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Estimation of Evapotranspiration for Irrigation
Performance Assessment Using Satellite Remote Sensing at
Kobo Valley Irrigation Project, Northern Ethiopia

By
Tegegne Molla



Thesis Submitted to School of graduate studies
Addis Ababa University to the partial fulfilment of MSc degree in
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List of frequently used symbols

Symbol	Representation	SI Unit
WGS	World Geodetic Survey	-
ERDAS	Earth Resource Data Analysis System	-
ETM+	Enhanced Thematic Mapper	-
<i>NDVI</i>	Normalized Difference Vegetation Index	-
<i>P</i>	Precipitation on the gross command area	mm
<i>P_{eff}</i>	Effective Precipitation	mm
α	Surface albedo	-
<i>r_{a,h}</i>	Near-surface aerodynamic resistance for heat transport	s/m
<i>R_n</i>	Net radiation flux density	W m ⁻²
<i>V_c</i>	Actual irrigation water supply from the main source to a command area	m s ⁻¹
<i>z_{oh}</i>	Roughness length for heat transport <i>L</i>	m
Δ	Slope of the vapor pressure curve	Pa K ⁻¹
ϵ_{NB}	Narrow band surface emissivity	-
ϵ_o	Broad band surface emissivity	-
γ	Psychrometric constant	Pa K ⁻¹
<i>A</i>	Evaporative fraction	-
λ	Latent heat of vaporization	J kg ⁻¹
<i>λET</i>	Latent heat flux density	W m ⁻²
<i>c_p</i>	Air specific heat	J/kg/K
FAO	Food and Agriculture Organization	-
MoWR	Ministry of Water Resources	-

Abstract

This paper describes the use of a remote sensing technique, the Surface Energy Balance Algorithm for Land (SEBAL), to assess actual evapotranspiration across Kobo valley irrigation project. The SEBAL model was applied to the Landsat 7 ETM+ image corresponding to December 05, 2003 to produce estimates of ET at 30×30m resolution. The actual evapotranspiration (ET_a) was integrated for 24 hours on a pixel-by-pixel basis from the instantaneous evapotranspiration (ET). SEBAL ET_a estimates vary from 0 to 4.86 mm/day over the image. Lowest ET_a was observed for barren fields and highest for water bodies. ET_a for vegetative areas ranges 3.5 to 4 mm/day. Irrigated areas, drip and sprinkler irrigation systems, appear to evaporate with average rate of 1.8 mm/day. Penman-Monteith reference crop evapotranspiration ET_0 on the same day was found to be 4.5 mm/day at the meteorological station. During the dry season, actual evapotranspiration increases with the availability of moisture in the soil instead of the temperature gradient. The performance of the irrigation system for the command area (September to January) was determined according to 5 indicators, namely overall consumed ratio (OCR), relative water supply (RWS), depleted fraction (DF), crop water deficit (CWD), and relative evapotranspiration (RET). Potential and actual evapotranspiration parameters used in determining these indicators were estimated according to the SEBAL (Surface Energy Balance) method using Landsat ETM+ image. Seasonal averages of the irrigation project calculated from the results were 0.55, for OCR; 1.23 for RWS; 0.29 for DF; 42.44mm/month for CWD; 0.43 for RET. According to the seasonal average values of all the performance indicators, the irrigation performance of the area is usually poor and only the overall consumed ratio indicator is within the range of acceptability. Thus, performance indicators showed that less irrigation water was supplied to the area than was needed.

Keywords: Performance indicators, performance assessment, evapotranspiration, SEBAL, remote sensing

1. Introduction

1.1 Water for irrigated agriculture

By the year 2025, about 83 % of the global population of 8.5 billion is expected to live in developing countries. Yet the capacity of available resources and technologies to satisfy the demands of this growing population for food and other agricultural commodities remains uncertain. The world's food production depends on the availability of water. The role of water as a social, economic, and life-sustaining good should be reflected in demand management mechanisms and be implemented through resource assessment, water conservation and reuse. Water demands are increasing rapidly and thereby, available water for agriculture is getting limited. However within a river basin water is used by numerous of users (UNCED, 2002).

Irrigation is the backbone of the peasant society. It is a sector where significant amount of the fresh water is required. About 70% of the world's total withdrawals are for irrigation, and it contributes to 30-40% of the world's food production. Water resources have to be managed very clearly from the Irrigation districts to the irrigated crops, eventually reaching to smaller areas and users.

The irrigation potential in Africa is estimated at more than 42.5 million ha (irrigation potential by basin and renewable water resources), while 13.4 million ha (31.5%) are water managed areas. Since numerous African countries consider water and irrigation management as key factors to upgrade their food security and to secure access to drinking-water, integrated water resources management and the development of small-scale irrigation are incorporated in various policies or legislative proposals (World Bank, 2003).

Ethiopia is the third most populous country in Africa and is rated the poorest in the world, ranked among the last out of 208 countries, with a per capita gross national income of USD 90 in 2003. According to the Central Statistical Agency of Ethiopia (CSA, 2008), the total population in Ethiopia for 2007 was estimated 73,918,505 about 83.83 percent of which lives in the rural areas depending on subsistence agriculture. Though agriculture is the dominant sector, most of Ethiopia's cultivated land is under rain-fed agriculture. Due to lack of water storage and large

spatial and temporal variations in rainfall, there is not enough water for most farmers to produce more than one crop per year and hence there are frequent crop failures due to dry spells and droughts which have resulted in a chronic food shortage currently facing the country (Awulachew et al. 2005). Insurance against short duration of drought, cool soil, and atmosphere making them more favorable for crop growth, washout or dilute salts in the soil reduce soil piping and soften tillage pans are important purposes of irrigation. Irrigation is an old practice for crop production in arid and semi-arid regions where annual evapotranspiration exceeds precipitation. However, due to population pressure, increased demand for food and fiber, irrigation is becoming increasingly important in cool and humid region (Bastiaanssen et al., 2000).

In Ethiopia, irrigation was an age old practice and continued to date with minimal scientific input in most parts of the country. The problem of food security had long been in a priori importance in Ethiopia. The problems of land degradation, population pressure, low productivity in agriculture, improper utilization of resources, poor infrastructure, absence or poor level of adoption of technological innovations, etc., contribute food insecurity in the country. The situation in the Amhara National Regional state as well as in Kobo Girana Valley is not of difference from the national situation (KGVDP, 1999).

Measuring the evapotranspiration is of highest importance for understanding and eventually intervening into the water cycle of natural systems, especially different critical users of water, like irrigated areas and their field crops. A number of research projects undertaken in the past have estimated reference ET from meteorological data and converted this to actual ET. The major disadvantage of this approach is that most methods generate only point values, resulting in estimates that are not representative of larger areas. These methods are also based on crop factors under ideal conditions and cannot therefore represent actual crop ET.

The use of Remote Sensing techniques to estimate evaporation is achieved by solving the energy balance of thermodynamics fluxes at the surface of the earth. Remote sensing used for calculating the actual evapotranspiration (ET_a) based on the equilibrium between the radiation balance and the energy balance at the surface of the Earth.

1.2 Irrigation Development in Ethiopia

Irrigation is practiced in Ethiopia since ancient times producing subsistence food crops. Irrigation activities started in the 1950s with principally large-scale projects for agricultural purposes and power generation (Dessalegn, 1999). Ethiopia has an area of 2,700,000ha potential irrigation areas. Today only 11% (289,530 ha) of the potential irrigation area is water managed.

The Ethiopian plateau is the source of the Abay, Awash, Tekeze, Mereb, Baro-Akobo and Omo rivers that flow to the west and southwest. Denakil river basin is the one from the major river basins which has an area of 74,002 km², which covers part of Tigray, Amhara and Afar regional states. The basin has no major river draining out of it. The basin has a lowest elevation of -197 m at Denakil depression, the lowest altitude of the country, and a highest elevation of 3,962 m. The total mean annual flow from the river basins is estimated to be 0.86 BMC. Around 12 small-scale, 33 medium-scale, and 8 large-scale, and a total of 53 irrigation potential sites are identified in the basin. A total of 158,776 hectares of potential irrigable area is also estimated. Out of these, a potential 2,309 hectares are for small-scale, 45,656 hectares for medium-scale and 110,811 hectares for large-scale development (Awulachew et al, 2007). Table 1 below shows the potential irrigation areas in Ethiopia separated by hydrological basins (Dessalegn, 1999).

River Basin	Irrigable Land (ha)
Awash	185,000.00
Wabe Shebelle	355,000.00
Genale-Dawa	300,000.00
Rift Valley (Lakes)	50,000.00
Gibe-Omo	250,000.00
Baro-Akobbo	600,000.00
Tekezze & Northern	200,000.00
Abbay (Blue Nile)	760,000.00
Total	2,700,000.00

Table 1 Potential irrigation areas in Ethiopia

Irrigated agriculture is facing new challenges that require refined management and innovative design. Formerly, emphasis was centered only on project design; however, current issues involve

limited water supplies with several competing users, the threat of water quality degradation through excess irrigation, and narrow economic margins. Meeting these challenges requires improved prediction of irrigation water requirements.

The amount and timing of precipitation strongly influence irrigation water requirements. In arid areas, annual precipitation is generally less than 10 inches and irrigation is necessary to successfully grow farm crops. In semiarid areas (those typically receiving between 15 to 20 inches of annual precipitation), crops can be grown without irrigation, but are subject to droughts that reduce crop yields and can result in crop failure in extreme drought conditions.

Modern irrigation systems were started in the 1960s with the objective of producing industrial crops in Awash Valley. Private concessionaires who operated farms for growing commercial crops such as cotton, sugarcane and horticultural crops started the first formal irrigation schemes in the late 1950s in the upper and lower Awash Valley. In the 1960s, irrigated agriculture was expanded in all parts of the Awash Valley and in the Lower Rift Valley. The Awash Valley saw the biggest expansion in view of the water regulation afforded by the construction of the Koka dam and reservoir that regulated flows with benefits of flood control, hydropower and assured irrigation water supply (MoWR, 2002).

Currently, the government is giving more emphasis to the sub-sector by way of enhancing the food security situation in the country. Efforts are being made to involve farmers progressively in various aspects of management of small-scale irrigation systems, starting from planning, implementation and management aspects, particularly, in water distribution and operation and maintenance to improve the performance of irrigated agriculture.

It is expected that through an optimal development of water resources, in conjunction with development of land and human resources, a sustainable growth of food production can be achieved. Since the mid-1980s, the Ethiopian government has responded to drought and famine through promoting and construction of irrigation infrastructure aimed at increasing agricultural production. These are traditional, small, medium and large-scale irrigation schemes performing at different levels. Irrigation development has positive socio-economic and some negative environmental impacts (Awulachew et al., 2007). The total irrigated area in year 2002 was 197,000 hectares with a coverage distribution of 38% traditional, 20% modern communal, 4

percent modern private and 38 percent public schemes (MoWR, 2002). The revised figure puts the total irrigated area at about 250,000 hectares (Awulachew et al. 2007). This number gives a per capita irrigated area of about 30 m². This figure is very small compared to 450 m² globally. Water resources management for agriculture includes both support for sustainable production in rain-fed agriculture and irrigation. Not overlooked should be soil protection and maintaining soil fertility. Currently, the MoWR has identified 560 irrigation potential sites on the major river basins. The total potential irrigable land in Ethiopia is estimated to be around 3.7 million hectares (MoWR, 2002).

1.3 Irrigation Development at Kobo Valley

The Kobo Irrigation Project is one of the many demonstration activities established under the special cooperation program developed by MASHAV, the Center for International Cooperation of the Israel Ministry of Foreign Affairs, in cooperation with the United States Agency for International Development (USAID).

Irrigated agriculture was one of the considerations in the study area with little emphasis to large scale development. The improvement of the existing small scale traditional schemes was done. The necessity of river training was recommended too, as the agricultural land lost by bank erosion and heavy sand gravel inundation is high.

Irrigation has been practiced for long time along those Gobu, Hormat and Golina rivers. In areas close to periodical rivers like Gobu and other flood courses the runoff is diverted to the field whenever available to supplement the rainfall. Irrigation using ground water is not also considered as promising due to its high investment cost, economy and energy problem for the operation. However a pilot scheme was proposed for further investigation of the economic and technical possibilities and today pressurized irrigation is practiced in most part of the Kobo Valley. The other irrigation activity was practiced by Ethio-Italy Programme for Rehabilitation and Development about twelve years ago. The programme was mainly focused on construction of diversion structures on Golina and Alawuha rivers for irrigation development of about 800ha on both schemes. The implementation of these structures are undergoing currently.

The successful achievement in the area with respect to the promotion of both gravitational and pressurized irrigation systems are the change in the attitude of farmers on the effectiveness of the gravitational irrigation systems. From the beginning, farmers were suspicious on the suitability of the pressurized irrigation system and the capacity of drips to satisfy crop water requirements. However, later, the farmers proved the potential and the capacity of the system. The pressurized irrigation system in the area is economically feasible even at farmers' level and farmers who exercised recommended practice gain good income (KGVDP, 1999).

Kobo-Girana Valley Development Programme Office was initiated in 1999 by the Amhara National Regional State with the goal of bridging the gap between the creation and utilization of irrigation potential and for optimizing production and productivity from irrigated lands on sustainable basis. The programme mainly involves crop husbandry, livestock resources development, natural resources development, and irrigation infrastructure development over a period of 25 years. The development of irrigation systems in the valley is increasingly coming to be the core activity of the program implementation.

1.4 Definitions of Terms

Different terms are used in this research and defining them is expected to fulfill the interest of the user. The terms are defined by different researchers and organizations but the concept is the same.

Irrigation- is referred as the process by which water is diverted from a river or pumped from a well and used for the purpose of agricultural production (FAO, 1986). It is the science and art of artificial application of water to soil to supplying the moisture essential for plant growth.

Evapotranspiration (ET)- is the amount of water that plants use in transpiration and building cell tissue plus water evaporated from an adjacent soil surface (Allen et al., 1998).

Actual Evapotranspiration- the physical process whereby water flows from evaporating surface in to the atmosphere (Thorntwaite, 1944 in Fetter, 1994).

Reference Evapotranspiration (ET_0)- is the Evapotranspiration rate from a reference surface, not short of water, which can be a hypothetical grass surface with specific characteristics.

Potential Evapotranspiration ET_p - may be referred as the water flux from crops that are grown in large fields under optimum soil moisture, excellent management and environmental conditions and achieve full production under the given climatic conditions (Allen et al., 1998).

Crop Water Requirement- crop water requirements can be defined as the quantity, or depth, of irrigation water in addition to precipitation required to produce the desired crop yield and quality and to maintain an acceptable salt balance in the root zone (Allen et al., 1998).

In view of this current concept, the annual or seasonal effective rainfall should be interpreted as that portion of total annual or seasonal rainfall which is useful directly and/or indirectly for crop production at the site where it falls but without pumping. It therefore includes water intercepted by living or dry vegetation, that lost by evaporation from the soil surface, the precipitation lost by evapotranspiration during growth, that fraction which contributes to leaching, percolation or facilitates other cultural operations either before or after sowing without any harm to yield and quality of the principal crops (FAO, 2006).

1.5 Statement of the Problem

The challenges in the promotion of irrigation development are not easy in the area as well as in other parts of the Amhara Region. The nature of farmland distribution is uneven and fragmented on the potentially irrigated lands. Some farmers have about a hectare of land in the irrigation system, may be more than a plot and unable to manage properly with the requirement of the irrigation system. These require accurate determination of Remote Sensing based water requirement of each crop on each fragmented farmland for appropriate water supply.

Performance gap in the area, the deviation of the actual performance of irrigation from the target level, is the determination of low performance. However, prior to take corrective measures, the cause for low performance needs be diagnosed. To increase the agricultural productivity through improved management of the available resources, the national goals are specified. In the goal achieving process, performance of the irrigated agriculture process and crop productivity determines whether the targets are attained or not.

The rationale behind performance assessment is to diagnose any performance gap in the goal achieving process and rectify the situation. Hence, Irrigation managers at different levels (from

irrigation experts up to DAs) should identify the performance gap, find the causes for the gap, and take corrective measures to cure the target performance.

Therefore, suitable performance assessment criteria have to be developed and assured. Also, appropriate performance indicators to assess the performance of the scheme have been identified. Water managers of an irrigation scheme should monitor the performance of key operations closely to identify shortcomings of irrigation activities and take corrective measures at the right time. Performance assessment provides relevant feedback controls to the management, where as performance indicators provide necessary information for those controls. In order to make decisions at the right time, the delays of acquiring and processing of field data should be minimized. Remote Sensing provides a potential capability for routinely monitoring ETa at irrigated areas by combining remotely sensed data and vegetation cover observation with near surface meteorological data in a SEBAL model. This provides appropriate supply of irrigation water for the field based on the water requirement of the crop.

1.6 Objectives

The objective of this research is to assess irrigation performance with remote sensing data and field data collected at **Kobo-valley Irrigation Project** by identifying the optimal combination of performance indicators on both methods (SEBAL and Penman-Monteith).

The specific research objectives of this study are:

- ❖ To determine actual evapotranspiration using SEBAL and Penman-Monteith Method
- ❖ To determine the relationship between actual evapotranspiration from Landsat 7 ETM+ image and Penman-Monteith Method
- ❖ To calculate water requirement of crop grown in the area
- ❖ To determine the performance gap based on the appropriate performance indicators
- ❖ To select appropriate strategies that will improve the performance of small-scale irrigation schemes in the valley

2. Materials and Methods

2.1 Data Sources and Materials

A LANDSAT ETM+ image (Path 168 Row 052), covering the entire Kobo valley, was acquired on 7th January 2003 and was downloaded from Global Land Cover Facility of the University of Maryland website (<http://glcf.umiacs.umd.edu/data/landsat/>).

The remote sensing input used for this study are Landsat ETM+ data having spatial resolution of 30m for visible and near infrared bands (b1 to b5 and b7) and 60m resolution for thermal band (b61 and b62) at satellite nadir.

Description of coordinate systems used in all of the maps and images in this study is as follows.

Projection: UTM

Spheroid: WGS 1984

Datum: WGS 1984

UTM zone: 37 North

2.1.1 Header File Information

TM images are generally created with an associated “header” file. The header file for the satellite image is a relatively small file that contains important information for the SEBAL process. The following information is obtained from the header file for entry into SEBAL:

- The satellite overpass date and time (17:22:36, 2000-12-05)
- The latitude and longitude of the center of the image (+11.5683756 (lat), +39.8775175 (log))
- The sun elevation angle (β) at the overpass time (47.9)

The satellite overpass time is expressed as Greenwich Mean Time (GMT) and is converted to local time. For Landsat 7, the header file includes the gains and biases for bands 1-5 and 7. These parameters are used to convert digital numbers (DN's) in the original files into energy units. For band 6, the thermal band, both high and low gain images are supplied and in this study low gain image, which yields slightly lower resolution, is recommended to use for SEBAL.

2.1.2 Weather Data

Meteorological data for a representative station was obtained from the National Meteorological Agency. Climatological data in daily and monthly time steps were collected from the two weather stations during the field work from the Ethiopian Meteorological Agency and Kobo-Girana Valley Development Programme (KGVDP). The wind speed (u) at the time of the satellite overpass is also acquired for the computation of sensible heat flux (H) and for the ETr calculation. Data were taken from Kobo and Alamata stations that are located inside and nearby the study area respectively. In addition to it, information about water resource, irrigation supply, irrigated crops and irrigated land area were collected from the local Bureau of Agriculture and Rural Development and KGVDP. Hourly and daily data were used in SEBAL processing. The weather conditions prevailing on 5th December 2003 are shown in table 3.

Table 2 Average/daily weather conditions at the time of satellite overpass

Satellite overpass time (5 December 2003)					
GMT 6:84					
Local time 9:84 AM					
	Temperature (°C)	Humidity (%)	Wind speed at 2m (m/s)	Actual daily sunshine (hours)	Daily precipitation (mm)
5 December 2003	26.9	61	1.8	8.9	0

Other data used for the research project are:

- ❖ Topographic maps for the areas 1:250,000 scale, produced by Ethiopian Mapping Authority
- ❖ Population, crop productivity, land use, are found from Central Statistical Authority, and other government offices
- ❖ drainage systems From Ethiopian Minister of Water Resource
- ❖ Meteorological data from National Meteorological Agency
- ❖ Other data, which described the study area, are found from the Region Bureau.
- ❖ FAO soil data and suitability description which is modified for Ethiopian cases.

2.2 Methods

2.2.1 SEBAL Remote Sensing Technique

Remote sensing methods are attractive to estimate ET as they cover large areas and can provide estimates at a very high spatial resolution. Intensive field monitoring is also not required, although some ground-truth measurements can be helpful in interpreting the satellite images.

The Surface Energy Balance Algorithm for Land (SEBAL) is a parameterization of the energy balance and surface fluxes based on spectral satellite measurements (Bastiaanssen et al. 1999). SEBAL requires visible, near-infrared, and thermal infrared input data, which means that applications of Landsat Thematic Mapper (TM) are useable.

Instantaneous net radiation values was computed from incoming solar radiation that is measured at Kobo ground station and outgoing thermal radiation estimated from cloud-free Landsat ETM+ images via surface albedo, surface emissivity, and surface temperature.

ET is calculated as a *residual* of the energy balance

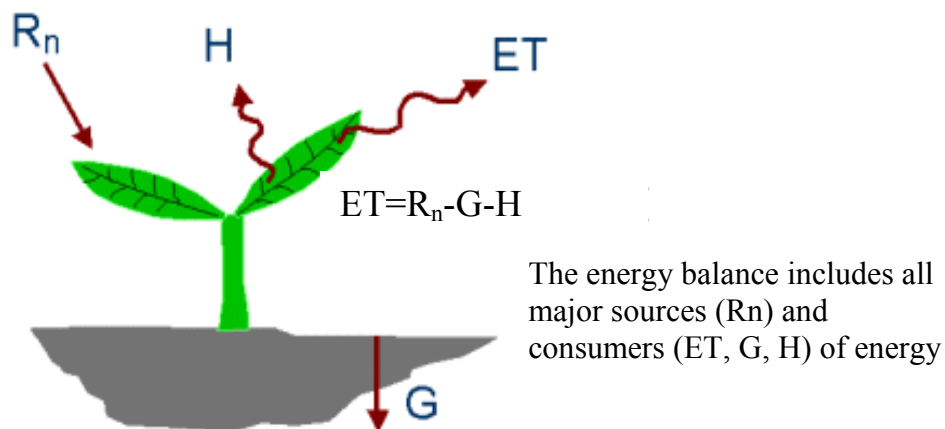


Figure 1 Energy Balance

2.2.2 Irrigation Performance Indicators

Water resource is always the most crucial component for the sustainable development of any society. But its rising scarcity has become a real challenge to water resource managers. Since it is an increasingly scarce resource, it is a must to better understand how to use it in ways that are

more productive, equitable and sustainable. As mentioned earlier, irrigation is outstandingly the largest sector that uses water. So, unless efficient use of water comes into practice in irrigation schemes, water resource conservation is simply out of the question. To understand the efficiency (or deficiency) of the irrigation systems, irrigation performance analysis was determined according to the indicators of overall consumed ratio (OCR), relative water supply (RWS), depleted fraction (DF), crop water deficit (CWD) (Bastiaanssen et al., 2001), and relative evapotranspiration (RET), which were calculated using parameters of ET_a and ET_o derived from remote sensing and penman Monteith method. The indicators help to describe the hydrological behaviour of irrigation schemes by means of a few and understandable numbers (Bastiaanssen et al., 2001).

2.2.3 Actual Crop Evapotranspiration

The Penman Monteith method was used to calculate reference evapotranspiration (ET_o). Crop water requirement (ET_c) was calculated by the formula ($ET_c = ET_o \times K_c$). Net irrigation (I_n) was also calculated as $I_n = ET_c - R_e$ and approximate net irrigation depth per irrigation application could be taken by assuming the root depth of each vegetable crop and soil type of the study area. Number of irrigation application is can be calculated from: irrigation water need over growing season / net depth of each irrigation application (FAO, 1995).

The amount of water that is lost through the evapotranspiration process from the disease-free and well-fertilized crops fields is known as potential crop evapotranspiration (ET_c). Value of ET_c is different for different crops as the groundcover; canopy properties and aerodynamic resistance of crops are different from each other. Before estimating ET_c for every crop, reference crop evapotranspiration (ET_o) has to be computed in monthly time step by using Penman-Monteith method (recommended by the FAO).

2.2.4 Crop Water Requirement

Crop water requirements (CWR) will be calculated on the basis of monthly effective rainfall (P_{eff}) and reference evapotranspiration (ET_o), the first being calculated from average rainfall following the Penman-Monteith approach (FAO-56, 2006).

The CROPWAT model - a computer program for crop water requirement calculations developed by FAO (FAO, 1995a) – was used to compute net irrigation water requirements. Inputs for the

model are climatic parameters - rainfall and ET_o - and crop coefficients. Output from CROPWAT includes monthly net irrigation water requirements by crop. Using the cropping pattern, and the actual and potential cropping intensity, net irrigation water requirements per year was calculated for a theoretical hectare of irrigated land in each area.

2.2.5 Geographical Information Systems Methods

GIS will be used for mapping Contours, Soils and ground data for land use classification to display of geo-referenced data.

2.2.6 GPS Application

Satellite based GPS provides accurate geo-referenced (in terms of latitude & longitude) positional locations, boundaries and also for the purpose of land use land cover classification for accurate assessment of evapotranspiration for different land uses.

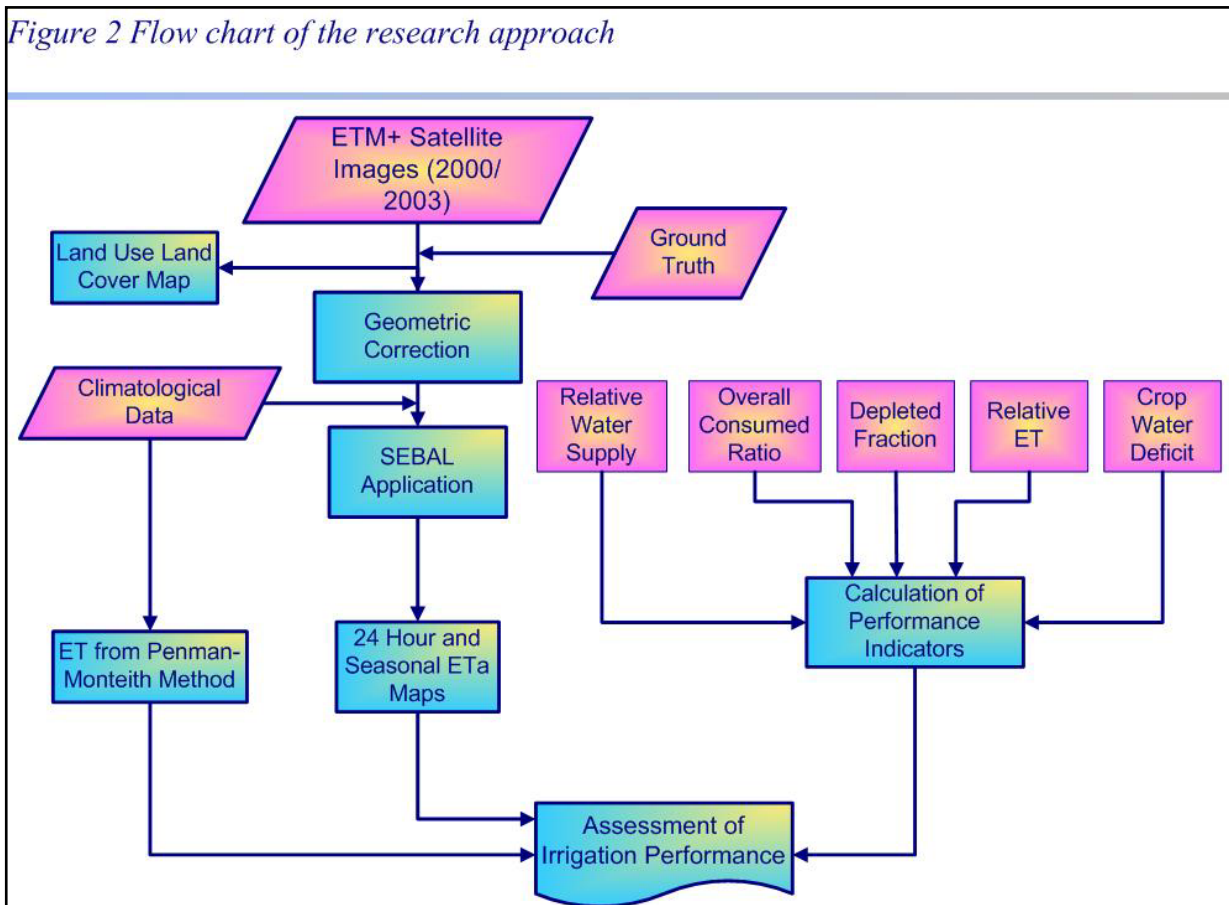


Figure 2 Flow chart of the research approach

3. General Overview of the Study Area

3.1 Location

The study area, Kobo Valley irrigation schemes, is located in the Northern dry zone of Ethiopia. The Kobo Valley lies some 600 km north of the capital Addis Ababa, on the road leading to Mekele. The Kobo valley irrigation scheme falls approximately between latitudes 11.92° and 12.21° North and longitudes 39.42° and 39.82° East. The Valley is surrounded both on the east and west by high mountains, some over 2500m high, whereas the Valley itself is 1500m above sea level; the mountains west of the Valley rise up to 4000m, and provide the main source of water streaming in the rivers.

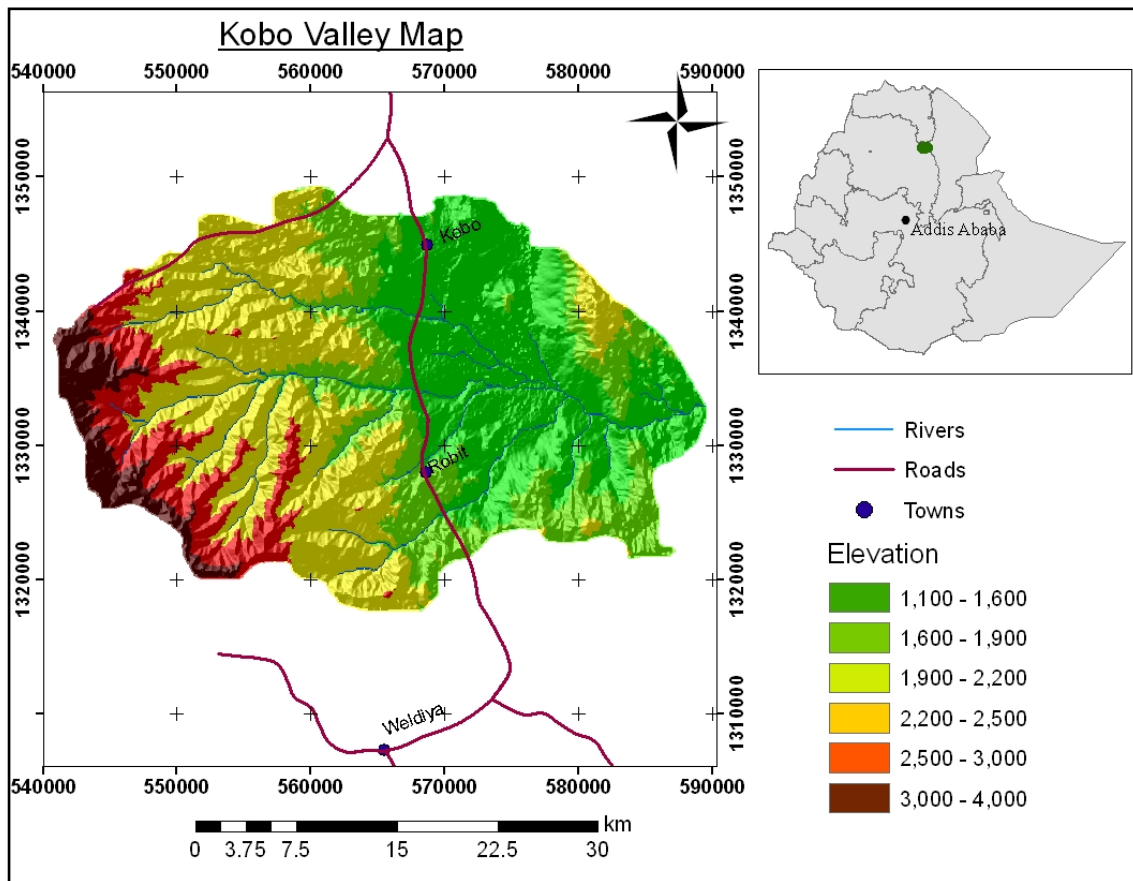


Figure 3 Geographical location and main features of the study area

3.2 Climatic Characteristics

3.2.1 Rainfall and Temperature

The Kobo valley is defined as semi-arid, bi-modal with precipitation occurring during two seasons each year relatively modest quantity of rainfall - around 400mm but rarely exceeding 1000mm annually. The climate is characterized by two rainy periods: a short one, from February to April, and a longer one that extends from June to September. On the other hand, the area can be very dry, with no rainfall for long periods, as was the case in the 1980s, when the Kobo Valley was most affected by drought. During the very hot years, temperatures may rise up to 35 °C; the average temperature in the area is 30 °C.

During the rainy season, a great quantity of water pours down on the area; the rivers, filled to the brim, gush into the desert and water is lost. Some of this water is carried via canals to be used for irrigation.

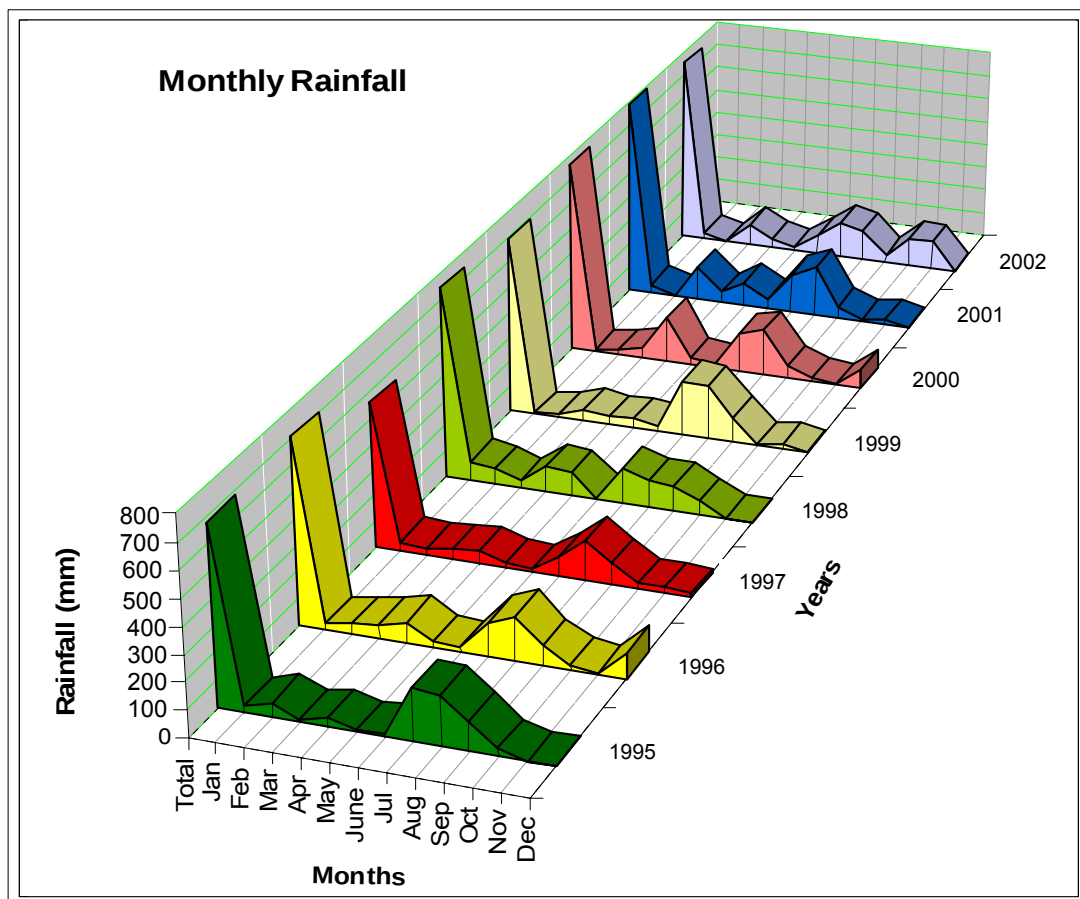


Figure 4 Monthly and annual rainfall distribution

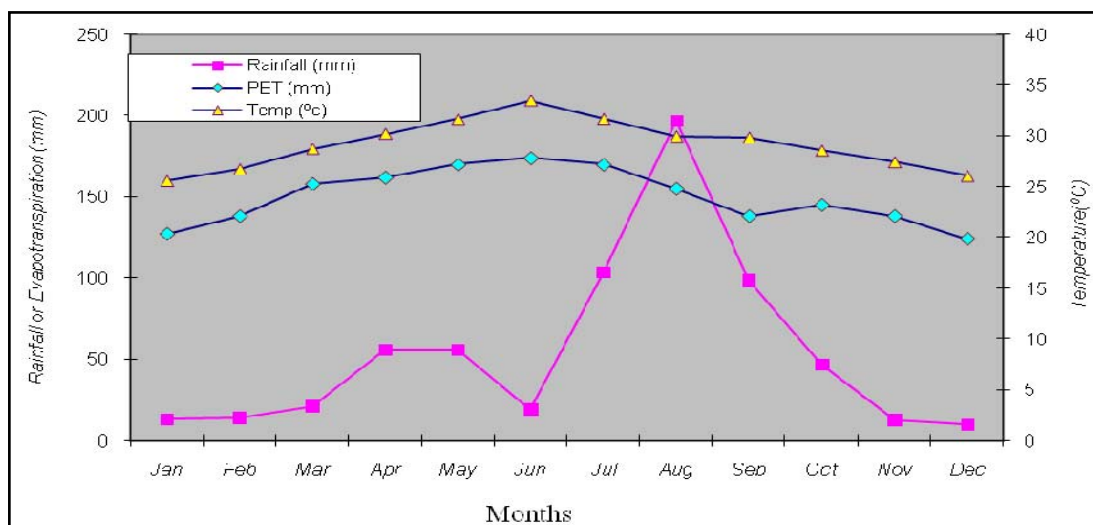


Figure 5 Patterns of temperature, rainfall and evapotranspiration in Kobo area

3.2.2 Relative Humidity

Relative humidity is classified as low if it is less than 50%, moderate if it falls between 50-80% and high if greater than 80%. Accordingly, during most of the months in a year the area is of moderate humidity. Only during May and June including July are of low relative humidity. Mean monthly relative humidity of the station is depicted in table 4.

Table 3 Mean monthly relative humidity (%) of Kobo station

Station	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Kobo	63	60	57	53	48	48	49	56	54	54	53	61
	Mean											
	54											

3.2.3 Wind

The general predominant wind direction during dry season, i.e., in the period of February to May is from west to northwest, and wind direction changes at the onset of rainfall. The easterly and southeasterly winds predominate the area beginning from March to May. Months from June to September are dominated by westerly winds. At Kobo the highest wind speed (2.1 m/s) occurs in the months of February and March. Wind speed decreases in August and attain minimum speed in September and October (Table 5).

Wind speed, as one of climatological factors affecting the rate of evapotranspiration and hence the water resource is largely dependent on the source, latitudinal setting, physiographic and vegetation cover of the area. Those areas located adjacent to elevated places such as Kobo and Robit towns have relatively low wind speed than areas located on flat area without natural wind barrier like Waja. In general being located between highly raised mountainous terrains, the Kobo valley has low wind speed than most areas.

Table 4 Mean monthly wind speed at Kobo (m/s at a height of 2m)

Station	Months												
	J	F	M	A	M	J	J	A	S	O	N	D	Mean
Kobo	1.9	2.1	2.1	1.9	1.6	1.9	1.9	1.6	1.3	1.5	1.7	1.8	1.8

3.2.4 Sunshine Hours

The number of daily sunshine hours is one of the climatic factors increasing the evaporation rate of water from soil and water bodies. Data on the percentage of twelve hours maximum possible sunshine hours are available for Kobo station as depicted in table 6 hereunder.

Table 5 Mean monthly percentage of maximum possible sunshine hours

Station	Months												
	J	F	M	A	M	J	J	A	S	O	N	D	Mean
Kobo	70	61	65	66	69	57	52	52	56	70	82	74	65

3.3 Land use and Soils

The Kobo Valley stretches over an area of 50,000 hectares and its land is very fertile, as it originates from the surrounding mountains. According to the terrain relief map of the area the undulating and rolling features are dominant land forms. The hilly and steep land accounts for large percentages and the flat lands are relatively small (figure 3).

Land use in the area is dominated by long period traditional rain-fed peasant farming system of individual holdings and grazing of livestock on communal grazing lands. The main produces of the area are cereals, teff and sorghum, these crops being drought resistant. Maize is sometimes

grown, in small quantities (as it is sensitive to aridity) and very few vegetables. Onions, chillies and tomatoes are grown nearer to sources of water.

The description of the soils of the study area is based on the information extracted from 1:500,000 scale soils map of Environmental Assessment and Sustainable Land use Plan for North Wollo (DHV, 2001) and the transect walk during the field work. According to the 1:500,000 scale soils map of Northern Wollo (DHV, 2001), the soils of the study area are mostly the result of the processes recent of alluvial deposits and is mainly occupied by Eutric, vertisol/Eutric and fluvisol soil association type. The types of soil found in the study area are mainly clay and sandy loam by texture, and black and grey by colour.

Soil texture	Apparent sp.Gr	FC %w/w	PWP %w/w	FC %v/v	PWP %v/v
Sand	1.65	9	4	14.85	6.6
Sandy loam	1.5	14	6	21	9
Loam	1.4	22	10	30.8	14
Clay loam	1.35	27	13	36.45	17.55
Silt clay	1.30	31	15	40.3	19.5
Clay	1.25	35	17	43.75	21.25

Table 6 Representative physical properties of soil in the study area

3.4 Hydrogeological setting

Kobo valley is found at the western most range of the down throw block in the vicinity of the great escarpment of the Ethiopian Rift Valley. Its origin is considered to be local tectonic development forming an intermountain trough. The main axis of the trough runs in a N-S direction. The frame of the trough is formed in the west by the rift escarpment and in the east by horst of the Zobul mountain ridge. The intermountain trough (Kobo valley) is dominantly composed of poorly compacted sedimentary basin fill deposits. The frame is mainly composed of Tertiary volcanic rocks. The Mendefra area Tertiary basalt ridge (surface water shed divide) oriented nearly west- east separates the Kobo valley into two parts (GES, 2005).

The western and eastern frames of the valley are composed of Tertiary basalt. It is highly faulted and fractured and forms high altitude difference. The western catchment, which is mountainous and covered with volcanic rocks have about 1019.38 km² (70.8%) while the Kobo valley plain is about 420.30 km² (29.2 %).

The unconsolidated sediment aquifers of Kobo valley are mainly recharged from the western escarpment in two ways. The first one seepage is from volcanic rocks of the mountainous areas. The groundwater which recharged into the fracture openings of the volcanic rock flows underground into the alluvial fill and recharges the ground water of the aquifer. The second recharge is from rainfall induced and other perennial surface runoffs that flow over the alluvial fan deposit and infiltrate and recharge the groundwater source. Most of the rivers crossing the valley from west to east are affected by the dry season, and stream only during the rainy season except the Golina river. The supply of water for the irrigation project originates from ground water and the Golina river, which flows all-year round.

4. Literature review

4.1 Opportunities of remote sensing for irrigation performance

The potentiality of remote sensing techniques in irrigation and water resource management has been widely acknowledged. Environmental physics based on electromagnetic radiation and micro-hydrology has evolved in the development of quantitative algorithms to convert remotely sensed spectral radiances into useful information such as evapotranspiration, root zone soil moisture, and biomass growth. Estimation of crop water parameters using remote sensing techniques is an expanding research field and development trends have been progressing since 1970s (Bandara, 2006). The remote sensing algorithm such as SEBAL (Surface Energy Balance Algorithm for Land) was originally developed in the Netherlands for use in Egypt by Bastiaanssen (1995) and was modified during the Idaho study for application to mountainous terrain and clear, Cold Lakes.

SEBAL modified by Bastiaanssen et al. (2003) is currently used approaches to estimate crop water parameters. The scale of satellite measurements is a measure of its quality and which is associated with two parameters, namely spatial resolution and temporal resolution. The spatial resolution measures the ability of a sensor to distinguish among closely spaced objects in the terrain. One pixel is the smallest area of the terrain that can be recorded as a unique element by the sensor.

Landsat-7 ETM+ satellite produce images of a more accurate shape of the ground object because of their smaller pixel size (e.g. $30\text{ m} \times 30\text{ m}$), compared to those of the MODIS or the NOAA-AVHRR satellites which have pixels of $1000\text{ m} \times 1000\text{ m}$ and $1100\text{ m} \times 1100\text{ m}$ respectively.

Calculation of water consumptions by remote sensing has been under high research efforts for the last 20 years, especially the energy balance models. Some reviews can be found in Bastiaanssen (1998). Some dedicated energy-balance models like the SEBAL (Bastiaanssen, 1995), SEBI, and also some related models calculating evapotranspiration are also available among others not mentioned here. To add to this non-extensive list, a lot of Global Climatologic Models use the energy-balance process for various outputs like ET or soil moisture. Typically, for crop ET monitoring, high spatial resolution satellites are required, but the list is restricted to

satellites having the capacity to calculate the surface temperature, as the latent heat flux of vaporization is temperature driven. Some coarser spatial resolution satellites up to 1 Km pixel size are still used for irrigation system temporal ET monitoring. Larger spatial resolution satellites, generally for meteorological purposes, even if used largely in GCMs, are not used for crop monitoring. SEBAL is one of the thermodynamically based models available, which partitions the sensible heat flux and the latent heat flux of vaporization.

The remote sensing technology application is under spreading in Ethiopia, but it has rarely been applied to support irrigation management practices because of the associated costs and quality of images.

4.2 Theoretical basis of SEBAL

Energy is required to change the state of the molecules of water from liquid to vapour. Direct solar radiation and, to a lesser extent, the ambient temperature of the air provide this energy. The driving force to remove water vapour from the evaporating surface is the difference between the water vapour pressure at the evaporating surface and that of the surrounding atmosphere. As evaporation proceeds, the surrounding air becomes gradually saturated and the process will slow down and might stop if the wet air is not transferred to the atmosphere. The replacement of the saturated air with drier air depends greatly on wind speed (FAO, 2006).

SEBAL uses digital imagery data collected by a remote-sensing satellite measuring visible, near-infrared and thermal infrared radiation. In the SEBAL model, ET is computed from satellite images and weather data using the surface energy balance. Since the satellite image provides information for the overpass time only, SEBAL computes an instantaneous ET flux for the image time. The ET flux is calculated for each pixel of the image as a “residual” of the surface energy budget equation. The principles and steps needed to apply SEBAL to estimate evapotranspiration are described in Bastiaanssen (1995), Bastiaanssen et al. (1998).

Evapotranspiration (ET) is computed as a residual of the energy balance equation on a pixel-by-pixel basis:

$$LE_{pixel} = \lambda * ET_{pixel} = Rn_{pixel} - H_{pixel} - G_{pixel} \quad (1)$$

where LE_{pixel} : latent heat flux for the pixel, ET_{pixel} : pixel ET, λ :latent heat of vaporization, and $R_{n\text{pixel}}$, H_{pixel} , and G_{pixel} are the net radiation, sensible heat flux and soil heat flux for each pixel, respectively.

The net radiation flux at the surface (R_n) represents the actual radiant energy available at the surface. It is computed by subtracting all outgoing radiant fluxes from all incoming radiant fluxes (Figure 6). This is given in the surface radiation balance equation:

$$R_n = R_{s\downarrow} - \alpha R_{s\downarrow} + R_{L\downarrow} - R_{L\uparrow} - (1 - \epsilon_o)R_{L\downarrow} \quad (2)$$

$RS\downarrow$ is incoming shortwave radiation (W/m^2), α is broadband surface albedo (dimensionless), $RL\downarrow$ is incoming longwave radiation (W/m^2), $RL\uparrow$ is outgoing longwave radiation (W/m^2), ϵ_o is surface thermal emissivity (dimensionless), R_n represents the actual radiant energy available at the surface ($100\text{-}700\text{ W/m}^2$).

Net surface radiation = gains – losses

In Equation (2), the amount of shortwave radiation ($RS\downarrow$) that remains available at the surface is a function of the surface albedo (α). Surface albedo is a reflection coefficient defined as the ratio of the reflected radiant flux to the incident radiant flux over the solar spectrum. It is calculated using satellite image information on spectral radiance for each satellite band. The incoming shortwave radiation ($RS\downarrow$) is computed using the solar constant, the solar incidence angle, a relative earth-sun distance, and a computed atmospheric transmissivity. The incoming longwave radiation ($RL\downarrow$) is computed using a modified Stefan-Boltzmann equation with atmospheric transmissivity and a selected surface reference temperature. Outgoing longwave radiation ($RL\uparrow$) is computed using the Stefan-Boltzmann equation with a calculated surface emissivity and surface temperature. Surface temperatures are computed from satellite image information on thermal radiance (Trezza, 2002).

The surface emissivity is the ratio of the actual radiation emitted by a surface to that emitted by a black body at the same surface temperature. In SEBAL, emissivity is computed as a function of a vegetation index. The final term in Equation (2), $(1 - \epsilon_o)R_{L\downarrow}$, represents the fraction of incoming longwave radiation that is lost from the surface due to reflection.

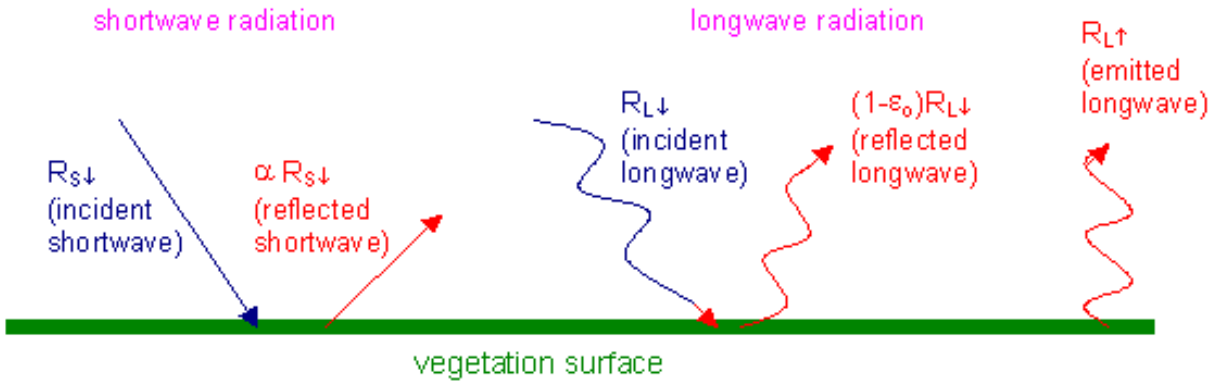


Figure 6 Surface radiation balance

Soil heat flux cannot be directly determined from satellite sensors and requires empirical formulation. Remote sensing derivable parameters that influence soil heat flux are used; these include NDVI, surface temperature and albedo. The soil heat flux (G) has been estimated using the following empirical equation proposed by Bastiaanssen (2000) for any condition of vegetation cover and type of soil is

$$\frac{G}{R_n} = \frac{T_s}{\alpha} (0.0038\alpha + 0.0074\alpha^2) (1 - 0.98 NDVI^4) \quad (3)$$

Where G : soil heat flux, α : surface albedo, T_s : surface temperature ($^{\circ}\text{C}$), and NDVI: normalized difference vegetation index. NDVI is calculated from the Landsat band 4 and band 3 reflectances (ρ_4 and ρ_3 , respectively) as $NDVI = (\rho_4 - \rho_3) / (\rho_4 + \rho_3)$; NDVI values normally range from 0 to 1, where a $NDVI > 0.7$ represents full cover conditions for most crops.

A considerable amount of solar radiation reaching the earth's surface is reflected. The fraction α , of the solar radiation reflected by the surface is termed as the albedo. The albedo is highly variable for different surfaces and for the angle of incidence or slope of the ground surface.

Table 7 Typical albedo values

Fresh snow	0.80 – 0.85	Water	0.025 – 0.348
Old snow and ice	0.30 – 0.70	Deciduous forest	0.15 – 0.20
Black soil	0.08 – 0.14	Coniferous forest	0.10 – 0.15
Clay	0.16 – 0.23	Rice field	0.17 – 0.22
White-yellow sand	0.34 – 0.40	Corn field	0.14 – 0.22
Gray-white sand	0.18 – 0.23	Grass or pasture	0.15 – 0.25

(Depending on solar elevation angle)

(FAO, 2006. guidelines for computing crop water requirements)

After calculating R_n and G , the calculation of the sensible heat flux H is required to obtain the parameters that will allow the computation of ET as a residual from the energy balance. The aerodynamic transfer of heat to air, H , is predicted using the following equation (Brutsaert, 1982):

$$H_{(x, y)} = \rho C_p \left[\frac{T_{aero} - T_a}{r_{ah}} \right] \quad (4)$$

Where ρ : air density, a function of atmospheric pressure; C_p : specific heat capacity of air; T_{aero} : aerodynamic surface temperature; T_a : reference height air temperature; and r_{ah} : aerodynamic resistance to sensible heat transport between the surface and the reference height. Accurate application of Eq. 4 from satellite data is hindered by the difficulty in estimating aerodynamic surface temperature (T_{aero}) accurately, due to uncertainty in atmospheric attenuation, contamination and radiometric calibration of the sensor, and because radiometric temperature T_s , as measured by satellite, deviates from aerodynamic temperature T_{aero} that drives the heat transfer process.

In SEBAL, instead of T_{aero} , the reference temperature is taken to be T_1 , an air temperature located at height z_1 close to the surface ($z_1 = 0.1m$). An upper height is taken at a height $z_2 = 2m$ and its corresponding temperature is called T_2 . The difference between T_1 and T_2 is referred as the "near surface air temperature difference" or dT . The sensible heat flux is then defined as

$$H = \frac{\rho \times c_p \times dT}{r_{ah}} \quad (5)$$

Where r_{ah} : aerodynamic resistance to heat transport between z_1 and z_2 , and dT : air temperature difference between the two heights z_1 and z_2 above the surface, $dT = T_1 - T_2$.

To determine the value of dT for each pixel, the SEBAL procedure assumes the existence of a linear relationship between dT and the surface temperature T_s :

$$dT = aT_s + b \quad (6)$$

Where T_s : radiometric surface temperature, and "a" and "b": empirical coefficients obtained from the so-called "anchor" pixels (Bastiaanssen, 1995). The assumption implicit in the SEBAL is that hot areas (with large thermal emittance) create a higher vertical dT than cold surfaces, and that this relationship is linear.

In summary, SEBAL is applied following these steps: **a)** calculation of R_n for each pixel from Eq. 2; **b)** calculation of G for each pixel from Eq. 3; **c)** definition of the dT function (Eq. 6) using dT and T_s obtained from the two "anchor" pixels; **d)** calculation of dT for each pixel from the pixel surface temperature, using Eq. 6; **e)** calculation of H for each pixel from Eq. 5; and **f)** calculation of LE (ET) from Eq.1. All energy balance fluxes (R_n , G , H , and LE) represent instantaneous fluxes corresponding to the instant when the satellite image was taken.

4.3 SEBAL application on the study area

The original SEBAL model was adjusted to be adapted to the limited weather and ground information existing for the study area, as well as the predominant crop cultivated in it. As already mentioned above, SEBAL uses a self-calibration procedure that controls the surface energy balance by defining it at two "anchor" pixels.

In general, the anchor pixels represent conditions of extreme evaporative behavior within the image, so-called the "cold (wet)" pixel and the "hot (dry)" pixel. The cold pixel is located in the image as a pixel having one of the lowest surface temperatures, which is taken in SEBAL as indication of wetness. In the "cold" pixel evaporation, most of the available energy ($R_n - G$) is assumed to be consumed by evapotranspiration, so that sensible heat flux (H), and consequently Near surface air-temperature difference, dT , are both assumed to be near zero. The "dry" pixel is represented by a pixel with high temperature, which is taken in SEBAL as indicator of lack of surface moisture, where evaporation is near zero so that all the available energy is converted essentially into sensible heat. dT is then calculated for the two extreme conditions. Then, a pair of dT and T_s values allows the definition of coefficients a and b for Eq. 7 and 8.

In SEBAL, the cold pixel is generally taken from a pixel located in deep water, and dT and H are assumed to be zero; therefore $H_{cold} = 0$ so that $dT_{cold} = 0$ (Eq. 10). The hot pixel is located in an area that shows high surface temperature where zero evaporation can be assumed; therefore $H_{hot} = R_{nhot} - G_{hot}$ and dT_{hot} is calculated from Eq. 9 (Bastiaanssen, 2000).

In this work, the two anchor pixels were re-defined. For the cold pixel, a pixel located at a full-cover cropped area was selected. The hot pixel was located at an agricultural bare soil area. Therefore, the dT coefficients were calculated as

$$a = \frac{dT_{\text{hot}} - dT_{\text{cold}}}{T_{\text{shot}} - T_{\text{scold}}} \quad (7) \text{ and}$$

$$b = dT_{\text{cold}} - aT_{\text{scold}} \quad (8)$$

Where dT_{hot} and dT_{cold} : DT values for the hot and cold pixels, respectively; $T_{\text{s hot}}$ and $T_{\text{s cold}}$: corresponding values of surface temperature. The values of dT for the cold and hot pixels were calculated using the following equations:

$$dT_{\text{hot}} = \frac{H_{\text{hot}} * r_{\text{ah_hot}}}{\rho_{\text{hot}} * C_p} = \frac{(R_n - G - \lambda * ET)_{\text{hot}} r_{\text{ah}}}{\rho C_p} \quad (9)$$

$$dT_{\text{cold}} = \frac{H_{\text{cold}} * r_{\text{ah_cold}}}{\rho_{\text{cold}} * C_p} = \frac{(R_n - G - \lambda * ET)_{\text{cold}} r_{\text{ah}}}{\rho C_p} \quad (10)$$

Where H_{hot} , $R_{\text{n hot}}$, ET_{hot} and G_{hot} : values of sensible heat, net radiation, evapotranspiration, and soil heat flux, respectively, for the hot pixel; H_{cold} , $R_{\text{n cold}}$, G_{cold} , and ET_{cold} : values of sensible heat, net radiation, soil heat flux, and evapotranspiration, respectively, for the cold pixel. Guidelines for proper selection of both the cold and hot pixel can be found in Bastiaanssen (1995), Trezza (2002).

ET in the cold pixel (ET_{cold}) was defined using the single crop coefficient approach of FAO-56 (Allen et al., 1998):

$$ET_{\text{cold}} = ET_c = K_c ET_o \quad (11)$$

Where ET_c : crop evapotranspiration, ET_o : grass reference evapotranspiration, and K_c : crop coefficient.

In 1948, Penman combined the energy balance with the mass transfer method and derived an equation to compute the evaporation from an open water surface from standard climatological records of sunshine, temperature, humidity and wind speed. This so-called combination method was further developed by many researchers and extended to cropped surfaces by introducing resistance factors. The value of ET_o was calculated using the FAO Penman-Monteith equation of FAO-56 (Allen et al., 1998). The equation uses standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed. To ensure the integrity of computations, the weather measurements should be made at 2m (or converted to that height) above an extensive surface of green grass, shading the ground and not short of water.

The hypothesis here is that the assignment of the calculated evapotranspiration (ET_c) to the cold pixel will produce a better approximation of the real ET that takes place in the study area, and serve as a self-calibration of the image. ET_c is calculated from ET_o , which incorporates the meteorological information of the site and from the crop coefficient (K_c), which is related to the actual crop that is available in cold pixel candidates inside the study area.

4.4 Extrapolation of instantaneous ET to daily ET values

The values of ET derived from SEBAL represent instantaneous values corresponding to the time at which the satellite image was taken. However, instantaneous ET values are not very useful inputs for many hydrological and ecological applications where daily, monthly, and seasonal values are commonly needed. To estimate the 24hr ET for the day of the image, SEBAL uses an approach based on the self-preservation theory of daytime fluxes, which states that the ratio between the latent heat flux and the available energy ($R_n - G$) remains fairly constant during the day (Bastiaanssen et al., 1998). This ratio between LE and $R_n - G$ is termed the evaporative fraction (EF). For this application, daily ET (ET_{24}) was estimated by assuming that the instantaneous crop coefficient (K_c), computed at image time, is the same as the average K_c over the 24h period. Therefore, the value of ET_{24} for each pixel is calculated as

$$K_c = \frac{ET}{ET_o} = \frac{ET_{24}}{ET_{o24}} \Rightarrow ET_{24} = K_c * ET_{o24} \quad (13)$$

Where K_c , ET , and ET_o : instantaneous values of crop coefficient, actual and reference evapotranspiration, for the time when the satellite image was taken; and ET_{24} and ET_{o24} : corresponding daily values (24h) of actual and reference ET. The hypothesis here is that the relationship between actual and reference ET remains relatively constant during the daytime as demonstrated in various experiments (Trezza, 2002; Allen et al., 2005). In other words, this approach assumes that the crop coefficient (K_c) remains constant during the day, which is reasonable if one takes into account that both actual and reference ET might have similar response to the variation of the weather parameters.

Remote Sensing estimates of actual evapotranspiration (AET) have been made in hydrology, agronomy and meteorology at a range of spatial scales. Remote Sensing data are used to derive

surfaces temperature, surfaces reflectance and vegetation indices, which are combined with local meteorological observations in models to estimate AET. Irrigation has contributed significantly to poverty reduction, food security, and improving the quality of life for rural populations. However, the sustainability of irrigated agriculture is being questioned, both economically and environmentally.

Remote sensing data and geographic information systems are increasingly becoming an important tool in Hydrology and water resources development. This is due to the fact most of the data required for hydrological analysis can easily be obtained from Remote sensed images. The greatest advantage of using Remote sensed data for hydrology is its ability to generate information in spatial and temporal domain (Jagadeesha, 1999), which is very crucial for successful model analysis, prediction and validation.

Calculation of water consumptions by remote sensing has been under high research efforts for the last 20 years, especially the energy balance models. Some reviews can be found in Bastiaanssen (1999). Typically, for crop ET monitoring, high spatial resolution satellites are required, but the list is restricted to satellites having the capacity to calculate the surface temperature, as the latent heat flux of vaporization is temperature driven. The author has originally developed SEBAL in Spain and Egypt using Landsat 5TM.

5. Data Processing/Analysis

5.1 Remote Sensing Based Data Analysis

a) Preparing the Original Satellite Image for Use in SEBAL

Landsat ETM+ measurement has been used as the remote sensing input in this study. The original Landsat image was checked for geo-rectified for use in SEBAL. This has been done by using scanned topographic map of the area that has appropriate coordinates. The rectified image was saved in the GeoTIF format and that nearest neighborhood resampling used during rectification to preserve spectral information.

During analysis, SEBAL used the following seven bands of the spectrum:

Band 1.....visible (blue)	Band 5.....near infrared
Band 2.....visible (green)	Band 6.....thermal infrared
Band 3.....visible (red)	Band 7.....near infrared
Band 4.....near infrared	

These bands were layered inside ERDAS IMAGINE, in order, from 1 to 7 to create an image file for use in the SEBAL process. After that, a smaller subset image created for Kobo valley catchment. The steps used for the layering a Landsat 7 ETM+ image is depicted as follows:

1. The GeoTIF format image was browsed
2. The details viewed
 - ❖ The six large files with a “t” in the name are the bands 1 - 5 and 7, in order.
 - ❖ The two large files with a “k” in the name are for band 6, low gain and high gain in that order (the low gain is used).
 - ❖ The large file with a “p” in the name is for band 8 (Panchromatic) and is not used.
3. In ERDAS modeler maker, the Layer stack process was made as follows
 - a. The input file was come from the file in a geo-TIFF format.
 - b. A unique output file name created. The name include the date, path, and row of the image.
 - c. The seven layers in order beginning with band 1 (the first large “t” file) up to band 5, band 6 (the first large “k” file for low gain) then add band 7 (the last large “t” file) were added.The area of interest can now be viewed with the ERDAS Viewer tool.

5.1.1 SEBAL Procedure

The first step used in the SEBAL procedure was to compute the net surface radiation flux (R_n) using the surface radiation balance equation. This was accomplished in a series of steps using the ERDAS Model Maker tool to compute the terms in the following equation. A flow chart of the process is shown in the Figure below.

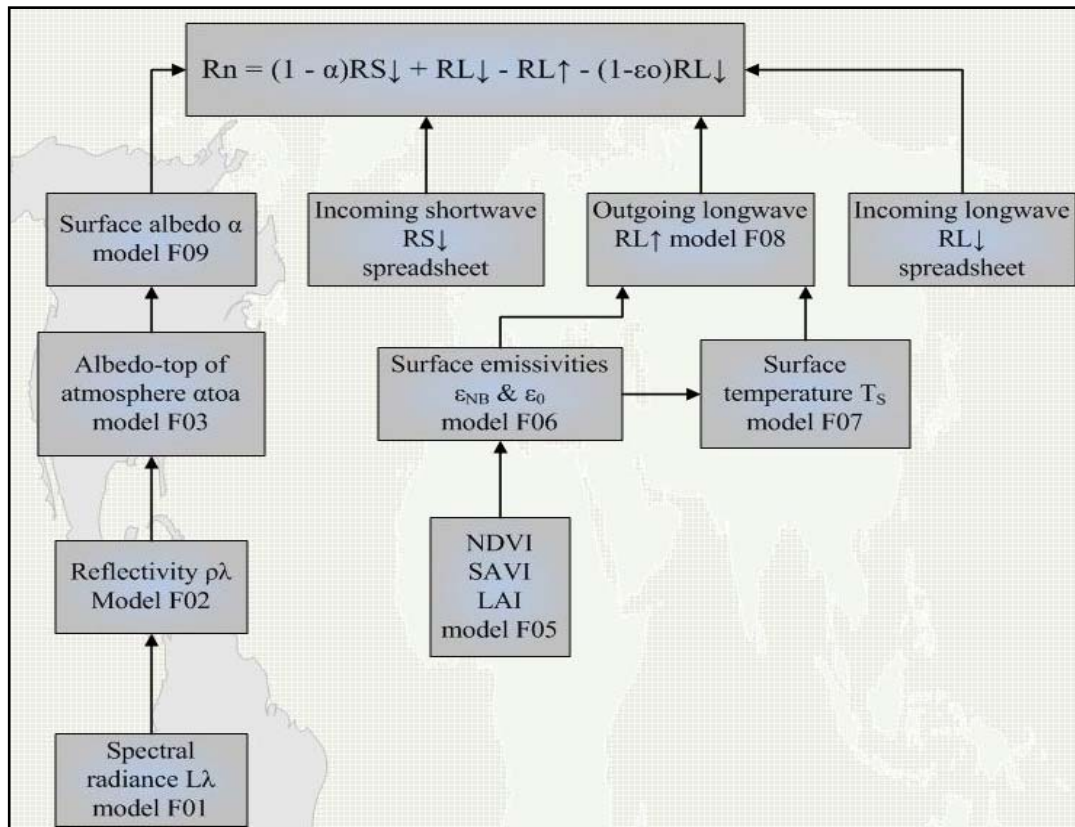


Figure 7 Flow Chart of the Net Surface Radiation Computation (Bastiaanssen, 2002)

The computer model number used for each computation is given along with the variable name. The computation steps begin at the bottom of the figure with model F01 and continue upward to model F09 for the computation of R_n . The two terms $R_{S\downarrow}$ and $R_{L\downarrow}$ are computed with a spreadsheet or a calculator rather than the Model Maker tool.

5.1.2 Surface Albedo

Surface albedo is defined as the ratio of the reflected radiation to the incident shortwave radiation. It was computed in SEBAL through the following steps given for Landsat images:

A. The spectral radiance for each band (L_λ) is computed (model F01). This is the outgoing radiation energy of the band observed at the top of the atmosphere by the satellite. Sensors on board satellite record radiance from earth surface as electrical signals in the form of Digital Numbers (DN) by the process of analog to digital converter to be readily usable for interpretation purposes. However, for temperature estimation the absolute radiance is used. Thermal band 6 of Landsat ETM+ band (B61) are used for the estimation of temperature in the study area. Especially for the second sensor, the low gain state is chosen because of the fact that it automatically calibrates the solar brightness situation of the Kobo valley area. It was calculated using the following equation:

$$L_\lambda = \left(\frac{L_{\max} - L_{\min}}{Q_{\text{cal max}} - Q_{\text{cal min}}} \right) * (DN - Q_{\text{cal min}}) + L_{\min} \quad (14)$$

$$((17.04 - 0.0) / (255 - 1) * (DN - 1) + 0.0)$$

Where; DN is the digital number of each pixel, LMAX (255) and LMIN (0) are calibration constants, QCALMAX (255) and QCALMIN (1) are the highest and lowest range of values for rescaled radiance in DN that are used in this research project. The units for L_λ are $\text{W/m}^2/\text{sr}/\mu\text{m}$.

B. The reflectivity for each band (ρ_λ) is computed (model F02). The reflectivity of a surface is defined as the ratio of the reflected radiation flux to the incident radiation flux. It was computed using the following equation

$$\rho_\lambda = \left(\frac{\pi * L_\lambda}{ESUN_\lambda * \cos\theta * dr} \right) \quad (15)$$

where; L_λ is the spectral radiance for each band computed in model F01, $ESUN_\lambda$ is the mean solar exo-atmospheric irradiance for each band ($\text{W/m}^2/\mu\text{m}$), $\cos\theta$ is the cosine of the solar incidence angle (from nadir), and dr is the inverse squared relative earth-sun distance.

Values for $ESUN_\lambda$ are known for each band of Landsat 7 (table 9). Cosine θ is computed using the header file data on sun elevation angle (β) is 47.9° during the image overpass at December 12, 2003 where $\theta = (90^\circ - \beta)$. The term dr is defined as $1/d_e^2$ where d_e is the relative distance

between the earth and the sun in astronomical units. d_r is computed using the following equation given in FAO 56 paper: *Crop Evapotranspiration* (Allen et al., 1998):

$$d_r = 1 + 0.033 \cos\left(DOY \frac{2\pi}{365}\right) \quad (16)$$

Where; DOY is the sequential day of the year (339), and the angle ($DOY \times 2\pi/365$) in radians for the image used in this research. Value of d_r is 1.03 with no dimension.

Table 8 $ESUN_\lambda$ for Landsat 7 ETM+ (Landsat 7 Science User Data Handbook Chap.11, 2002); both are in $W/m^2/\mu m$

	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7
Landsat 7	1969	1840	1551	1044	225.7	-	82.07

Note: a dummy value of 1 was entered for band 6.

C. The final step is to compute the **surface albedo** (model F04). Surface albedo is computed by:

$$\alpha = \frac{\alpha_{toa} - \alpha_{path_radiance}}{2\tau_{sw}} \quad (17)$$

Where; $\alpha_{path_radiance}$ is the average portion of the incoming solar radiation across all bands that are back-scattered to the satellite before it reaches the earth's surface, values for $\alpha_{path_radiance}$ range between 0.025 and 0.04 and for SEBAL 0.03 is a recommended value based on Bastiaanssen (2000) and τ_{sw} is the atmospheric transmissivity defined as the fraction of incident radiation that is transmitted by the atmosphere and it represents the effects of absorption and reflection occurring within the atmosphere. This effect occurs to incoming radiation and to outgoing radiation and is thus squared in the above equation. τ_{sw} is calculated by assuming clear sky and relatively dry conditions using an elevation-based relationship from FAO-56:

$$\tau_{sw} = 0.75 + 2 * 10^{-5} * Z \quad (18)$$

Where; Z is the elevation above sea level (1468m) which represents the area of interest that is the elevation of Kobo weather station. In the location or image date there was no atmospheric dusts or clouds that affect the atmospheric transmissivity in each band. So the result for τ_{sw} is 0.773.

The surface albedo for all pixels has now been computed and these values can be checked with the land use map of the area (figure 18) to see if they are realistic based on the standard (table 8). For example, trees generally have smaller albedo than agricultural crops. Generally, albedo values for clear water are very small (figure 8). Shortwave radiation penetrates into a water body according to the transparency of the water and is absorbed at a range of depths below the surface where it is converted into heat (G).

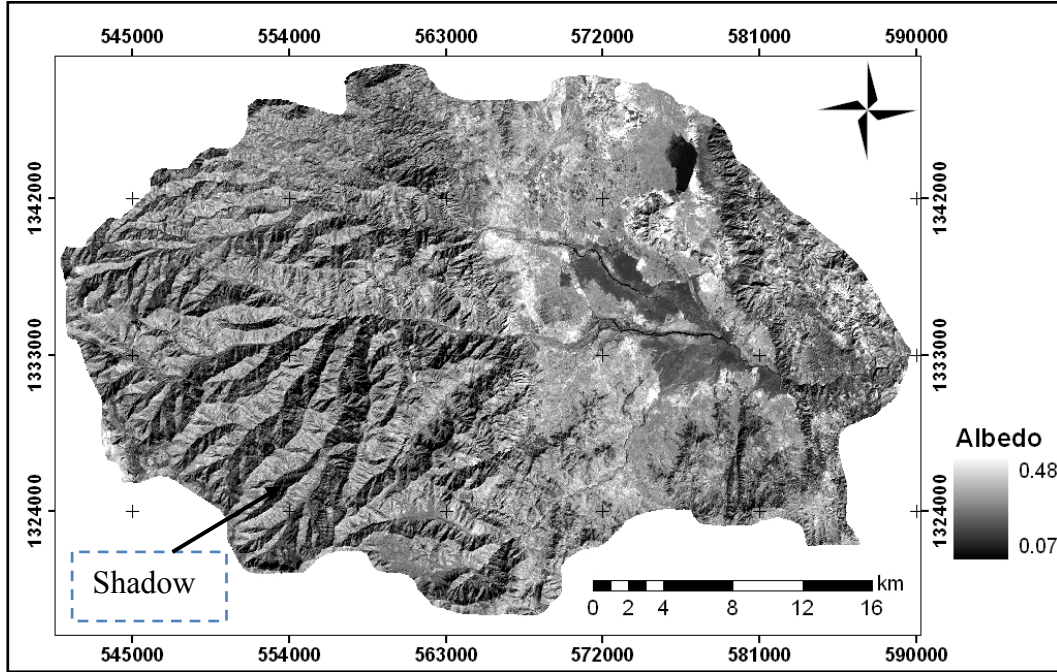


Figure 8 Surface Albedo image

5.1.3 Vegetation Indices

Three commonly used vegetation indices are computed (model F05). Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), and Leaf Area Index (LAI) were computed using the reflectivity values found in model F02. Any one of these indices can be used to predict various characteristics of vegetation in the study area. The NDVI is the ratio of the differences in reflectivities for the near-infrared band (ρ_4) and the red band (ρ_3) to their sum (Lellisand, 1999):

$$\text{NDVI} = (\rho_4 - \rho_3) / (\rho_4 + \rho_3) \quad (19)$$

Where; ρ_4 and ρ_3 are reflectivities for bands 4 and 3 and are found in the output file of model F02. The NDVI is a sensitive indicator of the amount and condition of green vegetation. The green surfaces have a NDVI between 0 and 1 and water is usually less than zero. Normally the

Values of NDVI range between -1 and +1 where in the study area the value range between -0.72 to 0.62. The highest NDVI is located on the lowlands of Raya valley covered by acacia species and agricultural crops.

The SAVI is an index that attempts to “subtract” the effects of background soil from NDVI so that impacts of soil wetness are reduced in the index. It is computed as:

$$SAVI = (1 + L) (\rho_4 - \rho_3) / (L + \rho_4 + \rho_3) \quad (20)$$

Where; L is a constant for SAVI. If L is zero, SAVI becomes equal to NDVI. As cited at Bandara (2006), value of 0.5 frequently appears in different literatures for L. So, this value is used to better represent soils of Kobo Valley as shown in figure 10. The value in the figure ranges between -0.41 to 0.46 that indicates the value of vegetation index where the value of wet soil reflectance is subtracted.

The LAI is the ratio of the total area of all leaves on a plant to the ground area represented by the plant. It is an indicator of biomass and canopy resistance. LAI is computed for Kobo basin using the following empirical equation:

$$LAI = - \frac{\ln\left(\frac{0.69 - SAVI}{0.59}\right)}{0.91} \quad (21)$$

The maximum value for LAI is 6.0, which corresponds to a maximum SAVI of 0.687. Beyond SAVI = 0.687, the value for SAVI “saturates” with increasing LAI and does not change significantly. The relationship between SAVI and LAI vary with location and crop type (Bastiaanssen et al., 2002). As shown in the land use land cover classification, the vegetation cover of the area is very low that leads to minimum leaf area coverage to the ground area of the plant since Kobo is located in semi-arid environment with 649 mm annual rainfall.

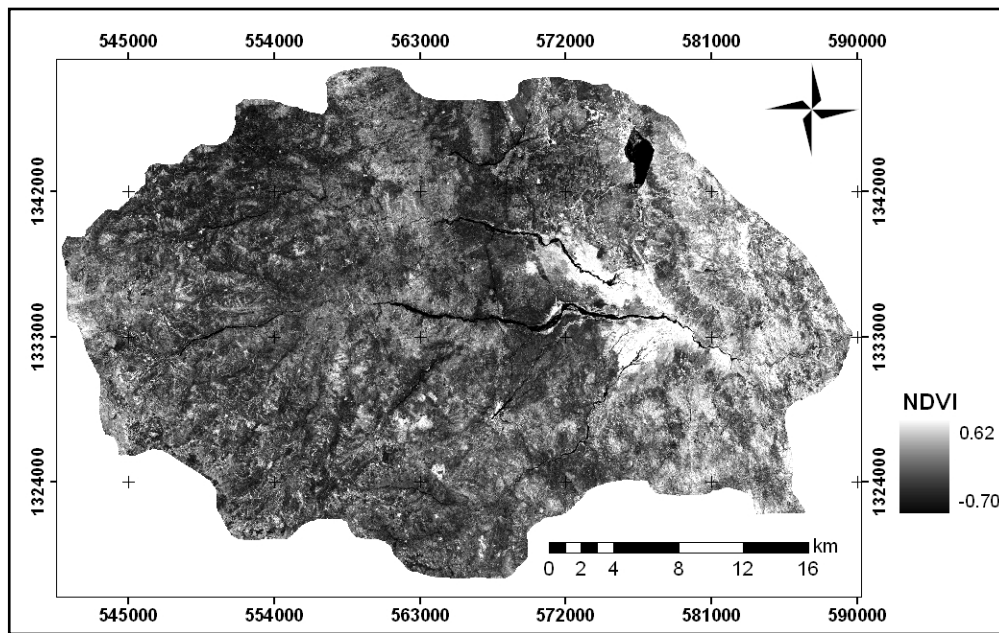


Figure 9 *NDVI Image*

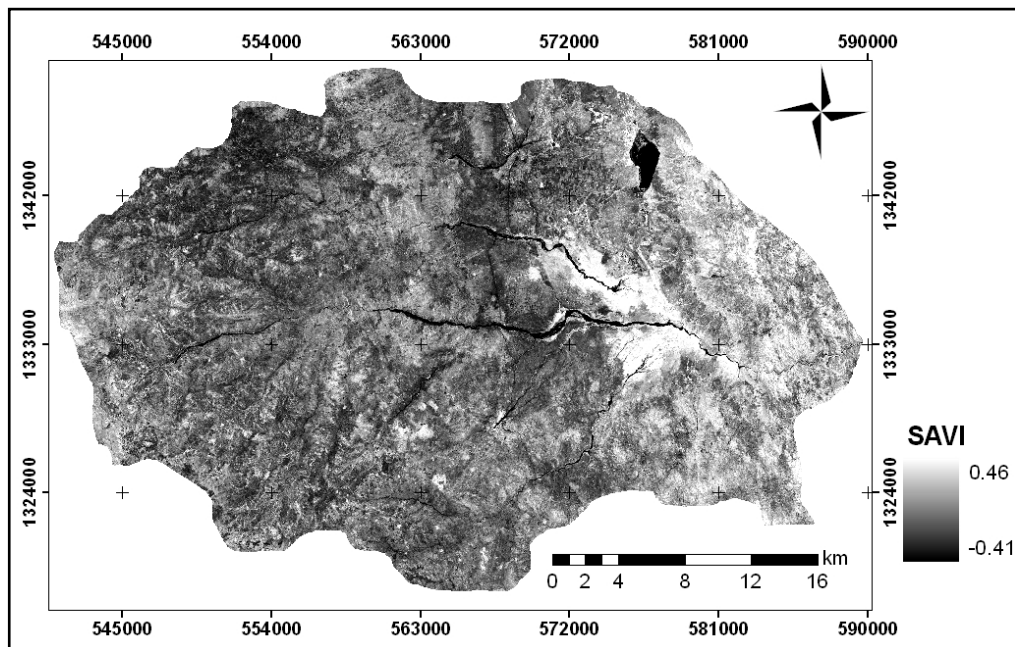


Figure 10 *SAVI Image*

5.1.4 Surface Emissivities

It is the ratio of the thermal energy radiated by the surface to the thermal energy radiated by a blackbody at the same temperature. The satellite thermal sensor measures the absolute temperature of a black body, which could be an ideal/perfect absorber and re-emitter of all the irradiance falling on it. However, in real sense, due to atmospheric effects, surface roughness,

moisture content, field of view and viewing angle of sensors, earth surface features have different gray levels other than being black. The emissivity of the study area is estimated based on NDVI images, through setting conditions for emissivity of crystal water to be .98 based on negative NDVI values with the assumption that they belong to water bodies which is regarded as near perfect emitter. Two surface emissivities were used in SEBAL. The first is an emissivity representing surface behavior for thermal emission in the relatively narrow band 6 of Landsat (10.4 to 12.5 μm), expressed as ϵ_{NB} . The second is an emissivity representing surface behavior for thermal emission in the broad thermal spectrum (6 to 14 μm), expressed as ϵ_0 . ϵ_{NB} is used in calculation of surface temperature (T_s) and ϵ_0 is used later on to calculate total long wave radiation emission from the surface in the study area.

The surface emissivities were computed in model F06 using the following empirical equations, where $\text{NDVI} > 0$:

$$\epsilon_{\text{NB}} = 0.97 + 0.0033 \text{ LAI}; \text{ for } \text{LAI} < 3 \quad (22)$$

$$\epsilon_0 = 0.95 + 0.01 \text{ LAI}; \text{ for } \text{LAI} < 3 \text{ and} \quad (23)$$

$$\epsilon_{\text{NB}} = 0.98 \text{ and } \epsilon_0 = 0.98 \text{ when } \text{LAI} \geq 3.$$

Then emissivity is modeled based on NDVI as:

$\text{EITHER } 0.98 \text{ IF } (\$n1_ndvi2003 \leq 0) \text{ OR } 1.009 + 0.047 * (\text{LOG } (\$n1_ndvi2003)) \text{ OTHERWISE}$
--

Therefore, the emissivity of the project area ranges from 0.742 to 0.9947 and 0.748 for 2003.

5.1.5 Surface temperature

The electromagnetic radiation exiting an object is termed radiant flux. The radiant temperature is highly correlated to the kinetic temperature. Thermal infrared system records radiant temperature. For a black body, the radiant temperature is the same as the kinetic temperature. The estimation of surface temperature depends on mineral composition of rocks, the condition of vegetation, roughness properties of land surfaces, thermal properties and moisture content of soils.

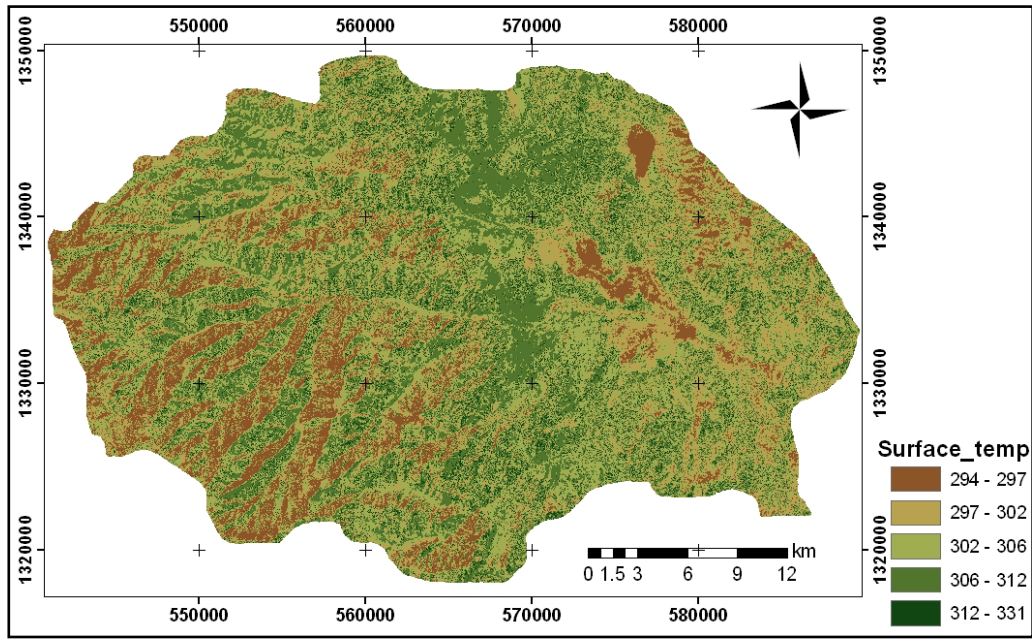


Figure 11 Surface temperature image

5.1.6 Soil Heat Flux

Soil heat flux is the rate of heat storage into the soil and vegetation due to conduction. SEBAL first computes the ratio G/R_n using the empirical equation (eqn.3) developed by Bastiaanssen (2000) representing values near mid-day. Land classification and soil type will affect the value of G and a land-use map is valuable for identifying the various surface types.

$$G = R_n \frac{(T_o - 273)}{\epsilon_{NB}} \left[0.0032 (\epsilon_{NB}) + 0.0062 (\epsilon_{NB})^2 \right] \left(1 - 0.978 NDVI^4 \right)$$

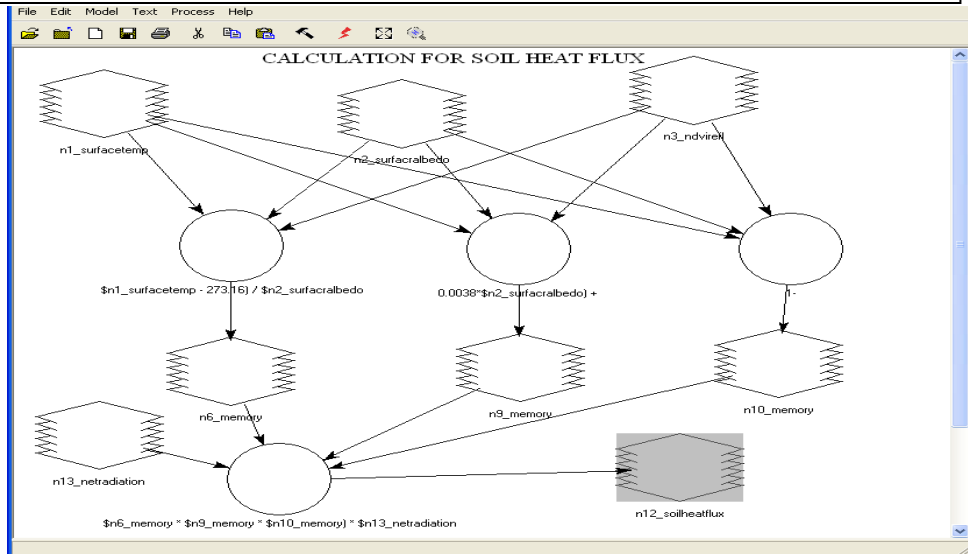


Figure 12 Soil Heat Flux model

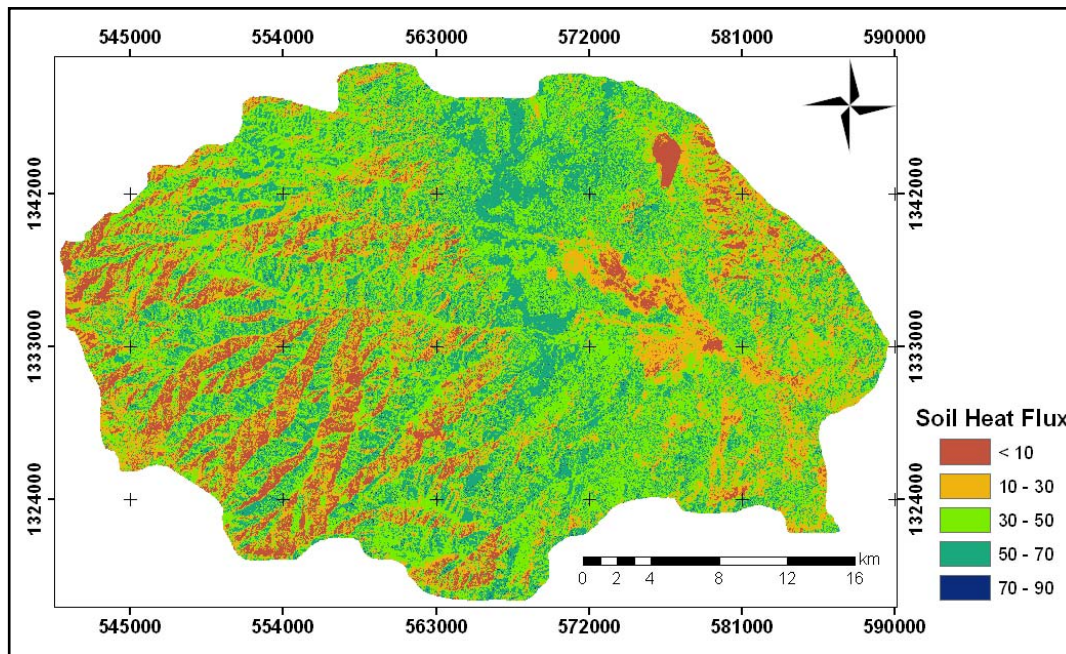


Figure 13 Soil Heat Flux image

5.1.7 Sensible Heat Flux

Sensible heat flux is the rate of heat loss to the air by convection and conduction, due to a temperature difference. It is computed using eqn.5 earlier for heat transport. The sensible heat flux (H) is a function of the temperature gradient, surface roughness, and wind speed.

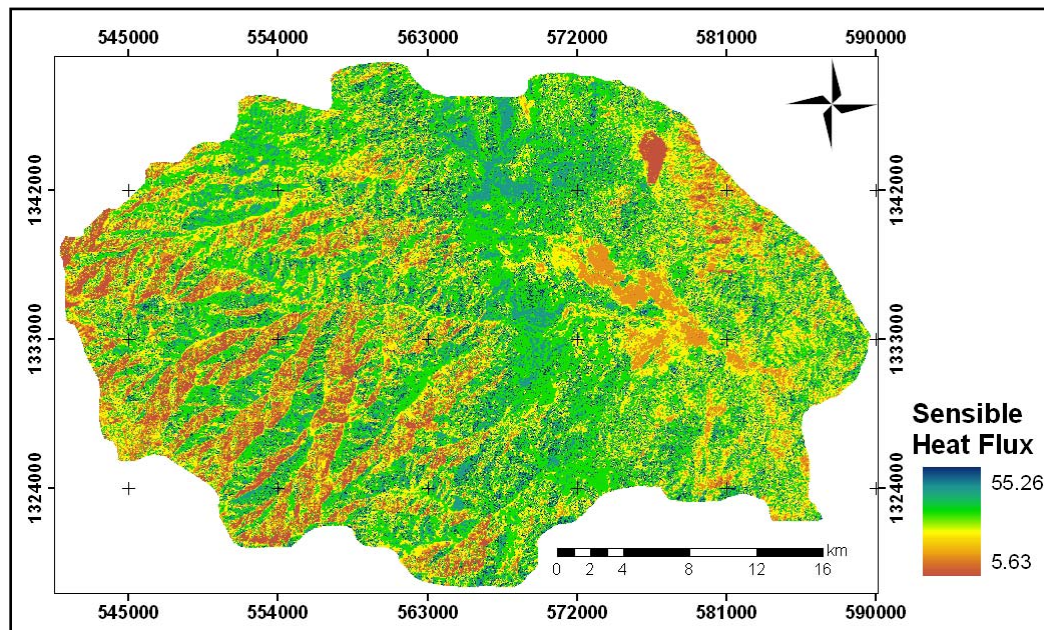


Figure 14 Sensible heat flux image

5.1.8 Instantaneous ET (ET_{ins}), and Reference ET Fraction (ET_rF)

Latent heat flux is the rate of latent heat loss from the surface due to evapotranspiration. It was being computed for each pixel. An instantaneous value of ET in equivalent evaporation depth is computed as:

$$ET_{ins} = 3600 \frac{\lambda ET}{\lambda} \quad (24)$$

Where; ET_{ins} is the instantaneous ET (mm/hr), 3600 is the time conversion from seconds to hours, and λ is the latent heat of vaporization or the heat absorbed when a kilogram of water evaporates (J/kg).

The Reference ET Fraction (ET_rF) is the ratio of the computed instantaneous ET (ET_{inst}) for each pixel to the reference ET (ET_r) computed from weather data:

$$ET_rF = \frac{ET_{ins}}{ET_r} \quad (25)$$

Where; ET_r is the reference ET at the time of the image (mm/hr). ET_rF is similar to the well-known crop coefficient, K_c . ET_rF is used to extrapolate ET from the image time to 24-hour or longer periods. At a totally dry pixel in the image, $ET = 0$ and $ET_rF = 0$. A pixel in a well established field of cultivated land has an ET slightly greater than ET_r and therefore $ET_rF > 1$, perhaps up to 1.1. However, ET_r generally represents an upper bound on ET for large expanses of well-watered vegetation. Negative values for ET_rF can occur in SEBAL due to systematic errors caused by various assumptions made earlier in the energy balance process.

5.1.9 24-Hour Evapotranspiration (ET_{24})

Daily values of ET (ET_{24}) are often more useful than instantaneous ET. SEBAL computes the ET_{24} by assuming that the instantaneous ET_rF computed in the model is the same as the 24-hour average. Finally, the ET_{24} (mm/day) computed as:

$$ET_{24} = ET_rF \times ET_{r_24} \quad (26)$$

Where; ET_{r_24} is the cumulative 24-hour ET_r for the day of the image. This is calculated by adding the hourly ET_r values over the day of the image.

Figure 15 shows a daily evapotranspiration map. The range of values for ET_{24} is colored using the ERDAS IMAGINE software so that ET intensity can be readily observed on the image.

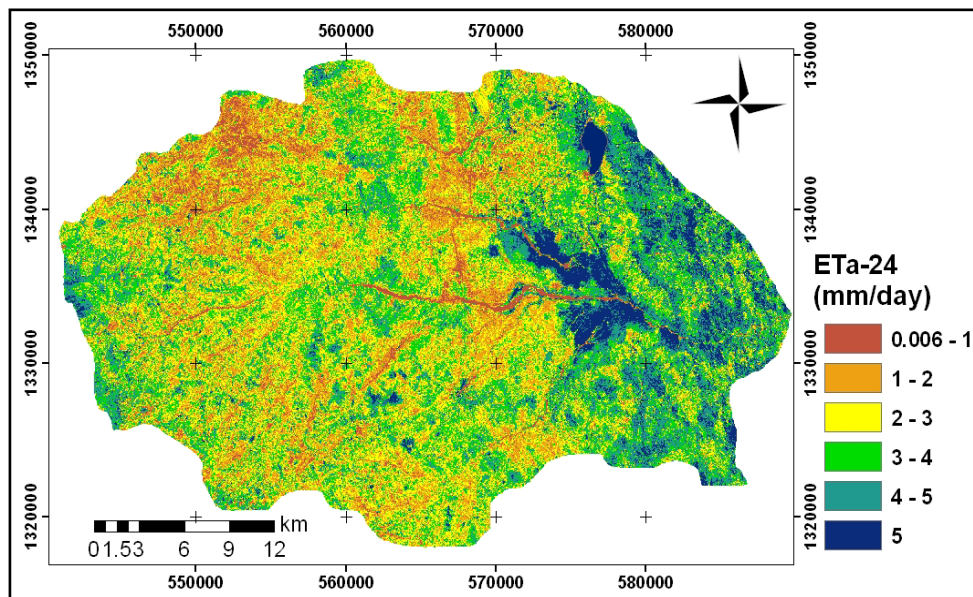


Figure 15 A Map of 24-hour Evapotranspiration (mm/d)

Actual ET is highest in the water body (4.86 mm/day) (Figure 15 and Table 10), followed by acacia species and cultivated land. It is least in the grass or bare land in poor condition, suggesting that runoff is responsible for water loss in the latter land use. The analysis serves to underscore the high evaporative ability of the climate, since the land with agricultural practice loses the highest amount of water by evapotranspiration. Acacia species with sparsely distributed, which occupies most of the catchment, has an average actual evapotranspiration of 3.8 mm/day.

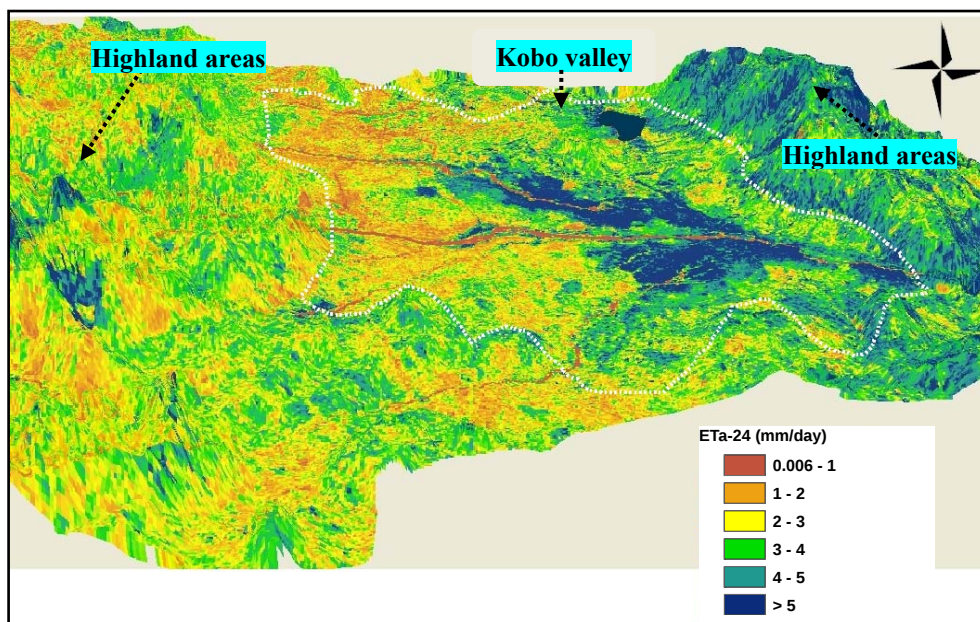


Figure 16 Pictorial of daily ET for 2003 for the Kobo valley

5.1.10 Seasonal Evapotranspiration (ET_{seasonal})

A seasonal evapotranspiration map that covers an entire growing season is often valuable. This was derived from the 24-hour evapotranspiration data by extrapolating the ET_{24} proportionally to the reference evapotranspiration (ET_r). It is based on the assumption that the ET for the entire area changes in proportion to the change in the ET_r at the weather station. ET_r is computed for a specific location and therefore does not represent the actual condition at each pixel. This does not matter, however, since ET_r is used only as an index of the relative change in weather, and therefore ET , for the image area. It is also assumed that the ET_rF computed for the time of the image is constant for the entire period represented by the image.

The seasonal evapotranspiration of the valley is low because there is no sufficient rainfall that can satisfy the moisture holding capacity of the soil in the area. So the soils keep the available moisture for future use by the plants.

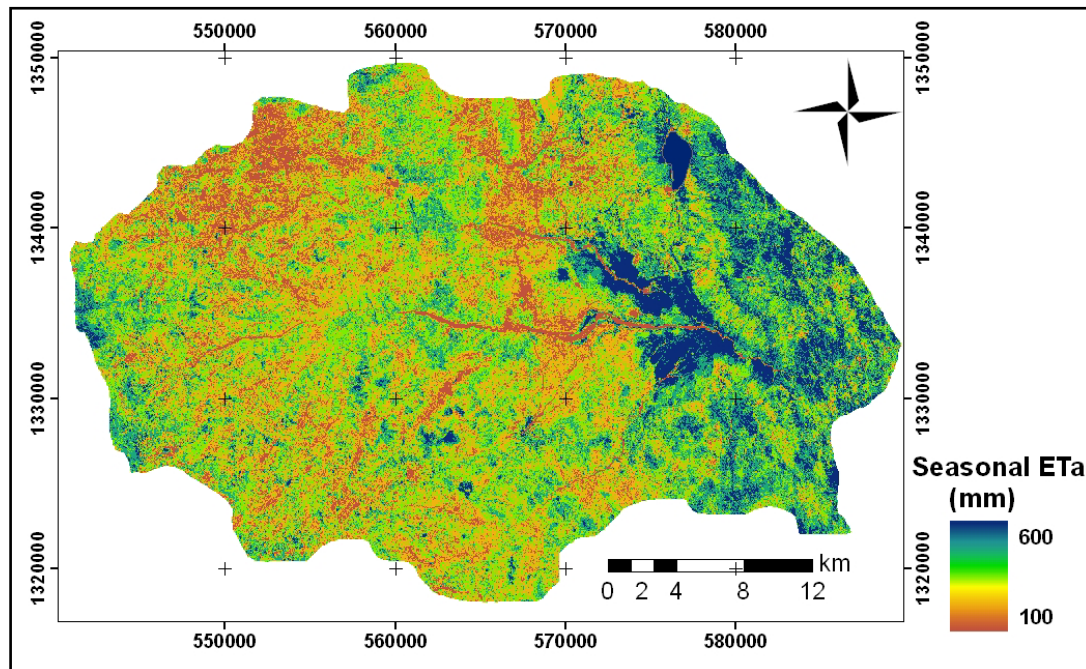


Figure 17 A Map of Seasonal Evapotranspiration

5.1.11 Actual Evapotranspiration and Land Cover

Statistics have been extracted from the ET_a map using an overlay of land cover/use map and are shown in table 10, as mean ET_a for each land cover/use. Water bodies have an average ET_a of 4.86 mm/day, inclusive of large and small water bodies that can consist of multiple mixed pixels

falling both on land as well as averaging differences in the water surface temperature due to turbidity.

Acacia species and shrub lands account for about 38.3% of the ET_a in this particular study site. About 44.9% is beneficial/agricultural field ET_a , but inferences based on these statistics are not accurate unless the contributions of each land use classes to livelihoods and productive use such as livestock feeding are known. September is usually a wet month and it is a month of lots of activity across all farming types as farmers are planting or have planted vegetables crops. It also means that vegetation ET_a will be higher than at other times of the summer season, due to minimum water stress. It is observed in the ET_a map that a greater part of the temporal dry land farming area has low ET_a , with values of 2mm/day or less. This could be an indication that most of the land has just been prepared. Under dry land or rain-fed conditions, planting depends on rainfall events that provide sufficient moisture for land preparation and planting. It is for that reason that most of the cultivated land would still be fallow, or just been prepared hence the close to zero values of ET_a at this time of the year (December).

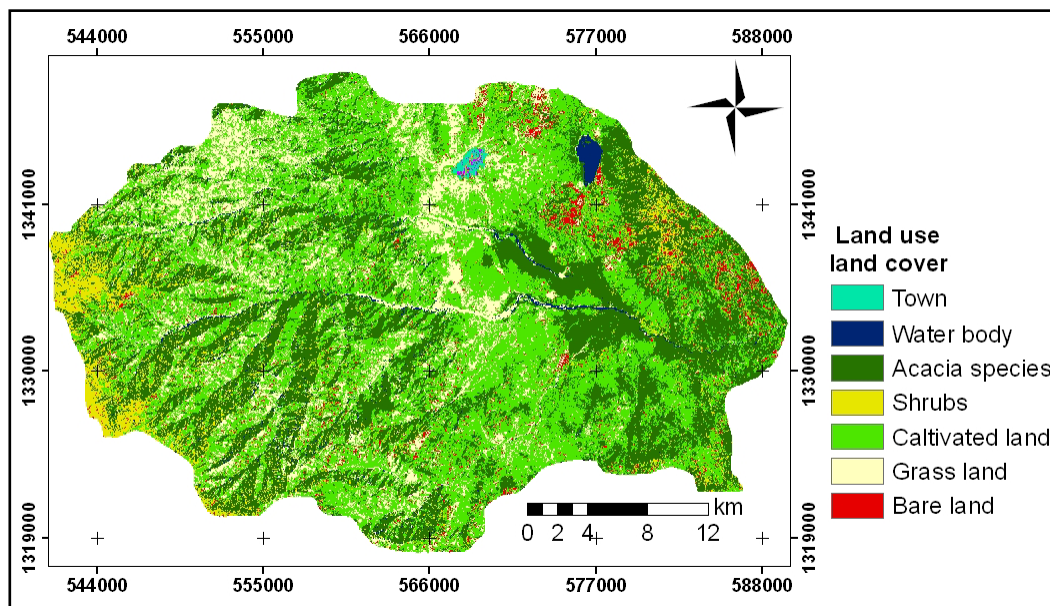


Figure 18 Land use land cover map of the area

Table 9 Land-use types and the average ET (mm/day) that is occurring over the catchment

Land Use/Land Cover	Area ha	% of area	Average ET (mm/day)
Water body	344.23155	0.320698	4.86
Acacia species	33847.7571	31.53378	3.80
Shrub land	7253.148825	6.757292	1.96
Cultivated land	48220.11473	44.92357	2.45
Grass land	15238.54103	14.19677	1.00
Bare land	2434.31325	2.267893	0.026
Total	107338.1065	100.00	

5.2 Methods of Crop Evapotranspiration (ET_c) Estimation

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process.

The Penman-Monteith method as modified by Allen (1986) was the most accurate for either environment to estimate evapotranspiration. Because of its accuracy, the Penman-Monteith method is used since air temperature, relative humidity, wind speed, and solar radiation data are available in the area. The method is adjusted to the physical features of the Kobo weather station.

5.2.1 Estimating potential evapotranspiration (ET_o)

It is evapotranspiration if adequate water supply is available to a vegetated surface. As water is abundantly available at the reference evapotranspiring surface, soil factors do not affect ET. Relating ET to a specific surface provides a reference to which ET from other surfaces can be related. It obviates the need to define a separate ET level for each crop and stage of growth. To obviate the need to define unique evaporation parameters for each crop and stage of growth, the concept of a reference surface was useful in cropped area. Evapotranspiration rates of the various crops were related to the evapotranspiration rate from the reference surface (ET_o) by means of crop coefficients (k_c).

The FAO Expert Consultation on Revision of FAO Methodologies for Crop Water Requirements accepted the following unambiguous definition for the reference surface:

"A hypothetical reference crop is with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m⁻¹ and an albedo of 0.23."

The only factors affecting ETo in the study area are climatic parameters. Consequently, ETo is a climatic parameter and is computed from weather data. ETo expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The FAO Penman-Monteith method is used as the sole method for determining ETo and explicitly incorporates both physiological and aerodynamic parameters.

$$ETo = \frac{0.408 \Delta (Rn - G) + \gamma \frac{900}{T + 273} u_2 (es - ea)}{\Delta + \gamma (1 + 0.34 u_2)} \quad (27)$$

Where	ETo	reference evapotranspiration [mm/month],
	Rn	net radiation at the grass surface [MJ m ⁻² month ⁻¹],
	G	soil heat flux density [MJ m ⁻² month ⁻¹],
	T	mean hourly air temperature [°C],
	Δ	saturation slope vapour pressure curve at T [kPa °C ⁻¹],
	γ	psychrometric constant [kPa °C ⁻¹],
	es-ea	saturation vapour pressure deficit [kPa],
	es	saturation vapour pressure [kPa],
	ea	average hourly actual vapour pressure [kPa],
	u ₂	average hourly wind speed [m s ⁻¹].

Rn and G is energy available per unit area and expressed in MJ m⁻² day⁻¹. To convert the energy units for radiation to equivalent water depths (mm) the latent heat of vaporization, λ is used as a conversion factor.

$$\gamma = \frac{c_p P}{\varepsilon \lambda} = 0.665 \times 10^{-3} P \quad (28)$$

where γ psychrometric constant [kPa °C⁻¹],
 P atmospheric pressure [kPa],

λ latent heat of vaporization, 2.45 [MJ kg⁻¹],

c_p specific heat at constant pressure, 1.013×10^{-3} [MJ kg⁻¹ °C⁻¹],

ϵ ratio molecular weight of water vapour/dry air = 0.622.

$$P = 101.3 \left(\frac{293 - 0.0065z}{293} \right)^{5.26} \quad (29)$$

Where P atmospheric pressure [kPa],

z elevation above sea level [m],

As saturation vapour pressure is related to air temperature, it is calculated from the air temperature. The relationship is expressed by:

$$e^o(T) = 0.6108 \exp \left(\frac{17.27T}{T + 237.3} \right) \quad (30)$$

Where $e^o(T)$ saturation vapour pressure at the air temperature T [kPa],

T air temperature [°C],

$\exp(..)$ 2.7183 (base of natural logarithm) raised to the power [..].

Due to the non-linearity of the above equation, the mean saturation vapour pressure for a day, week, decade or month should be computed as the mean between the saturation vapour pressure at the mean daily maximum and minimum air temperatures for that period:

$$e_s = \left(\frac{e^o(T_{\max}) - e^o(T_{\min})}{2} \right) \quad (31)$$

For the calculation of evapotranspiration, the slope of the relationship between saturation vapour pressure and temperature, Δ , is required. The slope of the curve at a given temperature is given by:

$$\Delta = \frac{4098 \left[0.6108 \exp \left(\frac{17.27T}{T + 237.3} \right) \right]}{(T + 237.3)^2} \quad (32)$$

The actual vapour pressure can also be calculated from the relative humidity. Depending on the availability of the humidity data, different equations should be used.

$$e_a = \frac{e^o(T_{\min}) \frac{RH_{\max}}{100} + e^o(T_{\max}) \frac{RH_{\min}}{100}}{2} \quad (33)$$

where ea actual vapour pressure [kPa],
 e°(Tmin) saturation vapour pressure at daily minimum temperature [kPa],
 e°(Tmax) saturation vapour pressure at daily maximum temperature [kPa],
 RHmax maximum relative humidity [%],
 RHmin minimum relative humidity [%].

The extraterrestrial radiation, Ra, for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year by:

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega_s)] \quad (34)$$

Where Ra extraterrestrial radiation (MJ m⁻² day⁻¹),
 Gsc solar constant = 0.0820 (MJ m⁻² min⁻¹),
 dr inverse relative distance Earth-Sun,
 ω_s sunset hour angle (rad),
 ϕ latitude (rad)
 δ solar declination [rad].

MONTHLY REFERENCE EVAPOTRANSPIRATION PENMAN MONTEITH							
Meteostation: Kobo				Country: Ethiopia			
Altitude: 2 m.				Coordinates: 12.16 South 39.63 East			
Month	MinTemp	MaxTemp	Humid.	Wind	Sunshine	Radiation	ETo-Penman
	°C	°C	%	km/month	Hours	MJ/m ² /month	mm/month
January	22.8	29.6	63	82	8.4	15.7	127
February	22.7	30.3	60	90	7.3	16.9	138
March	23.0	30.6	57	90	7.8	17.4	158
April	23.0	30.2	53	82	7.9	16.4	162
May	22.0	28.6	48	69	8.2	13.5	170
June	19.2	26.5	48	82	6.8	12.2	174
July	17.6	25.1	49	82	6.2	12.3	170
August	18.6	25.3	56	69	6.2	12.4	156
September	20.5	26.5	54	56	6.7	12.4	138
October	22.5	28.0	54	64	8.4	12.9	145
November	23.0	28.7	53	73	9.8	14.4	138
December	23.0	29.1	61	77	8.8	15.2	124
Year	21.5	28.2	54	77	7.7	14.3	1799
CROPWAT 7.0 Climate file: D:\Data from NMA\meteorological data							

Table 10 ETo computed by CROPWAT

As it is displayed in table 11, annual potential evapotranspiration rate of Kobo Valley is 1799 mm. It is calculated using Penman-Monteith method by using the CROPWAT software. Lower monthly potential evapotranspiration is occurred in the months of January and December (124 mm and 127 mm respectively) because of low rain fall in the area, and the available moisture is attached to the soil to satisfy the minimum crop water need. At Kobo, after the rainy season water supplies are short and the soil moisture is often well below field capacity and possibly down to the wilting point. It is well known that Kobo is arid environment, during the late-season the available moisture is highly attached to soil resisting the evapotranspiration caused by wind speed and higher daily sunshine hours. Most of the actual evapotranspiration during the dry season comes from sub-surface water via transpiration through the plant tissues.

5.2.2 Estimation of actual evapotranspiration (ETa)

Actual evapotranspiration is actually evapotranspired under the existing soil moisture supply. It is dependent on the unsaturated moisture storage properties of the soil. It is also affected by vegetated factors such as plant type and stage of growth (Freeze and Cherry, 1979). Actual evapotranspiration is the amount of evaporation that occurs under field conditions. If there is abundant moisture in the soil, the actual evapotranspiration rate is equal to potential evapotranspiration. When the moisture content in the soil is limited and vegetation unable to abstract enough water from the soil, then actual evapotranspiration becomes less than the potential evapotranspiration. Thus the relationship between ETa and ETo depends upon the soil moisture content.

If there is no rain to replenish the water supply, the soil moisture gradually become depleted by the demands of the vegetation to produce a soil moisture deficit (D). As soil moisture deficit increases, the ETa become increasingly less than ETo. The value of soil moisture deficit and ETa vary with soil type and vegetation (Shaw, 1988). Accordingly, the study area has clay and sandy loam soil type. Based on these soils and meteorological data the actual evapotranspiration of the catchment is calculated using Thornthwaite and Mather soil water balance model (Table 12).

A water balance model developed by Thornthwaite and Mather (1957) is applied to develop a rainfall-runoff water balance for the Kobo Valley catchment. Basically, in this study, Thornthwaite-Mather method is implemented as explained below. The water balance model for the catchment simulates the total runoff for the catchment. The total runoff from the catchment

is accumulated at the reservoirs on the Golina and Hormat rivers and used for Kobo Valley ground water recharge. So, the model estimates how much water is added to the ground water and used for pressurized and surface irrigation. Inputs of this model consist of monthly rainfall (P) and monthly potential evapotranspiration (ETo) (Dingman, 1994).

Components of the model could be explained as follows:

- a) The model assumes that a certain fixed percentage of the rainfall (P) will leave the area as a direct runoff (DRO). This percentage is known as direct storm runoff coefficient (C1). The remaining portion of the rainfall is called effective rainfall (P_{eff}).
- b) Accumulated potential water loss (APWL), is obtained by cumulating the negative values of the differences between monthly precipitation and evapotranspiration for dry season only; and the summation begins with the first month of dry season (September).
- c) Soil moisture (SM): Accumulated potential water loss is used to obtain the soil moisture during the dry months that results exponential soil moisture depletion and it is defined by the following formula:

$$SM_{(n)} = WHC * \exp\left[\frac{APWL_{(n)}}{WHC}\right] \quad (35)$$

Where: APWL is an accumulated potential water loss, which is always negative. It is the variable that describes the dryness of the soil. Soil moisture values for each wet month are obtained by adding the excess of rain of the current month to the soil moisture of the month before. However, this sum may not exceed the water capacity and excess is booked as moisture surplus.

- d) If the P is higher than the ETo, the actual evapotranspiration (ETa) equals the ETo. If not, it is computed as:

$$ETa = P - \Delta SM \quad (36)$$

Where: ΔSM is the difference between the soil moisture content of the current month and the previous month. It is given by

$$\Delta SM_{(n)} = SM_{(n)} - SM_{(n-1)} \quad (37)$$

- e) Soil moisture deficit is the difference between the ETo and the ETa of the same month. So, it is given by

$$Deficit_{(n)} = ETo_{(n)} - ETa_{(n)} \quad (38)$$

f) Soil moisture surplus is the difference between the effective rainfall and sum of the ΔSM and the ETa .

$$\text{Surplus} = P - [\Delta SM + ETa] \quad (39)$$

Calculation should be started from the first wet month.

g) Total available water for runoff (TARO) is determined starting from the first month of the water surplus period. The first months surplus is the TARO for that month, and from the surplus, 50% value is detained (D) and carried over to the next month TARO, and 50% is direct runoff (RO). Therefore, the TARO of preceding month is given by the surplus of that month (S) plus the detention of last month (D_{m-1}). The detention of the previous month is available for the surplus of the current month and so on.

Parameter	Average root zone soil water capacity of clay and sandy loam = 140 mm												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Not	Dec	
P	13.2	14.1	21.2	55.84	55.87	19.32	103.59	196.57	98.75	46.96	12.96	10.13	648.42
PET	127	138	158	162	170	174	170	155	138	145	138	124	1799
P - PET	-113.8	-123.9	-136.8	-106.16	-114.13	-154.68	-66.41	41.57	-39.25	-98.04	-125.04	-113.87	
(APWL)	-490	-613.9	-750.7	-856.86	-970.99	-1125.67	-1192.08		-39.25	-137.29	-262.33	-376.20	
S_m	4.22	1.74	0.66	0.31	0.12	0.05	0.03	140	105.77	52.50	21.50	9.53	
ΔS_m	-5.31	-2.48	-1.08	-0.35	-0.19	-0.07	-0.02	140	-34.23	-53.27	-31.00	-11.97	
AET	18.51	16.58	22.28	56.19	56.06	19.39	103.61	155	132.98	100.23	43.96	22.10	747.00
SMD	108.89	121.42	135.72	105.81	113.94	154.61	66.39	0	5.02	44.77	94.04	101.9	1052.51
S	0	0	0	0	0	0	0	42	0	0	0	0	42

Table 11 Monthly actual evapotranspiration (ETa) of Kobo valley catchment

Finally, as it is computed in the above table, the corresponding land use land cover units, and annual actual evapotranspiration (ETa) loss from the catchments is about 747.00 mm, here the actual evapotranspiration comes from rainfall, ground water through transpiration, irrigated agriculture (surface and pressurized irrigation). The annual surplus water in the soil is 42 mm occurred in the month of August since Kobo is located in arid environment.

5.2.3 Estimation of Crop Evapotranspiration (ETc)

Crop evapotranspiration is calculated by multiplying ETo by Kc , a coefficient expressing the difference in evapotranspiration between the cropped and reference grass surface. In this study the difference can be combined into one single coefficient that means the effect of crop

transpiration and soil evaporation are combined into a single K_c coefficient. The coefficient integrates differences in the soil evaporation and crop transpiration rate between the crop and the grass reference surface. As soil evaporation may fluctuate daily as a result of rainfall or irrigation, the single crop coefficient expresses only the time-averaged (multi-day) effects of crop evapotranspiration.

The time-averaged single K_c is used in the case for surface and sprinkler irrigation systems where the time interval between successive irrigation is of several days, often ten days or more. For typical irrigation management, the time-averaged single K_c is valid.

$$ET_c = K_c * ET_o \quad (40)$$

Where ET_c crop evapotranspiration (mm d^{-1}),
 K_c crop coefficient (dimensionless),
 ET_o reference crop evapotranspiration (mm d^{-1})



Figure 19 Drip and sprinkler irrigation for onion crop

Most of the effects of the various weather conditions are incorporated into the ET_o estimate. Therefore, as ET_o represents an index of climatic demand, K_c varies predominately with the specific crop characteristics and only to a limited extent with climate. This enables the transfer of standard values for K_c between locations and between climates.

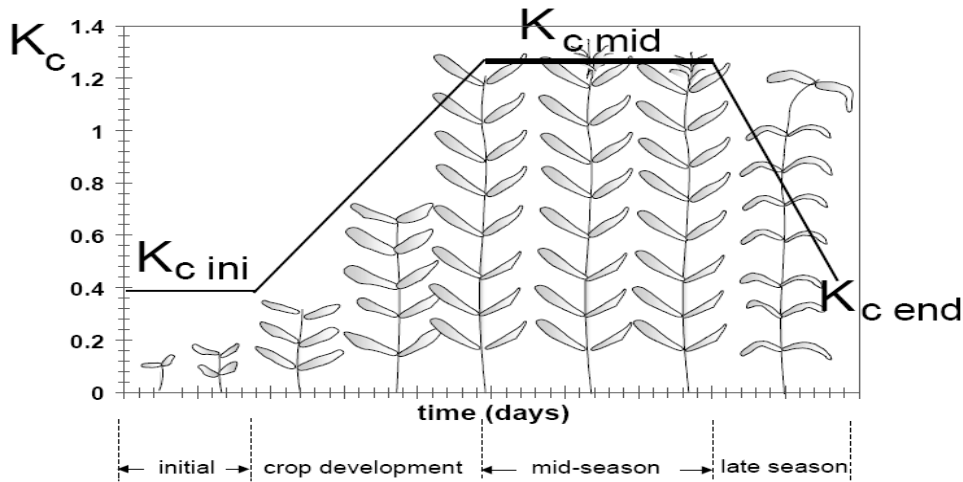


Figure 20 Crop coefficient curve for the single crop in the study area

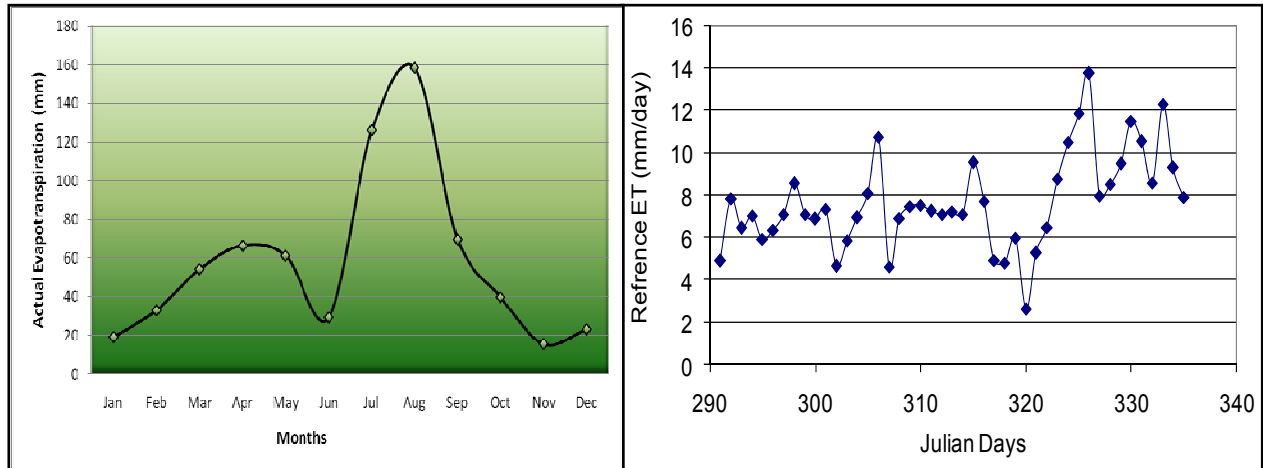


Figure 21 Actual evapotranspiration in months and in Julian days

5.3 Crop Water Requirement

The amount of water required to compensate the evapotranspiration loss from the cropped field is known as crop water requirement. Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. The irrigation water requirement basically represents the difference between the crop water requirement and effective precipitation. The required timing and amount of applied water is determined by the prevailing climatic conditions, the crop and its stage of growth, soil properties (such as water holding capacity), and the extent of root development (figure 22). Water within the crop root zone is the source of water for crop evapotranspiration.

Thus, it is important to consider the field water balance to determine the irrigation water requirements as calculated in annex 1.

All crops have critical growth periods when even small moisture stress can significantly impact crop yields and quality. Critical water need periods vary from crop to crop. Soil moisture during the critical water periods should be maintained at sufficient levels to ensure the plant does not stress from lack of water. As shown in the figure below onion crop requires 426.33mm supplemental water. The determination of irrigation water requirements and irrigation scheduling requires an accurate estimate of the crop water use rate.



Figure 22 Drip irrigation (onion crop)

Table 12 Water Requirement of crops during the growing season at Kobo Valley irrigation project

Crop	Total RF (mm)	Effective RF (mm)	CWR (mm)	Irrigation requirement (mm)
Onion	57.82	53.75	480.08	426.33
Tomato	148.27	128.30	774.26	648.96
Maize	164.37	141.33	657.96	516.63
Pepper	132.93	115.93	657.26	541.33
Cabbage	50.86	48.22	454.10	403.24
Potato	50.30	48.10	450.64	400.34

5.4 Water Resources of Kobo Valley

There are only two gauge sites having relatively longer period of data, one across Golina and the other on Hormat rivers from 1976-1983. However, by utilizing the available data, runoff and monthly yields of Kobo valley was generated at each river site. Hence the 75% dependable yields at the gauge sites are as follows: The total dependable surface runoff at gauge sites is estimated to be 76.54 mcm at the valley.

Based on the study document for KGVDP, the area has a potential of producing 156.2 million m³ subsurface water yield and 113 million m³ underground water yield, which totals 269.12 million m³ water yield per annum. On this basis, 5665 hectares of land is irrigated by using the subsurface water source and about 3600 hectares by using the underground water source, which altogether goes to 9265 hectares of land in the irrigation project (KGVDP, 2005).

Table 13 75% dependable yield for surface water resource

Gauge site	Catchment area (km ²)	Dependable yield (Mcm)
Hormat	100	14.423
Golina	213.2	31.613

5.4.1 Runoff

Runoff is the water which moves in defined channel or all the water that moves over the land surface in undefined channel. The runoff process is influenced by rainfall intensity and infiltration capacity of soil. The infiltration capacity varies not only from soil to soil, but also different for dry versus moist conditions in the same soil. If the rainfall intensity is lower than the infiltration equilibrium capacity, then all water reaching the land surface will infiltrate. If the rainfall intensity is greater than infiltration equilibrium capacity at the beginning all the water will infiltrate, but when the infiltration capacity drops below the rainfall intensity, some of the water starts to remain on the land surface. That water which is not infiltrate, forms flows as thin sheet of across the land surface, which is called over land flow or surface runoff (Ayenew and Alemayehu, 2001). In exceptional stormy rains, runoff might occur before the rainfall exceeds the infiltration capacity of soil. The pattern of runoff volume of any catchments or basin is a function of duration of intensity and aerial distribution of rainfall and other factors such as size,

shape, geology, topography, slope, land use and land cover of catchments. In the study area, in most rains are stormy that leads to runoff before the soil's infiltration capacity is satisfied.

The river discharge of data collected from these stations by the Ministry of Water resource shows that the 46.3million cubic meter (mcm) of water leaves annually from catchments of 313.2 km². This amount of water is not surface runoff only but there is base flow component within it.

5.4.2. Base flow separation method

From river discharge, surface runoff and base flow could be separated using conventional graphic separation and spreadsheet program (software) called TIMEPLOT method. The spreadsheet program (software) can estimate reasonably by taking in to consideration the topographic characteristics of the basin.

From soft ware base flow separation methods, the annual base flow and surface runoff of Golina river catchment is 54.34mm and 23.05mm respectively. For Hormat river catchment, the annual base flow and surface runoff is 16.54mm and 5.06mm respectively.

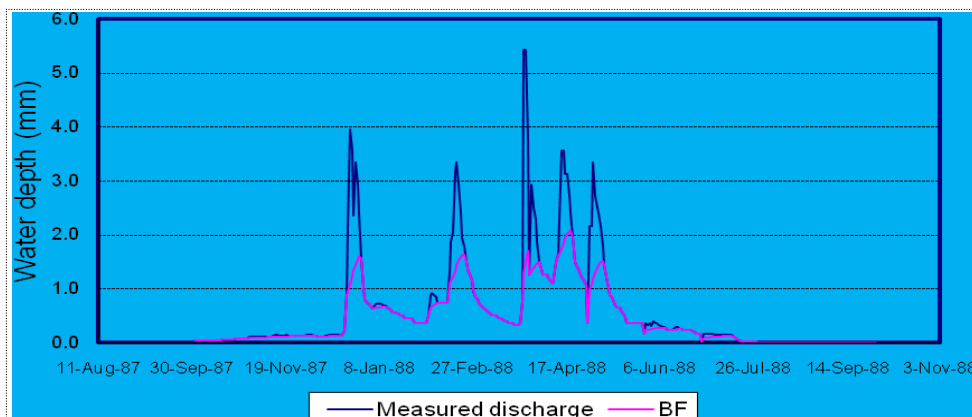


Figure 23 Base flow (mcm) and runoff separation from the Golina river discharge.

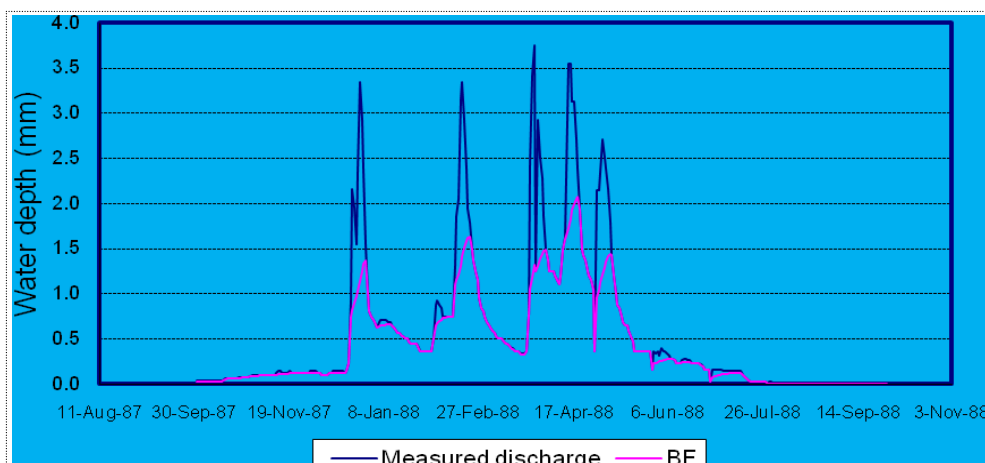


Figure 24 Base flow (mcm) and runoff separation from the Hormat river discharge.

5.4.3 Groundwater recharge and discharge

Kobo valley unconfined aquifer has a total of 434.7 sq.km area, elongated in north-south direction with a length of about 37km and with an average of 13 km width. For proper management of groundwater development of the Kobo sub basin for irrigation, it is important to estimate properly the annual replenishment (recharge) of the groundwater in the alluvial fill. The runoff from the mountainous areas is one of the components of recharges that recharge the groundwater of the valley.

There is high groundwater resources potential in the valley plain, which should be developed for irrigated agriculture for future irrigation projects (figure 25 and 26). The groundwater resource can be applied in combination with spate irrigation and can supplement additional water during rainfall shortage to the traditional rain-fed agriculture. It may serve as an additional water resource during dry seasons or to produce an extra harvest per year. The grain size of the sediment at the foot of the escarpment favours infiltration to enrich groundwater. Therefore, shallower groundwater depth condition is also expected along the proximity of dry riverbeds.

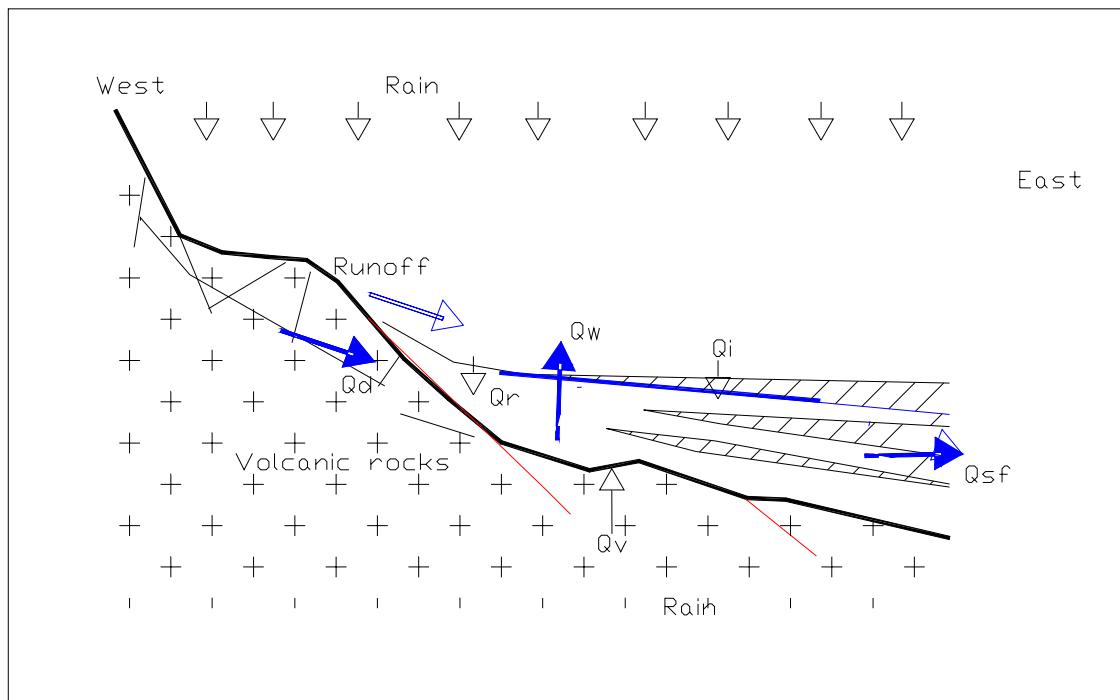


Figure 25 Pump installation for irrigation



Figure 26 Well development at the valley

The major sources of groundwater recharge for the unconsolidated sediment aquifer are subsurface seepage from the fracture openings of the volcanic rocks of the western mountainous area, seepage from runoff generated from precipitation in the highlands and infiltration from precipitation that takes place in the valley plain and irrigation return and contribution may also come from bedrock volcanic aquifer (Figure 28).



- Q_d - Recharge from draining from mountainous volcanic aquifer as subsurface flow
- Q_r - Recharge from runoff seepage at the foot of the escarpment
- Q_i - Recharge of Infiltration from rainfall at the plain and irrigation return
- Q_v - Probable replenishment from the bedrock volcanic aquifer
- Q_w - Discharge by wells for irrigation and other water supply
- Q_{sf} - Discharge of groundwater out of the valley through selen Wuha and Golina river outlet
- Q_{vr} - Recharge from volcanic inselberg ridges

Figure 28 Schematic Recharge and discharge condition of Kobo Valley unconsolidated sediment deposit

Geo-Engineering Service carried out the “Review and Appraisal of Hydrgeological Feasibility Study of Kobo Valley” starting from 2004 throughout the valley for implementation by KGVDP and computed values of hydrological data from Golina and Hormat rivers are available in the

Feasibility study report that are used for the calculation of discharge and recharge of Kobo Valley ground water system in this study.

The Hormat-Golina groundwater system (south of the groundwater divide) flow in southeast direction with a hydraulic gradient of about 0.01 on the western part and the hydraulic gradient highly decreases to the east along the Golina outlet. Similarly the Waja-Golesh groundwater system (north of the groundwater divide) flows in northeast direction to Selen Wuha with a hydraulic gradient of about 0.01 on the western part and the hydraulic gradient highly decreases to the east (GES, 2005).

In the appraisal report, a reliable water level and transmissivity map was prepared after generating additional aquifer parameters from geophysical survey and test wells drilling (figure 25).

Applying Darcy equation for groundwater systems for mountain recharge

$$Q = T * I * L * 365 \quad (41)$$

Where, Q - Average annual groundwater recharge in Mm³
 I - Hydraulic gradient
 T - Transmissivity in m²/day
 L - Width of flow at right angle to the direction of flows in meters

Calculated parameters of transmissivity and flow gradient values by Geo-Engineering Service for the groundwater system in Kobo valley unconsolidated sediment aquifer was taken for ground water recharge estimation.

a) *Hormat Golina Groundwater system*: in this system there are two groundwater flow directions, which concentrate at the southeast part of the valley to be discharged along the Golina river outlet to Afar depression.

At the western part of the groundwater system there are two concentrated flows along Golina and Kelkeli rivers

- i) Along Kelkeli river: T = 400 m²/day I = 0.14 L = 2630 meters
- ii) Along Golina river: T = 800 m²/day I = 0.009 L = 11040 meters

Calculating the recharge for Hormat Golina by the above formula gives:

$$Q_{hg} = 94201 \text{ m}^3/\text{day or } 34.38 \text{ MCM/year}$$

(MCM – Million Cubic Meters)

- b) Waja Golesha groundwater System: The major flow northeast direction to Selen Wuha outlet as one major concentrate flow

$$T = 800 \text{ m}^2/\text{day}$$

$$I = 0.008$$

$$L = 12700 \text{ meters}$$

$$Q_{wg} = 81,280 \text{ m}^3/\text{day or } 29.7 \text{ MCM/year}$$

The total mean annual dynamic groundwater recharge of Kobo valley unconsolidated sediment aquifer (alluvial) as subsurface seepage from the volcanic aquifer is estimated by summing the Hormat Golina and Waja Golesha recharge, which equals about **175,480 m³/day or 64.1 MCM/year**.

The mean annual groundwater balance of the unconsolidated sediment aquifer of Kobo valley:

❖ **Mean annual recharge (Dynamic water Resources).....71.0 MCM/year**

- Subsurface seepage from the volcanic aquifer of western escarpment and plateau64.10 MCM/Year
- Infiltration from rivers.....6.26 MCM/year
- Infiltration from runoff of ridges within the valley0.60 MCM/year

❖ **Mean annual Discharge (outflow).....71.0 MCM/year**

- A groundwater extraction for community water supply (from water point's inventory data of Feasibility report, 1999).....4.7 MCM/year
- Sub-surface outflow through the eastern escarpment66.3 MCM/year

Groundwater is a major source that Kobo valley has. It is one of the few valleys in the country that has reliable groundwater source. It has $4347 \times 10^6 \text{ m}^3$ groundwater in the valley. About $78.8 \times 10^6 \text{ m}^3$ of the groundwater can safely be exploited each year from this resource and the water can be used for irrigation and household consumption (GES, 2005).

5.5 Estimation of Performance Indicators

a) Relative Water Supply

The relative water supply (RWS), used as an indicator of adequacy of irrigation water delivery, compares the amount of the water supply with that of water demand. It is the ratio of total water supply (i.e., irrigation + total rainfall) to total water demand by crop (i.e., potential crop evapotranspiration, ET_p). It is computed as

$$RWS = \frac{V_c + RF}{ET_o} \quad (42)$$

Where; V_c is irrigation supply, P is total rainfall and ET_p is potential crop evapotranspiration. The target value of RWS indicator was considered 2.0 (Molden et al., 1998).

b) Overall Consumed Ratio

It is the ratio of irrigation demand (i.e., ET_o - effective rainfall) to irrigation supply. The overall consumed ratio quantifies the degree to which crop irrigation requirements are met by irrigation water in the irrigated area. The ratio is defined as.

$$OCR = \frac{ET_o - RF_{eff}}{V_c} \quad (43)$$

Where; P_{eff} is effective rainfall. It was calculated in the software CROPWAT. A target overall consumed ratio should be set within an existing irrigated area, and compared to the actual ratio on a monthly and seasonal basis 0.51, can be accepted as the target value at the field level in the conditions of study area (Bos et al., 2005).

c) Depleted Fraction

The depleted fraction (DF) is the fraction of available water that is depleted and no longer available for other water consumption processes. The depletion in the irrigation scheme is governed by ET_c . It is the ratio of actual evapotranspiration (ET_a) to total water supply (i.e., irrigation + total rainfall).

$$DF = \frac{ET_a}{V_c + RF} \quad (44)$$

For semi-arid and arid regions, the critical value of the depleted fraction averages about 0.6 (Bos et al., 2005). The acceptable range of DF was considered 0.6-1.1 (Bastiaanssen et al., 2001). In this study, a depleted fraction of 0.6 is considered.

d) Crop water deficit

Crop water deficit (CWD) over a period is defined as the difference between ETo and ETa of the cropping pattern within the area. A common period is 1 month. An average CWD of 30 mm/month is acceptable. It is defined as follows (Bastiaanssen et al., 2001):

$$CWD = ETo - ETa \quad (45)$$

e) Relative Evapotranspiration

To evaluate the adequacy of irrigation water delivery to a selected command area as a function of time, the dimensionless ratio of ETa over ETo gives valuable information to the water user/manager and is described as relative evapotranspiration (RET). It is a ratio of ETa to ETc.

$$RET = \frac{ETa}{ETc} \quad (46)$$

A value of $RET \geq 0.75$ is quite acceptable for irrigated agriculture in the growing season, although this is not constant over time (Molden et al., 1998).

The values of the ETa, ETo, Vc, RF, and RF_{eff} parameters that are needed to determine irrigation performance indicators are given in the following table. Performance indicators for the evaluation of the irrigation performance overall consumed ratio (OCR), relative water supply (RWS), depleted fraction (DF), crop water deficit (CWD), and relative evapotranspiration (RET) are 0.55, 1.23, 0.29, 42.44, and 0.43 respectively as shown in Tables 15 and 16 for Kobo Valley irrigation project.

Table 14 Values of ETc, ETo, Vc, RF and RF_{eff} for Kobo Valley irrigation project

Months	ETc	ETo	V _c	RF	RF_{eff}
September	40.74	138	0	98.75	88.6
October	72.84	145	284.2	46.96	42.6
November	65.44	138	285.6	12.96	10.5
December	51.65	124	152.4	10.13	8.6
January	54.23	127	191.9	13.2	11.2
Total	284.90	669	682	182	161.5

Where ETp is potential evapotranspiration in millimeters, RF_{eff} is effective precipitation in millimeters, and Vc is volume of irrigation water diverted from resource and/or groundwater in millimeters.

It can be seen that there are no values of OCR and DF indicators for some months because the values of the parameters V_c and RF_{eff} used to calculate these indicators are zero. These months were not considered when calculating the values of the coefficient of variation (CV).

Table 15 Values of OCR, RWS, DF, CWD, and RET for Kobo Valley irrigation project

Months	OCR	RWS	DF	CWD	RET
September	-	0.72	0.41	66.9	0.31
October	0.66	2.38	0.22	39.5	0.52
November	0.52	1.92	0.22	53.9	0.47
December	0.87	1.15	0.32	22.0	0.42
January	0.72	1.61	0.27	29.9	0.43
Total				212.2	
Seasonal Average	0.55	1.56	0.29	42.44	0.43

6. Results and Discussion

Daily weather data was collected from the National Meteorological Agency and from Kobo Girana Valley Development Program and used to calculate ETo using the modified Penman-Monteith equation (Allen et al. 1998). ETo was converted into potential crop evapotranspiration, ETc, by multiplying with the crop coefficient Kc ($ET_c = K_c ETo$). Based on the actual cropping calendar, the average seasonal single crop coefficient Kc for the satellite overpass dates were used in this study. The major crops grow in the area are maize, sorghum, onion and potato.

6.1 Comparison of NDVI and Surface Temperature for image 2003

The main purpose of the comparison is to show how temperature varies on land and water surfaces and with moisture content both soil and vegetation. In this regard, using modeler maker the NDVI and the surface kinetic temperature images were stacked for each year independently. Then the attributes of NDVI and surface temperatures were converted in to ASCII text format. Then by exporting to excel the following graph is produced.

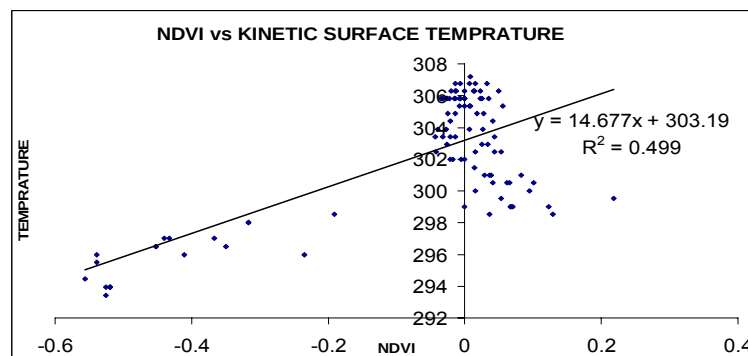


Figure 29 NDVI vs kinetic surface temperature (2003)

As it can be seen from the scatter plots there is a direct correlation between NDVI against surface temperature. The temperature is lower for water bodies and moist soils which are represented by negative NDVI values than other surface features.

6.2 Remote sensing Based Actual Evapotranspiration

In this study, the pixel values of ETa, calculated through SEBAL, corresponding to the date 05/12/2003 for the entire Kobo valley irrigation system and surrounding areas. ET values range between 0.006 (bare soil) to 4.86 (water body). The ET map also includes values for areas near

the irrigation system that include acacia species, bare soil and shrub vegetation. A summary of ET for the entire area is shown in the graph below. The average ET value for full cover agricultural crops and acacia species was 3.80mm on the irrigation system.

To quantify the linear relationship between the different means of estimation, the actual evapotranspiration values from SEBAL were compared with those from the FAO Penman-Monteith method using correlation coefficients.

The data derived from Landsat 7 (2003) image was compared with daily data from the weather stations. The average correlation coefficient was 0.79. This result indicated that there was a high linear relationship between the actual evapotranspiration from SEBAL and the FAO Penman-Monteith calculation (figure 30). Since the actual evapotranspiration computed by SEBAL was only calculated considering one image, the actual evapotranspiration on other days was determined using temporal interpolation. Thereafter, the actual evapotranspiration from the temporal interpolation (figure 17) was compared with the actual evapotranspiration from the FAO Penman-Monteith method. The average correlation coefficient was 0.69, which suggested that there was a good linear relationship between the actual evapotranspiration from SEBAL and the FAO Penman-Monteith method. In general SEBAL gives both temporal and spatial output. Then the attributes of ET24 map and the ET of the crop were converted in to ASCII text format. Then by exporting to excel the following graph is produced.

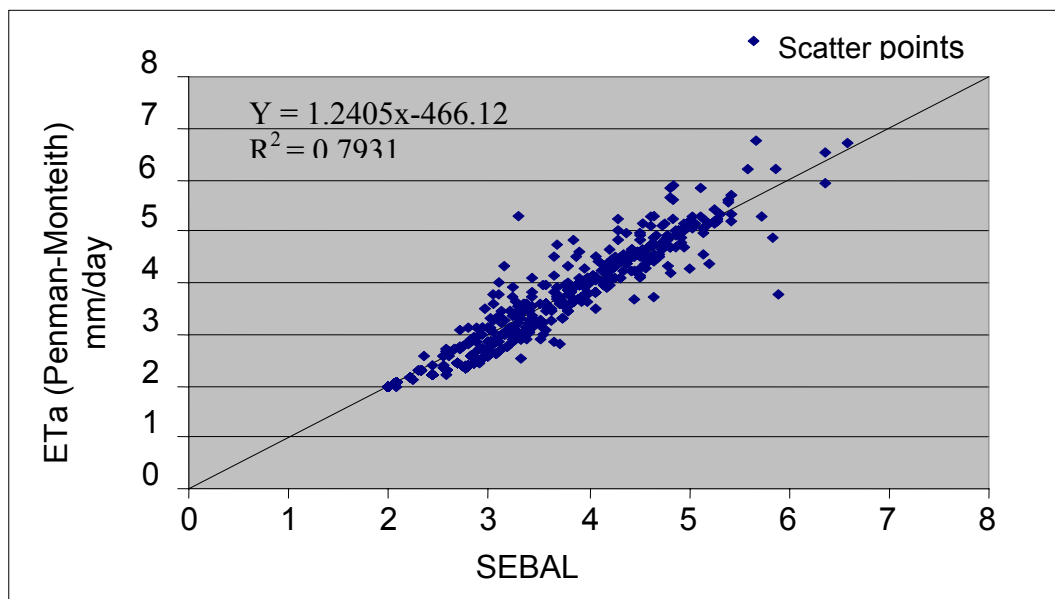


Figure 30 Comparison of SEBAL estimate and Penman-Monteith calculation, the Landsat ETa were extracted as average values from 30x30 pixel windows.

ET information from SEBAL was presented in mm/month and in terms of crop coefficients (K_c). The Kobo Valley crop area obtained high ET_a values whereas the bare and grass land area had very low ET_a . The monthly and seasonal ET maps for the basin are being studied to provide information on total water consumption.

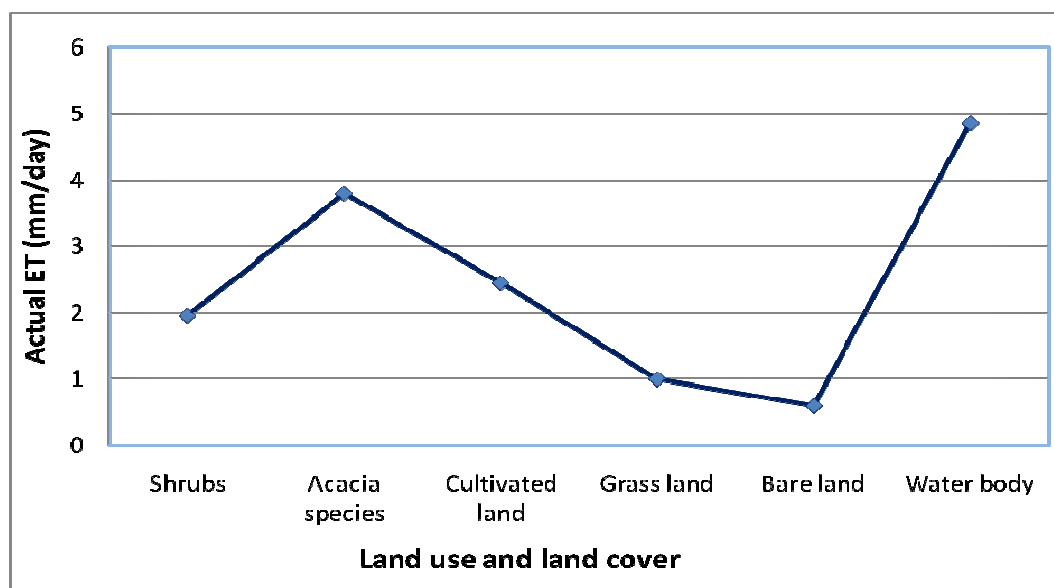


Figure 31 The variation of ET (mm/day) with the different land uses in the catchment

6.3 Implementation of Irrigation Performance Assessment

Strategic performance is assessed considering the water balance components depicted in Figure 28 for the Kobo Valley sub-basin, using indicators selected in Table 16. Landsat ETM+ image was taken for assessing irrigation performance during the dry season of Dec, 2003. The values of ET_a derived from the satellite measurements were combined with the field measurements. To estimate ET_a , daily weather data was associated with the satellite measurements.

At Kobo valley Groundwater is a major source for irrigation activity in the project area. It is one of the few valleys in the country that has reliable groundwater. The way of living of the people in the valley and the surrounding areas can greatly improve and the output from the production shall contribute to the general economy of the area if the water source is utilized for irrigation in proper manner as per the water requirement of the crop.

6.3.1 Overall Consumed Ratio

Because the total water supply to a command area is among the very first values that should be measured, the overall consumed ratio is the first indicator that should be available for the

irrigated area (figure 32). With the periods with low ratios, the non-consumed fraction of the water will cause the ground water table to rise. When this study was carried out the average seasonal overall consumed ratio value of the study area is 0.55 (table 16). The OCR performance indicator for the month of September could not be calculated because no water was delivered to the irrigation project (annex 1). The overall consumed ratio for the irrigation project was well below the target value of 0.51. This is a clear indicator of water insufficiency for the study area. The overall consumed ratio is not homogeneous from month to month; there is a month to month inconsistency in the ratio between monthly water requirements and the amounts actually obtained. In the late season of the crop growing period farmers reduce the amount of irrigation water before the harvest time in order to keep the crop content to rape and high quality. The OCR indicator for Kobo Valley irrigation project in September was very high because the amount of water delivered from the source was very much less than needed.



Figure 32 Kobo valley irrigation project: (a) and (b) are gravitational irrigation, (C) Pressurized irrigation (well head and mashow crop).

6.3.2 Relative Water Supply

Relative water supply is a suitable indicator to inform the irrigation manager or the irrigator whether sufficient water is being supplied to the area of cropped land in order to meet the total water demand. Relative water supply and overall consumed ratio have an inversely proportional relationship (Bastiaanssen et al., 2001).

Average values of the RWS indicator for Kobo valley irrigation system was 1.56 (Tables 16). This value is well below the target value of 2.0. This also shows that there is a problem with water supply.

6.3.3 Depleted Fraction

The seasonal average depleted fraction indicator for the study area is 0.29. A critical value of DF (0.6) implies that if ET_a is less than about 0.6 ($RF+V_c$), a portion of the available water goes into storage, causing the groundwater table to rise, while storage decreases if ET_a is greater than 0.6 ($RF+V_c$) (Bastiaanssen et al., 2001).

The DF value for the irrigation project that is located in a semi-arid area were generally lower than the critical value (0.6), and the unused portion of the water delivered from the source in these months may feed the groundwater (table 16). The fact that even though no water was delivered from the source in September, the plants consumed almost as much water as in the other months is a clear indication of this.

6.3.4 Crop Water Deficit

Seasonal average value of CWD indicator for Kobo Valley irrigation project in the growing period was 42.44 mm/month, while seasonal total value was 212.2 mm (Tables 16). This average value is above the permissible level (30 mm/month). In this study, the crop water deficit indicator for the study area in the months of December and January were the only ones that were an acceptable level. The biggest deficit was in September. However if the total water requirements (ET_p) in table 16 is evaluated along with the crop water deficit value, it can be said that about one-third of the water demand was not met over the whole growing season.

5.3.5 Relative Evapotranspiration

Seasonal average value of the RET indicator for study area was 0.43. Thus, seasonal RET performance of the irrigation was poor. In a study using remote sensing techniques, an average RET value of 0.77 was found. The RET average for the irrigation project in this study was lower, and thus it can be said that they had a greater problem with water supply. As was also shown with the CWD indicator, about one-third of the water needed was not met for Kobo Valley irrigation district. The lowest RET value in the area was in September. This is because no water was supplied for irrigation activity; in general about half of the crop water requirement was met. This result shows that the water that was stored in the crop root area from rain or irrigation may have been used when there was little or no rain. Taken on a monthly basis, RET did not reach the recommended value for irrigated agricultural land (≥ 0.75).

7. Conclusions and Recommendations

General information about this research and major conclusions are summarized in this part. In addition, some recommendations about further work that should be conducted are proposed.

7.1 Conclusions

SEBAL use digital image data collected by Landsat Remote Sensing satellites that record thermal infrared, visible and near-infrared radiation. ET is computed on a pixel-by-pixel basis for the instantaneous time of the satellite image. The process is based on a complete energy balance for each pixel, where ET is predicted from the residual amount of energy remaining from the classical energy balance, where $ET = \text{net radiation} - \text{heat to the soil} - \text{heat to the air}$ but requires routine meteorological measurement of air temperature, humidity, wind speed and sunshine duration. The cold pixel was taken in an agriculture area, cultivated land, having low temperature and high NDVI. The low temperature was taken as an indication of an adequate irrigation and the high NDVI was considered as an indicative of maximum cover by agricultural crop.

From the analysis described, it is concluded that the application of this SEBAL model is promising for estimating ET in agricultural areas at Kobo Valley. However, a better distribution of meteorological information is needed. SEBAL has been developed in such a way that the need for extensive measurements is partly eliminated, but there is a strong need for some daily weather information in order to tie the model to the climatologic condition of the area. The overall intent of this research was to explore a way for generating ET maps for the Kobo Valley Irrigation System, an area with more than 17000ha of irrigated land for assessing irrigation performance for different crops. The snapshot computed in this study demonstrates that water bodies have highest ETa, vegetations transpire at a higher rate than cultivated land on Dec. 5, 2003.

The proposed methodology allowed the estimation of water use for the irrigation system for the study area. Water consumption in the irrigated lands was estimated as 13977m^3 by spatially integrating the ET values for the entire area of seasonal crop growing period. These values represent critical information for the management of water resources in the study area.

When calculating performance indicators, the amount of irrigation water delivered to the system from the water source was taken into account. Whether taken on a monthly or a seasonal basis, the irrigation performance of the valley is poor. At the same time, the performance in the months when irrigation was not intensive (May and September) and in the months when it was most intensive (annex 1) was different. The basic factor in this poor performance is the insufficiency of water where surface irrigation is applied.

The map showed temporal variation as well as distribution of ET in space. Predicted ET compared well with ground data during the study. Concrete conclusions are therefore avoided because of the few available Remote Sensing observations. Many irrigation systems in Ethiopia have already been under infancy for ETa by remote sensing of the energy-balance. Time series of ETa are now emerging as important combined temporal & spatial analysis tools for irrigated crops water consumption. Assessment of irrigated crops performance is largely benefiting from such advancements of the remote sensing science combined with routine meteorological data.

The main limitation for the model application was the availability of weather data. Fortunately, the weather stations used in this study, "Kobo and Alamata", provide daily information, which is not the case for most agricultural areas at Kobo Valley, where mostly monthly data is available. Besides, the use of FAO-56 methodology for estimation of ET in the cold pixel makes the proposed model dependent on the accuracy of the crop coefficient value and the quality of the weather information for the estimation of the reference ET.

7.2 Recommendations

The application of remote sensing brings a significant contribution to estimate the spatial evapotranspiration in large scale for all types of land covers. However, the ground observation based methods are always very important, especially in verifying the results of different remote sensing based approaches.

Using the natural resource of the valley is the best way for improving the life of the people. The pressurized irrigation project that is under implementation is one of the development projects that can improve the life of the people. However, the surface water source is limited. The discharge of Golina and Hormat rivers are rather low during the dry seasons and almost all of the remaining rivers in the valley are intermittent or they have very low flows during the dry seasons. Therefore the land that can be irrigated using surface water source could not be much due to limited water resource and emphasis should be given for pressurized irrigation system.

Based on the above discussions the writer of this research would like to recommend the following points:

- ❖ Introduce a performance assessment program for the irrigation project, with a minimum number of indicators as used in this study.
- ❖ Arrange obtaining near real-time measurements of rain fall from weather stations, ETa from low cost satellite data and canal flows from regular field measurements.
- ❖ Carry out GIS operations and satellite remote sensing for estimating ETa through the SEBAL approach and thereby, for quantifying related parameters of the selected performance indicators.
- ❖ Cooperate with farmer organizations to achieve the objectives of the performance assessment program.

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Annex 1 Kobo valley irrigation project cropping pattern and water requirement (m³/ha)

Season	Crop type	Area coverage (%)	Monthly Requirement m ³												Total (m ³)
			Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	
Dry	Maize	27	444	879	1218	1005	164								3710
	Pepper	30	757	1007	990	841								581	4176
	Tomato	8	796	1156	1218	852								349	4371
	Onion	25	966	1258	1165	442								377	4208
	Irrig. Req. (m ³ /ha)		558.2	887.4	1042.7	779.6	82							190.2	3644
Wet	Sorghum	10								94	825	1130	825		2876
	Teff	15								3	623	1084	729		2439
	Maize	15								85	878	1218	947		3128
	Haricot bean	25								116	965	463			1544
	Chick pea	15								28	825	383			1236
	Ground nut	10								97	756	865			1658
	Irrig. Req. (m ³ /ha)									65.1	748.25	712	333.99		1859.34
Perennials	Citrus	3	673	637	552	539	647	1084	111		383	657	727	642	6652
	Papaya	2	983	981	913	881	984	1363	252	73	615	937	1044	948	9974
	Banana	5	983	981	913	881	984	1363	252	73	615	937	1044	948	9974
	Irrig. Req. (m ³ /ha)		89	87.78	80.47	77.84	89.1	127.93	20.97	5.11	54.54	85.3	87.4	85.62	898.55
Net Irrig. Req. (m ³ /ha)			647.2	975.18	1123.1	857.44	170.29	127.93	20.97	70.21	862.79	797.3	421.39	275.82	6289.6
Gross Irrig. Req. (m ³ /ha)			1438	2167.07	2495.8	1905.3	378.42	284.29	46.6	156.02	1783.98	1771.78	936.42	612.93	13977
Irrigable area: Dry season=1000 Wet season=1000 efficiency=0.47															