteorological Report, Series No 1
16	Assessment of drought in Ethiopia	NMSA, (1996) Meteorological Report, Series No 2
17	Climate variation and its impact on agriculture	NMSA,(1988), 20th NCIC
18	Agroecological zoning approach to length of growing period: towards the determination of agroclimatic zoning	Tafese Olkeba, ,(1988), 20th NCIC
19	Causes and characters of drought in Ethiopia.	Tesfaye Haile. (1988). EJAS. V 10 (1-2)
20	Ring and inter node indices as affected by climatic changes in coffee and shade trees	Yakob Edjamo & Alemseged Yilma SEBIL, Vol,6, CSSE,

Table 3. Characteristics, challenges and potential farming system strategies under different rainfall patterns in Ethiopia(tropical climate)

Rainfall/ Evaporation Characteristics		Associated Challenges/problems	Potential Strategies (thematic areas)
I) Cyclic	1) Total absence of rainfall/acute shortage/Sub-marginal	Rainfed agriculture very difficult (<250 mm of rainfall).	➢ Total irrigation ➢ Off season tillage and fallowing.
	2) Low amount: many rainfall values lower than the mean (curves skewed to the left of mean)	Cropping is possible, but rainfall is insufficient to sustainably meet crop water requirements from the economic point of view(*low potential* expression)	➢ Selection of drought tolerant crop varieties ➢ Moisture conservation measures ➢ Reduced seed rate /lower plant population ➢ Reduced fertilizer rate ➢ Protective/life saving irrigation plus extension of LGP
	3) Low predictability of effective onset and & cessation dates.	Difficult to adopt fixed date of sowing, crop/varieties, planting density and fertilizer levels.	➢ Building prediction capacity ➢ Off season tillage to capture early rains that comes any time out of the rainy season ➢ Development of crops varieties of wider ecological plasticity
	4) Short duration (short length of growing period), late onset, early cessation	Potentially high yielding long cycle crops cannot be grown successfully	➢ Development of early and extra early crops varieties) ➢ Water harvesting to extend the length of growing period ➢ Adjusting fertilizer rate accordingly (cut back cost of production) ➢ Adjust plant population
	5) Erratic distribution (high coefficient of variability-intra season & inter annual)	Difficult to adopt fixed date of sowing, plant population and fertilizer rate and cropping systems.	➢ Develop different crop varieties with high moisture use efficiency ➢ Moisture conservation(in situ and ex-situ) ➢ Split application of fertilizers ➢ Water harvesting to make life saving irrigation at critical growth stages
	6) Intermittent drought		

Early season (vegetative stage)	Reduced stand establishment Vegetative growth hang over(slow rate of growth)	➢ Change of crops and varieties according to the prevailing scenario ➢ Use of reduced plant population (thinning) ➢ Transplanting technique
Mid season (flowering/fertilization stage)	Total crop failure. Premature switchover from vegetative to reproductive stage Reduced pollination and fertilization	➢ Thinning down by certain percentage ➢ Protective irrigation ➢ Soil and moisture conservation ➢ Harvesting for feed/fodder
Terminal stress (grain filling/maturity stage)	Shortened grain filling period, shriveled grain Reduced yield (biomass and grain)	➢ Thinning, weed removal, mulching (and other soil and water conservation techniques) ➢ Repeated inter-cultivation ("hoes have water") ➢ Protective irrigation (life saving irrigation)
7) High intensity index over short time	Rainfall exceeds infiltration rate (considerable kinetic energy) Accelerated surface runoff Soil erosion and increased sedimentation load Nutrient depletion /leaching Shallow soil /crop root depth and low moisture holding capacity Breaking of soil aggregates and compaction of surface soil (sealing)	➢ Increase opportunity time for concentration and infiltration ➢ Runoff/water harvesting inter row, inter plot, dug-out farm pond ➢ Use sub soilers/crust breakers ➢ Employ appropriate soil conservation techniques (biological, physical, integrated)

	8) AET/PET>>rainfall amount	Quick moisture depletion due to high evaporative demand (low moisture availability index) Stiff competition among crop plants for scarce soil moisture	➢ Select drought tolerant crops varieties (improved water use efficiency) ➢ Repeated inter cultivation (soil mulching), residue and plastic mulches ➢ Soil conservation practices (biological, physical and integrated methods)
	9) Excess moisture/ Water logging/water surplus	Lack of gas exchanges system (Photosynthetic processes halt, choking of roots) Reduced functions and population of soil fauna Salinity problems (especially where evaporative demand is high) Nutrient leaching High erosivity Diseases and pest prevalence (high humidity)	➢ Fallowing ➢ Use of residual / stored soil moisture during off season for alternate farming ➢ integrated Surface and sub surface drainage(safe water ways) ➢ Appropriate soil conservation techniques (*biological, physical, integrated* ➢ Device appropriate disease and pest control technologies
II) Non cyclic:	1) Climate Change	Irreversible rainfall shifting and declining trend (amount, duration etc) Irregularity of the cycle	➢ Adjustment of research strategies according to the rainfall trend; reformulation of objectives. ➢ Natural resource rehabilitation projects (eg., watershed management approach)

On the other hand, many professionals still feel complacence with the existing capacity of the research system and argue that "why NARS need to go far, especially when the country has a big and independent Weather Bureau (NMSA), that can handle various aspects of the agroclimatic problems?" Others raise questions like "is there a mechanism, whereby the agricultural research and the NMSA establish operational linkages for the purpose of common goals?" or should EARO opt to institutionalize the full fledged agrometeorology research program? What are the visions, constraint and potentials along this line? It is believed that these questions are crucially valid to examine whether the NMSA's strategy matches the strategy of the agricultural research system to certain extent, so that the research system dwells only on closing the gaps, than duplicating efforts, which hamper the overall efficiency of resource use.

Specific gaps: Microclimatic level

As already discussed, the interaction of microclimate and growth/development of crops, livestock and vegetation can not be explained by simple information alone. And this is true, in tropical climates, especially in east Africa, where even if the climatic pictures fits that of the seasonal movement of the ITCZ, the spatial and temporal variations of climate are much more complex. More specifically for instance, the air temperature considered so far have been those measured in standard meteorological screen (usually at the height of 1.22 m). However, temperature changes rapidly below this height and above, because of the differential energy exchange taking place at each level and at a soil surface. Like wise; heat, relative humidity and wind circulation at various crops canopy levels are quite different from each other what is read from the standard meteorology station (Weig and Namken, 1966).

For an adequate scientific description and modeling of such crop environment, we must Therefore, measure the micro climatic conditions in an actual experimental fields, than relying much on the data collected from the standard meteorology stations (Butler, 1977). The point is that, in order to make effective decisions, the above mentioned microclimatic data and their analytical results must be integrated into the actual information generated from crops, soil, vegetation and livestock. For instance, this micro climatic can be integrated to the data on crop susceptibility/ tolerance to moisture stress at different growth stages or disease and pest prevalence or incidence.

Many other examples of the need for microclimatic level research could be cited. For instance, a length of growing period should be determined from rainfall coupled with details of the soil texture, moisture holding capacity, permanent wilting point and the likes. This helps to know whether the established seasonal rainfall and soil moisture availability relationship can influence the comfortable growth and development of crops, vegetation and livestock even if rainfall breaks for certain period. It also helps to model the environment in which we conduct field experiments; and identify researchable gaps and planning more enlightened research interventions and recommend alternate farming system.

In this regard, no such detail agrometeorological research has been began in EARO and microclimatic level studies are very limited, although preliminary studies of this sort are ongoing at limited research centers. The problem could be explained by the following terms:

1. Our limited knowledge of agrometeorology science in general hampers the establishment of meaningful relationships among the data from the standard meteorology stations and the location specific real farming system circumstances.

2. The data we have today is mainly of the open air and general-purpose type, that it, requires in-depth knowledge and experience to attach scientific and useful meaning to the analytical results when interpretation is made in relation to ones field level experimental results. This means, the microclimate in which the actual experiment is conducted differs significantly from the open-air climatic records, because of the reasons already discussed and the difference in data quality (at times, the result may reflect entirely differential pictures).

3. There are a multi-co-linearity problems i.e., the relationships among the climate elements themselves are complex that at times, it is not possible to distinguish which climatic factor or group of factors prominently influence/s ones particular experiments (confounding effects). For instance, the interaction among temperatures, solar radiation, relative humidity and wind speed highly influence the occurrence of rainfall by bringing-in or sweeping away the moisture laden winds.

4. The climatic variables also interacts with other factors; for instance, (a) crops- extractable moisture depends on soil texture, depth, moisture release characteristics, field capacity and permanent wilting point; (b) in areas where vegetation is available, surface run off is reduced and the soil moisture recharge increases as opposed to the areas where vegetation is denuded; (c) climate also influences the availability of feed and watering points for livestock and human consumption.

From the above discussions, agrometeorology seems every thing; and its importance in agricultural research is more than justified. Therefore,,, the answer to the question whether institutionalizing agrometeorology in Ethiopian Agricultural research system is very much in the affirmative. It is to be admitted however that, in order to realize its full benefits in practical senses, the most pressing and priority problem areas need to be identified from a gulf of problems across all the sector research directorates; and capacity should be built in order to address these problems.

Future directions and recommendations in agrometeorology research

In light of the foregoing discussions, the following sober conclusions and recommendations are being drawn.

1. It would be of historic importance that networks strengthened among concerned government organizations (at least among EARO, NMSA, MOA, CSA and DPPC), in order to overcome the scarcity of data and trained manpower. This helps implement inter institutional (stakeholders) research projects on national agricultural issues. Figure-2 summarizes the framework on how stakeholders' collaboration may practically be possible along this line.
2. To fully utilize agrometeorology, detail knowledge and information is required from many angles. Therefore,,, multi disciplinary research projects that involves agrometeorologists, crop researchers, soil scientists, foresters and livestock researchers need to be formulated and implemented.
3. Currently this young program exists at its pre-operational stage and needs to be equipped with trained manpower and facilities gradually and on predictable basis.
4. Applied research proposals in various sector directorates and programs should be designed in a way they could capture the influence of weather and climate on their experiments. For this, pressing problem areas needs to be identified and given priority. It is hoped, the newly formulated national research agenda fully accounts for this issue.
5. Number of meteorology stations should increase across various agro-ecologies mainly in drylands
6. Institutional capacity building in terms of human resources through employment, and training and facilities should be given due attention.

In that way only, agrometeorology may become a panacea in Ethiopian agricultural research and development system.

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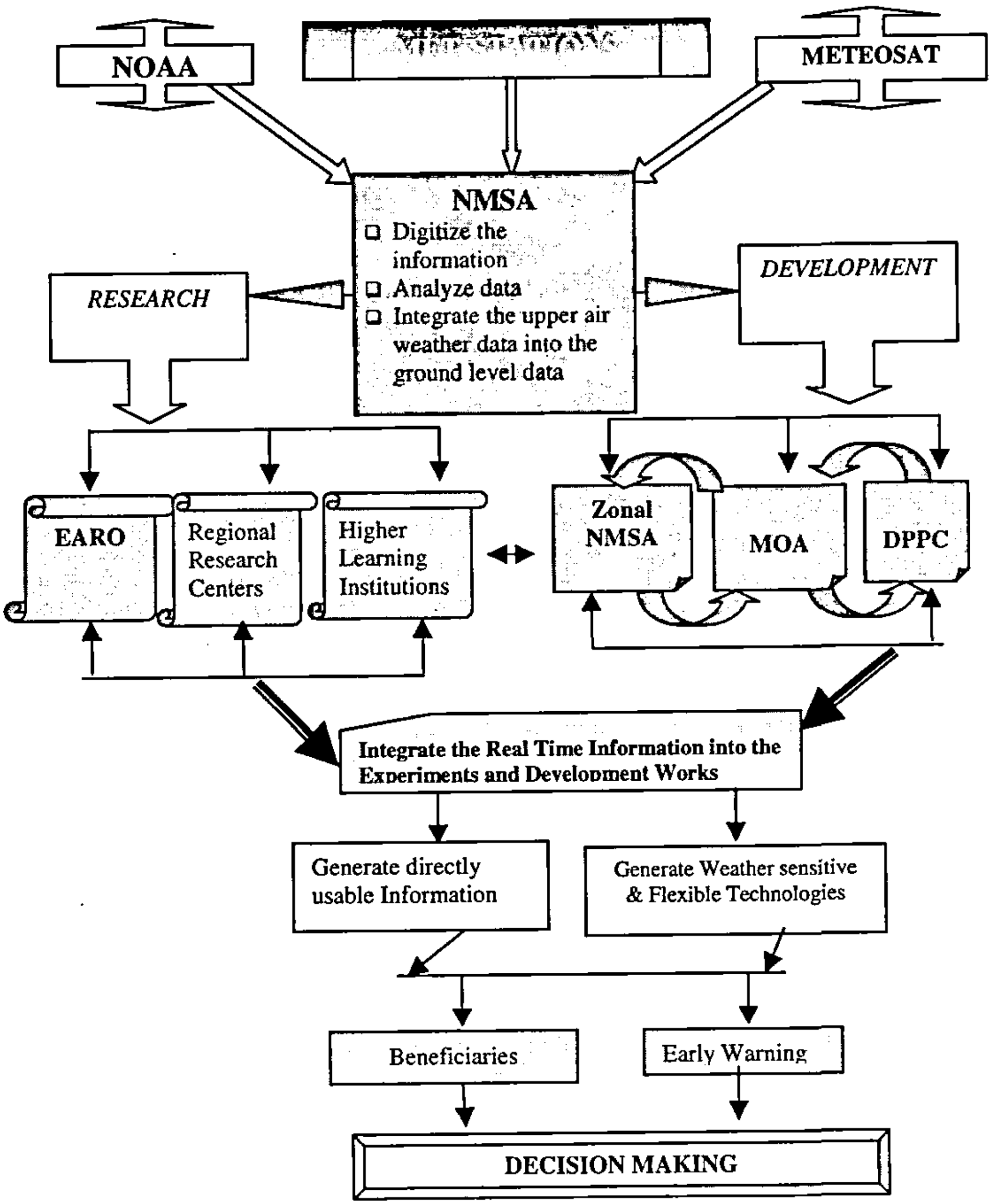
Figure 2. Proposed Inter-institutional (stakeholders) Collaboration to make use of Agrometeorology Information



AGRO-CLIMATIC BELTS OF ETHIOPIA - POTENTIALS AND CONSTRAINTS

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Abstract

Farmers and agricultural scientists have already realized the importance of growing season variables in crop production although success has been limited. The limited success have been achieved either through modifications of the local climate or adjusting to the local climate. However, modification of the local climate is possible only to a limited extent and it also incurs high costs. Therefore, the use of growing season information to adjust to the local climate is being applied throughout the world. The determination of growing season resources has been used to delineate growing season zones. To this end, try is made in this study to delineate the country into different growing season zones. The criteria used to delineate the growing season zones are the type of growing season, time of onset of the growing season and the length of the growing season. Hence, 21 growing season zones that are catagorized into 4 growing season belts are identified in the country. . It is believed that these subdivisions contribute substantially for planning in agriculture, land use development studies, irrigation development, growing season studies.

INTRODUCTION

Although sometimes success has been limited, the importance of growing season resources in crop production is realized by different people who are directly or indirectly involved in agriculture. Success in crop production can be achieved through either modification of the microclimate or by adjusting to the existing growing season conditions. However, success through modifications of microclimatic conditions is possible only to a limited extent at a very high cost. On the other hand, the other approach by which the agroclimate determines the crops have been widely attempted in the world

(Boshnoi, 1989). The determination of the growing season resources has been used to delineate growing season zones. Growing season zonation when well understood and wisely integrated with a particular objective` will become a valuable tool to exploit the growing season potential of an area particularly for agricultural production. Therefore, there is great need to delineate homogenous zones for different applications with a view ultimately improve crop productivity through scientific planning.

Different forms of indices of heat, light and moisture were superimposed to delineate homogenous zones for achieving different objectives. The methodologies adopted in different parts of the world to quantify growing season resources are so varied and large in number that it is difficult to find a universal method for growing season classification to apply for all types of their applications. Therefore, growing season zoning is a division of an area according to the objective required to be achieved. The main objective of this study is to delineate Ethiopia into different but homogenous growing season zones for the exploitation of the growing season resources to enhance agricultural planning and crop productivity.

The wide variation in altitude, climate and soils of Ethiopia has made possible the production of large varieties of crops. However, the majority of its population depends on rainfed based subsistence agriculture. This type agriculture is exposed to the vagaries of climate. The rainfall climatology of the country indicate that there are mainly four rainfall regimes in Ethiopia namely mono-modal (single maxima), bimodal type-1 (quasi-double maxima), bimodal type-2 (double maxima) and diffused pattern (Tesfaye Haile, 1986; Abebe Yeshanew, 1987). Based on the mean annual and mean monthly rainfall distributions and the rainfall regimes, in Ethiopia three seasons are identified (NMSA, 1996). Almost the western half of Ethiopia, designated as two season types is dominated by mono-modal rainfall regime: wet and dry. The wet season gradually decreases northwards, from about ten months in the southwest to only about two months in the northwest. The central and the south-eastern highlands and the adjoining low lands designated as bimodal rainfall regime is characterized by three season types, namely *bega*, *belg* and *kiremt* (Tesfaye Haile, 1986, Workineh Degefu, 1987).

There were some other works related to growing period assessment done in Ethiopia. The National Meteorological Services Agency (NMSA) classified the country into 14 growing season zones based on length of growing period (LGP) model developed on the basis of concepts and principles outlined by De Pauw (1982). This study uses dependable growing period concept than the average one and moreover, it uses different levels of soil moisture data. However the main limitation this study is that it uses aggregated climatic data that could not enable to assess the impact of short-duration dry spells on crop yield.

Moreover, the model does not assume the conserved soil moisture in determining the growing season. They also used a month interval for their analysis, which is long for the planning of agricultural operations.

The present study tries to avoid some of the limitations encountered in the above classification and uses a different approach to classify the country. It uses a ten days (dekad) time interval in the analysis. The dekadal data are computed from daily values, for every year within the period of record. Secondly, it assesses the growing season from the availability of soil moisture in addition to rainfall. This strategy allows identifying the merging possibility of two seasons that are separated by small dry spells period and considers the season as a single instead of fragmented two seasons.

MATERIALS AND METHODS

The data set includes some 139 stations distributed all over the country covering all climatic zones and moisture regimes of Ethiopia. The rainfall data set include a long series which is recommended for climatological assessment (WMO, 1983). That is above 65% of the stations have 26 years or above of rainfall record, about 23% of the stations have between 20 - 25 years of record and 12% of stations are with a data set of below 20 years of record. The reason why we include those stations with below 25 years of record is that to have a complete picture of that part of the country where long series data set is not available. Moreover, 19% of the stations do not have data gaps and 68% of the station have data gaps of 1 - 5 years and about 4% of the stations are with data gaps ranging from 8-10 years.

The rainfall data set doesn't cover the same period and the length of record is different. For this study, dekadal rainfall amounts are computed from the daily data set for each station used in the data set using standard dekads. The standard dekads are shown in Table 2. No attempt is made to fill the data gaps since each year was treated separately.

The PET data are used from the works of Engida Mersha (1999) which was computed from climatic normals using Penman formula as outlined by Frere and Popov (1979). However, the data for the estimation of PET is limited. It is only for little number of stations that complete data are available. For some stations some parameters for PET computation are available but not all. For these stations the missing parameters are estimated from one of the nearby stations with complete data set. For stations with only rainfall data, the other meteorological parameters used in the PET computations were estimated or interpolated from one of the stations with complete data set, which is found near the station in question.

The first well-published example of the use of the length-of-growing-period (LGP)-concept for water balance studies can be found in the work of Cocheme and Franquin (1967) detailing their agrometeorological investigations in the Sahel zone of West Africa. The Food and Agriculture Organization of the United Nations (FAO) has, with minor modifications, adopted the original LGP-concepts and model for many continental and country-level studies of land suitability (Kassam et. al., 1981-82;Le Houerou and Popov, 1981; Higgins et.al. 1983; Wood and Dent, 1983;Goebel and Odenyo, 1984). FAO advocated the LGP-concept as a standard tool for characterizing the agricultural climate (FAO, 1983; FAO, 1985).

To enable quantitative assessment of the growing season, the following working definition is used (FAO, 1978). The growing season is defined as the period (in days) during a year when rainfall exceeds half the PET, plus a period required to evapotranspire water from excess rainfall (or less if not available) stored in the soil profile. The LGS is calculated through a simple water balance model that relates rainfall and moisture stored in the soil to the PET of the crop. Crop production can then be estimated at least qualitatively in terms of the time during which plant growth can proceed without serious restriction due to moisture stress (Henricksen and Durkin, 1985).

The beginning of the growing season and the start of the rainy season is taken as the time when the rainfall equals half PET (FAO, 1978). The choice of half PET as the threshold value for moisture availability, is based on considerable experimental evidence which showed that important physiological changes are induced in many crops below half PET (Doorenbos and Kasam, 1979). Half PET has been considered as being sufficient to meet the water requirement of establishing crops. Moreover, germination also proceeds in most crops when rainfall exceeds half PET. The growing period for most crops continues beyond the rainy season and, crops often mature on soil moisture reserves. Soil moisture storage must be Therefore,, considered in determining the LGS. However, the data on the amount of soil moisture reserve is not easily available in Ethiopia. Hence, a general figure of 100-mm storage water has been added to the duration of the rainy season, to set the end of the growing period. The choice of 100 mm is based on experimental evidence from East and West Africa (FAO, 1978). To determine the stability of the onset of the growing season the standard deviation (SD) of the average onset dates is used (Panofsky and Brier, 1961). Table 1 is used to determine the stability of the start of the growing period based on the values of SD.

Table 1. Table used to determination of stability of the onset of growing season (Reddy, 1990).

Standard Deviation (SD)	Stability
≤ 1	Very high
1 – 2	High
2 – 4	Moderate
> 4	Low

To determine the drought condition, a year with LGS of below 90 days is considered to be a drought year. Because most crops grown in Ethiopia with the exception of some pulses and very low yielding varieties of teff and wheat, require a growing of at least 90 days (Henricksen and Durkin, 1985). The frequency of this below 90 days LGS divided by the total number of observation gives the frequency of occurrence of drought over that area. Reddy (1990) had developed a methodology to determine the drought frequency (D), (Table 2).

Table 2. Drought frequency index (D), in % (Reddy, 1990)

D %	Description
≤ 5	Nil
5 – 15	Low
15 – 40	Moderate
40 – 60	High
> 60	Very high

The variability of the LGS is determined by the value of the coefficient of variation (CV) of LGP.

Growing season classification of the growing season

The core idea of the classification is to delineate the country into different growing season zones that could be categorized into major growing season belts based on the characteristics of the growing season (table 3).

Table 3. Criteria and codes used to classify the growing season zones (ACZ).

ACB	ACZ		Different characteristics of growing season	Code
	Number of seasons		The time of the year when the season occurs	
	1. No seasons		1. No significant growing season	NS11;NS12;NS13;NS14
	2. One season		2. Occurs during the first half of the year	NS21;NS22;NS23;NS24
	3. Two seasons		3. Occurs during the second half of the year	NS31;NS32;NS33;NS34
			4. Occurs during both time intervals	
SS	Onset time		Length of the season	Code
	1. 13-15		1. LGS< 90 days	SS11;SS12
	2. 16-18		2. LGS > 90 days	SS21;SS22
	3. 19-21			SS31;SS32
TS	Onset time		Length of the season (days)	Code
	1st season	2nd season		
	1. 7-9	1. 16-18	1. LGS1 <90 & LGS2 >90	TS111;TS112;TS113;TS114
	2. 10-12	2. 19-21	2. LGS1 >90 & LGS2 <90	TS121;TS122;TS123;TS124
		3. 22-24	3. Both LGS > 90	TS131;TS132;TS133;TS134
		4. 25-27	4. Both LGS < 90	TS141;TS142;TS143;TS144
		5. 28-30		TS151;TS152;TS153;TS154
				TS211;TS212;TS213;TS214
				TS221;TS222;TS223;TS224
				TS231;TS232;TS233;TS234
				TS241;TS242;TS243;TS244
				TS251;TS252;TS253;TS254
MS	Onset time		Length of the season	Code
	3-6		1. LGS ≥ 300 days	MS11;MS12;MS13;MS14
	7-9		2. 250 ≤ LGS < 300 days	MS21;MS22;MS23;MS24
	10-12		3. 210 ≤ LGS < 250 days	MS31;MS32;MS33;MS34
			4. LGS < 210 days	

Results and Discussion

Based on the methodologies discussed in the previous paragraphs, Ethiopia is subdivided into four major growing season belts (Figure 1). These are: -

- No growing season belt -NS
- Single growing season belt -SS
- Two growing seasons belt -TS
- *Merging growing season belt -MS*

Based on the methodology, the four major growing season belts are subdivided into 80 growing season zones. However, in the case of the current classification only 21 growing season zones are identified in Ethiopia.

No Growing Season Belt - NS

Out of the 12-growing season zones that are identified in Table 3, only four growing season zones are identified in the case of Ethiopia in this growing season belt. The main characteristics of this belt are the rainfall in most years is not sufficient to grow crops. As a result, there is no growing season over this belt or if there is any, it is very insignificant to carry out rainfed agriculture. However, there are minor differences within the belt. The growing season zones within the NS belt are characterized by dry climate and most of the zones are not favorable for rainfed crop production. It is identified as the major pastoral area of the country.

NS11*:* There is no single dekad in which the rainfall equals or exceeds half PET. The length of growing season (LGS) here is practically none. This zone is found over eastern half of Afar especially over zones 1, 2 and parts of zone four and over the Shinile zone of the Somali region. The mean annual rainfall of the NS11 growing season zone is about 210 mm with very high annual variation. The mean annual PET amount is 2360 mm.

NS21: There is one growing season tat extends from the last dekad of April to the last dekad of May. Here the LGS is 40 days. The zone is favorable for pasture production. The mean annual rainfall and PET are 445 and 2117 mm respectively. The mean annual rainfall shows high variation. It is located over parts of zones one & three of the Afar region and Deghabur, Fik and parts of the Jijiga zones of the Somali region.

NS22: There is one growing season and the LGS over this zone is below 40 days. The season extends from the last dekad of July up to the last dekad of August. The difference between this zone and the NS21 zone is that, the growing season occurs during the second half of the year in this zone. The zone is favorable for pasture production. The mean annual rainfall over the area equals 428 mm with high variation. The mean annual PET is 2206 mm. The zone is located over zones three and five of the Afar region and over southern parts of the Shinile zone of the Somali region.

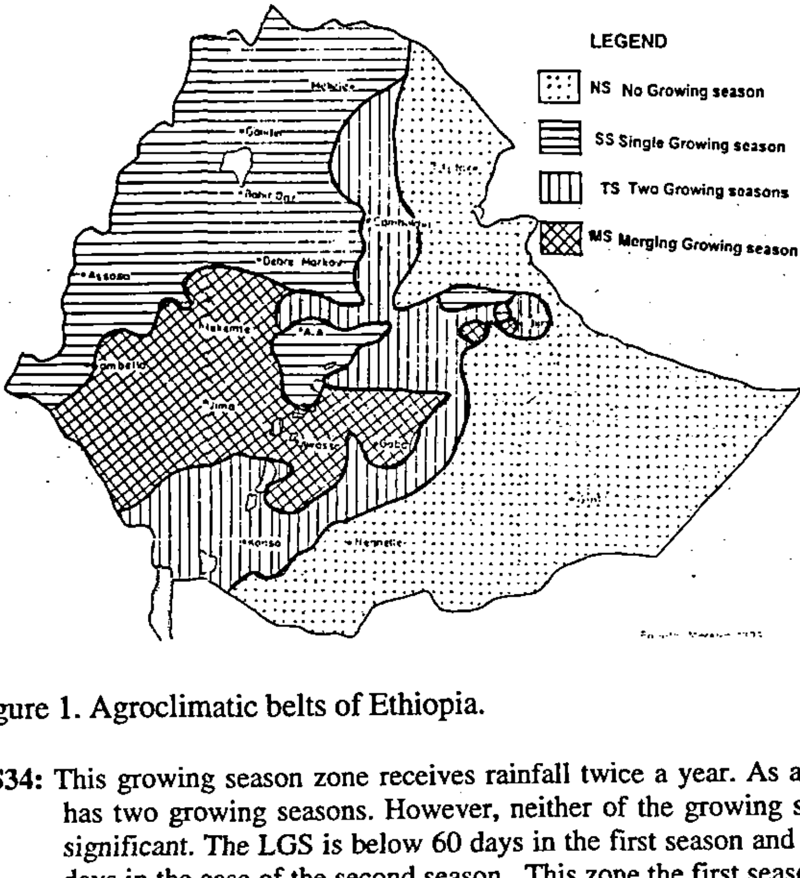


Figure 1. Agroclimatic belts of Ethiopia.

NS34: This growing season zone receives rainfall twice a year. As a result, it has two growing seasons. However, neither of the growing seasons is significant. The LGS is below 60 days in the first season and below 40 days in the case of the second season. This zone the first season is very important as compared to the second one. The first season occurs during March and the second season during October-November. The growing season zone is located over parts of Deghabur, Warder, Kebri Dahar, Gode, Liben, Afder and parts of Fik zones of the Somali region and the southern parts of Borena zone over the Oromiya zone. This zone receives about 580 mm of rainfall annually on the average. Moreover, the mean annual PET demand is about 1875 mm.

Single Growing Season Belt - SS

The single growing season zones are located over the mono modal rainfall receiving areas. The growing season on the average starts during May and extends up to October. Based on the onset date and the length of the season this belt is further subdivided into four growing season zones. Most parts of the belt with the exception of SS31 sub zone are characterized by moist climate.

SS12: The season starts during May and extends up to October. It covers most parts of North and south Gonder, east and west Gojam and Awi zones of the Amhara region, parts of west Tigrai, Benshangul Gumuz region, zones 1 and 3 and parts of zone 2 of Gambella region, west Wellega and parts of West Shoa zones of Oromiya. The average onset time of the season is during 11-20 May and it varies from 13th to 15th dekad if the onset is early and late respectively. The chance of crop failure is very negligible even during late onset and early withdrawal of the season. The average LGS is about 180 days.

SS22: The growing season in this growing season zone starts during the month of June. If the onset is early, then it starts at the 16^{th} dekad or if it is late, then its starts during the 18^{th} dekad. The mean length of the growing season over the zone is about 130 days. However, over some isolated pocket areas over central Ethiopia and pocket localities around Lake Tana it extends from 140-150 days. The crop failure risk over the zone is negligible. The zone is found over North Shoa, and South Gonder around Lake Tana area of the Amhara region and parts of west Shoa and East Shoa zones of Oromiya.

SS31: This growing season zone includes areas with below 90 days of LGS. The zone is found over wag Hamra, western parts of North & South Wello of the Amhara region, eastern parts of East Shoa zone and around Dire Dawa. The average LGS over the area is 70 days. The mean annual rainfall and PET amounts are about 680 and 1902 mm respectively. Hence, it is difficult for the crop to meet its water requirement under high evaporative demand due to less water available from rainfall. The average onset time of the season is during the second dekad of July. However, it starts at the beginning of July if it is early and extends up to the end of July if it late. In all cases the LGS varies between 60 - 80 days. The SS31 growing season zone is mostly characterized by a dry climate.

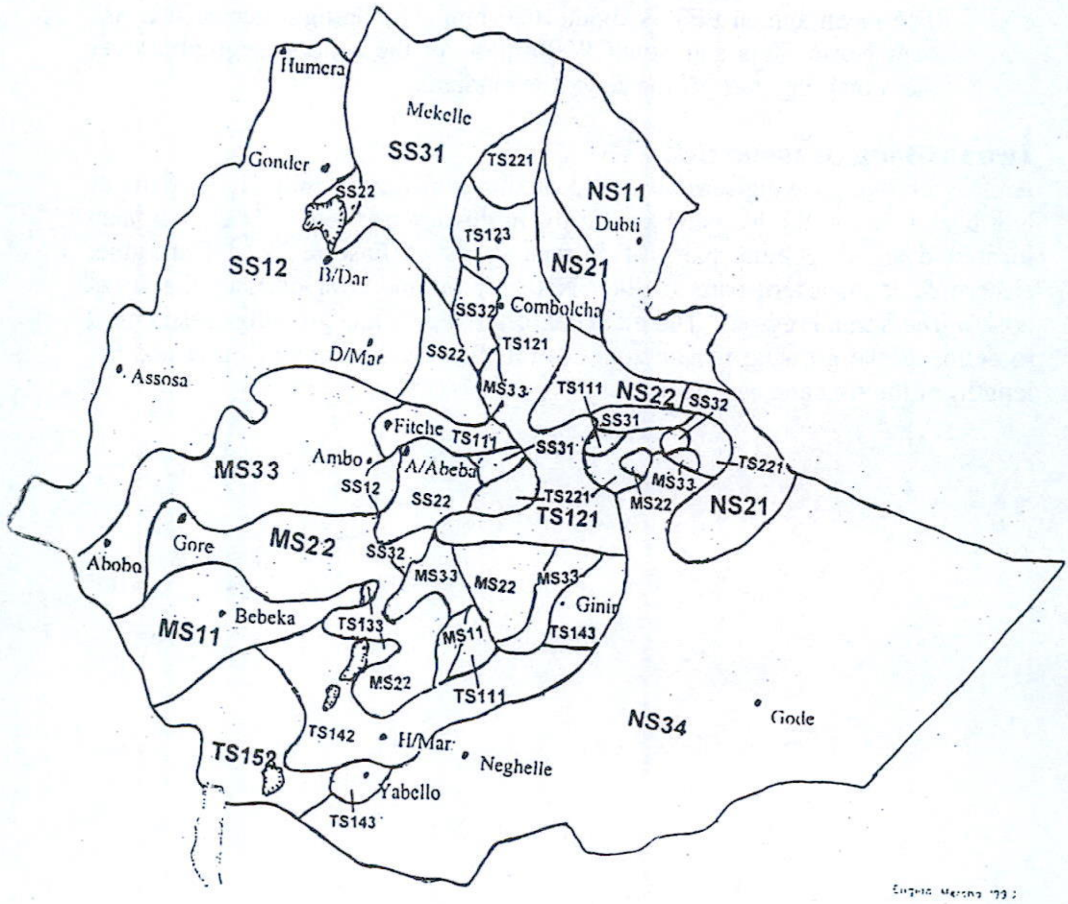
SS32: Areas with single growing season and with LGS of above 90 days are grouped into SS32 growing season zone. The average LGS over this zone is about 110 days. The average length of the growing season is about 100 days. Over this zone the season starts during the first dekad of July and extends up to the second dekad of October. The SS32 growing season zone is found over parts of North Shoa around Mehal Meda & in south Wello around Dessie, parts of East Hararghie around

Gursum and Southern parts of East Shoa around Adami Tulu. The SS32 growing season zone receives mean annual rainfall of 910 mm. The mean annual PET is about 1680 mm. The drought occurrence risk over North Shoa and South Wello parts of the zone is negligible over the remaining parts of the zone it is moderate.

Two Growing Seasons Belt - TS

Areas with two growing seasons are located over parts of south Tigrai, parts of North and South Wello, parts of North, northwest and East Shoa. It is also located over Arsi, Bale, parts of Borena, ·parts of East & West Hararghie, eastern & southeastern parts of the SNNP region and over parts of the Jijiga zone of the Somali region. The main characteristics of the growing season used to delineate the growing season zones in this belt are the time of onset and the lengths of the first and second seasons

Figure 2. Agroclimatic zones of Ethiopia



TS111: The onset time of the first season is during March and extends up to mid April. The second season starts during the last dekad of June and extends up to mid October. The length of the first season is below 90 days, while LGS for the second season is above 90 days. The average LGS during both season is 40 and 110 days respectively. Hence,, the second season is very important over this zone. It is located over northeastern parts of Bale, northern, north western and parts of West Shoa, and eastern parts of West Hararghie. The drought risk over most places during the first season is above 70% i.e. it occurs for 7 in 10 years. However, during the second season the crop failure risk is negligible. The mean annual rainfall and PET values are 990 and 1510 mm respectively. It is generally characterized by moist climate.

TS113: The first season starts during March and extends up to May with an average LGS of 90 days. The second season usually starts during mid June and extends up to the end of October. The LGS of the second season on the average is about 140 days. Over this zone both seasons are very important for crop production. Hence,, it is possible to use both seasons for crop production. However, care should be taken to consider the first season for crop production during late onset of the season, though drought risk is low. It is mainly located over the Kembata Alaba Tembaro (KAT) zone of the SNNP around Alaba Kulito. The drought risk during both seasons is very low. Moreover, the possibility of merging both seasons is about 65%. However, there is a 1 in 10 year's chance of drought risk to occur simultaneously during both seasons. The zone receives mean annual rainfall amount of 990 mm with mean annual PET of 1380 mm. The zone is characterized by moist climate.

TS 121: The first season starts during mid March and extends up to the first dekad of May with below 60 days of season length. The second season starts during the first dekad of July and extends up to mid October. The LGS during the second season is above 100 days. Hence,, the second season in this group is very important as compared to the first one. This is because first of all the LGS is below 90 days and the frequency of drought occurrence during the first season is high. However, during the second season the drought risk is below 10% with the exception of some isolated pocket areas of South Wello and West Hararghie. The TS121 growing season zone is mostly located over South Wello, parts of North Shoa, West Hararghie and eastern parts Arsi. The mean annual rainfall and PET amounts are above 1000 and 1600 mm respectively. On the average the zone is characterized by a moist climate.

TS 123: The first season starts at the beginning of March and extends up to the end of May, while the second season starts at the beginning of July and extends up to the end of October in this growing season zone. The LGS during the first and second seasons are above 90 and 120 days respectively. The main difference between TS123 and TS121 growing season zones is that the first LGS is below 90 days over TS121 zone and it is above 90 days over the TS123 zone. In this growing season zone both seasons are important. This zone is found over some pocket areas in south Wello around Haik. The LGS during both seasons here is above 90 days. However, there is high drought occurrence risk (51%) during the first season and negligible during the second season. Moreover, there is no chance of drought occurrence simultaneously during both seasons. The mean annual rainfall amount over the area is about 1140 mm with mean annual PET of 1480 mm.

TS133: The first season over this zone starts during the first dekad of March and extends up to the beginning of July. The LGS of the first season is above 130 days without drought risk. The second season starts during August with above 110 days of LGS. The difference between TS113 and TS133 growing season zones is the time of onset of the second season. Over TS113 zone the second season starts during June. The TS133 growing season zone is located over the Gedio zone of SNNP. Here both seasons are very important. The drought risk during the second season as well as during both seasons separately and simultaneously is very low. The merging possibility of both seasons is above 60%. The zone received about 1300 mm of rainfall annually on the average with evaporative demand of 1500 mm per year. The zone is characterized by moist climate

TS 142: The onset of the first season is during March and extends up to mid June with above 100 days of LGS. The drought occurrence risk with the exception of Burji is above 30% during the first season. The second growing season over this zone starts during September and extends up to mid November. However, the average LGS over the zone is below 60 days. In this growing season zone the first growing season is very important than the second one. The zone is located over most parts of north and south Omo, Burji special wereda and parts of the Borena zone. The frequency of drought occurrence is above 70% on the average over most places during the second season. However, the chance of drought occurrence over the zone simultaneously during both seasons is about 15%. The mean annual PET amount exceeds by far the mean annual rainfall amount. They are above 1600 and above 890 mm respectively.

TS 143: The first season over this growing season zone starts during the first dekad of March. The second season starts during September. The LGS during both seasons is above 90 days and hence, both seasons are equally important over this zone. This is the main difference between this zone and TS142 zone. It is located around Yabello in Borena zone and around Ginir in Bale zone. The frequencies of drought occurrence over both places vary considerably. Around Yabello it is very high during the second season and there is 60% chance of drought occurrence during both seasons simultaneously. On the other hand, around Ginir there is moderate (20%) chance of drought occurrence during the first season and negligible in the second season. Moreover the chance of drought occurrence during both seasons simultaneously is very negligible over this part of the zone. The mean annual rainfall is 650 and 1120 mm around Yabello and Ginir respectively. Moreover, the annual PET demand is 1700 and 1530 mm over both locations respectively.

TS 152: The first season starts during March and extends up to the end of June. The length of the season is above 120 days with moderate (22%) drought risk. The onset of the second growing is during the September with below 30 days of LGS. Moreover, the drought occurrence risk during the first season is about 20%, while it is 95% during the second season. The chance of drought occurrence simultaneously during both seasons is about 11%. The chance of merging both seasons is very low. Hence,, it is important in terms of crop production as compared to the second season. The mean annual PET is very high and exceeds the mean annual rainfall very significantly. It is located over South Omo around Keyafer area. The mean annual PET amount is about 1400 mm while the mean annual rainfall amount is about 600 mm.

TS 211: The first season over this zone starts during the month of April and extends up to mid May. Over this sub zone the second growing season starts during the month of June and extends up to the first dekad of October. The length of the first season is below 40 days and that of the second season is above 110 days. Hence,, the second season is more reliable and more important than the first one. The drought risk during the first season is very high (80%) and it is moderate (24%) during the second dekad. The zone is located over southern parts of South Tigrai. The area receives mean annual rainfall of about 790 mm the mean annual PET amount is 1700 mm.

RISK MANAGEMENT IN AGRICULTURE

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Abstract

Risk management in agriculture is the systematic application of management policies, procedures and practices to the tasks of identifying, analyzing, assessing, treating and monitoring agricultural risks. The major types of agricultural risk are production, price or market, institutional, personal and financial risks. Even though, from different angles, farmers, farm advisors, commercial firms selling or buying from farmers, agricultural research workers; and policy makers and planners need to deal with agricultural risk in their day-to-day decision making. This paper presents the importance of risk analysis in agriculture and the basic methodologies of analysis using a simplified example of potato growing farmer's marketing problem. In general, rational decision or choice under risk is a choice consistent with the decision maker's beliefs about the chances of occurrence of alternative uncertain consequences and with his relative preferences for those consequences. The decision maker's beliefs are reflected in probabilities he assigns (implicitly or explicitly) to uncertain events, while his preferences for consequences are captured in the way risky payoffs with their associated probabilities are converted to a utilities or certainty equivalent that can be used as the criterion for choice.

INTRODUCTION

The development of agriculture in early times was partly a response to the riskiness of relying on hunting and gathering for food. Since then, farmers and other have tried to find ways to make farming itself less risky by achieving better control over the production process. Yet, in agriculture, as in other areas of human concern, risk remains a seemingly inevitable feature of life (p. 1, Hardaker et al 1997). The control over the production process varies based on the production technologies available. For subsistence farming where the production is undertaken under rain fed condition, the agro-metrological risk remains the most important factor affecting the production. This is more relevant for developing countries like Ethiopia where the dominant economic activity is agriculture dependent on annual weather conditions.

Risk and uncertainty

Hardaker et. al. define uncertainty as imperfect knowledge and risk as uncertain consequence, particularly exposure to unfavorable consequence. For example, someone might say that he is uncertain about what the weather will be like in the coming days – a value free statement simply implying imperfect knowledge of the future. But the person might go on to mention that he is planning to sow his field the coming days and there is a risk that it might not rain, indicating preference for alternative consequences. To take risk, then, is to expose oneself to a significant chance of injury or loss. For many day-to-day decisions, the risk is usually unimportant since the scope of possible loss is small or the probability of suffering that loss is judged to be low. In farming, many farm management decisions can be taken with no need to take explicit account of the risks involved. But some risky farm decisions will warrant giving more attention to the choice among the available alternatives.

Types and sources of risk in agriculture

There are two major types of risk in agriculture: business and financial risks. The aggregate effect of production, market, institutional and personal risk is called business risk, whereas, financial risk results from the method of financing the farm.

Production risk

Production risk comes from the unpredictable nature of the weather and uncertainty about the performance of crops and livestock, e.g. through the incidence of pests and diseases, or from many other unpredictable factors.

Market risk

Prices of farm inputs and outputs are seldom known for certain at the time that the farmer must make decisions about the how much of which inputs to use or what and how much of various products to produce. Increasingly, farmers are exposed to unpredictable competitive markets for inputs and outputs both in developing and developed countries. Therefore,,, price or market risk is often significant in farm decision making.

Institutional risk

Governments are another sources of risk for farmers. Changes in the rules that affect farm production can have far reaching implication for farm profitability.

Human or personal risk

The people who operate the farm may themselves be a source of risk for the profitability of the farm business. Major life crises such as the death of the owner, or a divorce of a husband and wife owning a farm in partnership, may threaten the existence of the business.

GENERAL APPROACH TO RISK MANAGEMENT IN AGRICULTURE

Risk management is the systematic application of management policies, procedures and practices to the tasks of identifying, assessing, treating, and monitoring risk. It may be divided into a number of steps that should be gone through in a routine a cyclical way by every organization whether it is large corporation, government agency or small family farm. These steps are outlined in figure 1.

Establishing the Context

This step in risk management is concerned with setting the scene and identifying the parameters wthin which a particular risk or range of risks are to be considered. The context can be cosidered in terms of the strategic (the relationship between the organization and its enviroment), organizational (the process of setting and communicating goals and objectives and the division of reponsibility for various types of decision making) and risk-management (defining the scope of the current pass through the risk management process) aspects

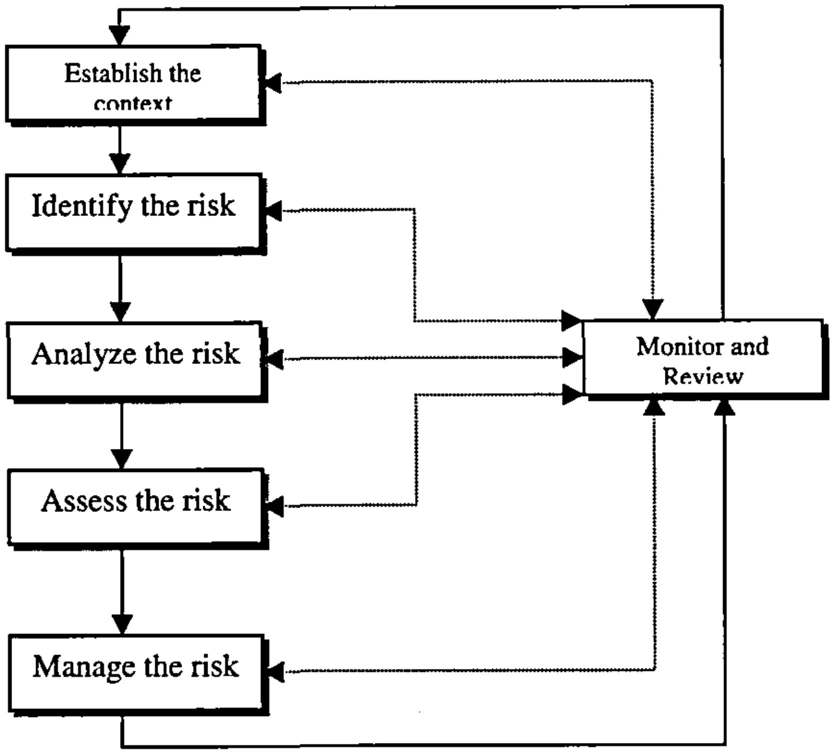


Figure 1. An outline of the steps in risk management. Source: Hardaker et al 1997

Risk identification

In identifying the risks to be managed, a systematic approach is important to ensure that important types of risk are not overlooked. The list of all possible risks is obviously endless, so the aim in risk identification is to make a list of all possible risks that may have an important effect on the performance of the organization.

Risk analysis

There are two steps to risk analysis: considering the chances of occurrence of the risk, and assessing the consequences, given current risk- management practices.

Risk assessment

Risk assessment is linked to the step of risk analysis. It is concerned with identifying those risks, for which current risk-management practices are not appropriate, so that future action is needed.

Risk management

Risk management means identifying the range of options for treating each particular risk, then evaluating those options, selecting the most suitable one, and implementing it.

Monitoring and review

Once a risk-management plan has been decided upon and implemented, it should, of course, be maintained. Moreover, because risk management involves choices made with imperfect information, it is likely that some risk-management options turn out to be unsatisfactory. Monitoring and review are Therefore,, necessary to establish that the risk-management plan is working and to identify aspects where further decisions need to be made.

Decision analysis

In all steps of risk management decision anaysis is very important. It is the name given to the family of methods that have been developed to try to rationalize choice in uncertain world. Decision analysis is a ***prescriptive model of choice***, which is a logical derivation from some "axioms" or supposedly self-evident truth about how a rational person would wish to act in making risky decisions. As is illustarted in figure 2, decisions are broken down into separate judgements about the nature of the uncertainty that affects the possible consequences of the decision, and about the preferences of the decision maker for different consequences. Then, the two parts of the analysis are reunited to show what is the "best" choice for a "rational" decision maker.

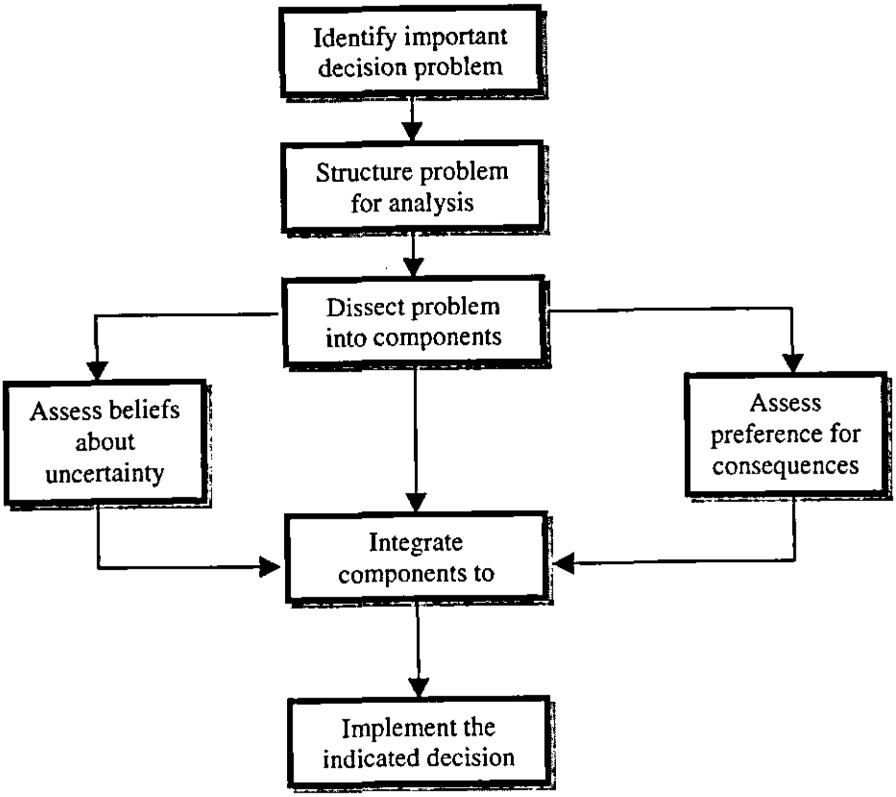


Figure 2. Outline of decision analysis
(Source: Hardaker et al. 1997)

Risky Decision Problem

To illustrate the application of the basic decision analysis, let us consider the following example adapted from Hardaker et al 1997 (page 24). A potato grower in Adama woreda has just harvested 100 quintals of the crop and would like to decide whether:

a) To sell the potatoes now at the current price in Nazareth or in Addis Ababa or

b) To store the crop and sell them later in the hope of a higher price either in Nazareth or in Addis Ababa

The first option is not risky since the farmer can assess the current price in both towns. Assume that the farmer has assessed the current price at Addis market to be 109 ETB/quintal and transportation cost per quintal to be 10 bir and at Nazareth the price to be 100 birr/quintal. The storage cost per quintal of potato is 27 birr. Lets assume further that the farmer knows from his experience that the future price of potato in Nazareth and Addis Ababa depends on the condition of growing season (a simplified assumption) in areas that supply potato for both markets. Most of the production supplied to Addis Ababa Market is from rain-fed condition and to the Nazareth market is from irrigated farms. Therefore,,, we can expect that there will be high price variability in Addis market as compared to Nazareth. Lets assume further that based on the long term growing season weather data, the following data were assessed (Table 1):

Table 1. Weather conditions and potato price at Addis Abeba and Nazreth markets.

	Probabilities and potato price			
	Addis Ababa Market		Nazareth Market	
Weather conditions	Probability	Price	Probability	Price
Very good weather	0.50	100	0.85	120
Good weather	0.25	150	0.10	145
Bad weather	0.25	200	0.05	180

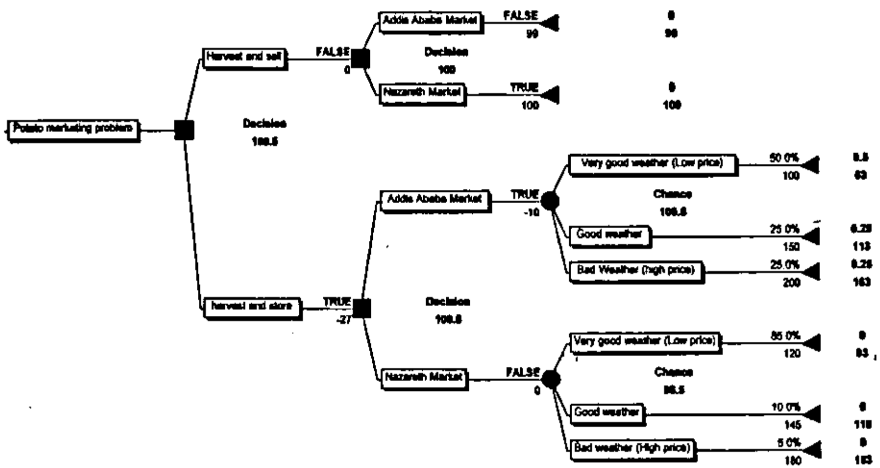
Decision Tree Representation

The above problem can be represented using a decision tree. This is a diagram that shows the decisions and events of the problem and their chronological relationships. Decision problems are shown with two different kinds of forks, one kind representing decisions and the other representing sources of uncertainty. Decision forks, conventionally drawn with Small Square at the node, have branches sprouting from the decision node representing alternative choices. Event forks, drawn with a small circle at the node, have branches sprouting from the event node representing alternative events or states.

The decision tree for the potato-marketing problem is shown in figure 3. In this case there are three decision forks (time of sell, place of sell with two alternatives) and two event forks reflecting the farmer's uncertainty about the future growing season weather condition in both potato production areas supplying Addis and Nazareth markets.

Figure 3

Decision tree representation for potato marketing problem



Note: values in the tree represent the expected payoffs (the probability *payoff)

Components of Decision Problems

As is shown in the potato-marketing problem, there are 6 components of decision problems:

1. Decisions or alternative actions, between which the decision-maker must choose, denoted by a_j. In the potato example these are decision on the time and place of sell.

2. Events or uncertain 'states of nature' over which he decision-maker has no control, denoted by S_i. In the example, these are the state of growing weather condition in the production areas of potato.

3. Probabilities measuring the decision maker's beliefs about the chances of occurrence of uncertain events, denoted by $P(S_i)$. In the example, these are the probabilities of the weather condition (Very good, good and bad) at both production areas that determines the supply level thereby the price.

4. Consequences or outcomes, sometimes called payoffs, indicating what might happen given that a particular action or sequence of actions is chosen, and that a particular event or sequence of event occurs – these consequences may be expressed in terms of a single attribute, such as profit, or the consequences of each action and event combination may have a number of attributes, such as cash for consumption, equity and debt level, denoted by X_{ij}. In the example, there are the prices of potato at both markets. The price is determined by the amount of potato supplied to each market. If there is very good weather the production will be high boosting the supply, which in turn reduces the price.

5. The decision-maker's preferences for risky consequences.

6. A choice criterion or objective function- taken, for the time being, to be choice of the option with the highest certainty equivalent.

Rational Choice Under Risk

Rational choice under risk can be defined as a choice consistent with the decision maker's beliefs about the chances of occurrence of alternative uncertain consequences and with his relative preferences for those consequences. The decision maker's beliefs are reflected in probabilities he assigns (implicitly or explicitly) to uncertain events, while his preferences for consequences are captured in the way risky payoffs with their associated probabilities are converted to a certainty equivalent that can be used as the criterion for choice.

Measuring uncertainty with subjective probabilities

There are different ways of thinking about probability. The first way of thinking is the 'frequentist' school of thought. According to this view, a probability is defined as a relative frequency ratio based on a large number of cases from historical data. In cases where this does not apply, the uncertainty can be accounted for by taking a 'subjective' view of probability. According to this view, a probability is defined as the degree of belief an individual has in a particular proposition.

In general probabilities provide a means of measure of uncertainty. In decision analysis they are viewed as subjective statements of the degree of belief that a person has in a given proposition. The view of a probability as a degree of belief can be given a formal basis by the so-called visual impact method.

To illustrate this method, let's consider the potato-marketing problem. From historical data the following growing season weather frequency data were obtained (table 2.).

Table 2. Growing season weather condition for Addis Ababa for the last 40 years

Weather condition	Counts	Implied probability
Very good	34	34/40 = 0.85
Good	4	4/40 = 0.10
Bad	2	2/40 =0.05

Since the assessed probabilities are the basis for decision making, it is important to take tremendous effort to make the subjective probabilities more reliable. There are two aspects that should be considered in making better probability judgments:

1. Psychological pitfalls in making probability judgments. Many experiments in psychological research have shown that there are many judgmental biases that affect probability assessments. Some of these are:

- Avoidance of uncertainty
- Representativeness
- Misconception of chance
- Anchoring and adjustment
- Motivational bias

2. Making better use of information in probability assessment

In addition to the use of all information available it is also important to take into consideration expert advice.

Attitude to risky consequences

As mentioned earlier, the attitude to risky consequences are expressed by preferences for the consequences, which are captured in the way risky payoffs with their associated probabilities are converted to a certainty equivalent that can be used as the criterion for choice.

As is shown in the example of the potato-marketing problem, risky decision problems can be solved by getting the decision-maker to convert the risky consequences of an event fork to a certainty equivalent (CE). However, that can become very tedious for the decision-maker if there are many such risky event forks. Therefore,,, it is desirable if the risk preferences of a given decision maker could be encoded in some way so that conversion of CEs could be programmed. Utility theory provides a means of encoding any risk preferences.

There are many functional forms that express utility. Among these forms negative exponential functional form of utility has been popular as it represents the utility for risk averse decision makers. It has the following functional form:

$$U = 1 - \exp(-cW)$$

Where: c is the coefficient of absolute risk aversion W is the payoffs

A number of different approaches have been developed to elicit the required information from decision-makers to be able to encode their preferences into a suitable utility function. One way of eliciting such a function is a direct approach whereby a decision-maker is asked to rate his relative preferences for consequences. Thus, if the utility of the best outcome is defined as having a utility value of say, one, and the utility of the worst outcome is defined as having a utility of zero, the decision maker could be asked to assess his utility value for a sufficient number of intermediate points to define a utility function. The other approach is the so-called ELCE (Equally Likely Certainty Equivalent) method, which enable to derive the certainty equivalents from the decision-maker for a sequence of risky prospects.

Integrating beliefs and preferences for decision analysis

In general one should follow the following method of resolving a decision tree using probabilities and utilities:

3. Assign probabilities to each event branch, making sure that these are coherent with probability principles.
4. Calculate money payoffs for each terminal branch by summing along the relevant act-event sequence.

5. Covert these money payoffs to utility values using the decision maker's utility function
6. Working back from the terminal branches, replace each event node by the corresponding expected utility (EU) value, or by CE value. Then resolve decision forks by selecting the branch with the highest EU or CE value.
7. Mark off dominated acts at each stage so that the optimal path through the tree is apparent.

Now, let's go back to the potato marketing decision problem to see how the probabilities and the utilities are integrated into the analysis following the above method. We know already the probabilities and the payoffs (see Figure 3). The utility function that represents the preference to the risky prospects of the potato grower is estimated to be:

$$U(X) = 1 - \exp(-0.06 \times X)$$

When converting the payoffs into utility values we get the values presented in the terminals of each decision branch in the decision tree representation, Figure 4. Now we know that the best decision for the grower is to harvest and sell now at Nazareth market.

CONCLUSION

This paper presented the importance of risk analysis in agriculture in general and the basic methodologies of analysis using a simplified example of potato growing farmer's marketing problem.

Risk management in agriculture is the systematic application of management policies, procedures and practices to the tasks of identifying, analyzing, assessing, treating and monitoring agricultural risks. The major types of agricultural risk are production, price or market, institutional, personal and financial risks. Even though, from different angles, farmers, farm advisors, commercial firms selling or buying from farmers, agricultural research workers; and policy makers and planners need to deal with agricultural risk in their day-to-day decision making.

In general, rational decision or choice under risk is a choice consistent with the decision maker's beliefs about the chances of occurrence of alternative uncertain consequences and with his relative preferences for those consequences. The decision maker's beliefs are reflected in probabilities he assigns (implicitly or explicitly) to uncertain events, while his preferences for consequences are captured in the way risky payoffs with their associated probabilities are converted to a utilities or certainty equivalent that can be used as the criterion for choice.

The specifics of Ethiopian agricultural system makes risk management more important because on one hand, it is heavily dependent on annual weather condition and on the other hand, it is dominated by subsistence and small-scale production making the production system more risky. Among the risk types, production risk is the most important one, even though, recent phenomena show that market risk is also becoming eminent in many parts of the country.

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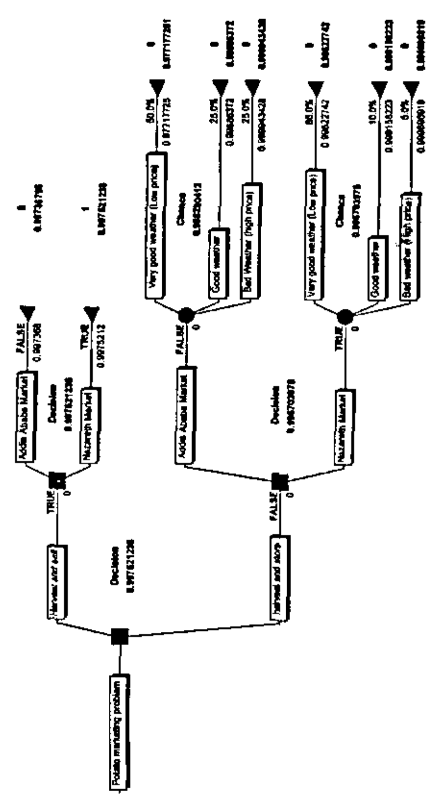
Figure 4

Decision tree representation for potato marketing problem

Integrating beliefs and preferences



Note: values in the tree represent Expected utility values (EU), which is the utility multiplied by the corresponding probability

CLIMATE CHANGE AND AGRICULTURE

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Abstract

One of the many environmental problems facing mankind today is antropogenic climate change (global warming). The cause of climate change is the increasing concentration of greenhouse gases in the atmosphere from human activities such as fossil fuel burning and deforestation. According to the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC), if steps are not taken to reduce emission of greenhouse gases (i.e. if business as usual scenario continues), the current mean annual air temperature of the earth will increase by 1.4 – 5.8 ^{0} before the end of the 21st century. Global mean sea level is projected to rise by 0.09 to 0.88 meters between 1990 and 2100. Frequency and intensity of extreme climatic events are also expected to change. Such drastic changes of climate in a short span of time are expected to have adverse impacts on the socio-economic development of nations. Experimental, empirical or mechanistic (processed based computer simulation models) approaches can be applied to assess vulnerability of agriculture to climate change. Agriculture which is already sensitive to current climate variability is one of the sectors that is at risk from global warming and Hence, a great concern for Ethiopia. Studies already made show that agriculture in low latitudes will be adversely affected by climate change. It is recommended that research has to be undertaken to understand and establish the level of the vulnerability of the country's agriculture to climate change and to identify best adaptation options. The need for collaboration among NMSA, EARO and other relevant institutions in terms of data exchange, experience sharing, etc. for climate change and agriculture research undertakings including enhancement of national technical capacity in the field of climate change through short and long term training is also emphasized

INTRODUCTION

The atmosphere plays a key role in the exchange of radiation energy between the earth and the sun. It is known that the greenhouse effect or the heat trapping property of the atmosphere keeps the annual average surface air temperature of the earth at about 15°C. Without this natural phenomena the earth's annual average temperature would be -18 °C and life as we know it would not exist at such cold situation. This important function of the atmosphere is being threatened by the rapidly increasing concentration of greenhouse gases (GHGs) in the atmosphere due to human interference.

Scientific measurements made around the world have shown that concentration of greenhouse gases (GHGs) has been increasing in the atmosphere since the industrial revolution (IPCC 2001). For example the atmospheric concentration of Carbon Dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) has increased by 31%, 151% and 17% respectively compared to the levels prior to the industrial revolution.

It is now widely accepted that increased concentrations of greenhouse gases will lead to global climate change by enhancing the natural greenhouse effect. According to the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC), if steps are not taken to reduce emission of greenhouse gases (i.e. if business as usual scenario continues), the current mean annual air temperature of the earth will increase by 1.4 – 5.8 ^{0}C towards the end of the 21st century. Global mean sea level is projected to rise by 0.09 to 0.88 meters between 1990 and 2100. Frequency and intensity of extreme climatic events are also expected to change. Such drastic changes of climate in a short span of time are expected to have adverse impacts on the socio-economic development of nations. IPCC also has concluded that African countries will be more vulnerable to climate change due to their low adaptive capacity (IPCC, 2001).

A number of evidences are emerging which shows that climate has already started changing as a result of antropogenic interference. The global average surface temperature has increased over the 20th century by about 0.6°C. Snow cover and ice extent have decreased. Global average sea level has risen between 0.1 and 0.2 meters during the 20th century and ocean heat content has increased. Changes in rainfall intensity and pattern have also been observed in different parts of the world.

Evidences that could be associated with climate change have also started appearing in Ethiopia. In the last 50 years the annual average minimum temperature over the country has been increasing by about 0.2^{0}C every decade.

We have experienced frequent and extensive droughts in recent decades which caused food shortages and famine in the country. The spread of malaria to highland areas which have never experienced before, loss of biodiversity and a decline in wildlife number have also been observed.

The United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1992 by world leaders to combat climate change. The ultimate objective of the UNFCCC is to stabilise the concentration of greenhouse gases in the atmosphere at a safe level. The Kyoto Protocol which commits developed country parties to reduce on average 5.2% of their 1990 greenhouse gas emission level by 2010 was also adopted in 1997. Ethiopia signed the UNFCCC at the Earth Summit held in Rio de Janeiro and later ratified it on 05 April 1994. Since then Ethiopia has paid great attention to the issues of climate change and various activities have been undertaken including conducting climate change country studies and participating in climate change negotiations. The Initial National Communication of Ethiopia to the UNFCCC was submitted in October 2001.

The Climate Convention commits all Parties to develop and submit "national communications" which should contain inventories of greenhouse gas emissions and information on steps taken to implement the Convention at the national level. Parties are also required to assess their vulnerability to climate change and identify adaptation options that could enable to cope with adverse impacts. Climate Change could have far reaching implications to Ethiopia for many reasons. Its economy mainly depends on agriculture, which is very sensitive to climate variations. A large part of the country is arid and semiarid and is highly prone to desertification and drought. It has also a fragile highland ecosystem which is currently under stress due to population pressure. Forestry, water and biodiversity resources of the country are also climate sensitive. Ethiopia is also affected by vector-born diseases, such as malaria, which are closely associated with climate variations. Under a warmer climate the problems mentioned above are may get worse.

Agriculture which includes crop production, animal husbandry, forestry, fisheries and apiculture remains by far the most important sector of the country for the following reasons. It directly supports about 85% of the population in terms of employment and livelihood. It contributes about 50% of the country's gross domestic product (GDP). It generates about 90% of the export earnings. It supplies around 70% of the raw material requirement of ago-based domestic industries (MEDaC, 1999). Agriculture is also the major source of food for the population of the nation and Hence, the prime contributing sector to food security. In addition agriculture is expected to play a key role in generating surplus capital to speed up the overall socio-economic development of the country.

Agriculture which is already sensitive to current climate variability is one of the sectors that is at risk from global warming and Hence, a great concern for Ethiopia. This paper highlights some of the methodologies used for climate change impact studies, results found adaptation options and recommendations for future actions

APPROACHES IN STUDYING IMPACTS OF CLIMATE CHANGE ON AGRICULTURE

The effects of changes in atmospheric composition are both direct, through changes in concentration of important gases, and indirect, through changes in climatic conditions. For example, rising concentrations of some of the greenhouse gases (CO2) have direct effects on plant physiological processes.

There are three approaches namely experimental, empirical and mechanistic (processed based) to assess vulnerability of agriculture to climate change. Most researchers use computer based simulation models for their studies but simulation models need a lot of data. For example input data that are needed to simulate crop weather models include baseline climate, climate scenarios, soil, management, soci-economic and crop.

Impacts of Climate Change on Agriculture

According to the recent IPCC report IPCC (2001) the response of crop yields to climate change varies widely, depending on the species, clavier, soil condition, treatment of CO2 direct effects and other location factors It is anticipated that a few degrees of projected warming will lead to general increase in temperate crop yields, with some regional variation. At larger amounts of projected warming, most temperate crop yield responses become generally negative. In the tropcs, where some crops are near their maximum temperature tolerance and where dry-land agriculture predominates, yield will decrease generally with even minimal change in temperature: where there is large decreases in rainfall, crop yields would be even more adversely affected. Extreme events also will affect crop yields. Higher minimum temperature will be beneficial to some crops, especially in temperate regions, and detrimental to other crops, especially in low latitudes. Higher maximum temperatures will be generally detrimental to numerous crops. In Ethiopia studies made on wheat in the central parts of the country shows that climate change would shorten length of the maturity period by about 10% compared to the base line climate.

Adaptation Options in Agriculture

Greenhouse gases will continue accumulating in the atmosphere in the 21st century which implies that climate change and global warming seem inevitable. Therefore,, there is a need to adapt to climate change. Adaptation options can help ameliorate agricultural vulnerability and crop yield loses. Adaptation options could be autonomous or anticipatory.

A number of possible adaptation options are suggested by researchers including Change in timing of planting, harvesting. and other management activities, minimum tillage practices, change in animal stoking rate on rangelands, switch to crops that are less water demanding, developing drought early warning system, Promotion of agro-forestry in dry land areas, conducting research to develop new cultivars, promoting revegitation and reforestation initiatives, assist natural migration of tree species, improve training and education of rural people.

RECOMMENDATION

Climate change will have adverse impacts on various socio-economic activities including agriculture. Work done so far at the national level in this area is very limited. Therefore,, research has to be undertaken to understand and establish the level of the vulnerability of the country's agriculture to climate change and to identify best adaptation options.

There is a need for collaboration among NMSA, EARO and other relevant institutions in terms of data exchange, experience sharing, etc. for climate change and agriculture research undertakings. There is also a need to enhance national technical capacity in the field of climate change through short and long term training.

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AGROCLIMATIC ANALYSIS IN RELATION TO CROP PRODUCTION

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Abstract

The production of crops depends on the understanding and interrelationships of four basic factors: the genetic potential of plants, soils, weather and the management. All these factors are not simple physical variables of one dimension but very complicated ones. In order to make reliable plans for the development of food production and to carry out such plans successfully, it is necessary to understand the effect of the combined action of these factors. Of all these four factors, weather is the most variable and unpredictable element that deserves the combined attention of researchers and development workers. This paper tries to briefly explain the theoretical background of agroclimatogy and its application in relation to crop production. The major characteristics of the rainfall pattern are its seasonality with distinct dry and rainy seasons. Recommendations of farming practices based on average data would mask extreme events and lead to an over estimation of the production potentials of an area. Therefore, selection of an appropriate risk level to stabilize crop production by maintaining a safety condition that allows full utilization of the potential in most years is of major interest in agroclimatology. Analysis of agroclimatic resources of 20 wheat-growing sites to enhance wheat improvement is presented to demonstrate its practical application. The wheat growing sites are defined and clustered based on rainfall, temperature, altitude, longitude, soil type, and length of growing season Of the parameters studied, annual rainfall, main season rainfall, and length and end of growing period were negatively correlated with longitude ($r = -0.73^{**}$, -0.82^{**}, -0.64^{**} and -0.43^{*}). Altitude was negatively correlated only with maximum and minimum temperatures ($r = -0.64^{**}$ and -0.86^{**}). Three main environmental groups and six subgroups were identified in the cluster analysis. Such clustering into homogeneous groups will assist the national wheat improvement program in making decisions about test site selection and proper targeting of released varieties. Improvement research in the western region (cluster groups 1 and 2) should focus on the development of long season genotypes resistant to waterlogging. For cluster group 4, breeding for waterlogging resistance and terminal drought stress is essential. Cluster group 5

requires a breeding effort to develop short cycle and drought tolerant varieties.

INTRODUCTION

After millennia of food self-sufficiency Ethiopia is no longer capable of feeding itself, and today food aid is a common activity for many government and non-government institutions. Population growth has already considerably out paced agricultural production. The gap between demand and supply of food is bound to widen even in the years to come. The land area can not be increased for increased production; on the contrary agricultural land is being encroached upon for urban purposes to meet the requirements of the increasing. population. Given the above scenario, self-sufficiency in Ethiopia seems difficult. However, cognizant of its potential, it is within the realm of practicability provided a sound policy of agricultural education, research and extension is devised.

The production of crops depends on the understanding and interrelationships of four basic factors: the genetic potential of plants, soils, weather and the management. All these factors are not simple physical variables of one dimension but very complicated ones. Neither are they independent of one another, on the contrary they are often very closely interrelated. In order to make reliable plans for the development of food production and to carry out such plans successfully, it is necessary to understand the effect of the combined action of these factors.

Of all these four factors, weather is the most variable and unpredictable element that deserves the concerted attention of researchers and development workers. Farmers felt powerless as in the face of something inalterable and they believed that they have to take the inclemency (punishment) as well as harvest the benefits as they come. However, much can be done to mitigate the unfavorable influence of the weather despite the impossibility of changing the microclimate.

DEFINITION OF AGROMETEOROLOGY

In its broadest sense agrometeorology is concerned with the interaction between meteorology and all the activities of man in the field of agriculture. This includes the production of forests and production related to the bodies of water of the earth. The widest conception of agrometeorology also includes the protection of the environment in which all production takes place. A more restricted definition of agrometeorology considers only the agricultural production of crops and domestic animals and their interactions with their environment.

The aim of agrometeorology is to make the efficient use of the physical environment for improving and sustaining agricultural production, both the quality and quantity. It takes into account the influence of the various climatic factors on agriculture. However these climatic factors never act in isolation but are combined together. When they are combined into a derived parameter, like water balance, for example, they will be much more significant than a single parameter such as precipitation.

Effect of Weather Elements on Crop Growth and Development

The state of the atmosphere that is constantly changing profoundly influences all physical, chemical and biological activities over the earth. Thus regulates the living conditions of plants and animals, their growth and multiplication. The living organisms are able to adjust themselves to the prevailing state of atmosphere to a certain extent, and those forms alone survive that adapt themselves to the particular state of atmosphere; the others get extinct. The effect of weather elements in relation to crop production is numerous.

1. *Weather elements affect plant growth and development:*
   i) Temperature: the velocity of chemical reactions increases with rise of T^0.
   ii) Sunshine: elaboration of sugars by plants takes place only in the presence of sunlight.
   iii) Rainfall: supplies water
   iv) Humidity: reduces transpiration in plants and evaporation of soil moisture.
   v) Wind: enhances pollination, keeps atmospheric t^0 low, Windmills, winnowing, wind erosion

2. *Climate dominates cultivation operations:*
   - Dominates all agricultural operations and their correct timing leads to increased production.
     e.g. ploughing, planting, weeding is best done when the soil is at the correct level of moisture.
   - The plant is affected at every stage of its growth by environmental conditions (Lodging, disease, pest,)
   - Post harvest operations, such as drying, storage life, etc. is affected by weather elements
   - Diseases and pests are associated with weather elements.
   - Climate and weather affects the mechanical, physical and chemical properties of the soil, the organism it contains and its capacity for retaining and releasing heat and moisture.

The Concept of Dependable Rainfall

Agriculture in Ethiopia, like elsewhere in the semi-arid tropics, depends largely on rainfall, which vary from area to area, giving uncertainties in agricultural production. Though it is expected to occur during a cropping season and be useful to plants, the rainfall does not occur with a fixed schedule in frequency, duration and intensity in any region showing effects of widė fluctuations in crop performances.

The rainfall amount and distribution are the generally accepted unpredictability complexities. The main features of rainfall distribution variability are the amount and intensity in time and space, it's dependability, variability of sequences of wet and day spells, floods, storms, effective cropping season, timeliness etc.. These limits: the choice of crops, sawing times, choice of varieties, agronomic practices, total production obtained.

An important characteristic of rainfall in marginal land is that storm events are short-lived. The intensity therefore, tends to be high and infiltration rates generally low particularly in areas with sandy soils. Regarding rainfall amount and its distribution, each season is different. As a result recommendations of farming practices based on average data would mask extreme events and lead to an over estimation of the production potentials of an area. Therefore, selection of an appropriate risk level to stabilize crop production by maintaining a safety condition that allows full utilization of the agroclimatic potential in most years is of major interest in agroclimatology. To this effect, the concept dependable rainfall, rainfall amount that has a specified probability based on the analysis of long term (>20 years) records of rainfall (most commonly 75%), is accepted (Hargreaves, 1975).

The main objective of calculating dependable rainfall is to selection of appropriate risk to stabilize agriculture production by maintaining a safety condition that allows full utilization of the agroclimatic potential in most years.

The Concept of Growing Degree Days (GDD)

Since temperature is directly dependent on altitude, it will be very important to take this factor into consideration, particularly as regards the length of the growing cycle of crops. In the semi-arid tropics the daily temperature amplitude is wide and the annual range is very narrow.

Most crops make their best development between 15°C and 32°C (160 - 90°F). The minimum temperature at which any plant can maintain fife during the growing season is freezing paint of water. The threshold value or point at which appreciable growth can be detected is called base temperature and varies for different crops (0 for C3 and 12 for C4 crops).

Within suitable temperature ranges, growth increases with each rise in temperature. Crops differ in the number of heat units required to mature them. Heat units are usually computed by a summation of degree-days for growing season. A degree-day is the average temperature above the base temperature.

$$\text{Degree Days} = \frac{T\ max + T\ min}{2} - \text{base } T^{o}$$

$$\text{Growing Degree Days (GDD)} = ❹ \frac{(T\ max + T\ min)}{2} - \text{base } T^{o}$$

The Length of Growing Period

The semi-arid climates are characterized by a long dry period during which the soil moisture and rainfall are insufficient to sustain crop production. The growing season considered is the period during which the soil moisture coming from rainfall is freely available to the crop with the condition that other climatic elements are with in the optimum range to allow normal physiological activity of the plant. Four periods characterize a growing season.

a) **Preparatory period**: During this period rainfall: PET ratio is between 0.3 and 0.5, this is a period for preparing fields or for dry seeding. However, sowing in dry soil of course involves the risk that the rainfall, while sufficing for germination, may fail to provide sufficient moisture for emergence and continued growth.

b) **Pre-humid period** (season begins: when the rainfall ranges from 0.5 PET to PET. The amount of rainfall received increases; consequently the soils become increasingly moist. However, there is no substantial build up of soil moisture. Planting of most crops, like maize, sorghum, millet and small cereals, can be done during this period.

The beginning of the growing season was defined using the following criteria, to ensure stability and minimize the risk of false rainfall starts:

- 20 mm of dependable rainfall in a decade or 30 mm of total rainfall in a decade provided it exceeds half the potential evapotranspiration in the previous decade, and
- A period without dry spell (a decade receiving below 20 mm of dependable rainfall) for at least the next three decades based on the historical analysis.

c) **Humid period**: During this period, the total precipitation is in excess of PET, and therefore, potential and real evapotranspiration are equal. The surpluses rainfall over evapotranspiration builds up the soil moisture reserves. What exceeds the soil moisture storage capacity is lost by run-off or deep percolation below the root zone. In vertisols this is the time of water logging problems, unless appropriate drainage system is designed.

d) **Post-humid period** (end of season): during this period, a progressive reduction and a possible cessation of the precipitation. This period covers the time range when PET > P > 0.5 PET plus a period during which the soil moisture accumulated is transpired at the potential evapotranspiration rate. If the crop growth cycle has been matched properly to the growing period, it is assumed that during this period, the crop has lower, but still substantial water requirements. The soil moisture storage capacity is a critical input that determines the length of the growing period and finally the yield. The role of soil moisture in extending the growing period after the termination of the rains and/or linking separate growing periods (as in bimodal rainfall situations), depends on many conditions: rainfall - evapotranspiration ratio, moisture holding capacity of the soil and the ability of the crops to extract the available soil moisture (DePauw, 1988).

In Ethiopian condition, end of growing season could be defined as the first decade in which the available soil water content dropped below 20 mm and remained below that level until the following growing season. The major weakness of this type of analysis is that no specific information about the upcoming season with which the farmer must deal. It may fall anywhere at all within the total range of possibilities revealed by the rainfall record. It would be useful if both short-term and long-term forecasting are also considered thoroughly, before the start of each season.

The Concept of Response Farming

Response farming is an approach in which crop management is systematically adjusted in response to the specific rainfall indicators in the early part of the season. Farmers are provided an assessment of the rainfall prospects prior to or at

The annual rainfall statistics indicated significant variability over time and space: the variability was more pronounced for the low rainfall eastern and northern regions. The standard deviation of annual rainfall varied from 96 (Sinana) to 483 (Nekemte). However, the time series analysis of individual sites did not show a clear trend of repeating events. The probability of receiving below normal rainfall (i.e., drought years) varied from 7% of years (Debre Birhan) to 22% (Debre Zeit), whereas above normal rainfall was expected from 0% (Bale-Robe) to 29% (Ginchi) of years.

A major feature of rainfall pattern or distribution in Ethiopia, like elsewhere in the semi-arid tropics, is its seasonality, with distinct dry and rainy seasons. Generally, the rainy season lasts from 2.5 (Mekele) to 6.5 (Yetnora) months. East of 39.4° E longitude in Ethiopia, rainfall distribution is bimodal, allowing two cropping seasons, viz. "belg" (short) and "meher" (long), whereas in the central, northern and western regions distribution is generally monomodal.

The effective start, end and length of the growing seasons for each location are given in Table 3. In the Eastern Highlands, the belg season starts from late March (Sinana) to early April (Alemaya), and continues until late June (Alemaya) to mid July (Bale-Robe). At Alemaya and Bale-Robe, the short belg rainy season merges with the main season in 30 and 40% of the years, respectively. The length of the meher season ranges from 84 days (Mekele) to 217 days (Nekemte) with a mean value of 150 days. Effective meher planting can begin from early May (Bekoji, Akaki, Ginchi, Yetnora, Nekemte) to early August (Bale-Robe, Sinana). The end of the growing period is also variable, ranging from the first week of October (Mekele) to the end of December (Sinana).

The probability of a dry spell occurring during each growing period for each site is given in Table 4. During the belg season, the probability of dry spell occurrence reaches as high as 25% (at Agarfa in June). Dry spell probability during the meher season is particularly high at the end of the season, peaking at up to 100% at some sites during October. The most severely affected region is Mekele, experiencing severe dry spells in July, September and October (23%, 55% and 100% probability, respectively). For the majority of the regions, October is the beginning of the dry season with the exception of Sinana and Bale-Robe.

The environmental variables that were used for correlation analysis were longitude (LON), latitude (LAT), altitude (ALT), annual rainfall (ANP), modality of rainfall distribution (MOD), main season rainfall (MSP), length of growing season (LGS), start of growing season (SGS), end of growing season (EGS), minimum temperature (Tmn), and maximum temperature (Tmx). The results of the correlation coefficient analysis are presented in Table 5. Of the parameters studied, annual rainfall, main season rainfall, and length and end of growing period were significantly and negatively correlated with longitude (r = -0.73**, -0.82**, -0.64** and -0.43*, respectively). The modality of rainfall distribution is positively correlated with longitude (0.67**). On the other hand, altitude is significantly and negatively correlated only with maximum and minimum temperatures (r = -0.64** and -0.86**, respectively). Annual rainfall correlated positively with main season rainfall, length of the growing period, and end of the growing period (r = 0.96**, 0.77** and 0.44*, respectively).

Among the climatic data and geographical descriptors studied, longitude, altitude, annual rainfall total and distribution, length of the growing period, and seasonal rainfall were found important for clustering the 20 sites into homogeneous agro-ecologies in an agronomic sense. Cluster analysis produced several classes at different levels (Figure. 1). Comparing the pseudo F and t2 values, a grouping of three major classes and six minor classes best explained the wheat growing regions of Ethiopia. The three major classes are: C1 (western cluster), Nekemte, Adet, Debre Markos, Yetnora, Holetta, Akaki, Ginchi and Gondar; C2 (highlands cluster), Debre Berhan and Bekoji and C3 (eastern cluster), Sinana, Bale-Robe, Agarfa, Mojo, Debre Zeit, Kombolcha, Mekele, Asasa, Kulumsa and Alemaya;. For more precise and efficient crop improvement research, cluster group 1 (C1) is further subdivided into two subgroups, C1-1 and C1-2, at the six-group level (Figure. 1, Table 6). Cluster group 3 (C3) is further subdivided into three subgroups, C3-1, C3-2 and C1-3.

DISCUSSION

The wheat growing regions of Ethiopia is highly heterogeneous, resulting in complex agro-ecological conditions. The potential for improved crop production and crop management practices in each region is affected by the interplay of many factors, including climatic elements, soil characteristics, and a range of socioeconomic and biological factors. Development of appropriate crop production technologies requires a thorough understanding of site-specific constraints. Such an understanding is required for the identification of production problems, the setting of research priorities, and targeting of technology that is agroecosystem-specific. A fuller understanding of the agro-ecological characteristics of specific wheat growing areas will also allow the dissemination of research results and improved technologies across areas with similar conditions.

It has been reported that altitude plays an important role in the distribution of wheat production in Ethiopia through its influence on rainfall and temperature (Hailu 1991). However, our analysis reveals that rainfall amount and distribution have no relationship with altitude (Table 5). Thus, the traditional classification of wheat growing regions based on altitude alone should be changed. Since rainfall amount and distribution changes along a west-east axis, longitude together with temperature and soil parameters should be utilized for a realistic site classification. However, altitude does affect mean air (and soil) temperature, and, therefore, affects crop maturity intervals, the incidence and severity of crop disease and insect pests, and the rate of evapotranspiration.

The most important objectives in developing a strategic plan for dryland farming are to define the effective start and end of the growing season, and the length of the season. Different definitions of these moisture sensitive parameters have been suggested, using rainfall amount (Stern et. al. 1982, Belay and Struik, 1993). However, crop moisture stress does not begin when rainfall ceases, but rather when plant roots can no longer obtain sufficient moisture from the soil to replenish that lost through transpiration. Therefore, these critical parameters are better defined on the basis of soil moisture reserves rather than upon rainfall records as demonstrated in this study.

Development of appropriate crop production technologies requires a good understanding of constraints and opportunities in the different wheat growing ecosystems. Such an understanding is needed for the identification of problems, the setting of research priorities, and targetting crop production technology that is agroecosystem-specific. Locations should be classified into homogeneous groups based on physical resources. The cluster analysis used in this study produced several classes at different levels of discrimination (Figure. 2). However, a cluster of three major and six minor classes could be useful for defining wheat crop improvement sites and in strategic planning for wheat production.

The western cluster is basically characterized by very high rainfall with monomodal distribution, a long growing period and high production potential. In terms of resource use efficiency, monocropping of wheat in these regions is not economical. Rather, relay cropping or double cropping systems should be emphasized. Other negative effects such as transient waterlogging during June and July, particularly on Vertisols, should not be neglected and mitigating measures should be applied to maximize resource use efficiency. Rainfall distribution in the eastern zone (i.e., between approximately 39.5° and 42.5° E) is effectively bimodal as a consequence of the movements of the Inter-Tropical Convergence Zone. In these regions, double cropping should be an effective means of maximizing return per unit area.

Such clustering into homogeneous groupings will assist the national wheat improvement program in making decisions regarding the selection of test sites and proper targetting of released varieties. Improvement research in the western region (cluster groups 1 and 2) should focus on the development of long season genotypes resistant to waterlogging. For cluster group 4, breeding for waterlogging resistance and terminal drought stress tolerance is essential. Cluster group 5 requires a breeding effort to develop short cycle and drought tolerant varieties. Detailed recommendations about how best to respond to this assessment in terms of land preparation, cultivar characteristics or ideotypes, cropping system components, seeding and fertilization rates, and time of seeding are vital for the different agro-ecological regions.

CONCLUSIONS AND RECOMMENDATIONS

- Analysis of historical weather data and clustering of regions into homogenous groups enhances both tactical and strategic decisions
- **Cluster group 1 and 2 (western) requires > longer maturity**
- **Cluster 4 > water logging resistance**
- **Cluster 5 > shorter maturity & drought resistance**
- **Management issues specific to different clusters**
- **Agroclimatic analysis and crop growth models are important tools to enhance crop improvement,**
- **By no means, they replace field experimentations,**
- **For effective delivery of results, interdisciplinary work with agronomists is worth considering.**

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Table 1. The geographical locations, altitude and database years used for the analysis of major wheat growing regions of Ethiopia.

	Site	Longitude (° E)	Latitude (° N)	Altitude (m)	Database years
1.	Alemaya	42.20	9.25	2125	85-95
2.	Sinana	40.10	7.12	2400	90-95
3.	Bale-Robe	40.00	7.08	2480	71-95
4.	Agarfa	39.49	7.16	2550	83-95
5.	Kombolcha	39.44	11.07	1903	71-95
6.	Debre Berhan	39.30	9.38	2750	80-95
7.	Bekoji	39.30	7.55	2700	72-95
8.	Mekele	39.29	13.30	2070	63-95*
9.	Asasa	39.20	7.05	2360	72-95
10.	Kulumsa	39.10	8.05	2200	67-95
11.	Mojo	39.07	8.37	1870	82-95
12.	Debre Zeit	38.57	8.43	1850	54-90
13.	Akaki	38.45	9.02	2354	64-95
14.	Ginchi	38.20	9.01	2250	89-95
15.	Holetta	38.14	8.58	2400	83-95
16.	Yetnora	38.09	10.12	2540	89-95
17.	Debre Markos	37.40	10.20	2515	71-95
18.	Gondar	37.25	12.33	1967	71-95
19.	Adet	37.43	11.17	2240	86-96
20.	Nekemte	36.35	9.2	2005	71-95
	Mean	38.92	9.09	2277	
	SD	1.24	1.74	280	

* 1989-93 missing

Source: Belay et al, 1999.

Table 2. Annual rainfall (ANP), standard deviation of annual rainfall (SD), percentage of years below normal (BNP) and above normal (ANP) rainfall, and the modality of rainfall pattern (MOD) of the selected wheat growing site-season combinations.

	Site	ANP (mm)	SD (mm)	BNP (%)	ANP (%)	MOD
1.	Alemaya	753	110	18	9	2
2.	Sinana	839	96	17	17	2
3.	Bale-Robe	798	125	13	0	2
4.	Agarfa	742	136	8	17	2
5.	Kombolcha	972	164	17	11	2*
6.	Debre Berhan	812	142	7	22	1
7.	Bekoji	1048	165	13	9	1
8.	Mekele	585	148	14	14	1
9.	Asasa	656	97	20	8	1
10.	Kulumsa	823	127	14	10	1
11.	Mojo	823	148	21	21	1
12.	Debre Zeit	769	192	22	17	1
13.	Akaki	1063	132	11	6	1
14.	Ginchi	1142	160	14	29	1
15.	Holetta	1079	137	15	23	1
16.	Yetnora	1385	313	14	14	1
17.	Debre Markos	1278	154	13	17	1
18.	Gondar	1033	208	12	16	1
19.	Adet	1238	183	20	20	1
20.	Nekemte	1784	483	13	17	1
	Mean	1010	-	14.8	14.9	-
	SD	328	-	4.0	6.7	-

* First (belg) season is too short for crop production

Source: Belay et al, 1999.

Table 3. The effective and dependable start (STR), end (END) and length of the growing period (LGP) for the selected wheat growing sites.

Site	Belg (short) season			Meher (long) season			Remark
	STR (Month, week)	END	LGP (days)	STR Month, week)	END	LGP (days)	
1. Alemaya	Apr.1	Jun.4	90	Jul.1	Oct.3	103	
2. Sinana	Mar.4	Jun.4	95	Aug.1	Dec.4	130	merged 30%
3. Bale-Robe	Apr.3	Jul.3	94	Aug.1	Nov.3	109	
4. Agarfa	Apr.2	Jun.2	84	Jul.4	Oct.3	90	merged 40%
5. Kombolcha				Jul.1	Oct.3	102	*
6. Debre Berhan				Jun.1	Oct.4	147	
7. Bekoji				May.1	Nov.4	207	
8. Mekele				Jul.2	Oct.1	84	
9. Asasa				Jul.1	Nov.2	129	
10. Kulumsa				Jun.2	Nov.3	163	
11. Mojo				Jun.4	Nov.3	137	
12. Debre Zeit				Jun.4	Oct. 3	113	
13. Akaki				May.1	Nov.2	190	
14. Ginchi				May.1	Nov. 3	203	
15. Holetta				May.4	Oct.4	157	
16. Yetnora				May.1	Nov.4	210	
17. Debre Markos				May.2	Nov.4	184	
18. Gondar				May.4	Oct.3	158	
19. Adet				Jun.1	Nov.2	162	
20. Nekemte				May.1	Dec.2	217	
Mean				Jun.2	Nov.2	150	
SD				33	20	42	

* First season not important

Source: Belay et al, 1999.

Table 4. Probability of dry spells during the effective growing seasons for the selected wheat growing sites.

		Probability of dry spell (%)						
		Belg season			Meher season			
	Site	Apr	May	Jun	Jul	Aug	Sept	Oct
1.	Alemaya	2	3	5	1	0	7	90
2.	Sinana	17	0	0	50	0	0	0
3.	Bale-Robe	22	12	0	12	12	0	0
4.	Agarfa	8	8	25	8	8	0	25
5.	Kombolcha				28	0	0	89
6.	Debre Berhan				33	0	0	73
7.	Bekoji				0	0	0	43
8.	Mekele				23	9	55	100
9.	Asasa				4	0	20	100
10.	Kulumsa				0	0	10	97
11.	Mojo				14	0	7	86
12.	Debre Zeit				0	0	0	93
13.	Akaki				0	0	0	89
14.	Ginchi				0	0	0	86
15.	Holetta				0	0	0	100
16.	Yetnora				0	0	0	71
17.	Debre Markos				0	0	0	57
18.	Gondar				0	0	0	40
19.	Adet				0	0	0	10
20.	Nekemte				8	8	0	13

Source: *Source*: Belay et al, 1999.

Table 5. Correlation coefficient analysis of longitude (LON), latitude (LAT), altitude (ALT), annual rainfall (ANP), modality (MOD), main season rainfall (MSP), length of growing season (LGS), start of growing season (SGS), end of growing season (EGS), minimum temperature (Tmn), and maximum temperature (Tmx).

Variable	LON	LAT	ALT	ANP	MOD	MSP	LGS	SGS	EGS	Tmn
LAT	-0.34									
ALT	0.12	-0.37								
ANP	-0.73**	0.20	-0.02							
MOD	0.67**	-0.29	0.03	-0.33						
MSP	-0.82**	0.29	-0.05	0.96**	-0.54*					
LGS	-0.64**	-0.01	0.26	0.77**	-0.60*	0.80**				
SGS	0.42	-0.30	0.07	-0.39	0.59*	-0.49*	-0.53*			
EGS	-0.43*	0.02	0.01	0.44*	-0.21	0.44*	0.55*	-0.05		
Tmn	-0.28	0.68**	-0.64**	0.11	-0.14	0.13	-0.09	-0.33	0.20	
Tmx	-0.21	0.58*	-0.86**	0.01	-0.13	0.08	-0.27	-0.26	-0.05	0.77**

* $P<0.05$; ** $P<0.01$

Source: *Source*: Belay et al, 1999.

Table 6. Results of cluster analysis and some agronomic characteristics of wheat growing regions in Ethiopia.

Cluster group Major	Minor	Sites	Cropping intensity	LGP[a] (days)	Major production constraints
C1 (Western)	C1-1	Holetta, Akaki, Ginchi, Gondar	one	150-200	waterlogging, low temperature, terminal stress
	C1-2	Nekemte, Adet, Debre Markos, Yetnora	one/double	160-220	excess rainfall, long LGP
C2 (High Altitude)	C2	Debre Berhan, Bekoji	one	150-200	frost, terminal stress
C3 (Eastern)	C3-1	Sinana, Bale-Robe, Agarfa	two	90-130	moisture stress
	C3-2	Mojo, Debre Zeit, Kombolcha	one	110-140	waterlogging, terminal stress
	C3-3	Mekele, Asasa	one	130-160	moisture stress
		Kulumsa, Alemaya[b]	one	105-160	terminal stress

[a] LGP = length of growing period
[b] Two cropping seasons, but clustering was done using the main season
Source: Belay et al, 1999.

RAINFALL ESTIMATION FROM SATELLITE DATA IN ETHIOPIA: CALIBRATION AND APPLICATION

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Abstract

Half-hourly digital data from European Meteorological Satellite (METEOSAT) has been received at the Ethiopian Meteorological Service's site since 1990. Apart from weather forecasting the digital data is used for estimating ten-day total rainfall by applying TMSAT methodology developed at the University of Reading, UK (Milford and Dugdale, 1989). Estimates are being validated using data collected from raingauge network. Results found are in good agreement with the observed data. However, the network density of conventional stations does not adequately reflect the various climatic zones of the country. In fact, the rain guage network does not represent some parts of the country. Establishing dense network is not economically viable. Therefore,,, this problem can be alleviated through the application of satellite data. The fact that satellite derived data is continuos in space and could be obtained regularly has made it very useful for early warning purposes.

The country faces recurring droughts and flash floods. Satellite derived data are used in drought monitoring and water resource management activities. The raw METEOSAT images are used to warn farmers against untimely rains during the harvest season or heavy rains during the peak rain season. The bulletin is used as input for various activities by governmental and non-governmental institutions and the accuracy of the estimate has so fare reasonable for most applications, especially for agricultural purposes. The paper describes procedures for estimating of rainfall from satellite data and the process of calibration and applications.

INTRODUCTION

In Ethiopia the distribution of rainfall stations is very sparse and non-evenly distributed. The Satellite estimated rainfall has been an essential supplement to the ground observation. Besides, most of the stations are located along the main roads. Thus, it is difficult to get rainfall information away from these roads, which are not many. What is worse, only about 8% of these stations are equipped with radios and thus report on regular basis. It takes months to collect data from the other stations. As a result their utility for operational purposes such as drought monitoring, pest control, flood forecasting, etc., is very limited.

To alleviate this problem the National Meteorological Services Agency (NMSA) decided to supplement the sparse station network with rainfall estimated from METEOSAT imagery. Accordingly, NMSA obtained a Primary Data Users Station (PDUS) in 1990 with the cooperation of the UK government. The PDUS system includes automatic rainfall estimation module, which is used to estimate dekadal rainfall

In Ethiopia the distribution of rainfall stations are very sparse and non-evenly distributed. The Satellite estimated rainfall had been essential supplement to the sparse surface rain gauge network. Over some parts of the country METEOSAT data is the only source of information on rainfall.

The coming sections of the paper will briefly present the methodology used, the calibration process, validation, and some applications, problems and future plans.

METHODOLOGY

We employ a methodology developed by the TAMSAT (Tropical Application of Meteorology using Satellite and other data) group at the University of Reading, UK. The TAMSAT methodology, Milford & Dugdale (1989) are based on the assumption that in tropical areas most of the rain comes from convective clouds. It also assumes simple linear relationship between rainfall and Cold Cloud Duration (CCD); CCD being the duration of a cloud, with top temperature below a predetermined threshold, over a given area. The relation between CCD and rainfall (RR) is given as

$$RR = a * CCD + b \quad \text{if } CCD > 0$$
$$RR = 0 \quad \text{if } CCD = 0$$

Instead of relating rainfall to CCD, the regression is performed between midpoints of CCD classes and the median of the rainfall in the CCD class in order to overcome the skewness of the rainfall frequency distribution.

We have been using the calibration parameters determined for Ethiopia by TAMSAT. Since 1993 we have started our own calibration. Our calibration, which uses smaller calibration zones, has shown better performance over TAMSAT calibration. The calibration process involves the following steps:

1. Delineation of zones of homogeneous rainfall characteristics

Over Ethiopia the spatial variation of rainfall is very high. As a result the rainfall characteristics is different for different parts of the country. A temperature threshold selected for one region might not serve for another one. We have been trying to use smaller calibration zones instead of the larger ones proposed by TAMSAT. Topography has been found to play an important role in the delineation of these homogenous zones. These homogenous zones could have any shape and size. Yet, the current rainfall estimation software accepts only a limited number of rectangular regions. This problem was solved by preparing the regions using another software and putting it into the system indirectly (Dinku 1994). Now, zones of any size and shape could be used.

2. Selection of a best temperature threshold which reasonably discriminates between rain giving and inactive clouds

Archived CCD is available with the TAMSAT at temperature thresholds of -40, -50 and -60 ^{0}C. This data is used along with ground rainfall measurements in our archive to select the best temperature threshold. Because the available temperature thresholds are limited to -40, -50, and -60, warmer thresholds have not been tested. Yet, it is not unusual to get rainfall from clouds much warmer than -40 ^{0}C over Ethiopia. Cirrus cloud is an other source of error over some parts of the country. Among the available temperature thresholds, -40 ^{0}C has been found to the best for most parts of the country

3. Parameter determination

The parameters of the above equation are determined for each selected region and chosen temperature threshold using historical CCD and ground rainfall data. CCD data is available since 1990.

VALIDATION

Lets first see how the estimate discriminates just between dry and wet conditions. In table 4 three arbitrary rainfall amounts (0, 10 and 20 mm) are taken as thresholds for "dry" and "wet" conditions. The percentage of accurate discrimination is given for 1994.

Table 1 Dry /Wet Discriminating accuracy (%) at 0, 10 and 20 mm rainfall thresholds for the whole country in 1994. N is the number of data pairs compared.

Month	0	10	20	N
June	87.81	85.18	78.35	911
July	97.17	95.42	94.35	1027
August	96.17	95.68	91.85	1044
Sept.	93.45	88.50	90.20	948

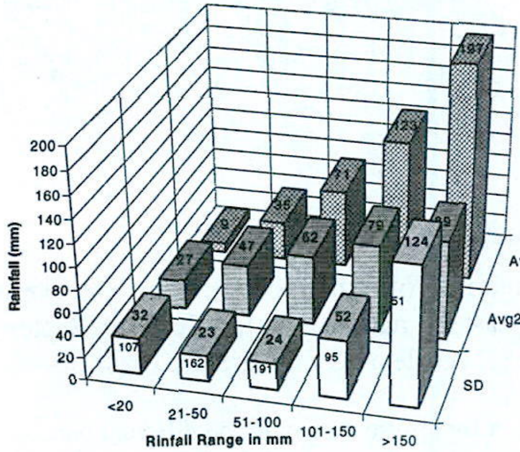

Figure1. Comparison of actual and estimated rainfall at different rainfall ranges, July 1995 for the whole country.

Avg1 is the average of all rain gauge stations and Avg2 the corresponding estimated rainfall. SD is the Standard Deviation between the measured and estimated rainfall. The labels are the corresponding values while the numbers on the first bars are number of data pairs compared.

Figure 1. Compares the actual and estimated rainfall of July 1995 for the whole country. Accuracy is relatively better for rainfall ranges of 21 to 50 and 51 to 100 mm; SD is relatively low for these ranges. There is an overestimation for rainfall values below 20 mm and sever underestimation for values above 150 mm. The data points falling in the below 20 mm and above 150 mm range are only about 26% of the total data. Besides the 21 to 100 mm rainfall is the important range for crop development. Thus, the presented accuracy is useful for the general monitoring of crop and pasture conditions.

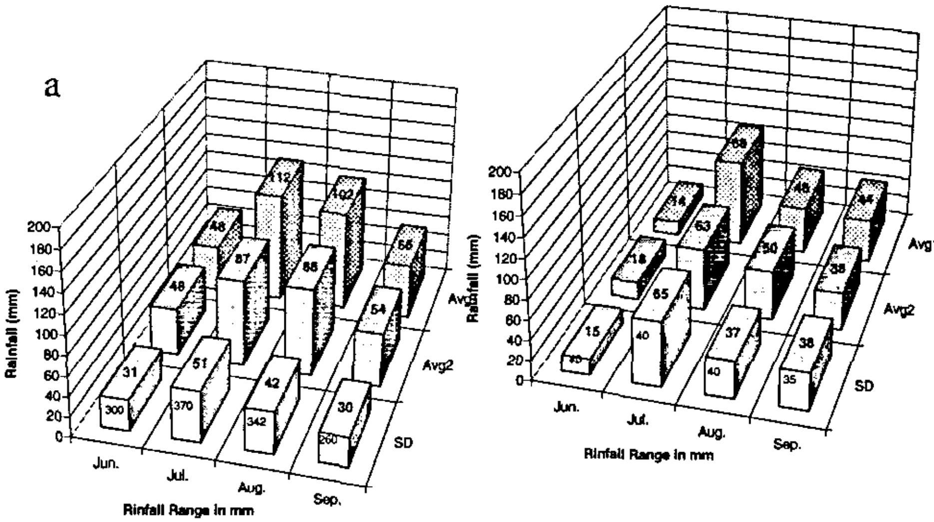

Figure 2. Comparison of estimation accuracy over western Ethiopia (a) and northeastern part (b) during June to September 1994 (refer to Figure.1 for details of the graph).

The accuracy is different for different months and different parts of the country. Figure 2 compares the accuracy for western part of the country (where estimation is relatively better) and northeaster parts (where the estimation is usually not good). For the western parts SD is always less than the estimates, while for northeastern parts it is very close to the estimates. There is also variation form one month to the other; for both regions accuracy is better in August.

As mentioned earlier satellite rainfall estimation has been going on since 1991. Now we have five years dekadal average. Figure 3 presents the validation of these data for western (a) and north-western (b) parts of the country from March to October. As in the previous case accuracy is better over the western part of the country. There is significant improvement in accuracy from individual year's estimate to the five-year average. We have started re-calibration to improve the quality of the historical data, and it has shown significant improvement in the accuracy.

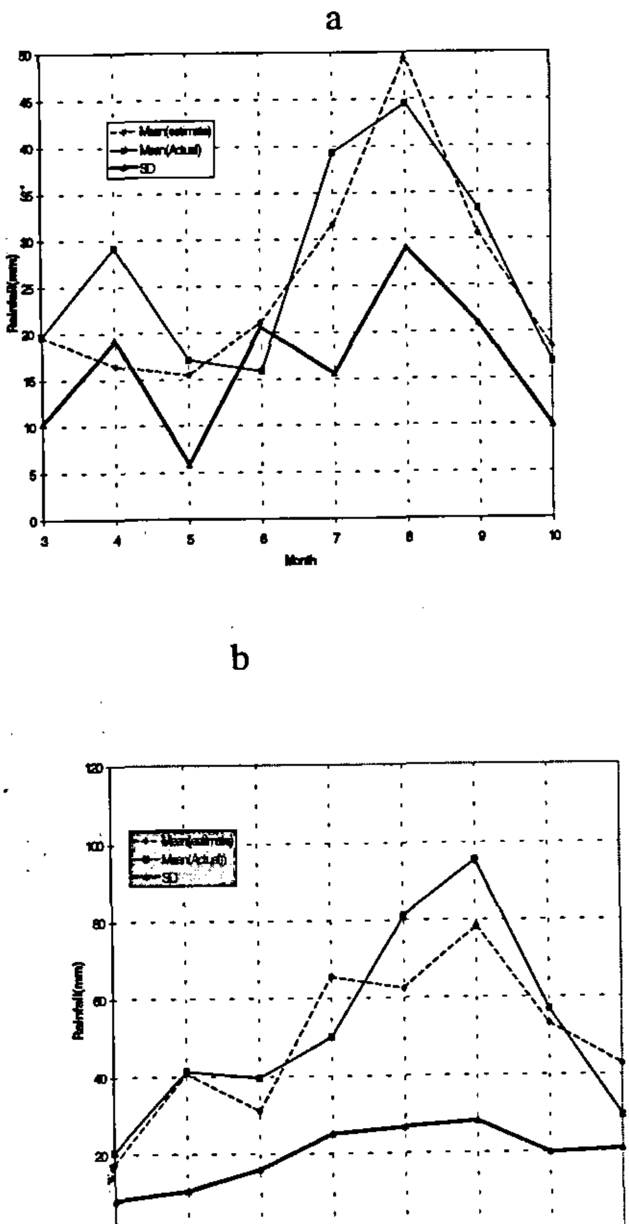

Figure 3. Comparison of actual and estimated 5-year average rainfall for western (a) and northeastern (b) parts of Ethiopia from March to October

APPLICATIONS

The main use of the data has so far been for drought monitoring. As the data is available on near-real time basis covering the entire country, it has been found to be very useful for crop early warning purposes. Beside drought monitoring mainly requires to know whether the rainfall amount is ample or not; and the level of accuracy achieved is acceptable for this purpose. We produce a ten-daily bulletin, which includes the map of the estimated rainfall and its comparison with expected mean values. Our users are mostly governmental and non-governmental organizations involved in food-early-warning activities.

The data is also used for desert locust control. It is the only source of rainfall data over desert and inaccessible areas. Assessment of the water resource of some river basins has also been another application. The rainfall estimation from METEOSAT data has been found to be very good supplement to this sparse rain gauge network. The advantages of satellite rainfall estimate include the following. It is continuous in space: As a result it enables the detection of small rainfall deficient pocket areas. These pocket areas might not be apparent when using the sparse rain gauge stations.

The raw Satellite images are used for routine weather forecasting, however the aim is to point out forecasting of untimely rainfalls which could have been very difficult without the use of Satellite data. Warnings are given to farmers during the harvesting season when ever there is a threat of untimely rainfall.

SUMMARY

We have been estimating rainfall from METEOSAT infrared images since 1991 using the TAMSAT methodology. Though suitable for automatic rainfall estimation, this methodology has some problems when applied to Ethiopia. Effect of topography, rainfall from warm clouds and the influence of Cirrus clouds have been some of the problems. An attempt has been made to reduce the effect of topography by using smaller calibration zones. This has shown some good results, but there is still some work to be done. The problem of warm clouds and Cirrus still persists and future plans are to find ways to solve it. Yet, the level of accuracy achieved so far is encouraging, and has already been found useful in many applications, the main one being the monitoring of crop and range land conditions.

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TEMPORAL ANALYSIS OF RAINFALL: AN APPLICATION TO MELKASA OBSERVATORY (NAZRETH) RAINFALL SERIES

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Abstract

The pattern and intensity of rainfall in Ethiopia is highly variable. Agricultural risk management requires an understanding of rainfall variability and the integration of this knowledge into the planning and decision-making process. Daily Rainfall data for 24 years has been collected at the Melkasa Agricultural Research Centre. In this paper attempt is first made to study the main characteristics of rainfall based on monthly and annual rainfall total time series by testing simple randomness of the series against serial correlation and against trend. Moreover, a trend analysis is applied in a sequential way to locate the period from which the trend is demonstrated and to understand the internal structure of the series in a better way. Secondly, identification of appropriate time series forecasting model was done using Box and Jenkins ARIMA modelling (Box and Jenkins, 1976) and multiplicative ARIMA model (0,1,1) (0,1,1) 12 was found to be the best. Finally monthly rainfall totals for 2002 for the Nazreth region were predicted for the short and main rainy season. The behavior and characteristics of the rainfall are graphed and discussed.

INTRODUCTION

More than 85% of the Ethiopian population lives on the country side, engaged in different forms of Agriculture, and 50% of the GDP of Ethiopia comes from agriculture. One of the main factors that affect agricultural production and productivity is rainfall. The intensity and the pattern of the rainfall are both critical to the total agricultural production and the productivity. Therefore,,, understanding the pattern of the rainfall in a given region is very important for farmers in order to conduct agricultural operations on time. Rainfall is characterized by high variation both temporally and spatially (Engida, 2001) and hence, introduces elements of uncertainty in planning.

The pattern and intensity of rainfall in Ethiopia is highly variable. Agricultural risk management requires an understanding of rainfall variability and the integration of this knowledge into the planning and decision making process. Correct interpretation of meteorological information and its effective application would help farmers to plan and execute their agricultural operations. This would lead to effective use of the rainfall and minimize the risks of drought.

Time series analysis provides great opportunities for detecting, describing and modeling climatic variability and impacts (Scott, 1997). Consequently, to understand the metrological information and integrate it into planning and decision making process, it is important to study the temporal characteristic and predict lead times of the rainfall of a region. This can be done by characterizing trends in climatological data using time series analysis, which is reduced to the determination of the internal structure of the series (Sneyers et.al,1997), and identifying the best time series model using (Box and Jenkins 1976) Autoregressive integrated moving average(ARIMA) modelling techniques.

The present study is therefore, initiated to temporally characterize rainfall pattern of the period 1977-2000 and give forecasted results for the main and short rainy seasons of the year 2002.

MATERIAL AND METHODS

A total of 24 years annual totals data and monthly data derived from daily rainfall totals was used in this study. All values have been double checked against the original records. The original data, monthly rainfall totals and annual rainfall totals from 1977-2000, were kindly provided by Melkasa (EARO), Nazareth station. Melkasa is located 8:24°N and 39:19°E with an altitude of 1540 meters above sea level. It is found in the East Shoa zone along the Rift Valley. Flood, drought, soil erosion and rainfall deficiency are some of the natural hazards that are frequent the zone.

The annual rainfall totals obtained from Nazareth station was subjected to time series analysis. In this study characterizing trends in climatological time series (i.e rainfall) and prediction was done.

TEMPORAL ANALYSIS OF CHARACTERIZING TRENDS

To characterize trends in climatological time series, the simple random model, the elements of which are independently and identically distributed (Sneyers 1992a, b), was first considered. Moreover, a progressive sequential onward and backward trend test was applied in order to clearly identify the internal structure of the series. To test the validity of this hypothesis, two non-parametric (distribution free tests) having optimal power relative to the corresponding parametric ones have been considered and analysed using Statistical (1993) and Genstat (2000) statistical Softwares. The tests are Serial correlation test (wald and wolfowitz 1943) and a trend test, Mann-kendell rank statistic (Mann 1945; Sneyers et.al., 1990). Various techniques are also used in identification of abrupt climatic change, characterized by a rather abrupt and permanent change during the period of records from one mean value to another, among these are , the low pass-filters (Mitchell,1961,1963,1966; Schonwiese 1983,1984), cramers test (Lawson et al.,1981), the spearsman rank statistic (Sneyers, 1990; Goossens, 1983), the pettitt test (Pettit, 1979; Buishand, 1983, 1984; Dameree, 1990). However, the efficiency of the non-parametric Mann-Kendell rank statistic has been compared to the above mentioned tests. They have been applied to a set of data and monte carlo method was applied for checking the reliability of the localization of the change time point by Goosens and Berger (1985) who concluded that the sequential version of the Mann-Kendall rank statistic as proposed by Sneyers (1975 and 1990) is an appropriate method for analyzing abrupt climatic changes in climatological time series. However the technique seems to lose its effectiveness when several changes are present in the record.

MODEL DEVELOPMENT

For the prediction purpose, Box and Jenkins times series analysis (Box and Jenkins 1976, Box, et.al 1994 and Abraham and ledltor 1983) was used because of the four reasons: First, it handles time series in which successive observations are highly dependent, in the second place, it gives the best estimates of a model and predicted results Thirdly, it perfectly handles non- stationery time series which is the case in most climatological time series which have diurnal and annual cycles. Finally, it produces a very superior results than the 'classical model' of time series which is useful for estimating the trend (T), cyclical (C), seasonal(S), and random (E)indices of the series (Chatfield 1983). The 24 years monthly total rainfall data was subjected to the Box and Jenkins method. A logarithmic transformation (logyt) was applied to the data to make the data homosediastic distribution.

The three stages in Box and Jenkins autoregressive integrated moving average (ARIMA) modeling; Identification, Estimation and diagnosis checking and forecasting, were done using the SAS ETS and GENSTAT softwares for developing the model and predicting lead times.

IDENTIFICATION OF MODEL

In this stage the plots of the correlations of the series with its past values at different lags were printed. These are sample autocorrelation function plot and sample partial autocorrelation plot. The former plot shows how values of the series are correlated with the past values of the series. The later plot measures the degree of association between yt and yt+k when the effect of other time lags 1,2, 3,...up to k-1 are somehow removed. In this data, a visual inspection of the autocorrelation function plot indicates that the rainfall series is nonstationary, since the autocorrelation function decays very slowly.

White Noise Test

The last part of the model identification is the check for white noise. This is an approximate statistical test of the hypothesis that none of the autocorrelations of the series up to a given lag are significantly different from 0. If this is true for all lags, then there is no information in the series to model, and no ARIMA model is needed for the series. But in this data the check for white noise test (Table 1) indicates that the change in rainfall is highly autocorrelated at. P<0.0001(see table) and the series is nonstationary. Thus, an ARIMA model might be a good candidate model to fit to this process.

Table 1. Autocorrelation check for white noise

To lag	Chi-square	df	Pr>chisq	Autocorrelations					
6	54.71	6	.0001	-0.408	-0.131	-0.042	0.06	0.067	0.029
12	129.91	12	.0001	-0.094	0.019	-0.131	0.17	0.170	-0.413

IDENTIFICATION OF THE DIFFERENCED SERIES

Since the series is nonstationary, the next step is to transform it to a stationary series by differencing. That is, instead of modeling the rainfall series itself, the change in rainfall from one period to the next was modeled. The logarithmic transformed rainfall series was differenced and the sample autocorrelation and partial autocorrelation functions were plotted. Visual inspection of the plots indicated that the series is not stationery and one degree of non-seasonal differencing was taken to obtain stationarity. Visual inspection of the plots shows still the autocorrelation function decays slowly ındicating nonstationerity. Since the line plot (Figure 1) of the log transformed data indicates seasonality, It was decided to take one more seasonal differencing and view the result. After the seasonal differencing, the autocorrelations decrease rapidly in this plot, indicating that the change in rainfall is a stationary time series.

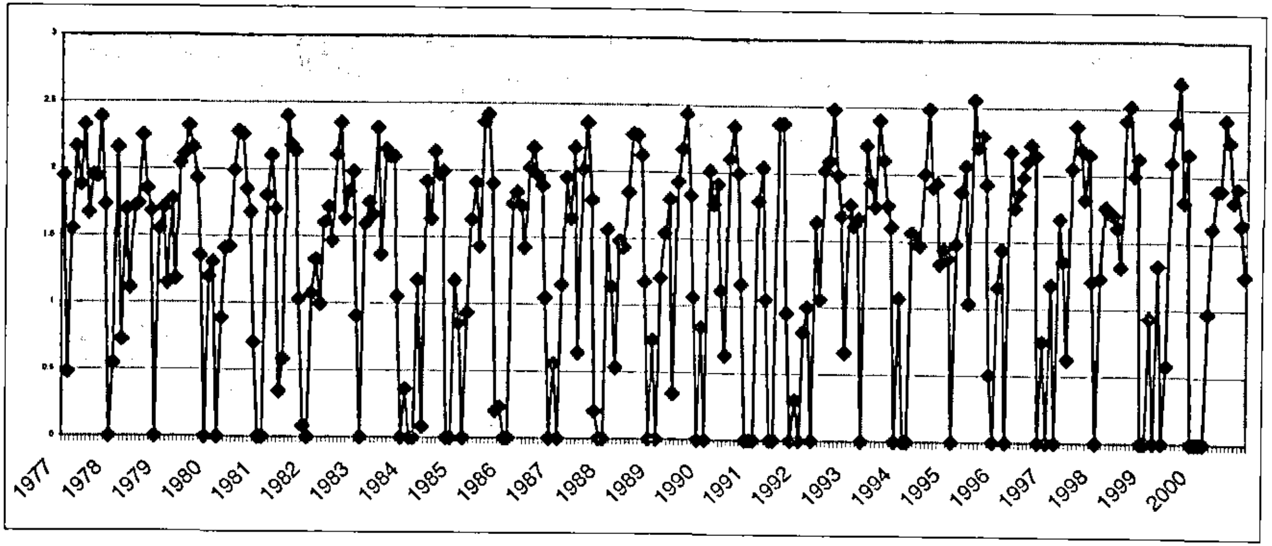

Figure 1. Time series plot of the log transformed annual rainfall series for the month of January (1977-2000)

Next, the patterns in the autocorrelation and partial autocorrelation plot was examined to choose candidate ARIMA models to the series. From Figure 2, the autocorrelation cuts off after lag 1 and 12 and zero other wise which implies that the moving average process of orders q=1 and seasonal moving average of order 1 i.e Q=1. The absence of damped exponentials and/sine waves in the sample and partial autocorrelation function plots indicates that there were no autoregressive terms to be included in the model. With this data a multiplicative ARIMA model with order (p,d,q) x (P,D,Q)12 was tentatively identified for predicting lead time monthly rainfall series. The partial autocorrelation function of the differenced series helps confirm the choise of the model to be purely moving average model. There were several significant paritial correlations (Figure 3.), implying that an autoregressive model for this series would require more than 4 parameters. Thus , ARIMA (0,1,1)(0,1,1)12 i.e $(1-\beta)(1-\beta^{12}) y_t=(1-\theta_1\beta)(1-\beta^{12}\gamma_1)\epsilon_t$ model was used which was more parsimonious (Liu, 1988).

```
                                  Sample Autocorrelations

Lag Correlation   -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
 0   1.00000      |                    |********************|
 1   -.40769      |            ********|  .                 |
 2   -.13089      |                 ***|  .                 |
 3   -.04157      |                 . *|  .                 |
 4   0.06719      |                 .  |* .                 |
 5   0.07814      |                 .  |**.                 |
 6   0.02928      |                 .  |* .                 |
 7   -.09376      |                 .**|  .                 |
 8   0.01912      |                 .  |  .                 |
 9   -.13138      |                 ***|  .                 |
10   0.17014      |                 .  |***                 |
11   0.18495      |                 .  |***                 |
12   -.41325      |            ********|  .                 |
13   0.16830      |                 .  |***                 |
14   -.05362      |                 . *|  .                 |
15   0.17214      |                 .  |***                 |

                  "." marks two standard errors
```

Figure 2. Plot of Sample Autocorrelation function for degree of non-seasonal differencing=1 and degree of seasonal differencing=1

```
Partial Autocorrelations

Lag   Correlation   -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1
  1    -0.40769      |          ********| .                 |
  2    -0.35633      |           *******| .                 |
  3    -0.35612      |           *******| .                 |
  4    -0.28110      |            ******| .                 |
  5    -0.14546      |               ***| .                 |
  6     0.01469      |                . | .                 |
  7     0.01227      |                . | .                 |
  8     0.07545      |                . |**.                |
  9    -0.16613      |              *** | .                 |
 10    -0.06199      |                .*| .                 |
 11     0.28282      |                . |******             |
 12    -0.18528      |              ****| .                 |
 13    -0.00871      |                . | .                 |
 14    -0.16530      |              *** | .                 |
 15     0.01803      |                . | .                 |
```

Figure 3. Plot of Partial autocorrelation function for degree of non-seasonal differencing=1 and degree of seasonal differencing=1

RESULTS AND DISCUSSIONS

Characterization

Annual rainfall totals time series and detailed analysis of monthly rainfall time series for trends is presented for station at Nazareth for the main and short rainy seasons (i.e June- September and February-May). Since record length of Nazreths data is 24 (less than 50 years) it is only assessed short-term trend/interannual and interdecadal fluctuations that either masks or overstates longer term trend.

When a monthly rainfall total is greater than the long term mean monthly rainfall, it is defined as "wet" month and when a monthly rainfall total is less than the long term mean monthly rainfall is defined as "dry" month.

Annual rainfall totals time series

Wald-Wolfz serial correlation test was first applied to check the simple randomness of the series of observations (Table 2) Mann-Kendell-Sneyers sequential trend test reveals that a significant (alpha=0.01) upward trend has existed since 1991(Figure 4b and Table 3). Thus, the annual rainfall totals time series at Nazreth 1977-2000 could not be interpreted as random successions of "dry" and "wet" periods of stationary rainfall process in the mean for the above considered reference periods.

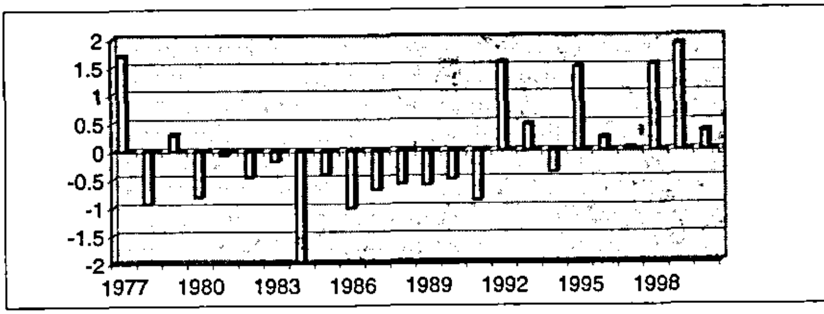

Figure 4a. Normalized rainfall departures of Annual rainfall amounts

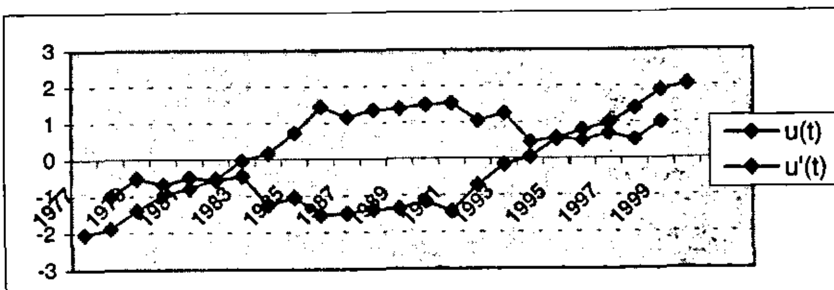

Figure 4b. Mann-Kendall-Sneyers sequential trend test of the time series of Figure 4a; u(t) for forward and u'(t) for backward .

The above conclusion is also reinforced by a posterior application of student's difference test for the mean, assuming unequal variances, which results in the rejection of the null hypothesis of equal means (that is for the data in the period 1977-1990 and 1991-89) at the 0.01 significance level.

It may also be seen from Figure 4a. in the period 1977-1990 Nazareth's annual rainfall totals were below the mean of 1977- 2000 with the exception of 1977 and 1979. Whereas, annual rainfall totals were above average for the period 1992-2000, with the exception of 1994. Larger variability was exhibited in the period 1977-1984 and 1992-2000 and lesser variability was exhibited from 1985-1991 (Table 4).

In general this variability has a great impact in handling agricultural productivity smoothly.

Table 2. Wald-Wolfowitz serial correlation test of the periods (1977-1990) and (1991-2000)

N1 (1977-90)	N2 (1991-00)	mean (1977-90)	mean (1991-00)	U	Z-adj	P-lev
14	10	9.214	17.10	24	.931469	.251629

Table 3. Mann-Whitney U test of the 2 periods (1977-1990) and (1991-2000)

N1 (1977-90)	N2 (1991-00)	Rank sum (1977-90)	Rank sum (1991-00)	U	Z-adj	P-lev
14	10	129	171	24	-2.69348	.007075**

Table 4. Variability of annual rainfall totals between periods

Period	Mean	sd	Cv
1977-83	785.9429	143.4739	0.18255
1984-1991	661.575	81.69228	0.123482
1992-2000	925.6667	133.8731	0.144623

Monthly Rainfall Totals Time Series Analysis

June

June rainfall totals time series can be interpreted as random successions of "dry" and "wet " periods of stationary rainfall processes in the mean. From Figure 6a. it is seen that there exists a one year "wet" period followed by a one year "dry" period and two years "wet" period followed by longest consecutive "dry" period 1981-1991, with the exceptions of 1986 and 1989.

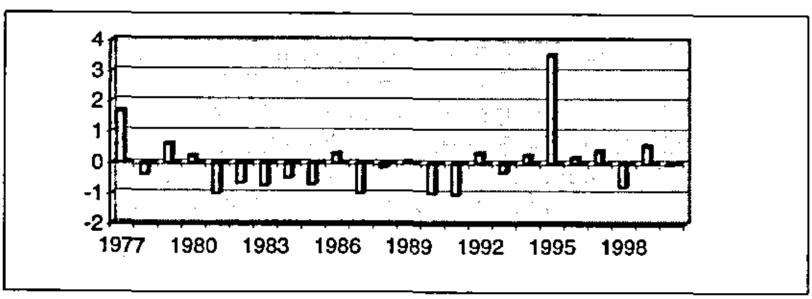

Figure 6a Normalized rainfall departures of June Annual rainfall amounts

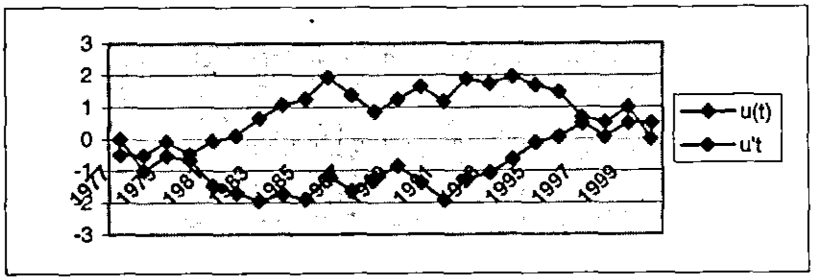

Figure 6b. Mann-Kendall-sneyers sequential trend test of the time series of Figure 5a; u(t) for forward and u'(t) for backward

July

From Figure b it can be visualized that July rainfall totals time series can be *interpreted as random successions* of "dry" and "wet " periods of stationary rainfall processes in the mean. However results of spearsman correlation coefficient and mann-kendel-sneyers statistic shows a positive significant trend in 1999 . It might Therefore,, be assumed that, if the trend is real, its effect is only recent and it is advisable to await later observations to obtain confirmation from them.

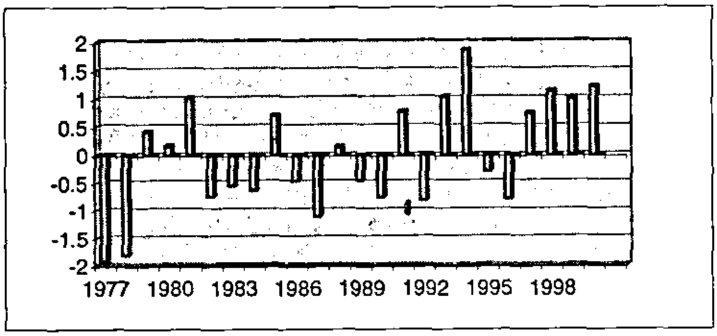

Figure 7a. Normalized rainfall departures of July Annual rainfall amounts

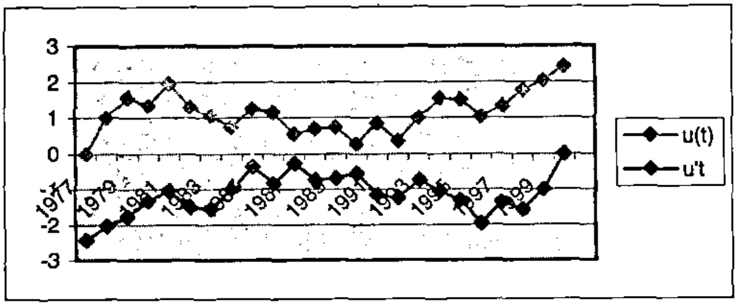

Figure 7b. Mann-Kendall-sneyers sequential trend test of the time series of Figure 5a; u(t) for forward and u'(t) for backward

August

Spearsman correlation test shows a positive significant (p=.05) trend however Mann-trend test(Figure 8b) doesn't enable to infer the existence of significant trend because the probability of no trend is 0.93 .

The variability of August rainfall in the period 1992-2000 has increased compared to the period 1977-1991 (Figure 8a and Table 5). Unusual and very high rainfall total was exhibited in 1992; such increased variability could mean a greater likelihood of more extreme weather affecting agriculture.

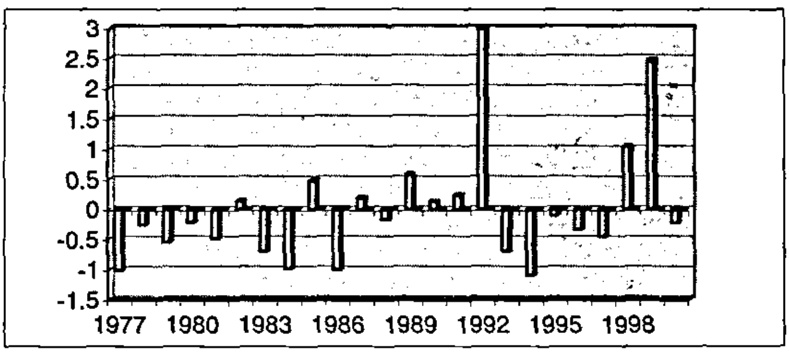

Figure 8a. Normalized rainfall departures of August Annual rainfall amounts

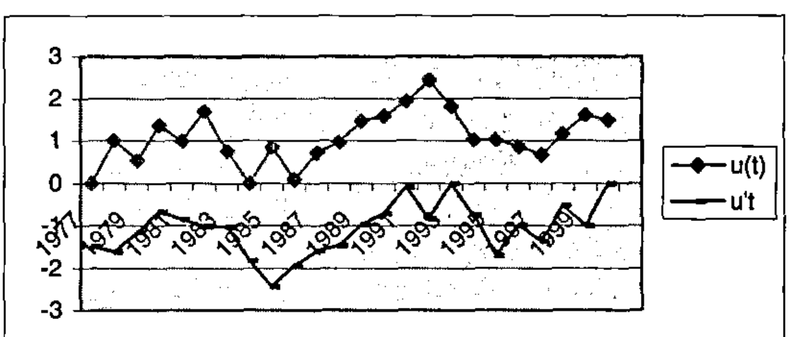

Figure 8b. Mann-Kendall-Sneyers sequential trend test of the time series of Figure 8a; u(t) for forward and u'(t) for backward

Table 5. Variability of august rainfall totals between two periods

Period	Mean	SD	Cv
1977-1991	177.76	61.53	0.34
1992-2000	251.87	167.14	0.66

September

September rainfall total exhibits a random succession of "wet" and "dry" periods of stationary rainfall process (see Figure) Mann - Kendell – Senyes test and spears Mann correlation test reveals a non-significant down ward trend as compared to the other months rainfall totals.

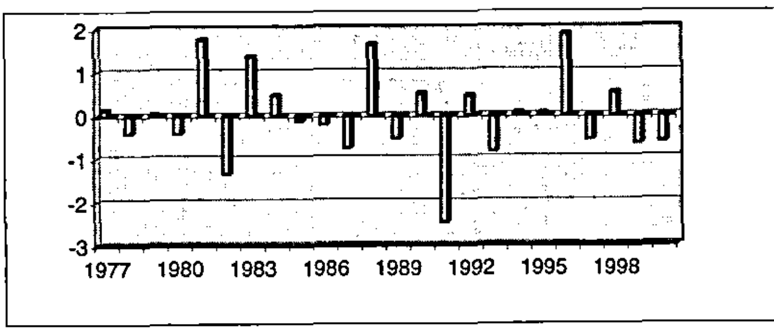

Figure 9a. Normalized rainfall departures of September Annual rainfall amounts

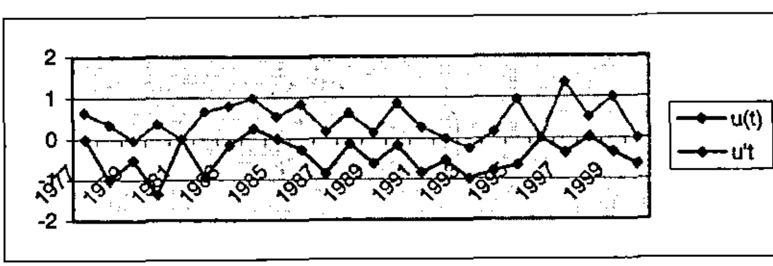

Figure 9b. Mann-Kendall-Sneyers sequential trend test of the time series of Figure 9a; u(t) for forward and u'(t) for backward

February-April

Graphical results of Mann-kendel statistic (Figure10a-Figure12b) shows that there is no clear trend towards February, March and April annual rainfall totals. However, the normalized Figure10a-12b of the 3-months annual rainfall time series indicates more than 73% of the series reflects a dry period for February and April and 60% for March respectively. This result with the May rainfall total time series characteristics discussed above indicates that Nazareth is not using the Belg (short rainy season) for normal agriculture usage.

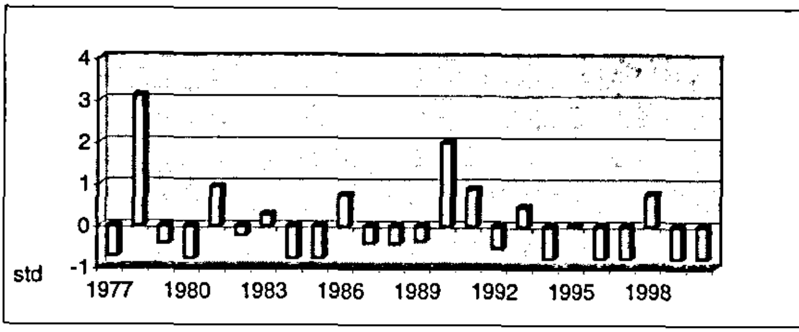

Figure 10a. Normalized rainfall departures of February Annual rainfall amounts

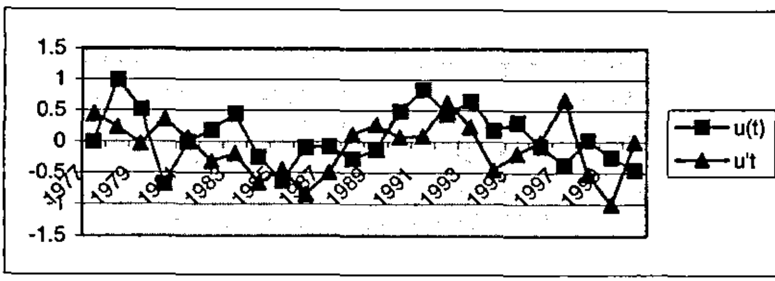

Figure 10b. Mann-Kendall-sneyers sequential trend test of the time series of Figure 8a; u(t) for forward and u'(t) for backward

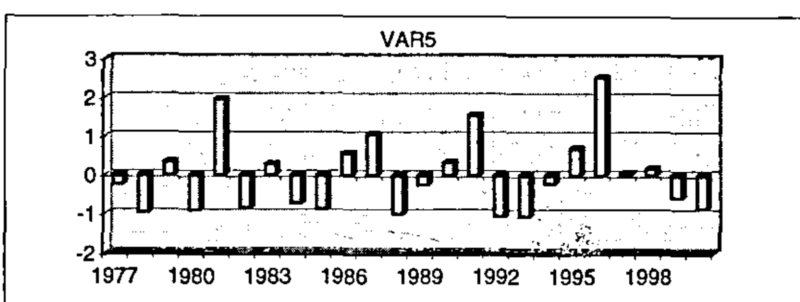

Figure 11a. Normalized rainfall departures of March Annual rainfall amounts

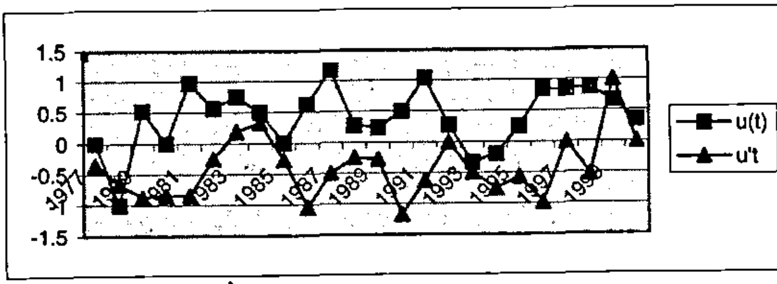

Figure 11b. Mann-Kendall-sneyers sequential trend test of the time series of Figure 11a; u(t) for forward and u'(t) for backward

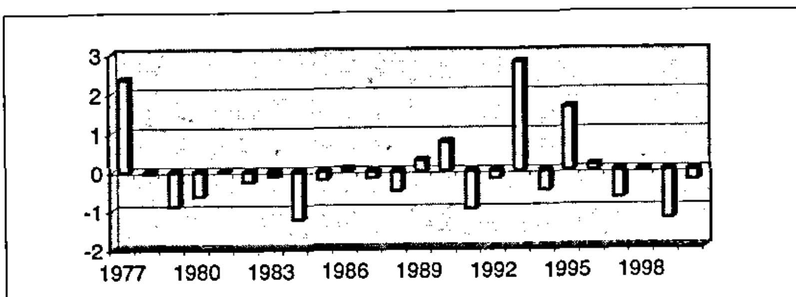

Figure 12a Normalized rainfall departures of April Annual rainfall amounts

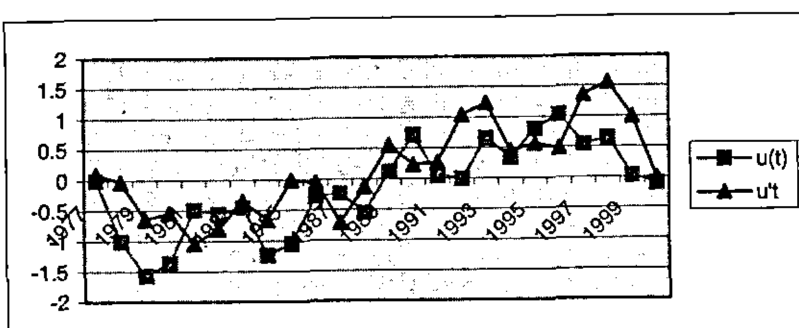

Figure 12b. Mann-Kendall-sneyers sequential trend test of the time series of Figure 11a; u(t) for forward and u'(t) for backward

May

Mann-Kendell-Sneyers sequential trend test was applied to the May rainfall totals time series for the reference period 1977-2000. From Figure. 5b it is seen that down ward trend exists in the statistic u(t) in the period 1987-1992. But it doesn't enable to infer the existence of significant trend because the probability of no trend is 0.8531.

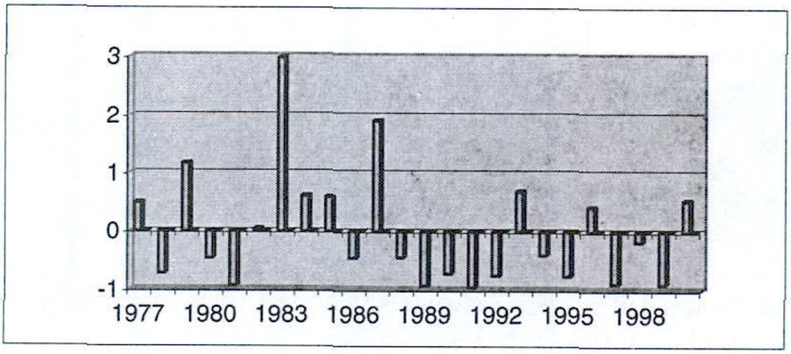

Figure 5a. Normalized rainfall departures of May Annual rainfall amounts

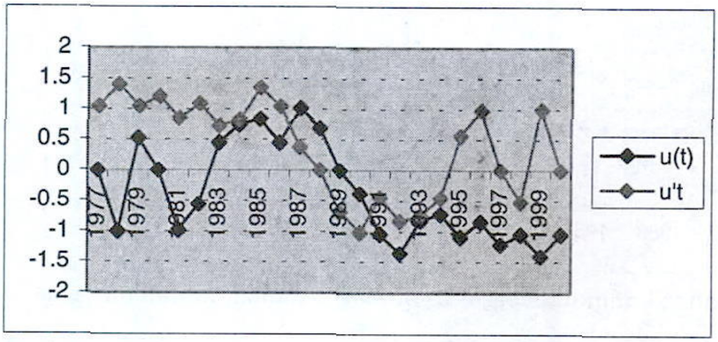

Figure 5b. Mann-Kendall-Sneyers *sequential trend test of the time series of* Figure 5a; u(t) for forward and u'(t) for backward

Prediction

The unified statistical model and testing procedures proposed appear to provide a comprehensive means to choose structural time series for annual rainfall totals trend detection purposes. Hence, after identification of the tentative model, two parameters were estimated with the sas Ets software. The 2- coefficients estimated were significant (P<0.0001) (Table 6). The adequacy of the model was checked for different ARIMA family and arima (0,1,1)x(011)12 was found to be the most appropriate model with the minimum AIC SBC, variance estimate and std error estimate (Table 6). The check for white noise residuals x2 test (table 7) shows that we cannot reject the hypothesis that the residuals are uncorrelated. Thus, it is again confirmed that the seasonal multiplicative ARIMA (0,1,1)(0,1,1)12 model is adequate for this series. The model fitted is:

(1-β) (1-β^12^) yt=(1- 0.91421β) (1-99998β^12^)∈t

Table 6. Unconditional Least Squares Estimation of parameters

Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|	Lag
MA1,1	0.91421	0.03236	28.25	<.0001	1
MA2,1	0.99998	0.12156	8.23	<.0001	12

Variance Estimate	0.350981
Std Error Estimate	0.592437
AIC	535.161
SBC	542.3945
Number of Residuals	275

Table 7. Autocorrelation check of residuals

To Lag	Chi-Square	DF	Pr > ChiSq
6	7.68	4	0.1042
12	15.18	10	0.1256
18	25.44	16	0.0625
24	28.66	22	0.1550
30	33.94	28	0.2030
36	37.88	34	0.2969
42	40.79	40	0.4357
48	44.52	46	0.5345

Since Arima model prediction might not give good result for noisy parts of a series. The Bega season which has unstable rainfall pattern which ranges from (0-242mm) was decided to be left with out prediction. Hence,, the prediction for the year 2002 was done only for the two rainy seasons (i.e the main and the short seasons) (Table 8).

Table 8. The forecasted results of the main and short rainy seasons of 2002

Date	Log (predicted)	Stderr	Predicted Prec.(mm)
Jan	-	-	-
February	1.1222	0.6201	13.2495
March	1.5136	0.6222	32.6287
April	1.6683	0.6243	46.5908
May	1.5289	0.6263	33.7987
June	1.7853	0.6284	60.9958
July	2.3593	0.6305	228.718
August	2.3951	0.6325	248.37
September	2.024	0.6345	105.682
October	-	-	-
November	-	-	-
December	-	-	-

CONCLUSIONS AND RECOMMENDATIONS

- According to the results of the mann-kendel Whitney test statistics and the visual inspection of the plots it was seen that during the main-rainy season Nazareth almost have a stationery rainfall process in the mean reference period 1977-2000 with the exception of August rainfall totals which has great variability. This result could mean a greater likelihood of weather affecting agriculture.
- During the short rainy seasons Graphical results of the normalized annual rainfall totals time series reflects overall dry period which indicated Nazreth's short rainy season (Belg) is not used for consumption of Agriculture.
- According to the ARIMA model predicted result it is seen (table 8) Nazareth is anticipated to get normal (wet) rainfall during the main season and below average (dry period) during the belg season.
- It is very appealing for the meteorologists to try an interpretation of the statistical results obtained for characterizing Nazreth's prec totals in terms of ciculation patterns.:surface atmospheric pressure
- The predicted results given in this study (table 8) will be operational along with those existing in the National meteorological services Agency of Ethiopia, *in conjunction with the additional information obtained from the* global climate prediction centers.
- Since for the ARIMA model the result of goodness of fit of statistic (R2) shows still there is some additional information not accounted for by the model, it is advised to study the relationship of rainfall with the global Sea Surface Temperature (SSTs) to identify the best structural time series model.

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REMOTE SENSING AND GIS TECHNOLOGY IN ETHIOPIA:
PROSPECTS AND CHALLENGES

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Ethiopian Mapping Authority

INTRODUCTION

Remote sensing refers to the group of techniques of collecting information about an object and its surroundings form a distance without physical contact This technique of data gathering leads to some form of satellite imageries, aerial photographs or space photographs in different fields of applications (Sabins: 1987). Although at the very beginning the technology was for strategic or military applications, recently it has been in use in the civilian applications such as agriculture, archaeology, forestry, geography, geology engineering, planning, mapping, decision making and similar resources inventory and analysis.

The prime objective of remote sensing is to extract environmental and natural resource data related to the earth. Information about the resource concerned is conveyed to the sensor (loaded on aircraft or spacecraft) which is an information carrier and thus provides the communication link with the earth data acquisition and distribution canters. Therefore, the data or information can be carried out through the basic knowledge of an electromagnetic spectrum which ranges from Ultra Violate to microwave (which includes visible infrared, thermal infrared and radar portions of the wave length).

Geographic Information system is defined as a powerful set of tools for collecting, storing, retrieving, transforming and displaying spatial world from the real world for particular set of purposes (Vlaenzuela, 1990). With integration of both RS and GIS on can make the spatial data analysis more complete and powerful for sustainable studies of natural and human resources. Fro such natural and human resource studies different types of platforms ranging from low altitude oblique aerial photographs to space and satellite photographs and images can be applied.

Sources of Remotely Sensed Data

The major sources of remotely sensed data/information about the earth resources are:

- Aerial photographs
- Space photographs like that of Apollo, Gemini, KATE, KFA and the likes
- Satellite imageries like the images from Landsat, SPOT, Meteosat, Radarsat, NOAA AVHRR, ERS and the likes (Degelo, 1995).

The information gathered using these sources of remotely sensed data can be represented in terms of black and white photographs or images, infrared photographs or images, thermal infrared photographs or images, false colour photographs or images, and natural colour photographs or images. The quality of the photographs or images depends on the resolution of the photographs and the resolving power of the sensors. Without better spatial, spectral, radiometric and temporal resolutions, it may not be easy for the appropriate study of earth resources. Furthermore, during resource analysis the most decisive factors in RS/GIS applications are the experiences of the interpreters, quality of the data, quality of the sensor, quality of the film paper or hard copy, physiographic characteristics or the area, and quality of the software and hardware applied in the processing.

With satellite imageries and space photographs, supported by GIS techniquès, a given area's resource can be studied and exploited with cheaper price in comparison to the conventional method of using aerial photographs. In addition large coverage, especially in the case of satellite images, and multi spectral information or multiple bands or channels repetitive coverage is made possible. Also, better spatial spectral and radiometric resolution. etc. is achieved (Mather,1986) Moreover, the technique provides data of inaccessible areas such as swampy dense forest, and areas with annual cloud coverage like the tropical rain forest areas using RADAR images.

Historical background of remote sensing and GIS technology in Ethiopia

Satellite remote sensing has been introduced to the developing countries from the developed countries like other fields in science and technology. For most of the developing countries even mapping the national resources is a result of colonial history (Asfaw, 1992). The same is true for countries like Ethiopia which have not been colonized; the technology of RS and GIS is imported introduction. Therefore we can generalize that the RS and GIS technology has been introduced to Ethiopia is through:

- Incorporated projects by government agencies and foreign counterparts like NGOs or UN agencies,
- Students trained or at least oriented about RS and GIS abroad directly or indirectly
- Courses related to photogrammetry, cartography, ground surveying and photo-geology in the Departments or Geography and Geology of Addis Ababa University, respectively, .
- Map processing and producing organizations like the Ethiopian Mapping Authority which acquires relevant data and geo-information, produces and processes aerial photographs and satellite imageries and give short term training courses for mapping and geo-information technicians
- Commercial companies especially in the areas of Information technology, space data acquisition.
- Workshops and seminars concerning earth and land resources, early warning systems, Information technology, Food security, Spatial data management etc. on global, regional and national level.

Objective of the study

Based on the above discussion, the major objectives of this paper include:

- Introducing remote sensing and GIS technology for sustainable resources analysis
- Assessing major problems in introducing, establishing, and processing remotely sensed data and GIS.
- Recommending relevant information and concepts in simplified and applicable ways about remotely sensed data and GIS applications for sustainable resource exploitation with the aid of recent technology.
- Making good forum for disintegrated remotely sense data and GIS users in different organizations for cooperation, experience sharing and technological transfer at national level.
- Initiating further studies and use of remote sensing and GIS technology for future use in Ethiopia.

Table –1 Recent Developments in Satellite and Sensor Systems

Country	Platform	Sensor	# Bands (range)	Spectral Bands								GSD(m) or mili radians (mr)	Digitisation (bits)	Frequency of Coverage (days)	Point-able	Data Availability (years)
					B		R		S		P					
China/Brazil	CBERS	CCD	5		1		1				1	20m		26 nadir 3 pointing	Yes/±3 2 side looking	(1996)
China/Brazil	CBERS	IR-MSS	4						2		1	78m 156m Thermal		26		(1996)
China/Brazil	CBERS	WFI	2				1					212m	8	5-Mar	No	(1996)
CIS /USSR	Resurs-F3	KFA-3000 (film)	2				1					2m	8	NA	No	1975-Present
CIS /USSR	Resurs-F1	Kate-200 (film)	3				1					12-30m	8	NA	No	1974-Present
CIS /USSR	Resurs-F1	KFA-1000 (film)	2				1					5-7m	8	NA	No	1972-Present
CIS /USSR	Resurs-F1	MK-4 (Film)	4 of 8		1		1				1	8m	8	NA	No	1988-Present
France	SPOT 1-3	HRV	4				1				1	20m 10m pan	8	26 nadir 2-3 pointing	Yes	1986-Present
France	SPOT 4	HRVIR	5				1		1		1	20m 10m pan	8	26 nadir 2-3 pointing	Yes	(1997)
France	SPOT 4	VEGETAT ION	6		1		1		1		1	1,000m	8	1	No	(1997)
Germany	U.S.Space Shuttle	MOMS 1	2				1					20m	8	NA	No	(1983-1984)
Germany	U.S.Space Shuttle	MOMS 2	7		1		1				3	13.5 m 4.5 m pan	8	NA	No	1993
India	IRS-1A, 1B	LISS I	4		1		1				1	37m	8	22	No	1991-Present
India	IRS-1A, 1B	LISS II	4		1		1					73m	7	22	No	1994-Present
India	IRS-1C, 1D	LISS III	5				1		1			24m 10m Pan	7	24 nadir, 5 off nadir	Yes/±2 6	(1995)

Cont'd Table 1.

India	IRS-1C, 1D	MOS-B	13		x	:	x	:			1	1,500m	7	24	No	(1995)
India	IRS-1C, 1D	MOS-C	2						2			1,500m	12	24	No	(1995)
India	IRS-1C, 1D	WiFS	2				1					188m	12	5 at equator	No	(1995)
Japan	ADEOS	AVNI	5		1		1 1					16m 8m Pan	7	41	Yes/±4 0 along track	(1996)
Japan	MOS-1, MOS-1B	MESSR	4				1	:				50m			No	1987-Present
Japan	ADEOS	OCTS	12		3	:	1	:				700m	10	41	Yes/±2 0	(1996)
Japan	JERS-1 (FUYO-1)	OPS	8				1	:	4			18 X 24m	6	44	No	1992-Present (SWIR no longer functioning)
United States	EOS-Am1	ASTER	14				1		4	:		15m VNIR 30 m SWIR 90mTIR	8 8 12	1-7	Yes	(1998)
United States	NOAA 10-12	AVHRR	5						6	:		1,100m nadir 4,000moff nadir long-track		8	No	Pre 1994-present NOAA 6-12

MATERIALS AND METHODS

To reduce the limiting effects on this study of the factors mentioned above, the writer tried to use different sources of information. The main one is his own experience in remotely sensed data and geo-information processing, producing and application in different disciplines for more than a decade. Various materials used in many areas of study have been thoroughly referred. Studies undertaken by other researchers in the country are also analysed for widening general understanding of the sustainable resource exploitation. Because of the nature of the study and the above-discussed limitations, the study is more of descriptive than analytic. For reasons of simplicity, remote sensing technology here is applied only for multi-spectral and multi-temporal satellite imageries and space photographs.

APPLICATION OF REMOTE SENSING AND GIS IN ETHIOPIA

Detailed assessment of the present level and status of remote sensing application in the Sub Saharan Africa with the exception of South Africa has not yet been made. It was only in the 1980s that some studies concerning the status of remote sensing in the developing world took place (Ihemadu, 1987). In fact there are some monitoring of such technology by UNECEA.

The studies on remote sensing and GIS applications in Ethiopia were very much limited and mostly related with topographic mapping and some natural resources assessment with the aid of aerial photographs. The fields and applications were limited to forestry, crop monitoring, mineral exploration, meteorological studies, early warning systems and so on.

After the launching of Landsat-1, in 1972, the availability of satellite images (in hard copy), application of such data for resource management have been informally introduces. The problem is that the introduction of satellite images took more than 12 years (up to 1985). In unpublished documents it is mentioned that in those days different governmental and non governmental organization were using RS and GIS in multiple applications like hydrology, geology, mineral exploration, monitoring physical environment, biomass surveying, etc, Furthermore, different analogue and analytical optical instruments were used for photogrammetric and cartographic applications.

In 1985 FAO organized a training program for some staff members from EMA and Ministry of Agriculture. That was supported with some analogue instruments installations like Procom-2. That was supported with some analogue instruments installations like Procom-2, Optical Pantograph and

Diazo colour composites processing machines. The latter ones helped for colour composites superimpositions suing additive and /or subtractive diazo films from multi spectral images or photographs. Though it was a very elementary level remote sensing laboratory, it played a significant role in different disciplines of remote sensing applications. This was especially true regarding multi - 0 spectral image processing and analysis. It significantly improved the level of the skill of the staff members in RS/GIS technology.

In 1989 the first advanced level remote sensing instruments such as Bausch and Lamb Zoom Transfer Scope, Digital system with ERDAS software and all basic devices such as Scanner, Tape drive, Inkjet printer, Film Write and the likes were installed at EMA. ·Experts trained (especially more of geographers, who are very relevant for the application of the technology) abroad and at home played a very significant role in data processing and application of RS and GIS for sustainable use of resources at the national level. The establishment of colour photo laboratory and installation of a film writer which converts the data from digital format to film and hard copy enhanced the local processing capability and satisfied most of the users' demand. The recent installation of ERDAS IMAGINE and ARC/INFO in network system is expected to meet the requirements of most of the earth resources data users. With the progress of image processing techniques and development of technical staff, importing some remotely sensed data became among the main factors of increase in the number of users.

In the 1980s and early 1990s, the demand for the need of remotely sensed data and GIS applications found to be highly increased in Ethiopia. The main users now are those organizations dealing with earth and land resources such as like land use cover, hydrological study areas, cropland monitors, geologists, urban studies, etc. Most of the users are directly or indirectly related to NGOs. Research is given more emphasis than production to introduce the technology.

Major Challenges in Introducing Remote Sensing And GIS Technology in Ethiopia

Although the remote sensing and GIS technology has been introduced in most of the natural resource data user organizations, there are dozens of problems which have been affecting the application of the technology. The problems are both internal and external. The major ones include data acquisition, financial problems, shortage of skilled personnel, problems from the users, the dynamic nature of the technology itself and so on.

Data acquisition

A decade ago, most of the remotely sensed data in Ethiopia were acquired from aerial photographs. However, such data are in analogue format, that is neither in digital -scanned format nor in the multi spectral format. Although the whole country is covered by high and low altitude aerial photographs which have been used for large and small-scale map production. Multi temporal data acquisition is limited mostly for areas with developmental changes in their infrastructure. In fact, the cost of aerial photographic data acquisition system plays a negative role in this respect because to have multi-temporal photographs to replace the existing ones may take about ten years even in the developed world. GIS in digital format is a very recent technology. Consequently, very few spatial data are in digital format. The data banks are now introducing the technology in software and hardware which means that only few research results considered a good beginning are found.

After the launching of Landsat-1 satellite in 1972, satellite imageries became available form EOSAT or other distributing companies. Even though its images are with four multi - spectral bands and radiometrically 128 bits data, its spatial resolution which is 79 X 56 meters for a pixel area hindered the production of large-scale thematic maps. Besides this, the non-stereoscopic nature of the images is also a factor disallowing the production of topographic maps Data acquisition is related to:

1. Types of data
2. Source of data
3. Data processing facilities
4. Data exchange
5. Data security and safety, and
6. Price of data

Types of data

In Ethiopia, most of the remotely sensed and other spatial data are in terms of hard copy which can be generalized as:

- Digital in some areas, especially in TM and SPOT, IKONOS, IRS
- Analogue format for most of the country with KATE (Soviet space photographs). Landsat MSS and SPOT Panchromatic,
- Very limited multi - temporal data
- Aerial photographs covering the whole country
- Topographic maps of 1:250,000 covering the whole country
- Topographic maps of 1:50,000 covering about 50% of the country
- Topographic maps larger than 1:10,000 for urban and development areas.

From this point of view one can conclude that the data are very much limited for GIS and remote sensing purposes.

Source of data

The main remotely sensed data, especially those of satellites, are not produced in Ethiopia. Neither there are distribution canters in neighbouring countries. Therefore, contact should be made with Europe or America-based distribution companies which entails the problems of shipment that may take months to arrive. In addition, there is no receiving station of satellite data except the meteorological and communication ones. The only one located nearby is that of Riyadh in Saudi Arabia but most parts of Ethiopia are out of the radius of this receiving station. That forces us to make contact with EOSAT or CNES headquarters in off distant continents. Even if there are other distributing centres, there are some rumours that they do not have good quality output because of inefficient data duplication and reduction process.

RS/GIS data processing facilities

The major data processing facilities including both hard ware and software are:

Digital image processing:

- Conversion form digital to analogue format using film recorders
- Conversion from analogue to digital format using scanner
- Colour laboratory with large format of at least A2 or A1 size papers, and
- Plotters and printers for both raster and vector output.

Unless such facilities are provided any remote sensing centre is greatly incomplete. In fact, the absence of some equipment like scanners, and digitiser may not hinder from producing some incomplete hard and soft copies.

Data Exchange, Security and Safety Problems

During the purchasing of satellite images, especially in digital format, agreement is signed not to transfer it to a third party. On the other hand, most users are interested to get the information in soft copies which are easily transferable. The reasons are to make the data compatible with the software the use, to upgrade and revise subsequent changes easily, and lastly, for commercial purposes.

Although there are agreements between countries and satellite data acquisition and producing or distributing companies, there is no guarantee to cross check the agreement before the illegal selling to a third party takes place. When a processed data (with all raster, points, vectors, attribute and other relevant information) are prepared in soft copies, there should be an agreement and/or regulation at national or organizational level. As discussed above, most of the remotely sensed data and GIS users agree on not transferring the raw data, but what about the processed one?

Price of data

Satellite data can be distributed on commercial basis. (Laur, et al, 1991). After 1980 the Landsat program exceeded the revenues costs, started to flourish. For example, in the 1970s satellite photographic images were priced between $50 and digital multi spectral scanner (MSS) tape cost $200 in those days.

Since 1980, prices of MSS and TM Photographic products have increased by 1000 to 2000 percent and MSS digital tapes by 500% (Donald, 1991). Because of the increase in price, governments of developing countries are now purchasing much less data than they did a few years ago. As Donald and others commented, the workshop of Directors of National Remote Sensing Centres in Asia, expressed strong dissatisfaction concerning the prohibitive price increase or remote sensing data coming from the developing countries. The Regional based in Nairobi reported," the computer tapes comprising one Landsat TM scene cost the same in Africa as the salary of a competent car driver for four years". However, it should be noted that galloping price rises are reflections of the growing demand for satellite images.

Currently there is significant reduction of Landsat TM data especially after the launching of Landsat-7 satellite.

Another problem in countries like Ethiopia a purchasing such an expensive digital data is that of the precious foreign currency. The only solution to over come such problems is by:

- Making coordination for sustainable resource studies using remote sensing and GIS data with different organizations;
- Making good relations with NGOs dealing with the exploitation of natural resources and conservation:
- Purchasing, if possible, when there is discount. for example, for a certain time EOSAT was selling digital satellite data in magnetic tapes of 6250 bpi with a discount of 65% (PE & RS, 1994)

Problems of Skilled Manpower in Remote Sensing and GIS Fields

This problem is twofold:

- The shortage of skilled manpower in Remote Sensing and GIS, and b)
- Problems of training centres. The two are inseparable.

As mentioned above, the number of universities or colleges with remote sensing technology courses are almost nothing. Even the few that exist, have got considerable problems. Let us discuss about the skilled manpower.

Problems of Skilled Manpower in Remote Sensing and GIS Fields

This problem is twofold:

- The shortage of skilled manpower in Remote Sensing and GIS,
- Problems of training centres.
- Standardizing of the training program

All the above are inseparable Most of the trainers are from foreign countries. To train personnel in RS and GIS needs a significant amount of foreign currency. In Addition, very few organizations have got an objective of training their personnel on basics of remote sensing which include principles, digital and analogue data processing and data management and integration. These are the core techniques of RS/GIS. On the contrary, most of the organizations are interested in very conventional ways of interpretation and application of remotely sensed data and also, GIS for many users is something to be learnt through memorizing. Unless priority is given for data processing the output for the users could be very much limited and incomplete.

Absence of distinction between data processors and users (IT groups and Application professionals)

Many users, unnecessarily, like not only to interpret and make integration of remotely sensed and GIS data with processing and distributing organizations but also to process the data which is already expensive and needs sophisticated equipment. It is common, therefore, to see different organizations importing expensive software, hardware and data in an uncoordinated manner. Therefore, different projects or departments under the same ministry import different software with similar capacity of data processing for the same objective. This shows that there is no exchange of ideas among them.

Absence of Remote Sensing and GIS Courses In Higher Education Institutions

The undergraduate programme of the Department of Geography, Addis Ababa University, enables its students to learn, at least, some terms related to remote sensing and GIS in photogrammetry and aerial photo interpretation. For geology students there is a similar photo-geology course. However, only a theoretical study of remote sensing and GIS technique is incomplete and limits the magnitude of their knowledge. On the contrary, some computer training or Information technology specialized commercial centres are observed providing with training only the software without including basics of remote sensing and/or GIS. Software cannot be RS/GIS but serve as a tool. In addition it may not answer all the questions raised by the science but minimizes. According to this observation, training and data processing centres do not have any exchange of ideas on designing curriculum or use of the available facilities.

As part of its objectives the EMA offers a six-month course for its mapping technicians and geoinformaion. The course gives the trainees good opportunities to learn remote sensing technology practically and theoretically.

Absence of Forum

As we can observe from different sources, remote sensing and photogrammetry specialists have got associations at national, regional, continental and global levels. In such forums, besides the exchange of ideas, they may solve some discuss the overall natural resources, environmental systems and the monitoring of them. They can discuss new techniques of remote sensing and GIS and publish the results in journals and newsletters.
According to (Owolabi, 1994) the solutions applicable to the problems of absence of forums include:

- Establishment of professional and scientific bodies in the country;
- Publication and dissemination of professional journals;
- Creation of RS and GIS networks as any informatics, and
- Exchanging ideas with other similar forums.

Brain Drain

Brain drain is a common phenomenon and a daily issue of the developing world. As Owolabi stated, brain drain from Africa's intellectual pool is like capital flight from the African economy. In fact, there could be multiple factors like better economic opportunities and conducive working environment in the developed world for the brain drain. It can be assumed that these factors are responsible for most of the brain drain problem of Ethiopia. For example, when agreements between the developing and economically advanced countries or NGOs, include training abroad, many trainees of not return home. After graduation the most successful are provided jobs in the host or other countries facilities may mean a professional and personal sacrifice. Such problems can only be avoided by providing comparable benefits at home, setting up reasonable database, equipment and materials to work, encouragement of challenging and useful research in the field, and opening new fields of study in higher education areas and so on.

Problems from the Users Part

As it is discussed in the previous parts, the RS/GIS technology is imported one. Therefore, most of the users have got direct and indirect relationship with foreign remotely sensed data and geo-information producers, distributors, suppliers, and software and hardware companies. Relationship is also established when some organizations run projects in cooperation with foreign counterparts. Because of such factors, there are some problems in understanding the level of remote sensing and GIS technology processing and application at home. The following are the major factors.

Dependency on foreign consultancy

Most of the projects using RS/GIS technology have been undertaken in cooperation with foreign companies. In these projects, many participants have been expatriates. These experts have experiences in other parts of the world which are not similar to the Ethiopian physical and agro-climatic conditions. It is not only in the fields of remote sensing and GIS that we need local experience, but also in all disciplines dealing with natural and human resources. Foreign experts may have good background knowledge in their environment. Many may be from Europe or America where the spectral nature of most of the features is completely different from those of Ethiopia. For example, in temperate zones, deciduous forests shade their leaves in the rainy seasons. In our case, the reverse is true. In most of the tropical areas including Ethiopia, data acquisition takes place in dry seasons when the skies are free of clouds. In addition, experience tells us that identification of exposed dark soil from dense deciduous forest could be problematic because of similar spectral values in multi-spectral images. Another example is the limited and randomly distributed farm lands. Most of the interpreters from temperate and polar areas may take them for exposed areas or open plots in the forests. The main point here is to stress the need for well-experienced interpreters on such and similar areas whether it is from home or abroad.

Misunderstanding independent advantages of analogue and digital interpretation and processing

Most of the users are biased of the advantages of digital image processing. Therefore, they take it as a substitute for the visual or analogue interpretation. Both techniques have their unique advantages. The most important thing here is the third advantage that results from the integration of the two. None could be substitute for other.

Other related problems from the user's side

Users misunderstand the level of use and application of different types of remote sensing and GIS data. They also tend to cling conservatively on black and white aerial photographs because of long time experience in their use Misunderstanding the importance of different types of data and their output such as Landsat MSS for thematic maps of up to 1:250,000, Landsat TM for thematic maps of up to 1:100,000, SPOT-XS for both thematic and topographic maps of 150,000 is another problem. Also, Underestimating the local experts and their output and the individualistic and independent nature of most of the users are other related problems. In this case, its observed that instead of establishing cooperation and smooth relationship locally, some may like to work independently in data processing interpretation and analysis. Therefore, seeing different organizations running projects in cooperation is very rare though the sustainable use of natural resources needs cooperative work to optimise exploitations.

Dynamic Nature of the Technology

Remote sensing and GIS are very dynamic science in different aspects such as data acquisition, data interpretation techniques or parameters, hardware and software facilities, data storage etc. Few decades ago aerial photographs were the only means of data acquisition in analogue format.

Extension of the Application Fields of Remote Sensing

At the very beginning, the application fields of RS were limited to strategic and /or military purposes. As different resolutions developed, more natural and manmade resources became easily identifiable and interpretable using remote sensing and GIS technology.

Recently, SPOT panchromatic stereoscopic possibilities led to topographic mapping of up to 1:50,000 (Nigusu, 1994). On the other hand, Russian space satellite KFA has spatial resolution ranging from two to three metres IKONOS one meter, Quick Bird 70 Cms. and so on. This could be used for larger scale topographic mapping. In addition, studies could be made not only at the regional level but also at the local level on the basis of RS data. Thus, RS data could be applied from crop monitoring at the local level to climatic and geological studies at the global level. Here again, the following points generalize the dynamic nature of remote sensing and GIS (Andrew et al., 1991):

- The number of system installations has doubled yearly during the last two to five years,
- The annual growth rate of GIS market is estimated to be around 35%
- Sales figure of GIS /RS products is estimated at close to 100%
- A rapidly increasing number of regional, national, and international institutions continue focusing on the technological advancement, theoretical orientation, and application for specific domains of the GIS /RS,

- An increasing number of disciplines like geography, engineering, forestry, medicine, and environmental management and monitoring etc. started to use more and more GIS and remote sensing techniques,
- Many universities and training institutions are adding RS/GIS courses in their curriculum, and

Hardware Development

At the beginning, installing RS/GIS facilities required air-conditioned rooms. The recent products of hardware can be installed in rooms without air conditioning. For RS/GIS the hardware includes many accessories.
Such accessories for digital processing consist of:

- Film writer,
- Digitizer,
- Tape driver,
- CD ROM drivers,
- Colour printer,
- Plotter,
- Text printer,
- Colour photo facility which can print at least up to A1 and A2 size papers.

The accessories required for analogue processing are:

- Interpretoscope,
- Zoom transfer scope,
- Procom 2,
- Optical pantographs, etc.

Table 2. Application of Remotely sensed data in relation to Spectral

Feature Type Band in micro meter	UV .3-.4	Blue .4 -.5	Green .5-.6	Red .6-.7	NIR .7-1.0	SWIR 1-3	THIR 3-15
VEGETATION							
Crop Type			*	*	*	*	
Biomass Stress, freeze, insect				*	*		
Drought nutrient, salinity, fire				*	*	*	*
Cultivation boundaries				*	*		
Crop harvest				*	*	*	
Forest type		*	*	*	*		
Logging / regrowth				*	*	*	
Wetland mapping				*	*	*	
Range land mapping		*	*	*	*	*	
Dune encroachment				*	*		
Desertification			*	*	*	*	
WATER		*	*	*			
Clear water penetration		*	*	*			
Bathymetry		*	*	*			
Clear water depth		*	*	*			
Monitor navigation channels		*	*	*			
Under water hazard detection		*	*	*	*		
Water quality /eutriphication		*	*	*	*		
Current mapping		*	*	*	*		
Effluents and plumes		*	*	*			*
Near shore water pollution		*	*	*	*		*
Land water boundaries				*	*	*	
Flood extent			*	*	*	*	*

Assess irrigation system effectiveness			*	*	*	*
Snow cover extent			*		*	
Snow properties				*	*	*
Snow/ cloud discrimination					*	
Marine oil seeps /slick- type	*				*	*
Marine oil seeps /slick-thickness					*	*
Sea ice mapping			*		*	*
SOIL						
Soil type	*	*	*	*	*	*
Soil moisture content					*	*
Soil salinity			*	*	*	*
Soil erosion		*	*		*	*
Buried features				*	*	*
GEOLOGY						
Mineralogical mapping	*	*	*	*	*	*
Terrestrial hydrocarbon seeps					*	*
Salinization			*	*		
CULTURAL						
Urban features	*	*	*			
Distinguish improved and				*	*	*
Unimproved roads						
Residential / commercial /industrial		*	*	*	*	*
Urban/ rural areas		*	*	*		
Land transportation routes		*	*	*		
Parks and recreational areas			*	*	*	
Waste site management			*	*	*	*
Fire mapping					*	*
Land use /cover	*	*	*	*	*	*

Source: Extracted from Multispectral User Guide.

In terms of size, speed, and capacity, the hardware changes at least, every year time. Always, the new version is portable in size, faster in speed, with higher data capacity storage.

The main problem here is competition among the high facilitative remote sensing and GIS centres of the developed countries and the gradually developing countries of the developing world. In such cases, in fact, application of 'frog leap` outlook is more preferable. Side by side, the new versions should be compatible with existing systems. Otherwise, changing every thing every years is so expensive that such centres can not afford. When an RS/GIS data processing centre plans to change the system, compatibility, flexibility, conversion possibility, and user interface and integration of vector, raster and attribute format of data, etc have to be taken into consideration.

Software development

The dynamic nature of software, especially in the field of remote sensing and GIS, is not as fast as that of hardware. Currently, hundreds of RS/GIS software are developed in many parts of the globe. Some are useful for data processing and analysis and others for training purpose. Of such software, ERDAS, ILWIS, ARCINFO, MAPINFO, AUTOCAD, IDRSI, MIPS, etc., have been introduced in Ethiopia. Although some software have been already introduced, the following issues should be taken into consideration.

- What is the coverage of the processing software?
- Does it include digital image processing steps like geometric radiometric correlation, enhancement classification and output processing?
- Does it include raster, vector and attribute data processing and their integration?
- Is there any possibility of conversion form one system to another?
- Is it friendly to operate and popular among users?

Unless software meets the needs mentioned above, it is not worth installing. Of course, some training institutions may not be interested in the sophisticated and complete software so long as their limited objectives are met. In countries like Ethiopia, where software maintenance and system development are not easy, care should be taken to select the appropriate software. Besides selecting the appropriate software, training of at least system developers and software maintenance personnel can reduce the cost of running RS/GIS.

On the whole, the challengers mentioned above have been affecting the introduction of remote sensing and GIS technology in Ethiopia, directly or indirectly. This has been affecting the sustainable use of natural resources.

CONCLUSION AND RECOMMENDATION

As it is stated in several parts of this paper, the main emphasis was to advocate the introduction of RS and GIS to help sustainable use of natural resources. The application of RS and GIS to the analysis of natural resources is one of the most common uses of RS/GIS technology. Both use the same hardware and software.

The discussion has shown us that RS/GIS application is relevant and of particular importance to Ethiopia now. In developing countries like Ethiopia, acquisition of aerial photography data is very expensive. As a result, the study of natural resources and their exploitation has been de be facilitated. Hence, remote sensing and GIS can play significant role.

Most of the organizations and institutions have not been using remotely sensed data. There are many reasons for this. The major limiting factors are data acquisition including: data type, data price, limited facility of data processing and exchange or RS/GIS data, Shortage of skilled manpower is another limiting factor. Shortage of skilled manpower includes data processors, producers, distributors, users, programmers and system developers. In addition, absence of forums for the exchange of ideas among remote sensing and GIS environment scholars and brain drain are other limiting factors.

One can add to this list of limiting factors the dynamic nature of RS and GIS. There are advanced courses that can help to improve the situation, but they are unfortunately expensive. Observations indicate that they are progressively getting cheaper and smaller in size.

Based on the discussions above, the writer would like to recommend the following.

- There should be good relationship between RS/GIS data processors and users at home.
- Before looking for a foreign consultant for every small RS/GIS technical problem local expertise should be assessed.
- The objectives of data processors, suppliers, and distributors must be based on users' needs and national interests.
- It must be recognized that RS/GIS data can be applied for various disciplines.
- Local hardware stock holders should have some knowledge about RS/GIS so that they may meet, at least, some basic needs.
- Forum should be created for RS/GIS data users as this is very important for the exchange of ideas on new developments.
- Researchers and post graduate students should be encouraged to make

research on sustainable resource exploitation using RS and GIS techniques.

- The curricula, especially in applied geography courses and environmental sciences, should include RS/GIS at both undergraduate and postgraduate levels.
- Efforts should be made to coordinate different organizations developing new projects in order to avoid unnecessary duplications.

The exploitation of explored and unexplored resources can be realized using RS/GIS techniques only if steps like the ones suggested above are taken. Environmentally sustainable development requires such applications conventional techniques have brought us to this stage. Now. It is time to apply these dynamic, more productive, and more effective technologies.

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THE NEED FOR INTRODUCING GIS AND REMOTE SENSING IN THE AGRICULTURAL RESEARCH SYSTEM OF ETHIOPIA

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Abstract

Even though agriculture is the basis of Ethiopia's economy, there has been no significant improvement in this sector. This is partly due to lack of rational spatial decision-making by identifying the spatial and temporal distribution of production potentials and constraints. The extent, quality and distribution of spatial variables which influence the production and productivity of the agricultural sector are not systematically studied, documented and made available for appropriate planning of land use, research and development. Such decision is needed because most of the agricultural activities are largely influenced by spatial and temporal distribution of physical, economic and social factors. The newly emerging technological tools (GIS, Remote Sensing and Global Positioning Systems), if appropriately setup and used in an organization, and appropriate and timely data readily available, will have significant contribution in the agricultural research system of Ethiopia. Geo-information systems, by their high potential in data collection, processing and sharing flexibility, will assist researchers in research prioritization, identification and targeting of recommendation domains, agricultural technology transfer, research impact, and adoption (extent, risk and safety) assessment, etc. With this viewpoint, establishing a comprehensive GIS and remote sensing laboratory at the Headquarter to promote, strengthen and popularize use of geo-information systems in the agricultural research system of the country is quite indispensable. This paper attempted to provide basic perception of introducing and using GIS and Remote Sensing systems in agricultural research.

INTRODUCTION

Ethiopia's economy is largely dependent on the traditional farming system. Though agriculture is the basis for our economic development, there has been no significant development in the sector. This is partly due to lack of appropriate decision making on resource management and planning for sustainable use of our resources. The goals of sustainable development in developing countries are not being met, partly because of lack of access to appropriate technologies (Remote sensing and GIS) foı environmental monitoring and for development of sound and sustainable land management practices (Sanchez-Azofeifa,' 1997). Remote Sensing (RS) techniques and Geographic Information Systems (GIS) are unique and important state-of-the-art tools for monitoring the degradation of ecosystems; for defining priority areas of conservation and development; and for verifying accurately the effectiveness of land use planning" (Sanchez-Azofeifa, 1997)

For the research and academic users, GIS not only enhances the opportunity to describe, explain and predict spatial patterns and processes, but it also allows them to formulate and test sophisticated and realistic models (Meade and Kapetsky, 1991).

Establishing and using GIS, requires trained personnel, hardware and software components and timely and appropriate data. In view of this, it seems important to provide a perspective account on the considerations, implementation challenges and opportunities of introducing GIS and RS in the agricultural research system of the country.

Since there is no a single universally accepted definition provided for GIS, different authors defined it from different perspectives. Burrough (1986) defines it as " GIS is a powerful tool for collecting, storing, retrieving, at will, transforming and displaying spatial data from the real world for a particular set of purpose". Aronoff (1993) defines GIS in two ways: in its broader sense, he defines it as "any manual or computer-based set of procedures used to store and manipulate geographically referenced data. And considering it more specifically, he defines it as a computer-based system that provides the following four sets of capabilities to handle geo-referenced data: 1) input; 2) data management (data storage and retrieval); 3) manipulation and analysis; and 4) output. From the definition it is possible to realize the requirements for a GIS setup and how powerful the tool is.

Whichever definition is given, most of the definitions rely on the computer-based GIS. This is because; it is the computer technology that realized the potential of GIS for handling retrieval and analysis of large amount of data. GIS is becoming popular as a result of the rapid access to data, flexibility, easy update opportunity and other features that enable to analyze different databases. Its popularity has become more pronounced as a result of parallel developments in satellite technology and computer sciences.

For a GIS functioning, there should be sufficient and relevant data. To meet this, there is a need for efficient data collection mechanism. The data source for a GIS could be remotely sensed imagery, including aerial photography, laboratory analysis, GPS, etc. Among the new data collection systems, GPS and RS satellites are cost effective and contributing a lot.

To answer questions, having spatial component, we need to collect, process, and analyze data on our resources and generate relevant information; the following new and powerful technological tools will have significant promise for the future.

- Geographic Information Systems (GIS),
- Remote Sensing (RS), and
- Global Positioning Systems (GPS).

Remote Sensing

Remote sensing is acquisition of data/information about an object without being in direct physical contact with it using electromagnetic radiation. McCloy (1995) defined remote sensing as the acquisition of data using remotely located devices and the extraction of information from that data. In this definition there are two main subdivisions: data acquisition and information extraction. The data acquisition is possible using electromagnetic radiation.

Many countries have launched a wide variety of RS satellite systems that have variety of characteristics. In general, there is a significant improvement in radiometric, spectral, and temporal resolutions. As a result of such developments, the potential of remotely sensed data is increasing and accordingly it is being widely applied.

There are also various image-processing software developed, which assist for information extraction from remotely sensed imageries. Among such software, IDRISI and ERDAS imagine are widely used.

Global Positioning System

Global Positioning system (GPS) is a satellite-based navigation system which uses satellite ranging to determine positions. It is made up of 24 satellites that continuously send radio signals containing position and time information for each satellite back to earth. Minimums of three satellite signals are required simultaneously to fix the latitude and longitude coordinates and need at least four satellite signals for altitude fixing. The position is determined by using a GPS receiver, which receives and compares the signals from satellites. There are however, inaccuracies in GPS, which are caused by atmospheric and ionospheric distortions, satellite clock or orbital errors, receiver type used, processing strategies adopted and by intentional degradation imposed by the U.S. Department of Defense (known as Selective Availability) (Meaden and Chi, 1996). But, the omission of selective availability in 2000 is expected to greatly improve the positioning accuracy and Hence, the applications. The accuracy level required depends on the application. There are wide varieties of GPS receivers and positioning techniques available to improve the accuracy of positioning.

Cognizant of these potentials of such tools, this paper attempted to provide the importance of introducing and using GIS and RS systems in the agricultural research system of Ethiopia.

Functional Considerations and Implementation Challenges and Opportunities

There are several potential challenges and options which will be encountered in the course of implementing and developing GIS and RS systems. It is Therefore,, after a thorough understanding of the advantages and disadvantages of these technological tools that an organization can be convinced whether to implement the systems or not.

Some Functioning Considerations

GIS and remote sensing are dynamic tools requiring relatively sophisticated facilities and higher initial investment for purchasing software, hardware and data, manpower development and data input processes.

The table below shows the investments on GIS by various international institutions involved in agricultural research and development and resource management.

Table 1. Investment in staff, hardware and software by the CGIAR centers

CGIAR center	STAFF ('000 US$)	HARDWARE ('000 US$)	SOFTWARE ('000 US$)
CIAT	>250	>250	100-250
CIMMYT	100-250	50-100	10-50
CIP	100-250	10-50	<10
ICARDA	50-100	50-100	10-50
ICLARM	10-50	<10	<10
ICRAF	100-250	50-100	10-50
ICRISAT	100-250	50-100	10-50
IFPRI	10-50	<10	<10
IIMI	50-100	10-50	<10
IITA	10-50	10-50	<10
ILRI	100-250	50-100	10-50
IPGRI	<10	<10	<10
IRRI	100-250	100-250	50-100
ISNAR	10-50	<10000	<10
WARDA	100-250	10-50	<10

Source: Chator, S. (1999); with some modification and corrections

Some of the requirements to be considered, which can have a negative or positive influence in the adoption of these systems, are the following.

- **Hardware considerations**: for GIS implementation, there are some input and output hardware required to be fulfilled in addition to the computer system. These required input and output devices include; digitizer and/or Scanner (for inputting) and Plotters and/or Printers (for data outputting). Since wide varieties of GIS hardware are available, the compatibility and capability issues have to be carefully considered and ensured.
- **Software consideration:** A range of GIS software which vary in capacity they offer, compatibility and the platform on which they can perform are available on the market. Though it is not easy to choose among various GIS software, we should at least evaluate these in terms of the cost and capability of the software to provide the various manipulation and analysis requirements. In addition the full compatibility to the available and future hardware should be assured.
- **Personnel considerations**: simply purchasing and setting up GIS facility will not address GIS needs of an organization. The capacity building should consider manpower development through training and employing specialists with relevant background in the fields. In addition to the GIS specialists involved, there should be a system to build the awareness of users in various disciplines through hands-on GIS trainings and workshops.
- **Databases buildup and maintenance:** there should be enough and relevant spatial and attribute data in a digital form to be manipulated in a GIS for generating information to meet user-and objective-specific requirements.

The database establishment is costly and time-consuming. It is one of the most costly and time taking components of GIS. Conversion of existing analogue data to digital (digitizing) and purchasing digital data like satellite imageries is very costly. As much as possible, it is preferred to have a common data standard with interrelated organizations so as to ease data sharing and exchange and thereby reduce redundancy and cost of data input.

Challenges

Even though there are several potential advantages of introducing GIS and RS, there are some challenging issues that need due considerations. The establishment, implementation and use of geo-information systems, especially for Ethiopia, have got several constraints. The most important challenge is that, meeting the requirements for establishment of the GIS and RS systems. Some constraints are specific to the country or organization and others are related to the system itself.

Some of the potential challenges facing throughout setting up and implementing GIS &RS systems in Ethiopia are:

- lack of awareness on the potentials of new tools and realizing the needs;
- lack of well organized relevant and timely spatial data in the required extent, scale and format;
- lack of coordination and cooperation in data generation, sharing and exchange so as to avoid effort duplication;
- lack of enough budget allocation both for capacity building and maintenance
- lack of trained manpower in the field;
- lack of institutions which provide GIS-related trainings;
- high initial cost of system setup and data input; etc.

A detailed account on challenges in introducing GIS and remote sensing in Ethiopia is provided in Degelo (1996).

Opportunities for optimizing the potential benefits of GIS

To efficiently use GIS and RS, emphasis should be given to the setup and implementation aspect. As stated earlier, if the appropriate data, facility and personnel exist, it will be possible to exploit the optimum potential of GIS. The potential of GIS as a research tool can be optimized if it integrates various technological tools such as GPS, RS, DSS, and various models. GPS and RS make the data collection and processing easy and cost-effective. Technological advances in computer, satellite remote sensing, and GPS simplified geographic data input and integration techniques and storage, retrieval and analysis capabilities for extracting more reliable information. Furthermore, there has been a reduction in costs of hardware and data and an increase in capability, accessibility and flexibility of computer and satellite systems.

The potential and prospect of GIS in combination with RS and GPS tools, could contribute information for a variety of resources management applications, which include, inventory, evaluation, and monitoring of resources and the decision process on the use, development, and management of resources.

The following are some of the opportunities one can get advantages by introducing and using GIS:

- Large quantities of spatial data capture, storage, retrieval and analysis are easy, flexible and rapid.
- Database updating and maintenance can be done at a greater speed and lower cost;
- Handling voluminous and historical data storage, retrieval and analysis will be easy;
- Improve data exchange and sharing and Hence, avoiding duplication of data and effort comes possible;
- Manipulating and integrating diverse spatial and non-spatial data and procedures is possible;
- More flexible and inexpensive output can be provided; etc.

A detailed listing on the advantages and disadvantages of introducing GIS in an organization is provided in Meaden and Chi (1996).

Geo-information Needs and Gaps

The needs for spatial information for agricultural decision-making are increasing from time to time. However, enough consideration has not been given to the Georeferenced spatial data collection, maintenance, documentation and dissemination.

Needs

Ethiopia is known for its diverse Agro-ecologies. Accordingly, the Ethiopian agricultural research system is mainly based on the agro-ecological zones (AEZ) of the country. The existing AEZs map divided the country into 18 major and 48 sub- AEZs. There are complains on the details of the AEZs map available since it is very generalized. This shows that there is a need for a refinement work.

The limits of environmental adaptation of species and varieties will, in most cases, not coincide with the limits of the established zones, or nor does the zonation as such provide information on the stability of, the risk associated with, or the sustainability of particular agricultural technologies (new or traditional) at a given site (Goble and Thomas, 1999). In order to be effective and to attain the intended goal by addressing such gaps there should be adequate, appropriate and timely information on the status of various resources and tools (GIS and RS) to analyze and generate information specific to the needs of applications, organizations and individual users.

For appropriate planning and decision-making there should be adequate and timely information on the availability of resources and socioeconomic conditions of the country or location. To make informed decisions about adaptation zones of crop variety and resource allocation, accurate and relevant information appropriate to the scope and scale at which these decisions are made is needed (Collis and Corbett, 1999). In Ethiopia however, there is no enough information/data collected and documented systematically on the potentials and constraints of our land resources. Consequently some of the agricultural land uses do not match with the actual potential of the land. So there should be information on the quality and extent of land available so as to allocate for appropriate use. By doing so, the ongoing land degradation in the country can be reduce or hampered.

Some of the basic information necessary in the agricultural sector include information on soils, geology, hydrology, AEZ, physical infrastructures, administrative divisions boundary, demographic, terrain (elevation, slope, aspect, etc.), land use/cover, farming system, climate (rainfall, temperature, LGP, etc.), etc. From such data other derived layers targeted to the specific objective could be generated by means of GIS analysis and models.

Geo-information Gaps

Identification of information gap is important for future decision in data collection. In Ethiopia there is no sufficient and relevant data available in the required format, quantity, quality and time. Most of the available data are in the form of statistical and verbal descriptions and also most of the existing mapped and mapable data are in analogue (paper) form. Some of the reasons include the following.

1. There is lack of institution which is responsible for assembling, archiving and managing geo-spatial data of the country in digital format and for disseminate to potential users. Ethiopian Mapping Authority, which provide limited remote sensing and GIS-related services in the country is among some exceptions.

2. GIS and remote sensing facilities are deficient in the country. Donors and projects for a particular project established most of the existing limited facilities. Such projects and organizations have generated their own database based on their specific needs and interests. When the projects are closed some or all experts who have been working in such projects may be layoff. Hence, the database which was generated and archived throughout the project life could be missed or remain ineffective as there will be no one responsible to maintain and provide the information. So, in most of such establishments, due to lack of clearly defined data standard and documentation, data exchange and sharing opportunities are less. Data availability in the appropriate format is one of the greatest constraints in applied research and this is particularly true for georeferenced weather and soils data in developing countries (Collis and Corbett, 1999). The existing spatial data may have several limitations to satisfy users' needs. Even it may lack documentation on the projection, scale, date and methods of collection and source of compilation, and/or may not be properly georeferenced to match with other data in the required detail and quality of information at a particular scale

3. There is lack of awareness on the new tools for Geo-information processing (DSS, GIS, RS, GPS). Even if these powerful tools are simplifying the data capture and processing, the cost of establishment and getting expertise for generation and use of these tools is not easy for developing countries. Due to the high cost of establishment and lack of emphasis to the technology, the development of these powerful tools in our country, and in most other developing countries is at an infant stage. Since some GIS database producers do not introduce their products for potential users, the existence of some valuable datasets held by various organizations is not known. From the users side, the awareness on what data source or tool to use for what application and at what scale is limited.

Potential Applications and Need for Introducing GIS and RS in the Ethiopian Agricultural Research System

Potential applications in agriculture and natural resource management

The following are some of the areas in which remote sensing, in combination with GIS could be applied for agriculture and resource management.

- Soil survey and land evaluation/agricultural land capability /suitability analysis
- Identification of potential sites for research and development
- Rangeland and forest inventory, condition assessment and monitoring
- Natural vegetation mapping
- Plant diversity research
- Land degradation and rehabilitation assessment
- AEZ characterization
- Land use/ Land cover change and trend assessment and mapping
- Climatic inventory, assessment and modeling
- Hydrology /drainage interpretation and mapping
- Impact assessment of land use policy
- Infrastructure mapping
- Terrain classification and mapping
- Inventory and Estimation of crop yield/area production, etc.

GPS tools are needed and are applied to several activities of Geo-information generation. Some of these activities are:

- Geo-referencing photogrammetric (aerial photographs) satellite imageries; Digital map data (by collecting ground control points);
- Field checking satellite imagery, aerial photograph data, etc;
- Updating Databases (e.g. map revision);
- Collection of line (route) and area (polygon) data;
- Locating point sampling of
    - Soil sampling sites (profiles, pits)
    - Germplasm collection sites
    - Locating training sample sites for supervised image classification
    - Pest and disease outbreak site locating
    - Collecting spot-height data
- Locating meteorological station towns and trial sites, etc.

All such data could be downloaded into a computer and processed using appropriate GIS or RS software for analyzing and generating relevant information and outputting.

The Need

Though GIS and RS have high potential to offer in the agricultural research, they have not been used efficiently in this area. The applications of these tools for agricultural research have had short history. Nowadays, since most of the agricultural research and development activities have many spatial and temporal components, there is a push towards a geo-information generation and use in every aspect of research and development applications.

The needs for introducing Geo-information systems in an institution may vary. Though there could be various organizations which generate, use and distribute various geo-information, the type of information generated and used depends on the responsibility and mandates of an Organization. Accordingly, the need for adopting GIS in the agricultural research system is believed to help to meet the objectives and goals of the research.

As noted earlier, the Ethiopian agricultural research strategy is mainly based on the Agro-ecological Zones (AEZ). "Agro-ecological zoning (AEZ) is an important basis of sustainable agricultural land use planning of a region. GIS technology is very useful for automated logical integration of bio-climate, terrain and soil resource information, which are required for delineating AEZ in a region" (Bhan et al, 1997).

As long as adequate and relevant data is available, GIS enables researchers to define-objective specific zonations targeted to various applications. To make clear the issue of flexibility for user specific zonation and targeting, the following maps on climate similarity (figure 1) analysis and moisture regimes (aridity index) (figure 2) can be seen as an example.

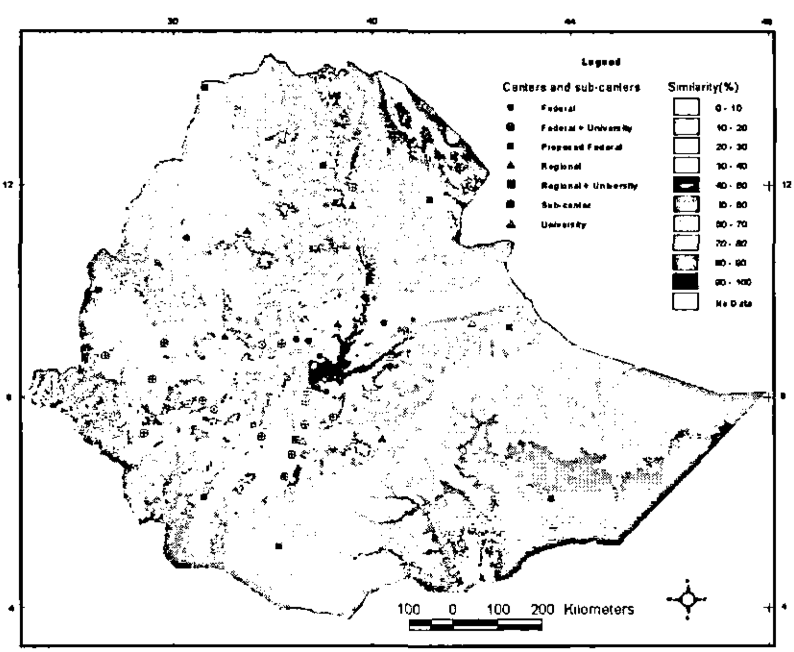

Figure 1. Climatic similarity with Nazreth, %

The characterizations were done using ArcView, Excel and Clim_map (Unpublished). The Data employed were Meteorological station data, Digital elevation model and, mean monthly and annual temperature and precipitation.

We can also explore sites, which have similar environment to which we are making trials on different varieties and identify the type of problem and the geographical extent we can or address. figure 1 is on similarity analysis. The map was prepared taking Nazareth station as a reference. It shows the extent of similarity in percentage considering the mean monthly rainfall and mean monthly temperature surfaces. This function is particularly suitable for the targeting of new germplasm, technologies and ideas (Corbett et al, 2001). Using such analysis, we can have a general view of the extent we can cover by the agro-technology obtained from a research at Nazareth or where we can make our possible test of a variety which performed well at Nazareth or elsewhere having a similar environment.

This implies that there is much less need for all institutions working in agriculture and natural resource management to agree on a single 'Agro-ecological' zonation scheme. Researchers can produce different zonations based on their objective and target provided that appropriate digital spatial data, analysis tools and expertise are available.

Hence,, the main objective of introducing GIS and RS in the agricultural research system of the country is to overcome the aforementioned problems and gaps i.e. "Creation of a system capable of providing quantitative and predictive geo-referenced information on land resources and their interactions with crops and farming systems for the benefit of EARO researchers and EARO's clients (other federal and regional services and the farming community) (Gobel and Thomas, 1999). According to Pande et al (1999), GIS is used in agricultural and environmental research and development to meet four basic purposes:

1. to diagnostically help research planning
2. to target research products accurately to areas where users will find them relevant and acceptable;
3. to assess the impact of research or development; and
4. to further research, used as pure (strategic) tool.

To sum up this section, though it is not possible to list all the generic potential benefit of geo-information systems, research using GIS will help to meetthe following purposes.

To improve generation and capturing resource information

- GIS assist to generate spatial and temporal information on land resources and their interrelationship;
- It also helps assess and model the effect of spatial and temporal variations of resources on the agricultural production and productivity;

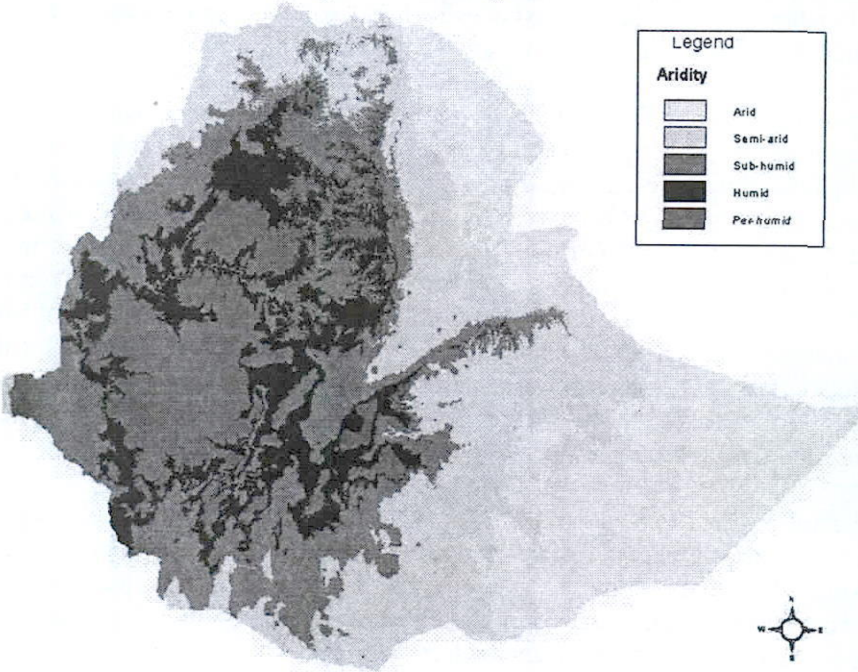

Figure 2. Aridity index

The second example (figure 2), the aridity index map, showing the moisture regimes, was prepared to demonstrate the capacity of GIS in map calculation. Dividing the annual precipitation surface with the annual PET surface derived this map.

To identify potentials and constraints: The tool is specifically advantageous to:

- perform dynamic spatial characterization, and objective specific zonation and targeting (Corbett, 1999).
- to study how lands with different potentials and constraints distributed (FAO, 1997).
- enable researchers identify distribution patterns of constraints and potentials, and assess the significance of specific phenomena to the agricultural production and resource management.

Prioritization
- facilitates prioritization and targeting of research themes (problems)
- facilitates research site (location) prioritization and targeting.

Research planning and executing
By its potential in:
- data capture and integration,
- analysis and flexibility, and
- one means of research output, GIS can facilitate research design, planning and execution.

Formulating Recommendations: The tool help to
- identify environments for generating site specific technologies and make appropriate recommendations the appropriate areas,
- select verification trail site.

Adaptation
From an analysis of spatial distribution of various biological, physical, and socio-economic parameters, one can:
- identify and visualize the extent of a geographical area to which improved agricultural technologies are adapted and can adapt;
- identify potential and actual adaptations
- identify needs and gaps for adaptations of specific varieties or technologies in a specific area.
- assess how yields vary among locations, years and seasons. (FAO, 1997).

Extension/technology generation and transfer
- For provision of appropriate, area-specific extension information and advice (FAO, 1997);
- For setting agricultural research priorities and establishment of network for technology transfer (FAO, 1997);
- For assisting extension specialists to visualize the geographic domain in which a particular agro-tech can be extended

Adoption
Even if a specific technology generated is feasible for transfer to a particular area, there may be various conditions, which have influence on adoption/non-adoption. So, GIS assists researchers in identifying the socioeconomic and biophysical factors which have an effect on the extent of adoption /non-adoption of a certain agricultural technology.

Risk and impact assessment

- assess the risk associated with the use of a given agro-technology across environments and the impact of environmental variability on the outcome in time so that they can position their research product between the competing poles of performance and stability (Gobel and Thomas, 1999);
- provide qualitative and quantitative information across space and time on the impact of agro-technologies and on the resource base in order to identify and devise technologies and strategies that minimize environmental degradation(Gobel and Thomas, 1999.

Linking models with spatial data

To exploit the full potential of GIS for agricultural research, there is a need to integrate it with other tools and programs like crop simulation models. Linking crop simulation models to spatial data:

- enables the creation of germplasm-specific zones with accompanying risk assessment and scenario information (Collis and Corbett, 1999).
- enables characterizing the spatial extent of the adaptation zone for specific germplasm while providing detailed information which is not possible through any other mechanism save a massive (and probably extensive) field trial experiment (Collis and Corbett, 1999).
- facilitate simultaneous analysis of spatial and temporal variation in processes"(Hartkamp et al, 1999).
- help to estimate, forecast and monitor various socioeconomic and environmental phenomena spatially.

The Current and Anticipated Status of GIS and RS at EARO

Current Status

Presently, the system is not yet established. But the procuring of the GIS laboratory software and equipments is underway. Though the laboratory at the Headquarter is not fully established, some activities are underway. Most of the activities are advice and services using the available database, computer and software. There is a significant improvement in awareness on the importance of the new tools. As a result, the number of researchers requesting GIS, RS and GPS services has increased to the extent that we cannot provide with the available facility (i.e. without appropriate GIS software, GPS and digitizers). The unit has two computers; two experts and various databases produced by different organizations (Characterization, Assessment, and Applications Group; Soil Conservation Research Project; Key Indicator Mapping system-

FAO; AEZ digital map obtained from MOA). The unit has also limited capability GIS-software. Using these data and software, the unit has prepared and provided different maps to users, mostly for researchers. Most of such activities include preparing location maps of research sites, preparing location and distribution maps from point. Besides this, limited digitizing services were provided. Since we have no digitizer, we scanned the maps to be digitized and digitized then using Arcview by screen digitizing and provided for users.

Anticipated status

Considering the potentials of GIS and RS for agricultural research application, EARO is on the way to setup a GIS and RS laboratory at the HQ of EARO. The Laboratory has been identified to act as the central database, and maintain links with each of the other research centers and institutions. It will act as a central depository of relevant Geo-information to agricultural research in the country. At Debre Zeit, a Mini GIS system is being installed. Such small systems are also expected to be setup at the National Soils Research and at Nazret Research Centers. All these mini-GIS laboratories will be harmonized to meet the geo-information needs of EARO in particular and the country in general. To ensure the successful setup and promotion of use of these powerful tools, it needs an interdisciplinary work among researchers from various disciplines of EARO or elsewhere. In the Ethiopian agricultural research organization, there are multidiscipline for full participation in the promotion of use and creation of Geoinformation and models. The unit will provide support and advice to researchers and also let researchers use the laboratory. In addition, the unit will undertake GIS-based research in collaboration with multidisciplinary field specialists at EARO.

The software to be purchased and utilized is preferred to be common to all centers; easing data exchange and sharing. The software ordered for the laboratory at the Headquarter includes Arc\Info, ArcView, Erdas Imagine, and Visual Basic Studio.

Once the establishment is done and the wide area network to connect research centers is realized, the information dissemination and data exchange will be much easier. Together with these facilities, if enough and qualified human-power is in place and adequate budget is allocated, it is envisaged that the project will involve in advanced GIS based modeling, forecasting and monitoring activities.

CONCLUSION

Considering trends and opportunities in geo-information, the government and NGOs should recognize the importance of GIS as a powerful tool for research and development applications and should allocate sufficient budget. GIS has a multidisciplinary application for research. So, using GIS needs collaboration both for data exchange/sharing and for specific fields of application.

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GIS FOR SMALL-SCALE MODELING OF ENVIRONMENTS AND SPATIAL RECOMMENDATION OF AGRICULTURAL TECHNOLOGIES: A CASE STUDY IN GIMBICHU WOREDA

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INTRODUCTION

Maps and geographic analysis have been employed in few instances in agricultural research, although there exist precise and accurate topographic and thematic maps, and other spatially referred meteorological and statistical abstracts produced for the country by various governmental organizations. Currently, however, the advancement of computer science and the need for spatial data handling led to the development of Geographic Information Systems (GIS), which becomes a user friendly and easy to implement tool for several applications particularly agricultural research and other planning and decision making activities. GIS has a great role in the prioritization, design, assessment, feed back and other aspects of agricultural research.

Gimbichu Woreda is representative of large areas of the central highlands of Ethiopia found in Eastern Shoa Zone of the Oromia National Regional State. The topography is mostly flat with slopes close to the boarders. At Chefe Donsa, the center of the Woreda, the altitude is 2450 meters above sea level with wetter climate with average annual rainfall of about 850mm. There is seasonal occurrence of frost, which affect the performance of crops. There are several permanent and temporary rivers flowing with in the Woreda. The major soil types are also seasonally waterlogged black clays called Vertisols in the flat areas, and andosols and other soils occur in the steeper parts of the Woreda. As the other part of the highlands of Ethiopia, the people are engaged in subsistent mixed crop and livestock production. Crop production is the dominant activity of the farmers. Livestock also plays an important role in the farming system. Livestock are largely dependent on crop residues and grazing in hillsides, field verges and roadsides. Accordingly, there is considerable variability in environmental and socio-economic conditions within the Woreda, which need to be studied.

A research sub-station has been established Chefe Donsa, the center of the Woreda by the Debre Zeit Agricultural Research Center since about two decades ago. Mainly crop genotypes and other improved practices have been tested at the sub-station. There have been also on-farm trails, where the performances of improved technologies have been evaluated in comparison with farmer's varieties and practices. With this long endeavor several crop varieties and agronomic practices have been recommended by the center and are being used by farmers increasing their productivity.

The performances of the improved agricultural technologies are not, however, consistent all over the Woreda due to the considerable variation of the environment and socio-economic conditions, although most of the technologies are widely applicable in the woreda. Thus, a case study has been made in the Woreda with the following objectives:

- develop a digital spatial database of relevant environmental and socio-economic conditions of Gimbichu Woreda.
- Assess the potential role of GIS for characterization and prioritization of research for the Woreda, and spatial recommendation of improved agricultural technologies within the Woreda

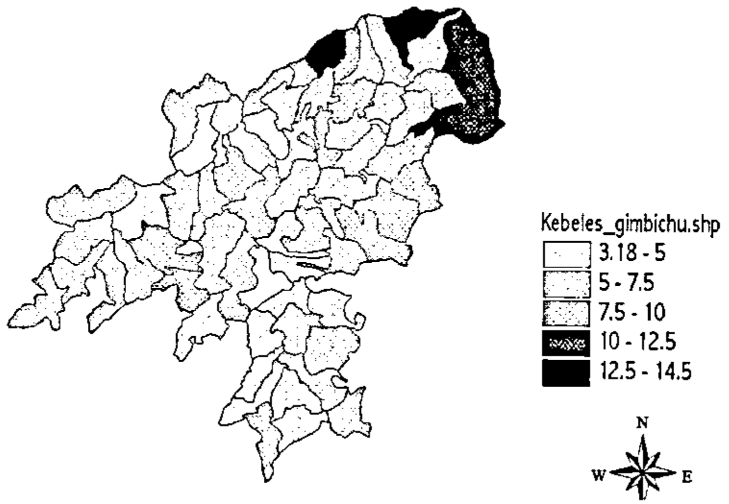
Spatial Database Development

Administrative base map: The administrative base map of the Woreda was the basic spatial data which enables the other environmental and socio-economic parameters to be studied and indicated in each of the kebeles of the Woreda. This map was initially digitized using ArcInfo vector GIS software and then it was imported to ArcView Shape file. ArcView was relatively very convenient for edition and spatial analysis of thematic mapping. The administrative map has been prepared with levels of each Kebele of the Woreda .

Socio-economic conditions: Population of human beings and households were attached to each of the Kebeles of the administrative map of the Woreda, as attribute database using Microsoft Excel and ArcView GIS Software. The Population of the Kebele was extracted from the census made by the Central Statistical Authority (CSA, 1994). Population density in 1994 was spatially calculated using ArcView Vector GIS software by dividing the number of people in each Kebele with its corresponding area. The population density in each kebele varied from 38.9 to 145 people per square kilometer (Figure. 2). Human beings are densely settled in the highlands than the lowlands mainly due to the suitability of environmental conditions for agricultural production.

Accessibility to roads and market could be also one of the factors as people are densely settled close to such infrastructure. The average land available for a house hold has been calculated by dividing the total area of the Kebele with the respective number of households in that Kebele. A minimum 3.18 ha is available in the highlands and a maximum 14.5 ha is available in the lowlands for a household in the Woreda (Figure 3).

Figure 3. Average size of land (ha/household) available for gimbichu wereda



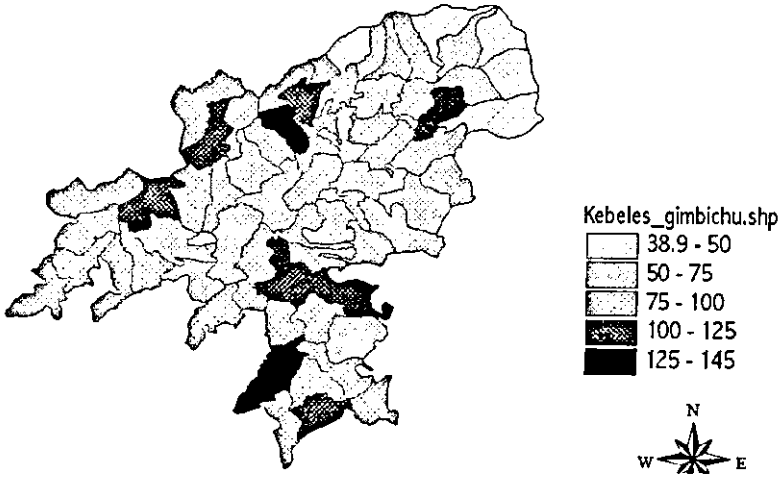


Figure 2. Population density in Gimbichu wereda

Digital Elevation Model: Gimbichu Woreda is located within a longitude range of $38^0 59'59''$ and $39^0 21'31''$, and latitude range of $8^0 47'27''$ and $9^0 9'17''$. Five 1:50,000 scale topographic maps were acquired from the Ethiopian Mapping Authority, which cover the Woreda. A mosaic of the topographic map of the Woreda was prepared by attaching the adjacent maps together on a light table. The mosaic topographic map of the Woreda was divided into three blocks so as to fit the size of A0 size digitizing tablet. Contour lines on each of the blocks were first digitized using ArcInfo vector GIS software. The three blocks were then merged together to obtain a vector digital map of the Woreda. Additional edition was also made using ArcView vector GIS software after the data was imported from ArcInfo coverage format to ArcView Shape file.

The Vector contour map data was imported from ArcInfo Coverage file to a vector file format of IDRISI for Windows, raster GIS software with corresponding tabular data of the identifiers and elevation of the contour lines. The extent and resolution of the woreda was initially specified using Universal Transverse Mercator geographical projection system. The resolution of the map has been defined to be 80m by 80m, where the number of columns and rows were calculated to be 493 and 503, respectively that could enable to cover the Woreda. Those pixels of the initial map, which had 0 values, were assigned with the corresponding elevation of the contours lines which pass over them. A linear interpolation was then made between the pixels which already got altitude values, to obtain the elevations of the undefined values in between the rasterized contour lines. The linear interpolation equation shown below, which is based on the altitude of the higher and lower contour lines and the distance to both of them has been employed.

$$h = H_2 + (d_2/(d1+d2) * (H_1 - H_2),$$

where: h is the height of undefined pixel, H_1 and H_2 are the height values of the higher and lower contour lines, d_1 and d_2 are the distances from the pixel to the higher and lower contour lines.

The result DEM was very useful for studies was a very important input to estimate the other environmental parameters including temperature, rainfall, length of the growing period and slope as it will be discussed latter. The precision of the date is very adequate for precise planning and assessment in agriculture. The DEM was classified into traditional agroecological zones (Figure 4)

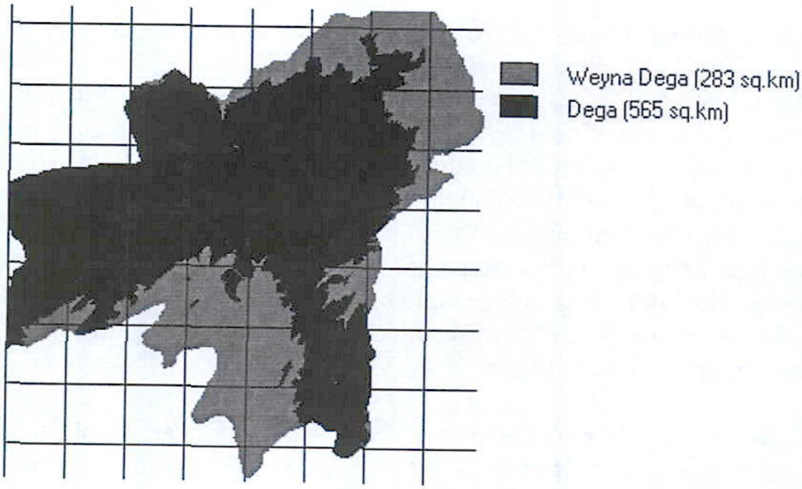


Figure 4. Traditional agroecological zones of Gimbichu wereda

Temperature

Mean annual temperature is one of the important land characteristics identified to determine performance of agriculture. A regression equation which was generally developed for Ethiopian, except south-eastern Ethiopia was employed to estimate the average mean temperature during the growing period (FAO/UNDP, 1984), which is presented below.

$$T(^{0}c) = 30.2 - 0.0059 * altitude$$

The map of average temperature during the growing season of Gimbichu Woreda was calculated using Idrisi for Windows in raster format. Further, the map was classified into thermal zones (Figure 5).

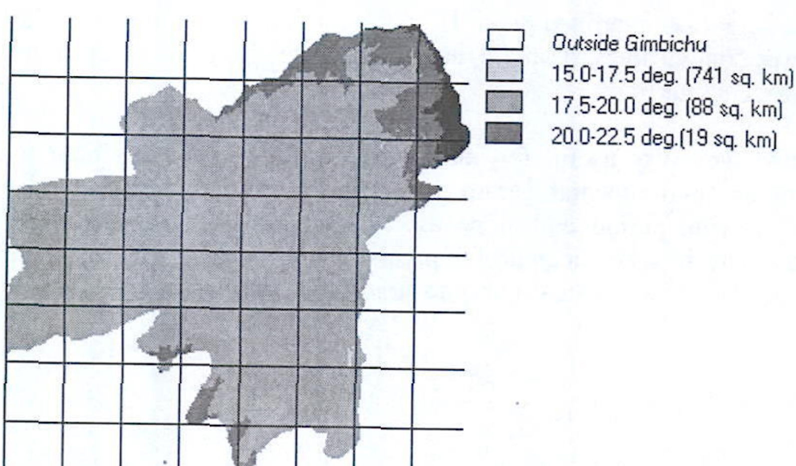


Figure 5. Distribution of average annual temperature in Gimbichu

Potential Evapo-transpiration (PET)

PET is an indicator for the potential soil moisture content. Together with the spatial pattern of the rainfall distribution, PET determines the Length of Growing Period. In the central highlands of Ethiopia, PET correlates strongly with altitude. The following regression equation has been derived for Ethiopia (De Pauw, 1988).

$PET\ (mm/year) = 2389 - 0.4341 * altitude$

PET of Gimbichu Woreda was calculated employing the above equation (Figure 6).

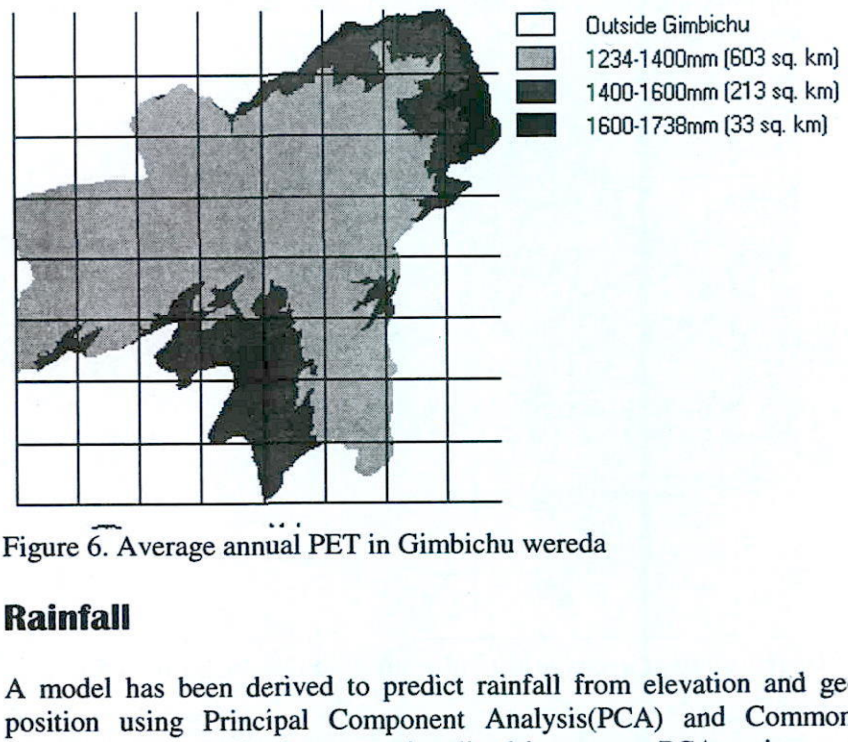


Figure 6. Average annual PET in Gimbichu wereda

Rainfall

A model has been derived to predict rainfall from elevation and geographic position using Principal Component Analysis(PCA) and Common Factor Analysis(CFA). Ethiopia was regionalized into seven PCA regions, where the rainfall is precisely predicted. The following regression equation was developed for the PCA region B, where Gimbichu Woreda is located (Eklundh and Pilesjo, 1990).

$\sqrt{Y} = -41.9 + 12.61 * lnX - 0.0889 N_x^2$

Where: Y predicted mean annual rainfall (mm), X = elevation (m), N_x = south-east to north-west axis value (degree decimal).

To employ this model three raster maps i.e altitude, longitude and latitude have been used. A similar procedure used to derive the DEM, was employed to produce longitude and latitude raster maps. The longitude was calculated from three vertical lines, which were drawn in ArcView at 38^0 59'59'', 39 and 39^0 21'31'' within the latitude range of $8^0$47'27'' and 9^0 9'17. This vector map was imported to Idrisi Software, where the extent and resolution of the pixels were set the same with the DEM. The longitude map was also produced by running linear interpolation, as discussed above, among those pixels which have been assigned longitude values from the imported and rasterized map, and those which did not get values. The latitude map was similarly derived from three lines drawn at $8^0$47'27'', 9 and 9^0 9'17'' within a longitude extent of 38^0 59'59'' to 39^0 21'31''. The average annual rainfall, average rainfall during the main season and that during the short rainy season have been derived using the formula indicated above (Figures 7-9).

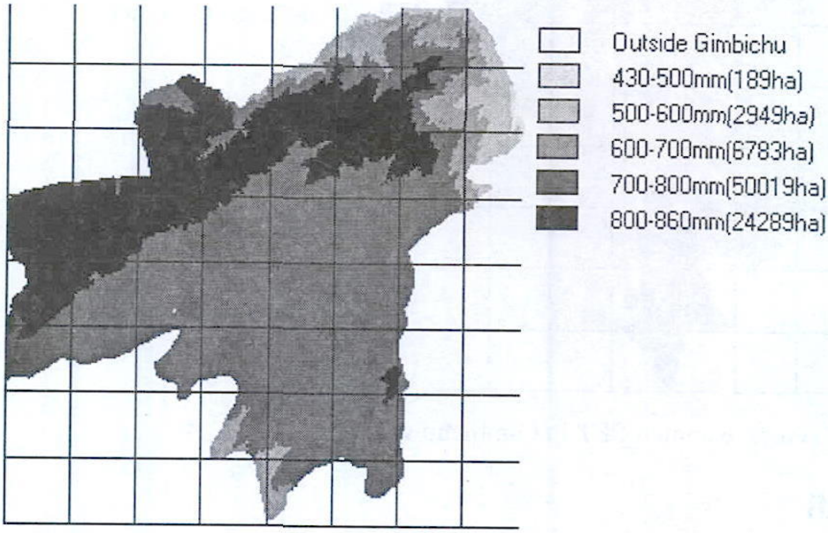


Figure 7. Distribution of average annual rainfall in Gimbichu wereda

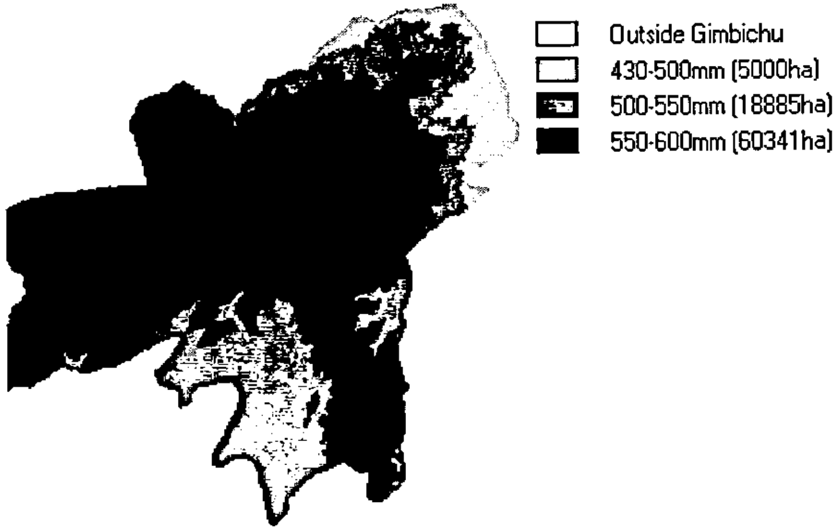


Figure 8. Rainfall distribution during the main season in Gimbichu wereda

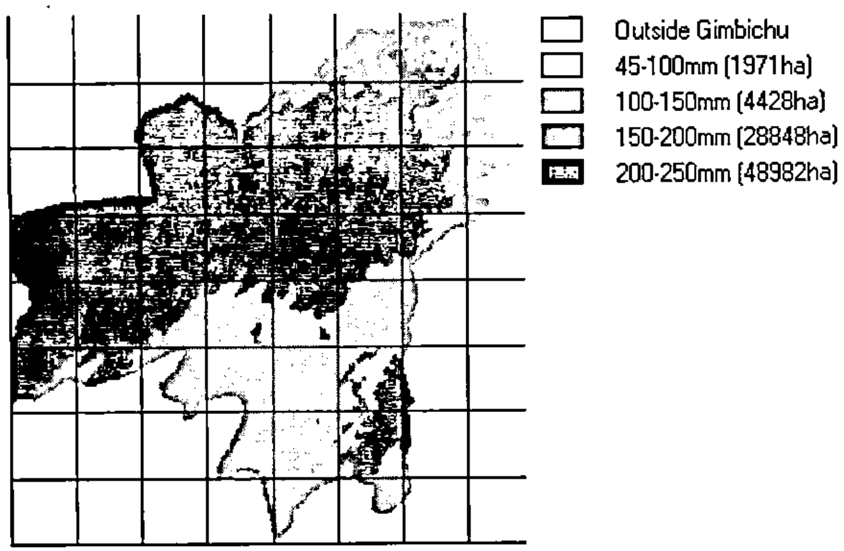


Figure 9. Rainfall distribution of the short rainy season in Gimbichu

Length Growing Period (LGP)

Moisture availability is a very critical component in determining suitability in rain-fed agriculture. A growing period is a part of the year during which the moisture supply from precipitation and soil water storage and the temperature are adequate for crop growth. It may consist of a single transitional moist period or a combination of humid and moist periods or of a year round moist period. As LGP is the required environmental parameter for agricultural production.

A regression equation was developed by FAO (1984) to estimate the mean total annual length of growing period (LGP in days), mean length of the short rains (LGP_1 in days) and mean length of main rainy season (LGP_2 in days) for each of the second order rainfall pattern regions of Ethiopia based on mean annual rainfall (P_a). Gimbichu Woreda is located in the E_1 second order rainfall pattern regions, which has the following regression equation.

$$LGP_a = -66 + 0.017 + 0.24*P_a$$
$$LGP_1 = 12 + 0.505*LGP_a$$
$$LGP_2 = -12 + 0.495*LGP_a$$

Maps of LGPa, LGP1 and LGP2 have been derived employing the above formula and their extent has been also calculated(Figures 10-12).

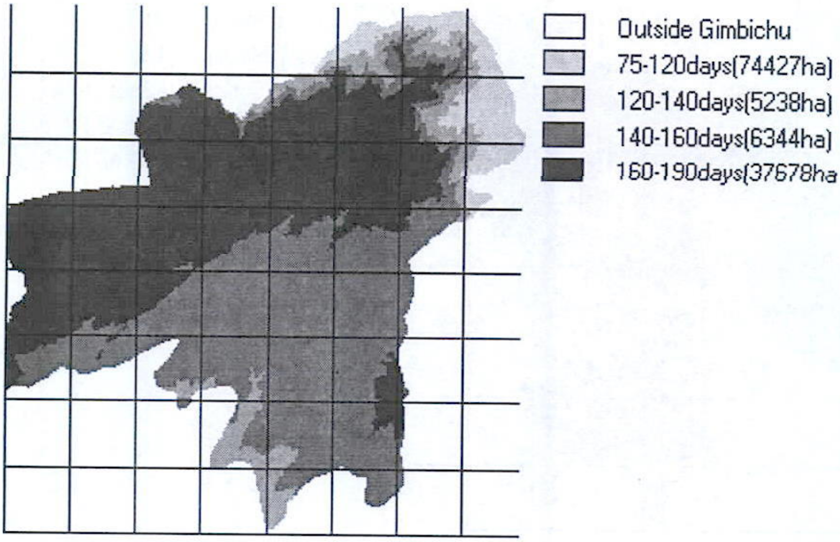


Figure 10. Distribution of length of growing period in Gimbichu

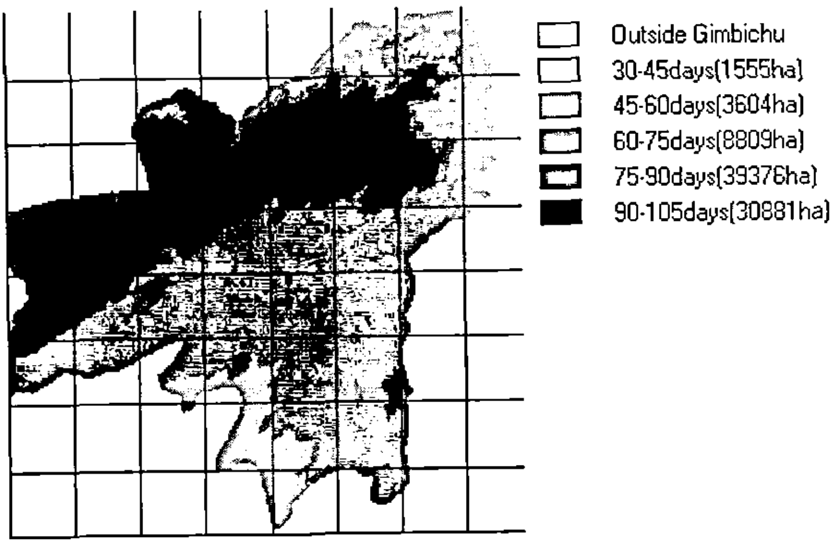


Figure 11. Main season length of growing period in Gimbichu

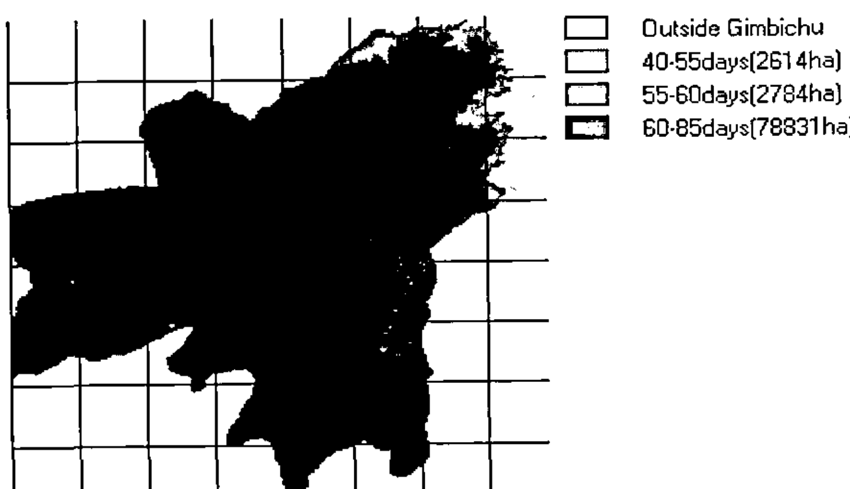


Figure 12. Short rain length of growing period in Gimbichu

Slope is one of the important environmental factor that determine sustainable agricultural production. Slope was calculated from the Digital Elevation Model of the Woreda using IDRISI for Windows. Slope was calculated as the maximum gradient around each pixel from the local slopes in X and Y. Only the neighbors above, below, and to either side of the pixel are accounted for in this procedure. Slopes are output in either decimal degrees or percents. Slope gradients in percents represent the tangent of the angle multiplied by 100. Therefore,,, a 45 degree angle = 100%, while a 90 degree angle will approach an infinite percent. In this study slope has been calculated in per cent.

A surface drainage technology known as broadbed and furrow (BBF) has been found to give significantly better crop yield on dark and clayey Vertisols. The BBF is prepared as an 80cm wide bed with furrows. The technology has been introduced and is being used by several end users after several on-station and on-farm research in various Vertisol areas of the country (Teklu Erkossa et al., 1999). However, the technology is recommended for areas, which have a slope of less than 2% in the highland (greater than 1500m elevation) and for wheat, chickpea, lentil and other crops which are sensitive to waterlogging (Teklu, 2001). As shown in Figure. 4, all parts of Gimbichu have elevation above 1500m. In Gimbichu Woreda also soils which are located with slope of less than 8% are Vertisols. Thus, areas with these characteristics need to be identified on a map and the extent of the area need to be calculated for specified use of the technology.

The slope of Gimbichu Woreda was classified into flat, BBF suitable, medium slope and steep slope(Figure. 13). The area of each of these classes was also calculated and shown in the same figure. Accordingly, it is now possible to assess the extent, where the BBF technology be potentially employed in Gimbichu Woreda.

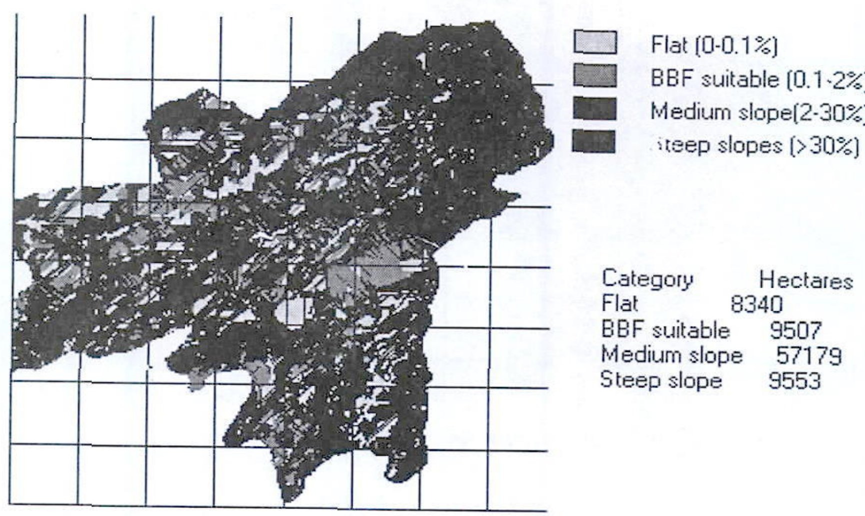


Figure 13. BBF suitable areas in Gimbichu wereda

Conclusion and Recommendations

Geographic Information Systems (GIS) was found to be a very helpful tool to study the diverse environmental and socio-economic condition at woreda level at 50,000 scale. The spatial database generated which comprises the administrative map, population density, average area availabe for a household, DEM, temperature, rainfall (main and short season), LGP (main and short season) and slope are very important databases to study the spatial distribution of natural and manmade phenomena so as to identify priority research areas. It is also very convinient to make spatial recommendation of improved technologies. Hence, at a small scale GIS enables to precisely identify the geographic distribution and extent of potential and suitable areas for growing a particular crop, improved genotype or a technology which has a specified environmental requirement by using the spatial databases which have been derived for important environmental factors and with simulation of other undetermined variables and the requirements or recommendation of the crop or variety.

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APPLICATIONS OF GEOGRAPHICAL INFORMATION SYSTEM (GIS) FOR SOIL RESOURCE STUDY IN ETHIOPIA

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Abstract

Soil survey activities in Ethiopia have started in nineteen sixties as area based development studies. Over the years, quite large amount of soil resource data has been generated and almost all are in paper-based copies in the form of reports and maps. Nevertheless, reliable and up-to-date information on the soils of Ethiopia is unavailable. Moreover, the existing data are not properly organized and stored, managed and shared at will among institutions and stakeholders.

In conventional soil and related land resource studies most of the operations are carried out manually and are time-consuming. The derivation of single factor information and its cartographic presentation from soil studies, or multi-factor information from different thematic layers were even cumbersome. Moreover, in developing countries where administrative boundaries change very often the re-tabulation and spatial re-presentation of land resources by new administrative units is also an arduous task.

GIS provides a very good capability of storing and analyzing large amount of data collected from various fields and sources and produce either maps, tables, reports or both. Tasks, which are difficult and time consuming by conventional methods, are much easier and simpler using GIS. There is much to be done about the available soil resource information of Ethiopia with the advanced capability of GIS. However, it should be noted that the GIS software itself has no inherent answer to any problem, only those of the analyst. It is just an advanced and powerful tool that supports its users in the wide field of spatial data assessment, analyses, planning and decision-making. Consequently, the introduction of GIS in an institution will have its maximum application when there is an institution-wide education and training for the experts in the applications of GIS and not just for few individuals assuming them to carry out the expertise analysis of all the fields. Yet, for the sustainability of the system detailed training on the science and engineering aspect as well as the application techniques should be given to experts working in such as national database center.

INTRODUCTION

Ethiopia is a country with an enormous diversity in climatic conditions, landscapes and water resources. It has a large number of agro-climatic zones, which result from the interaction of different rainfall pattern, soil moisture and temperature regimes. Ethiopia has equally diverse soil resources with widely different productivity and management problems. Highly productive soils can be found but also soils with severe limitations for agriculture, owing to shallow depth, rockiness, salinity, poor drainage or severe nutrient deficiencies.

Owing to this agro-climatic diversity land use systems are equally diversified. Over three-quarter of the population depend on agriculture for their living. In such an economic set-up the importance of the soil condition is eminent. Soil is an important land resource influencing agricultural development prospects and other related development endeavors such as civil engineering. The study and understanding of its properties and distribution over an area has proved effective for the development of soil management plans as well as land use planning.

Reliable and up-to-date information on the soils of Ethiopia is unavailable. Moreover, the existing data are not properly organized and stored, managed and shared at will among institutions and stakeholders. People are not trained on data storage and management. Traditional data storage and handling systems are not only difficult to update but also take so long time to analyze. Nowadays, GIS techniques provide very easy and efficient data storage, retrieval, updating and analysis capability. The spatial and attribute data linking and multi-layer thematic map integration capability of GIS facilitates the generation of customer-oriented products. The unprecedented growth in remote sensing technology over the last few decades has improved the systematic mapping of soils as baseline information. The integrative use of remote sensing with the allied GIS technology provides systematic, authentic and up-to-date information on natural resources on a geographic base.

The objective of this paper is the role GIS could play in storing and analyzing the paper-based soil resource information generated in Ethiopia over the years, not only for safeguarding and updating it, but also enabling a much wider and more efficient use.

Soil Survey in Ethiopia

Soil and climate are the major natural resources determining the agricultural potential of a given area. Soil resource inventories are the basis for agrotechnology transfer and for national or regional planning. A soil survey is a field investigation of the soils of a specific area whereby the kinds of the soils are identified and their extent shown on a map, and an accompanying report describes, defines, classifies, and interprets the soils. Interpretations predict the behavior of the soils under different uses and the soils response to management. Thus, the fundamental purpose of soil survey is to identify the different soil types occurring in a given area, map their extent and spatial distribution, describe their characteristics and predict their suitability to different land uses.

The key element in soil survey is delineation of uniform zones of area (mapping units) defined on the basis of selected characteristics, which depend on the purpose and scale of the survey. The end product of every soil survey is area based report and soil map (spatial data). Description of soil-mapping units includes the land use, topography, geology, and the physical and chemical characteristics of the soils (attributes). The prediction of soil suitability to different land use is made on the basis of the mapping units. Soil survey results are applied for variety of purposes such as agricultural development, engineering and drainage works, and urban and regional planning.

Soil survey activities in Ethiopia have been started in nineteen sixties as area based studies mainly for the identification of agricultural development potentials. These studies vary widely in kind, scale, quality and approach (Table 1 to 3). It was in 1978 that the activities of soil survey have gained a sort of institution by the establishment of a project "Assistance to Land Use Planning" (ALUPP) under the Ministry of Agriculture, which was funded by the United Nations Development Program (UNDP) with the technical assistance of the Food and Agricultural Organization (FAO) of the United Nations.

During its three-phases, the project has conducted soil surveys at a national level as well as area based studies at various scales primarily for the preparation of land use plan and crop suitability evaluation. However, since the decentralization of the Federal Government into Regional States in 1993 the soil survey unit of the Ministry of Agriculture has relinquished its role and apparently no institution is there at a national level for the soil resource studies of the country. The former Institute for Agricultural Research (AIR), now renamed the Ethiopian Agricultural Research Organization (EARO), has carried out soil surveys at some of its research stations and also generated point soil data for many locations. Recently (1999) EARO has reinitiated the survey of research stations by establishing a Soil Survey Unit under the National Soil Research Laboratory.

Table 1. Area Based Soil Resource Studies by Different Organizations

Location	Total Area (km^2)	Scale	Organization	Year
Blue Nile River Basin	204,000	1:100,000	U.S. Dept. of Interior	1963
Wabi Shebelle Survey	180,000	1:1,000,000	ORSTROM, Paris	1973
- Lower Wabi Shebelle and Fafen River	382	1:50,000	ORSTROM, Paris	1973
Awash River Basin Survey	70,000	1:1,000,000	FAO, Rome	1975
- Middle and Lower Awash	*19,570* *5,020*	*1:250,000* *1:100,000*	*FAO, Rome*	*1975*
Southern Rift Valley	55,000	1:1,000,000	Ministry of Overseas Dev., England	1975
Tigrai Rural Development Study	20,000	1:250,000	Hunting T.S.Ltd., England	1976
- Tigrai, North Mekelle	3,400	1:50,000	Hunting T.S.Ltd., England	1976
The Humera Report	10,000	1:1,000,000	TAMS A.D.G. Group, New York	1973
W&E Shores of Lake Abaya and Chamo	8,800	1:100,000	IRAT, Paris	1977
Kobo-Alamata Agri. Dev. Program	800	1:50,000	German Consult, Essen	1976
Gambella Project Feasibility Report	665	1:60,000	TAMS A.D.G., New York	1973
Sothern Gamu-Gofa Project	430	1:60,000	Sogreah, Grenoble, France	1979
Weito Irr. Project Feasibility Study	60	1:50,000	Halcrow-ULG Ltd., England	1982
Dabus Irr. Project Feasibility Study	239	1:50,000	Halcrow-ULG Ltd., England	1982
Meki & Gelana Areas Land Eval. Survey	329	1:50,000	Sogreah, Grenoble, France	1982
Prospects for Irr. Dev. Around Lake Zwai	190	1:50,000	Ministry of Overseas Dev., England	1976

Table 2. Soil Resource Studies by the Assistance to Land Use Planning Project (MoA)

Location	Total Area (km2)	Scale	Year
Geomorphology and Soils of Ethiopia	112.3 million	1:1,000,000	1984
Provisional Soil Association Map of Ethiopia	112.3 million	1:2,000,000	1981
Soils of Borkena Area	3,000	1:50,000	1985
Soils of Bichen Area	3,655	1:50,000	1986
Soils of Hosaina Area	2,296	1:50,000	1987
Physiography and Soils of Hykoch and Butajira; Yerer and Kereyu Awrajas	23,597	1:250,000	1989

Table 3. Soil Resource Studies by the Ministry of Water Resources

Location	Total Area (km2)	Scale	Year
Soils of Baro-Akobo River Basin	75,718	1:250,000	1995
Soils of Omo-Gibe River Basin	77,205	1:250,000	1995
Soils of Abay River Basin	198,508	1:250,000	1998
Soils of Tekeze River Basin	87,773	1:250,000	1998
Soils of Mereb River Basin	23,455	1:250,000	1998

In addition, land resource studies of River Basins of Ethiopia have been carried out in nineteen eighties under the Ministry of Water Resources for the preparation of Integrated Development Master Plan. These studies have covered quite a large part of the country at a relatively larger scale and are computerized.

The above Tables indicate that the soil resource of the whole country has been studied at a scale of 1:2,000,000. In addition, the soil resource assessment under the River Basins Project alone has covered more than 40% of the country at 1:250,000 scale. Taking into consideration the soil surveys carried out by different organization at different times, it is can be concluded that greater proportion of the country has been covered by reconnaissance level surveys.

However, there is a variation in kind, amount and quality of data among the studies. Some of the studies have employed the French soil classification system, while others have employed either FAO/UNESCO or the USDA classification system. Except the studies of the Ministry of Water Resources, most of the findings have not been computerized. Moreover, as different institutions possess these studies, the access to the data is not easy, if not impossible, due to various reasons. Thus, the collection and compilation of the available soil resource information for the better understanding of the soils of Ethiopia is a major task to be carried out.

Relevance of GIS to Soil Resource Study

GIS is a computer-assisted system for the acquisition, storage, analysis and display of geographic data. It is a powerful tool with facilities such as spatial and attribute data storage, cartographic display, map digitizing, database management, geographic and statistical analyses, image processing and decision support system.

In line with this, ALUPP has introduced a computerized land evaluation and data storage system named Geographical Information and Land Evaluation System (GILES). It was designed mainly for automation of land suitability evaluations for different land utilization types by matching the crop environmental requirement database with the physical land resource database, which composed both land unit maps and their attributes (land characteristics and qualities) including the climatic elements. However, neither the system could be advanced nor the computerized data could be preserved, firstly due to lack of trained counterpart to takeover the job and secondly due to absence of concern during decentralization of the Ministry into Regional Bureaus.

As it has been indicated, soil resource data has the nature of both spatial and attribute. Thus, all the paper-based information acquired over the years can be handled by the system. Soil resource data is one of the land resource data required for development planning and it provides very important clue of the environment when used together with other socio-physical resources.

In conventional soil and related land resource studies most of the operations are carried out manually and are time-consuming. One of the simplest, and yet conventionally time consuming, is aerial estimation. To measure and calculate the extent (area) of the polygons on one map (vertisol extent in Ethiopia, for example) was an arduous task. These processes are fast and straight foreword and also automatic using GIS. Moreover, derivation of single or multi-factor soil information, or the study of combined effects of soil and other related data, fore example the effect of slope and land use/vegetation on soil depth and its cartographic presentation require the combination of different overlays and generation of a new map, is even cumbersome. However, the application of GIS can significantly reduce the time of operation of data analysis producing output in a retrievable way (any one can make the same product using a set procedures). The attribute (tabular) and spatial data linking and integrating capability of the system simplifies the generation of new products that can satisfy customer (researcher, farmer, planner, etc.,) needs.

In most developing countries where there is less political stability, administrative boundaries change very often. The change in the boundary is accompanied by a change in the status/extent of land resources. Each administrative unit (Region/State) bases its development plan on the resources offered by the land within its territory. In such cases, the measurement and tabulation of the land resources by conventional methods is an arduous task. Whereas, in the cases where all the data has been computerized, updating of the variant and tabulation accordingly is much easier with GIS.

Like any technology GIS has the science and engineering aspect on one hand and the aspect of application on the other. Technically it is not difficult to set-up a computerized data analysis systems in an organization nowadays. Computers and other hardware have become relatively cheap, while software is easy obtained and installed. However, it should be noted that the GIS software itself has no inherent answer to any problem, only those of the analyst. It is just an advanced and powerful tool which supports its users in the wide field of spatial data assessment, analyses, planning and decision-making. Learning GIS involves learning to think about patterns, space and processes acting in a system. Therefore,,, much attention should be given to the training of the analyst in the applications of the tools rather than to the installation of the system. Consequently, the introduction of GIS in an institution will have its maximum application when there is an institution-wide education and training for the experts on the applications of GIS and not just for few individuals assuming them to carry out the expertise analysis of all the fields. On the other hand, as GIS is a technology, there are advancements in time. Moreover, valuable data generated by different institutions should be collated to a central (national) base for various purposes. Detailed training on the science and engineering aspect as well as the application techniques should be given to experts working in such centers.

Conclusions

For successful soil resource data storage and management and its rational utilization, GIS is of great importance to researchers and planners. There is much to be done about the available soil resource information with the advanced capability of GIS. It is a matter of investment in human resource development both on the application techniques at large and on the science and engineering aspect, and a good supportive management system.

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Application of Geographic Information Systems in Agriculture: A Case Study on Development of a Forecast Model for Strategic Control of Ruminant Liver Fluke Disease in Ethiopia

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Introduction

In the varied agroclimatic zones of Ethiopia (Figure. 1), ruminant livestock are important sources of income for rural communities and one of the nation's major sources of foreign currency earnings from export. The rich potential from the livestock sector is not efficiently exploited, however, due to the presence of several constraints including malnutrition, traditional management and disease (Bekele et al.,1992; Daynes and Graber, 1974). Economic losses of several million dollars per year has been reported due to fasciolosis in terms of mortality, liver condemnations at slaughterhouses, poor weight gain, infertility, reduction in traction power of oxen, and low calf weight at birth (Ngategize, *et al.*, 1993, Njau et al., 1988). Despite the huge economic losses incurred and the widespread distribution of fasciolosis in the country, significant measures have not yet been undertaken to control the disease at the national and regional levels. Routine treatment of clinical illnesses is the norm rather than prevention of infection. More rational prophylactic programs based on local epidemiological information are needed for sound fasciolosis control strategies for Ethiopia.

Geographic Information Systems (GIS) can be used to complement conventional ecological monitoring and modeling techniques, and provide a means to portray complex relationships in the ecology of disease. GIS permits computer database management, storage and manipulation of spatial data, including standard maps, aerial photographs, satellite images, climate zones and ground survey maps. The relative importance of fasciolosis and the abundance of its snail intermediate host in different agro-climatic regions are dynamic features influenced by local climatic, thermal and moisture regime, and soil type. The potential value of careful definition of factors affecting the dynamics of fasciolosis on a geographic basis is considerable. Such information may be particularly useful for policy makers and researchers in making decisions on resource allocation and setting of research priorities and directions.

The purposes of the present study were twofold: 1) to develop a GIS forecast and risk assessment model for fasciolosis in Ethiopia based on physical environmental determinants including moisture and thermal regimes, 2) to validate the model by comparing risk indices and environmental determinants to available survey data

METHODS

A geographic information system for Ethiopia was constructed by exporting physical and selected agro-climatic variables from the Crop Production System Zone (CPSZ) data matrix (IGADD-FAO, 1995) to Atlas GIS 3.0 (a computer software program developed by Environmental System Research Institute, Redlands, CA). Data on climate, terrain, Normalized Difference Vegetation Index (NDVI) and available fasciolosis prevalence were entered in Microsoft Excel 5.0, exported to Atlas GIS 3.0 as separate database layers, and linked to map units in order to permit geo-referenced analysis and display of spatial data. NDVI was obtained from the FAO-NDVI image bank of Africa 1981-1991 (a computer software/database program developed by IGADD-FAO, 1995); composite images are available for each 10-day period and represent an important source of remote sensing data for monitoring the response of vegetation to weather conditions in the region.

Using growing degree day (GDD) values [average annual mean temperature minus 10°C (Armour, 1978) or 16°C (Dinnik and Dinnik, 1963) base temperature for *F. hepatica* and *F. gigantica*, respectively] and water budget analysis using the Penman method for calculating Potential Evapotranspiration (PET), forecast indices were calculated for both species (Yilma and malone, 1998). Annual fasciolosis risk assessment was based on cumulative index values over the year. Average annual mean temperatures of over 23°C were considered to be the maximum threshold temperature limit for *F. hepatica* development based on altitude and known distribution *of F. hepatica* in Ethiopia (Malone, *et al.* 1997). Model validation, which was carried out by computer based statistical computations to assess the relationship of the known distribution of fasciolosis, forecast indices and physical environment determinants from the CPSZ databases.

RESULTS

The forecast model showed that varying degrees of *F. hepatica* risk occur all over Ethiopia except in the northeast and east of the country. High-risk areas were localized in the western humid zone (Figure. 2). *F. gigantica* covers the entire western zone of the country with localized foci in the south and east. High risk of *F. gigantica* infection was indicated only at a small focus along the Blue Nile River. The central and north central highlands were free of *F. gigantica* according to the risk model (Figure. 3). Taken together, the annual forecast of both species encompassed the productive and marginally productive highland plateau, an area, which is inhabited by more than 85% of the human and livestock populations of the country (EMA, 1988).

Results are in fundamental agreement with literature reports on the distribution of fasciolosis in Ethiopia. The infection prevalence data revealed that with the exception of a few foci in the north, east and south arid escarpments, fasciolosis is widespread in Ethiopia, particularly north and west of the great Rift Valley that divides the country into two parts of unequal size. Analysis of results showed that there was a remarkable spatial correlation between the combined forecast indices for *F. hepatica* and *F. gigantica* and the known distribution of fasciolosis in Ethiopia. A comparison employing Spearman's rank order correlation statistics of forecast indices and linear regression test of average NDVI (Figure. 4) versus the ranked prevalence data indicated that a significant relationship ($P<0.05$) exists between them. In addition, annual rainfall ($P<0.01$), readily available soil moisture and average terrain slope were significantly correlated ($P<0.05$) with fasciolosis infection prevalence. A statistically significant ($P<0.05$) linear relationship of surplus water and fasciolosis infection prevalence above 1900 m elevation was also observed. Conversely, a significant inverse correlation ($P<0.05$) was revealed between infection prevalence and PET at elevations below 1950m. In the temperate central highlands (elevation above 2800m) completion of an infection cycle requires more than one year, a distinctive feature of the complex epidemiology of *F. hepatica* transmission in such areas. The altitude range suitable for the occurrence of *F. gigantica* infection was found to vary between 1455m and 2563m. Completion of one infection cycle of *F. gigantica* in a single year, however, was only possible at sites with elevations of less than 1700m.

DISCUSSION AND CONCLUSION

In this study, a GIS for fasciolosis in Ethiopia was created using FAO crop production system zone (CPSZ) databases and a monthly adaptation of a daily climate forecast model. The GIS model clearly delineated the distribution and importance of fasciolosis in the country. In addition, both spatial and statistical analysis results proved the validity of the forecast model in predicting disease risk in different agro-climatic regions of Ethiopia.

The unique biology and life cycle strategy of *Fasciola* make it amenable to effective use of GIS control models in several respects. High environmental sensitivity and the focal nature of transmission typically result in wide variation in infection prevalence in animals in fluke enzootic regions. Climate forecast models for fasciolosis have been developed for use in Europe (Ollerenshaw, 1966) and United States (Malone, *et al*., 1987; Malone *et al*., 1992) based on the effects of annual climatic variation on transmission intensity. As compared to more ephemeral vectors such as mosquitoes, snails tend to be present year after year in same habitat and population generations times are relatively long. However, due to the difference in local vector habitat nidality, considerable annual variation in infection prevalence may occur within and between farm operations. A 100-fold difference in parasite burden in cattle can occur between two years owing to the effect of climate variation alone on snail host population, intramolluscan asexual multiplication, survival of fluke eggs and persistence of metacercariae on pasture (Zukowski *et al*.,1991). Similar variation in prevalence between farms in the same region may result from site-specific differences in fasciolosis risk associated with soils prone to snail habitat In the present paper, GIS was used to provide a means of incorporating such variables into a single model.

F. hepatica was shown to be the most important fluke species in Ethiopian livestock, with a distribution over three-quarter of the nation. The finding that surplus water significantly influenced infection prevalence due to *F. hepatica* at altitudes above 1900 m is consistent with previous work on geographic patterns of liver fluke species distribution in Ethiopia (Graber, 1978); Bergeon and Laurent, 1970). At extreme high (>1800m) and low (<1200m) elevations, pure *F. hepatica* and *F.gigantica*, respectively, characterize the prevalence scenario while at intermediate altitude zones (1200-1800m) mixed infections are encountered, with domination of one or the other species towards their favored altitude gradients. It was found in this study that risk of *F. gigantica* might exist up to 2600m of elevation although an effective transmission cycle in a single year can only be maintained at elevations below 1700 m. The effects of terrain slope on infection prevalence were presumably indirect and reflect the habitat's water logging potential and presence of surplus water in grazing fields. The forecast model also indicated that prevailing climate in the central and north-central highlands is unsuitable for *F. gigantica* and that this species is distributed mainly in the western humid zone of the country, an area that encompasses covering approximately one-fourth of the nation (Figure. 3).

The fasciolosis prevalence data used in model validation in the present study offered the best databases available. However, there is a need for standardization of data collection and development of computerized spatial databases that can be regularly updated with information relevant to the disease and the vector. Such databases can be incorporated into improved GIS models. Significant correlations were shown between fasciolosis infection prevalence and climate features, terrain and NDVI data. Climate risk data can be included in a GIS as separate layers on long-term climate pattern, maps of annual values or as surrogates of climate such as NDVI. Rogers and Randolph (1993) showed that distribution of *Tsetse* vectors of trypanosomosis and tick vectors of theileriosis could be successfully characterized by supplementing long-term climate average records with monthly NDVI values derived from NOAA environmental satellite imagery. NDVI was strongly correlated with long-term average rainfall values (Figure. 5) and saturation deficit (humidity), and with important biological variables of vector population density, mortality rate and size.

Distinct regional differences in *F. hepatica* seasonal cercariae-shedding and consequently in fluke transmission patterns, and need for treatment, were evident Hay may serves as a vehicle for disseminating fasciolosis to areas distant from endemic foci in the highlands. This partly explains the relatively high prevalence of the disease in some warmer and drier zones of the country. Local crowding of animals along banks of streams and ponds during the dry season when nutritional conditions are generally compromised provides an important dynamic for infection transmission. Epidemiological characterization of the disease at regional levels thus requires knowledge of husbandry practices in addition to the specific local thermal and moisture conditions necessary for transmission of *Fasciola*.

RECOMMENDATIONS

Chemotherapy

On the basis of the results obtained from the present studies on forecast and fasciolosis transmission patterns in Ethiopia, and as per the criteria set by FAO (1994), the authors recommend two obligatory treatments (preventive and preventive- curative) per year for all regions in the country where fasciolosis risk were predicted plus an optional curative treatment for western and southern regions:

Western Ethiopia - A preventive treatment in February, an optional curative treatment in August and a preventive-curative treatment in October.

Southern Ethiopia - A preventive treatment in February, an optional curative treatment in July and a preventive-curative treatment in October.

North-Central Ethiopia - A preventive treatment in April and a preventive-curative treatment in October

Central Ethiopia - A preventive treatment in February and a preventive-curative treatment in September

It is anticipated that strict adherence to the recommended scheme will effectively control the disease caused by both fluke species. The first treatment is prophylactic and is administered towards the end of the dry season when development of free-living stages and intra-lymneid phases of *Fasciola* are retarded and reproduction and activity of snails is minimum. The optional summer treatment is recommended in high-risk years and when outbreaks of disease occur. The last obligatory treatment removes the bile duct forms prior to the commencement of the dry season. For economic reasons or otherwise, if only one treatment may be affordable, the second obligatory strategic treatment is the best choice in all study areas.

Future studies

I. Critical field evaluations of the validity of these regional strategic chemotherapeutic control schemes and assessment of the associated economic benefits are needed.

II. The present study indicates that GIS is an important tool in predicting fasciolosis risk in Ethiopia and in designing sound control strategy. The model makes it possible to develop fasciolosis risk indices by extrapolation to all CPSZ map units in Ethiopia.

III. Results of studies reported here for *Fasciola* suggest that it is possible, using much the same data, to develop similar GIS forecast models for other vector borne diseases of economic and public health importance in the region, including such environmentally sensitive diseases as schistosomosis, trypanosomosis, myiosis, rift-valley fever, african horse sickness and tick-borne diseases.

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Application of Geographic Information Systems (GIS) in Plant Pathology

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Abstract

Plant disease assessment is fundamental to epidemiological studies and to the selection of appropriate disease management practices. Standard area diagrams have been traditionally used to facilitate assessment of plant diseases. However, the conventional assessment techniques and classic interpretation of the measurements have not fully enabled researchers to make objective quantification of disease symptoms. And thus the need for refinement of our techniques is crucial to make more meaningful assessment of plant diseases.

The now available geographic information system (GIS) is used to integrate spatial and character data coming from different sources in a computer. For instance, data originated from various sources such as remote sensing, aerial photography, videography, digital image analysis, satellite imagery and radiometry, global positioning system (GPS), and crop monitoring could be analyzed and integrated using GIS softwares. These softwares can provide overlays and geographic analyses of multiple mapped layers, representing disease intensities and other related variables of interest.

GIS can also provide possibilities of geo-referenced assessment of plant diseases, determining the spatial pattern of crop diseases over a larger area, identifying hot-spot areas for plant diseases, determining spatial recommendation domain for improved disease management technologies, and/or forecasting disease outbreaks.

The objectives of this manuscript are Therefore,, to indicate the limitations of the conventional techniques and to see the possibilities of using GIS in plant pathological studies.

Introduction

Diseases are among the major biotic stresses in crop production systems. Although much improvement has been done in the past with respect to the management of crop diseases, they still remain to be among the major problems in crop production; and the need for the refinement of the assessment techniques and management practices becomes more evident than ever before.

Assessment of plant diseases and the subsequent interpretation of measurements are crucial for most plant pathological studies.

According to Star and Estes (1990), "GIS is an information system that is designed to work with data referenced by spatial or geographic coordinates. In other words, a GIS is both a database system with specific capabilities for spatially-referenced data, as well as a set of operations for working with the data". GIS software can provide for overlays and geographic analyses of multiple mapped layers, representing the spatial patterns of crop diseases and other variables of interest in an agricultural system. GIS is the principal technology used to integrate spatial data with other data of interest in a computer which will be then processed and interpreted to enable disease management adjustments.

This manuscript therefore, focuses on the merits of GIS over the conventional techniques in assessing plant diseases, determining spatial pattern of crop diseases, identifying hot-spot areas, determining the spatial recommendation domain for plant disease control technologies, and in forecasting plant disease outbreaks.

COMPARISON BETWEEN CONVENTIONAL TECHNIQUES AND GIS

Before we conclude that the use of the now available GIS is more advantageous than the conventional one in plant pathological studies, it is customary to examine the merits and demerits of both systems.

Quantification of disease severity based on symptom expression is fundamental to epidemic analysis, and is traditionally carried out with the aid of standard area diagrams (James, 1971). Estimates associated with standard area diagrams are known to be subjective and liable to both rater and environmental errors, and thus for detailed investigations visual assessment based on pictorial diagrams is inadequate (Gaunt, 1995). Pictorial diagrams are mostly black and white in color and have fixed levels of disease severity percentages (e.g. 5, 10, 15, 20, …, 100%) in uniform patterns and a difficulty arises when raters are required to compare actual diseased plant parts that have different patterns, colors, and size of spots to a fixed representation of disease on a diagram (Nutter and Schultz, 1995). Individuals differ in their sensitivity to different wavelengths in the visible spectrum and this will affect their perception of visual stimuli and subsequently their ability to discriminate among disease levels (Nutter and Schultz, 1995; Nilsson, 1995).

In addition, illumination unsuitable in color and intensity, background color, raters' tiredness and lack of concentration, and visual interference are among the major factors influencing visual assessment (Nilsson, 1995).

One other problem of the conventional method, in spatial studies and in other studies involving large-scale surveys, is the difficulty of verifying location and repeating observation of established sample points (Gaunt, 1995). Global positioning system (GPS) and geographic information systems (GIS) are ideally suited to such investigations (Birrell *et al*., 1993; Loss & Callihan, 1993).

Input data collection

Remote sensing and image analysis

Remote sensing refers to methods of measuring an object and interpreting the measurements without physical contact between the measuring device and the object.

According to Nilsson (1995), human vision is unique and individuals may differ in their light or color perception, and Hence, variations among individual raters remain an important source of error in crop disease assessment based on color, shape, size, and pattern of factors such as disease symptoms. However, such symptoms can be quantified accurately, precisely and rapidly using remote sensing and image analysis. All the collected data may be integrated by a remote sensing instrument and then the data can be computerized, reduced or enhanced before they are analyzed and evaluated using GIS softwares.

At a larger scale, imaging and remote sensing by infrared reflectance and radiothermometry has been taken up slowly by epidemiologists. The techniques are readily applicable to both disease and yield assessments. Instruments and methods are now available which make the analysis routine (Gaunt, 1995).

Aerial photography and photogrammetry

Aerial photography using both conventional and infrared films was frequently used in the Second World War for camouflage detection and this experience became valuable after the war in studies of vegetation stresses and diseases in agriculture and forestry (Nilsson, 1995). For instance, Colwell (1956) demonstrated the potential of aerial photography to detect and quantify diseases such as cereal rusts and viral diseases.

Aerial photography is a valuable tool in selecting the most suitable area for field plot experiments because photography and stereo photography permit photogrammetric measurements of the size and architecture of healthy and diseased plants.

Zhinsky *et al.* (1985) recommended negative processing of a color infrared film to achieve better color distinction. The early films were mostly analyzed using densitometry, but recently more advanced image processing and spectral analysis, including enhancement, have facilitated evaluation (Nilsson, 1995).

Air photos such as the USGS's orthophotos are very common input layers to a GIS. Air photos are usually black and white and are produced from scanning or accessed from CD-ROM.

Satellite imagery and aerial radiometry

Satellite images are among the most common input layer to a GIS. Satellites such as LANDSAT and SPOT have provided an enormous amount of valuable remote sensing data for agriculture and forestry, including data on various kinds of stresses, diseases and pests (Nilsson, 1995). However, the high altitude systems are of value for surveillance over large areas but their geometric resolution is insufficient for practical use in phytopathometry; moreover, satellite measurements are often impeded by cloud cover and the period from measurement until the data are available for analysis is too long (Nilsson, 1995).

Aerial radiometry has been used frequently in agriculture and forestry in many countries for surveillance of stress, diseases and pests (Jackson, 1986). An advantage over the satellite measurements is that the most suitable time and height can be selected and coordinated with conventional ground assessments (Nilsson, 1995). In recent years, airborne imaging radiometers have also been used in the USA (Wessman, 1990).

Videography

According to Nilsson (1995), video cameras have been used for remote sensing for more than a decade; however, the use of aerial videography has extended during the past few years. Exposure quality can be tested and via various image processing functions, such as those of disease symptoms, can be enhanced, selected, and examined in the field. A great advantage over IR films is that the video images are instantly accessible for evaluation.

A new advancement for close range studies is the Keyence Portable Fibre Optic Microscope VH-6100 (Keyence Corp., Osaka, Japan). The fibre optic probe can be fitted with various microscope lenses. The images are displayed on a color screen and can be stored on floppy disks. A similar instrument is the Finlay Portable TV-microscope (Finlay Microvision Co. Ltd, Southam, Warwickshire, UK).

Digital image analysis

Digital image analysis has become an important tool for obtaining information at all levels of in biological research. It is used in the analysis of satellite images, aerial photography, and videographs, and macroscopic and microscopic images, as well as in reconstruction of 3D-images from confocal microscopy, acoustic images, nuclear magnetic resonance images (NMRI), and electron micrographs.

Image processing may comprise a reduction of the total information to a manageable amount, enhancement of edges and other detail, geometric corrections, etc. after which analyses can be performed, such as measurements of size and area, identification of shape and pattern, or counting specific details. Digitized images can be added or subtracted: this allows the calculation and display of differences between two images. One image can be divided by another, pixel for pixel in order to determine ratios (Nilsson, 1995).

One great advantage of digital image processing is that we can display particular areas in specific or contrast color and thus facilitate visual interpretation and interactive analysis by the operator and the computer. Contrast-enhanced images are also an excellent tool in lectures and demonstrations in plant pathology (Nilsson, 1995).

Nilsson (1995) also concluded that digital image analysis at macro-and microscopic levels is attracting growing interest, and its importance and potential in plant pathology is growing with the technical improvements in the quality of cameras and capacity of computer hardware and softwares.

Global positioning system (GPS)

GPS is used to determine the precise location (latitude and longitude) based on radio signals from satellites. Here, a more exact location of disease appearance could be recorded using the integral GPS receiver and the control program can be alerted depending on the information collected. Information on status of diseases and economic threshold analysis can be done and the type of control measure to be used can be determined. The data can be collected and combined in onboard computers to estimate the spatial distribution of crop diseases in a given area.

According to Gaunt (1995) GPS technology can be used successfully to check or guide sampling patterns in large fields (especially of tall crops), to verify the accurate location of samples, to provide ground truth in conjunction with remote sensing of plant diseases, and to find predetermined sample sites in difficult terrain, such as in forests. It also provides excellent data capture methods that can simplify subsequent data analysis.

Crop monitoring

Crop monitoring refers to periodic ground-level inspection of the crop for the occurrence of diseases. Monitoring often involves assessing the severity or incidence of diseases based on expression of symptoms. The epidemiology of diseases can also be studied during crop monitoring. The data or information obtained through crop monitoring for disease appearance may be processed and analyzed using GIS software in order to come up with more meaningful conclusions.

Data analysis and interpretation of results

The input data collected through remote sensing, aerial photography, satellite and aerial radiometry, videography, digital image analysis, global positioning system, and/or crop monitoring will be analyzed using appropriate GIS software in order to meet our objectives.

The interpretation depends on our objectives, the type and quality of data collected, and the type of GIS software used. Then the interpretation may come in the form of geo-referenced quantification of disease symptoms, determining the spatial pattern of crop diseases over a larger area, identifying hot-spot areas for the occurrence of a disease, determining spatial recommendation domain for improved disease management technologies, and/or forecasting disease outbreaks.

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GIS-SUPPORTED ASSESSMENT OF LAND DEGRADATION: THE CASE OF THE CENTRAL CORRIDORS IN ABOTE, KUYU AND DEGEM WOREDAS (NORTH SHEWA ZONE, OROMIA REGION)

Assefa Guchie
GTZ-LUPO

STUDY OBJECTIVES

- Assess the extent of land degradation;
- Avail crucial data for assessment of land degradation (*for intermediate land resource management planning);*
- Investigate the major causes of degradation;
- Provide recommendations.

THE STUDY AREA

Scope

- Two sub-water watersheds (corridors) *location map*) in North Shewa :
  - Northern sub-area
  - Southern sub-area
- Land Size: 28x14 = 392 km^2.
- Population size = 60,240 persons (21.0 of the 3 Woredas population)
- Average population density = 153 p/km^2
- Per annum density growth = 3.3 %

Basic GIS data used for Analysis

- Digital topographic data:
  - Contour lines;
  - Woreda administrative boundary map;
  - Kebele Boundaries;
  - Rivers;
  - Roads.

- Satellite image (SPOT Pan, of 1997);
- 1994 population census;

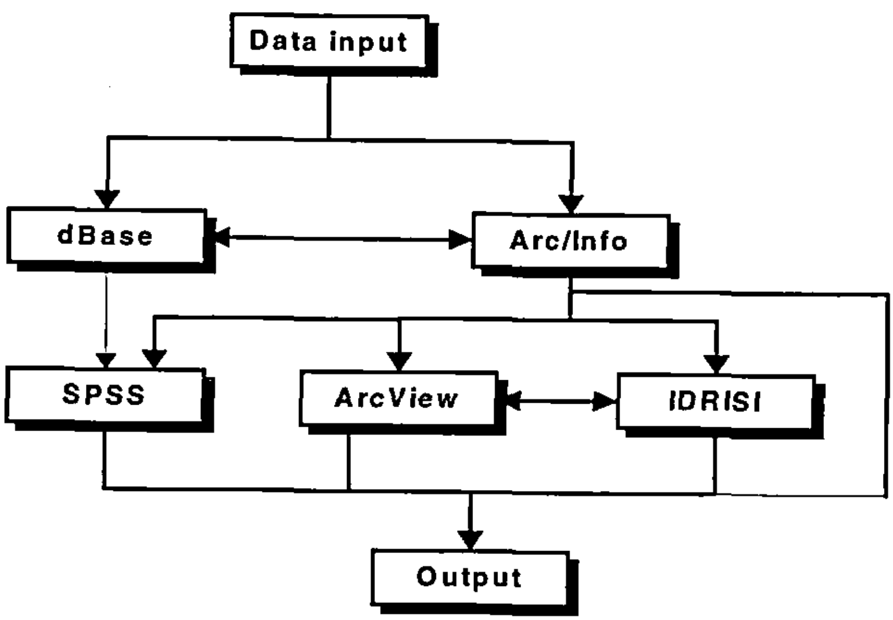
Resolution for raster data analysis

- Woreda = 50m x 50m;
- Study Corridor = 25m x25m;

SPOT Pan Data:

- Ground truthing / field survey;
- Classification and definition of land use/cover units
- Visual interpretation of the spot data was done;
- Digitizing /data input, and editing;
- Data verification;
- Data integration;
- Analysis;
- Reporting, presentation, and documentation.

General Approaches and Procedures of Processing



DEFINITION OF LAND DEGRADATION

Degrade (*simple dictionary meaning*)

- To cause something to become worse in quality or, to make something become less complex in structure;
- Process by which the quality and physical condition of an object gets impoverished

Land Degradation (FAO)

- Consists of deterioration of the biological potential of the land due to human activities and natural factors. It is something that everybody agrees is bad.
- Is purely a dis-investment in a stock of land in which more value is being extracted from it than is being replaced either by man or nature.

MAJOR RESULTS

Agroecological Indicators

Table1. Altitude ranges (as derived from DEM):

Altitude Range	Northern sub-area		Southern sub-area		Both areas		
	Area	%	Area	%	Area	%	Cum.%
1,800 – 2,000	-	-	53.8	0.3	53.8	0.2	0.2
2,001 – 2,500	12,830.1	65.5	4,729.3	24.1	17,559.4	44.8	45.0
2,501 – 3,000	5,891.9	30.1	13,521.5	69.0	19,413.4	49.5	94.5
3,001 – 3,300	864.5	4.4	1,294.9	6.6	2,159.4	5.5	100.0
Total	19,586.5	100.0	19,599.5	100.0	39,186.0	100.0	-

- The two watershed areas fall within the Weyna Dega to High Dega altitudinal agroecology;
- Generally: Weyina Dega to High Dega altitudinal agroecology;

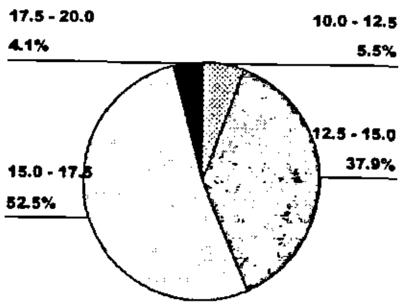
Thermal Zones

- The amount of heat available for plant growth and development during the growing period, usually defined by the mean daily temperature during the growing period (B. Debele; 1999).
- Calculated as $T_{gp} = 30.2 - 0.0059\ H$, where H a.s.l. in meters, i.e. DEM image layer.

Table 2. Thermal Zone and Respective Land Size Coverage

Thermal zone,°C	Northern sub-area		Southern sub area		Both areas		
	Area	%	Area	%	Area	%	Cum.%
10.0 - 12.5	862.9	4.4	1,290.0	6.6	2,152.9	5.5	5.5
12.5 - 15.0	4,720.2	24.1	10,117.8	51.6	14,838.0	37.9	43.4
15.0 - 17.5	13,189.4	67.3	7,392.0	37.7	20,581.4	52.5	95.9
17.5 - 20.0	814.0	4.2	799.6	4.1	1,613.6	4.1	100
Total	19,586.5	100.0	19,599.4	100.0	39,185.9	100.0	-

Figure 1. Thermal Zone and Land area coverage in Northern and Southern Watersheds



- Generally, 90.4 % of the areas in both watershed areas have a mean temperature ranging between 12.5 - 17.5 ^{0}C.
- The Dega to Weyina Dega zones (52.5%) mean temperature temperature ranges of 15.0 - 17.5 ^{0}C.
- Suitable temperature for barley (12.5 - 17.5 ^{0}C).

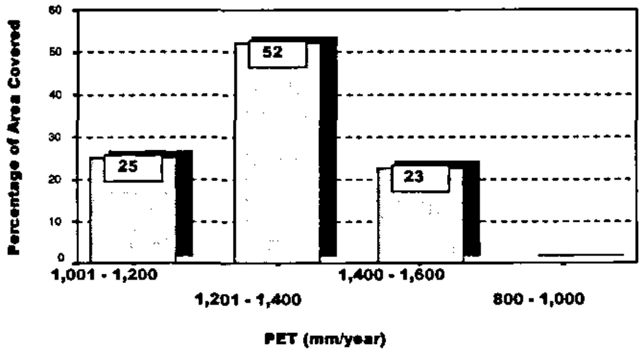
Annual Potential Evapotranspiration

- Indicated the potential soil moisture content, given certain range of temperature and rainfall during the growing period.
- Computed as PET(mm/year) = 2389.0 - 0.4341 H, where, H is a.s.l. in meters, or DEM image layer ⇨ Pauw (1988) formula.

Table 3.Annual Potential evapotranspiration in Northern and Southern sub-areas

PET (mm/year)	Northern		Southern		Both areas		
	Area	%	Area	%	Area	%	Cum. %
800 - 1,000	0.6	0.0	56.9	0.3	57.5	0.1	0.1
1,001 - 1,200	3,802.0	19.4	6,021.5	30.7	9,823.5	25.1	25.2
1,201 - 1,400	8,768.3	44.8	11,638.7	59.4	20,407.0	52.1	77.3
1,400 - 1,600	7,015.6	35.8	1,882.3	9.6	8,897.9	22.7	100.
Total	19,586.5	100.0	19,599.4	100.0	39,185.9	100.0	-

Figure 2. Annual Potential evapotranspiration in Northern and Southern Watershed



Length of Growing Period

- Growing period is a part of the year during which the moisture supply from precipitation and soil water storage and the temperature are adequate for crop growth (UNDP and FAO).
- The length of growing period is the time in the days between the beginning and the end of the growing period, less the length of the dormant period.
- Calculated as LGP1 = 20 +0.331 LGPa, where, LGPa is the mean annual total length of growing period, LGP1 is first mean LGP.

Table 4 Length of Growing Period in Southern sub-area

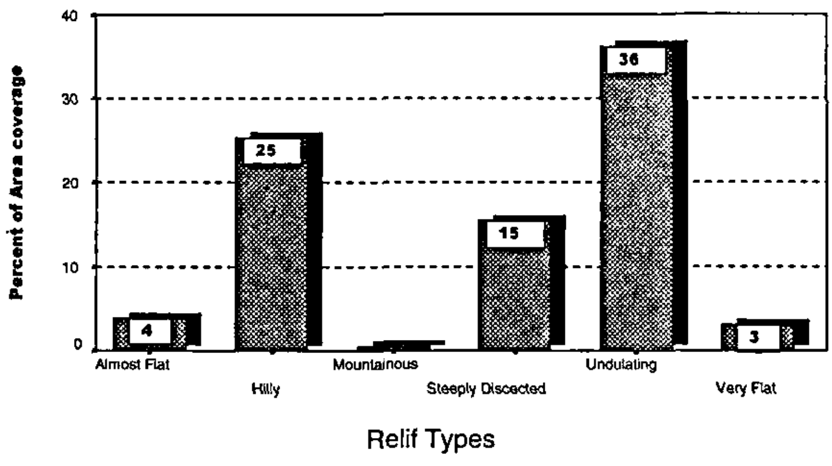
LGP in days	Southern area	
	Area	%
151 - 180	3,167.2	16.2
181 - 210	10,787.3	55.0
211 - 240	4,178.1	21.3
241 -270	1,466.8	7.5
Total	19,599.4	100.0

Relief Characteristics

Table 5. Slope gradient and relief types of northern sub-area (Area coverage in hectare)

No	Slope range	Relief type	Area coverage	% of area	Cumu. %
1	< 1.0	Very flat	581.5	3.0	3.0
2	1.0 – 1.9	Almost flat	757.5	3.9	6.9
3	2.0 – 6.9	Undulating	7,070.2	36.1	43.0
4	7.0 – 12.9	Rolling	4,956.2	25.3	68.3
5	13.0 – 19.0	Hilly	3,022.4	15.4	83.7
6	20.0 – 54.9	Steeply dissected	3,109.1	15.8	99.5
7	55.0 and above	Mountainous	89.6	0.5	100.0
Total			19,586.5	100.0	-

Figure 3. Slope gradient and relief types of northern watershed (Area coverage in hectare)



- Inundable areas (very falt) = 3.0 %;
- Stable areas = 68. %;

Land use/land cover

Land use /land cover classification (12 types):

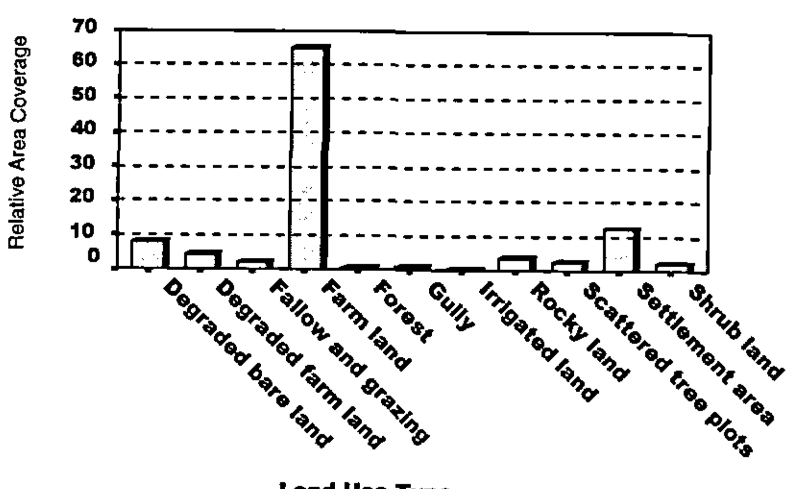
- Farm (cultivated) land;
- Grazing and fallow land;
- Degraded bare land;
- Degraded farm land;
- Degraded farm land;

- Rocky land;
- Gully;
- Scattered tree plots;
- Shrub land;
- Settlement area;
- Irrigated land;
- Forest area; and eroded land.

Tables 5. Distribution of land use in northern watershed (area in hectares)

Code	Land use component	Area	%
1	Farm land	12,687.2	64.8
2	Fallow and grazing	351.3	1.8
3	Degraded bare land	1,503.8	7.7
4	Degraded farm land	853.7	4.4
5	Rocky land	692.2	3.5
6	Gully	122.2	0.6
7	Scattered tree plots	464.4	2.4
8	Shrub land	409.4	2.1
9	Settlement area	2,359.5	12.0
10	Irrigated land	29.9	0.2
11	Forest	113.0	0.5
Total		19,586.5	100.0

Figure 4. Percentage distribution of land use components in northern watershed



- Cultivated land in general covers close to 70.0 %;
- Intensive cultivation through slope 7.0 - 20 was observed.
- Stone bunds failed to meet the purpose they are constructed for (e.g., Ejere area);

- Grazing is below 2.0 % of the total land use/cover and a serious problem in thenorth;
- Irrigation is less practiced in the north due to:
- limited number and discharge rates of perennial rivers;
- heavy damages happened to the banks of existing perennial rivers.
- Fallow land seldom exists;

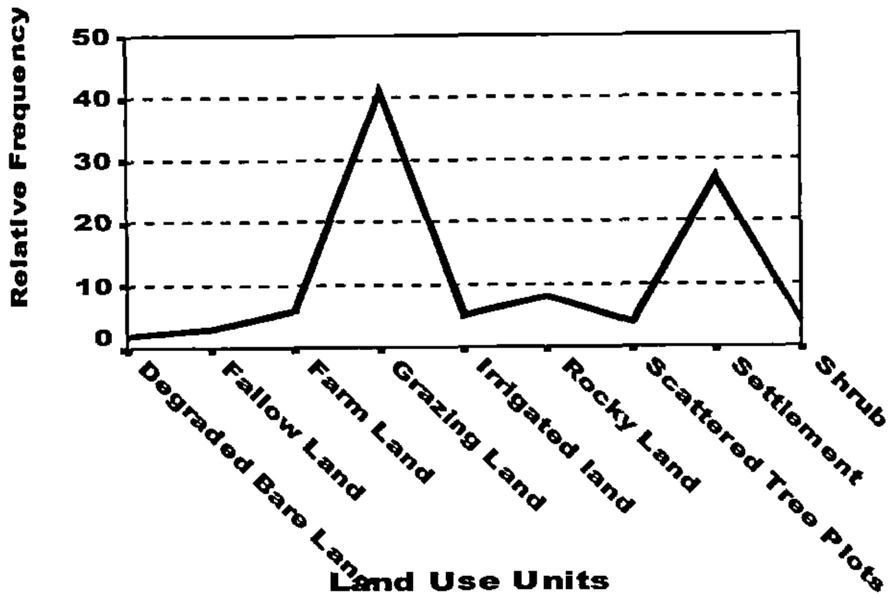


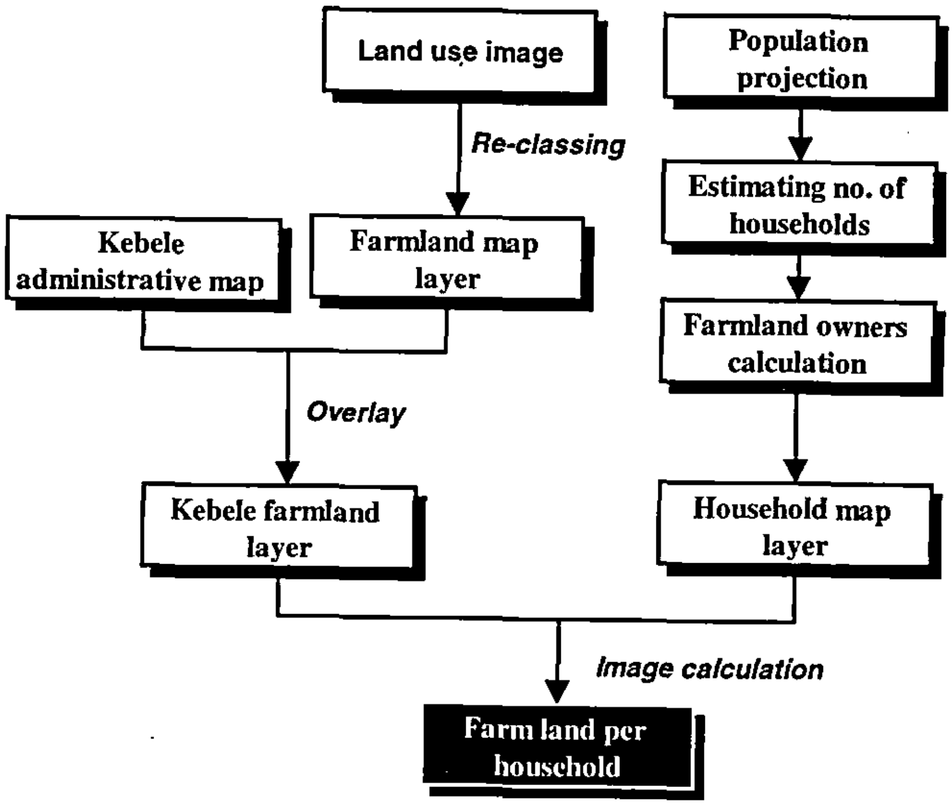
Figure 5. Frequency distribution of land use/cover units in the study area, (1999)

Assessment of Farm Land Shortage

Objective

- Is sound relation among population density, relative farmland shortage, pressure on land resource and land degradation?

Assessment (Modeling) Methodology

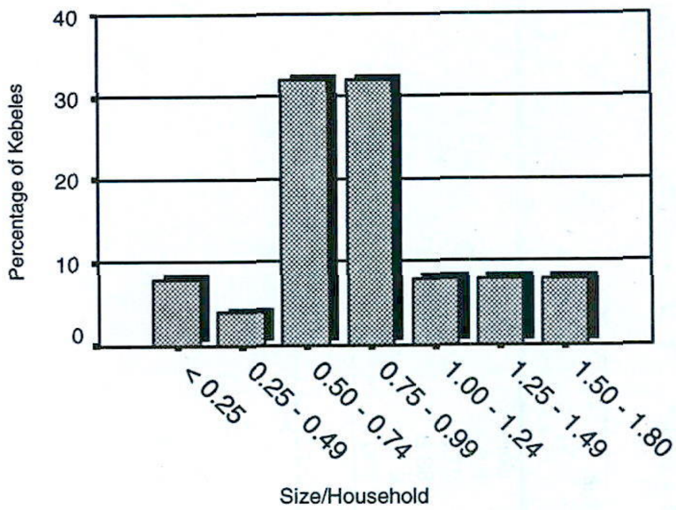


Farm land size distribution per farming household

Table 6. Distribution of Farmland size per farming household by number of Kebeles (size/household in hectare)

No.	Farmland size	Number of Kebeles	%
1	< 0.25	2	8.0
2	0.25 – 0.49	1	4.0
3	0.50 – 0.74	8	32.0
4	0.75 – 0.99	8	32.0
5	1.00 – 1.24	2	8.0
6	1.25 – 1.49	2	8.0
7	1.50 – 1.80	2	8.0
Total		25	100.0

Figure 6. Farm Land Shortage by number of Kebeles and Size of Net Holding



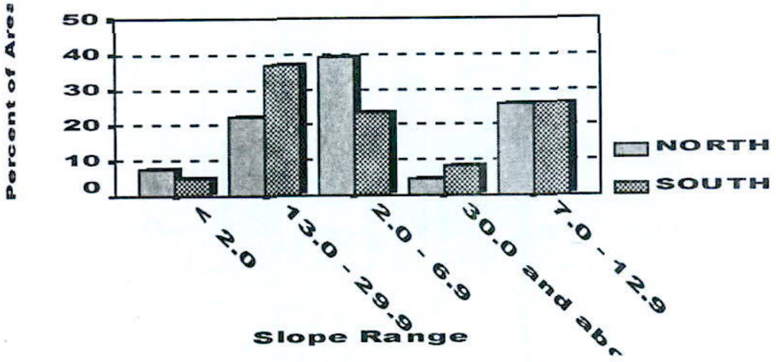
- Average size per a household = 0.74 hectare
- In two-thirds of the Kebeles, average size of holding is between 0.5 - 1.00 hectares, low for average HH size of 6.0 persons/HHH.
- Serious shortage is in high population density low land areas;
- Less problematic in high land Kebeles of:
- Kesi;
- Ali Doro (not village);
- Yaya Dede;
- Jiru and Bishan Diima.
- Shortage of farm has had a strong impact on the expansions/ 'invasion' of hillsides and other marginal land units.

Distribution Of Farm Land at Different Slope Gradients

Table 7. Distribution of farm land at different slope gradients in both Watershed areas (Area in hectare)

Slope ranges (%)	Northern		Southern		Both watershed areas		
	Area	%	Area	%	Area	%	Cum. %
< 2.0	1,039.06	7.6	701.44	5.0	1,740.5	6.3	6.3
2.0 – 6.9	5,343.32	39.3	3,302.66	23.4	8,645.98	31.2	37.5
7.0 – 12.9	3,531.54	26.0	3,688.20	26.1	7,219.74	26.1	63.6
13.0 – 29.9	3,039.99	22.4	5,249.99	37.2	8,289.98	29.9	93.5
≥30.0	629.07	4.7	1,175.26	8.3	1,804.33	6.5	100.0
Total	13,582.98	100.0	14,117.55	100.0	27,700.53	100.0	-

Figure 7 Percentage distribution of farmland at different slope classes



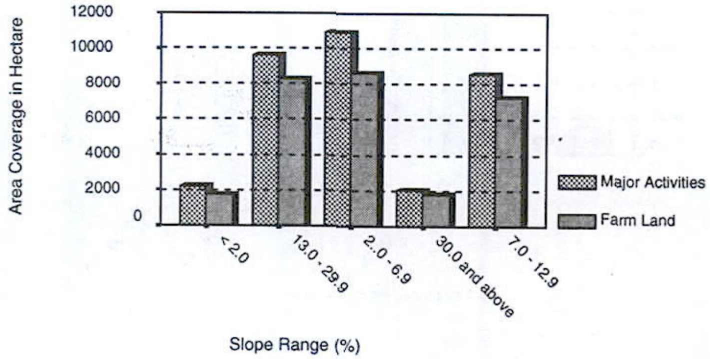
Spatial Distribution of Major Human Activities

- Major activities:
- Degraded farm land;
- Non-degraded farm land'
- Grazing and fallow;
- Settlement areas;
- Irrigated land.
- The lion's share (83.0%) is cultivated land;
- Its proportion constantly increases at all levels of slope;
- Average rate of increment has been calculated to be 2.6%;
- The impact had extensively been stretching over the relatively stable areas as big gullies are formed due to land erosivity and surface run-off;

Table.8. Distribution major Human Activities at Different Slope Ranges in Kuyu, Abote and Degem, (Area in hectare)

Slope ranges (%)	Major Activities		Farm Land	
	Area	%	Area	Overall share (%)
< 2.0	2,206.72	6.6	1,740.50	78.9
2.0 – 6.9	10,915.65	32.7	8,645.98	79.2
7.0 – 12.9	8,603.61	25.8	7,219.74	83.9
13.0 – 29.9	9,629.76	28.8	8,289.98	86.1
30.0 and above	2,019.19	6.1	1,804.33	89.4
Total	33,374.93	100.1	27,700.53	83.0

Figure. 8.Comparison of Major Human Activities and Farm Land at Different Slope Ranges

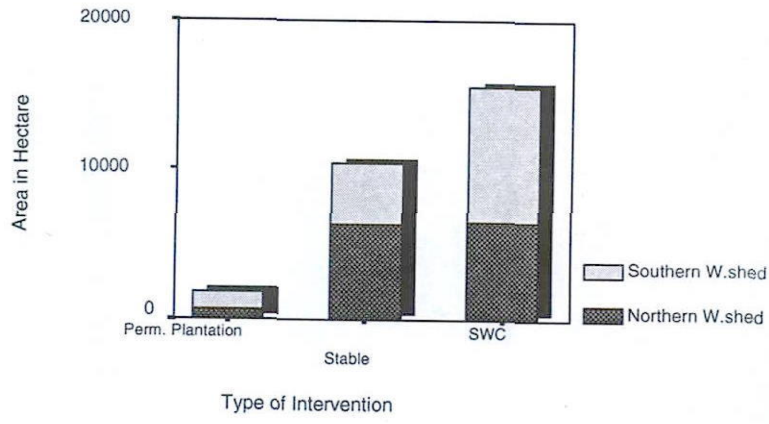


Identification of Problem Areas for Potential Intervention

Table 9. Size of areas Identified for Potential Intervention in Northern and Southern Watersheds Areas (areas in hectare).

Slope Range (%)	Type of intervention	Northern area		Southern area		Both areas	
		Area	%	Area	%	Area	%
0.0 - 6.9	Stable	6,382.4	47.0	4,004.1	28.4	10,386.5	37.5
7.0 - 29.9	SWC	6,571.5	48.4	8,938.2	63.3	15,509.7	56.0
≥30.0	Permanent plantation	629.1	4.6	1,175.3	8.3	1,804.4	6.5
Total		13,583.0	100.0	14,117.6	100.0	27,700.6	100.0

Figure 9 Proportion of Cultivated Areas Proposed for Intervention



Spatial distribution of these areas are clearly displayed on maps

Frameworks/Policy Considerations

- Strengthen community participation and gradual changes of attitudes;
- Strong institutional concern and continued commitment must be in place for abating land resource degradation and creating sustainable land use systems;
- Appropriate mechanisms need to be developed in order to improve soil fertilities and increase the productivity of land on sustainable basis.
- In order to resolve the growing conflict between crop cultivation and pasture, farmers' attitude of keeping more stocks of cattle will have to be changed;
- Farmers should decide on their own priorities: which animals to retain and for what purpose to;
- Natural resources, programs focusing on controlling population growth have to be introduced;
- The land tenure policy should build a sense of ownership for the user communities if sustainable land resource management and rehabilitation of the resources is to in place;
- Special arrangements will be needed for resolving potential conflict of interests that may arise due to land rehabilitation measures;

APPLICATION OF GIS IN RIVER BASIN MASTER PLAN STUDIES

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Abstract

The Ethiopian Highlands are divided into two broad groups by the rift system running from southeastern Africa to the Arabian Peninsula. These are the south western and the south eastern highlands that are the Nile-Tekeze and the Wabishebele-Genale river basins systems respectively. Several major rivers form the nation's twelve river basin areas. The rivers that form the Baro-Akobo basin system are the Baro, the Akobo, the Alwero, and the Gilo, drain into the Nile (White Nile).

The downstream countries (Sudan and Egypt) are utilizing the water of the Nile River. As it is known, Ethiopia has made no use of the water of this river. To date, there is recognition among the riparian countries for equitable utilization and development of the Nile system. For this purpose, the Government of Ethiopia has commissioned different types of river basin studies. One of these studies has been the Baro-Akobo River Basin Integrated Development Master Plan. Similar to other major river basin studies, the output expected from this study have been:

- *To review existing database*
- *To site development priorities*
- *To provide a master plan for integrated development of the basin*
- *To provide pre-feasibility study out puts for priority water resources projects*
- *To provide information for cooperative development, particularly with downstream countries*

To this end, Geographic Information System (GIS) was used in the Project to automate and produce geo-referenced data of the Basin. The method was intended to recommend integrated master plan areas for proper allocation and utilization of water, land, socio-economic and related resources on basin-by-basin bases for the next 50 years.

Several geographic data of the Basin area were produced using conventional techniques and Computer Aided and Design (CAD) software before GIS was introduced. This paper, however, highlights how GIS is used to improve processing and presentation of spatial data

by analyzing and integrating essential resources of the Master Plan area. As integrated water resources development is gaining a paramount worldwide importance, GIS is highly needed in river basin studies to systematize geo-referenced resources of different sectoral studies for efficient development.

INTRODUCTION

Twelve major river basins have been identified in Ethiopia (see Map 1 and Table 1). These are broadly divided as those draining to Nile, The Somali lowland and the Dry Basins of Afar and Ogaden. The Baro-Akobo River Basin is part of the Nile basin that drains to the western side of the country.

Table 1. Major river basins, their area coverage (Km2, %) and water volume

River basin	Area (Km^2)	Area (%)	Volume ($X 10^9 m^3$ /Annum)
Tekeze (Atbara)	90,001	7.89	8.13
Abbay (Blue Nile)	***210,846***	***18.50***	***52.62***
Baro Akobo	***75,912***	***6.66***	***11.81***
Omo Glbe	78,213	6.86	17.96
Rift Valley	52,739	4.63	5.63
Genale Dawa	***171,042***	***15.00***	***5.88***
Wabi Shebele	***202,697***	***17.78***	***3.16***
Ogaden	72,121	6.33	0.00
Awash	112,696	9.89	4.60
Afar Denakil	62,882	5.52	0.86
Aysha	2,223	0.20	0.86
Mereb Gash	8,628	0.76	-
Total	**1,140,000**	**100.00**	**111.51**

The Baro-Akobo basin lies in the southwestern Ethiopia between latitude 5 and 11 degrees N and longitude 33 and 37 degree E. The basin occupies an area of 75912 km2 (see Map 2). It includes four Regional States: Oromyia, SNNPR, Gambela and Benshangule and Gumuz and have 48 Woredas.

Previously, the Basin was dividing as the Upper Baro-Akobo and Lower Baro-Akobo Basin. The Upper basin includes most of the mountainous Illibabor and the Lower Basin is part of the large areas of the Gambella Plain (see Map 3). But now the new study combined the to basin to produce one boundary.

The climate of the basin is warm and humid. Monthly temperature in general ranges between 26 to 30 ^{0}C. Average rainfall ranges between 600mm in the lowland and reaches normally 2000 and oboe in the highlands.

Baro and Akobo are the major rivers. Others rivers are Birbir, Geba, Sor, Alwero, Gilo, Kashu. Elevation ranges between 3000 in the Upper Baro Akobo and around 400 in the Lower part. Common landforms existed are: plain, plateau, escarpment, mountains, etc. Dominant soils are Dystric Nitosols (40%) that are found in association with Pellic Vertisols, and Orthic Aeriasols. The geology of the basin consists of preliminary of basement crystalline rocks in eastern uplands with covering Tertiary lavas in places and Quaternary Sediments in low lands to the west. Although the area is known for its forest, little climatic climax vegetation remained in the Basin. Dominant land use types are low-input individual holdings. The major crops produced in the area are maize (66%), sorghum (33%). Coffee and tea are largely grown in the Upper parts of basin. More than 75 % of livestock is owned by cultivators and the rest by pastorialists.

The paved highway from Addis Ababa to Gambella traverses the entire study area from north to south.

THE NEED FOR RIVER BASIN INTEGRATED MASTER PLAN

The master plan study regarded a river (water resources) as a major spatial planning entity because of its significance to delineate planning boundaries between water divides. These divides incorporate important land resources of the master plan. The resources were further delineated and analyzed using administration boundaries for institutional undertaking. The results have been used to meet the needs of immediate and long-term development objectives.

A comprehensive water resources plan was prepared for the Lower Basin (Selkhozpromexport Company, USSR) and the Upper Basin (ARDCO-GEOSERV Company, Ethiopia). This project, however, had attempted in presenting integrated assessment on availability, utilization and allocation of water, land and other resources for the two Basins. The expected outputs have been optimum planning areas for establishment of efficient and suitable usage of water.

SECTORS OF THE MASTER PLAN STUDY

The following major sectors were identified: Natural Resources and Agriculture, Environment, Water and Engineering, Economics and Population, Physical Planning and Infrastructure, etc. Geology, Soil, Land Cover and Land Use, Agriculture, Livestock, Forestry, Soil and Water Conservation, Power and Energy, etc were the sub sectors. The GIS and Cartography Division was also stood as a major sector during the study. This was internally subdivided as Cartography & Drafting and Geographic Information System (GIS).

GEOGRAPHIC INFORMATION SYSTEM (GIS)

GIS is a computer-assisted system for acquisition, storage, analysis and display of spatial data. A GIS enables us to bring all spatial and non-spatial information collected by multidisciplinary group and further these data are brought together or analyzed to give an output that can be used for planning and implementation phases.

GIS is Needed

- To present data in map form quickly and accurately
- To keep geo-referenced data current
- To handle large volume of data (bulky). Because digital in format.
- Its cost/unit product is low once established
- It has the ability to retrieve information (multiple sets of data) and performs complex spatial analysis
- It is useful in making decisions under uncertain condition (modeling)

A GIS answers the following questions

- Related with location? What exists at a particular location (identify)
- Related to condition: Where is it (search): to find a phenomena with certain conditions are satisfied.
- Related to trend: Change occurs within the area over a given time (Spatio-temporal variations)
- Related with pattern: Whether a phenomenon is occurring in a given space, as most badlands (eroded areas) occur on steep slopes, (repeated ness)
- Related with modeling: What if? What happens if land use change occurs in a specific locality (abstraction)

GIS tasks

Include Input, Management, Analysis and Presentation of geographic data

OBJECTIVES OF USING GIS IN THE BARO-AKOBO

A GIS emerged because of a great deal of computer technology and managerial demand for decision support. Moreover, national geo-spatial data are becoming very important in assisting resources persons and users in making informed decisions about land and water resources development, natural disaster mitigation, transport planning, urban development, etc. Therefore,,, GIS based studies like national water resources planning will promote development by providing optimum spatial unit for resources allocation and utilization.

Previous Problems of the Basin Regarding Use Of Geographic Data Were

- Continuation of the inefficient manual (conventional) system,
- Organizational and operational needs for digital mapping were not clearly stated,
- There were not any clear decisions to specify digital geo-data requirements and use
- There was no any capacity to do digital mapping, particularly lack of the necessary GIS staff to implement a full-scale GIS and
- The absence of sufficient computer resource and other facilities

General objective

The General objective of using GIS in the Baro-Akobo is to present (comprehensive) water-resources-based river basin master plan areas for water allocation and utilization. It is further designed to support equitable use of water (Nile) and alternative development in the sector. This particular plan of the Baro-Akobo was recommended for the coming 30 to 50 years.

Specific objectives

- To Inventorize (geo-reference) and systematize the resources of Baro-Akobo
- To integrate Upper Basin and Lower Basin data in order to produce geographic data of the entire basin.
- To establish river basin (water-resources-based) spatial database
- To integrate the system of the Baro-Akobo with other basin development studies
- To define present and future potentials of the system: How it grows?
- To develop digital mapping tools and techniques
- Staff capacity building

ESTABLISHMENT OF A GIS FACILITY IN THE OFFICE

It was initially proposed by TAMS-ULG and jointly worked with counterpart (MoWR). The Ministry was having a GIS Division and facility before this study. But it was not capable to handle the needs of the Baro-Akobo Project since the Division has other missions of the Ministry. Therefore,,, a dedicated system was suggested and configured for Project.

Following this:

- Available resources were inventorized: computer, manpower and maps
- Specifications were prepared (suppliers visited, system capabilities determined and the best were chosen)
- The kind computer hardware and software needed were decided
- The system is evaluated by visiting different organizations having experience such as MoWRs Master Plan Studies Offices and WBISPP. Specifications were regularly updated following every visit
- Decision makers evaluated the system before acquisition
- Establishment: selection of appropriate place and installation (power and room)
- Hardware: 3 computers (1 GB capacity, 24 RAM, 100 Mhz speed), one digitizer, one printer and one plotter were dedicated for the GIS
- Software: Arc Info / Arc View and AutoCAD were installed. Also backup software
- The system was tested and demonstrated. Decision makers were analyzed the system's capability.

Simultaneously the following conditions were examined:

- Whether any national GIS database exists or not?
- If local institutions are exist for assistance.
- What is (are) the dominant GIS software in the country?
- Are local suppliers of hard and software are available
- Is there any possible maintenance of the GIS system available in the country, particularly for digitizer, plotter and GIS software?

Table 2. Final configuration of computer and computer related items

Quantity	Item description
2	Pentium 100 (or grater) system with -Intel 100 (or greater) MHZ Pentium Processor & Triton PCI Chipset -24 MB RAM, 256 KB Fast Cache -1 GB (or greater) 10ms IDE HDD -3$^{1/2}$ inch FDD; 101-Key K/B; Mouse: 2p/2s; Mid Tower case -PCI Video Accelerator with 2 MB RAM -MS DOS 6.2; Windows for Workgroups 3.11 -420 MB Internal Tape Back Up
2	17 inch SVGA Color 26 dot pitch NI Monitor
1	Quad-speed external CD-ROM drive with parallel port adopter
1	12" X 12" Digitizing tablet serial interface cable
1	36" X 48" Digitizing tablet with tilt-base and serial interface cable
1	HP 650C E-size color inkjet plotter with parallel interface cable
1	HP LaserJet 4 Plus printer with parallel interface cable
1	Electronic printer sharing unit with cables capable of switching up to 4 PCs to 2 parallel out put devices
1	Licensed copy of PC Arc Info and Arc View software
1	Licensed copy of AutoCAD Release 13 software
1	600 VA UPS system & appropriate power strips
	Consumables -Plotter paper (36 roll, each roll 36" X 150") -HP Design Jet ink cartridge (90 pieces: Black, Red, Yellow, Magenta)

CAPACITY BUILDING (STAFF)

One Consultant (the GIS Team Leader, Geographer)
One GIS Expert (the Ministry's counterpart, Geographer)
Two Digitizers/Technicians (Draftsman and Draftswomen)

THE DATABASE

The major sources of analog and digital data were:

- The Upper Baro Akobo Basin study (by ARDCO-GEOSERV),
- The Lower Baro Akobo Basin study (by USSR)
- The Ministry's River Basin Master Plan studies (Abay and Omo-Gibe)
- Ministry of Agriculture, the Woody Biomass Inventory and Strategic Planning Project (WBISPP)
- Supplementary analog data were derived from hard copy maps of CSA, EMA and NMSA
- Original data of TAMS-ULG resulted from field survey and data analysis.

DATABASE DESIGN

- Initially, the analytical potential of existing analog and digital maps (data) was studied.
- Map scale was determined in relation to the scale needed for the study. Digital maps were generated mainly from 1:50000 and 1:250000 maps analog data
- Then, data were classified and organized before data input.

Data entry (digitizing and importing)

- Hardcopy maps were digitized and attributes were encoded.
- Maps from digital sources were imported using the common DXF format.
- Attributes were imported as DBASE files.

Processing and analysis

- Maps and attribute data were edited and cleaned before analysis.
- This is, then, formatted to Arc Info software and plotted in Arc View.

Two types of analysis were employed:

Sectoral analysis

Included analysis of selected theme for the sector: combining of the Upper and Lower Basins soil, geology, land cover and use, etc maps.

Some the spatial data analyzed were:

Soil: Different formats and legends of the Upper and the Lower Basin data were combined together.

Land capacity: the land capacity maps of the two Basins were generalized using Arc Info to give a map for the whole basin.

Land suitability: This was prepared for separate basins. Finally, the two data were merged using Arc Info to result the whole basin data.

Integrated analysis:

Used different sectoral maps to create combined map such as land capacity and farming system and master plan development map:

Farming system: GIS overlay of farming system and Wereda was made to present statistical information related to each farming system

Potential irrigation areas: Areas were mapped. Finally the areas were overlaid on soil map to assess their potential and rank.

Population Support Capacity Model map: A window for the project area was taken from the WBISPP. In the model land use, farming system distribution, physiography and population projection made at the national level were integrated.

The master plan development map: This was prepared from essential map layers of the study such as soil, potential irrigation, land use, dam sites, etc.

DATA PRESENTATION AND DISSEMINATION

Presentation

Maps

The Map Album was the major out. It is prepared on 1:1,750,000 scale on A3-size format. A4-sized maps were presented for reporting. The Master Plan Development map was produced on 1:250 000 and fitted to two A0-size papers.

Very important layers (maps) produced during the study and their sources:

- The Baro Akobo boundary and location map (MoWRs and TAMS-ULG)
- Baro Akobo sub basins (MoWRs and TAMS-ULG)
- Baro Akobo administrative boundaries (CSA and TAMS-ULG)
- Soil map (USSR: Selkhozpromexport study and MOA, LUPRD)
- Geology map (Ethiopian Geological Institute)
- Hydro-geological map (FAO)
- Land cover and land use map (MoA, LUPRD and WBISPP)

- Farming system (TAMS-ULG, CSA and Australian consulting company)
- National Forest Protection Areas (modified from WBISPP)
- Population distribution and density (CSA and TAMS-ULG)
- Dam site map (TAMS-ULG, ARDCO/Soyuz)
- Road development program (Road Development Authority & TAMS-ULG)
- Potential irrigation projects (TAMS-ULG, ARDCO/Soyuz)
- Land capacity map (MoA)
- Population Support Capacity Model (WBISPP and Australian Consult.Co.)
- Potential irrigation projects (MOWR and TAMS-ULG)
- Master plan development map (TAMS-ULG)

Relational tables

For most maps two-dimensional tables were also presented and attached to the Map Album.

Data dictionary and reports produced

A summary or data dictionary for the whole database was prepared. Accompanying short reports were also attached.

Data backup

Data was finally backed and handed over to the management when the project is finalized.

Dissemination

More than 50 copies of the Map Albums were distributed. These were given to key government (government offices Regional bureaus) and international organizations.

CONCLUSIONS AND RECOMMENDATION

Future Plans of the Master Plan

General overview: There are few offices in Addis Ababa that are successfully operating GIS and establishing their own databases like WBISPP, MoWR, WFP. These offices employ different objective, projections, and formats in presenting their work.

The Water Resources Master plan studies work for river basin master planning, widely use Arc Info software and UTM projection to systematize their spatial databases.

In the future the study planned:

- To complete master plan database of all river basins.
- To present pre-feasibility and feasibility study of sub-basins. For example, the pre-feasibility studies of Baro and Geba (from Baro-Akobo Basin), Genale (Genale Dawa Basin) and Guder (part of Abay Basin) for hydropower and irrigation development were completed in 1999 (MoWR and Norplan/Norconsult Consulting Plc).
- A Project for watershed development of highly degraded areas is started in 1999 (MoWR and RODECO Consulting Company)
- The trans-boundary rivers (the Nile) initiative is strengthened because of these master plans.
- Linkage with Regional States is highly developed. Data sharing, site visiting, technical supports have been strengthening.

What EARO learn from the River Basin Master Plans

Common problems (pitfalls) in GIS are absence of long term planning and goals, failure to consider issues that can be answered using GIS, failure to specify requirements, overstating benefits, using GIS as an experiment, lack of management support, lack of users involvement, computerizing all existing problems, continuation of unnecessary manual system, no training, lack of user research. While working to set-up a GIS facility in any organization, one should analyze the above common problems and design some mechanisms to challenge when they prevail. Sometimes, problems are job or project specific. We need to tackle the immediate ones.

Several problems that have been identified by EARO have been also shared by other organizations such as MoWR and MoA. However, EARO should maximize it benefits by looking at the best experiences of others GIS studies. Therefore,,, comparison of the Baro-Akobo and EARO system is very essential to analyze the set up of entire system and to calculate benefits that we get from others that it may be costly if we are doing it by ourselves.

As Ministry of Water Resources (MoWR) works for water-resources based master plan development, Ethiopian Agricultural Research Organization (EARO) should work (has to be mandated) for agricultural-based database development.

River basins (major and sub-basins) are optimum units for water resources studies (see Map 4). Agro-ecological Zones (AEZs) are best to plan and map agricultural resources (see Map 19).

For both studies Regional, Zonal and Wereda and Peasant Association set up are essential to present institutional geo-referenced information of the entire nation.

To be operational EARO should strengthen its capacity in all aspects (particularly equipment, manpower and national database). If this condition is fulfilled the GIS research can sound and stand by itself.

The root problem in GIS implementation lies in organizational and operational issue rather than equipment and software. Coordination or a multidisciplinary group set up is needed in EARO to do GIS related projects. The group can assess GIS implementation problems, set objectives, jointly decide on geo-data to be used, recommend out puts and identify potential users of the resource.

Continue with small GIS based projects as watershed management, Livestock Early Warning System, suitability mapping of priority crops (as CIMMYT does for wheat).

Do a joint project like Ethiopian Country Almanac (EthCA) database to develop the GIS and EARO's analytical capability.

Try to produce standard and quality products. Also, establish strong organization/data banking,

Get feedback, whenever required, to improve working conditions. In the Baro Akobo case, the National Steering Committee was forwarded its valuable comments after completing the Inception, Interim, Draft Final Phase reports and maps. The committee was composed of a group of multidisciplinary specialist working under government organizations.

Along with the above activities, work in cooperation with other organizations for data sharing, interoperability, standards and other issues. Local applications/pilot projects may be the starting point. Nowadays, there is a strong indication to set-up comprehensive countrywide GIS.

Work with national and international research centers having GIS capacity (Debre Zeit, ILRI, ICARDA). The international community has a rapidly expanding need for integrated spatial data for use as inputs to resource assessments land evaluation and classification, econometric models, national resources policy information and large number of specialized scientific investigation. This leads to the inevitable global spatial information infrastructure.

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GIS APPLICATIONS WITHIN AN INTEGRATED FOOD SECURITY PROGRAM (IFSP)

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Abstract

Soil erosion by water has been a serious problem in the Ethiopian Highlands, ever since land was first cultivated more than 2000 years ago. Erosion rates assessed on test plots in different parts of the Ethiopian Highlands are 72 tons/ha and year in average (Hurni, 1985). It can be assumed that the reduction of soil depth by topsoil erosion will have serious implications on the future crop yields.

The intervention area of the 'Integrated Food Security Programme (IFSP) South Gonder' of the German Technical Cooperation (GTZ) lies in the northern part of the Ethiopian Highlands, where droughts and food shortage hits the local

population regularly. IFSP tackles the problem of soil degradation to reduce annual soil loss rates to an acceptable minimum, in order to maintain the soil fertility and its productivity in the long run. In general, a maximum soil loss can be tolerated that will permit a high level of crop productivity to be sustained economically and indefinitely (Figure 1).

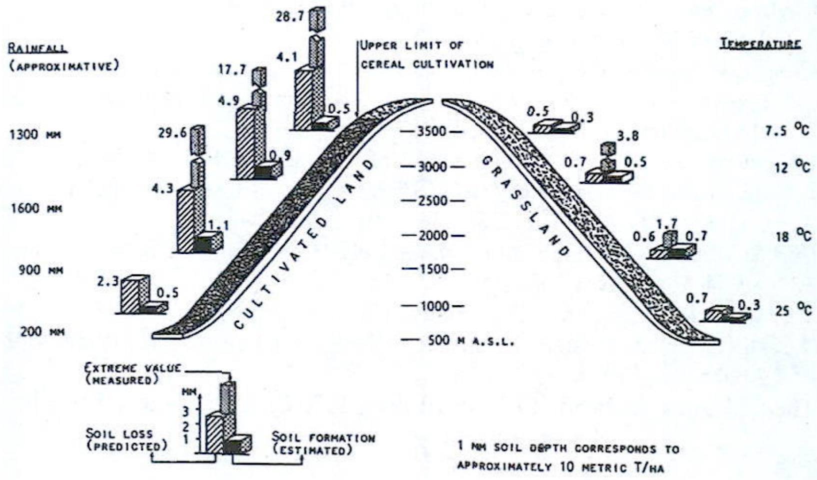

Figure 1. Soil Erosion and Soil Formation in Ethiopia dependent on Altitude and Land Use (Hurni et al. 1999)

Apparently, soil loss rates and soil formation rates are not in balance. This is why soil conservation measures have to be undertaken to reduce soil loss rates and to contribute to new soil formation.

The presented article condenses the outcome of a consulting mission at the IFSP. It's main objective is to present a methodology on how to produce a soil erosion risk maps by using remote sensing data and GIS techniques. The resulting information products should then serve as a basis for the identification of priority areas for planning of soil conservation measures and the development of land use strategies.

DESCRIPTION OF THE PROJECT AREA

The area of investigation is located in the central Ethiopian Highlands West of Lake Tana and touches both, the watersheds of Tekeze and Blue Nile River. The figures of the hillshaded Digital Elevation Model (DEM) and of the altitude range (Figure 3 & 4) give a first impression of the heterogeneous relief and the topography within the area. The topography is characterized by an extremely high relief energy with almost 3000 m altitude difference between the highest elevation (Guna Terara, 4135 m.a.s.l.) and the lowest river beds the Blue Nile and its tributaries.

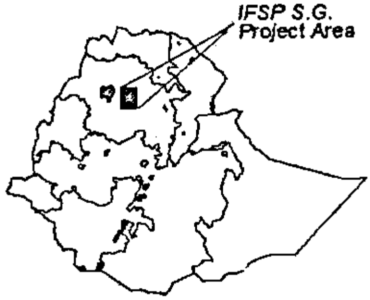

Figure 2. Reference Map Ethiopia

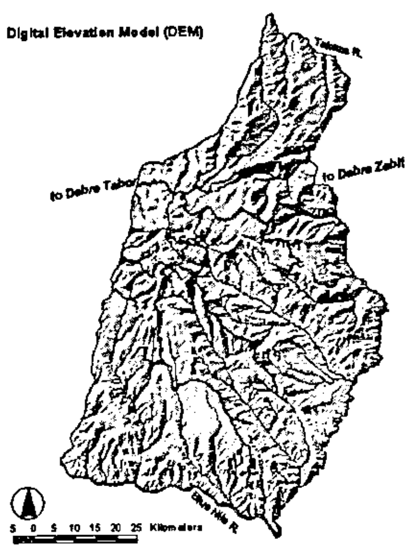

Figure 3. Hillshaded DEM

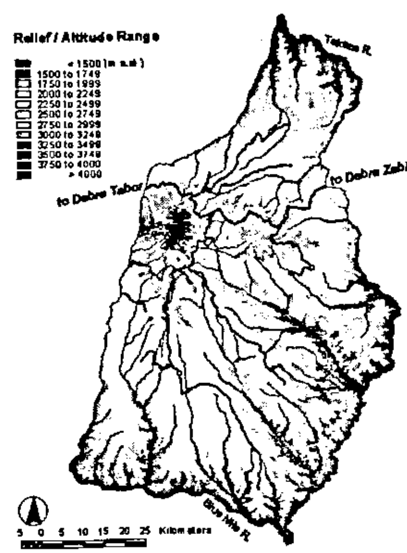

Figure 4. Relief / Altitude Range

METHODOLOGY

A GIS is an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information (Figure 5).

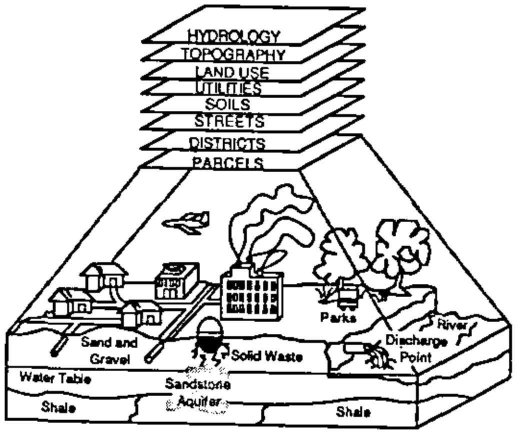

Figure 5. The Real World represented as a number of related data layers (ESRI, 1990)

Apart from analogue Topographic Maps in scale 1:250,000 the results of a visual classification of Landsat TM satellite images served as main input data for further processing within the GIS. The commercial software products ARC/INFO and ArcView served for the analysis of the vector data, and Idrisi for the raster data analysis.

Soil Erosion Modelling

The Universal Soil Loss Equation (USLE) is an erosion model designed to compute long-term average soil losses from sheet and rill erosion (Wischmeier & Smith, 1978). It is an empirical model, combining different soil erosion factors as variables by a multiplicative combination.

$$A = R * K * L * S * C * P$$

(Wischmeier & Smith, 1978)

where:

A = average annual soil loss [tons/ha∗year].

R = Rainfall erosivity and runoff factor.

K = Soil erodibility factor.

L = Slope length factor.

S = Slope gradient factor.

C = Land cover and management factor.

P = Support or conservation practice factor.

The USLE was adapted to Ethiopian conditions by Hurni (1985), who established test plots at different locations throughout the country for empirical research and Helldén (1987) by developing regression equations based on Hurni's findings. It has to be mentioned that soil loss rates computed with the USLE are only best available estimates, that describe avarage values but not absolutes.

Rainfall Erosivity Factor R

Ethiopia is characterized by high rainfall variability. However, there are only around 200 meteorological stations that deliver regularily reliable data. The rainfall intensity itself is not systematically measured at all. This made it necessary to calculate the mean annual rainfall distribution with a model and use the values as input for the calculation of the R Factor.

Eklund performed multiple regression analysis, in order to develop models, which explain the mean annual rainfall pattern of Ethiopia. According to this, the project area is located in the FAO rainfall pattern region A, which is characterized by one short rainy season in summer (Eklund et al., 1990).

After having developed a raster surface, based on the respective multiple regression equation and by incorporating a linear regression factor for the altitudinal effects, the R-Factor values could be calculated, using the following equation:

$$R\text{-}Factor = -8.12 + 0.562 * Mean\ Annual\ Rainfall\ [mm] \qquad (r^2 = 1.00)$$

(Helldén, 1987)

Soil Erodibility Factor K

The soil properties decide on the susceptible to erosion. The comprehensive legend of the map 'Geomorphology and Soil 1:1.000.000' (FAO/UNDP, 1987) describes dominant soil types within each geomorphologic unit, depending on the slope gradient. Prior to the calculation of a slope gradient layer, a DEM was generated, based on 100 m contour lines. Both, the digitized map and the slope gradient layer were then combined by an overlay analysis, in order to produce a soil type layer. Finally, an individual K Factor was assigned to each soil type according to the commented legend of the mentioned map.

Slope Length Factor L

According to the conventional approach of the USLE, the slope length is the determining variable of the L Factor. Recent research showed that especially for larger areas, an alternative way could be followed in order to derive L Factor values. In the case of raster image analysis, it is being recommended to calculate the flow accumulation for each pixel of the surface. Each pixel value then represents an approximation of the total water run-off length, which can be described as the catchment area for an individual raster cell. The flow accumulation layer was calculated based on a flow direction surface that was derived through the slope gradient information. The flow direction generally corresponds to the aspect of slopes in the eight main compass directions. It then serves as input for the calculation of a flow accumulation image by accumulating the weight for all cells that flow into each dowNSRCope cell. Output cells with a high flow accumulation are areas of concentrated flow and may be used to identify the stream network by applying a threshold value. Output cells with a flow accumulation of 0 are local topographic highs and may be used to identify ridges. In general, the flow accumulation is an indicator for the catchment area of each individual raster cell. Last but not least, the L Factor was calculated for each pixel applying the following regression equation, which describes the L Factor as a function of the slope length.

$$L\ Factor = 0.799 + 0.0101 * Slope\ Length\ [m] \qquad (r^2 = 0.95)$$

(Helldén, 1987)

Slope Gradient Factor S

The slope gradient was derived from the DEM by calculating the maximum rate of change in value around each pixel to its neighbours. After having calculated a continuous slope gradient surface, the following equation, expressing a linear regression, could be applied to develop an S Factor surface.

$$S\ Factor = 0.344 + 0.0798 * Slope\ Gradient\ [\%] \qquad (r^2 = 0.97)$$

(Helldén, 1987)

Land Cover Factor C

The most time- and cost-effective way to derive an accurate land cover data for larger areas is to interprete satellite remote sensing data. This is why the project purchased hardcopy prints of a current Landsat TM scene (185x185 km) that covered the entire IFSP project area. A ground check served for the comparison of image signatures with the reality in the field and for the definition of land cover classes. Within around two weeks, all prevailing agro-ecological zones of the project area were visited with exception of the inaccessible valley bottoms. Detailed notes and photographs were taken from all occurring land cover classes and compared with their signatures within the image. Based on the experience from the fieldwork, a visual land cover classification was performed in a working scale of 1:100,000.

The C Factor image was generated by assigning respective values to all land cover classes according to different references and own experience.

Table 1. Area Statistics of the Land Cover Types within IFSP S.G. Project Area

ID	Land Cover	C-Factor	Area [sqkm]	Area [%]
1	Forest Land, Eucalyptus Plantation	0.001	30	0.54
2	Woodland	0.010	96	1.75
3	Bushland, Shrubland	0.038	570	10.44
4	Grassland	0.013	101	1.85
5	Afro-alpine Vegetation	0.042	50	0.92
6	Cultivated Land (Highland)	0.250	562	10.29
7	Cultivated Land (Highland) / slightly degraded	0.250	798	14.60
8	Cultivated Land (Highland) / heavily degraded	0.250	114	2.08
9	Cultivated Land (Escarpment), Settlements, Bushland	0.150	2449	44.83
10	Settlement, Eucalyptus Plantation	-	255	4.67
11	Bareland, Rock Outcrops	1.000	27	0.50
12	Cultivated Land (Lowland)	0.100	408	7.46
			5463	**100.00**

Support Practice Factor P

For the entire area, it was assumed that contour ploughing is a common soil conservation practice, which is applied throughout the entire area. According to ratio tables, the P Factor varies with the slope steepness according to the following table.

Table 2. P-factor values for the USLE (modified: Morgan, 1995)

Management practice	Slope Gradient [°]	P-factor
Contouring	< 1	0.60
Contouring	2 to 5	0.50
Contouring	6 to 7	0.60
Contouring	8 to 9	0.70
Contouring	10 to 11	0.80
Contouring	12 to 14	0.90
Contouring	> 14	1.00

Although further erosion-control practices exist within the project area, it was not possible to incorporate them into the model. Intensive field-inventories would be necessary in advance, in order to map the spatial distribution of soil conservation measurements.

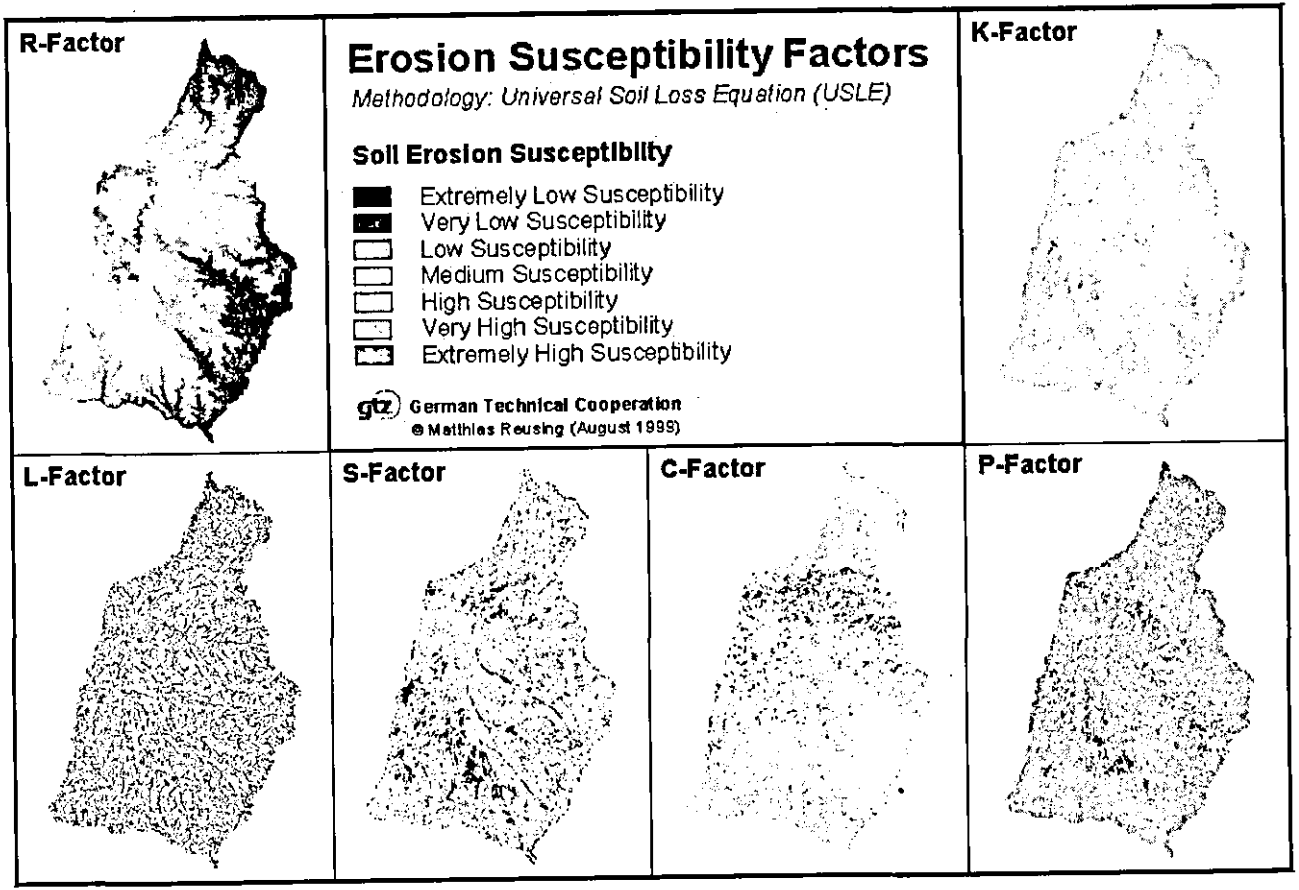

Figure 6. USLE Factors

Calculation of the Mean Annual Soil Loss

The final assessment of mean annual soil loss rates could be performed by doing an overlay analysis of all developed factor images by simply multiplying them together. It has to be underlined that the absolute figures of soil loss rates [tons/ha*year] might vary considerably from year to year. Nevertheless, the overall message and qualitative assessments, which are visually and statistically documented, are highly reliable. This means that in areas where soil loss rates of more than 400 tons/ha*year were calculated, the risk for further erosion is in fact extremely high, even if the actual amounts might be slightly lower. However, if it comes to planning soil conservation measures, minor errors of the absolute soil loss rates can be neglected.

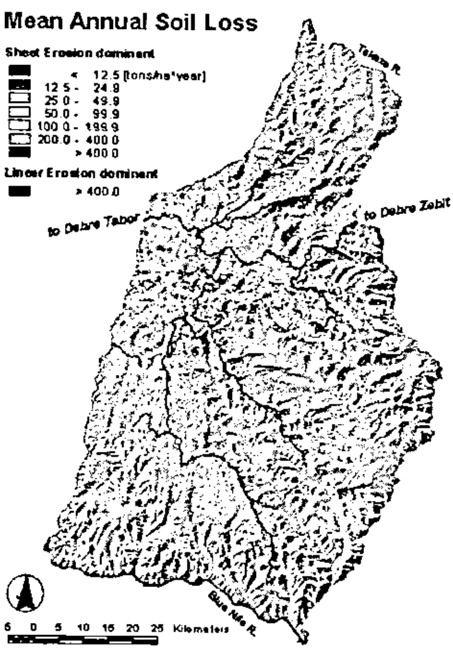

Figure 7. Mean Annual Soil Loss

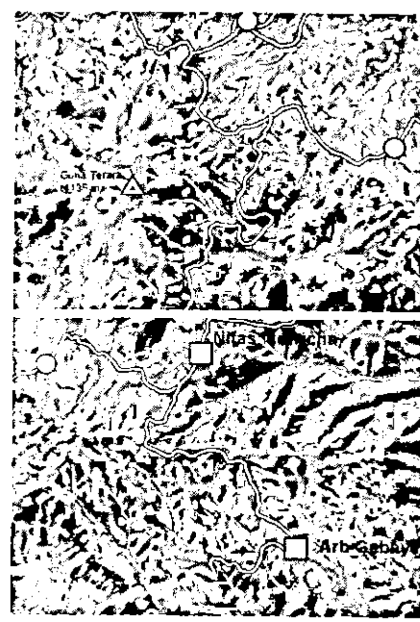

Figure 8. Mean Annual Soil Loss, Details

Table 3. Area Statistics of the Mean Annual Soil Loss within IFSP S.G. Project Area

ID	Soil Loss [tons/ha*year]	Area [sqkm]	Area [%]
1	< 12.5	193	3.53
2	12.5 to 25.0	393	7.20
3	25.1 to 50.0	744	13.61
4	50.1 to 100.0	1030	18.84
5	100.1 to 200.0	1029	18.82
6	200.1 to 400.0	826	15.12
7	> 400.0	508	9.30
	Linear Erosion	489	8.94
	Linear Erosion, Settlement	12	0.23
	Settlement	243	4.44
		5467	**100.00**

OUTLOOK

The results show that it is possible to perform detailed assessments of soil erosion susceptibility, based on high-resolution satellite images and GIS techniques.

With an on-going population growth, more land than ever will have to be cultivated in search of feeding more people.

Although the Ethiopian Government and the Bureau of Agriculture in Bahir Dar are aware of the soil erosion problem, the efforts will have to be increased considerably, in order to reverse the current situation in future. However, the greatest resources are the farmers themselves, who have to be motivated and whose workforce will have to be utilised in order to tackle the problem of soil conservation.

Land degradation by soil erosion can never be stopped, but only be reduced to an acceptable minimum. This can be achieved by the application of appropriate and well-adapted soil conservation measures and by farming practices, which sustain the fertility and productivity of the soil.

The results study and the developed statistics and maps will help to identify potential intervention areas where immediate measures have to be undertaken and can support planners and decision-makers to apply suitable conservation techniques.

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WEATHER AND CROPS

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INTRODUCTION

Weather plays a key role in crop adaptation and distribution. Weather is related or influenced by altitude, latitude, and longitude. In the tropics and sub- tropics the temperature and rainfall regimes are usually influenced by altitudes. This has direct influence on crop adaptation. For instance, faba bean is not a crop of tropics or sub- tropics but it grows in the Ethiopian highlands with the major concentration in over 1800 m above sea level. The adaptability and stability of crops and crops' varieties is also dependant on the amount of rainfall and distribution or temperature regime (heat or frost). Where there is a heavy frost incidence susceptible crop to frost can not survive. Thus such crops will be limited to only warm regions. Normally in the highlands of Ethiopia where the temperatures are low during cropping season barley, faba beans, field peas and lentil are the major crops grown by the Ethiopian farmers. The varieties of these crops have been screened and adapted to these environments for centuries and have been grown by the Ethiopian farmers. Similarly, varieties of a crop like sorghum which has been cultivated in the drier, intermediate and highlands have gone under evolutionary process and adapted to the changing weather conditions over years.

The four most important cereals grown for human food in the tropics are rice, maize, sorghum and pearl millet. However, the temperate cereals wheat and barley are also grown to a limited extent in the tropics largely at high altitudes of Kenya (wheat) and Ethiopia (wheat & barley).

The classification of regions into tropics and temperate is mainly based on the weather elements such as temperature, sunshine, rainfall, humidity and even wind. All these weather elements have effect on crop growth and development.

Rainfall: Rainfall is the primary element of weather that supplies moisture. It is directly and indirectly the only major source that supplies water to crop. This is because most of the rivers, ponds, wells etc. get enough water during rainy season and then be used as water sources for supplemental irrigation. Shortage of rainfall during crop establishment and grain filling affects the yield and some times lead to complete crop failure. On the other hand, heavy rains cause flood or waterlogging and damage crops. Heavy rains also cause soil erosion and leach soil nutrients that are essential for crop growth and development. When rain comes at maximum crop growth stage after grain filling, it causes severe lodging and affects yield and quality of the grains. It has a significant influence on the aboundance of weed, number of ploughing and weedings. Continuous rainfall favours development of weeds and has an implication on the amount of money to be spent to control weeds to avoid competition with the crops.

Humidity: Humidity is the percentage of water found in the atmosphere (air) and the rainfall usually influences it. High relative humidity reduces evaporation of soil moisture and transpiration from plants. When humidity is low and temperature is high, it increases the water requirement of the crops. If this occurs at critical stages of crop such as flowering/heading and grain filling, supplemental irrigation will help to over come this low moisture stress. Where supplemental irrigation is not possible, the crop will suffer and the grain yield is reduced dramatically.

Temperature: Temperature has a significant influence on the growth and development of crop plants, plant pathogens and insect pests incidence. Different crops, pathogens and insect pests have all their optimum temperature requirements. Thermal time is particularly helpful in describing the effect of temperature on the time taken by seeds to germinate at different temperatures as shown in Table 1. for rice.

Weather Elements and their Influence on Development of Diseases and Insects

Diseases: Several researchers have reported the effects of weather on disease development. For instance, Kaiser (1973) studied the survival of Ascochyta blight disease on chickpea and found out that the fungus survived for 2 years in naturally infected tissues at 10-35^{0}C and 0.3% relative humidity at the soil surface, but it lost its viability rapidly at 65-100% relative humidity and soil depth of 10-40 cm. Similarly, Luthra et al. (1935) indicated that this disease is spread rapidly when it is wet and windy and the temperatures are around 22-26^{o}C. Physical forces such as temperature, moisture, pressure, light etc. are generally capable of disturbing the delicate state of balance in the protoplasmic material in the bacterial cell (Singh, 1983). However, bacteria can survive temperatures of 0^o to 85^{0}C or even more depending upon the species. Sudden lowering in temperature is more lethal than gradual change in temperature. For instance. In Ethiopia, different wheat rusts are distributed in different regions based on their adaptability to different environments. Yellow rust in mainly important in the cool highlands of Arsi and Bale whereas leaf and stem rusts are important in the mid- altitudes such as Debre Zeit and similar environments. This indicates that the optimum weather elements are required for the survival and development of diseases.

Insects: Temperature, light and humidity are known to adversely affect insect development and survival. Nayar et al (1985) indicated that extremes of temperature and the temperature ranges tolerable by different insects and sexes greately vary. According to their report temperature exerts a profound influence on fecundity, rate of egg production, speed of development, and rate of migration. In addition to temperature, humidity has a great influence on insects survival. In some insects like grasshoppers, the evaporation through spiracles has been found to be 60 to 70% and it is more closed in dry air than in high relative humidities. Therefore, weather elements such as rainfall, relative humidity, temperature and length of sunshine have great influence on biotic factors such as diseases and insects and have indirect influence on crop productivity and production.

Brinkman (1987) described edapho- climatic zones for cassava production and their main characteristics and illustrated how weather influences crop, diseases and insects distribution. (Table 2). In the Ethiopian context, 18 major agroecological zones and 49 sub- agroecological zones were identified based thermal and moisture regimes. These two elements of weather have direct effect on crop distribution, biotic and abiotic factors that affect crop production (Table 3 and 4).

Table 1. Effect of temperature on various process of rice

Growth stage	Critical temperatures (^{0}C)		
	Low	High	Optimum
Germination	16-19	45	18-40
Seedling emergence and establishment	12-13	35	25-30
Rooting	16	35	25-28
Leaf elongation	7-12	45	31
Tillering	9-16	33	25-31
Anthesis	22	35-36	30-33
Ripening	12-18	>30	20-29

Source: The ecology of tropical food crops taken from Yoshida (1977). P.87

Table 2. Edapho- climatic zones for cassava production and their main characteristics*

General description of edapho-climatic zone	Representative areas for germplasm evaluation and technology testing	Sites in Colombia	Main yield constraints
Lowland tropics with long dry seasons. Small to moderate annual rainfall. Hot year- round temperature	Northeastern Brazil. North coast of Colombia, northern Venezuela. Southern India. Thailand. Sub- Sahelian Africa	Caribia. Fonseca. Media Luna. Nataima. Rionegrio	Drought, mites, thrips, mealybugs. Termites. bacteriosis, root rots, viruses
Acid- soil savannas with moderate to long dry season, small relative humidity during dry season	Llanos of Colombia and Venezuela, Cerrados of Brazil, savanna of southern Mexico	Carimagua	Low soil fertility, drought, bacteriosis, superelongation, anthracnose, *Cercospora leafspot*, mites, mealybugs. Lace bugs
Lowland tropics with no pronounced dry season, large rainfall, constant large relative humidity	Amazon basins of Brazil, Colombia, Ecuador, and Peru: rainforests of Africa and Asia	Chigorodo. Florencia	Low soil fertility
Medium- altitude (800-2200m) areas. Mean temperature approx. 17-20°C	Medium- altitude areas of the Andean zoene. Boliva. Brazil. Costa Rica. Indonesia. Philippines. Vietnam, India	Caicedonia, CIAT-Palmira CIAT-Quilichao	Thrips. Mites, mealybugs, bacteriosis, mycoplasma, anthracnose, droot · rots, viruses
Cool, tropical highland (1600-2200m) areas. Klmean temperature approx. 17-20oC	Highlands of the Andean zone and tropical Africa	Popayan	Cool temperature, *Phoma* leafspot, anthracnose, mites
Subtropical areas, with cool winters and fluctuating daylengths	Southern Brazil, Paraguay, northern Argentina, Cuba, northern Mexico, southern China, Taiwan	None	Low winter temperature, bacteriosis. Superelongation. anthraconse

Brinkman, R. 1987.

Table 3. Distribution of crops by Agroecological Zones (AEZs) in Ethiopia

A1	Maize, sorghum, cotton, citrus, banana, mango
A2	Sorghum, chat
SA1	Sesame, tef, sorghum, maize, vegetables, fruits
SA2	Maize, lowland pulses, vegetables, fruits, tef
SM2	Sorghum, maize, wheat, tef , oats, barley, oil crops, tobacco, chat, fruits
SM1	Sorghum, maize, beans, cotton, wheat, sesame, vegetables, chat groundnut, finger millet, lentils, chickpea, fruits
SM3	Barley, faba beans, field peas
M1	Maize, sorghum, root crops, fruits, sugarcane, tef, beans, vegetables, chat
M2	Tef, wheat, barley, finger millet, maize, highland pulses
SH1	Maize, sorghum, tef, root crops, coffee, enset, chat fruits, sugarcane, cotton, Pineapple, vegetables, barley, wheat
SH2	Tef, maize, sorghum, finger millet, wheat, pulses, fruits, sugarcane, vegetables, coffee, chat, enset, oilseeds (noug, linseed)
SH3	Barley, wheat, teff, chat enset, pulses.
H1	Maize, sorghum, beans, cotton, fruits, vegetables, spices, coffee, sugarcane, root crops, sunflower
H2	Sorghum, maize, tef, cotton, sunflower, wheat, barley, enset, sugarcane, fruits, coffee, pulses, linseeds
H3	Barley, wheat, faba bean, fieldpeas, lentil
PH1	Maize, sorghum, coffee, enset, fruits, sugarcane, vegetables, root crops
PH2	Maize, sorghum, tuber crops, root crops, enset, fruits, sugarcane, spices, vegetables

Table 4. Influence of weather on the distribution of diseases, insects, parasitic weeds in different agroecological zones of Ethiopia.

AEZs	Constraints
A1:	African ball worm (ABW), stalk borer, *parthenium, orobanche,* common weeds\ bacterial stripe, bacterial streak, bacterial wilt
SA2:	Root- knot nematodes; bacterial wilt, leaf and fruit rust, smut, striga, *parthenium* army worm, worm, stalk borer
SM1:	*Anthracnose,* rust, *aschochyta,* wilt/root rot, steam rust, leaf rust, smut, *striga parthenium,* armyworm, bollworm stalk borer
SM2:	wilt, root rots, rust, chocolate spot, powdery mildew, downy mildew, *aschochyta,* smuts, head smudge, MSV, FBNYV, BWYV, BWYV, BYDV, foot/root rots *striga, orobanche, xanthium*
M1:	*striga, orobanche, parthenium,* bacterial streak, bacterial stripe, common bacterial blight, halo blight, bacterial wilt, leaf and fruit spot, rust, head smudge, root rot.
M2:	Storage pest, *Cocconeids,* aphids, bollworm, stalk borer, foot/root rots, *orobanche, cuscuta, bromus, phalaris, xanthium,* wild oat, bacterial streak, bacterial stripe, black BYDV, pepper viruses, FBNYV, caff, blight, bacterial wilt, leaf and fruit spot, root rot, wilt, chocolate spot, downy mildew, powdery mildew, *aschochyta,* eye spot, late blight, early blight.
M3:	Bacterial stripe, spot, blight fand wilt, BYDV,FBNYV,enset badna virus
SH1:	Termites, stalk borer, bollworm; MSV, SCMV, enset badna virus, root-knot nematodes; bacterial streak, stripe and blight
SH2:	Stalkborrer, sweet potato buttertly, termites, bollworm; poty viruses in maize and sorghum, MSV, Root-knot, lesion and stuby nematodes, foot/root rots, *orobanche, cuscuta,* common weeds, wild oat, bacterial streak, bacterial stripe, black chaff, bacterial blight, bacterial wilt, leaf and fruit spot, *anthrachnose,* angular leaf spot, rust, wilt, root rot.

DISTRIBUTION OF RESEARCH CENTERS

The existing agricultural research centers represent only 8 agroecological zones. Accordine to the short-term plan both existing and newly proposed research centers will cover 11 agroecological zones However, the remaining small and fragmented agroecologies are not represented by any of these research center (table 5). These agroecological zones will be addressed by opening new sub-centers and testing sites which will operate as satellites of the main research centers.

Table 5. Distribution of existing and proposed research centers to address the problems of each agroecological zones.

No.	Name AEZ	Major 18 Agroecological Zones	Research Centers
1.	A_1	Hot to warm arid lowland plains	Worer Dubti (Proposed)
2	A2	Tepid to cool arid mid highlands	Jijiga (proposed)
3	SA_1	Hot to warm semi-arid lowlands	Humera (Proposed)
4	SA_2**	Tepid to cool semi arid mid highlands	-
5	SM_1	Hot to warm sub moist lowlands	Kobo
6	SM_2	Tepid to cool sub- moist mid highlands	Mekele, Sheno, Debre zeit, Melkasa, Sokota (Proposed)
7	SM_3**	Cold to very cold sub-moist sub-afroalpine to afroalpine	-
8	M_1	Hot to warm moist lowlands	Pawe
9	M_2	Tepid to cool moist mid highlands	Adet,Alemaya, Sirinka, Ambo, Holleta, Sinana, Kulumsa, Yabello (Proposed)
10	M_3**	Cold to very cold moist sub-afroalpine to afroalpine	-
11	SH_1	Hot to warm sub- humid lowlands	Asosa, Abobo

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INTEGRATION OF SOCIO-ECONOMIC ATTRIBUTES WITH SPATIALLY COHERENT BIOPHYSICAL DATA FOR TECHNOLOGICAL DECISION ON ANIMAL PRODUCTION

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INTRODUCTION

Natural resources, which influence the efficiency of animal production, are climate, soil and water availability. These natural resources affect the efficiency reproduction, production and behavior and adaptation of animals. The indirect effects of these resources are on their regulation on feed both yield and quality and also incidence of pests and diseases. Elevation through its impact on rainfall and temperature has great influence on the distribution or livestock densities in Ethiopia. Cattle densities are more closely related to human population and elevation. Bioclimatic assessment of regions or defined areas is very important criteria of breeding and technological decision taking for successful animal production. In addition, bioclimatic data are inputs for risk analyses of management and additional investment.

However, animal production system and technological interventions preside over given eco-system. Eco-system is the biological community in an area plus the environment with which it interacts (human, animal, environment, institutional arrangements). Application of eco-based research approach is very important in understanding opportunities for and constraints to improving the productivity. The approach requires to clearly to define a given eco-system with the attributes of production factors such as soil and vegetation types, livestock populations, socio-economic and intuitions. Wide-range decisions are likely to be based on this information.

Studies that generate characterization of a system have to rely on accurate data. The data base would have major implications in targeting of research and land management that benefit both the environment and resident human and livestock population. Data base on weather and geo-referenced spatial and temporal distribution of resources are critical both for research and development and the research system has to strive to maintain its capacity in these areas.

The following sections are structured to elaborate the issues raised above by providing elaborations on effects of climate on animal production and role of bioclimatic data in designing targeted research. Role of climate is only stressed on adaptation of the animals and production of feed. However, this does not mean not to acknowledge the role of bio-climatic attributes in disease incidence, distributions and management strategies. Topics regarding to this issue is treated by other paper in this workshop.

EFFECT OF CLIMATE ON ANIMAL

Climatic values and their complex derivations for thermoregulation of the animal and their nutrient intake are critical. Management and breeding practices options are designed to meet the demands of the climatic environment needed by the animals for normal physiological process and optimum production. Cattle maintain a stable body temperature within a wide range of environmental temperatures. It was observed that young bulls were able to maintain homothermy at an environmental temperature of down to about -30^0c. Assuming a normal range of the body temperature between 37.5^0c and 39.5^0c, young bulls were capable of compensating for an environmental temperature of about 70^0C below body temperature. On the other hand it was reported that body temperature began to increase when the environmental temperature exceeded 43^0C i.e. only 4^0C higher than the normal temperature

The larger cold tolerance is based on a great variety of adaptation reactions, which reduce heat loss or increase heat production. The thermoregulation nerve center in the hypothalamus triggers adaptive behavioral reactions when the environmental temperatures fall below the boundary of the thermo neutral zone. Behavioral responses reduce heat loss and are allowed by physiological reactions when the exposure to cold is extended. Shivering thermo genesis is one of their physiological reactions and consists of involuntary tonic or rhythmic contractions of the muscles which increase the basal metabolic rate. Non-shivering thermo genesis is the process of heat production in specialized tissue such as brown adipose tissue and is mainly observed in young animals. Further, the basal metabolic rate is raised by hormonal factors. A cold induced increase in the basal metabolic rate will decrease fertility and reproductive performance of a cow.

Major constraints in tropical Africa on animal behavior and performance are effect of heat stress. Magnitude of heat stress is determined by the temperature and humidity. For normal function, maintaining the animal's homoterms is very essential to ensure a normal physiological function and optimum production. Breeds have specific but relatively narrow thermal zones. Heat stress of cattle is expressed by the climatic analogue Temperature-Humidity Index. According to Du Preez et al (1990), THI of < 70 is normal, 71 to 78 to be alarm and 79 to 83 as dangerous. They mapped the spatial distribution of THI for each month of the year so that appropriate management practices can be designed according to the index. Knowledge of characteristic behavioral signs of increasing heat stress may alert the farmers to impending heat distress. The application of such approach may need consideration for Ethiopia.

Most herbivores can withstand heat and water shortage quite well. The physiology and grazing behavior of cattle however are not wholly adapted to the natural dry land environment especially during drought. At high temperatures evaporative cooling is the principal mechanisms for heat decapitation in cattle. It is influenced by humidity and wind speed and physiological factors such as respiration rate, and density and activity of sweat glands. The failure of homeostasis at high temperature may lead to reduced productivity or even death.

Under heat stress, Bos indicus breeds and their crosses have better heat regulatory capacities than Bos tarus, due to the differences in metabolic rate, food and water consumption, sweating rate, and coat characteristics and color. Bos tarus have a higher heat loading at the skin; Therefore, they must evaporate substantially more sweat than Bos indicus to maintain normal body temperature.

EFFECT OF ENVIRONMENT ON FORAGE PRODUCTION

Graminae family includes about 10, 000 species worldwide and this is divided into genra, again into subfamilies or groups of genera. Of these, the festucoid, panicoid and chloidoid groups are of particular interest as they include practically all the cultivated and a large number of the wild grasses that are available as forage. The panicoid and chloridioid grasses are found mainly in the tropics and sub-tropics. These groups differ with festucoid (C_3) grasses in their anatomy and their pathways of photosynthesis. The two groups has C_4 pathway in such grasses as Napier, panicum and sorghum species.

Under topical conditions, C_4 plants are much more efficient than C_3 plant in converting solar energy into biomass. Tropical grasses also produce large biomass but nutrient concentration in the biomass is lower due to the effects of climate. It was pointed out that high temperature results combination of high lignin synthesis and elevated metabolism.

Leguminosae plant family contains about 17,000 species divided into three subfamilies. Caseslpinoideae and Mimosoidea are confined mainly to the tropics and encompass mainly woody species. In all legumes, phosynthesis takes the c3 pathway.

Forage from trees and shrubs include leaves, young shoots, pods and seeds. Yield and quality differ immensely between the different varieties and between years of a given variety. The pod yield can vary greatly from year to year.

The cumulative effects of environment during growth and stage of maturity determine the digestibility of plant material. Rate at which forage plants mainly is a function of the environment and nutrient supply. The growth of all plants is affected by weather in the form of radiation, temperature, and water

Thus, the resurgence of interest in knowledge of bioclimatic assessment is to develop options that achieve more efficient use of resources under the prevailing environment. The assessment of biocliamtic variables of a region helps to select for better species. Rainfall has of great value in the advent of decisions and advance knowledge of forecasting would also assist in decision making process. However, it should be noted that not only the attribute of amount and distribution of rainfall, but also a function of other influential factors such as temperature, soil characteristics and management of the land will have great impact.

In dryland areas, the long term of water shortages has resulted complex challenges to the ecology and socioeconomic conditions of the pastoralists. Variability of rainfall (in space, time) and thus periodicity of rainfall becomes the major factor affecting the natural base. Dry ecosystems are more unstable with large variability between years and largely prone to inter-annual variations. The rainfall is typically skewed (many dry areas and a few wary wet areas); and the degree of skewness increases as the climate becomes drier (Glantz and Katz 1977). A lot of criticisms is made on the use of calculation of normal precipitation to define drought centers (Thurow and Taylor, 1999) and use generally accepted use of 30 years of precipitation records to reflect the actual long-term climatic record (Wilhite and Glantz 1985). It was commended that the in most cases appropriate method of expressing normal precipitation is the median (Thurow and Taylor, 1999)

Application of Geographical Information System in research and development of animal production

Geo-referencing is the process of assigning position (coordinates) to geographic objects on, above or below the earth's surface. A geographic information system is defined as observations on spatially distributed features, activities or events, which are definable in space as points, lines, or areas.

GIS has three main components. The first component is that the data is a geographical data – information on the location of geographical features- *where* the feature is.

The second component is attribute data, which is the type of information handled by a traditional information system. Attribute data describes features, or says *what* they are. In a livestock demographics database, attribute data may describe a village, and list the populations of different livestock species. In a GIS attribute data must be able fo be identified with its location – for instance, the name of the village or a village code could be used to link the attribute data to the geographical data, that information which describes where the village is. The third component of a GIS is data manipulation and analysis system, which joins the two types of data and performs analysis taking spatial distribution into account.

GIS has been used as a tool in decision making of animal productions. Monitoring of forage resources is a relevant indicator in pastoralist areas. Forage performance can be monitored by use of remote sensing technology, aerial photography and ground surveys. A remote sensing technique such as Normalized Difference Vegetation Index (NDVI) has been used to assess the forage abundance. NDVI, which shows vegetation greenness, can with complementary fieldwork be used to estimate forage biomass development. By comparing the monthly progressive NDVI values with long-term average pattern, areas experiencing adverse weather conditions.

Research in Thailand and Laos have demonstrated that appropriate active surveillance techniques and GIS could be effectively implemented in a developing country to improve the collection and management of animal health information. The research demonstrated that appropriate active surveillance techniques and GIS could be effectively implemented in a developing country to improve the collection and management of animal health information.

GIS also used a tool in environmental management. These integrate data of baseline studies and inventories (human activities, demographic and social data, economic activity and infrastructure, land use) and environmental inventory (natural resources inventory, land evaluation, environmental and conservation data).

The animal science research used geo-referenced tools in defining similar eco-regions for planning and management of livestock early warning system for Southern Pastoralist areas. The focus is on accessible pastoral households, which share common climatic, edaphic and production system attributes distributed throughout the area. This is Global Livestock Collaborative Research Support Program (GL-CRSP) in with collaboration with the Texas A&M University to develop in an integrated Livestock Early Warning System specifically designed to suit pastoral and agro-pastoral areas.

The Almanac Characterization Tool (ACT) was used initially to stratify large regions into units of similar environments called "effective environments" (Corbett, 1995). The SCT system provides a gridded (1 km x 1 km, 4 km x 4 km) geo-referenced database of a wide array of climatic attributes, soil types, human populations, road networks, livestock density, etc. Using principle component and cluster analysis, given area classified into units which meet the specified constants or attributes selected to define the geographical extent and subdivision in the region. The attributes are:

- Pastoral environment-arid, semi-arid, savanna,
- Livestock density
- Long-term monthly rainfall
- Population densities
- Market distance
- Access to road

Using principle component and cluster analysis, pastoral landscapes were classified into units which meet the specified attributes selected to define the geographical extent and subdivision in the region. Sampling within the clusters assures that time and funds are targeted for maximum impact and representations.

GPS technology is used to physically locate the sampling households. The Navstar Global Positioning System (GPS) is a network of 24 satellites in orbit around the earth that provides users with information about their position and movement. A GPS receiver computes position information by comparing the time it takes for signals from three or four different GPS satellites to reach the receiver.

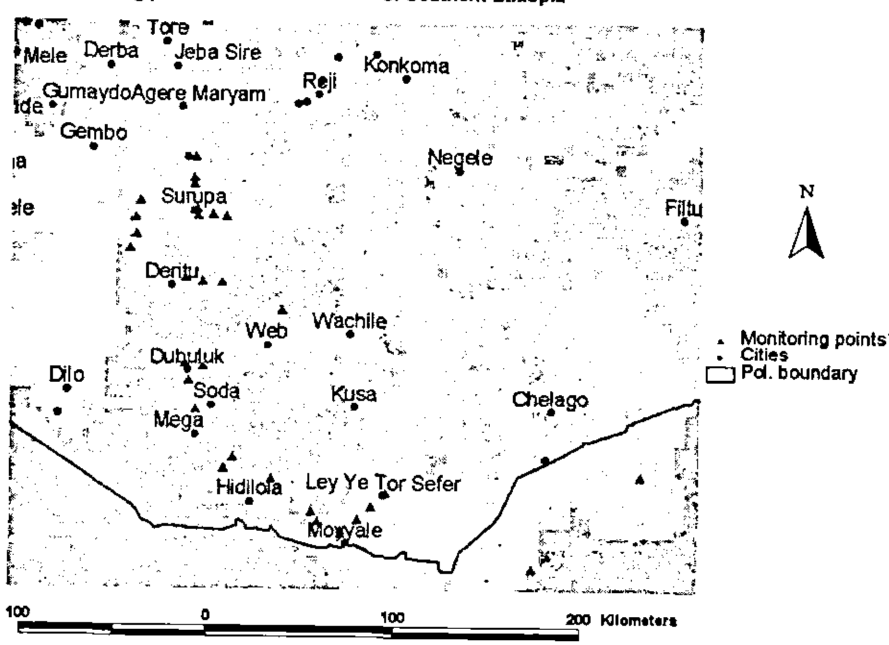
The biophysical models outputs of plant (PHYGROW is a hydrologic based plant growth simulation model), decision rules of grazing animals (models of multi-species plant communities grazed by multiple herbivores) are linked with spatial interpolation functions in ACT.

In summary, the spatial characterizations employed has assisted in

- ➢ Spatially characterization of climatic conditions and ecologically unique soil/plant systems
- ➢ To carefully select limited number of points /grids across a given area

- Selection of household monitoring sites considered the variables that affect production and thus delineate climatic cluster
- Climatic cluster provided a mechanism to help define the maximum extent of extrapolation of point-model output and allowed an objective mechanism to ensure that the monitoring points were located in a manner that optimized the subsequent geo-statistical analysis of the model output from the area in question
- Monitoring households, key resource areas (water, grazing areas) and migration staging area are geo-referenced using GPS.
- Able to integrate bio-physical models and spatial extrapolation using NDVI

Monitoring points in the Borana zone of Southern Ethiopia



Each color represents climatic cluster or effective environments

Future research area of Focus

In a given agro-ecosystem, communities of plants and animals; their interaction with their physical and chemical environments and the management of the farmers determine the animal production system. Effects of technologies differ across social and spatial locations due to political, physical and biological specificities of the area. Social knowledge is local-specific and more attuned to the ecological environment. The socio-economic factors influence of the daily decisions, choices of production system and thus effects of technological interventions vary accordingly. Access to capital, livestock assets, land tenure rights, access to markets, institutional development (Dorward, Kydd and Poultion 1998) and government policy have determinant effect on technological interventions and animal production system. For example, intensification of the system depends of socio-economic (knowledge, social structure, returns to investment, market), institution (access to credit, inputs, sustainability of inputs) and policy issues (farmers cooperatives, land tenure system). Integration of crop-livestock production system is largely determined by population/labor availability and land availability.

Thus integration of socio-economic attributes with spatially coherent biophysical data are needed for better understanding of animal production system, in developing appropriate technological decision and also to facilitate measurement of progress. Quite often agro-climatic zones are based on estimating the length of the growing period using rainfall and temperature data, on the ratio of precipitation to potential evapo-transpiration. However these are only part of the attributes that determine animal production system.

Focus has to be made in development of sector specific criteria, indicators and verifiers that can describe and categorize production environment, environmental stressors and institutional arrangements. Information are required on the pattern of demand and products of animal products, its changes across AEZ according to income and social class in order to guide technology development and investment in livestock.

Rational management is based on information of the physiology of the animal, the production system and the environment. The bioclimatic data are thus required for the following areas:

- For effective designing feed technological interventions
- Assess a useful heat tolerance index using physiological and biochemical changes
- Establish physiological processes contributing to the efficiency differences among animals in terms of reproduction rate, adaptive processes and nutritional status.
- Ecology of animal diseases
- New information on the physiology and ecology of rangelands and pasture plant species to contribute to better management
- Understanding of the ecology of emerging pathogens and management systems
- To address niche related problems - biophysical –degraded, vulnerable, potential for intensification
- Designation of benchmark areas as local focal points for strategic and diagnostic research
- Land potential and land use practices between attitudes

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CLIMATE AND FORESTS: IMPLICATIONS FOR DEVELOPMENT, CONSERVATION AND SUSTAINABLE UTILIZATION

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Abstract

This paper is a compilation of information relevant to climate and forests. It provides definitions of forests and climate followed by discussions on effect of climate and climate variability on forests as well as importance of Carbon Dioxide, light, temperature, precipitation/moisture and wind in forestry. It also summarizes the past and present status, achievements and gaps/constraints in the application of agro-meteorology, GIS and remote sensing in research and development related to forest resources in Ethiopia.

It, then, concludes with the way forward by enumerating the major topics that require attention in future endeavours of research and development pertinent to climate and forest resources in the country.

INTRODUCTION

Forests are not merely stands of trees but the total assemblage of trees, substrate on which they depend for support, nutrition and moisture; other plants which they interact in terms of mutual shelter, competition, benefit or antagonism; the animals that feed on, shelter under or benefit the plants; micro-organisms that exert direct or indirect beneficial or antagonistic effects on the trees and other living organisms; soil and atmospheric climate, including fire and moisture, that influence distribution and abundance of all organisms in the forest (Kimmins, 1997). They are, therefore, complex biological and physical systems in which there is enormous variety of interaction and interdependency among the different parts. The complexity, interaction and interdependency can be expressed using the following formulae: *Vegetation* = *f* (soil, climate, parent materials, topography, biota, time); and *Soil* = *f* (vegetation, climate, parent material, topography, biota, time).

Climate can be defined as an average state of the atmosphere over an area during a long period of time while weather refers to the particular condition of the atmosphere at one time in one place (Botkin and Keller, 1995). Climate elements include precipitation, temperature, humidity, sunshine, wind, etc. (Anonymous, 1997). Depending on the local condition, frost, fog, lighting, thunder, drought, flood, etc. could also be included (Anonymous, 1997). Climate shows tremendous variability on a global scale and, as a result, determines what kind organisms live where. If we know the climate, we can predict a great deal about what kind of life we will find in an area and what kinds could survive there if introduced.

Climate is an over riding factor that has great influence on all human activities as well as on research and development programs. Thus, it is an important resource. Therefore, it is necessary to understand the magnitude as well as the spatial and temporal distribution of climate parameters and their derivations, in order to exploit the climate resource of the country.

Effect of Climate and Climate Variability on Forests

Climate variability can be defined as fluctuations of climate above and below the mean state (Salinger, 1994). Climate extremes such as high and low temperature, heavy rainfall, drought, etc. are of particular significance to forests. Forests tend to be well adapted to the mean climate conditions of a region and show little sensitivity to moderate variations around those means. However, as conditions become progressively more extreme, the ability of tree species to adjust and respond without stress and damage declines, so that forest can be vulnerable to climate variability (Salinger, 1994).

For instance, high temperatures can exacerbate drought conditions, damage forests and reduce yields. Low temperatures are expressed through frosts and heavy snowfalls and the former usually curtail yields in frost sensitive plants. High winds cause significant damage to forests through mechanical damage to plants themselves as well as to any supporting structure. Heavy rainfall and floods are very costly, and any increases in flood magnitude may increase costs exponentially as areas previously considered safe require securing. Changes in frequency of heavy rainfall events would also increase the occurrence of landslips and landslides. Drought directly impacts on forest yields by reducing number of days available for plant growth. Climate variability and extreme events lower the resilience of forest ecosystems, both changing the occurrence of and making the ecosystems more susceptible to diseases and pest outbreaks (Salinger, 1994).

The effect of climate and climate variability on forestry is very significant. As climate affects many aspects of plant and animal biology, the effects of climatic elements and their extremes will significantly alter productivity in forest ecosystems, and in turn the socio-economic conditions of many societies, both developing and developed. Climate plays a major role in determining the yield levels, year-to-year variability and regional patterns of forests. Forests also affect climate, both on micro and local scale. Climate effects exercised by the forests can be altered by height, density and leaf area. On the micro-scale, forest cover has the effect of reducing wind speed within the forest itself and in clearings. On a large scale, forest cover affects climate through the changes in hydrological cycle.

Importance of Climate Variability in Forestry

Forest ecosystems are characterised by time scales over which considerable climate variability is known to occur. Therefore, the establishment and evolution of forest ecosystems, their status, and the life cycle of many individual ecosystem components intrinsically represent successful adaptation to local and regional climate and to the variability of that climate (Sommers, 1994). Components of those ecosystems composed mainly of long-lived individuals, trees for example, demonstrate such adaptation in individual members as well as in the overall population. Components of short-lived individual members, such as insects, demonstrate it through population dynamics. A full representation of forest ecosystem responses to climate variability should include responses of vegetation, wildlife, soils, water, air, pathogens, several other factors, and their interactions.

Disturbance phenomena should also be considered when characterising forest ecosystem responses to climate variability. While forest ecosystems evolve slowly, major changes occur very rapidly in such catastrophic events as forest fires, insect and disease outbreaks, wind storms, etc. When these disturbance phenomena take place, wholesale ecosystem changes occur at the minor catchment to landscape scales in periods ranging from a few hours to a few years. These disturbance events often result after multiple stresses have seriously weakened trees. Climate variability in the form of moisture stress (drought) and temperature stress (extreme cold or heat at the wrong time) is included in a list of primary stressors. Thus, forest ecosystems respond to climate variability through both long-term stress and disturbance phenomena. These responses are most often manifested in those parts of forest ecosystems that are closest to the margins of age and distribution for the particular ecosystem. Put simply, old, decadent tree stands and tree stands growing at the margins of species adaptability are most likely to succumb to stress, pathogen attack, forest fire and physiological damage from wind and ice. These introductory comments set the context for placing the following subsections on Carbon Dioxide, light, temperature, wind, and moisture in forestry (Sommers, 1994).

Importance of Carbon Dioxide in Forestry

Metabolism of CO_2 is essential to tree ring growth and Carbon composes about 50% of the dry weight of trees (Sommers, 1994). Forests occupy about one third of the area of global terrestrial ecosystems and are estimated to hold 60-90% of the total terrestrial Carbon pool (Sommers, 1994). Net primary production of Carbon from metabolism of atmospheric CO_2 is estimated to be of the order of 36 x 1015 g/yr. Thus forest ecosystems are, thus, dependent on atmospheric CO_2 for existence and growth. They are a primary factor in the flux of Carbon between the atmosphere and the biosphere, and a principal Carbon storage agent in trees and soils (Sommers, 1994). Therefore, deforestation does not only lead to shortage of wood for various purposes, degradation of land and water bodies, and decline/loss of biodiversity (EFAP, 1994) but also to significant increase in atmospheric concentration of CO_2 and contributes 50-60% of the anthropogenic green house gas effect (Global Warming) (Botkin & Keller, 1995).

In turn, global warming could make the forests more vulnerable to the possible impacts of global warming, because of their slower adaptation compared to agricultural systems. Therefore,,, the possible global warming effects could be: (1) vertical and horizontal displacement of vegetation;(2) decline of/ changes in forest biodiversity; (3) change in types, location or intensity of pests and diseases; (4) frequent forest fire (due to inductive climatic conditions); (5) inhibition of regeneration; (6) recurrent drought that reduces growth rate; and (7) expansion of desertification. The impact assessment made for Ethiopia as well as for the regions that have a significant forest cover based on the Holdridge Model, which correlates forests to climate indices indicated expansion of tropical desert scrub, dry and very dry forests, shifting of forests and disappearance of montane and lower montane forests (Negash Mamo, 2001).

IMPORTANCE OF LIGHT IN FORESTRY

Availability of light is the second major external factor (after CO_2 concentration) that determines photosynthetic rate. On a global scale, light availability is primarily of latitude and secondarily a function of cloud cover. Ecosystem composition in terms of predominant, co-dominant and other species reflects adaptive response to light availability among other environmental factors (Sommers, 1994).

In terms of light variability, the most important responses are associated with microclimatic effects within the forest ecosystem. The forest ecosystem, thus, becomes internally regulating through the relative availability of light reaching the various leaf surfaces of component members of the ecosystem. A critical stage in forest evolution, from establishment to maturity and decadence, is the point where canopy closure takes place. Canopy closure acts to limit or eliminate growth of sub-canopy and forest floor species by limiting light availability. Prior to canopy closure, sufficient light reaches sub-canopy trees and the forest floor to allow for sufficient photosynthesis by non-dominant species. The interaction with wildlife is important here since closed canopy forest ecosystems seldom permit enough light to penetrate and adequately support optimal vegetative growth for browsing animals. Thus, the basic composition of forest ecosystems responds to light variability (Sommers, 1994).

Light plays a very important role in the management of forests. Forest nursery manager should be aware of the influence of light on plant morphology. Damage of plants as a result of sudden increase in light intensity involves the foliage, but also stems because of the heating effects of solar radiation.

Sunscald, i.e. the killing of bark following sudden exposure to sunlight, commonly occurs when thin-barked species growing in dense stands are suddenly exposed to direct sunlight by removal of adjacent trees (Kimmins, 1997). Similarly, new or epicormic branching common in previously shaded hardwood stems that experienced a great increase in light intensity can have important implications for timber quality.

Failure to recognize the relationship between light intensity and plant morphology in the forest stand can result in poor resistance to wind, drought damage and poor growth form with heavy branching. Also, light regime created by stand thinning will have a major influence on the species diversity of natural regeneration. Therefore, manipulation of light conditions in the stand to give trees of desirable form and timber quality and to obtain desired species composition and stand structure is a major objective of Silviculture (Kimmins, 1997).

IMPORTANCE OF TEMPERATURE IN FORESTRY

Temperature is a main determinant of forest ecosystem placement. A global mapping of average temperatures and ranges of temperature would roughly map forest type distributions (Sommers, 1994). Of the global forest area, approximately half is tropical forest growing in environments where temperatures are relatively unvarying and generally not extreme. Temperatures that limit biological activity and may pose problems for the forest manager at some time of the year characterize the other half. Extreme temperatures and rapid changes in temperature can damage trees in many ways, namely bud killing that gives rise to multiple leaders, cracking of stems that reduces timber value and leads to invasion by decay organisms. This is most severe on the most productive sites than drier and less productive sites (Kimmins, 1997). Temperature variability causes forest ecosystem responses through effects on photosynthesis, growth and water loss. These physiological responses, along with other temperature effects such as winter injury damage, produce stresses in trees that can lead to insect and disease attacks, forest fires, and other disturbance phenomena (Sommers, 1994).

Photosynthesis depends on temperature in a manner similar to many chemical reactions (Sommers, 1994). Photosynthetic rate increases with temperature to a certain point and then begins to decrease (Kozlowski et al., 1991, Sommers, 1994; Kimmins, 1997). The maximum rate of photosynthesis for a given light intensity is therefore, temperature driven. There is a range of temperatures below which and above which a given plant's photosynthetic rate is negligible. Temperature is thus seen to cause a direct photosynthetic response.

Tree growth responds to temperature variability in various other ways (Sommers, 1994). Cold temperatures tend to produce a more definitive limit to growth than warm temperatures because of the freezing point of water. As with photosynthesis, growth increases with temperature up to a certain optimum and then decreases rapidly. Temperature affects the ability of tree roots to absorb moisture, with very little moisture movement occurring when the soil is frozen. Tree growth responds to temperature variability in different ways according to species. Damage, dieback and decline of forest species have been related to temperature variability. Higher than normal soil temperatures are though to damage root mycorrhizae that are needed to facilitate nutrition of trees. Ecotypes from different regions have different environmental calendars, and if moved to a new climatic region, they may suffer frost damage because of inadequate hardening. For example seedlings grown in nurseries at lower attitudes may suffer frost damage when planted out at higher altitudes if their temperature experiences in the nursery have not prepared them for the temperature conditions at the planting site (Kimmins, 1997). The planting of a single species over a wide range of sites, aspect, altitudes, and latitudes that vary greatly in temperature has naturally resulted in variable regeneration success. Microclimate, especially the thermal regime of the microenvironments, is often very important for forestry. Micro sites that are only a few meters apart may differ greatly in temperature regime according to aspect, slope, shading, soil moisture and soil colour. Frost pockets may preclude reforestation of microclimates that are adjacent to areas only a couple of degree warmer but in which regeneration is successful.

Importance of Precipitation/Moisture in Forestry

Water is the material that makes life possible since it acts as the medium in which all life processes occur. It is the most important prerequisite for life, second only to energy, and forms a continuum in trees from soil, through roots, stems, trunks and leaves to the atmosphere. Water is a vital part of photosynthesis, which is also needed in exchange of gases with atmosphere. It acts as a transporting system permitting nutrient uptake from the soil and moving metabolites around. It removes waste products by regulating the temperature of organisms (Kimmins, 1997).

Whereas temperature is a main determinant of forest placement, moisture is the main determinant of forest existence (Sommers, 1994). The division between forest and non-forest lands closely follows mean annual precipitation patterns. Moisture in forest ecosystems should be considered in terms of precipitation, evaporation, transpiration and soil moisture. Moisture variability is of major importance in terms of long-term forest health and as it contributes to increased or decreased probability of catastrophic disturbances. While variability in the form of increased moisture can occasionally cause some disease problems, most negative forest responses to moisture variability arise from moisture deficit situations. Variability in the supply of moisture, thus, traNSRCates very directly into variability in the basic life and growth process of forests. At larger scales, the variability of moisture results in long-term forest ecosystem responses in terms of tree species, other vegetation, soils, wildlife, and almost all other components. In sum, forests respond to moisture variability in ways that affect the productivity, health and diversity of almost all ecosystem components, and to a degree much greater than variability in any other atmospheric parameter.

Large forest areas exert a major influence on water cycle (Kimmins, 1997). Manipulation of forest vegetation results, in many, modification of the water cycle in the treated area. Removal of tree cover reduces interception and eliminates canopy redistribution of precipitation. It also eliminates transpiration, increases evapo-transpiration, and reduces infiltration, if soil is compacted during harvesting. As a result, increased overland flow and accompanying erosion may occur. Total stream flow is increased by the reduction of interception and transpiration, and peak stream flow will be increased if surface run-off to streams is increased significantly. Increased stream discharge produces a variety of changes in the stream environment, such as bank erosion, flooding and disturbance to fish habitat.

Moisture stress (excess or deficit) plays a major role in determining the success of artificial regeneration programs. Alteration in the hydrological cycle following logging can play a major role in determining the success or failure of regeneration. Tree productivity in developing stands is closely related to soil moisture conditions because soil moisture dictates the biomass foliage and photosynthetic efficiency. Any forest management activity that reduces the moisture status of either dry or moist sites will probably be accomplished by loss of production. Conversely, on excessively wet sites, reduction in moisture will normally be highly beneficial for tree growth (Kimmins, 1997).

Forests are important for maintaining the quality and regimen of stream water that make it suitable environment for aquatic life and a useful commodity for agricultural, domestic and industrial use. Socio-economic value of steam flow regulation, stream water quality control and maintenance of fish habitat may exceed the socio-economic value of timber in many watersheds. Therefore, in such areas, timber management must take second place to watershed management. This may require radical modification of harvesting plans or even a total restriction of harvesting (Kimmins, 1997).

IMPORTANCE OF WIND IN FORESTRY

Wind has a wide variety of ecological effects (Kimmins, 1997), and plays a principal role in the life cycle of forest ecosystems (Sommers, 1994). It transports water vapor from lakes and oceans to the land and, thus, ensures the supply of moisture. It also carries pollen, disperses seeds, transports insects and diseases, drives forest fires, and causes damage through breakage and blow down (Sommers, 1994; Kimmins, 1997). It removes dust and organic particles from one ecosystem to another. It removes fine soil particles and converts medium textured soils to sand and rocky substrates with accompanying changes in soil fertility and moisture. This is an important mechanism in the process of desertification.

Wind influence evaporation and transpiration and causes desiccation damage and even death of plants. Wind transports heat energy and moderates temperature by carrying warm air to cold region and vice versa. It also disperses atmospheric pollutants and destroys property, uproot trees, sink ships, erode soils and destroy farm and forest crops. Wind (high wind) can be used as a source of energy. Friction of one turbulent air mass on another generates static electricity that results in lighting and causes wildfires. And also it supplies nitrogen to ecosystems by producing oxides of N_2 in the atmosphere.

Forest structure interacts with wind to determine wind distribution within a forest and the stress individual trees receive from the wind. Large differences in wind speed profiles relate to canopy structure and density, with higher in-forest wind speeds associated with more open canopies. Large openings in forests result in stronger winds at the forest edge along the downwind side of the opening. With deciduous forests, the effect of wind varies significantly depending on the presence or absence of leaves.

Many species of forest insects depend on wind within the forest for transport to new host trees. Dispersal of fungi within the forests is heavily dependent on, and related to, wind variability. There are complex dynamic interactions between wind and trees that can add to the damage caused by wind (Sommers, 1994). Wind variability in the form of speed, gusts or directions of a climatologically unusual nature causes vibration frequencies in trees that can lead to excessive breakage or uprooting. Wind variability in the form of major disturbance phenomena associated with tornadoes, thunderstorm downbursts or cyclonic storms such as hurricanes can cause significant amounts of forest damage and blow down that are related directly to canopy structure.

Another major category of forest response to wind variability involves the fluxes of heat, momentum, gases and particles between the forest and the atmosphere. These fluxes primarily involve transfers between the atmosphere and forest canopy. In sum, fluxes of all variables between forests and the atmosphere are enhanced by increased wind variability (Sommers, 1994).

Forest fires represent one of the most critical considerations of the response of forests to wind variability. When catastrophic forest fires occur, in all places in the world, stronger than normal wind conditions are usually present. Forest fires may be affected by ambient wind variability in a small area, or at times be influenced by ambient wind variability over areas of thousands of hectares. Fires often grow large enough for fire induced convective winds to become a major factor in wind variability. When dry forest conditions, high temperatures, low humidity and ignition sources, such as from lighting, combine with strong and variable winds on a regional scale, fire complexes result (Sommers, 1994).

Most historic forest fires worldwide were actually fire complexes where more than one individual fire was involved. Under the most severe wind conditions, large fires can merge with other large fires and result in million hectare conflagrations. Fortunately, only a very small percentage (less than 2%) of forest fires ever reach conflagration size (Sommers, 1994). Strong winds can drive forest fires forward at rates of spread approaching 2 to 3 meters per second. In addition, these strong and variable winds can lift burning embers and send them kilometers ahead of the main fire to start new fires, a mechanism known as spotting. These types of catastrophic fires are usually not controlled until the wind decreases or the fire runs out of forest to burn.

Agro-Meteorology, GIS, Remote Sensing And Forest Resources In Ethiopia

In the following sub-section, brief accounts about past and present status on the application of agro-meteorology GIS, remote sensing in research and development of forest resources in Ethiopia, achievements made thus far and gaps/constraints encountered in this regard are presented. It is hoped that this chapter would help to lay the foundation for mapping the way forward.

Past and Present Status and Achievements

The development, sustainable utilization and conservation, in general, the welfare of forest resources is closely dependent on meteorological phenomena. Therefore, establishment of meteorological stations/centers inside or in the proximity of forest areas and the application of GIS/remote sensing to monitor, document and evaluate climatic conditions continuously are of paramount importance.

However, none of the 58 Forest Priority Areas (NFPA) and other forests have meteorological station except the recent modern mini meteorological station, which is being used for our joint project with the University of Bayreuth in Munessa natural forest. As a result, meteorological information/data especially on our forest resources is lacking. Hence, published meteorological data on Ethiopian forests is adopted from nearby meteorological stations with their own limitations. Similarly, application of GIS and remote sensing as tools research and development on forest resources in Ethiopia is at its infancy.

In spite of the apparent gaps mentioned above, different institutions and individuals have made encouraging initiatives and achievements. These include:

- Ethiopian Mapping Authority: generated valuable meteorological and remotely sensed data, and produced different maps and aerial photos.
- Ex-Land Use Planning and Regulatory Department within the then Ministry of Natural Resources Development and Conservation and Environmental Protection: generated valuable meteorological data and produced several maps.
- Woody Biomass Inventory and Strategic Planning Project, Ministry of Agriculture (MOA): generated valuable meteorological data and produced several maps.
- Natural Resource Management and Regulatory Department (MOA) in cooperation with GTZ: produced a document entitled "*Monitoring Forest Resources in Ethiopia*" (Reusing, 1998) using remotely sensed data and aerial photos.
- Ministry of Water Resources: generated valuable meteorological data and produced several maps.
- Several individuals: produced GIS/remotely sensed data-based PhD (Getachew Eshete, 1998) and MSc (Betre Alemu, 1998; Kebede Seifu, 1998; Bedru Sherefa, 2001) thesis and Scientific publications (Negash Mamo, 2001), just to mention a few.

Gaps/Constraints

During our reviewing of available information on the relationship between climate and forest resources, particularly in Ethiopia, we have identified some gaps/constraints that should be given attention in future research and development efforts relevant to climate and forest resources. These include:

- lack of or insufficient/inadequate knowledge on the climatic (ecological) requirements of even the most important commercial timber and non timber products producing forest plants;

- lack of or insufficient/inadequate knowledge on responses of forest ecosystems and their components to climate variability;
- lack of or inadequate facilities/ technologies (including software and images) and knowledge/skill for the application of meteorological information/data, GIS and remote sensing in forestry research and development;
- lack of database and documentation system(s) for the acquisition, storing, processing, documenting or compiling, dissemination and exchange of meteorological data (information) on forest resources in the country;
- inadequate or lack of linkage or networking and collaboration of forestry research with national, regional, continental and international meteorological and mapping institutions or agencies;
- absence of stations/centers specially established to collect meteorological data in forest ecosystems;
- lack of exact current coverage of forest resources and tree species of at least economic importance in the country;
- absence of systems and appropriate facilities for monitoring decline or expansion of forest resources in the country;
- lack of reliable climate data of longer time span and wider coverage;
- complete lack of trained manpower in forest climatology and insufficient financial and physical resources;
- lack of refined agro-ecological and vegetation maps for research and development; and
- lack of systems for monitoring meteorological conditions continuously to provide reliable empirical data on possible risk of forest fire hazard in the different forest areas of the country;

The Way Forward

As concluding remarks, we would like to underline that in our future endeavours of research and development pertinent to climate and forest resources in the country, the following topics have to be addressed properly.

- Design strategies or mechanisms to bridge the gaps enumerated above.
- Develop research projects or proposals, whenever feasible, in close collaboration with the Agro-Meteorology and GIS Program in EARO and other relevant institutions within and outside the country, on the following themes:
- Climatic requirements and ability of Carbon sequestration (ecophysiology) of economically important forest trees or plants.

- Effects of the spectral quality and quantity of light in the regeneration (seed germination, seedling establishment and growth), floristic diversity and population structure in forest ecosystems.
- Relationship between light, morphology of trees and their timber quality.
- Spatial and temporal monitoring of forest resources in the country, thereby providing accurate information on the extent of forest cover as well as the rate and extent of deforestation or afforestation.
- Inventory of and predictions on woody biomass resources in the country.
- Screening of trees or shrubs that are tolerant to moisture stress and periodical or permanent water-logging.
- Impact of wind on natural, plantation and farm forests as well as woodlands and bushlands, i.e. evapo-transpiration, enhancing forest reproduction (pollination, seed setting and dispersal) and causing damage (wind throw, breakage of parts or whole trees or shrubs, forest fire, forest diseases and pests), etc.
- Effect of climate (light, temperature, rainfall, wind, etc.) variability (including drought and global warming) on development, conservation and sustainable utilisation of forest ecosystems (vegetation, wild animals, micro organisms, pathogens and pests, soils, water, air, etc.).
- Characterising forest ecosystem responses to climate variability combined with long-term stress and disturbance phenomena, e.g. forest fires, insects and disease outbreaks, wind storms, etc.

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