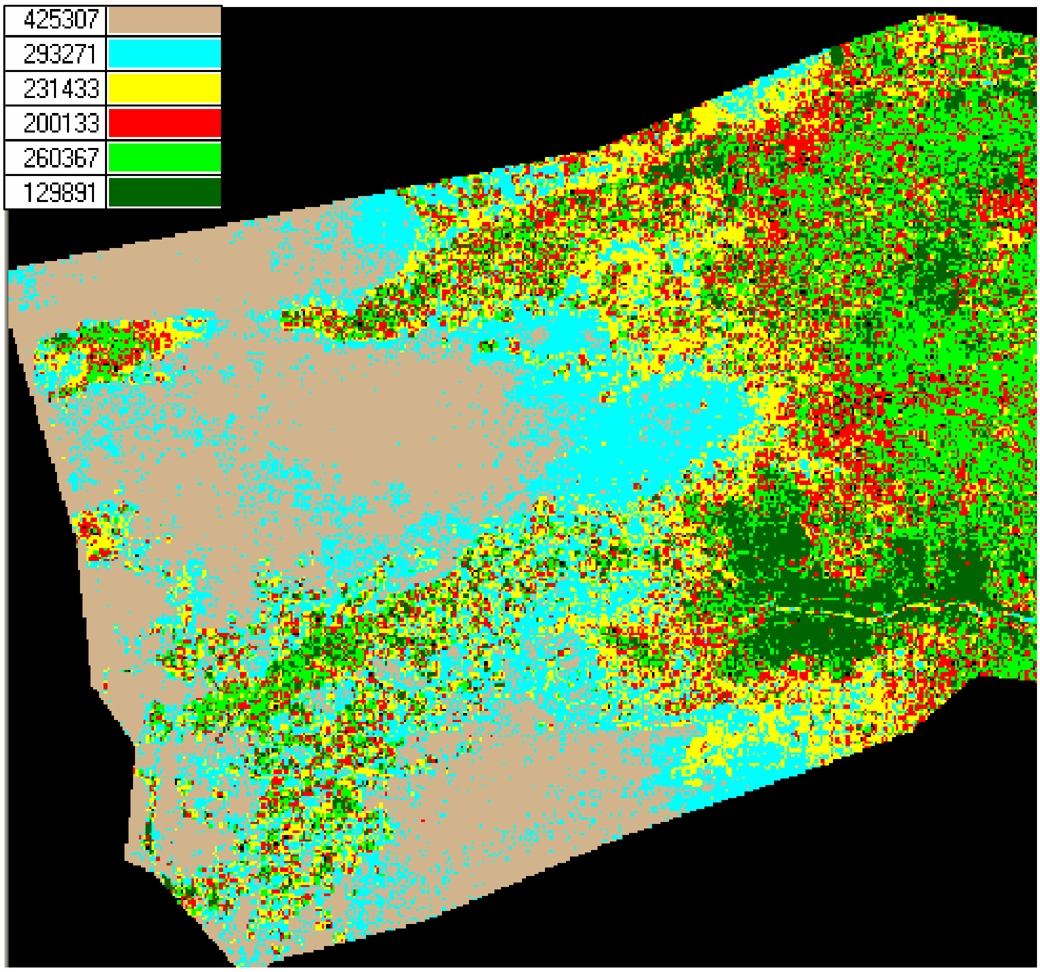
Second draft Report for

Remote Sensing for Assessment of Water budget in Wadies Zabid &Rima

Understanding analysis the Water Balance of the Wadies Zabeed and Rima western wadies - Yemen



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Sana'a - November 2011

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DEFINITIONS RELATED TO EVAPOTRANSPIRATION

ETact actual evapotranspiration

Evapotranspiration that occurs from plant and soil under *actual* field conditions. In this study ETact is calculated spatially using satellite images and the SEBAL algorithm.

ETpot potential evapotranspiration

Evapotranspiration that maximally occurs from plant and soil under actual field and *optimal* soil water conditions.

ETpot is calculated spatially using satellite images and the SEBAL algorithm.

ETrain evapotranspiration as result from rainfall

Actual evapotranspiration that occurs from rainfed areas, i.e. areas where rainfall is the only water source.

ETirr evapotranspiration as result from irrigation

Incremental actual evapotranspiration that occurs from irrigated agricultural areas and irrigation practices in excess of ET that originates from rainfall.

ETgross gross evapotranspiration

Gross evapotranspiration is equal to actual evapotranspiration of a certain non-homogeneous area that is composed of irrigated and non-irrigated land It is the sum of evapotranspiration from rainfall and evapotranspiration from irrigation:

$$ETgross = ETrain + ETirr$$

1. INTRODUCTION

In recent years, water resources management has become an important issue. This is especially true with the increased demand and competition for fresh water between different users and climate change. Consequently, monitoring the consumption of water has become one of the most popular issues regarding water resources management (almhab, 2009). Water strategy requires scientifically sound information on water availability which includes the quantification of spatial and temporal changes of water balance components like rainfall and evapotranspiration. These components are inextricably linked with climate, so the prospect of global climate change has serious implications for water balance partially in arid and semi arid regions. In order to investigate the best methodology input data to hydrological and water energy balance models that are the central support for hydrological decision making (mamo, 2010).

Precipitation (P) and Evapotranspiration (ET) are the main parameter to estimation of water balance; they give highlight information on water availability. Currently remote sensing data which available free online with different algorithms and models was develop is widely used for estimation of these two parameters. Models and data source selection for accurate estimate of P and ET from remote sensing observation are also continuously improving. The data for this paper were two Satellite product from MODIS and TRMM and 14 ground metrological station (Y-NWRA) on the study area Yemen. In this study that rainfall estimation from TRMM images and ET was estimated from MODIS satellite images and ground based data using M-SEBAL (Modified -Surface Energy Balance Algorithm for Land) model. Daily P and ET for Yemen using satellite image and ground metrological station was comparison. In addition the performance of M-SEBAL model over different land cover classes was tested by comparison of daily ET from the model with ETa estimation from ground metrological station over different land cover. Finally climatologically water balance estimation “Precipitation minus evapotranspiration” was carried out over rainfed crop land during study period Jane to December 2007using rainfall product from TRMM images and daily ET estimated by M-SEBAL model from MODIS images.

The objectives of this research are to estimate of precipitation, evapotranspiration and climatology water balance. (Precipitation minus evapotranspiration” in large area by combined used of remote sensing and based meteorological data.

4. METHODOLOGY

This chapter introduces the main techniques used to identify the Precipitations based TRMM satellite images, Evapotranspiration and water balance for wadi Zabeed and wadi Rema in wester wadie's in Yemen. The algorithm used to map the water consumption is the Modified Surface Energy Balance Algorithm for Land (M-SEBAL). The M-SEBAL algorithm uses as main input satellite and weather data for predicting evapotranspiration (ET) from data from the Moderate Resolution Imaging Spectrometer (MODIS) on the Terra satellite and ground meteorological data was developed in the Republic of Yemen.

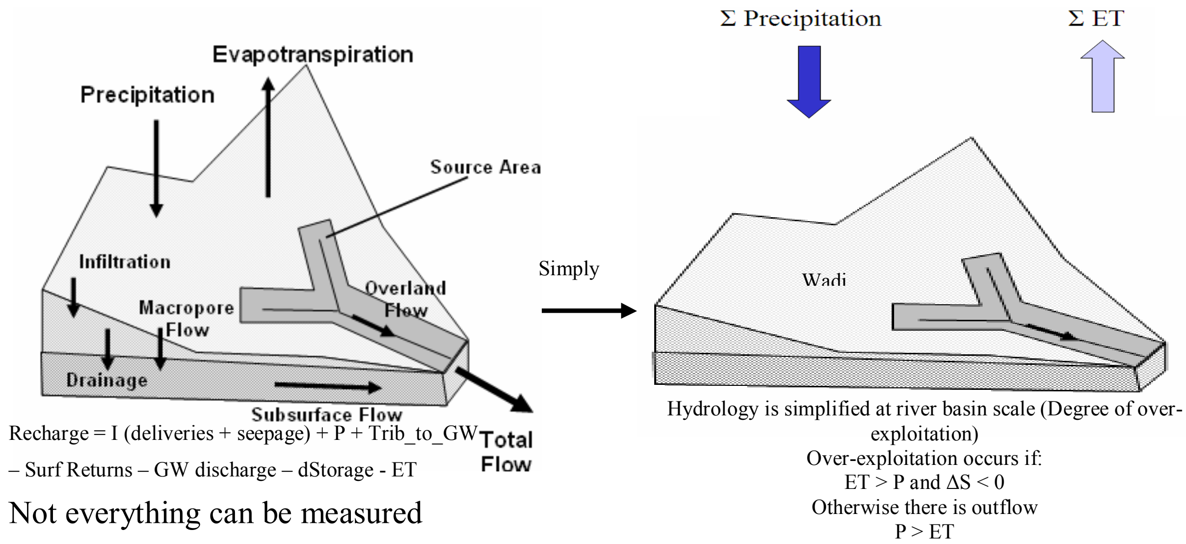


Figure 14 diagram summarize the methodology applied in this study for estimation of water balance in Wasi's Zabeed & Rima Yemen

4.1 PRECIPITATION ESTIMATION BASED TRMM SATELLITE

Satellite-based precipitation estimation has quite long story and became one of the more intense research topics in the discipline of satellite meteorology. The major problem of all methods is the in-direct relation between the precipitation on the ground and the measured satellite signal; therefore various studies have been carried out to address and solve these issues. This part will give a brief explanation of the main types of rainfall retrievals from space using VIS/IR, PMW, active sensors and blending techniques.

Rainfall data for daily periods from January 2010 to December 2010, measured and collected by the National Water Resources Authority (NWRA) Republic of Yemen, were used to prepare the monthly accumulated rainfall data. The monthly TRMM 3B43(V6) accumulated rainfall(0.25°×0.25°) product acquired from TRMM Online Visualization and Analysis System (TOVAS) is used to prepare it satellite database.

In this study the monthly rainfall product of TRMM 3B43, which is the combination of TRMM Precipitation Radar (PR) and TRMM Microwave Imager (TMI), was compared with the values of ground-based NWRAGS (rain gauges) throughout Yemen. Although Tropical Rainfall Measuring Mission (TRMM) precipitation products have been extensively validated at ground sites around the world, none of these sites lies in Yemen, therefore in the paper (Almhab and Tol,2010) has been tried to validated TRMM (3B43 product) annually, monthly and daily periods in order to using TRMM satellite data in Yemen meteorological studies. For a more technical description of validation the TRMM data for Yemen see Appendix 1

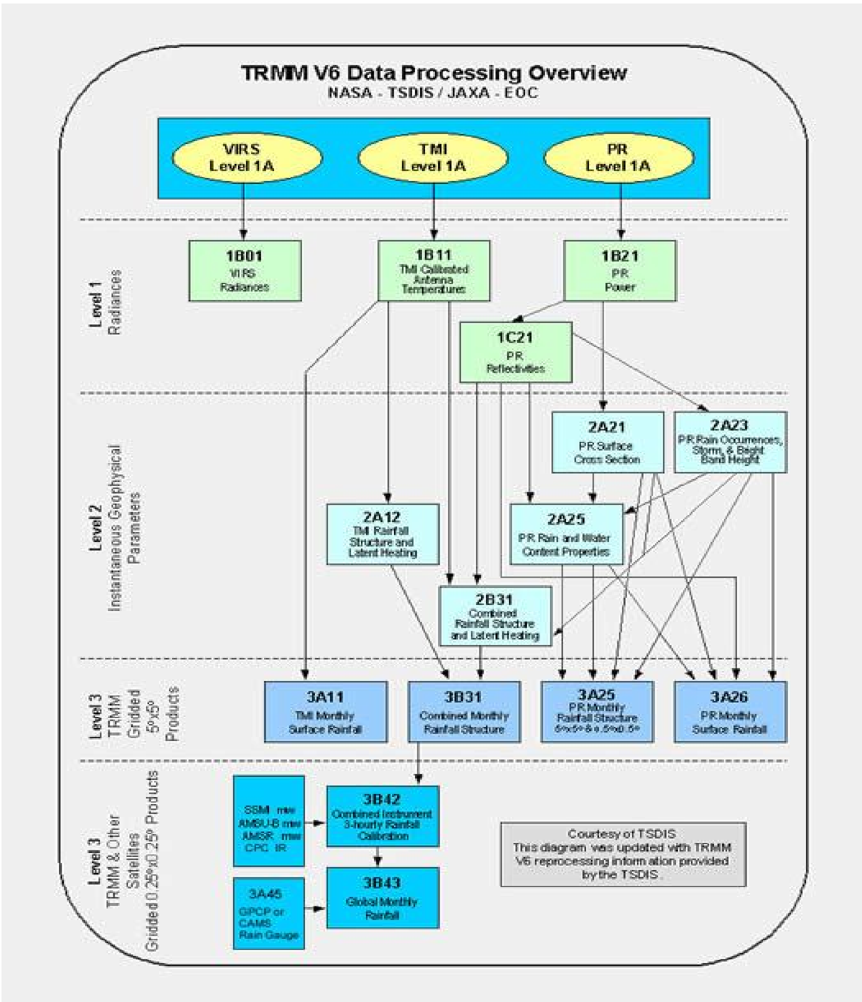


Figure 15 TRMM data processingand products

4.2 EVAPOTRANSPIRATION ESTIMATION USING M-SEBAL MODEL

M-SEBAL model was develop by introducing some changes into the existing SEBAL model which developed from (Bastiaanssen. et. al, 1998) .Notably, the inclusion of terrain, mountains and deserts effect in to calculations of surface radiation.

The M-SEBAL model was calculated using model builder in ERDAS IMAGINE 8.5 image processing package. All model parameters are programmed in to the model builder and values are computed automatically based on the input data. The general flowchart for the modified SEBSL model is shown by Figure 14.

The method uses the energy budget equation to calculate each pixel $\lambda(ET_{ins})$ (instant latent heat loss) at the time of the satellite over flight.

$$\lambda(ET_{ins}) = R_n - G - H \qquad \text{Eq. 1}$$

Where: $\lambda(ET_{ins})$ is the instant latent heat loss (w/m^2) , which is calculated as a residual of the energy budget, λ is the latent heat (i.e. the heat needed to evaporate unit mass of water), ET_{ins} is the rate of evapotranspiration at the time of the satellite overflight, R_n is net solar raids (w/m^2), G is soil heat flux into the soil (w/m^2), H is the sensible heat flux into the air (w/m^2).

The M-SEBAL algorithm can be used to compute maps of actual evapotranspiration , crop coefficient (Kc) and crop water requirement (CWR) . In the current project the main focus lies on actual evapotranspiration (ET). The key input data for M-SEBAL consists of raster values of spectral radiance in the visible, near-infrared and thermal infrared part of the spectrum and DEM images. Hence, the measurements are unique for every pixel.

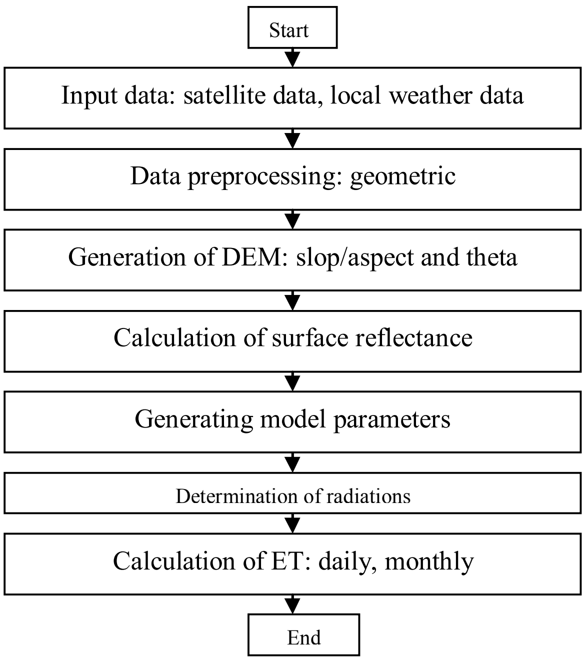


Figure 14 the general flowchart of the M-SEBAL model

Satellite radiances will be converted first into land surface characteristics such as surface albedo, leaf area index, vegetation index and surface temperature.The land surface characteristics can be derived from different types of satellites in this study derived from

Landsat 7 ETM images and MODIS (MODerate resolution Imaging Spectroradiometer) images. For a more technical description of M-SEBAL model see Appendix 2.

2.4 Theory

2.4.1 Net Radiation (R_n) : The radiation balance at the Earth's surface is composed of four spectral radiant fluxes, the incoming short wave (0.14 to 4 µm) radiation that arrives from the sun ($R_{s\downarrow}$), the amount of this energy that is reflected from the surface ($R_{s\uparrow}$), the incoming long wave (> 4 µm) radiation from the atmosphere ($R_{L\downarrow}$), and the amount of long wave radiation emitted from the surface ($R_{L\uparrow}$). Thus the net radiation is:

$$R_n = R_{s\downarrow} - R_{s\uparrow} + R_{L\downarrow} - R_{L\uparrow} \qquad \text{Eq. 2}$$

The instantaneous net amount of radiation received by a surface can be written in the form:

$$R_n = (1-\alpha)R_{s\downarrow} + \varepsilon_a \sigma T_a^4 - \varepsilon_s \sigma T_s^4 \qquad \text{Eq. 3}$$

where R_s is the incoming short-wave solar radiation, α is the surface short-wave albedo, σ is the Stefan–Boltzmann constant (5.67×10^{-8} W m^{-2} K^{-4}), T_a is the air temperature measured at the wet pixel (K), T_s derived from a remotely sensed radiometric surface temperature (K), ε_a is the air emissivity taking as [Bastiaanssen, 1995]:

$$\varepsilon_a = 1.08(-\ln\tau_{sw})^{0.265} \qquad \text{Eq. 4}$$

where τ_{sw} is two way atmospheric transmissivity [$\tau_{sw} = 0.75+2x10^{-5} z$],z is elevation meter. where ε_s= surface emissivity which is calculated from normalized vegetation index (NDVI) using the logarithmic relation of Van de Griend and Owe (1993) as:

$$\varepsilon_s = 1.0094 + 0.047 * \ln(NDVI) \qquad \text{Eq. 5}$$

The weighting factors for each band are the proportions of solar radiation incident at the earth surface in each segment. This approach was adopted here to derive α from narrow bands. α is calculated by the equation in Tasume et al. (2000)for LANDSAT surface reflectance data.

$$\rho^{TOA} = 0.293\rho 1^{TOA} + 0.274\, \rho 2^{TOA} + 0.233\, \rho 3^{TOA} + 0.157\, \rho 4^{TOA} + 0.033\, \rho 5^{TOA} + 0.011 \rho 7^{TOA} \qquad \text{Eq. 6a}$$

ρi is the reflectance for LANDSAT data band i. We adopted the equation of Chemin et al. (2000) for NOAA-AVHRR surface reflectance data.

$$\rho^{TOA} = 0.035 + 0.0545\rho 1^{TOA} + 0.32\, \rho 2^{TOA} \qquad \text{Eq. 6b}$$

ρi is the reflectance for NOAA-AVHRR data band i.

The incoming short wave radiation *($R_{s\downarrow}$)* was computed in this study, by equation (7) as follows (Fu 1998, Tasuni et al. 200) in which the diffuse radiation was neglected:

$$R_s \downarrow = \frac{G_{SC}}{d^2_r} \cos\theta \times \tau \qquad \text{Eq. 7}$$

Where G_{sc} *is the solar constant(1367 w/m²),* d_r *is inverse squared relative distance earth-sun (dimensionless) calculated by* dr=1+0.033cos{[2π(DOY)]/365}, cosθ *is cosine of the solar zenith angle calculated by* cosθ=cos(π/2-ϕ) *where* ϕ *is sun elevation angle in radians (in the flat area) in the slop and mountain terrain areas (like our case study) solar incident angle changes with surface slope and aspect. Therefore the equation suggested by Duffie and Bekman,(1991) is applied.*

$$\cos\theta = \sin(\delta)\sin(\phi)\cos(s) - \sin(\delta)\cos(\phi)\sin(s)\cos(\gamma) + \cos(\delta)\cos(\phi)\cos(s)\cos(\omega) + \cos(\delta)\sin(\phi)\sin(s)\cos(\gamma)\cos(\omega) \qquad \text{Eq. 8}$$

Where: δ is solar declination(rad); ϕ is geographic latitude of the pixel (rad); s is ground slope (rad); γ is the surface aspect angle (rad); ω is the hour angle of the sun(rad).

*2.4.2 Soil Heat Flux (*G*):*

Soil heat flux is usually measured with sensors buried just beneath the soil surface. A remote measurement of G is not possible but several studies have shown that the day time ratio of G/R_n *is related to among other factors, such as the normalized difference vegetation index(NDVI). In this study equation (9) is adapted with the regression equation.*

G as an empirical fraction of the net radiation using surface temperature, surface albedo (α) and NDVI and was adopted here to compute G as:

$$G = R_n\left(-0.4005NDVI^2 + 0.2207NDVI + 0.2715\right) \qquad \text{Eq. 9}$$

Where T_s is the surface temperature, NDVI is the normalized difference vegetation index. is calculated as the following:

$$NDVI = (R_4 - R_3) / (R_4 + R_3) \qquad \text{Eq. 10}$$

where R_4 and R_3 are the reflectance data of bands 4 and 3 in LANDSAT and bands 2 and 1 in NOAA-AVHRR respectively.

2.4.3 Sensible Heat Flux (*H*):

For the sensible heat flux calculation, two pixels are chosen in the satellite data. One pixel is a wet pixel that is a well-irrigated crop surface with full cover and the surface temperature (T_s) close to air temperature (T_a) The second pixel is a dry bare agricultural field where λE is assumed to be 0. The two pixels tie the calculations for all other pixels between these two points. At the dry pixel, assume λE =0, then according to equation (1) and the definition of specific heat capacity

$$H = R_n - G \qquad \text{Eq. 11}$$

$$H = \frac{\rho c_p dT}{r_{ah}}$$ Eq. 12

Where ρ is the air density (mol m^{-3}), c_p is the specific heat of air (29.3 J mol^{-1} °C^{-1}), dT is the near surface temperature difference (K), r_{ah} is the aerodynamic resistance to heat transport m/s, where

$$r_{ah} = \frac{\ln\left(\frac{z_2}{z_1}\right)}{u^* k}$$ Eq. 13

z_1 is a height just above the zero displacement distance height of plant canopy set to 0.1 m for each pixel, and z_2 is the reference height just above the plant canopy set to 2 m for each pixel, u* is the friction velocity (m/s), and k is the von Karman constant (0.4).

$$u^* = \frac{u(z)k}{\ln(\frac{z-d}{z_m})}$$ Eq.14

Where $u(z)$ is the wind speed at height of z, d is the zero displacement height (m, d=0.65h), h is the plant height (m), and z_m is the roughness length (m, z_m=0.1h)[Campbell and Norman 1998]. According to equations 13-14 and the input data, dT_{dry}, dT at the dry spot can be calculated. At the wet spot, assume H=0 and dT_{wet} =0 (dT at the wet spot). Then according to the surface temperature at the dry and wet spots (T_{sdry} and T_{swet}), we can get one linear equation for each pixel (wing et al, 2006),

$$dT = \left(\frac{dT_{dry} - dT_{wet}}{T_{s\,dry} - T_{s\,wet}}\right) \times T_s - \left(\frac{dT_{dry} - dT_{wet}}{T_{s\,dry} - T_{s\,wet}}\right) \times T_{s\,wet}$$ Eq. 15

Then, according to the equation, the H each pixel can be calculated according to equations 11-14. We assumed at 200 m the wind speed is the same for each pixel and the wind speed at 200 m is calculated for the weather station first, and then u* can be solved for each pixel (equation 14). The parameter d in equation 14 is set to 0 which is negligible when z =200 m. The z_m for each pixel is calculated by a regression equation according to the pixel value. The equation is obtained by three pairs of known values of z_m and $NDVI$.

Due to the fact that atmospheric stability may have effects on H, the atmospheric correction is conducted (16). First the u* and wind speed at 200 m at the local weather station are calculated. Then the z_m, u^* and dT for each pixel are computed. Then the r_{ah} and H without the atmospheric correction are obtained.

For atmospheric correction, the stability parameter, the Obukhove length, L (m) is calculated. Then using the stability parameter, u^*, r_{ah} and H are corrected. Then an iteration is conducted for L, u^*, r_{ah} and H calculation until H does not change more than 10%. The correction equation is as follows (Campbell and Norman 1998; Stull 2001).

$$L = -\frac{u^{*3} T_s}{kgH}$$ Eq. 16

When L<0, H is positive and heat is transferred from the ground surface to the air, under unstable condition; when L>0, H is negative and heat is transferred from air to ground surface, under stable condition; when L=0, no heat flux occurs, and is under neutral condition, because the satellite over flight occurred at local noon time, the atmosphere should have been unstable. Thus, when a stable condition occurred, we forced L=0 (neutral). After H is corrected by the atmospheric effects, $\lambda(ET_{ins})$ for each pixel is calculated using equation 1.

2.4.4 Regional ET model:

The actual 24 hour ET can be estimated from the instantaneous evaporative fraction EF, and the daily averaged net radiation, $R_{n,24}$ (Tasumi, et al, 2000):

$$ET_{24} = EF\{R_{n,24}[106(2.501-0.002361T_s)]\} \quad \text{Eq. 17}$$

where ET_{24} is the actual 24-hour evaporation (mm/day), $R_{n,24}$ is the 24-h net radiation (W/m^2), T_s the surface temperature (°C). The EF is the instantaneous evaporative fraction calculated as:

$$EF = \lambda\, ET /(R_n - G) \quad \text{Eq. 18}$$

where R_n is the instantaneous net radiation and G is the instantaneous soil heat flux.
Finally, the instantaneous latent heat of evapotranspiration (λ ET) may be computed as the residual of the surface energy balance equation (Eq. 1). However, in order to facilitate comparison with the sensible heat flux, is use made of the instantaneous evaporative fraction *EF*, defined as follows :

$$EF =(R_n - G)- H/(R_n - G) \quad \text{Eq. 19}$$

Assuming that the evaporative fraction (*EF*) is constant over the day the daily average sensible heat (H_{24}) can be derived from *EF* and the daily average net radiation (R_{n24}) as follows :

$$H_{24} = (1- EF)R_{n,24} \quad ((W/m^2)) \quad \text{Eq. 20}$$

The improved daily net radiation parameterization scheme and daily actual evapotranspiration.
The daily net radiation can be expressed as:

$$R_{n24} = (1-\alpha)R_{s24} + R_{L24} \quad ((W/m2)) \quad \text{Eq. 21}$$

Where R_{s24} is the daily solar radiation and R_{L24} is the daily net long wave radiation (wm^{-2}).
As the mountain and terrain of our study area is complex with undulations, the impact topography, the impact of slope and azimuth of surface on available radiation shod be considered pixel by pixel in the calculated instantaneous and daily net radiation, the shaded areas (pixels) were excluded from imageries with the model maker in ERDAS imagine software brakeage. Through importing parameters of solar azimuth and solar elevation at the satellite overpass time. The daily net radiation is estimated by an integral of equation (7) transmittance for one-way transmittance τ with ($c+dn/N$):

$$R_{s24} = (c + d\frac{n}{N}) * \int_{-\pi}^{+\pi}\left[\frac{G_{sc}}{d_r^2}\sin\delta.a + \cos\delta.\cos\omega.b + \cos\delta\sin s.\sin\gamma.\sin\omega\ \right]d\omega \quad \text{Eq. 22}$$

$$R_{s24} = (c + d\frac{n}{N}) * \int_{\omega 1}^{\omega 2}\left[\frac{G_{sc}}{d_r^2}\sin\delta.a + \cos\delta.\cos\omega.b + \cos\delta\sin s.\sin\gamma.\sin\omega\ \right]d\omega \quad \text{Eq. 23}$$

$$R_{a24} = (c + d\frac{n}{N}).\frac{G_{sc}}{2\pi d_r^2}\left[a.\sin\delta.(\omega_2 - \omega_1) + b.\cos\delta(\sin\omega_2 - \sin\omega_1) - \sin s.\sin\gamma\cos\delta(\cos\omega_2 - \cos\omega_1)\right] \quad \text{Eq. 24}$$

$$a = \sin\phi\cos s - \cos\phi\sin s.\cos\gamma$$
$$b = \cos\phi\cos s + \sin\phi\sin s.\cos\gamma$$

$$N = \frac{12(\omega_2 - \omega_1)}{\pi} \qquad \text{Eq. 25}$$

Where: *c* and *d* are coefficients of the solar radiation depending on the latitude climate and other factors of study area, respectively; *c+d* is the fraction of exterritorial radiation reaching the earth on clear sky days. *n* is the actual sunshine duration, *N* the potential sunshine duration, ω_1 and ω_2 are the sunrise and sunset angle, respectively. The difficulty in retrieval of the daily solar radiation focuses on calculation of the sunrise and sunset angle for the tilted surfaces.
The sunrise and sunset angles for horizontal surfaces are given by Fu (1983) and Tasumi et al. (2000)

$$\omega_H = \cos^{-1}(-\tan\phi.\tan\delta) \qquad \text{Eq. 26}$$

The sunrise and sunset angle for tilted surfaces can be obtained by simple mathematical manipulation from equation (8) by setting cosθ=0, leading to

$$\omega = \cos^{-1}\left(\frac{-a.b.\tan\delta \pm \sin\gamma.\sin s\sqrt{1-a^2(1+\tan^2\delta)}}{1-a^2}\right) \qquad \text{Eq. 27}$$

The positive or negative sign of equation (above) in the numerator are determined by equation:

$$\omega = \sin^{-1}\left(\frac{-a.\sin\gamma.\sin s.\tan\delta \pm b\sqrt{1-a^2(1+\tan^2\delta)}}{1-a^2}\right) \qquad \text{Eq. 28}$$

Let ω_{s1} and ω_{s2} be the roots of ω, respectively, and $\omega_{s1} > \omega_{s2}$. Note the surface receives the solar radiation only if *cos θ* in equation (8) is greater than 0. several relationships are given below to determine the sunrise and sunset angles (ω_1 , ω_2),
- if $\omega_{s1} \leq \omega \leq \omega_{s2}$ and cosθ ≥0, then $\omega_{s1} \geq \omega_{s2}$, $\omega_{s2} \leq \omega_{s1}$;
- if $\omega \leq \omega_{s1}$, ωs1 >ω_{s2} and cos>=0 then $\omega_1 \leq \omega_{s1}$,$\omega_2 \geq \omega_{s2}$.
- Meanwhile, the sunrise and sunset angles for tilted surfaces must also satisty the condition that sunrise is no earlier and sunset is no later than those for horizontal surfaces. Namely $\omega_1 \geq -|\omega_H|$, $\omega_2 \geq$ $\omega_{s2} \leq |\omega_H|$.

Daily net long wave radiation:

$$R_{L24} = \varepsilon_a \sigma T_a^4 - \varepsilon_s s T_s^4 \qquad \text{Eq. 29}$$

Where ε_a is the daily average atmospheric emissivity (Campbell and Norman, 1998) and T_a is the daily mean atmospheric temperature (k). due to the surface temperature obtain at 10h30, it could represent the daily average surface temperature for estimation of the surface daily long wave radiation (granger, 2000).

4.3 LAND USE CLASSIFICATION

A land use classification is the result of the process of converting raw satellite images into a map with meaningful classes. The basis for the discrimination between different classes is that land cover types often differ in reflective behaviour. However, there always some overlap between classes. If for example, the crop has no full ground cover the resulting spectral behaviour is also dependent of the soil, the specific reflectance which can be attributed to the vegetation is more difficult to extract. In addition, during certain periods of the crop development, the spectral reflectance can be similar for different crops.

In case crops have the same spectral reflectance at a certain time they are indistinguishable. If on an earlier or later date the spectral behaviour is different it is possible to differentiate between the two by using another satellite image. This type of multi-temporal classifications generally yields higher accuracies. (Pelgrum. et al, 2009).

Field work is necessary to compliment the image classification. By sampling a large number of fields with different crops at different dates it is possible to use this a priori information to enhance the land use classification. Also at a later stage these part or all of the field data can be used to assess the quality of the land use classification.

Figure 14 some air photo for the study area in wadi Zabeed

4.4 FIELD WORK

Shortly after the acquisitions of the Landsat images a field visit will organize to each area. Based on the information and patterns on the image, suitable areas will select. In general 10 to 30 sites will select for each image to visit. At each site several fields, ranging from 10 to 150, will identified on the images and the crop type noted. During the subsequent visits 64 sites will visit in wadi's Zabeed, and Rima. Figure 15 below gives an example of the sites to will be visit in Zabeed during the field campaign in …….future 2011. During the first field work campaigns it became clear that a typical growing season does not exist

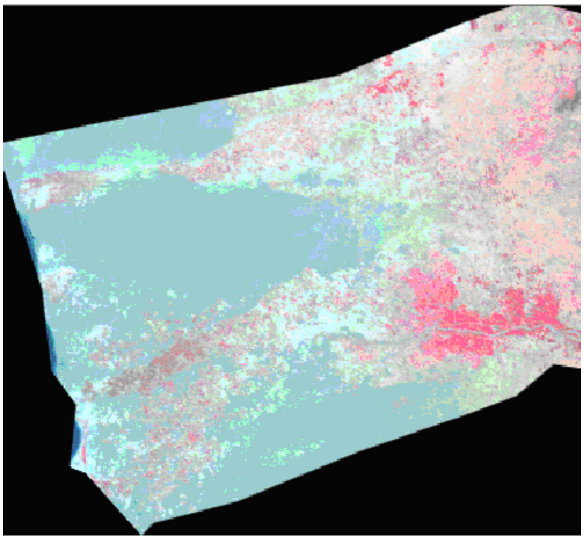


Figure 15 gives an example of the sites to will be visit in Zabeed and Rima during the field work

4.5 CLASSIFICATION PROCEDURES

The first approach to the discrimination of different classes is through the visual inspection of the satellite images. In Figure 18 the same image is displayed as RGB:3,2,1 and RGB:3,4,2 (RGB is the combination of bands represented by Red, Green and Blue). The first one is very useful for the visual differentiation between the vegetated and non vegetated areas. The second one is the most useful combination for the visual discrimination between crops. The classification is independent of the display combinations.

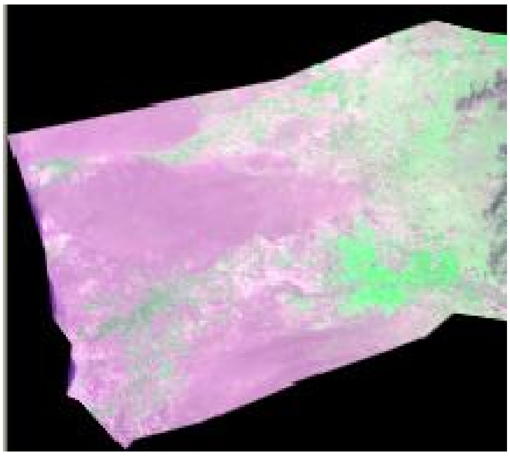


Figure 18 the same image is displayed as RGB:3,2,1 and RGB:3,4,2 (RGB is the combination of bands)

5. WADI ZABEED AND WADI RIMA (water management RESULT)

General

This chapter gives an overview of the result of different types of satellite imagery used. Also a listing of the acquisition dates of the imagery is given. One of the requests in the tender document leading to this report was to provide a level of detail of 30 m multispectral bands. In the discussions leading towards the project inception, all parties agreed that the crop water use analysis would be done based on a 30 m resolution Landsat7 ETM+, DEM 30m & 250m images, MODIS Images 250 m and TRMM 0.25 degree images (=250m) dataset.

5.1 PRECIPITATION

Precipitation is derived from the Tropical Rainfall Measuring Mission (TRMM) sensor1. The product used in this study is the calibrated monthly rainfall (43b4) which is available worldwide in a 0.25-degree by 0.25-degree spatial resolution. Figure 19, 20, 22 depicts average daily , monthly and annualy rainfall for a large area in Yemen's plains covering all irrigation schemes investigated. Rainfall is absent or marginal during January to April and in November/December. The rains start in May/June, but the majority of the annual rain is measured in July (120 mm) and August (118 mm). Total annual rainfall is 363 mm for the entire area, but differs significantly between the irrigation schemes (see also **Figure 23**). Annual rainfall in Zabeed areas. is as high as 492, while average annual rainfall in Zabeed Extension is only 238 mm.

Figure 19. Daily calibrated precipitation from the TRMM sensor /4/2010 (in mm per day).

Figure 20. Average monthly precipitation in 2010 measured by the TRMM sensor (in mm per month).

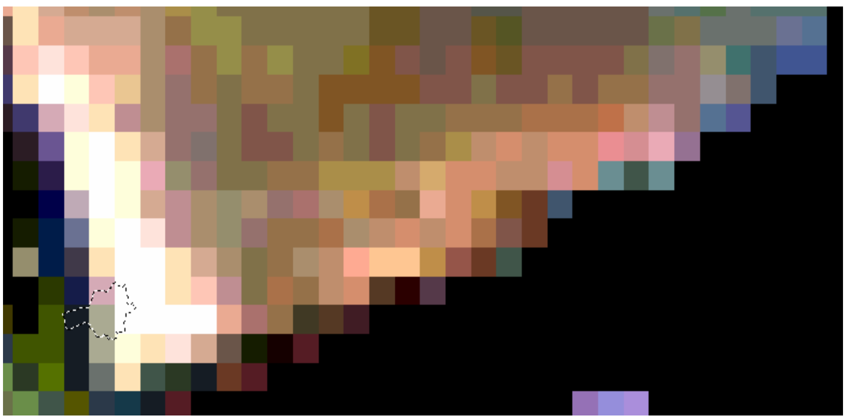


Figure 21. Monthly calibrated precipitation from the TRMM sensor (in mm per month).

Table 8. Annual average rainfall for six major Land use class (in millimeter per year).

Rainfall (mm/yr)

Land use class	P	P
	mm/year	mcm/year
Uncroped	510	133.9821
Rainfed	390	80.640846
Irrigation area	480	182.72779
Single Season Crops	335	60.347637
Double Season Crops	480	112.39128
Perennial Crops	340	39.488688

1 For more information on the TRMM sensor, visit http://trmm.gsfc.nasa.gov/

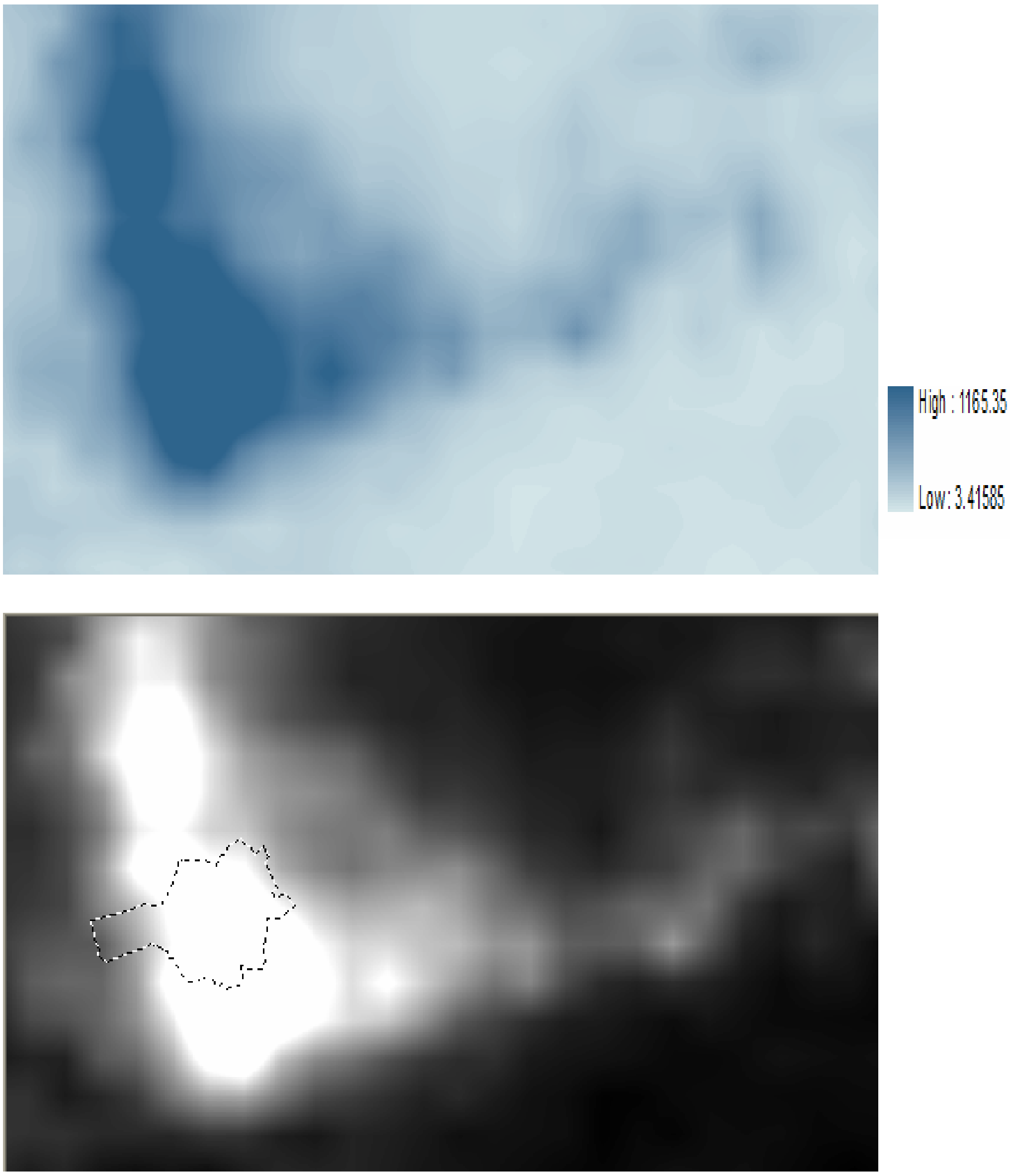


Figure 22. Annual calibrated precipitation from the TRMM sensor (in mm per year).

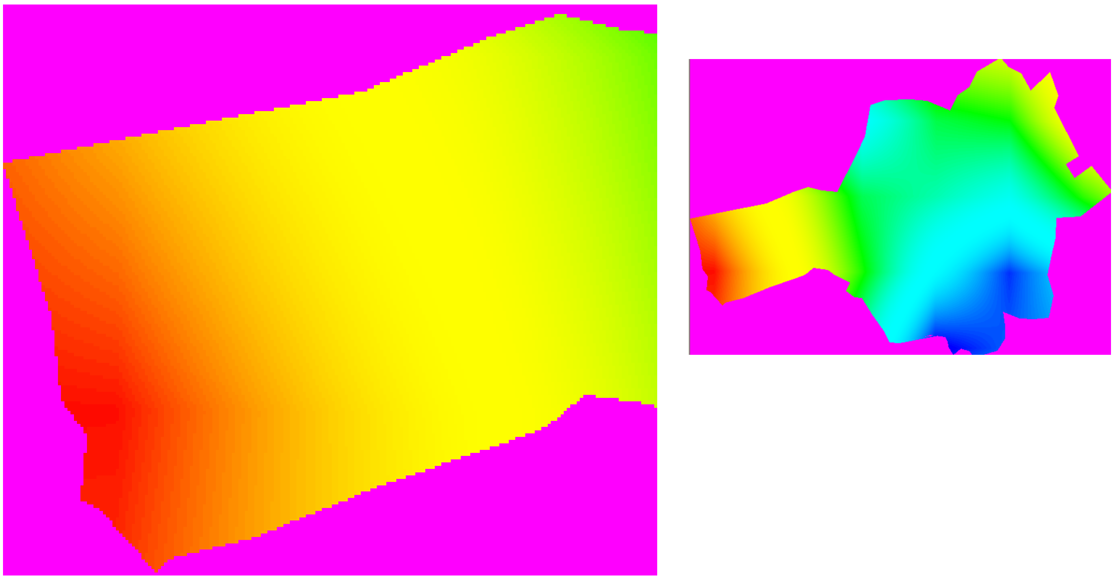


Figure 23. Annual calibrated precipitation for Wadi Zabeed &Rema areas using the TRMM sensor (in mm per year) Range is 3 to 1060 mm/yr

5.2 ACTUAL EVAPOTRANSPIRATION

The actual evapotranspiration has been calculated using the M-SEBAL algorithm which converts the satellite measured spectral radiances into surface energy balances including evapotranspiration. The algorithm is collect independent and uses satellite data with a thermal infrared sensor. In this study MODIS satellite images and Landsat7 ETM images were used. Meteorological data were the additional inputs besides the remote sensing data. Meteorological data were obtained from the NWRA gage stations. The output from the M-SEBAL analysis consists of 12 maps of total monthly actual evapotranspiration. The maps have a resolution of 250*250 m and actual evapotranspiration is expressed in millimeter per month. Since the 250*250 m area related to irrigated fields and other land use classes, evapotranspiration is an equivalent layer that applies to a mixed land use. The gross actual evapotranspiration in Million cubic meters (MCM) was derived by multiplying the monthly average equivalent evapotranspiration (in millimeter) with the gross irrigated area. The results are presented in the figures 24 and table 9 below.

Average actual evapotranspiration for gross irrigated areas in Zabeed areas is between 452 mm and 2107 mm/year. It must be emphasized here that these layer-wise evapotranspiration results are averages from MODIS pixels that are flagged as irrigated land. Real crop evapotranspiration from irrigated land will be higher as the average values from MODIS pixels include non-irrigated land.

Monthly evapotranspiration values are high in July/September for all study area, but strongly decrease in the winter and spring period. The Zabeed area depict high monthly evapotranspiration rates throughout the year and peak values between 80 and 100 mm/month can be found in July/September. In the non irrigation area monthly evapotranspiration is between 10 to 30 mm/month from January to July (see **Figure 24)**

Finally, the evapotranspiration as result from irrigation (ETirr) is calculated by determining annual evapotranspiration from a rainfed non-irrigated area adjacent to the irrigation scheme (ETrain) and deducting this amount from the gross evapotranspiration (ETgross). Depending on the surrounding land use/vegetation and the amount of precipitation, the amount of water evapotranspiring from non-irrigated land differs. Figure 25 the ET using Landsat ETM images shows that ET from non-irrigated land ranges between 167 and 252 mm/year and that the effective rainfall factor (defined as the evapotranspiration from non-irrigated land divided by the gross precipitation) is higher (±0.9) at lower rainfall rates than at higher rainfall rates (0.5).

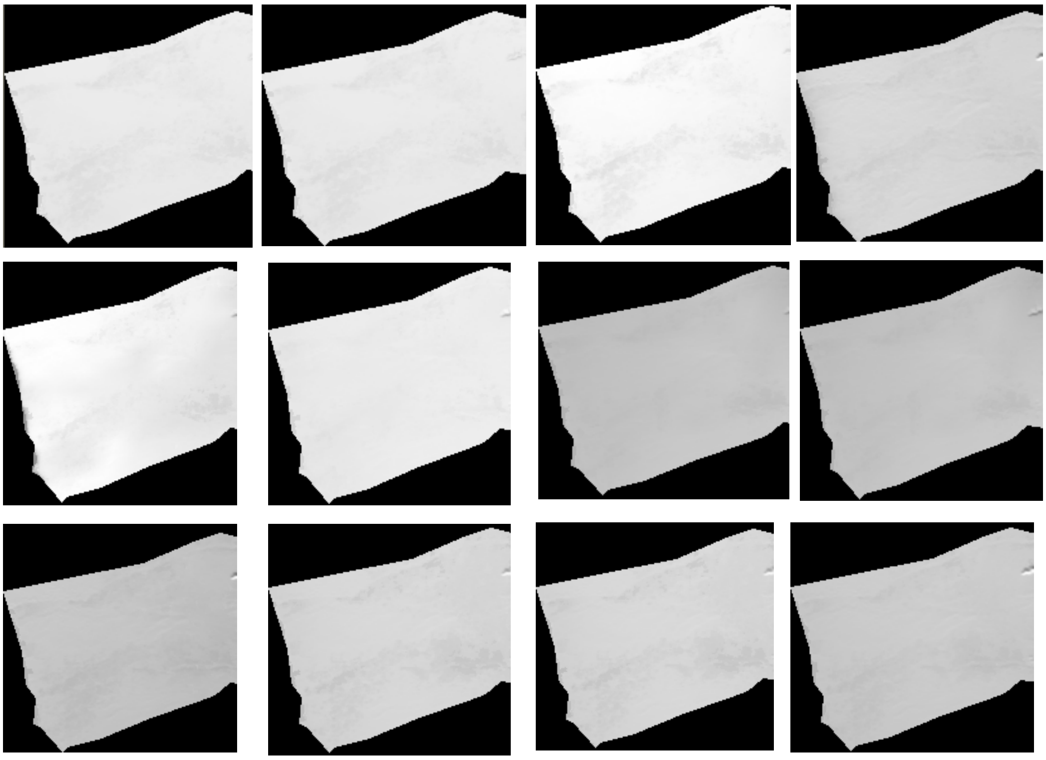


Figure 24. Monthly gross actual evapotranspiration in 12 months 2010 for the study areas Wdi Zabeed and Rema, using M-SEBAL model and MODIS images.

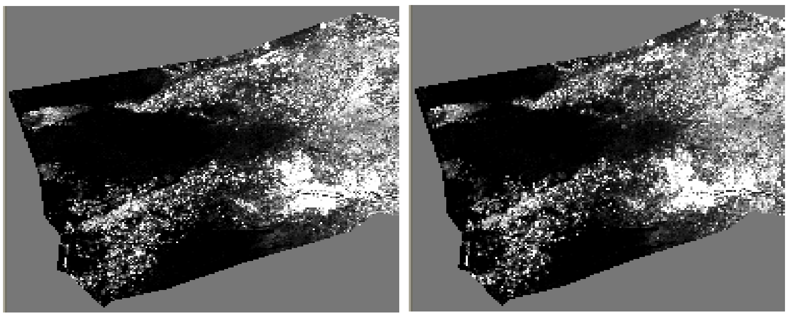


Figure 25. Monthly actual evapotranspiration calculated by M-SEBAL model and Landsat ETM images at July/October 2010

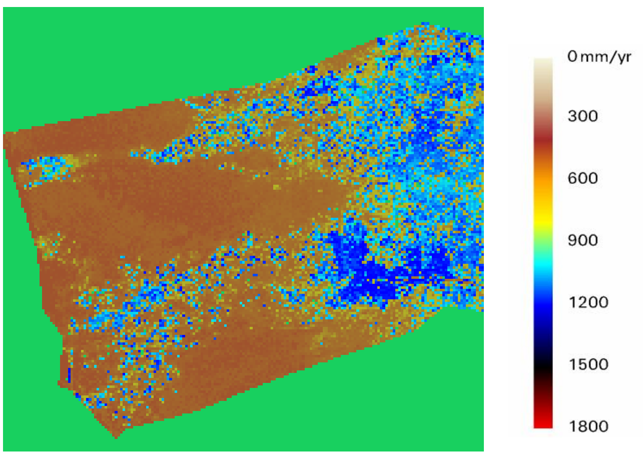


Figure 26. Annual actual evapotranspiration in 2010 for the study ara using M-SEBAL Range from 0 to 1890 mm/yr

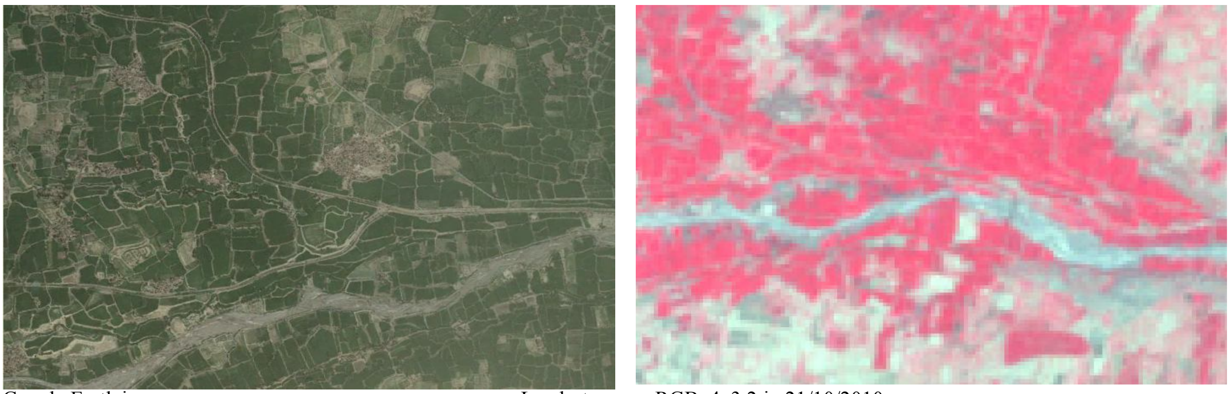
Table 9. Monthly gross actual evapotranspiration (in mm/year) in 2010 for the Zabeed areas, averaged for the gross irrigated area.

Land use class	ET	ET	ET	ET
	mm/day	mcm/day	mm/year	mcm/year
Uncroped	2	0.52542	73	19.177
Rainfed	3.5	0.7237	651	134.608
Irrigation area	11	4.187	967	368.120
Single Season Crops	6	1.080	706	127.180
Double Season Crops	10	2.341	1117	261.543
Perennial Crops	9	1.045	1087	126.247

5.3 LAND USE

Spate irrigation is a type of water management unique to semi-arid environments. Flood water from mountain catchments is diverted from Wadi's and spread over large areas. Spate irrigation is very risk prone, due to the unpredictability of the wadi floods and frequent changes in the course of the wadi from which the water is diverted. Due to uncertainty of floods, the amount of water available for irrigation can differ greatly from year to year.

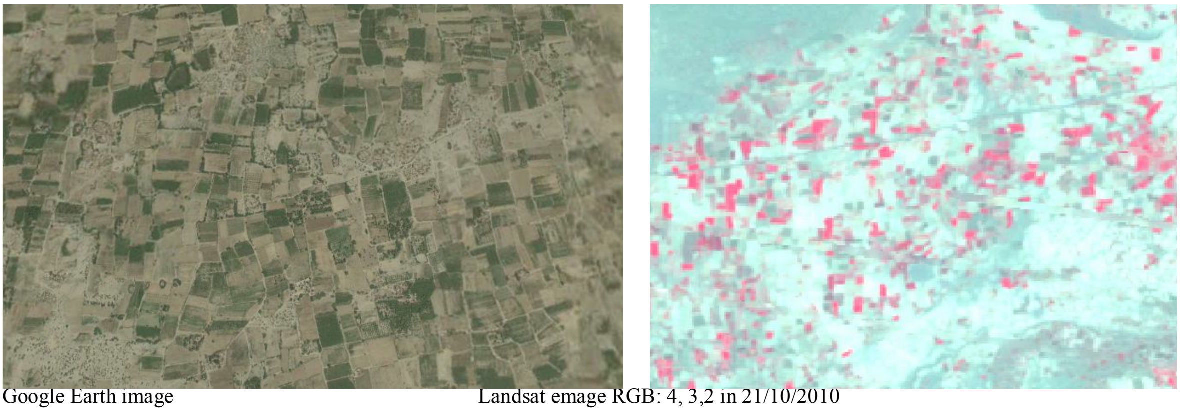
Groundwater irrigation uses a more reliable source of water: groundwater. With pumps the groundwater can be pumped to the surface, where it can be used to irrigate the agricultural fields. It can be used on demand and there is no reliance on weather or flood events. The major issue with groundwater irrigation is the necessity to use the groundwater in a sustainably way. Overexploitation of groundwater can lead to a number of negative consequences, like increasing soil salinity, water quality detoriation, depletion of available water resources. This can lead to serious socio-economical problems. Drinking water for the domestic sector could for instance be at threat. Fields in Wadi Zabeed that are cropped in April, October and December are irrigated by means of groundwater because spates only occur during the rainy and flood season.



Google Earth image Landsat emage RGB: 4, 3,2 in 21/10/2010

Figure 27: Example of spate irrigation in upper Wadi Zabeed

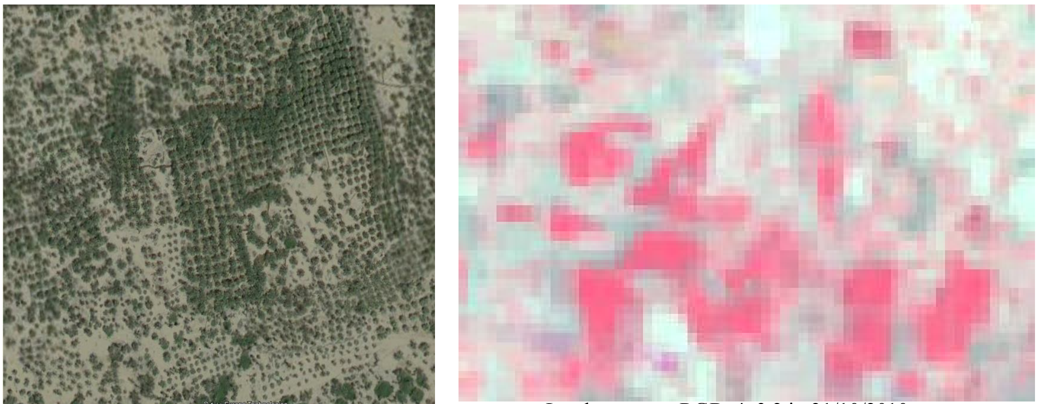
Figure 27 shows an example of spate irrigation from the upper Wadi Zabeed. The blue track is the course of the Wadi. The dark fields are freshly ploughed or harrowed fields with a higher soil moisture content. some fields are very dark indicating an irrigation application with residual tailwater ponding at the lower end of the field.the October image most fields show a healthy crop although within the fields there is a large difference between the upper and lower part of the fields. While most fields are harvested on the December.



Google Earth image Landsat emage RGB: 4, 3,2 in 21/10/2010

Figure 28: Example of rainfed agriculture and groundwater irrigation in the plain

Groundwater irrigation is practised on the plain between the two Wadi's. These fields are visible as the bright red fields on October image of Figure 28. The image the area appears reddish indicating a rainfed crop with partial vegetation cover.



Google Earth image Landsat emage RGB: 4, 3,2 in 21/10/2010

Figure 29: Example of groundwater irrigation in Wadi Zabeed

Because of the inability to discern different crop types, agricultural land use classes have been classified instead of individual crops. The land use classification divided the land use with regard to the management practices. The classes defined are:

Uncropped (including water bodies, cities and plain areas)

Rainfed Agriculture

Single Season Crops

Double Season Crops

Perennial Crops

The land use classification cannot distinguish spate and groundwater irrigation in the Wadi Zabeed area. It is quite certain however that perennial crops and double season crops must be irrigated by groundwater outside the flood season. When spate irrigation is applied is something which cannot be inferred from satellite imagery.Table 10 shows the area covered by the different agricultural land use in the Zabeed area.

Table10: Agricultural Land Use in the Zabeed area. The total area agrees with the area of the Landsat 7 image depicted.

Land use class	**Area (ha)**	**% of total area**	**% of cropped area**
Uncroped	26271	0.1902871	0.235006
Rainfed	20677.14	0.1497694	0.184966
Irrigation area	38068.29	0.2757376	0.340538
Single Season Crops	18014.22	0.1304813	0.161145
Double Season Crops	23414.85	0.1695993	0.209456
Perennial Crops	11614.32	0.0841253	0.103895

Table 10 contains the total irrigated area expressed as single season crops, double season crops and perennial crops. Approximately half of all cropped area is rainfed agriculture and the other half is irrigated agriculture. The distinction between rainfed and irrigated agriculture has been made using the amount of rainfall in 2010 as mapped by the TRMM satellite. If the actual evapotranspiration from a cropped field was less than the yearly rainfall than that field was identified as rainfed agriculture. By using the TRMM rainfall map the spatial variability of the rainfall was taken into account.

The two Landsat ETM images have been used to calculate the Normalized Difference Vegetation Index (NDVI). Pixels with a high NDVI have a large amount of fresh green vegetation. Pixels with a low NDVI have sparse vegetation being either crops or natural vegetation. By comparing the four NDVI images at different dates it was possible to discern fields with a constant high NDVI (perennial crops), fields with a single peak in the NDVI (single season crops) and fields with two peaks in different times of the year (double season crops). The amount of area for both perennial crops (2%) and double season crops (1%) is limited for Zabeed. The majority of the irrigation activities (ca 80%) is applied only for one growing season, and is thus essentially a spate irrigation system.

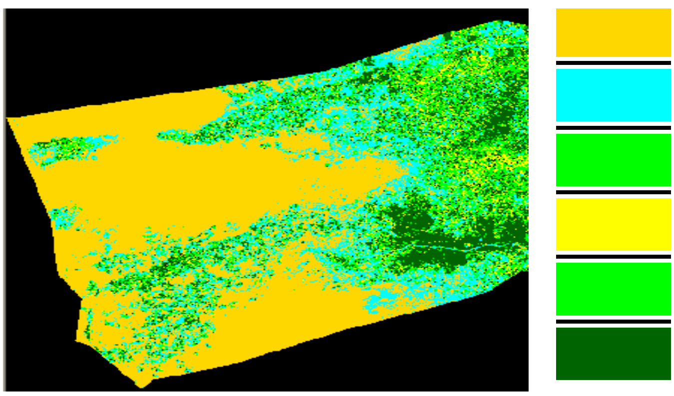


Figure 30: classification result in Wadies Zabeed and Rema colour composite is shown.

Figure 30 shows the detail as land use classifications show season crops. Spate irrigation is limited to a single crop per year. The lower parts of the fields receive most of the water. The upper part of the field is usually classified as rainfed agriculture, which actually is a good reflection of the reality.

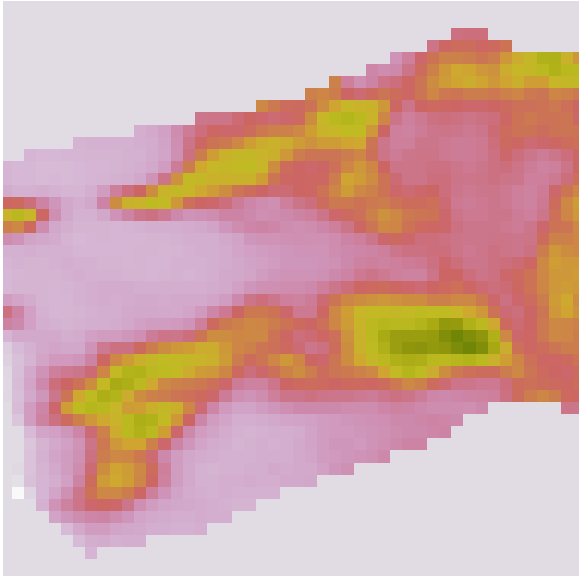
Fieldwork must be taken in Zabeed at four different times in different seasons. Because of the shift in classification from specific crops to agricultural land data to perform an assessment on the accuracy of the classification. The most straightforward assessment is whether the distinction between cropped area and uncropped area is sufficient. The field data the fieldwork will also mapping as crop area. This provides an accuracy of 97% for mapping cropped area.

5.4 WATER USE

The actual and potential evapotranspiration (ET) have been calculated using the M-SEBAL algorithm. Actual ET represent crop water consumption and potential ET crop water demand. Annual ET is obtained from the 12 MODIS satellite images Figure 24. The available Landsat data have been used to downscale the results to a resolution of 30 m. For a map of actual ET for the whole Zabeed area Figure 32, for a map of potential ET for the whole Zabeed area see figure 33. From the ET maps it can be seen that there is a clear decreasing trend in ET from the mountains towards the Red Sea Coast. The two Wadi's can be clearly identified with high ET values due to the heat from the surrounding desert in combination with wet irrigated soils. Also the natural vegetation in the mountains have a high evapotranspiration, mainly caused by rainfall in the mountains originating from storms in the Red Sea. The runoff of these mountains is used to harvest water in the plains for spate irrigation in the Wadi's. The Wadi's display a large amount of variability of actual ET. This is due to the different management practices. Fields with groundwater irrigation can use water throughout the whole year, whereas the spate irrigation fields have limited access to water. The rainfed agriculture is only able to use approximately 470 mm per year, which is the average rainfall for the Zabeed region.

Figure 32 and 33 shows the actual and potential ET of an area with rainfed agriculture and groundwater irrigation. The irrigated fields consume considerably more water than the rainfed agriculture, which are corresponding high ET values. The area in Figure 34 These fields must be irrigated with groundwater.

Figure35 shows the actual and potential ET of an area with spate irrigation. All fields with spate irrigation have a heterogeneous distribution of ET values. The lower lying areas in the field receive more water than the higher lying areas. This can be seen at the triangular shapes on the ET image. This phenomenon is related to the geographical nature of these fields. In general the ET values of fields with spate irrigation are lower than with groundwater irrigation. Also the fields show a less homogeneous distribution of water.



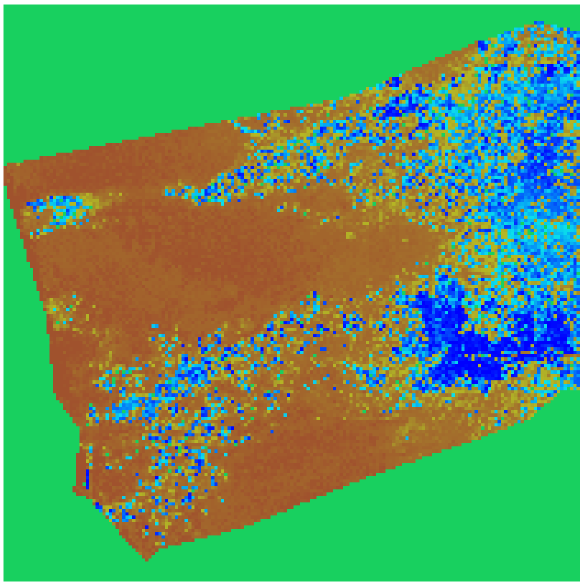
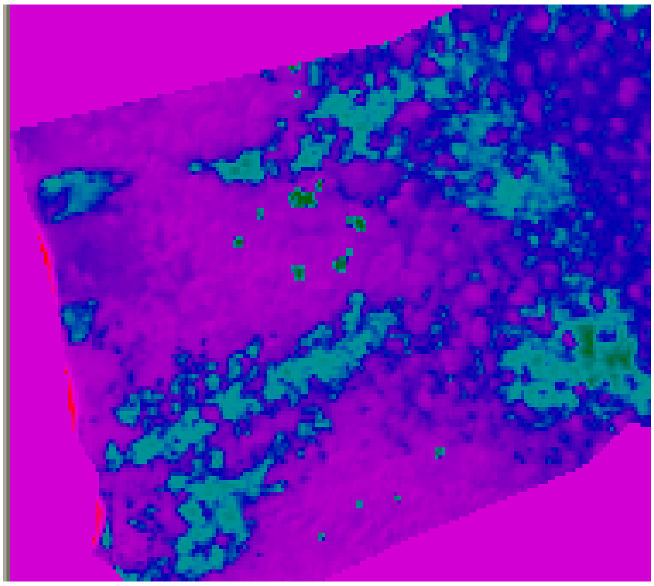


Figure 32 for Actual ET for the Zabeed area&Fig 33 the potential ET for the whole Zabeed area



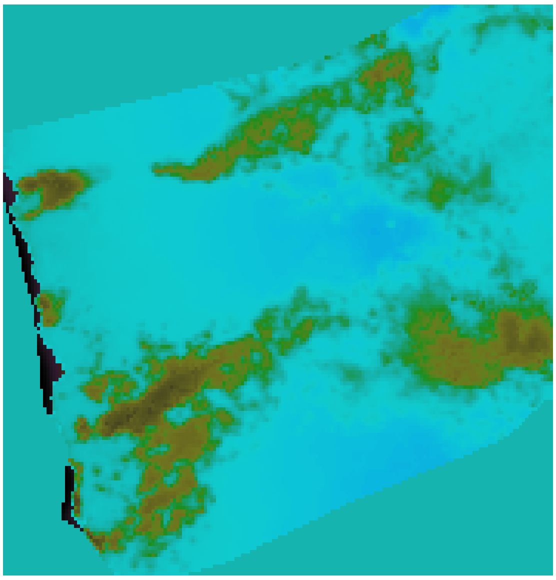


Figure 34 fields must be irrigated with groundwater.

In Table 12 the mean potential and actual ET values for the different agricultural land use classes are summarized. Also the standard deviation is given for the different classes.

Table 12: Potential and Actual annual ET values for all agricultural land use classes in the Zabeed area.

Land use class	Actual evapotranspiration		Potential evapotranspiration	
	mm/yr	mcm/yr	mm/yr	mcm/yr
Uncroped	73	19.17783	2089	548.8012
Rainfed	651	134.6081814	1922	397.4146
Irrigation area	967	368.1203643	1870	711.877
Single Season Crops	706	127.1803932	2055	370.1922

Double Season Crops	1117	261.5438745	1952	457.0579
Perennial Crops	1087	126.2476584	1932	224.3887

Table 13 gives an estimate how much irrigation water has been applied. The assumption has been made that an irrigation efficiency of 55% holds. This means that 55% of applied water is consumed by the plants (in addition to ET originating from rainfall). The remainder of the irrigation water applied goes either to surface runoff, drainage or groundwater recharge and is not available for the plant. The ET from the rainfed crops is taken as the ET which is due to rainfall. The following definitions are used in Table 13:

Table 13 Irrigation supply for agricultural land use classes in wadis Zabeed and Rimaa areas

Land use	Area	Actual ET	Potential ET	Net Irrigatio supply		Gross Irrigation supply	
	He	mm/yr	mm/yr	mm/yr	mcm/yr	mm/yr	Mcm/yr
Cross basin area							
Uncropped	26271	73	2089	0			
Rainfed	20677.14	651	1922	0			
Irrigated areas	38068.29	967	1870	903			
Single season Crop	18014.22	706	2055				
Double Season Crop	23414.85	1117	1952				
Perennial Crop	11614.32	1087	1932				

The total ET of an irrigated crop:

ETactual = ETrain + ETirrigated.
ETrain = ET of Rainfed Agriculture
Net Irrigation Supply = ETirrigated
Gross Irrigation Supply = Net Irrigation Supply / Efficiency

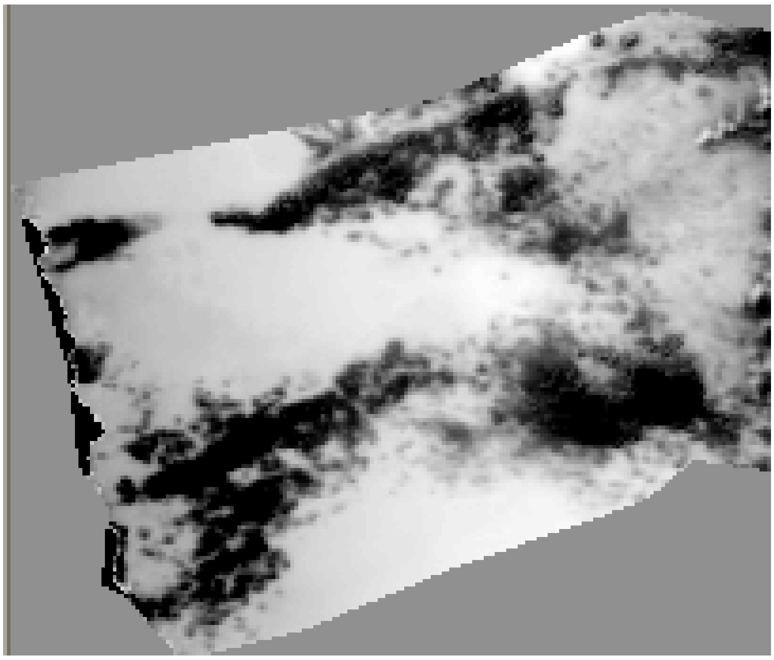
From Table 13 it can be seen that although the Single Season crops apply less irrigation water per unit of land the total volumetric amount of irrigation water applied is with,….. mcm/yr….

5.5 WATER BALANCE

Monthly precipitation and actual evapotranspiration are depicted for the study area in **Figure 35**. Only during July and October there is sufficient precipitation to meet the crop's water demand. In the other months, irrigation water is required.

Table 14 show the yearly water availability by precipitation and water diversion.

Land use class	P-ET	P-ET
	MM/YR	MCM/YR
Cross basin area	-1955.02	-546.801
Uncropped	-1841.36	-393.915
Rainfed	-1687.27	-700.877
Irrigated areas	-1994.65	-364.192
Single season Crop	-1839.61	-447.058
Double Season Crop	-1892.51	-215.389
Perennial Crop	-1955.02	-546.801

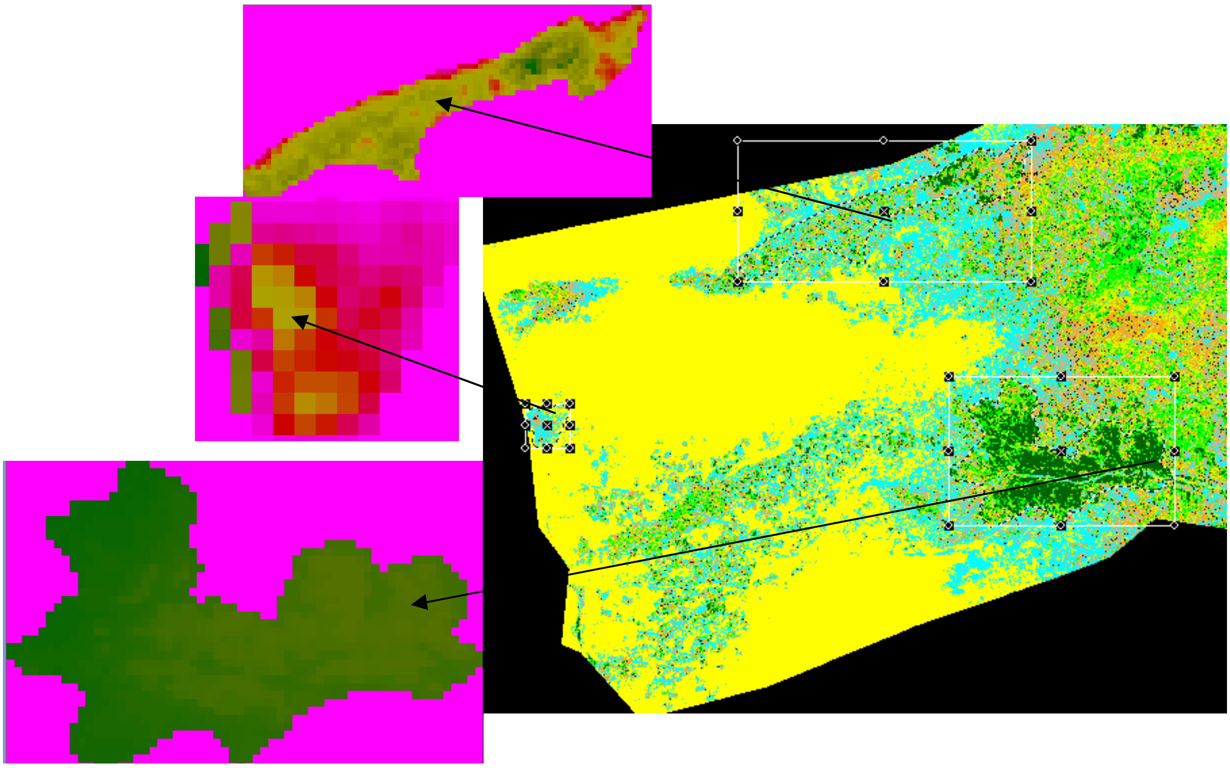


Figurev35 show the yearly water availability by precipitation and water diversion

In figure 35. P – ET . Including surface water diversions, groundwater abstractions range from -1450 to +633 mm/yr

Even though agricultural activities are absent during May-July, considerable amounts of water are diverted if the numbers are correct. Also during the winter and spring season, the amounts of water diversion exceed ETgross by up to 4.6 times the ETgross. In August sufficient water is available to agriculture due to the rainfall, but in the following months the water supply is much lower than the demand. (It must be noted that groundwater pumping for irrigation is not included as a potential water source.) Similar trends are also depicted in **Figure 36** where the monthly gross irrigation demands (ETirr divided by an irrigation water supply efficiency of 55%) are related to the water diversions from official statistics. The oversupply in the winter/summer period and the shortage during September to October indicates that irrigation water supply does not match with the demand at all.

Because the water balance in the wide areas show mines result and the runoff and the flood irrigated areas is centralizes in the mean valley so we have select three areas to study the water balance every pixel , this thee study areas as showing in the figures 36 bellow it is wadi Zabeed irrigated areas and Almujilees areas and wadi Rimaa irrigated areas , the tables 15 to 24 is showing the actual ET , potential or reference ET, Precipitation and water balance in every selected site .



Figurev35 show the thee study areas as case studies

Tables show the actual and reference evapotranspirations in wadi Zabeed

WadiZabeed refernce et

Area Hectar	histogram	rferencel ET valu	No. pixel
7500	1200	0	
0	0	8.092256	1
0	0	16.18451	2
0	0	24.27677	3
0	0	32.36902	4
0	0	40.46128	5
0	0	48.55353	6
0	0	56.64579	7
0	0	64.73804	8
0	0	72.8303	9
0	0	80.92256	10
0	0	89.01481	11
0	0	97.10707	12
0	0	105.1993	13
0	0	113.2916	14
0	0	121.3838	15
0	0	129.4761	16
0	0	137.5683	17
0	0	145.6606	18
0	0	153.7529	19
0	0	161.8451	20
0	0	169.9374	21
0	0	178.0296	22
0	0	186.1219	23
0	0	194.2141	24
0	0	202.3064	25
0	0	210.3986	26

WadiZabeed actual et

Area Hectar	histogram	actual ET valu	No. pixel
7500	1200	0	
0	0	5.795356	1
0	0	11.59071	2
0	0	17.38607	3
0	0	23.18143	4
0	0	28.97678	5
0	0	34.77214	6
0	0	40.56749	7
0	0	46.36285	8
0	0	52.15821	9
0	0	57.95356	10
0	0	63.74892	11
0	0	69.54428	12
0	0	75.33963	13
0	0	81.13499	14
0	0	86.93034	15
0	0	92.7257	16
0	0	98.52106	17
0	0	104.3164	18
0	0	110.1118	19
0	0	115.9071	20
0	0	121.7025	21
0	0	127.4978	22
0	0	133.2932	23
0	0	139.0886	24
0	0	144.8839	25
0	0	150.6793	26

0	0	218.4909	27
0	0	226.5832	28
0	0	234.6754	29
0	0	242.7677	30
0	0	250.8599	31
0	0	258.9522	32
0	0	267.0444	33
0	0	275.1367	34
0	0	283.2289	35
0	0	291.3212	36
0	0	299.4135	37
0	0	307.5057	38
0	0	315.598	39
0	0	323.6902	40
0	0	331.7825	41
0	0	339.8747	42
0	0	347.967	43
0	0	356.0592	44
0	0	364.1515	45
0	0	372.2438	46
0	0	380.336	47
0	0	388.4283	48
0	0	396.5205	49
0	0	404.6128	50
0	0	412.705	51
0	0	420.7973	52
0	0	428.8895	53
0	0	436.9818	54
0	0	445.0741	55
0	0	453.1663	56
0	0	461.2586	57
0	0	469.3508	58

0	0	156.4746	27
0	0	162.27	28
0	0	168.0653	29
0	0	173.8607	30
0	0	179.656	31
0	0	185.4514	32
0	0	191.2468	33
0	0	197.0421	34
0	0	202.8375	35
6.25	1	208.6328	36
6.25	1	214.4282	37
6.25	1	220.2235	38
0	0	226.0189	39
0	0	231.8143	40
6.25	1	237.6096	41
0	0	243.405	42
0	0	249.2003	43
0	0	254.9957	44
0	0	260.791	45
6.25	1	266.5864	46
0	0	272.3817	47
6.25	1	278.1771	48
12.5	2	283.9725	49
6.25	1	289.7678	50
12.5	2	295.5632	51
6.25	1	301.3585	52
0	0	307.1539	53
6.25	1	312.9492	54
6.25	1	318.7446	55
12.5	2	324.54	56
12.5	2	330.3353	57
12.5	2	336.130	58

0	0	477.4431	59
0	0	485.5353	60
0	0	493.6276	61
0	0	501.7198	62
0	0	509.8121	63
0	0	517.9044	64
0	0	525.9966	65
0	0	534.0889	66
0	0	542.1811	67
0	0	550.2734	68
0	0	558.3656	69
0	0	566.4579	70
0	0	574.5501	71
0	0	582.6424	72
0	0	590.7347	73
0	0	598.8269	74
0	0	606.9192	75
0	0	615.0114	76
0	0	623.1037	77
0	0	631.1959	78
0	0	639.2882	79
0	0	647.3804	80
0	0	655.4727	81
0	0	663.565	82
0	0	671.6572	83
0	0	679.7495	84
0	0	687.8417	85
0	0	695.934	86
0	0	704.0262	87
0	0	712.1185	88

		7	
18.75	3	341.926	59
18.75	3	347.7214	60
18.75	3	353.5167	61
12.5	2	359.3121	62
18.75	3	365.1074	63
0	0	370.9028	64
6.25	1	376.6982	65
18.75	3	382.4935	66
18.75	3	388.2889	67
18.75	3	394.0842	68
37.5	6	399.8796	69
25	4	405.6749	70
18.75	3	411.4703	71
25	4	417.2657	72
12.5	2	423.061	73
18.75	3	428.8564	74
18.75	3	434.6517	75
31.25	5	440.4471	76
31.25	5	446.2424	77
31.25	5	452.0378	78
31.25	5	457.8331	79
18.75	3	463.6285	80
37.5	6	469.4239	81
25	4	475.2192	82
25	4	481.0146	83
50	8	486.8099	84
25	4	492.6053	85
25	4	498.4006	86
37.5	6	504.196	87
18.75	3	509.9914	88

0	0	720.2107	89
0	0	728.303	90
0	0	736.3953	91
0	0	744.4875	92
0	0	752.5798	93
0	0	760.672	94
0	0	768.7643	95
0	0	776.8565	96
0	0	784.9488	97
0	0	793.041	98
0	0	801.1333	99
0	0	809.2256	100
0	0	817.3178	101
0	0	825.4101	102
0	0	833.5023	103
0	0	841.5946	104
0	0	849.6868	105
0	0	857.7791	106
0	0	865.8713	107
0	0	873.9636	108
0	0	882.0559	109
0	0	890.1481	110
0	0	898.2404	111
0	0	906.3326	112
0	0	914.4249	113
0	0	922.5171	114
0	0	930.6094	115
0	0	938.7016	116
0	0	946.7939	117
0	0	954.8862	118
0	0	962.9784	119

43.75	7	515.7867	89
37.5	6	521.5821	90
56.25	9	527.3774	91
68.75	11	533.1728	92
31.25	5	538.9681	93
37.5	6	544.7635	94
18.75	3	550.5588	95
56.25	9	556.3542	96
18.75	3	562.1496	97
31.25	5	567.9449	98
18.75	3	573.7403	99
75	12	579.5356	100
43.75	7	585.331	101
68.75	11	591.1263	102
18.75	3	596.9217	103
31.25	5	602.7171	104
37.5	6	608.5124	105
25	4	614.3078	106
37.5	6	620.1031	107
18.75	3	625.8985	108
25	4	631.6938	109
50	8	637.4892	110
18.75	3	643.2845	111
25	4	649.0799	112
31.25	5	654.8753	113
18.75	3	660.6706	114
31.25	5	666.466	115
31.25	5	672.2613	116
18.75	3	678.0567	117
25	4	683.852	118
31.25	5	689.6474	119

0	0	971.0707	120
0	0	979.1629	121
0	0	987.2552	122
0	0	995.3474	123
0	0	1003.44	124
0	0	1011.532	125
0	0	1019.624	126
0	0	1027.716	127
0	0	1035.809	128
0	0	1043.901	129
0	0	1051.993	130
0	0	1060.085	131
0	0	1068.178	132
0	0	1076.27	133
0	0	1084.362	134
0	0	1092.455	135
0	0	1100.547	136
0	0	1108.639	137
0	0	1116.731	138
0	0	1124.824	139
0	0	1132.916	140
0	0	1141.008	141
0	0	1149.1	142
0	0	1157.193	143
0	0	1165.285	144
0	0	1173.377	145
0	0	1181.469	146
0	0	1189.562	147
0	0	1197.654	148
0	0	1205.746	149
0	0	1213.838	150

56.25	9	695.4428	120
31.25	5	701.2381	121
50	8	707.0335	122
50	8	712.8288	123
25	4	718.6242	124
68.75	11	724.4195	125
31.25	5	730.2149	126
31.25	5	736.0102	127
37.5	6	741.8056	128
31.25	5	747.601	129
37.5	6	753.3963	130
62.5	10	759.1917	131
37.5	6	764.987	132
31.25	5	770.7824	133
43.75	7	776.5777	134
62.5	10	782.3731	135
50	8	788.1685	136
31.25	5	793.9638	137
25	4	799.7592	138
37.5	6	805.5545	139
50	8	811.3499	140
50	8	817.1452	141
43.75	7	822.9406	142
56.25	9	828.7359	143
100	16	834.5313	144
68.75	11	840.3267	145
62.5	10	846.122	146
43.75	7	851.9174	147
75	12	857.7127	148
56.25	9	863.5081	149
56.25	9	869.3034	150

0	0	1221.931	151
0	0	1230.023	152
0	0	1238.115	153
0	0	1246.207	154
0	0	1254.3	155
0	0	1262.392	156
0	0	1270.484	157
0	0	1278.576	158
0	0	1286.669	159
0	0	1294.761	160
0	0	1302.853	161
0	0	1310.945	162
0	0	1319.038	163
0	0	1327.13	164
0	0	1335.222	165
0	0	1343.314	166
0	0	1351.407	167
0	0	1359.499	168
0	0	1367.591	169
0	0	1375.683	170
0	0	1383.776	171
0	0	1391.868	172
0	0	1399.96	173
0	0	1408.052	174
0	0	1416.145	175
0	0	1424.237	176
0	0	1432.329	177
0	0	1440.421	178
0	0	1448.514	179
0	0	1456.606	180

68.75	11	875.0988	151
50	8	880.8942	152
100	16	886.6895	153
68.75	11	892.4849	154
56.25	9	898.2802	155
81.25	13	904.0756	156
25	4	909.8709	157
81.25	13	915.6663	158
43.75	7	921.4616	159
68.75	11	927.257	160
37.5	6	933.0524	161
68.75	11	938.8477	162
68.75	11	944.6431	163
75	12	950.4384	164
37.5	6	956.2338	165
43.75	7	962.0291	166
75	12	967.8245	167
87.5	14	973.6199	168
62.5	10	979.4152	169
68.75	11	985.2106	170
31.25	5	991.0059	171
43.75	7	996.8013	172
75	12	1002.597	173
87.5	14	1008.392	174
56.25	9	1014.187	175
31.25	5	1019.983	176
75	12	1025.778	177
62.5	10	1031.573	178
43.75	7	1037.369	179
81.25	13	1043.164	180

0	0	1464.698	181
0	0	1472.791	182
0	0	1480.883	183
0	0	1488.975	184
0	0	1497.067	185
0	0	1505.16	186
0	0	1513.252	187
0	0	1521.344	188
0	0	1529.436	189
0	0	1537.529	190
0	0	1545.621	191
0	0	1553.713	192
0	0	1561.805	193
0	0	1569.898	194
0	0	1577.99	195
0	0	1586.082	196
0	0	1594.174	197
0	0	1602.267	198
0	0	1610.359	199
0	0	1618.451	200
0	0	1626.543	201
0	0	1634.636	202
0	0	1642.728	203
0	0	1650.82	204
0	0	1658.912	205
0	0	1667.005	206
0	0	1675.097	207
0	0	1683.189	208
0	0	1691.281	209
0	0	1699.374	210
0	0	1707.466	211

56.25	9	1048.959	181
62.5	10	1054.755	182
43.75	7	1060.55	183
81.25	13	1066.346	184
68.75	11	1072.141	185
18.75	3	1077.936	186
56.25	9	1083.732	187
75	12	1089.527	188
56.25	9	1095.322	189
87.5	14	1101.118	190
56.25	9	1106.913	191
75	12	1112.708	192
87.5	14	1118.504	193
68.75	11	1124.299	194
87.5	14	1130.094	195
56.25	9	1135.89	196
43.75	7	1141.685	197
43.75	7	1147.481	198
43.75	7	1153.276	199
37.5	6	1159.071	200
43.75	7	1164.867	201
50	8	1170.662	202
37.5	6	1176.457	203
37.5	6	1182.253	204
18.75	3	1188.048	205
43.75	7	1193.843	206
12.5	2	1199.639	207
18.75	3	1205.434	208
31.25	5	1211.229	209
25	4	1217.025	210
6.25	1	1222.82	211

0	0	1715.558	212
0	0	1723.65	213
0	0	1731.743	214
0	0	1739.835	215
0	0	1747.927	216
0	0	1756.019	217
0	0	1764.112	218
0	0	1772.204	219
0	0	1780.296	220
0	0	1788.388	221
0	0	1796.481	222
0	0	1804.573	223
0	0	1812.665	224
0	0	1820.758	225
0	0	1828.85	226
0	0	1836.942	227
0	0	1845.034	228
0	0	1853.127	229
0	0	1861.219	230
0	0	1869.311	231
0	0	1877.403	232
62.5	10	1885.496	233
362.5	58	1893.588	234
493.75	79	1901.68	235
443.75	71	1909.772	236
337.5	54	1917.865	237
168.75	27	1925.957	238
350	56	1934.049	239
468.75	75	1942.141	240
493.75	79	1950.234	241
306.25	49	1958.326	242

25	4	1228.616	212
25	4	1234.411	213
25	4	1240.206	214
31.25	5	1246.002	215
31.25	5	1251.797	216
18.75	3	1257.592	217
18.75	3	1263.388	218
12.5	2	1269.183	219
12.5	2	1274.978	220
12.5	2	1280.774	221
18.75	3	1286.569	222
18.75	3	1292.364	223
18.75	3	1298.16	224
12.5	2	1303.955	225
18.75	3	1309.751	226
18.75	3	1315.546	227
18.75	3	1321.341	228
43.75	7	1327.137	229
12.5	2	1332.932	230
25	4	1338.727	231
18.75	3	1344.523	232
25	4	1350.318	233
6.25	1	1356.113	234
12.5	2	1361.909	235
31.25	5	1367.704	236
43.75	7	1373.499	237
31.25	5	1379.295	238
18.75	3	1385.09	239
25	4	1390.886	240
12.5	2	1396.681	241
0	0	1402.47	242

250	40	1966.418	243
175	28	1974.51	244
93.75	15	1982.603	245
256.25	41	1990.695	246
256.25	41	1998.787	247
387.5	62	2006.879	248
331.25	53	2014.972	249
400	64	2023.064	250
581.25	93	2031.156	251
481.25	77	2039.248	252
531.25	85	2047.341	253
262.5	42	2055.433	254
6.25	1	2063.525	255

		6	
12.5	2	1408.272	243
12.5	2	1414.067	244
6.25	1	1419.862	245
0	0	1425.658	246
6.25	1	1431.453	247
0	0	1437.248	248
18.75	3	1443.044	249
6.25	1	1448.839	250
0	0	1454.634	251
0	0	1460.43	252
0	0	1466.225	253
6.25	1	1472.02	254
6.25	1	1477.816	255

Table showing the precipitations and the surface water balance without the runoff of the valley in wadi Zabee Areas

surface water balance (SWB) P - ETa	WadiZabeed presepitation Area Hectar	histogram	rainfall p valu	No. pixel
	7500	1200	0	
-3.67494	0	0	2.120414	1
-7.34989	0	0	4.240827	2
-11.0248	0	0	6.361241	3
-14.6998	0	0	8.481654	4
-18.3747	0	0	10.60207	5
-22.0497	0	0	12.72248	6
-25.7246	0	0	14.84289	7
-29.3995	0	0	16.96331	8
-33.0745	0	0	19.08372	9
-36.7494	0	0	21.20414	10
-40.4244	0	0	23.32455	11
-44.0993	0	0	25.44496	12
-47.7743	0	0	27.56538	13
-51.4492	0	0	29.68579	14
-55.1241	0	0	31.8062	15
-58.7991	0	0	33.92662	16
-62.474	0	0	36.04703	17
-66.149	0	0	38.16744	18
-69.8239	0	0	40.28786	19
-73.4989	0	0	42.40827	20
-77.1738	0	0	44.52868	21
-80.8487	0	0	46.6491	22
-84.5237	0	0	48.76951	23
-88.1986	0	0	50.88993	24
-91.8736	0	0	53.01034	25
-	0	0	55.13075	26

95.5485					
-99.2235		0	0	57.25117	27
-102.898		0	0	59.37158	28
-106.573		0	0	61.49199	29
-110.248		0	0	63.61241	30
-113.923		0	0	65.73282	31
-117.598		0	0	67.85323	32
-121.273		0	0	69.97365	33
-124.948		0	0	72.09406	34
-128.623		0	0	74.21447	35
-132.298		0	0	76.33489	36
-135.973		0	0	78.4553	37
-139.648		0	0	80.57571	38
-143.323		0	0	82.69613	39
-146.998		0	0	84.81654	40
-150.673		0	0	86.93696	41
-154.348		0	0	89.05737	42
-158.023		0	0	91.17778	43
-161.697		0	0	93.2982	44
-165.372		0	0	95.41861	45
-169.047		0	0	97.53902	46
-172.722		0	0	99.65944	47
-176.397		0	0	101.7799	48
-180.072		0	0	103.9003	49
-183.747		0	0	106.0207	50
-187.422		0	0	108.1411	51
-191.097		0	0	110.2615	52
-194.772		0	0	112.3819	53
-198.447		0	0	114.5023	54
-202.122		0	0	116.6227	55

-205.797		0	0	118.7432	56
-209.472		0	0	120.8636	57
-213.147		0	0	122.984	58
-216.822		0	0	125.1044	59
-220.497		0	0	127.2248	60
-224.172		0	0	129.3452	61
-227.846		0	0	131.4656	62
-231.521		0	0	133.5861	63
-235.196		0	0	135.7065	64
-238.871		0	0	137.8269	65
-242.546		0	0	139.9473	66
-246.221		0	0	142.0677	67
-249.896		0	0	144.1881	68
-253.571		0	0	146.3085	69
-257.246		0	0	148.4289	70
-260.921		0	0	150.5494	71
-264.596		0	0	152.6698	72
-268.271		0	0	154.7902	73
-271.946		0	0	156.9106	74
-275.621		0	0	159.031	75
-279.296		0	0	161.1514	76
-282.971		0	0	163.2718	77
-286.646		0	0	165.3923	78
-290.32		0	0	167.5127	79
-293.995		0	0	169.6331	80
-297.67		0	0	171.7535	81
-301.345		0	0	173.8739	82
-305.02		0	0	175.9943	83
-308.695		0	0	178.1147	84
-312.37		0	0	180.2352	85
-316.045		0	0	182.3556	86

-319.72		0	0	184.476	87
-323.395		0	0	186.5964	88
-327.07		0	0	188.7168	89
-330.745		0	0	190.8372	90
-334.42		0	0	192.9576	91
-338.095		0	0	195.078	92
-341.77		0	0	197.1985	93
-345.445		0	0	199.3189	94
-349.12		0	0	201.4393	95
-352.795		0	0	203.5597	96
-356.469		0	0	205.6801	97
-360.144		0	0	207.8005	98
-363.819		0	0	209.9209	99
-367.494		0	0	212.0414	100
-371.169		0	0	214.1618	101
-374.844		0	0	216.2822	102
-378.519		0	0	218.4026	103
-382.194		0	0	220.523	104
-385.869		0	0	222.6434	105
-389.544		0	0	224.7638	106
-393.219		0	0	226.8842	107
-396.894		0	0	229.0047	108
-400.569		0	0	231.1251	109
-404.244		0	0	233.2455	110
-407.919		0	0	235.3659	111
-411.594		0	0	237.4863	112
-415.269		0	0	239.6067	113
-418.943		0	0	241.7271	114
-422.618		0	0	243.8476	115
-426.293		0	0	245.968	116
-429.968		0	0	248.0884	117
-		0	0	250.2088	118

433.643					
-437.318		0	0	252.3292	119
-440.993		0	0	254.4496	120
-444.668		0	0	256.57	121
-448.343		0	0	258.6905	122
-452.018		0	0	260.8109	123
-455.693		0	0	262.9313	124
-459.368		0	0	265.0517	125
-463.043		0	0	267.1721	126
-466.718		0	0	269.2925	127
-470.393		0	0	271.4129	128
-474.068		0	0	273.5333	129
-477.743		0	0	275.6538	130
-481.417		0	0	277.7742	131
-485.092		0	0	279.8946	132
-488.767		0	0	282.015	133
-492.442		0	0	284.1354	134
-496.117		0	0	286.2558	135
-499.792		0	0	288.3762	136
-503.467		0	0	290.4967	137
-507.142		0	0	292.6171	138
-510.817		0	0	294.7375	139
-514.492		0	0	296.8579	140
-518.167		0	0	298.9783	141
-521.842		0	0	301.0987	142
-525.517		0	0	303.2191	143
-529.192		0	0	305.3396	144
-532.867		0	0	307.46	145
-536.542		0	0	309.5804	146
-540.217		0	0	311.7008	147

-543.892	0	0	313.8212	148
-547.566	0	0	315.9416	149
-551.241	0	0	318.062	150
-554.916	0	0	320.1824	151
-558.591	0	0	322.3029	152
-562.266	0	0	324.4233	153
-565.941	0	0	326.5437	154
-569.616	0	0	328.6641	155
-573.291	0	0	330.7845	156
-576.966	0	0	332.9049	157
-580.641	0	0	335.0253	158
-584.316	0	0	337.1458	159
-587.991	0	0	339.2662	160
-591.666	0	0	341.3866	161
-595.341	0	0	343.507	162
-599.016	0	0	345.6274	163
-602.691	0	0	347.7478	164
-606.366	0	0	349.8682	165
-610.04	0	0	351.9886	166
-613.715	0	0	354.1091	167
-617.39	0	0	356.2295	168
-621.065	0	0	358.3499	169
-624.74	0	0	360.4703	170
-628.415	0	0	362.5907	171
-632.09	0	0	364.7111	172
-635.765	0	0	366.8315	173
-639.44	0	0	368.952	174
-643.115	0	0	371.0724	175
-646.79	0	0	373.1928	176
-650.465	0	0	375.3132	177
-654.14	0	0	377.4336	178
-657.815	0	0	379.554	179
-661.49	0	0	381.6744	180

-665.165	0	0	383.7949	181
-668.84	0	0	385.9153	182
-672.515	0	0	388.0357	183
-676.189	0	0	390.1561	184
-679.864	0	0	392.2765	185
-683.539	0	0	394.3969	186
-687.214	0	0	396.5173	187
-690.889	0	0	398.6377	188
-694.564	0	0	400.7582	189
-698.239	0	0	402.8786	190
-701.914	0	0	404.999	191
-705.589	0	0	407.1194	192
-709.264	0	0	409.2398	193
-712.939	0	0	411.3602	194
-716.614	0	0	413.4806	195
-720.289	0	0	415.6011	196
-723.964	6.25	1	417.7215	197
-727.639	25	4	419.8419	198
-731.314	31.25	5	421.9623	199
-734.989	50	8	424.0827	200
-738.663	75	12	426.2031	201
-742.338	100	16	428.3235	202
-746.013	125	20	430.4439	203
-749.688	137.5	22	432.5644	204
-753.363	143.75	23	434.6848	205
-757.038	156.25	25	436.8052	206
-760.713	175	28	438.9256	207
-764.388	212.5	34	441.046	208
-768.063	206.25	33	443.1664	209
-771.738	212.5	34	445.2868	210

-775.413	212.5	34	447.4073	211
-779.088	212.5	34	449.5277	212
-782.763	193.75	31	451.6481	213
-786.438	200	32	453.7685	214
-790.113	206.25	33	455.8889	215
-793.788	206.25	33	458.0093	216
-797.463	212.5	34	460.1297	217
-801.138	212.5	34	462.2502	218
-804.812	243.75	39	464.3706	219
-808.487	231.25	37	466.491	220
-812.162	218.75	35	468.6114	221
-815.837	193.75	31	470.7318	222
-819.512	150	24	472.8522	223
-823.187	137.5	22	474.9726	224
-826.862	106.25	17	477.093	225
-830.537	93.75	15	479.2135	226
-834.212	87.5	14	481.3339	227
-837.887	93.75	15	483.4543	228
-841.562	75	12	485.5747	229
-845.237	68.75	11	487.6951	230
-848.912	81.25	13	489.8155	231
-852.587	87.5	14	491.9359	232
-856.262	93.75	15	494.0564	233
-859.937	100	16	496.1768	234
-863.612	106.25	17	498.2972	235
-867.286	118.75	19	500.4176	236
-870.961	112.5	18	502.538	237
-874.636	106.25	17	504.6584	238
-878.311	112.5	18	506.7788	239
-	118.75	19	508.8993	240

881.986				
-885.661	112.5	18	511.0197	241
-889.336	118.75	19	513.1401	242
-893.011	106.25	17	515.2605	243
-896.686	112.5	18	517.3809	244
-900.361	106.25	17	519.5013	245
-904.036	100	16	521.6217	246
-907.711	106.25	17	523.7421	247
-911.386	93.75	15	525.8626	248
-915.061	100	16	527.983	249
-918.736	106.25	17	530.1034	250
-922.411	100	16	532.2238	251
-926.086	100	16	534.3442	252
-929.761	81.25	13	536.4646	253
-933.435	62.5	10	538.585	254
-937.11	43.75	7	540.7055	255

Tables show the actual and reference Evapotranspirations in Almujilees Area

		refernce et		actual et			
Area Hectar	histogram	rferencel ET valu	No. pixel	Area Hectar	histogram	actual ET valu	No. pixel
325	52	0		325	52	0	
0	0	8.310074806	1	0	0	9.001037598	1
0	0	16.62014961	2	0	0	18.0020752	2
0	0	24.93022442	3	0	0	27.00311279	3
0	0	33.24029922	4	0	0	36.00415039	4
0	0	41.55037403	5	0	0	45.00518799	5
0	0	49.86044884	6	0	0	54.00622559	6
0	0	58.17052364	7	0	0	63.00726318	7
0	0	66.48059845	8	6.25	1	72.00830078	8
0	0	74.79067326	9	0	0	81.00933838	9
0	0	83.10074806	10	0	0	90.01037598	10
0	0	91.41082287	11	0	0	99.01141357	11
0	0	99.72089767	12	0	0	108.0124512	12
0	0	108.0309725	13	0	0	117.0134888	13
0	0	116.3410473	14	0	0	126.0145264	14
0	0	124.6511221	15	0	0	135.015564	15
0	0	132.9611969	16	0	0	144.0166016	16
0	0	141.2712717	17	12.5	2	153.0176392	17
0	0	149.5813465	18	6.25	1	162.0186768	18
0	0	157.8914213	19	0	0	171.0197144	19
0	0	166.2014961	20	0	0	180.020752	20
0	0	174.5115709	21	0	0	189.0217896	21
0	0	182.8216457	22	0	0	198.0228271	22
0	0	191.1317205	23	25	4	207.0238647	23
0	0	199.4417953	24	0	0	216.0249023	24
0	0	207.7518702	25	0	0	225.0259399	25
0	0	216.061945	26	18.75	3	234.0269775	26
0	0	224.3720198	27	0	0	243.0280151	27
0	0	232.6820946	28	12.5	2	252.0290527	28
0	0	240.9921694	29	12.5	2	261.0300903	29
0	0	249.3022442	30	25	4	270.0311279	30
0	0	257.612319	31	6.25	1	279.0321655	31
0	0	265.9223938	32	6.25	1	288.0332031	32
0	0	274.2324686	33	12.5	2	297.0342407	33
0	0	282.5425434	34	0	0	306.0352783	34
0	0	290.8526182	35	12.5	2	315.0363159	35
0	0	299.162693	36	0	0	324.0373535	36
0	0	307.4727678	37	0	0	333.0383911	37
0	0	315.7828426	38	6.25	1	342.0394287	38
0	0	324.0929174	39	6.25	1	351.0404663	39
0	0	332.4029922	40	0	0	360.0415039	40
0	0	340.7130671	41	12.5	2	369.0425415	41
0	0	349.0231419	42	12.5	2	378.0435791	42
0	0	357.3332167	43	12.5	2	387.0446167	43
0	0	365.6432915	44	6.25	1	396.0456543	44
0	0	373.9533663	45	6.25	1	405.0466919	45
0	0	382.2634411	46	6.25	1	414.0477295	46
0	0	390.5735159	47	12.5	2	423.0487671	47

0	0	398.8835907	48	6.25	1	432.0498047	48
0	0	407.1936655	49	25	4	441.0508423	49
0	0	415.5037403	50	0	0	450.0518799	50
0	0	423.8138151	51	0	0	459.0529175	51
0	0	432.1238899	52	6.25	1	468.0539551	52
0	0	440.4339647	53	12.5	2	477.0549927	53
0	0	448.7440395	54	0	0	486.0560303	54
0	0	457.0541143	55	0	0	495.0570679	55
0	0	465.3641891	56	0	0	504.0581055	56
0	0	473.674264	57	6.25	1	513.0591431	57
0	0	481.9843388	58	6.25	1	522.0601807	58
0	0	490.2944136	59	6.25	1	531.0612183	59
0	0	498.6044884	60	12.5	2	540.0622559	60
0	0	506.9145632	61	6.25	1	549.0632935	61
0	0	515.224638	62	0	0	558.0643311	62
0	0	523.5347128	63	12.5	2	567.0653687	63
0	0	531.8447876	64	6.25	1	576.0664063	64
0	0	540.1548624	65	6.25	1	585.0674438	65
0	0	548.4649372	66	0	0	594.0684814	66
0	0	556.775012	67	6.25	1	603.069519	67
0	0	565.0850868	68	6.25	1	612.0705566	68
0	0	573.3951616	69	6.25	1	621.0715942	69
0	0	581.7052364	70	18.75	3	630.0726318	70
0	0	590.0153112	71	0	0	639.0736694	71
0	0	598.325386	72	25	4	648.074707	72
0	0	606.6354609	73	12.5	2	657.0757446	73
0	0	614.9455357	74	12.5	2	666.0767822	74
0	0	623.2556105	75	0	0	675.0778198	75
0	0	631.5656853	76	12.5	2	684.0788574	76
0	0	639.8757601	77	0	0	693.079895	77
0	0	648.1858349	78	0	0	702.0809326	78
0	0	656.4959097	79	0	0	711.0819702	79
0	0	664.8059845	80	6.25	1	720.0830078	80
0	0	673.1160593	81	0	0	729.0840454	81
0	0	681.4261341	82	6.25	1	738.085083	82
0	0	689.7362089	83	6.25	1	747.0861206	83
0	0	698.0462837	84	18.75	3	756.0871582	84
0	0	706.3563585	85	6.25	1	765.0881958	85
0	0	714.6664333	86	12.5	2	774.0892334	86
0	0	722.9765081	87	0	0	783.090271	87
0	0	731.2865829	88	0	0	792.0913086	88
0	0	739.5966578	89	6.25	1	801.0923462	89
0	0	747.9067326	90	6.25	1	810.0933838	90
0	0	756.2168074	91	12.5	2	819.0944214	91
0	0	764.5268822	92	0	0	828.095459	92
0	0	772.836957	93	0	0	837.0964966	93
0	0	781.1470318	94	12.5	2	846.0975342	94
0	0	789.4571066	95	12.5	2	855.0985718	95
0	0	797.7671814	96	6.25	1	864.0996094	96
0	0	806.0772562	97	12.5	2	873.100647	97
0	0	814.387331	98	12.5	2	882.1016846	98
0	0	822.6974058	99	0	0	891.1027222	99

0	0	831.0074806	100	12.5	2	900.1037598	100
0	0	839.3175554	101	0	0	909.1047974	101
0	0	847.6276302	102	0	0	918.105835	102
0	0	855.937705	103	0	0	927.1068726	103
0	0	864.2477798	104	0	0	936.1079102	104
0	0	872.5578547	105	0	0	945.1089478	105
0	0	880.8679295	106	0	0	954.1099854	106
0	0	889.1780043	107	0	0	963.1110229	107
0	0	897.4880791	108	0	0	972.1120605	108
0	0	905.7981539	109	0	0	981.1130981	109
0	0	914.1082287	110	6.25	1	990.1141357	110
0	0	922.4183035	111	6.25	1	999.1151733	111
0	0	930.7283783	112	0	0	1008.116211	112
0	0	939.0384531	113	0	0	1017.117249	113
0	0	947.3485279	114	6.25	1	1026.118286	114
0	0	955.6586027	115	6.25	1	1035.119324	115
0	0	963.9686775	116	0	0	1044.120361	116
0	0	972.2787523	117	0	0	1053.121399	117
0	0	980.5888271	118	0	0	1062.122437	118
0	0	988.8989019	119	6.25	1	1071.123474	119
0	0	997.2089767	120	0	0	1080.124512	120
0	0	1005.519052	121	0	0	1089.125549	121
0	0	1013.829126	122	0	0	1098.126587	122
0	0	1022.139201	123	0	0	1107.127625	123
0	0	1030.449276	124	6.25	1	1116.128662	124
0	0	1038.759351	125	0	0	1125.1297	125
0	0	1047.069426	126	0	0	1134.130737	126
0	0	1055.3795	127	6.25	1	1143.131775	127
0	0	1063.689575	128	0	0	1152.132813	128
0	0	1071.99965	129	0	0	1161.13385	129
0	0	1080.309725	130	0	0	1170.134888	130
0	0	1088.6198	131	6.25	1	1179.135925	131
0	0	1096.929874	132	0	0	1188.136963	132
0	0	1105.239949	133	0	0	1197.138	133
0	0	1113.550024	134	0	0	1206.139038	134
0	0	1121.860099	135	0	0	1215.140076	135
0	0	1130.170174	136	6.25	1	1224.141113	136
0	0	1138.480248	137	0	0	1233.142151	137
0	0	1146.790323	138	6.25	1	1242.143188	138
0	0	1155.100398	139	0	0	1251.144226	139
0	0	1163.410473	140	0	0	1260.145264	140
0	0	1171.720548	141	0	0	1269.146301	141
0	0	1180.030622	142	0	0	1278.147339	142
0	0	1188.340697	143	0	0	1287.148376	143
0	0	1196.650772	144	0	0	1296.149414	144
0	0	1204.960847	145	0	0	1305.150452	145
0	0	1213.270922	146	0	0	1314.151489	146
0	0	1221.580997	147	0	0	1323.152527	147
0	0	1229.891071	148	0	0	1332.153564	148
0	0	1238.201146	149	0	0	1341.154602	149
0	0	1246.511221	150	0	0	1350.15564	150
0	0	1254.821296	151	0	0	1359.156677	151

0	0	1263.131371	152	0	0	1368.157715	152
0	0	1271.441445	153	0	0	1377.158752	153
0	0	1279.75152	154	0	0	1386.15979	154
0	0	1288.061595	155	0	0	1395.160828	155
0	0	1296.37167	156	0	0	1404.161865	156
0	0	1304.681745	157	0	0	1413.162903	157
0	0	1312.991819	158	0	0	1422.16394	158
0	0	1321.301894	159	0	0	1431.164978	159
0	0	1329.611969	160	0	0	1440.166016	160
0	0	1337.922044	161	0	0	1449.167053	161
0	0	1346.232119	162	0	0	1458.168091	162
0	0	1354.542193	163	0	0	1467.169128	163
0	0	1362.852268	164	0	0	1476.170166	164
0	0	1371.162343	165	0	0	1485.171204	165
0	0	1379.472418	166	0	0	1494.172241	166
0	0	1387.782493	167	0	0	1503.173279	167
0	0	1396.092567	168	0	0	1512.174316	168
0	0	1404.402642	169	0	0	1521.175354	169
0	0	1412.712717	170	0	0	1530.176392	170
0	0	1421.022792	171	0	0	1539.177429	171
0	0	1429.332867	172	0	0	1548.178467	172
0	0	1437.642941	173	0	0	1557.179504	173
0	0	1445.953016	174	0	0	1566.180542	174
0	0	1454.263091	175	0	0	1575.18158	175
0	0	1462.573166	176	0	0	1584.182617	176
0	0	1470.883241	177	0	0	1593.183655	177
0	0	1479.193316	178	0	0	1602.184692	178
0	0	1487.50339	179	0	0	1611.18573	179
0	0	1495.813465	180	0	0	1620.186768	180
0	0	1504.12354	181	0	0	1629.187805	181
0	0	1512.433615	182	0	0	1638.188843	182
0	0	1520.74369	183	0	0	1647.18988	183
0	0	1529.053764	184	0	0	1656.190918	184
0	0	1537.363839	185	0	0	1665.191956	185
0	0	1545.673914	186	0	0	1674.192993	186
0	0	1553.983989	187	0	0	1683.194031	187
0	0	1562.294064	188	0	0	1692.195068	188
0	0	1570.604138	189	0	0	1701.196106	189
0	0	1578.914213	190	0	0	1710.197144	190
0	0	1587.224288	191	0	0	1719.198181	191
0	0	1595.534363	192	0	0	1728.199219	192
0	0	1603.844438	193	0	0	1737.200256	193
0	0	1612.154512	194	0	0	1746.201294	194
0	0	1620.464587	195	0	0	1755.202332	195
0	0	1628.774662	196	0	0	1764.203369	196
0	0	1637.084737	197	0	0	1773.204407	197
0	0	1645.394812	198	6.25	1	1782.205444	198
0	0	1653.704886	199	6.25	1	1791.206482	199
0	0	1662.014961	200	0	0	1800.20752	200
0	0	1670.325036	201	0	0	1809.208557	201
0	0	1678.635111	202	0	0	1818.209595	202
0	0	1686.945186	203	0	0	1827.210632	203

0	0	1695.25526	204	0	0	1836.21167	204
0	0	1703.565335	205	0	0	1845.212708	205
0	0	1711.87541	206	0	0	1854.213745	206
0	0	1720.185485	207	0	0	1863.214783	207
0	0	1728.49556	208	0	0	1872.21582	208
0	0	1736.805634	209	0	0	1881.216858	209
0	0	1745.115709	210	0	0	1890.217896	210
0	0	1753.425784	211	0	0	1899.218933	211
0	0	1761.735859	212	0	0	1908.219971	212
0	0	1770.045934	213	0	0	1917.221008	213
0	0	1778.356009	214	0	0	1926.222046	214
0	0	1786.666083	215	0	0	1935.223083	215
0	0	1794.976158	216	0	0	1944.224121	216
0	0	1803.286233	217	0	0	1953.225159	217
0	0	1811.596308	218	6.25	1	1962.226196	218
0	0	1819.906383	219	18.75	3	1971.227234	219
0	0	1828.216457	220	6.25	1	1980.228271	220
0	0	1836.526532	221	0	0	1989.229309	221
0	0	1844.836607	222	0	0	1998.230347	222
0	0	1853.146682	223	0	0	2007.231384	223
0	0	1861.456757	224	0	0	2016.232422	224
0	0	1869.766831	225	0	0	2025.233459	225
0	0	1878.076906	226	0	0	2034.234497	226
0	0	1886.386981	227	0	0	2043.235535	227
0	0	1894.697056	228	0	0	2052.236572	228
0	0	1903.007131	229	0	0	2061.23761	229
0	0	1911.317205	230	0	0	2070.238647	230
0	0	1919.62728	231	0	0	2079.239685	231
0	0	1927.937355	232	0	0	2088.240723	232
0	0	1936.24743	233	0	0	2097.24176	233
0	0	1944.557505	234	0	0	2106.242798	234
0	0	1952.867579	235	6.25	1	2115.243835	235
0	0	1961.177654	236	0	0	2124.244873	236
0	0	1969.487729	237	0	0	2133.245911	237
0	0	1977.797804	238	0	0	2142.246948	238
0	0	1986.107879	239	6.25	1	2151.247986	239
6.25	1	1994.417953	240	0	0	2160.249023	240
25	4	2002.728028	241	0	0	2169.250061	241
6.25	1	2011.038103	242	0	0	2178.251099	242
31.25	5	2019.348178	243	0	0	2187.252136	243
31.25	5	2027.658253	244	0	0	2196.253174	244
12.5	2	2035.968328	245	0	0	2205.254211	245
18.75	3	2044.278402	246	0	0	2214.255249	246
25	4	2052.588477	247	0	0	2223.256287	247
31.25	5	2060.898552	248	0	0	2232.257324	248
62.5	10	2069.208627	249	0	0	2241.258362	249
62.5	10	2077.518702	250	0	0	2250.259399	250
125	20	2085.828776	251	0	0	2259.260437	251
112.5	18	2094.138851	252	0	0	2268.261475	252
93.75	15	2102.448926	253	0	0	2277.262512	253
56.25	9	2110.759001	254	6.25	1	2286.26355	254
31.25	5	2119.069076	255	6.25	1	2295.264587	255

Table showing the precipitations and the surface water balance in Almujilees Area

surface water balance (SWB) almujilees presepitation

P - ETa	Area Hectar	histogram	rainfall p valu	No. pixel
	325	52	0	
-7.94389	0	0	1.057151	1
-15.8878	0	0	2.114301	2
-23.8317	0	0	3.171452	3
-31.7755	0	0	4.228602	4
-39.7194	0	0	5.285753	5
-47.6633	0	0	6.342904	6
-55.6072	0	0	7.400054	7
-63.5511	0	0	8.457205	8
-71.495	0	0	9.514355	9
-79.4389	0	0	10.57151	10
-87.3828	0	0	11.62866	11
-95.3266	0	0	12.68581	12
-103.271	0	0	13.74296	13
-111.214	0	0	14.80011	14
-119.158	0	0	15.85726	15
-127.102	0	0	16.91441	16
-135.046	0	0	17.97156	17
-142.99	0	0	19.02871	18
-150.934	0	0	20.08586	19
-158.878	0	0	21.14301	20
-166.822	0	0	22.20016	21
-174.766	0	0	23.25731	22
-182.709	0	0	24.31446	23
-190.653	0	0	25.37161	24
-198.597	0	0	26.42877	25
-206.541	0	0	27.48592	26
-214.485	0	0	28.54307	27
-222.429	0	0	29.60022	28
-230.373	0	0	30.65737	29
-238.317	0	0	31.71452	30
-246.26	0	0	32.77167	31
-254.204	0	0	33.82882	32
-262.148	0	0	34.88597	33
-270.092	0	0	35.94312	34
-278.036	0	0	37.00027	35
-285.98	0	0	38.05742	36
-293.924	0	0	39.11457	37
-301.868	0	0	40.17172	38
-309.812	0	0	41.22887	39
-317.755	0	0	42.28602	40
-325.699	0	0	43.34317	41
-333.643	0	0	44.40033	42
-341.587	0	0	45.45748	43
-349.531	0	0	46.51463	44
-357.475	0	0	47.57178	45
-365.419	0	0	48.62893	46
-373.363	0	0	49.68608	47

-381.307	0	0	50.74323	48
-389.25	0	0	51.80038	49
-397.194	0	0	52.85753	50
-405.138	0	0	53.91468	51
-413.082	0	0	54.97183	52
-421.026	0	0	56.02898	53
-428.97	0	0	57.08613	54
-436.914	0	0	58.14328	55
-444.858	0	0	59.20043	56
-452.802	0	0	60.25758	57
-460.745	0	0	61.31473	58
-468.689	0	0	62.37189	59
-476.633	0	0	63.42904	60
-484.577	0	0	64.48619	61
-492.521	0	0	65.54334	62
-500.465	0	0	66.60049	63
-508.409	0	0	67.65764	64
-516.353	0	0	68.71479	65
-524.297	0	0	69.77194	66
-532.24	0	0	70.82909	67
-540.184	0	0	71.88624	68
-548.128	0	0	72.94339	69
-556.072	0	0	74.00054	70
-564.016	0	0	75.05769	71
-571.96	0	0	76.11484	72
-579.904	0	0	77.17199	73
-587.848	0	0	78.22914	74
-595.792	0	0	79.2863	75
-603.735	0	0	80.34345	76
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-619.623	0	0	82.45775	78
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-635.511	0	0	84.57205	80
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-659.343	0	0	87.7435	83
-667.287	0	0	88.80065	84
-675.23	0	0	89.8578	85
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-699.062	0	0	93.02925	88
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-714.95	0	0	95.14355	90
-722.894	0	0	96.2007	91
-730.838	0	0	97.25786	92
-738.781	0	0	98.31501	93
-746.725	0	0	99.37216	94
-754.669	0	0	100.4293	95
-762.613	0	0	101.4865	96
-770.557	0	0	102.5436	97
-778.501	0	0	103.6008	98
-786.445	0	0	104.6579	99
-794.389	0	0	105.7151	100

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-818.22	0	0	108.8865	103
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-834.108	0	0	111.0008	105
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-849.996	0	0	113.1151	107
-857.94	0	0	114.1723	108
-865.884	0	0	115.2294	109
-873.828	0	0	116.2866	110
-881.771	0	0	117.3437	111
-889.715	0	0	118.4009	112
-897.659	0	0	119.458	113
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-913.547	0	0	121.5723	115
-921.491	0	0	122.6295	116
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-945.323	0	0	125.8009	119
-953.266	0	0	126.8581	120
-961.21	0	0	127.9152	121
-969.154	0	0	128.9724	122
-977.098	0	0	130.0295	123
-985.042	0	0	131.0867	124
-992.986	0	0	132.1438	125
-1000.93	0	0	133.201	126
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-1016.82	0	0	135.3153	128
-1024.76	0	0	136.3724	129
-1032.71	0	0	137.4296	130
-1040.65	0	0	138.4867	131
-1048.59	0	0	139.5439	132
-1056.54	0	0	140.601	133
-1064.48	0	0	141.6582	134
-1072.42	0	0	142.7153	135
-1080.37	0	0	143.7725	136
-1088.31	0	0	144.8296	137
-1096.26	0	0	145.8868	138
-1104.2	0	0	146.9439	139
-1112.14	0	0	148.0011	140
-1120.09	0	0	149.0582	141
-1128.03	0	0	150.1154	142
-1135.98	0	0	151.1725	143
-1143.92	0	0	152.2297	144
-1151.86	0	0	153.2868	145
-1159.81	0	0	154.344	146
-1167.75	0	0	155.4011	147
-1175.7	0	0	156.4583	148
-1183.64	0	0	157.5154	149
-1191.58	0	0	158.5726	150
-1199.53	0	0	159.6297	151
-1207.47	0	0	160.6869	152
-1215.41	0	0	161.744	153

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-1239.25	0	0	164.9155	156
-1247.19	0	0	165.9726	157
-1255.13	0	0	167.0298	158
-1263.08	0	0	168.0869	159
-1271.02	0	0	169.1441	160
-1278.97	0	0	170.2012	161
-1286.91	0	0	171.2584	162
-1294.85	0	0	172.3155	163
-1302.8	0	0	173.3727	164
-1310.74	0	0	174.4298	165
-1318.69	0	0	175.487	166
-1326.63	0	0	176.5442	167
-1334.57	0	0	177.6013	168
-1342.52	0	0	178.6585	169
-1350.46	0	0	179.7156	170
-1358.4	0	0	180.7728	171
-1366.35	0	0	181.8299	172
-1374.29	0	0	182.8871	173
-1382.24	0	0	183.9442	174
-1390.18	0	0	185.0014	175
-1398.12	0	0	186.0585	176
-1406.07	0	0	187.1157	177
-1414.01	0	0	188.1728	178
-1421.96	0	0	189.23	179
-1429.9	0	0	190.2871	180
-1437.84	0	0	191.3443	181
-1445.79	0	0	192.4014	182
-1453.73	0	0	193.4586	183
-1461.68	0	0	194.5157	184
-1469.62	0	0	195.5729	185
-1477.56	0	0	196.63	186
-1485.51	0	0	197.6872	187
-1493.45	0	0	198.7443	188
-1501.39	0	0	199.8015	189
-1509.34	0	0	200.8586	190
-1517.28	0	0	201.9158	191
-1525.23	0	0	202.9729	192
-1533.17	0	0	204.0301	193
-1541.11	0	0	205.0872	194
-1549.06	0	0	206.1444	195
-1557	0	0	207.2015	196
-1564.95	0	0	208.2587	197
-1572.89	0	0	209.3158	198
-1580.83	0	0	210.373	199
-1588.78	0	0	211.4301	200
-1596.72	0	0	212.4873	201
-1604.67	0	0	213.5444	202
-1612.61	0	0	214.6016	203
-1620.55	0	0	215.6587	204
-1628.5	0	0	216.7159	205
-1636.44	0	0	217.773	206

-1644.38	0	0	218.8302	207
-1652.33	0	0	219.8873	208
-1660.27	0	0	220.9445	209
-1668.22	0	0	222.0016	210
-1676.16	0	0	223.0588	211
-1684.1	0	0	224.1159	212
-1692.05	0	0	225.1731	213
-1699.99	0	0	226.2302	214
-1707.94	0	0	227.2874	215
-1715.88	0	0	228.3445	216
-1723.82	0	0	229.4017	217
-1731.77	0	0	230.4588	218
-1739.71	0	0	231.516	219
-1747.66	0	0	232.5731	220
-1755.6	0	0	233.6303	221
-1763.54	0	0	234.6874	222
-1771.49	0	0	235.7446	223
-1779.43	0	0	236.8017	224
-1787.37	0	0	237.8589	225
-1795.32	0	0	238.916	226
-1803.26	0	0	239.9732	227
-1811.21	0	0	241.0303	228
-1819.15	0	0	242.0875	229
-1827.09	0	0	243.1446	230
-1835.04	0	0	244.2018	231
-1842.98	0	0	245.2589	232
-1850.93	0	0	246.3161	233
-1858.87	0	0	247.3732	234
-1866.81	0	0	248.4304	235
-1874.76	0	0	249.4875	236
-1882.7	0	0	250.5447	237
-1890.65	0	0	251.6018	238
-1898.59	0	0	252.659	239
-1906.53	0	0	253.7161	240
-1914.48	0	0	254.7733	241
-1922.42	25	4	255.8304	242
-1930.36	37.5	6	256.8876	243
-1938.31	56.25	9	257.9447	244
-1946.25	56.25	9	259.0019	245
-1954.2	62.5	10	260.059	246
-1962.14	87.5	14	261.1162	247
-1970.08	62.5	10	262.1733	248
-1978.03	75	12	263.2305	249
-1985.97	68.75	11	264.2877	250
-1993.92	62.5	10	265.3448	251
-2001.86	43.75	7	266.402	252
-2009.8	37.5	6	267.4591	253
-2017.75	31.25	5	268.5163	254
-2025.69	25	4	269.5734	255

Tables show the actual and reference Evapotranspirations in Wadi Rimaa Area

		WadiRimaa refernce et		WadiRimaa actual et			
Area Hectar	histogram	rferencel ET valu	No. pixel	Area Hectar	histogram	actual ET valu	No. pixel
13725	2196	0		13725	2196	0	
0	0	8.200598717	1	0	0	4.861699	1
0	0	16.40119743	2	0	0	9.723397	2
0	0	24.60179615	3	0	0	14.5851	3
0	0	32.80239487	4	0	0	19.44679	4
0	0	41.00299358	5	0	0	24.30849	5
0	0	49.2035923	6	0	0	29.17019	6
0	0	57.40419102	7	0	0	34.03189	7
0	0	65.60478973	8	0	0	38.89359	8
0	0	73.80538845	9	0	0	43.75529	9
0	0	82.00598717	10	0	0	48.61699	10
0	0	90.20658588	11	0	0	53.47868	11
0	0	98.4071846	12	0	0	58.34038	12
0	0	106.6077833	13	0	0	63.20208	13
0	0	114.808382	14	0	0	68.06378	14
0	0	123.0089808	15	0	0	72.92548	15
0	0	131.2095795	16	0	0	77.78718	16
0	0	139.4101782	17	0	0	82.64888	17
0	0	147.6107769	18	0	0	87.51058	18
0	0	155.8113756	19	0	0	92.37227	19
0	0	164.0119743	20	0	0	97.23397	20
0	0	172.2125731	21	0	0	102.0957	21
0	0	180.4131718	22	0	0	106.9574	22
0	0	188.6137705	23	0	0	111.8191	23
0	0	196.8143692	24	0	0	116.6808	24
0	0	205.0149679	25	0	0	121.5425	25
0	0	213.2155666	26	0	0	126.4042	26
0	0	221.4161654	27	0	0	131.2659	27
0	0	229.6167641	28	0	0	136.1276	28
0	0	237.8173628	29	0	0	140.9893	29
0	0	246.0179615	30	0	0	145.851	30
0	0	254.2185602	31	0	0	150.7127	31
0	0	262.4191589	32	0	0	155.5744	32
0	0	270.6197577	33	0	0	160.4361	33
0	0	278.8203564	34	0	0	165.2978	34
0	0	287.0209551	35	0	0	170.1595	35
0	0	295.2215538	36	0	0	175.0212	36
0	0	303.4221525	37	0	0	179.8828	37
0	0	311.6227512	38	0	0	184.7445	38
0	0	319.82335	39	0	0	189.6062	39
0	0	328.0239487	40	0	0	194.4679	40
0	0	336.2245474	41	0	0	199.3296	41
0	0	344.4251461	42	0	0	204.1913	42
0	0	352.6257448	43	0	0	209.053	43
0	0	360.8263435	44	0	0	213.9147	44
0	0	369.0269423	45	0	0	218.7764	45
0	0	377.227541	46	0	0	223.6381	46
0	0	385.4281397	47	0	0	228.4998	47

0	0	393.6287384	48	0	0	233.3615	48
0	0	401.8293371	49	0	0	238.2232	49
0	0	410.0299358	50	0	0	243.0849	50
0	0	418.2305346	51	0	0	247.9466	51
0	0	426.4311333	52	0	0	252.8083	52
0	0	434.631732	53	0	0	257.67	53
0	0	442.8323307	54	0	0	262.5317	54
0	0	451.0329294	55	0	0	267.3934	55
0	0	459.2335281	56	18.75	3	272.2551	56
0	0	467.4341269	57	0	0	277.1168	57
0	0	475.6347256	58	0	0	281.9785	58
0	0	483.8353243	59	0	0	286.8402	59
0	0	492.035923	60	0	0	291.7019	60
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0	0	508.4371204	62	0	0	301.4253	62
0	0	516.6377192	63	0	0	306.287	63
0	0	524.8383179	64	12.5	2	311.1487	64
0	0	533.0389166	65	6.25	1	316.0104	65
0	0	541.2395153	66	0	0	320.8721	66
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0	0	557.6407127	68	6.25	1	330.5955	68
0	0	565.8413115	69	0	0	335.4572	69
0	0	574.0419102	70	0	0	340.3189	70
0	0	582.2425089	71	6.25	1	345.1806	71
0	0	590.4431076	72	12.5	2	350.0423	72
0	0	598.6437063	73	6.25	1	354.904	73
0	0	606.844305	74	0	0	359.7657	74
0	0	615.0449038	75	12.5	2	364.6274	75
0	0	623.2455025	76	12.5	2	369.4891	76
0	0	631.4461012	77	0	0	374.3508	77
0	0	639.6466999	78	12.5	2	379.2125	78
0	0	647.8472986	79	6.25	1	384.0742	79
0	0	656.0478973	80	0	0	388.9359	80
0	0	664.2484961	81	12.5	2	393.7976	81
0	0	672.4490948	82	12.5	2	398.6593	82
0	0	680.6496935	83	0	0	403.521	83
0	0	688.8502922	84	6.25	1	408.3827	84
0	0	697.0508909	85	12.5	2	413.2444	85
0	0	705.2514896	86	18.75	3	418.1061	86
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0	0	721.6526871	88	25	4	427.8295	88
0	0	729.8532858	89	6.25	1	432.6912	89
0	0	738.0538845	90	12.5	2	437.5529	90
0	0	746.2544832	91	18.75	3	442.4146	91
0	0	754.4550819	92	6.25	1	447.2763	92
0	0	762.6556807	93	18.75	3	452.138	93
0	0	770.8562794	94	37.5	6	456.9997	94
0	0	779.0568781	95	12.5	2	461.8614	95
0	0	787.2574768	96	12.5	2	466.7231	96
0	0	795.4580755	97	12.5	2	471.5848	97
0	0	803.6586742	98	12.5	2	476.4465	98
0	0	811.859273	99	18.75	3	481.3082	99

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0	0	844.6616678	103	6.25	1	500.755	103
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0	0	877.4640627	107	12.5	2	520.2018	107
0	0	885.6646614	108	31.25	5	525.0635	108
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0	0	934.8682537	114	6.25	1	554.2336	114
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0	0	975.8712473	119	37.5	6	578.5421	119
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0	0	1016.874241	124	31.25	5	602.8506	124
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0	0	1057.877234	129	31.25	5	627.1591	129
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0	0	1074.278432	131	6.25	1	636.8825	131
0	0	1082.479031	132	62.5	10	641.7442	132
0	0	1090.679629	133	18.75	3	646.6059	133
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0	0	1107.080827	135	31.25	5	656.3293	135
0	0	1115.281425	136	31.25	5	661.191	136
0	0	1123.482024	137	56.25	9	666.0527	137
0	0	1131.682623	138	37.5	6	670.9144	138
0	0	1139.883222	139	62.5	10	675.7761	139
0	0	1148.08382	140	37.5	6	680.6378	140
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0	0	1164.485018	142	50	8	690.3612	142
0	0	1172.685616	143	43.75	7	695.2229	143
0	0	1180.886215	144	56.25	9	700.0846	144
0	0	1189.086814	145	50	8	704.9463	145
0	0	1197.287413	146	43.75	7	709.808	146
0	0	1205.488011	147	25	4	714.6697	147
0	0	1213.68861	148	43.75	7	719.5314	148
0	0	1221.889209	149	37.5	6	724.3931	149
0	0	1230.089808	150	12.5	2	729.2548	150
0	0	1238.290406	151	50	8	734.1165	151

0	0	1246.491005	152	31.25	5	738.9782	152
0	0	1254.691604	153	75	12	743.8399	153
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0	0	1271.092801	155	37.5	6	753.5633	155
0	0	1279.2934	156	75	12	758.425	156
0	0	1287.493999	157	50	8	763.2867	157
0	0	1295.694597	158	50	8	768.1484	158
0	0	1303.895196	159	56.25	9	773.0101	159
0	0	1312.095795	160	62.5	10	777.8718	160
0	0	1320.296393	161	56.25	9	782.7335	161
0	0	1328.496992	162	81.25	13	787.5952	162
0	0	1336.697591	163	50	8	792.4569	163
0	0	1344.89819	164	56.25	9	797.3186	164
0	0	1353.098788	165	25	4	802.1803	165
0	0	1361.299387	166	62.5	10	807.042	166
0	0	1369.499986	167	75	12	811.9037	167
0	0	1377.700584	168	81.25	13	816.7654	168
0	0	1385.901183	169	62.5	10	821.6271	169
0	0	1394.101782	170	50	8	826.4888	170
0	0	1402.302381	171	87.5	14	831.3505	171
0	0	1410.502979	172	25	4	836.2122	172
0	0	1418.703578	173	50	8	841.0739	173
0	0	1426.904177	174	31.25	5	845.9356	174
0	0	1435.104775	175	81.25	13	850.7973	175
0	0	1443.305374	176	43.75	7	855.659	176
0	0	1451.505973	177	50	8	860.5207	177
0	0	1459.706572	178	81.25	13	865.3824	178
0	0	1467.90717	179	31.25	5	870.2441	179
0	0	1476.107769	180	50	8	875.1058	180
0	0	1484.308368	181	68.75	11	879.9675	181
0	0	1492.508966	182	100	16	884.8292	182
0	0	1500.709565	183	68.75	11	889.6908	183
0	0	1508.910164	184	43.75	7	894.5525	184
0	0	1517.110763	185	43.75	7	899.4142	185
0	0	1525.311361	186	62.5	10	904.2759	186
0	0	1533.51196	187	50	8	909.1376	187
0	0	1541.712559	188	62.5	10	913.9993	188
0	0	1549.913157	189	56.25	9	918.861	189
0	0	1558.113756	190	43.75	7	923.7227	190
0	0	1566.314355	191	18.75	3	928.5844	191
0	0	1574.514954	192	50	8	933.4461	192
0	0	1582.715552	193	18.75	3	938.3078	193
0	0	1590.916151	194	43.75	7	943.1695	194
0	0	1599.11675	195	43.75	7	948.0312	195
0	0	1607.317348	196	31.25	5	952.8929	196
0	0	1615.517947	197	43.75	7	957.7546	197
0	0	1623.718546	198	43.75	7	962.6163	198
0	0	1631.919145	199	25	4	967.478	199
0	0	1640.119743	200	43.75	7	972.3397	200
0	0	1648.320342	201	12.5	2	977.2014	201
0	0	1656.520941	202	12.5	2	982.0631	202
0	0	1664.721539	203	0	0	986.9248	203

0	0	1672.922138	204	12.5	2	991.7865	204
0	0	1681.122737	205	6.25	1	996.6482	205
0	0	1689.323336	206	12.5	2	1001.51	206
0	0	1697.523934	207	37.5	6	1006.372	207
0	0	1705.724533	208	6.25	1	1011.233	208
0	0	1713.925132	209	6.25	1	1016.095	209
0	0	1722.125731	210	18.75	3	1020.957	210
0	0	1730.326329	211	12.5	2	1025.818	211
0	0	1738.526928	212	0	0	1030.68	212
0	0	1746.727527	213	6.25	1	1035.542	213
0	0	1754.928125	214	6.25	1	1040.404	214
0	0	1763.128724	215	12.5	2	1045.265	215
0	0	1771.329323	216	0	0	1050.127	216
0	0	1779.529922	217	0	0	1054.989	217
0	0	1787.73052	218	12.5	2	1059.85	218
0	0	1795.931119	219	12.5	2	1064.712	219
0	0	1804.131718	220	6.25	1	1069.574	220
0	0	1812.332316	221	0	0	1074.435	221
0	0	1820.532915	222	6.25	1	1079.297	222
0	0	1828.733514	223	18.75	3	1084.159	223
0	0	1836.934113	224	18.75	3	1089.02	224
0	0	1845.134711	225	6.25	1	1093.882	225
0	0	1853.33531	226	12.5	2	1098.744	226
0	0	1861.535909	227	0	0	1103.606	227
0	0	1869.736507	228	18.75	3	1108.467	228
0	0	1877.937106	229	6.25	1	1113.329	229
0	0	1886.137705	230	6.25	1	1118.191	230
0	0	1894.338304	231	6.25	1	1123.052	231
0	0	1902.538902	232	0	0	1127.914	232
0	0	1910.739501	233	0	0	1132.776	233
0	0	1918.9401	234	6.25	1	1137.637	234
0	0	1927.140698	235	12.5	2	1142.499	235
0	0	1935.341297	236	0	0	1147.361	236
0	0	1943.541896	237	0	0	1152.223	237
0	0	1951.742495	238	0	0	1157.084	238
0	0	1959.943093	239	6.25	1	1161.946	239
6.25	1	1968.143692	240	0	0	1166.808	240
87.5	14	1976.344291	241	0	0	1171.669	241
131.25	21	1984.544889	242	6.25	1	1176.531	242
156.25	25	1992.745488	243	0	0	1181.393	243
187.5	30	2000.946087	244	12.5	2	1186.254	244
231.25	37	2009.146686	245	6.25	1	1191.116	245
325	52	2017.347284	246	0	0	1195.978	246
450	72	2025.547883	247	0	0	1200.84	247
450	72	2033.748482	248	0	0	1205.701	248
856.25	137	2041.94908	249	0	0	1210.563	249
812.5	130	2050.149679	250	0	0	1215.425	250
750	120	2058.350278	251	6.25	1	1220.286	251
412.5	66	2066.550877	252	0	0	1225.148	252
106.25	17	2074.751475	253	0	0	1230.01	253
56.25	9	2082.952074	254	6.25	1	1234.871	254
18.75	3	2091.152673	255	12.5	2	1239.733	255

Table showing the precipitations and the surface water balance in Wadi Rimaa Area

				WadiRimaa presepitation	
P - ETa		Area Hectar	histogram	rainfall p valu	No. pixel
		13725	2196	0	
-2.84179		0	0	2.019911766	1
-5.68357		0	0	4.039823532	2
-8.52536		0	0	6.059735298	3
-11.3671		0	0	8.079647064	4
-14.2089		0	0	10.09955883	5
-17.0507		0	0	12.1194706	6
-19.8925		0	0	14.13938236	7
-22.7343		0	0	16.15929413	8
-25.5761		0	0	18.17920589	9
-28.4179		0	0	20.19911766	10
-31.2597		0	0	22.21902943	11
-34.1014		0	0	24.23894119	12
-36.9432		0	0	26.25885296	13
-39.785		0	0	28.27876472	14
-42.6268		0	0	30.29867649	15
-45.4686		0	0	32.31858826	16
-48.3104		0	0	34.33850002	17
-51.1522		0	0	36.35841179	18
-53.994		0	0	38.37832355	19
-56.8357		0	0	40.39823532	20
-59.6775		0	0	42.41814709	21
-62.5193		0	0	44.43805885	22
-65.3611		0	0	46.45797062	23
-68.2029		0	0	48.47788239	24
-71.0447		0	0	50.49779415	25
-73.8865		0	0	52.51770592	26

-76.7282		0	0	54.53761768	27
-79.57		0	0	56.55752945	28
-82.4118		0	0	58.57744122	29
-85.2536		0	0	60.59735298	30
-88.0954		0	0	62.61726475	31
-90.9372		0	0	64.63717651	32
-93.779		0	0	66.65708828	33
-96.6208		0	0	68.67700005	34
-99.4625		0	0	70.69691181	35
-102.304		0	0	72.71682358	36
-105.146		0	0	74.73673534	37
-107.988		0	0	76.75664711	38
-110.83		0	0	78.77655888	39
-113.671		0	0	80.79647064	40
-116.513		0	0	82.81638241	41
-119.355		0	0	84.83629417	42
-122.197		0	0	86.85620594	43
-125.039		0	0	88.87611771	44
-127.88		0	0	90.89602947	45
-130.722		0	0	92.91594124	46
-133.564		0	0	94.935853	47
-136.406		0	0	96.95576477	48
-139.248		0	0	98.97567654	49
-142.089		0	0	100.9955883	50
-144.931		0	0	103.0155001	51
-147.773		0	0	105.0354118	52
-150.615		0	0	107.0553236	53
-153.456		0	0	109.0752354	54
-156.298		0	0	111.0951471	55
-159.14		0	0	113.1150589	56
-161.982		0	0	115.1349707	57
-		0	0	117.1548824	58

164.824					
-167.665		0	0	119.1747942	59
-170.507		0	0	121.194706	60
-173.349		0	0	123.2146177	61
-176.191		0	0	125.2345295	62
-179.033		0	0	127.2544413	63
-181.874		0	0	129.274353	64
-184.716		0	0	131.2942648	65
-187.558		0	0	133.3141766	66
-190.4		0	0	135.3340883	67
-193.242		0	0	137.3540001	68
-196.083		0	0	139.3739119	69
-198.925		0	0	141.3938236	70
-201.767		0	0	143.4137354	71
-204.609		0	0	145.4336472	72
-207.45		0	0	147.4535589	73
-210.292		0	0	149.4734707	74
-213.134		0	0	151.4933825	75
-215.976		0	0	153.5132942	76
-218.818		0	0	155.533206	77
-221.659		0	0	157.5531178	78
-224.501		0	0	159.5730295	79
-227.343		0	0	161.5929413	80
-230.185		0	0	163.6128531	81
-233.027		0	0	165.6327648	82
-235.868		0	0	167.6526766	83
-238.71		0	0	169.6725883	84
-241.552		0	0	171.6925001	85
-244.394		0	0	173.7124119	86
-247.235		0	0	175.7323236	87
-250.077		0	0	177.7522354	88

-252.919		0	0	179.7721472	89
-255.761		0	0	181.7920589	90
-258.603		0	0	183.8119707	91
-261.444		0	0	185.8318825	92
-264.286		0	0	187.8517942	93
-267.128		0	0	189.871706	94
-269.97		0	0	191.8916178	95
-272.812		0	0	193.9115295	96
-275.653		0	0	195.9314413	97
-278.495		0	0	197.9513531	98
-281.337		0	0	199.9712648	99
-284.179		0	0	201.9911766	100
-287.02		0	0	204.0110884	101
-289.862		0	0	206.0310001	102
-292.704		0	0	208.0509119	103
-295.546		0	0	210.0708237	104
-298.388		0	0	212.0907354	105
-301.229		0	0	214.1106472	106
-304.071		0	0	216.130559	107
-306.913		0	0	218.1504707	108
-309.755		0	0	220.1703825	109
-312.597		0	0	222.1902943	110
-315.438		0	0	224.210206	111
-318.28		0	0	226.2301178	112
-321.122		0	0	228.2500296	113
-323.964		0	0	230.2699413	114
-326.805		0	0	232.2898531	115
-329.647		0	0	234.3097649	116
-332.489		0	0	236.3296766	117
-335.331		0	0	238.3495884	118
-338.173		0	0	240.3695002	119

-341.014		0	0	242.3894119	120
-343.856		0	0	244.4093237	121
-346.698		0	0	246.4292355	122
-349.54		0	0	248.4491472	123
-352.382		0	0	250.469059	124
-355.223		0	0	252.4889708	125
-358.065		0	0	254.5088825	126
-360.907		0	0	256.5287943	127
-363.749		0	0	258.5487061	128
-366.591		0	0	260.5686178	129
-369.432		0	0	262.5885296	130
-372.274		0	0	264.6084414	131
-375.116		0	0	266.6283531	132
-377.958		0	0	268.6482649	133
-380.799		0	0	270.6681767	134
-383.641		0	0	272.6880884	135
-386.483		0	0	274.7080002	136
-389.325		0	0	276.7279119	137
-392.167		0	0	278.7478237	138
-395.008		0	0	280.7677355	139
-397.85		0	0	282.7876472	140
-400.692		0	0	284.807559	141
-403.534		0	0	286.8274708	142
-406.376		0	0	288.8473825	143
-409.217		0	0	290.8672943	144
-412.059		0	0	292.8872061	145
-414.901		0	0	294.9071178	146
-417.743		0	0	296.9270296	147
-420.584		0	0	298.9469414	148
-423.426		0	0	300.9668531	149
-		0	0	302.9867649	150

426.268					
-429.11		0	0	305.0066767	151
-431.952		0	0	307.0265884	152
-434.793		0	0	309.0465002	153
-437.635		0	0	311.066412	154
-440.477		0	0	313.0863237	155
-443.319		0	0	315.1062355	156
-446.161		0	0	317.1261473	157
-449.002		0	0	319.146059	158
-451.844		0	0	321.1659708	159
-454.686		0	0	323.1858826	160
-457.528		0	0	325.2057943	161
-460.369		0	0	327.2257061	162
-463.211		0	0	329.2456179	163
-466.053		0	0	331.2655296	164
-468.895		0	0	333.2854414	165
-471.737		0	0	335.3053532	166
-474.578		0	0	337.3252649	167
-477.42		0	0	339.3451767	168
-480.262		0	0	341.3650885	169
-483.104		0	0	343.3850002	170
-485.946		0	0	345.404912	171
-488.787		0	0	347.4248238	172
-491.629		0	0	349.4447355	173
-494.471		0	0	351.4646473	174
-497.313		0	0	353.4845591	175
-500.154		0	0	355.5044708	176
-502.996		0	0	357.5243826	177
-505.838		0	0	359.5442944	178
-508.68		0	0	361.5642061	179
-511.522		0	0	363.5841179	180

-514.363		0	0	365.6040297	181
-517.205		0	0	367.6239414	182
-520.047		31.25	5	369.6438532	183
-522.889		43.75	7	371.663765	184
-525.731		50	8	373.6836767	185
-528.572		56.25	9	375.7035885	186
-531.414		50	8	377.7235003	187
-534.256		56.25	9	379.743412	188
-537.098		56.25	9	381.7633238	189
-539.94		50	8	383.7832355	190
-542.781		56.25	9	385.8031473	191
-545.623		56.25	9	387.8230591	192
-548.465		56.25	9	389.8429708	193
-551.307		62.5	10	391.8628826	194
-554.148		56.25	9	393.8827944	195
-556.99		56.25	9	395.9027061	196
-559.832		56.25	9	397.9226179	197
-562.674		50	8	399.9425297	198
-565.516		62.5	10	401.9624414	199
-568.357		62.5	10	403.9823532	200
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-574.041		68.75	11	408.0221767	202
-576.883		75	12	410.0420885	203
-579.725		81.25	13	412.0620003	204
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-588.25		100	16	418.1217356	207
-591.092		125	20	420.1416473	208
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-596.775		118.75	19	424.1814709	210
-599.617		112.5	18	426.2013826	211

-602.459		100	16	428.2212944	212
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-608.142		75	12	432.2611179	214
-610.984		62.5	10	434.2810297	215
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-616.668		56.25	9	438.3208532	217
-619.51		68.75	11	440.340765	218
-622.351		62.5	10	442.3606768	219
-625.193		56.25	9	444.3805885	220
-628.035		68.75	11	446.4005003	221
-630.877		56.25	9	448.4204121	222
-633.718		56.25	9	450.4403238	223
-636.56		62.5	10	452.4602356	224
-639.402		43.75	7	454.4801474	225
-642.244		68.75	11	456.5000591	226
-645.086		56.25	9	458.5199709	227
-647.927		50	8	460.5398827	228
-650.769		62.5	10	462.5597944	229
-653.611		43.75	7	464.5797062	230
-656.453		62.5	10	466.599618	231
-659.295		68.75	11	468.6195297	232
-662.136		43.75	7	470.6394415	233
-664.978		68.75	11	472.6593533	234
-667.82		68.75	11	474.679265	235
-670.662		50	8	476.6991768	236
-673.503		75	12	478.7190886	237
-676.345		81.25	13	480.7390003	238
-679.187		68.75	11	482.7589121	239
-682.029		125	20	484.7788239	240
-684.871		106.25	17	486.7987356	241
-687.712		106.25	17	488.8186474	242

-690.554		112.5	18	490.8385592	243
-693.396		118.75	19	492.8584709	244
-696.238		106.25	17	494.8783827	245
-699.08		87.5	14	496.8982944	246
-701.921		87.5	14	498.9182062	247
-704.763		68.75	11	500.938118	248
-707.605		68.75	11	502.9580297	249
-710.447		62.5	10	504.9779415	250
-713.289		50	8	506.9978533	251
-716.13		37.5	6	509.017765	252
-718.972		25	4	511.0376768	253
-721.814		25	4	513.0575886	254
-724.656		25	4	515.0775003	255

6. CONCLUSIONS

MODIS satellite images were used to classify the *gross* major irrigated areas in Zabeed Area in Yemen. The resolution of the MODIS satellite images is 250 by 250 meter and does not allow to distinguish individual fields. The *actual* irrigated area is lower and was determined by multiplying the gross irrigated area with an irrigated fraction that was derived from Landsat satellite images that have a spatial resolution of 30 by 30 meter. The actual irrigated area is estimated 71,304 ha.

The annual average total system efficiency for Zabeed is 47%. Monthly discharge data are highly questionable because the flow data do not match with the gross irrigation requirements based on SEBAL and TRRM precipitation, and the agricultural seasons monitored with MODIS. Nevertheless, a monthly water balance is provided, which suggests that groundwater is abstracted in September to November.

The land use classification has been ground truthed, and the average accuracy appeared to be 83%. Such performance is in agreement with similar studies conducted outside Yemen. Because of these accuracies and acceptable results on water use, it is concluded that satellite remote sensing has potential.

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Appendix 1 Precipitation validation

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Appendix 2 M-SEBAL model

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Appendix 3. Land Use Map Zabeed

Appendix 4. Actual Evapotranspiration

Appendix 5. Potential Evapotranspiration Zabeed