ISTANBUL TECHNICAL UNIVERSITY ★ EURASIA INSTITUTE OF EARTH SCIENCES

ESTIMATION OF EVAPOTRANSPIRATION OVER HARRAN PLAIN USING SEBS MODEL

M.Sc. THESIS

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<u>ISTANBUL TEKNİK ÜNİVERSİTESİ ★ AVRASYA YER BİLİMLERİ ENSTİTÜSÜ</u>

SEBS MODELİ KULLANARAK HARRAN OVASI ÜZERİNDE BUHARLAŞMA –TERLEME TAHMİNİ

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Maryam-SAFARI, a M.Sc student of ITU Eurasia Institute of Earth Sciences 601151014 successfully defended the thesis entitled “ESTIMATION OF EVAPOTRANSPIRATION OVER HARRAN PLAIN USING SEBS MODEL”, which he/she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Dedicated to my parents for their endless Love, Support & Encouragement

FOREWORD

This study is about the estimation of evapotranspiration (ET) in the Harran plain farm lands, by using Surface Energy Balance System based on MODIS satellite data and station measurement. It is aimed to calculate more accurate ET in shorter time and less costs by using data set which is accessable for free in NASA website.
I would like to thank to my advisor Prof. Dr. Ömer Lütfi ŞEN for guiding me in this study. My special thanks go to Dr. Mustafa GÖKMEN for teaching SEBS model and for being beside me, step by step, during this study. Endless thanks to my precious parents who have always encouraged me all my life

November 2019 Maryam SAFARI

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ABBREVIATIONS

ASTER	: Advanced Spaceborne Thermal Emission and Reflection Radiometer
DOY	: Day Of Year
ET	: Evapotranspiration
ET$_a$	: Actual Evapotranspiration
ET$_0$	: Reference evapotranspiration
ET$_p$	: Potential Evapotranspiration
FAO	: Food and Agriculture Organization
GAP	: Southeast Anatolian Project
LAI	: Leaf Area Index
LST	: Land Surface Temperature
MODIS	: Moderate Resolution Imaging Spectroradiometer
NDVI	: Normalized Difference Vegetation Index
SEBAL	: Surface Energy Balance Algorithm for Land
SEBS	: Surface Energy Balance System
NASA	: National Aeronautics and Space Administration
GLDAS	: Global Land Data Assimilation System
TARBIL	: Agricultural Monitoring and Information System
RMSE	: Root Mean Square Error
rRMSE	: Relative Root Mean Square Error

SYMBOLS

F	: Chemical energy stored
G	: Soil heat flux
H	: Sensible heat fluxes
K	: Thermal conductivity
Rn	: Net radiation
z	: Soil depth
$\boldsymbol{\alpha}$	: Albedo
$\boldsymbol{c_p}$	: Specific heat of air
$\boldsymbol{\lambda_E}$	: Latent heat fluxes
$\boldsymbol{T_s}$	: Land surface temperature
$\boldsymbol{T_r}$	: Reference temperature above the surface
$\boldsymbol{\rho}$	: Air density
$\boldsymbol{r_a}$	: Aerodynamic resistance
Δ	: Slope vapour pressure curve
Rn	: Net Radiation
$\boldsymbol{\gamma}$	: Psycrometric constant
$\boldsymbol{U_z}$	: Wind Speed
$\boldsymbol{e_s}$	: Saturated vapour pressure
$\boldsymbol{e_a}$	: Actual vapour pressure
$\boldsymbol{K_c}$	: Crop Coefficient
S↓	: Incoming shortwave radiation
L↓	: Incoming longwave radiation
L↑	: Outgoing longwave radiation
$\mathbf{ET_{\circ}}$	: Reference evapotranspiration
P	: Atmospheric pressure
$\boldsymbol{U_2}$	: wind speed at 2 m height
$\mathbf{e^0(T)}$	: Saturated vapour pressure at the air temperature T
RH	: Relative humidity
$\boldsymbol{e_s - e_a}$	: Vapour Pressure Deficit

$\boldsymbol{R_{nl}}$: Net longwave radiation

$\mathbf{R_a}$: Extraterrestrial radiation

$\boldsymbol{a_s}$: Regression constant

$\boldsymbol{a_s + b_s}$: Fraction of extraterrestrial radiation reaching the earth on sunny days

n/N : Relative Sunshine Duration

σ : Stefan-Boltzmann constant

$\boldsymbol{R_{so}}$: Calculated clear-sky radiation

$\boldsymbol{C_s}$: Soil heat capacity

ΔT : Length of time interval

ΔZ : Effective soil depth

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ESTIMATION OF EVAPOTRANSPIRATION BASED ON MODIS SATELLITE DATA BY SEBS MODEL OVER HARRAN PLAIN

SUMMARY

In recent years, human activity and climate change greatly threaten water resources. Evapotranspiration (ET) is one of the most important components in the water cycle. Estimation of evapotranspiration has always been faced with many uncertainties. Estimating evaporation based on physical and experimental equations is very common. These methods are based on meteorological data whose shortcomings limit the use of these relations. For instance, this information is point-specific and related to meteorological stations. Another uncertainty problem is regional estimation by using statistical methods. Over the past few decades, many studies have been carried out on estimating evapotranspiration using remote sensing technology. One of the methods which are widely used for estimating ET is SEBS algorithm. The SEBS was proposed for estimating fluxes of heat or energy and estimating evaporation fraction [24]. This study aims to estimate ET over the Harran Plain that has the largest agricultural irrigation systems in the Southern Anatolian Project. Evapotranspiration is estimated for 2015. Cloud-free days in each season of 2015 are selected. Results compared with data obtained from TARBIL and evapotranspiration extracted from GLDAS products. TARBIL project gives reference evapotranspiration. For calculating the actual ET from TARBIL data crop coefficient (Kc) was required. The assumption for estimating Kc is based on cotton plants. Kc for this study considered from 0.35 to 1.3. SEBS shows very good compatibility results with TARBIL data with a 10% error but ET extracted from GLDAS was not in the expected range (0 to 2.7 mm/day). GLDAS generates ET in 0.25-degree (27.5×27.5 km) resolution that it is not enough for relatively small areas like Harran plain while SEBS estimates ET in high resolution (1×1 km). For studies of water management, water budget, land surface fluxes in the area with low vegetation cover and also in large scales GLDAS can be used but in case of our target that it is the estimation of ET in agricultural lands especially in a relatively small area SEBS gives us more accurate and more trustworthy ET.

SEBS MODELİ KULLANARAK HARRAN OVASI ÜZERİNDE BUHARLAŞMA –TERLEME TAHMİNİ

ÖZET

Son yıllarda, insan etkinliği ve iklim değişikliği su kaynaklarını büyük ölçüde tehdit etmektedir. Terleme ve buharlaşma su döngüsünde en önemli bileşenlerdendir. Evapotranspirasyon (ET) hesaplanması esnasında her zaman belirsizlikler yaşanmıştır. Fiziksel ve deneysel eşitliklere dayalı buharlaşma tahmini oldukça yaygındır. Bu yöntemler meteorolojik verilere dayanmaktadır. Verilerde yer alan eksiklikler bu ilişkinin kurulmasını zorlaştırmaktadır. Örneğin, bir meteoroloji istasyonundan alınan bir veri sadece o noktaya özgüdür. Bir diğer belirsizlik yaşanan alan da istatistiksel yöntemler kullanılarak yapılan bölgesel tahminlerdir. Son zamanlarda, uzaktan algılama teknolojisini kullanarak terleme ve buharlaşmanın tahmini konusunda birçok çalışma yapılmıştır. ET tahmini esnasında yaygın olarak kullanılan yöntemlerden biri SEBS algoritmasıdır [24]. SEBS, ısı veya enerji akılarının hesaplanması ve buharlaşma tahmini için önerilmektedir. Bu çalışmada, Güney Doğu Anadolu Projesinde (GAP) en büyük tarımsal sulama sistemine sahip olan Harran Ovası'ndaki ET değerinin SEBS ile hesaplanması amaçlanmaktadır. 2015 yılı için tüm mevsimlerdeki bulutsuz günler seçilerek ET hesaplanmıştır. TARBIL ve GLDAS ürünlerinden elde edilen ET verileri, hesaplanan evapotranspirasyon ile karşılaştırıldı. TARBIL verisinden aktüel ET hesaplamak için ürün katsayısı (Kc) gerekmektedir. Kc'nin hesaplanması pamuk bitkilerine göre yapılmıştır dayanmaktadır. Bu çalışma için Kc 0.35 ile 1.3 arasında kabul edildi. SEBS, TARBIL verileriyle oldukça iyi (%10 hatayla) uyumluluk sonuçları göstermektedir, ancak GLDAS'tan üretilen daha uyumsuzdur. GLDAS, 0.25 derece çözünürlükte ET üretmektedir ve bu çözünürlük Harran ovası gibi görece küçük alanları yeteri kadar iyi çözememektedir. SEBS ise ET'yi daha yüksek çözünürlükte tahmin etmektedir. Su yönetimi çalışmalarında, su bütçesi hesaplamalarında, bitki örtüsünün düşük olduğu bölgelerde, ve aynı zamanda büyük alanlardaki toprak yüzeyinde akışların takibi gibi konularda GLDAS kullanılabilmektedir, ancak bu çalışmadakine benzer görece küçük alanlarda bulunan tarım arazilerinin ET tahmininde SEBS bize daha güvenilir ve doğru sonuç vermektedir.

1. INTRODUCTION

1.1 Background

Water circulation in nature, which is called the hydrology cycle, is the movement of water in different parts affected by different forces such as gravity, pressure changes and solar energy. This rotation takes place in three different parts of the Earth: the atmosphere, hydrosphere and the lithosphere or the rock. Water flows in and between these three layers in a 16-km-thick layer with 15 km in the atmosphere and only 1 km in the lithosphere.

The hydrological cycle is essentially a cycle without beginning and end, where water enters the atmosphere evaporated from the sea and land and then re-enters the atmosphere through various processes.

Some of the water that penetrates into the soil either returns to evaporation or enters underground water sources, eventually re-appearing on the ground through springs or seeps. In all these cases, the water is supplemented by evaporation and reconstitution of the hydrologic cycle or water flow in nature. The most important elements of water circulation in nature are rainfall (p) - runoff (R) - evaporation (E) transpiration (T) - infiltration (I) and underground currents (G). The largest flow of material in the biosphere is the movement of water through the hydrologic cycle [1]. Transfer of water from soil and water surfaces through evaporation and the loss of water from plants through stomata as transpiration represent the largest movement of water to the atmosphere. The sum of evaporation from soil surface and transpiration from plants is called evapotranspiration (ET).

Evaporation as an important component in the monitoring and management of water resources, its estimation has always been faced with many uncertainties. Estimating evaporation based on physical and experimental relations is very common. These methods are based on meteorological data that the lack or impairment of these data has limited the use of these relations. On the other hand, this information is point-specific and related to meteorological stations, and its regional estimation by using statistical methods is another uncertainty problem. Over the past few decades, many studies have been carried out on estimating evapotranspiration using remote sensing technology. However, few studies have been conducted on the use of remote sensing technology for estimating evaporation from free water levels, and only two SEBAL and SEBS algorithms have been modified to estimate evaporation from free water levels. The SEBS model was proposed for estimating fluxes of heat or energy and estimating evaporation fraction [24]. He uses satellite imagery along with meteorological information to solve the energy balance equation. Surface Energy Balance System (SEBS) was developed [24]. The model is proposed for the estimation of turbulent heat fluxes and evaporative fraction by using satellite earth observation data, in combination with meteorological information at regional scales. SEBS has been widely applied for ET and land surface flux estimation [2].

Evapotranspiration is a very complex process that involves the interaction of a wide range of land and atmospheric variables, including land temperature, air temperature, wind speed, humidity, as well as height and vegetation. Climatic or meteorological methods based on point data can not provide a good estimate of large-scale evapotranspiration. On the other hand, the water balance method can estimate the evapotranspiration only in the scale of the basin, and in the long term annually, in general, which can not meet the requirements of short-term studies. By observing these issues, there is an applied method for estimating the distribution of spatial heat fluxes in the field and basin scales through the use of remote sensing techniques. Remote sensing methods can be used to estimate evapotranspiration in pixel to pixel scale for short-term at a large spatial level. A number of remote sensing evapotranspiration models, such as SEBS, SEBAL and METRIC, were developed with a successful spatial validation of suitable-resolution satellite imagery (for example, Landsat , ASTER and MODIS sensors).

Evapotranspiration is an energy-dependent process that involves a change from liquid to vapor state [3] . Evapotranspiration is the sum of the water loss by the plants (transpiration) and the amount of evaporated water from the soil surface and rainfall. According to the global average, 57 percent of the rainfall returns to the atmosphere through evapotranspiration and this amount can reach 90-100 percent in dry and desert areas. To express the concept of evapotranspiration in general, three terms are used.

Reference evapotranspiration (ET_0) is The evapotranspiration rate from the reference level. The reference level is the level that the grass reference plant has been cultivated with its specific characteristics [4]. Actual evapotranspiration (ET_a) is any water that converts to atmospheric vapor, near or land-level conditions [5]. Potential evapotranspiration (ET_p) is amount of the water sufficiently is available to the plant and the plant utilizes it at its maximum usage [6]. Potential evapotranspiration is measurable by direct and indirect methods. Direct methods using the lysimeter station and providing the highest accuracy, require experimental plots and soil moisture control and weather forecasting to find the input and output of water in a wide area [7]. Potential evapotranspiration ETP is the most important element of air and climate after rainfall and temperature. ETP plays an important role in the heat and mass changes of the global atmospheric system and has a key role in international scientific programs [8]. The calculation of potential evapotranspiration is directly difficult and, in many cases, calculated by meteorological data. The most used method is the FAO Penman-Monteith method, which requires data from radians, temperature, humidity and wind state [9]. In most parts of the world, 90% of rainfall evaporates, and most of the water in the hydrological system is consumed by evapotranspiration, and this suggests that evapotranspiration is of great importance [11]. Potential evapotranspiration is measurable by direct and indirect methods. The direct method is lysimeter [7]. Evapotranspiration plays an important role in the global climate change and the primary production of soil ecosystems. Limiting the measurement of large-scale evapotranspiration by land methods has led to the development of remote sensing techniques [10]. Potential evapotranspiration is the most important element of air and climate after temperature and rainfall, and plays an important role in the heat and changes in the masses of the global atmospheric system and has a key role in international science programs. The use of remote sensing data, the geographic information system and simulation models are the appropriate tools for collecting and analyzing such data. In recent years, remote sensing has recognized as one of the most important means for estimating evapotranspiration and its distribution on regional scale. With the use of evapotranspiration-related algorithms, a large step in managing water resource can be done by NLDAS, ALEXL [10], SEBS, METRIC [12], SEBAL [13].

1.2 Importance of calculating Evapotranspiration

One of the prerequisites for optimal water management in basins is the accurate calculation of water balance components, and potential evapotranspiration is one of the factors affecting water balance. The accurate estimation of evapotranspiration plays an important role in studies such as global climate change, environmental evolution and water resources control [14].

The phenomenon of evapotranspiration causes water and moisture losses from the levels of water, soil and vegetation and it is important to calculate it using a suitable method with regard to the small amount of rainfall and the limitation of water resources in arid and semiarid region. The sources of fresh water, whether surface or underground in many countries have been declining. One of the most consuming sectors in the field of fresh water is agriculture. Since water resources are subject to severe restrictions, the agricultural sector is forced to consume water more efficiently [15]. In other words, one of the processes that improves water management and, ultimately, increased efficiency of consumed water is estimation of the exact amount of evapotranspiration. Evapotranspiration is one of the main components of the water balance of each area and is also one of the key factors for proper irrigation planning to prosper water use efficiency. Evapotraspiration is one of the most important factors in the management of aquatic systems, changes in their water levels and the calculation of water levels, but its precise estimation faces particular difficulties and complexities. Due to the limitations of physical and experimental methods of estimating evapotranspiration, the use of remote sensing technology, due to the possibility of estimating spatial data and minimizing the use of meteorological data, may have a widespread application in evaporation calculations. Many algorithms have been developed to estimate evapotranspiration using remote sensing technology. Studies on the use of these algorithms for estimating evaporation from free water levels have been conducted, but less research has been done to assess their accuracy in estimating evaporation from water levels. The accurate estimation of reference evapotranspiration is necessary in order to meet the water requirements of the plants, to plan irrigation and to study the level of water reservoirs. However, measuring evapotranspiration with this method is costly and time-consuming. Hence, in most cases, indirect methods such as the wide range of simple experimental simulations, such as radiation, temperature, humidity and evaporation pan methods to complex methods such as FAO Penman-Monteith, are used. Evapotranspiration is the primary mechanism for transferring water and heat between land and atmosphere. One of the methods for estimating evapotranspiration is the use of remote sensing data. Many algorithms have been developed to estimate real evapotranspiration using remote sensing technology. In general, two indirect methods can be used to estimate evapotranspiration from the basin level. The first method, widely used to estimate actual evapotranspiration through the water level equation. The time and spatial details of the ET data should be sufficient to allow for proper analysis in the basin area. ET is an essential element in water resource management, especially in arid and semi-arid regions. The calculation of actual evapotranspiration through practical and experimental methods with great precision is possible using weighing methods, disturbed correlations, or Bawen ratio technique, but these methods only determine the actual evapotranspiration at a single point or region and are not applicable to wider areas . This limitation prompted the use of satellite data to determine actual evapotranspiration as an indirect method and to replace the water level at a widespread ranges. The important advantage of using remote sensing data can be that real evapotranspiration can be calculated without the need to quantify the complex hydrological processes. Actual evapotranspiration is a highly variable quantity in spatio-temporal dimensions. Because of wide spatial variations, rainfall, soil hydrodynamics, vegetation cover types, actual evapotranspiration in the spatial dimension is variable. On the other hand, it varies by time, because the climate changes during the time. Satellite imagery can be a desirable tool in providing a map of the spatial and the temporal structures of evapotranspiration, so a mathematical determination, taking into account all the effective factors, is a problem with a lot of sources of error and a large amount of information that is difficult to measure and time consuming. One of the most prominent methods of estimating evapotranspiration in the last decade is the surface energy balance method. Using this method, various components of the energy balance are calculated on a regional scale with the lowest land data. Briefly, the relationship between the radiation received by satellites from the land surface in reflective and infrared heat strips and also the great difference in the hydrological characteristics of the land surface are the basis of the equations in the energy balance algorithm. In this algorithm, considering the input flux to land surface cover the surface and its exit through short and long wavelengths, it is possible to calculate the pure radiation absorbed by each pixel at the land surface. This radiation is divided into various components such as the soil heat flow, the sensible heat flow and the latent heat flow of evaporation due to the difference in air temperature and land cover, the intensity and lack of the vegetation cover and the aerodynamic resistance of land surface. The latent heat flux of evapotranspiration results from the residual energy balance equation [16]. Remote sensing is capable of evaluating evapotranspiration even in spatial distribution because it is the only scientific and technical knowledge that can extract important factors such as surface temperature, reflection coefficient and vegetation index in a compatible manner with the environment economically . There are many remote sensing methods for estimating actual evapotranspiration, but classic remote sensing algorithms are not suitable for medium and large (macro) scales. As a result, the use of more advanced algorithms for widespread and heterogeneous regions with varying geostrategic perspectives is essential. One of these algorithms is the SEBS algorithm.

On the other hand, evapotranspiration plays a major role in the global climate through the hydrological cycle, and its estimation has important implication for the prediction of runoff and the design of irrigation channels, and on natural disasters , Such as drought is also effective [17]. Therefore, according to the importance of evapotranspiration, this factor should be accurately estimated. Evapotranspiration is a function of soil and climatic properties, land use, vegetation cover and regional characteristics, which varies with spatio-temporal variables [18]. A dual evaluation of SEBS using remote sensing and meteorological information from the soil Nivar experiments is conducted. The results of this study showed a high potential for prediction of surface heat flux using remote sensing data and meteorological information.

1.3 Previous Studies

In a study, the SEBS algorithm was modified by Chinyepe to estimate evaporation from Lake Mutirikwi in Zimbabwe [25]. This study uses MODIS / Terra images for this item and obtains evaporation based on 10 images for each month for a winter month and a summer month in 2009, and compares the results of SEBS with the obtained evaporation from the evaporation pan. The results show that the estimated evaporation rate with SEBS is slightly higher than the evaporation values obtained from the evaporation pan, but there is no significant difference between these values and SEBS; so it can be used for evaporation in large scales. In another study SEBS algorithm used to calculate evaporation from freshwater and saltwater. This study uses the AATSR / Envisat satellite imagery. First modified freshwater algorithm to the lake Ijsselmeer in the Netherlands, then results compared with field measurements. It also uses special tools to calculate the energy balance components and ultimately obtains evaporation. For saltwater, it also uses salinity factors based on salinity concentration. SEBS also used for calculating the evaporation from saltwater and freshwater lakes and oceans at global scales and compares the results with ECMWF data, which is the European Centre for Medium-Range Weather Forecasts. The results of the research show a high correlation for freshwater and saltwater [26].

In another study 19 images of the MODIS and SEBS algorithm used to assess the available water in the Karkheh basin during a one-year period [27]. SEBS model also applied on the Nile River Delta to estimate evapotranspiration [28]. In this study, for verifying the model, points network of real measurement with 92 points in the study area was used that the results of the SEBS model were comparable to these values. Therefore, the performance of the SEBS model in the estimation of evapotranspiration was proved.

Importance of soil moisture in ET estimated by SEBS also is investigated. Microwave soil moisture is integrated into SEBS. Results compaired with measurments done by bown ratio stations. Results showed SEBS without considering soil moisture factor overestimates ET but by integrating soil moisture in SEBS, he catched significant improvement for ET [31].

Estimating the actual evapotranspiration of the Girbaygan plain in Fars province-Iran by SEBS method and Landsat 5 satellite imagery is done [29]. In this research, net solar radiation and actual evapotranspiration were estimated and compared with reference evapotranspiration. The results showed that net solar radiation was more consistent than SEBS with reference evapotranspiration. But the SEBS model indicated a good capability in spatio-temporal estimation of evapotranspiration.

Accuracy of the SEBS model for estimating actual evapotranspiration in Yazd – Iran (arid area) using the Landsat 5 satellite sensor and the SEBS algorithm investigated and the results compared with the results of evaporation pan and the FAO Penman-

Montheit equation. Results showed that the actual evapotranspiration with SEBS algorithm had a significant correlation with evapotranspiration of the FAO Peneman-Monteith method [30].

1.4 Objectives

The objective of this study is to estimate the water consumption of irrigated area in Harran plain using the Surface Energy Balance System (SEBS) driven by products of Terra/MODIS satellite data and meteorological observations data from Sanliurfa and Akcakale meteorology stations. The general objective of this research is to estimate actual daily evapotranspiration using remote sensing technology and meteorological forcing dataset in Harran Plain. Others includes:

- Quantification of daily actual evapotranspiration ET_a using SEBS model (surface energy balance system) for Harran Plain.

- Comparison of the estimated ET_a with ET_a taken from TARBIL and GLDAS product.

- Investigation of the model input parameters/variables derived from geo-stationary satellite to the ET accuracy.

The research questions are:

- Is it possible to use SEBS model to estimate daily ET in Harran Plain?

- What is the spatial and temporal variation of ET products for Harran Plain?

1.5 Thesis Outline

This thesis consists of five chapters.

Chapter 1 provides an introduction of this study, the previous studies, research objectives and questions. Chapter 2 gives information about study area and introduction of data sets used for this study, like characteristic of satellite images. Chapter 3 contains of methedos and data collection. Chapter 4 contains out puts and results of the model. Chapter 5 discusses the SEBS model followed by its application in this study area and comparing ET estimated via SEBS with ET calculated by other methods.

2. STUDY AREA AND DATA COLLECTION

2.1 Location

The study area is the Harran Plain, located in Southeast Anatolia, Turkey, between 36° 54′ 9″ N and 39° 0′ 55″ E, and as basin it belongs to Basra Korfezi hydrologic basin. By starting GAP project which is the biggest investment project in Turkey Republic history with the aim of developing agricultural products, Harran Plain changed to the widest area in this region in terms of the under cultivation area (almost 160,000 ha) that is applied by under pressure irrigation systems. According to the data released by Koruklu Talat Demirören synoptic station, yearly precipitation is 365 mm, yearly temperature 17.2 mm and yearly evapotranspiration is 1848 mm. In addition this area is located in a semi-arid region.

Harran Plain is limited to Sanliurfa and Germis mountains form north, by Tek Tek montains from east, by Ackakale and Syria’s border from south and Fatik mountain from west. This region with the 65 km length from north to south covered on area about 225,000 ha. Figure 2.1 show the location of the study area on entire Turkey map [20].

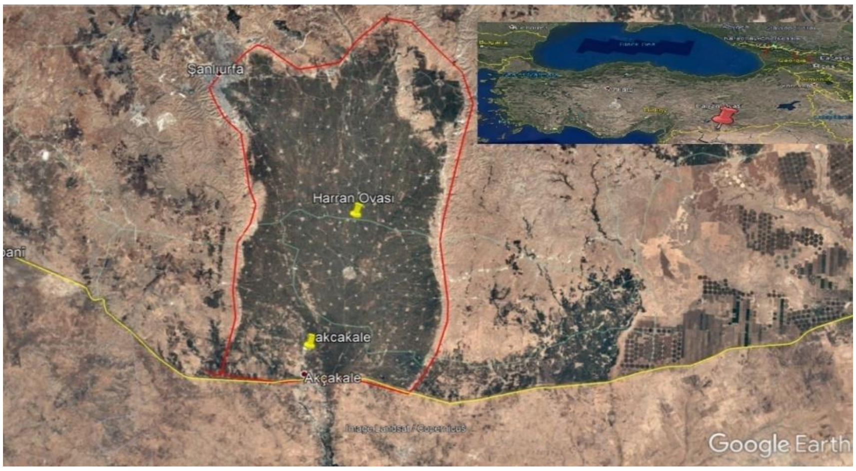

Figure 2.1 : Study area.

2.2 Topography

The general shape of Harran Plain is like a rectangle. Northern, eastern and western sides are high, and southern is low. The highest elevattion is 946 m and the lowest part has about 305 m height in the south.

2.3 Climate

The climate is warm and dry. The rain in Harran falls mostly in the winter, with relatively little rain in the summer. According to Köppen and Geiger, climate stays on Csa class. In Harran, the average annual temperature is 18.0 ° C. The average annual rainfall is 361 mm [23]. Table 2.1. shows mounthly temperature and precipitation in study area.

Table 2.1 : Temperature and Precipitation in Study Area.

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Avg (°C)	6	7.7	11.3	16.2	21.8	26.9	30.4	29.9	25.6	19.6	12.8	7.7
Min (°C)	1.5	2.5	5.3	9.3	13.9	18.5	21.7	21.1	16.7	11.7	6.2	3
Max (°C)	10.6	12.9	17.4	23.1	29.7	35.4	39.2	38.8	34.5	27.5	19.4	12.5
Rainfall (mm)	68	54	49	38	28	4	0	0	2	21	35	62

2.4 Land Cover

Since 1995, when the GAP irrigation projects began, a dramatic increase in under cultivation area has been seen, as between 1984 to 1992 the farm land was about 43.290 hectares, and after GAP project from 1992 to 1999, farm lands increased to about 78,950 hectares., which is about 40.28%. Harran Plain area is an agricultural area and with the development of irrigation systems in this area, in order to the use of more sunny hours cropping pattern is changed. The main products of this region are wheat, cotton, barley, corn and lentil.

2.5 MODIS Sattellite Data

The MODIS satellite observes point to point of the world in the form of 36 discrete spectra and a wavelength of 0.4 µm to 14.4 µm with the band width of 2330 km every day or two days. Similarly, MODIS detects a wider array of vital landmarks from any other Terra sensor. For example, sensor measures percentage of earth's surface covered with clouds daily. A large set of data is extracted from MODIS observations that describe the characteristics of the planet. Characteristics of earth, oceans, and atmosphere are used in studies and research at the regional or global level. As it is mentioned MODIS data in various sources have been placed for users to use for free. In these studies we downloaded the satellite data from NASA's Data Collection website.

2.5.1 Albedo

The Albedo is the flux reflectance ration of solar radiation level to the solar radiation received from the sun. Albedo is an important parameter in the study of the energy balance of the surface, because the amount of Albedo determines the amount of radiation absorbed by the earth's surface and it is also one of the parameters of earth's surface that has a significant impact on biosphere processes and climate processes. Albedo is related to surface characteristics and solar zenith angle and solar spectrum. Albedo's estimated approach is based on the use of measured data along with vegetation and soil types. For this study, MODIS Albedo MCD43A3 products have been used. This product provides 500 meters data with a oriented-hemisphere reflection (Albedo Black Sky) in the sun era and a reflection of the hemisphere (white Albedo). This much of Albedo MCD43A3 produce from 16-day models presented in MCD43A3. Both of the Aqua and Terra sensors data are used in the production of this product. The name MCD is the indicator of hybrid products derived from two Aqua and Terra sensors. The specifications of this product are listed in Table 2.2.

Table 2.2 : Specifications of MCD43A3 product.

Short name	MCD43A3
Platform	Combined Aqua Terra
Instrument	MODIS
Collection	6
Processing Level	Level-3
Temporal Resolution	daily
Spatial Resolution	500 m

2.5.2 NDVI and vegetation fraction

NVDI is an indicator that is developed for vegetation and with the use of difference between near infrared (that strongly reflected by the plants) and red light (that absorbed by the plants) can display vegetation points. NVDI maps use the combination of wavelength of near infrared and red wavelength in order to measuring plants health.

To determine MODIS daily vegetation indexes, the use of blue, red and near infrared reflectors are estimated at 469nm, 645 nm and 858 nm. Plant growth index is a simple and effective assessment of surface plant activities and it can show some evolutionary vegetation data. Concept of normal vegetation index (NVDI) can be combining with satellite detection data in different bands. For the earth, the minimum amount of NVDI is close to 0 and the maximum is close to 0.8. The negative amount shows that earth has been covered with clouds, water and snow which strongly reflect visible light. In these studies, the MOD13A1 has been used to calculate the NDVI. It is presented every 16 days with a resolution of 500 meters as a 3-level. The specifications of this product are listed in the following Table 2.3.

Table 2.3: Specifications of MOD13A1 product

Short name	MOD13A1
Platform	Terra
Instrument	MODIS
Collection	6
Processing Level	Level-3
Temporal Resolution	16 day
Spatial Resolution	500 m

2.5.3 Land surface emissivity and land surface temperature

Land Surface Emissivity is the flux of radiation from the surface to radiation of a completely black object in the same temperature. This parameter is a function of surface, sub surface and wavelength characteristics. In the equation of energy balance these physical parameters are used for computing net radiation (total long wave radiation emission from the surface). There are several ways to estimate Land Surface Emissivity. In these studies, we extract Emissivity from MOD11A1 products. MODIS/Terra Land Surface Temperature and Emissivity (LST/E) products give us the amounts of Land Surface Temperature and Emissivity (LST/E) on a daily basis on L3. The specifications of this product are listed in the following Table 2.4.

Table 2.4 : Specifications of MOD11A1 product

Short name	MOD11A1
Platform	Terra
Instrument	MODIS
Collection	6
Processing Level	Level-3
Temporal Resolution	daily
Spatial Resolution	MOD11A1

2.5.4 Leaf area index (LAI)

The Leaf Area Index is a dimensionless amount that identifies the plant canopy. In fact, the ratio of the shadow of the leaf is one square meter. In these studies, we extract LAI from MCD15A2H products. Level-4 MODIS global Leaf Area Index (LAI) and fraction of photo synthetically active radiation products register the amount of LAI every 8 days with a resolution of 500 meters in a Sinusoidal grid. LAI variable determines the number of leaves equivalent to a unit of land. The specifications of this product are listed in the following Table 2.5.

Table 2.5: Specifications of MCD15A2H product

Short name	MCD15A2H
Platform	Combined Aqua Terra
Instrument	MODIS
Collection	6
Processing Level	Level-4
Temporal Resolution	8 day
Spatial Resolution	500 m

2.6 Meteorological Observation Data

For using of SEBS model to assess ET, standard meteorological information is required. We can provide reliable meteorological information from meteorological station data or modeling data. For this research we use meteorological data set of AKCAKALE and SANLIURFA stations taken from the meteorological organization of Turkey. The required parameters included wind speed, hourly temperature, pressure at reference height, pressure at surface, mean daily temperature and sunshine hours per day.

3. SURFACE ENERGY BALANCE SYSTEM (SEBS)

3.1 SEBS Model

The SEBS algorithm is presented for daily, monthly and annual evapotranspiration in a semi-arid area and also for drought monitoring [24]. Model uses satellite imagery, along with meteorological information, to solve the energy balance equation. The advantage of this algorithm is the estimation of evapotranspiration for different levels and scales. This model was used for large scale in the Netherlands, China and Spain for actual evapotranspiration in agricultural lands. The results indicated that in 80% of the cases, the data from the model had been coordinated with field data without any calibration. Other research has been done in this regard, which can be noted.

SEBS is iheoretıcal and computatıonal basic models that widley used in estımatıng energy fluxes. In general, in the SEBS model, the amount of evapotranspiration from the satellite image is determined by the use of an energy balance on the surface where the consumed energy by evapotranspiration is as a residual of the surface energy equation.

3.2 Input Information for SEBS Model

The input information for the SEBS model consists of three sets as follows:

The first set contains the land surface albedo, emissivity, temperature, vegetation cover fraction and LAI leaf area index and plant height (or roughness height). When the plant information is not available, the NDVI index is used as an alternative. This set can be derived from remote sensing data with other surface information of the area. The second set contains the vapor pressure, temperature, humidity and wind speed at the reference height. The reference height is the same as that measured at the applied point of the PBL (Planetary Boundary Layer) for the studied region. The third set consists of incoming solar radiation and input long wavelengths that can be directly measured or modeled. To estimate turbulent fluxes, it is necessary to calculate the energy balance separately in the equation, and then the latent heat flux is estimated to eventually be converted to evapotranspiration (ET). SEBS ingrates all these parameters and estimates actual evapotranspiration .final outouts of mode is in the form of grided map that for every grid ET estimated separately. These maps are in different resolutions. Characterisation of each gride exist in the model such as pixel size, pixel number etc. By this model evpotranspiration in every point of Earth is obtainable.

3.3 The Importance of SEBS

The SEBS algorithm is a method based on experimental and physical relations that estimates the actual evapotranspiration with the lowest land data. The estimation of spatial distribution of ET values for agricultural and water management is essential. Three satellite images of ASTER from dry matter are used to evolve land cover changes and estimated evapotranspiration using the SEBS algorithm. The results showed that ASTER images have an appropriate representation of the effect of any land cover on actual evapotranspiration.

Actual evapotranspiration is more important than the other components of the energy balance equation at land level, which includes distribution of net radiation, sensible heat flux and soil heat flux, because the main energy flux exiting from the land in the water cycle is related to evapotranspiration. In general, evapotranspiration is calculated directly and indirectly [21]. In direct method, a lysimeter or scintillometer device can be used. In indirect methods, evapotranspiration is calculated using existing mathematical relations. Then the evapotranspiration of the reference plant (ETr) can be obtained. In this regard, remote sensing technology makes it possible to achieve actual evapotranspiration without spending too much cost for the vast surface area and according to the conditions governing the region using satellite data. Regarding the fact that soil and water conditions were necessary for plant growth in the FAO-56 region, it was necessary at the level of a large basin due to soil salinity, the rate of irrigation and its management limitations, the potential evapotranspiration calculated by the FAO Penman–Monteith is lower. Therefore, in order to calculate the actual evapotranspiration of plants at the surface of a basin, it is recommended to use remote sensing methods. The SEBS algorithm estimates the actual evapotranspiration (ET-SEBS) using sensible heat flux in the regional scale, the average error of the SEBS model is about 20%, which is dependent on the average of the sensible heat flux [24].

The SEBS algorithm includes tools for estimating surface physical parameters such as surface temperature, albedo, and land emissivity. Several studies have been carried out in the world on the use of remote sensing to estimate the actual evapotranspiration by using the SEBS model. Flow chart of SEBS has been shown in figure 3.1[31].

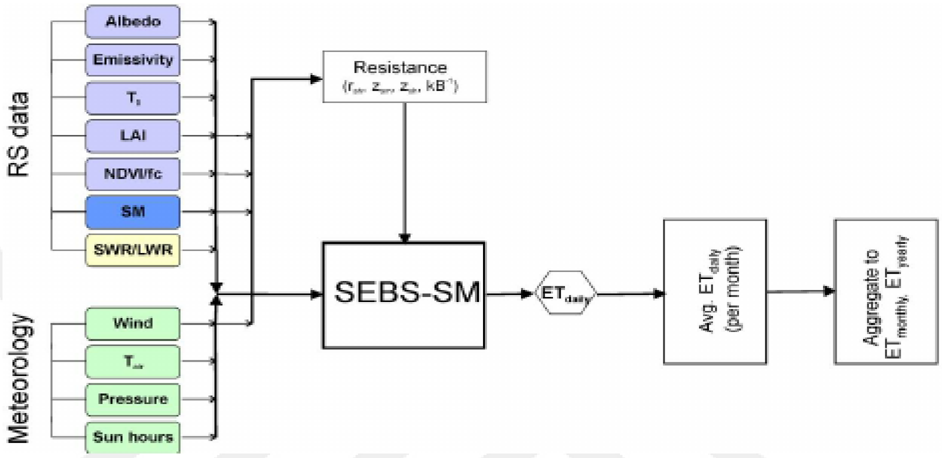

Figure 3.1 : Flow chart of SEBS.

3.4 Main Concepts of SEBS

3.4.1 Net Radiation

Incoming shortwave radiation from the sun, reflected, absorbed or transmitted by the atmosphere.

Part of that energy received by the earth and the rest of that are reflected (depending on the albedo α). Almost 46 percent of incoming shortwave radiation are absorbed by the land surface [22] (Figure 3.2).

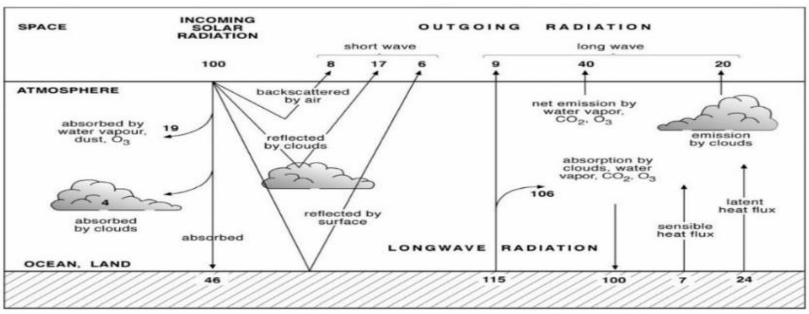

Figure 3.2 : Incoming and outgoing radiation.

In addition Earth's surface receives shortwave radiation and emittes. Longwave radiation which effect the land surface temperature and atmosphere temperature. The difference between incoming shortwave solar radiation recibed by atmosphere and land surface and and out going long wave radiation emitted by landsurface and atmosphere is called net radiation. Net radiation is a function of spatial and temporal characterization. For example equador has the most Rn and polars have the lowest Rn, also during the day earth recieved more radiation than the night. It is calculated by the following equation:

$$Rn = S\downarrow(1 - \alpha) + L\downarrow - L\uparrow \tag{3.1}$$

Figure 4.2 shows the amount of the total energy entered to the atmosphere and how it devided to different parts, until reachs to the land surface. İn this concept we encounter with two important parameters; one is sensible heat flux and another is latent heat flux. These parameters consist of 31 percent of entire solar energy which enter to atmosphere. The portion of sensible flux and latent heat flux determines the land surface temperature and creats intercation between land surface and atmosphere. Other parameters are soil heat flux and chemical energy stored (F). Soil heat flux has an effect on the net radioan because it heats up the soil. Chemical energy stored (F) during the photosynthesis and released by respiration [22]. Total net radiation should be moderate by a collection of these four fluxes, sensible heat flux, latent heat fluxe, soil heat flux and chemical energy.

$$Rn = H + \lambda_E + G + F \tag{3.2}$$

On the other hand net radiation, sensible and heat fluxes will change by changing in albedo value. For all these changes there are feedbacks that show how change in one component affects other parameters. Albedo directly is related with solar angel, landcover, etc. For example Glaciers, snow, oceans have the highest albedo. Recently human activity caused some changing in albedo; due to global warming and melting of glaciers, albedo has been decreased.

Base law of SEBS is surface energy balance equeation that shows the amount of exchanges of fluxes.

3.4.2 Sensible heat flux

Sensible heat flux has important rule in keeping balance between land surface interaction and atmosphere. It is conductive heat flux from surface to the atmosphere. Generally eddy covariance is used for calculating this parameter. H can be represented as a quasi-diffusive process, equation (3.3)

$$\mathrm{H} = \frac{T_s + T_r}{r_a}\rho c_p \tag{3.3}$$

Where T_s is land surface temperature, T_r is a reference temperature above the surface, ρ is the air density and c_p is the specific heat of air and r_a is aerodynamic resistance which is the link between surface characteristics and the turbulence that drives the exchange of H.

3.4.3 Latent heat flux

The flux of heat from the Earth's surface to the atmosphere that is related with evaporation or transpiration of water at the surface and subsequent condensation of water vapor is the troposphere is called Latent heat flux. It is one of the important parameters on Earth's surface energy budget. One the methods that is common for measuring this parameter is Bowen ratio.

Incontrast to sensible heat flux, Latent heat flux is a complicate process, becacuse is consist of some parameter that effect the water evaporation. One of the common methods for obtaining Latent heat flux in aerodinamic equation. [22].

$$\lambda_E = \left(\frac{e^*(T_s) - e_r}{r_s + r_a}\right)\left(\frac{\rho\, c_p}{\gamma}\right) \tag{3.4}$$

In the equation, $e^*(T_s)$ is the saturated vapor pressure at T_s, e_r is the vapor pressure at a reference height and γ is the psychrometric constant, r_s is the surface resistance to the transfer of water from the surface to the air. This resistance includes the resistance to water evaporating from the soil through stomates, or within the plant. The inclusion of stomates in the surface resistance means that λ_E from vegetated surfaces is tightly coupled to biological activity through photosynthetic activity, which, in turn, is linked to carbon uptake by plants.

3.4.4 Soil heat flux

After the surface of soil absorbs solar radiation, heat flux will transfer to the lower soil layer. On the contrary, heat will be transferred from the soil when the soil temperature lower than the deep layer soil temperature. This process is the soil heat exchange process. Soil heat flux is an important component which has an effect on soil evaporation and surface energy exchange.

The soil heat flux G can be calculate by:

$$G = -K\ dT_s/d_z \tag{3.5}$$

where z is soil depth and K (W m−1 K−1) is thermal conductivity.

3.5 Penman-Monteith Equation

In the last decades in order to cumpute evapotranspiration many empirical methods have been developed. Evaluating the accuracy of these methods takes time and costs more than expectation so for overcoming these difficulties FAO presents some approaches. Methods presented by FAO are Blaney-Criddle, Radiation, modified Penman and Pan evaporation methods. Among methods Penman-Monteith has shown the minimum error. In this study we utilized the FAO Penman-Monteith for calculating ET_0. This method is based on meteorological data. According to this method two kinds of data are required, meteorological data and parameters that are computable or obtainable from tables prepered by FAO. Meteorological data direclty measured in weather stations, on the other hand formula prepared by FAO calculates reference evapotranspiration. Reference evapotranspiration is the amount of evapotranspiration in special condition, the characterizasion of this condition is 0.12 meter plant height, adequetly watered, actively growing green grass. As every plant and every region has its own characterization for modifying ET_0 a coefficient is required. This factor is in equation (3.6).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \tag{3.6}$$

Where:

$ET_\circ$, is reference evapotranspiration [mm day-1].

Δ, is slope vapour pressure curve [kPa °C-1].

Rn, is net radiation at the crop surface [MJ m-2 day-1].
G, is soil heat flux density [MJ m-2 day-1].
γ , is psychrometric constant [kPa °C-1].
T, is mean daily air temperature at 2 m height [°C].
U_2, is wind speed at 2 m height [m s-1].
e_s, is Saturated vapour pressure [kPa].
e_a, is actual vapour pressure [kPa].

3.5.1 Meteorological Data

We used meteorological data obtained from Akcakale and Sanliurfa stations. Wind speed, average air temperature, relative humidity and daily sunshine hours provide required energy for evaporation Parameters that are applied in the Penman-Monteith equation. Other parameters are Julian days, elevation from the sea level (altitude), and latitude. Regarding these data we started to calculate evapotranspiration. Physical Parameters calculated by empirical formulas and also FAO has prepared tables for each of them. Parameters are Atmospheric Pressure, Latent heat of vaporization, Psychrometric Constant, Slope of saturation vapor pressure curve, Actuaal vapour pressure Vapoure pressure deficit, Extraterrestrial radiation, etc. Atmospheris Presure (P), is the pressure that enters from atmosphere weight.

$$P = 101.3\left(\frac{293 - 0.0065z}{293}\right)^{5.26} \tag{3.7}$$

P, is atmospheric pressure.
z, is elevation above sea level [m].

Latent heat of vaporization (λ), it is the energy released during water vaporates. In FAO Penman-Monteith equation it is assumed that latent heat in $20^{℃}$ is 2.45 MJ kg^{-1}.

$$\gamma = \frac{C_P P}{\varepsilon\lambda} = 0.665 \times 10^{-3} P \tag{3.8}$$

γ , is psychrometric constant [kPa °C-1].
P, is atmospheric pressure [kPa].

Mean Saturation Vapour Pressure (e_s), water vapour is in the form of the gass and effects the total atmospheric pressure. It is a function of temperature so it can been calculated from the air temperature.

$$e^0(T) = 0.6108\exp\left[\frac{17.27T}{T + 237.3}\right] \quad (3.9)$$

$e^0(T)$, is saturation vapour pressure at the air temperature T [kPa].

Slope of Saturation Vapour Pressure Curve (Δ) is the slope of the curve between saturation vapour pressure and temperature.

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27T}{T + 237.3}\right)\right]}{(T + 237.3)^2} \quad (3.10)$$

T, is air temperature.

Actual Vapour Pressure (e_a), the pressure which is exerted from vapour to the atmosphere it can be calculated from relative humidity.

$$e_a = \frac{e^0(T_{min})\frac{RH_{max}}{100} + e^0(T_{max})\frac{RH_{min}}{100}}{2} \quad (3.11)$$

RH, is relative humidity.

Extraterrestrial Radiation (R_a), is the power of solar radiation out of the earth, it controls the exchange of water and heat it is also necessary part of evapotranspiration and hydrologicacl models.

$$R_a = \frac{24(60)}{\pi} G_{SC} d_r[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)] \quad (3.12)$$

Shortwave Radiation (R_s), sun emites an radiated energy in form of shortwave radiation.

$$R_s = \left(a_s + b_s\frac{n}{N}\right)R_a \quad (3.13)$$

n, is actual duration of sunset [hr].
a_s, is regression constant.
$a_s + b_s$, is fraction of extraterrestrial radiation reaching the earth on sunny days.

Relative Sunshine Duration (n/N), is the ratio of actual sunshine hours to the maximum sunshine hours per day.

Albedo, is taken 0.23.

Net Longwave Radiation (R_{nl}), after solar radiation reached to the earth some parts of it absorbed some parts emitted and remind of it reflected to the atmosphere as a longwave radiation.

$$R_{nl} = \sigma \left[\frac{T_{maxK^4} + T_{minK^4}}{2}\right] \left(0.34 - 0.14\sqrt{e_a}\right) \left(1.35 \frac{R_s}{R_{so}} - 0.35\right) \qquad (3.14)$$

R_{nl}, is Net outgoing longwave radiation [MJ m-2 day-1].
σ, is Stefan-Boltzmann constant [4.903 10-9 MJ K-4 m-2 day-1].

T_{maxK^4} ,is maximum absolute temperature during the 24-hour period [K = °C + 273.16].
e_a, is actual vapour pressure [kPa].

R_s, is measured or calculated solar radiation [MJ m-2 day-1].
R_{so}, is calculated clear-sky radiation [MJ m-2 day-1] .

$\frac{R_s}{R_{so}}$, is relative shortwave radiation (limited to £ 1.0).

Net Radiation (R_n), different between incoming shortwave solar radiation and out going longwave radiation is net radiation. It is calculated by equation (3.15).

$$R_n = R_{ns} - R_{nl} \qquad (3.15)$$

In FAO formula soil heat flus it is ignored and alse FAO prepared table for daylight hours (N) or maximum sunshine hours, according to altitude and Julian days according prepared by FAO.

Clear-sky Solar Radiation (R_{so}), is amount of solar radiation that reaches to the earth's surface when sky is cloud-free.

$$R_{so} = (0.75 + 2 \times 10^{05} Z) R_a \qquad (3.16)$$

Z, is station elevation above the sea level [m].

Wind Speed (U_2) is the speed of wind measured in 2 meter height, our weather station measure wind speed in the 10 meters height so we exchanged it to 2 meter wind speed by using a coefficient presented by FAO.

$$e_s = \frac{e^0(T_{max}) + e^0(T_{min})}{2} \qquad (3.17)$$

e_s, is saturation vapour pressure [kPa].

C_P, is specific heat at constant pressure, 1.013 10-3 [MJ kg-1 °C-1].

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

λ, is latent heat of vaporization, 2.45 [MJ kg-1].

$$G = C_s \frac{T_i - T_{i-1}}{\Delta T} \Delta Z \tag{3.18}$$

The last parameter is called Crop Coefficient (K_c), evapotranspiration calculated by FAO Penman-Monteith equation is reference evapotranspiration, for calculating actual evapotranspiration a coefficient is required it is called crop coefficient. K_c, varies in different stages of plant growth, climate conditions also plant type. Each plant has its own K_c, at least a curve is drawn. In Harran farmland products are corn, cotton, wheat and barley. We considered cotton as a prevailing crop and calculated K_c for cotton Growth period of the cotton is less than 180 days, growing season starts in May and ends in September.The curve we utilized for this study is given in Figure 3.3, it is taken from previous studies [32] and evaluated with the guideline given in FAO website.

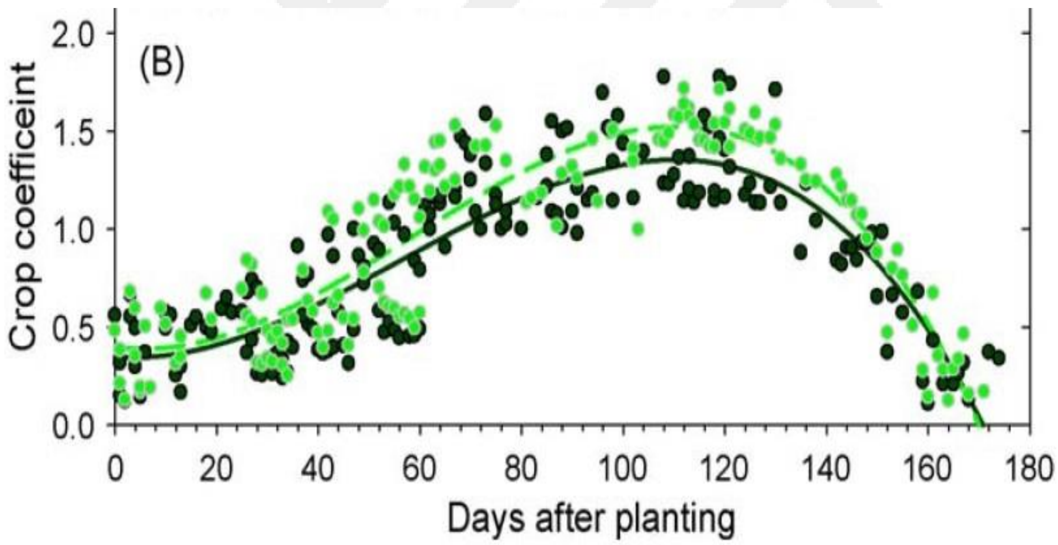

Figure 3.3: Crop coefficient for Cotton [32].

According the curve crop coefficient considered 0.35 for initial growth stage, 0.65 to 1 for mid growth stage 1.3 for developed growth stage of cotton.

3.6 Global Land Data Assimilation System (GLDAS)

Global Land Data Assimilation System wich is known as GLDAS, integrates land surface and sattelite based observations in order to calculate field water and energy status and energy fluxes. GLDAS products are available in three different temporal resolutions, 3hourly, daily and monthly, two spatial resolutions, 1°×1° and 0.25°×0.25°and for levels from 1948 to present. In addition GLDAS applied 5 kinds of models, VIC-LSM, Noah-LSM, CLM-LSM, Catchment-LSM and Mosaic-LSM. GLDAS products are available in NetCDF, GeoTIFF, and KMZ formats. For this study we used "GLDAS Noah Land Surface Model L4 3 hourly 0.25 x 0.25 degree V2.1" products. For each day we had 8 sets of data in 00:00, 03:00, 06:00, 9:00, 12:00, 15:00, 18:00, 21:00 hours. After applying required operations on data sum of 8 products gives us daily evapotrasprasion.

4. RESULTS

4.1 ET Comparison Between SEBS and TARBIL

In this study ET for 2015 estimated by SEBS and results compared with TARBIL data. There are eight TARBIL stations (63.15, 63.16, 63.17, 63.18, 63.23, 63.25, 63.34, 63.35) over the study area. Stations are shown in figure 5.1 by code numbers. This figure is spatial ET map estimated by SEBS algorithm for one sunny day in the summer. Pink and orange area show the farmlands. SEBS algorithm estimates ET separately for each pixel. Resolution of each pixel is 1×1 km. ET value for each station given by TARBIL compared with the ET value estimated by SEBS in related grid.

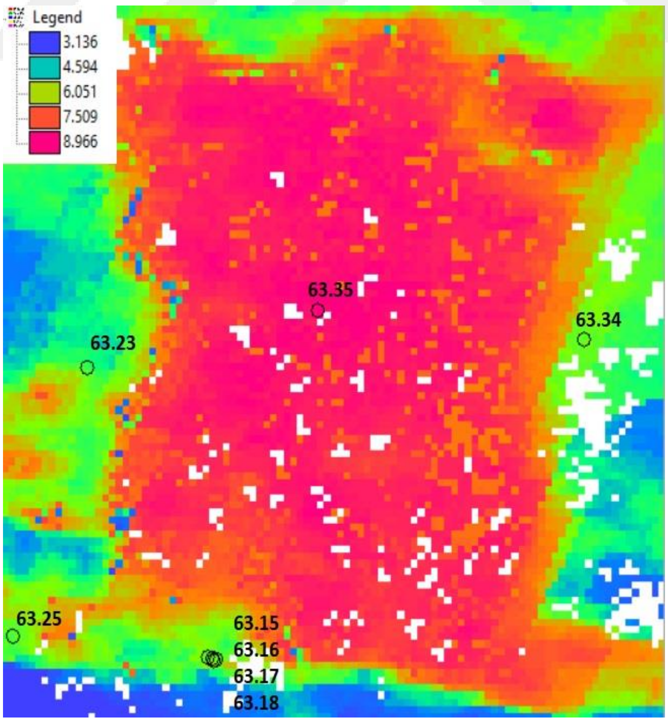

Figure 4.1: TARBIL stations.

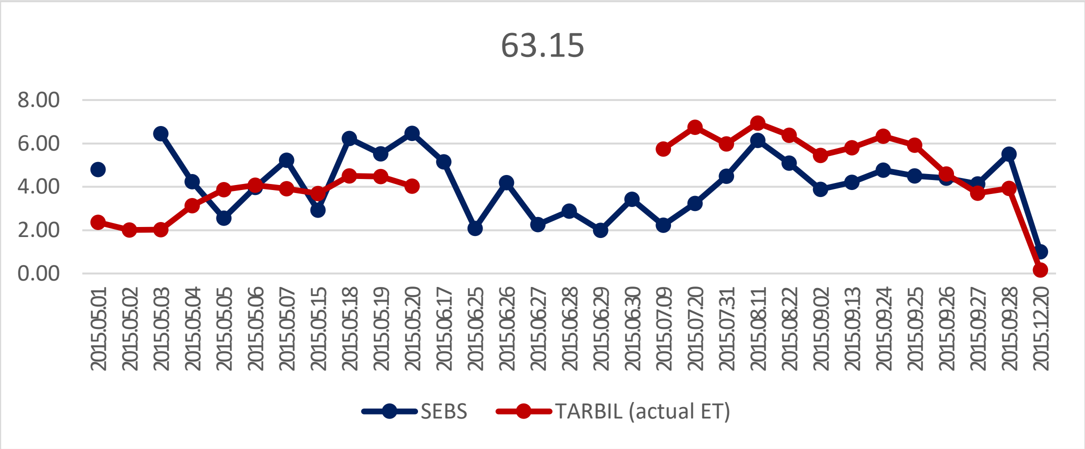

Figure 4.2 : ET_SEBS Vs ET_TARBIL for 63.15 station.

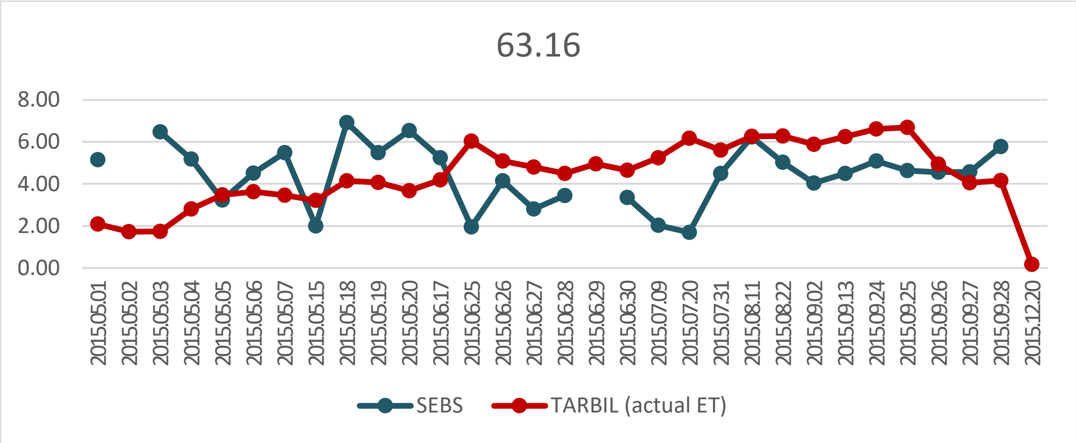

Figure 4.3 : ET_SEBS and ET_TARBIL for 63.16 station.

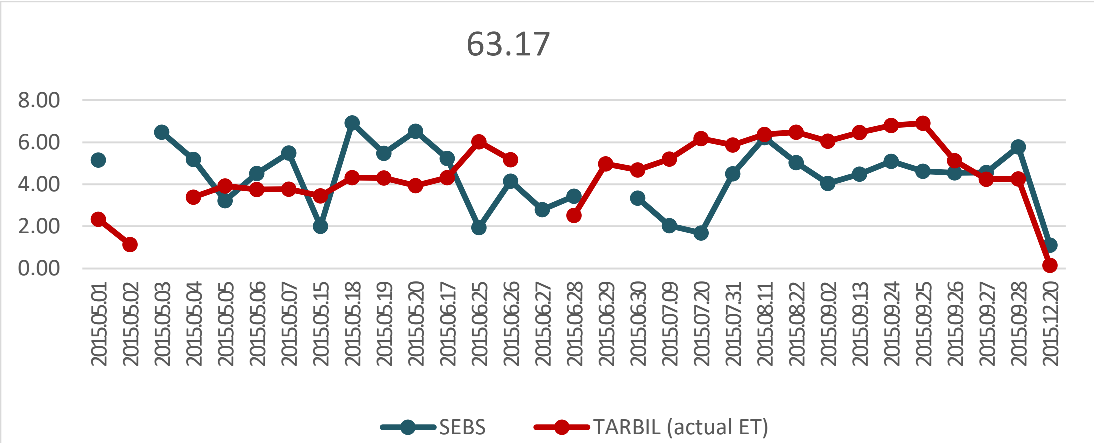

Figure 4.4 : ET_SEBS and ET_TARBIL for 63.17 station.

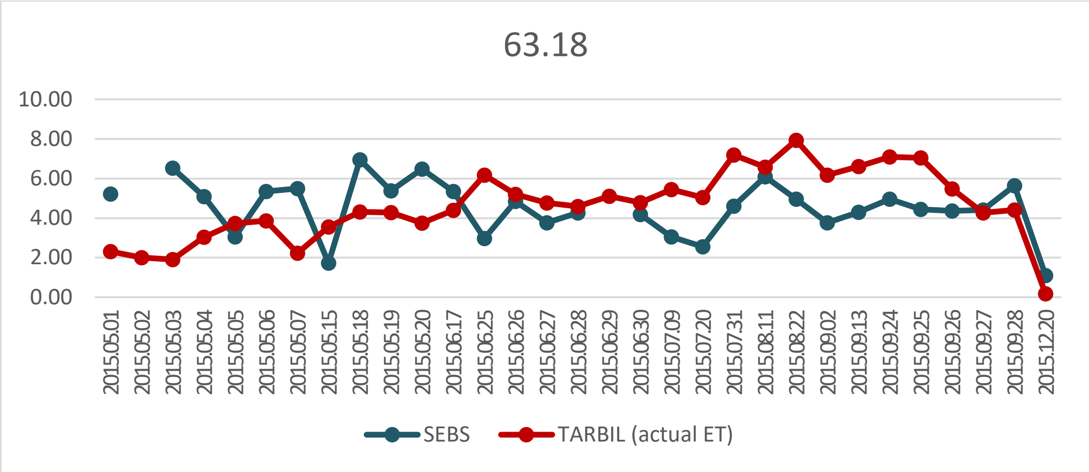

Figure 4.5 : ET_SEBS and ET_TARBIL for 63.18 station.

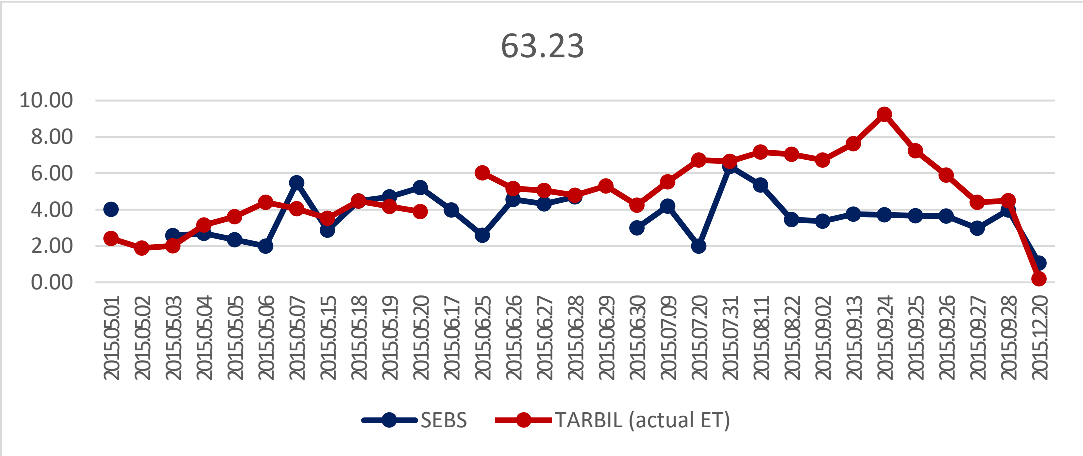

Figure 4.6 : ET_SEBS and ET_TARBIL for 63.23 station.

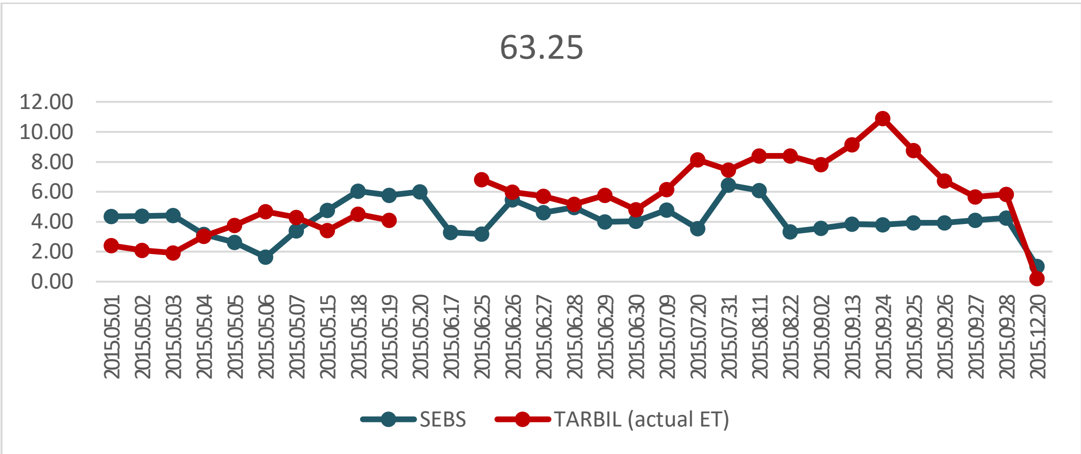

Figure 4.7 : ET_SEBS and ET_TARBIL for 63.25 station.

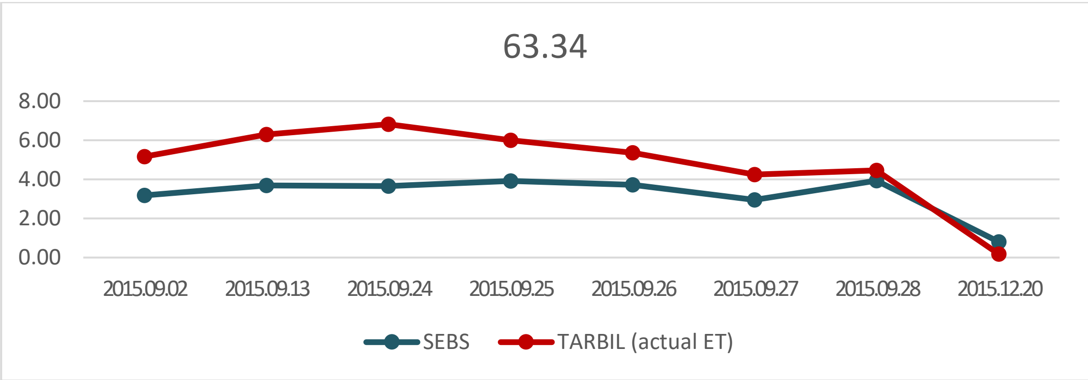

Figure 4.8 : ET_SEBS and ET_TARBIL for 63.34 station.

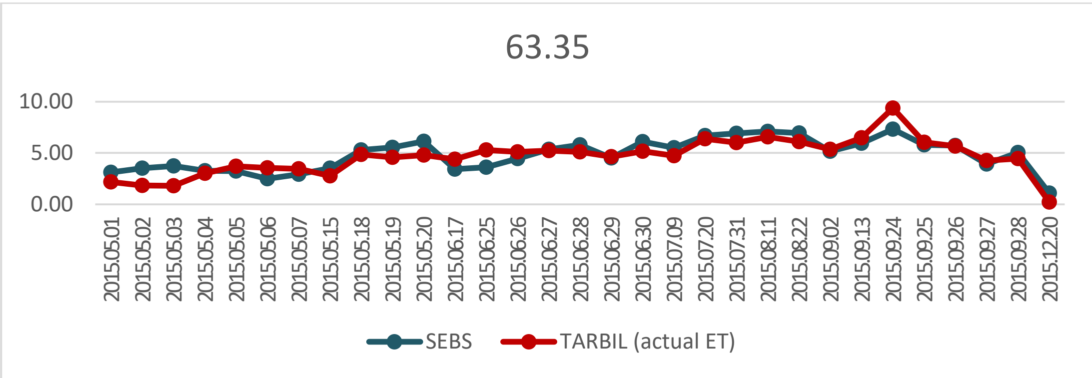

Figure 4.9 : ET_SEBS and ET_TARBIL for 63.35 station.

Figure 4.2 to 4.9 show the estimated ET by SEBS and TARBIL data. Among stations the 63.35 station is more noticeable than others because it is located exactly in the middle of the farmlands. In both methods during the cultivation seasons (from May to September) ET varies between 5 to 9 mm/day. The important point is that in this study Kc is estimated according to the experimental data so some parts of the differences between SEBS and TARBIL may originate from that issue. Kc diagram is shown in the figure 3.3. It is assuming according to the date of plant for cotton. In this time period Kc starts from 0.35 and increase to 1.3, after developed stage it starts decreasing again with more steep slope. In the first day of May plant is in initial growth stage so Kc is considered about 0.35. In July cotton is in the mid growth stage so Kc is increasing to 0.8 in August; plant enters to the developed grow stage and Kc increase up to 1.3. Kc influenced by land cover therefore as plant grows Kc increases until the harvesting time. After harvesting Kc decreases again. Cotton farming starts in June and harvesting is in September; developed stage of cotton which has the largest Kc is almost at the end of the August. Difference between yearly SEBS_ET and yearly TARBIL_ET is 0.64 mm/day also in the cultivation seasons from May to September when ET is more important than other seasons SEBS estimates ET about 0.49 mm/day higher than TARBIL.

4.2 ET Comparison between SEBS and GLDAS

In this step ET estimated by SEBS is compared with ET extracted from GLDAS. GLDAS Noah Land Surface Model L4 3 hourly 0.25 x 0.25 degree product is used for this step for every day there is eight 3 hourly data set that the sum of them is daily ET. Spatial resolution of GLDAS product is 0.25 x 0.25 degree that is equal to almost 27.5 x 27.5 kilometers (1degree = 110 km). Figure 4.10 shows this comparison.

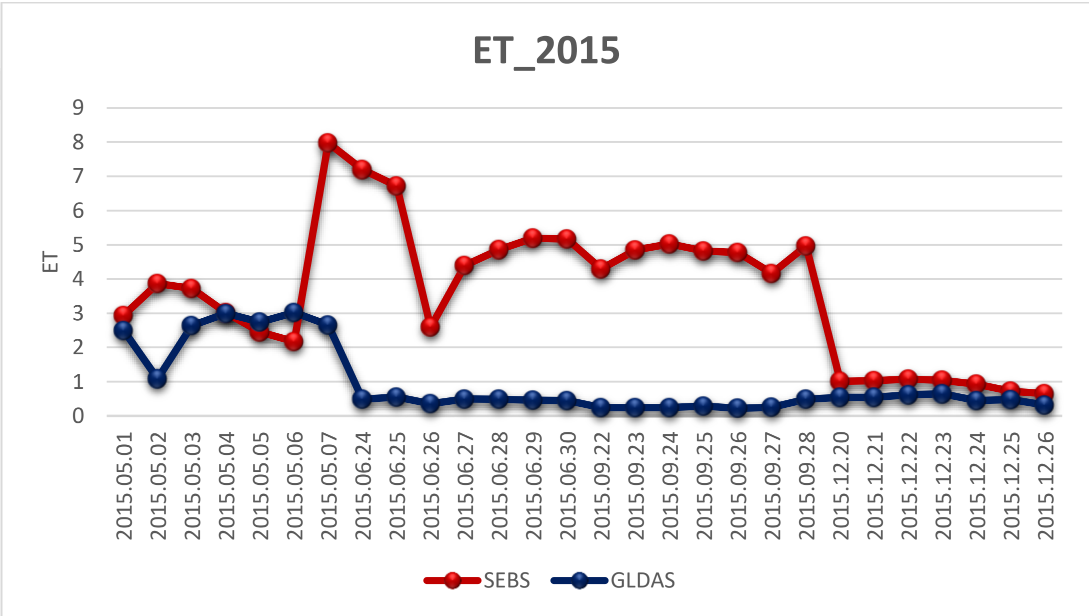

Figure 4.10 : ET_SEBS and ET_GLDAS for 2015.

According to the figure, although we expect high value for ET during spring and summer but ET extracted from GLDAS doesn’t show a sicnificant change in defference season. Just in the winter SEBS and GLDAS have similar results. In addition for understanding the trend of ET obtained from the GLDAS, I separately drew 3hourly GLDAS products for different seven days of 2015 in the Figure 4.11. Maximum ET is observed in the 12:00 PM; maximum monthly ET is in the spring; in other seasons ET change between 0 to 1 mm/day (Figure 4.11).

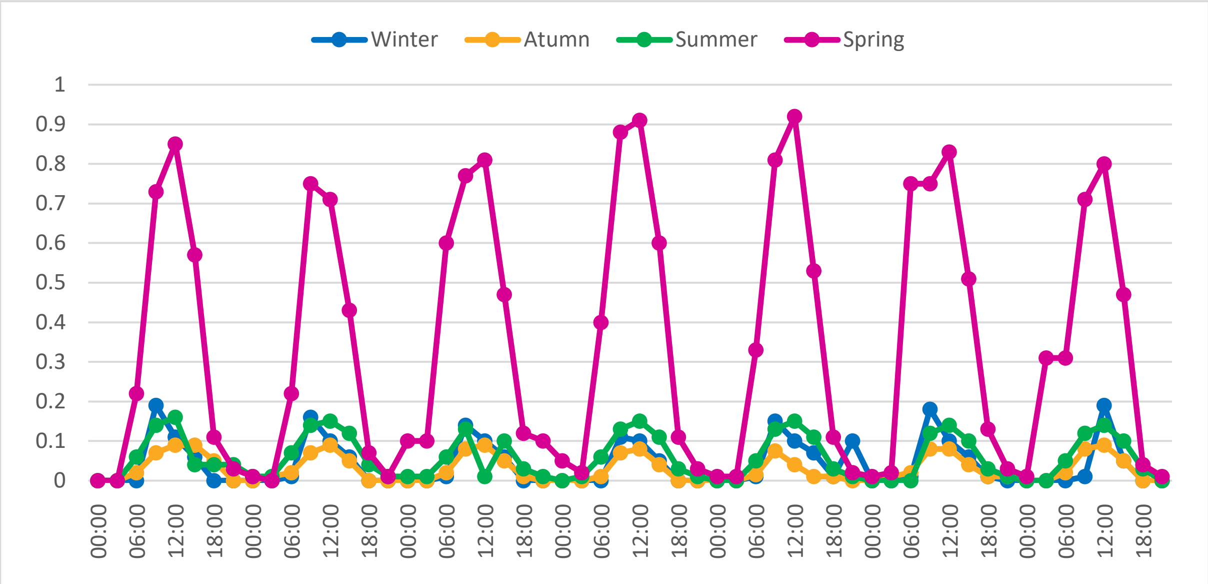

Figure 4.11 : 3Hourly ET_SEBS and ET_GLDAS for 2015.

5. CONCLUSION AND DISCUSSION

5.1 Comparison of SEBS and TARBIL results

This study is evaluation of evapotranspiration estimated by SEBS trend in 2015 in Harran plain. According to the results parameters control evapotranspiration change spatiotemporaly. For evaluating the accuracy of SEBS results RMSE and rRMSE are calculated for SEBS and TARBIL data, equation 4.1 is Root Mean Squre Error RMSE, and equation 4.2 is Relative Root Mean Squre Error.

RMSE for this study is about 0.92 mm/day and rRSME is about 0.1 or 10% which means SEBS estimated evapotranspiration by 10% error of TARBIL. Low value for rRMSE shows the accuracy of SEBS results.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x}_i)^2}{n}} \tag{5.1}$$

$$\mathrm{rRMSE}=\left(\frac{RMSE}{\bar{X}_{max} - \bar{X}_{min}}\right) \times 100 \tag{5.2}$$

in the equation x_i is SEBS value, $\bar{x}_i$ is TARBIL value, n is the number of data. Acceptable range for rRMSE is between 0 to 1; in this study it is about 0.1 or 10%.

5.2 Comparison of SEBS and GLDAS results

Evapotranspiration estimated by SEBS ranges from 3 to 8 mm/day and ET obtained from GLDAS ranges between 0 to 2.7 mm/day. SEBS values follow the trend that we expect during a year. In spring and summer due to high value of land surface temperature (LST) and leaf area index (LAI) and Normalized difference vegetation index (NDVI), ET is higher than ET in the winter and fall but GLDAS model doesn't show impressive changes in different seasons. In winter and fall parameters that directly affect ET value are in the minimum ranges. GLDAS generates ET in 0.25-degree (27.5×27.5 km) resolution which is not enough for small area like Harran plain (dimension of the study area is almost 35×55 km) while SEBS estimates ET in high resolution (1×1 km). It seems that studied of water management, water budget, land surface fluxes in winter and in the area with low vegetation cover and also in large scales GLDAS can be usable, but in case of our target that is the estimation of ET in agricultural lands especially in a small area SEBS gives us more accurate and more trustable ET.

5.3 Discussion

As suggestions for reaching more accurate results in the following studies it is better to find solutions for the sources of errors that are mentioned bellow:

- Having access to the agriculture calendar and more details about stages of crop developments in order to calculate more exact Kc.
- Error related to calibration of MODIS parameters in the region, lack of caliboration tools for calibrating parameters like albedo, Leaf area index and land surface temperature.

Setting up lysimeters or Bowen Ration stations in the target location to measure evapotranspiration for comparison with SEBS results.

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