CROP WATER CONSUMPTION MODELLING AT OUTLET LEVEL BY USING REMOTE SENSING AND GIS

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ABSTRACT: The enlarged demand of water due to agriculture expansion, increasing industrial and domestic needs, compounded with climate change is causing scarcity of water globally and Pakistan is also facing same conditions. Due to limited availability of water, it is necessary to adopt global best practices being employed for sustainable agricultural water management. Remote sensing techniques are being intensively used around the globe with confidence to monitor the crops growth and crop water use. The aim of the research is to develop crop water consumption monitoring system at the outlet level to regulate irrigation water distribution at farm level. Surface Energy Balance Algorithm for Land (SEBAL) is used to develop pilot case study for year 2017-18 at a distributary canal command level named 5R-Yousafwala located in Sahiwal District. Crop classification based on Landsat-8 imagery was provided by Punjab Irrigation Department. Landsat-8 and Sentinel-2 images were acquired for NDVI monitoring. Metrological data for Penman Monteith based evapotranspiration calculation was acquired from Global Land Data Assimilation System (GLDAS). Analogue cadastral maps of outlet command areas were converted to digital georeferenced format. The provided crop classification was verified after discussion with farmers during detailed field survey. In Rabi season of 2017-18, mean evapotranspiration (ET) actual was estimated about 352 mm, while in Kharif season of 2018, it was estimated as 425 mm. The crop water deficit was estimated as 36 % in rabi season and 30 % in kharif season. Irrigation share was only 37 % in Rabi season and 48% in Kharif season. Rainfall contributed 09 % in Rabi season and 30% in Kharif season. Groundwater was paramount contributor with 54 % share in rabi season while in Kharif season it contributed relatively minor share of 22%. The ET potential and ET actual fluctuate in all outlet commands due to the diverse crop cover and economic capacity to pump groundwater. The results could be proved very useful for irrigation department to monitor and reform the irrigation supplies at particular outlets by observing the crop demand, weather conditions and crop stage instead of monitoring outlet discharge only.

Keywords: Agriculture, Water Scarcity, Irrigation, SEBAL, Remote Sensing, Evapotranspiration, Canal Outlets.

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INTRODUCTION

The water war is sky rocketing with the passage of time around the globe as well as in Pakistan due to the scarcity of water. A huge portion of water is being utilized in agriculture sector in Pakistan and on parallel water demand in industries and domestic use is also on the rise. Pakistan is characterized as arid or semi-arid region so water resources in the country are limited. Agriculture is considered as backbone of the economy of Pakistan, so sustainable water management is necessary to meet water demand in this Era. Talking about on-farm water management evapotranspiration is an important parameter to estimate crop water requirement and crop water consumption. Evapotranspiration is an integrated process of water loss from plants. Evapotranspiration is affected by variations in the weather. Evapotranspiration and water supply are directly proportional to each other. To measure the evapotranspiration direct is extravagant and grueling so it is convenient to measure it with the help of Geospatial techniques (Naheed & Rasul, 2010).

In the previous works different methods are utilized to estimate the evapotranspiration like Penman-Monteith equation (Allen, et al., 1998). More over Radiation based equation of IRMAK3, TURC, 1957MAKK and MODTURC are also used in different scenarios for the estimation of evapotranspiration (Pandey, et al., 2016). Although it’s difficult to evaluate the crop water consumption and crop water requirement by remotely sensed data. Prime intent of the research is to develop a prototype for crop water budget estimation at outlet level within a distributary canal command Sahiwal division Lower Bari Doab Canal (LBDC) by using Surface Energy Balance Algorithm for Land (SEBAL). SEBAL works on the bases of the energy balance equation and latent heat flux. Secondary objective is to estimate contribution of canal supplies, ground water and rainfall between different outlet commands within distributary canal. After examined evapotranspiration by the surface energy balance algorithm for land the overall highlights of crop water prerequisite are exceptionally imperative and accommodating to extend water effectiveness and water management in the direction of sustainable agriculture.

This research provides an innovative decision support system to monitor the irrigation supplies within a distributary canal command against the crop water demand at farm level. The estimation of crop water requirement and crop water consumption would be useful for irrigation department to overcome the estimated deficit for sustainable agricultural management. Moreover, it would be favorable for researchers in future to learn Geo-Spatial techniques in this domain.

MATERIALS AND METHODS

The procedure followed in this research provides the base for crop water budgeting in a systematic way by using RS techniques to overcome the deficiency of water. The chapter depicts the methods and data sources that were utilized in this research work and includes a flow chart that portrays the detailed strategy of the research methodology step by step in the Figure 1.

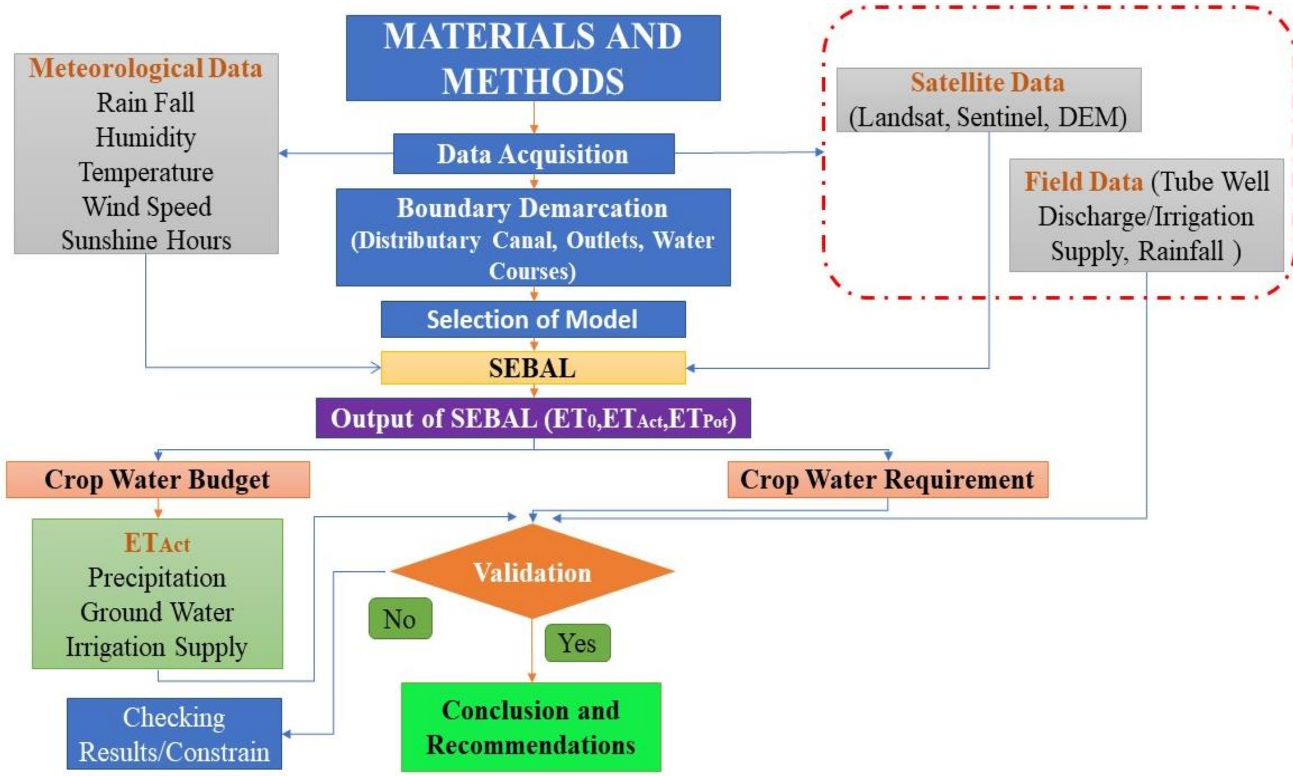

Figure 1: Materials and Methods Flow Chart

Study Area: The study area was chosen from Lower Bari Doab Canal (LBDC) Sahiwal an irrigation division. Main irrigation source is (LBDC) in the division. Irrigation network consisted on distributaries, minors, sub-minors and outlets to provide water for agriculture. 5R canal is a distributary canal of LBDC to serve four villages. 8 outlets escape from 5R-Distributary canal with a network of watercourses to provide water at farm level.

It is located 160 km away from the province capital Lahore and at the distance of 200 km east of Multan. Area of concern is located along Grand Trunk Road between Sahiwal and Okara. It lies from 30°40'47" to 30°44'39" N latitude and 73°10'43" to 73°15'01"E longitude. The terrain is varying from 565 to 580 feet above sea level. Although it is characterized as arid or semi-arid area (ur Rehman et al., 2019) but agriculture is managed through intensive canal irrigation. The lower Bari Doab Canal isolates the division in two equals. The main source of watering in the command area is 5R distributary canal. As area is located on semi-arid plain so topographical features are limited. Soil of the area is very fertile. The climate of the division is severe. In summer season temperature increase and warm winds locally called loo blow in day time. In summer season maximum temperature during the month of June reaches 45^{o}C and in winter season the minimum temperature during the month of January it reaches 2^{o}C. Annual rainfall is 11.20``. The district is located in east side of country so monsoon brings most of rain. Soil of the area is very fertile.

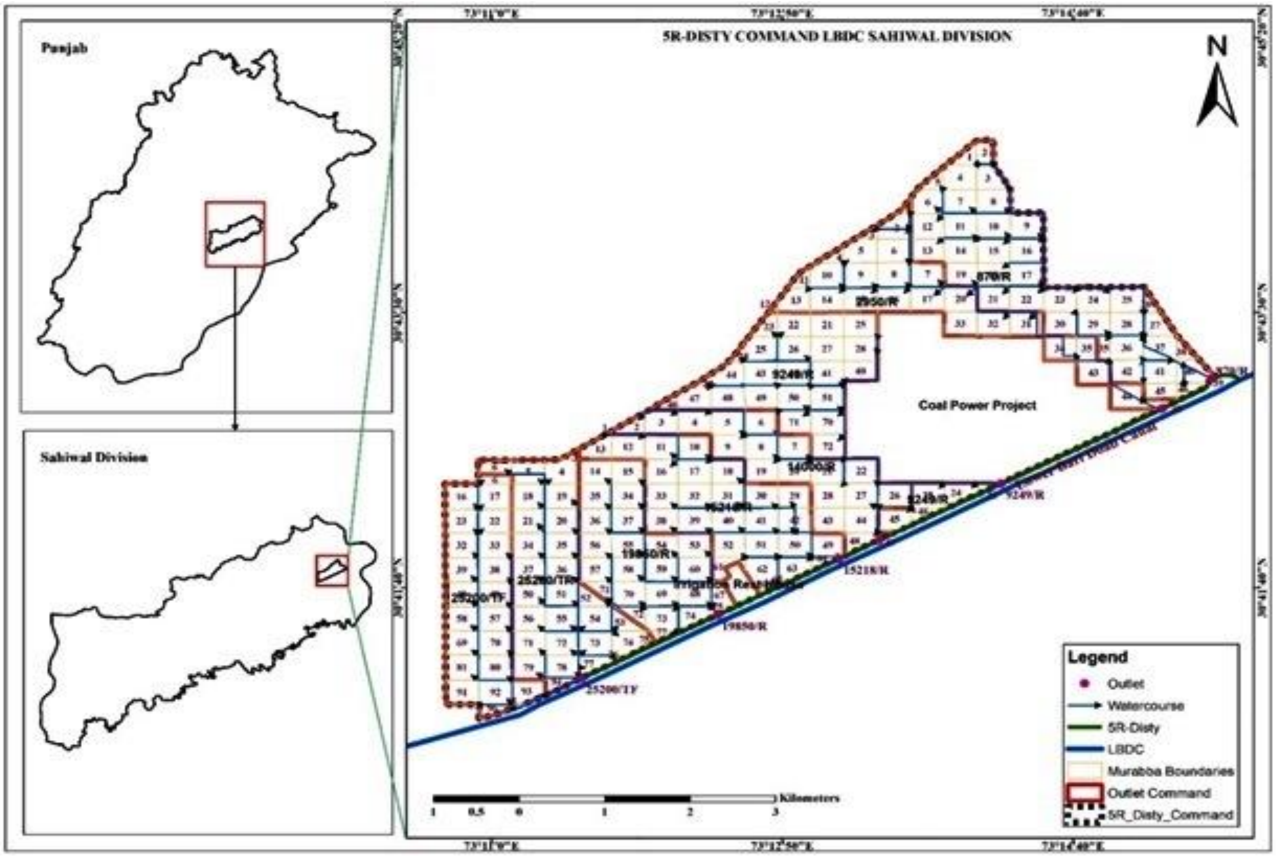

Figure 1: Study Area Map

Data Acquisition: In this section data acquiring sources and characteristics are provided which is required for the prime objective of this study. The all material is consisting on satellite images (Sentinel-2 (10 m), Landsat-8 (30 m) weather parameters, irrigation supply, Demarcation of distributary canal (5R-Disty) detailed command area including outlets boundary and water courses also marked till field level including watercourse outlets (Nakka). The detailed data summary also described in the table3.1.

Satellite data: The satellite data Landsat-8(30m) and Sentinal-2 (10 meter) acquired from different sources, Landsat-8 (Path 149, Row 39) images downloaded from the site https://earthexplorer.usgs.gov and Sentinel-2 (RCQ) downloaded from open source https://scihub.copernicus.eu/ and processed them for further procedure to propagate the research to achieve the objectives. The images dates detail is in the Figure 3.

Table 1: Data Summary.

Data Types	Data Products	Data Sources	Data Specification
Satellite Data	Landsat-8(30m) Sentinal-2 (10 meter)	(https://earthexplorer.usgs.gov) (https://scihub.copernicus.eu/)	RCQ Sentinel-2 Images Landsat-8
Meteorological Data	Min & Max temperature, Precipitation, wind speed, humidity and sun shine hours.	Chirps Satellite Data	All data on daily bases from October 2017 to October 2018
Irrigation Supply	Irrigation Canal Supply	Punjab Irrigation Department	October 2017 to October 2018
Field Data	Questionnaire	Field Visit and Farmers	Tube Wells Discharge Results verification

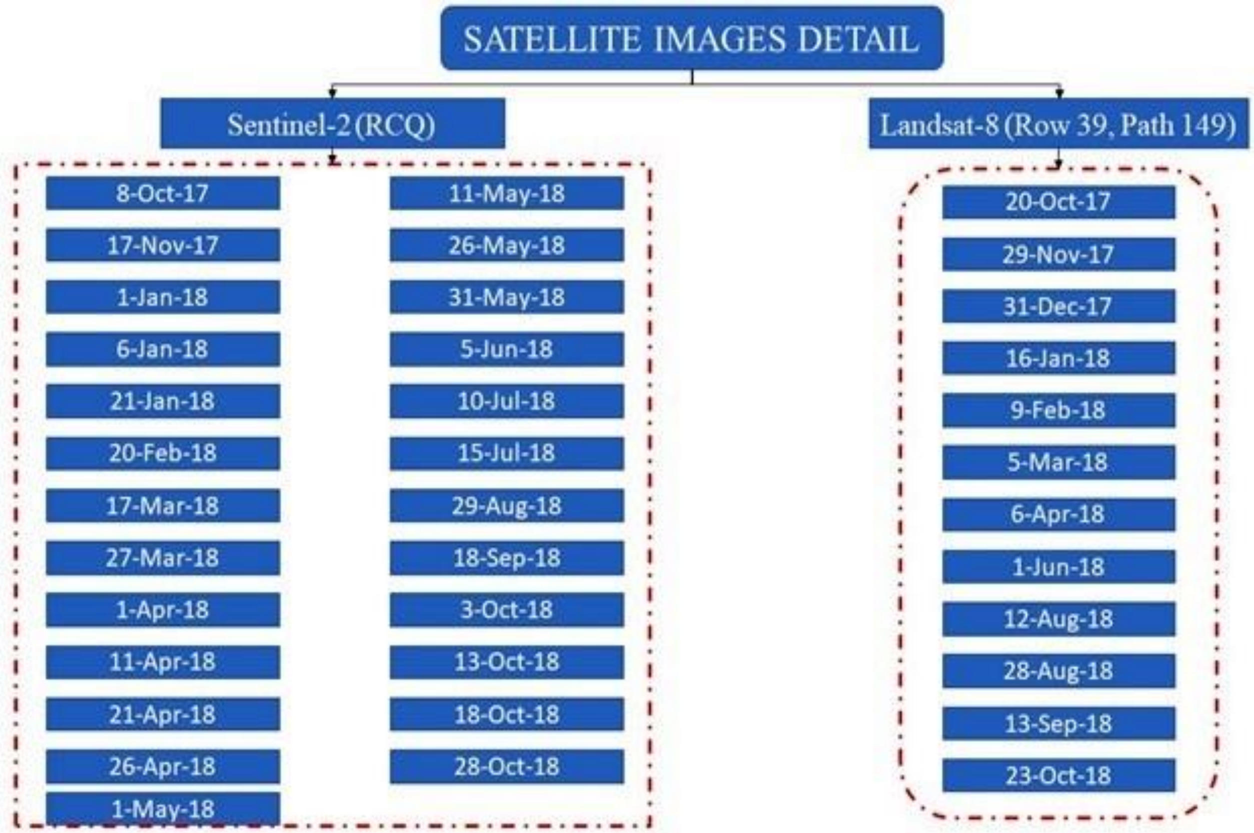

Figure 3: Satellite Images Dates

Meteorological data: All meteorological data downloaded from Chirps Satellite source and also acquired from PMIU and processed it according to the research.

Irrigation supply and its efficiency: Irrigation canal supply data has been collected from Punjab Irrigation department Sahiwal division. Canal supply data provided was on daily basis that were converted and used according to study requirement and period. 5R-Distributry canal and all water courses almost paved that's why the irrigation supply efficiency is 75 % in rabi season and 70 % in Kharif. Moreover, Outlet design discharge also verified during field visit and compared with existing discharge as shown in the Table 2.


Outlet (14000/R)


Tail (F&R)

Table 2: Outlets Discharge Detail.

Outlet No	Outlet Type	Design Discharge (cusec)	Existing Discharge (Cusec)
870/R	APM	1.08	1.22
2950/R	APM	2.08	2.49
9249/R	APM	1.47	2.39
14000/R	APM	1.89	1.55
15218/R	APM	1.89	2.42
19850/R	APM	1.70	2.20
25200/TR	OF	1.98	2.60
25200/TF	OF	1.58	2.10

Field data: As tube wells are also an integral part of irrigation system. To evaluate the ground water consumption, tube wells discharge and flow rate was collected by a field visit from farmers through a structured questionnaire and trajectory method is used to measure tube well discharge flow. Secondly cropping pattern is also verified from farmers which are practicing in the canal command area for the development of crop calendar. Training samples are shown in the Figure 4.

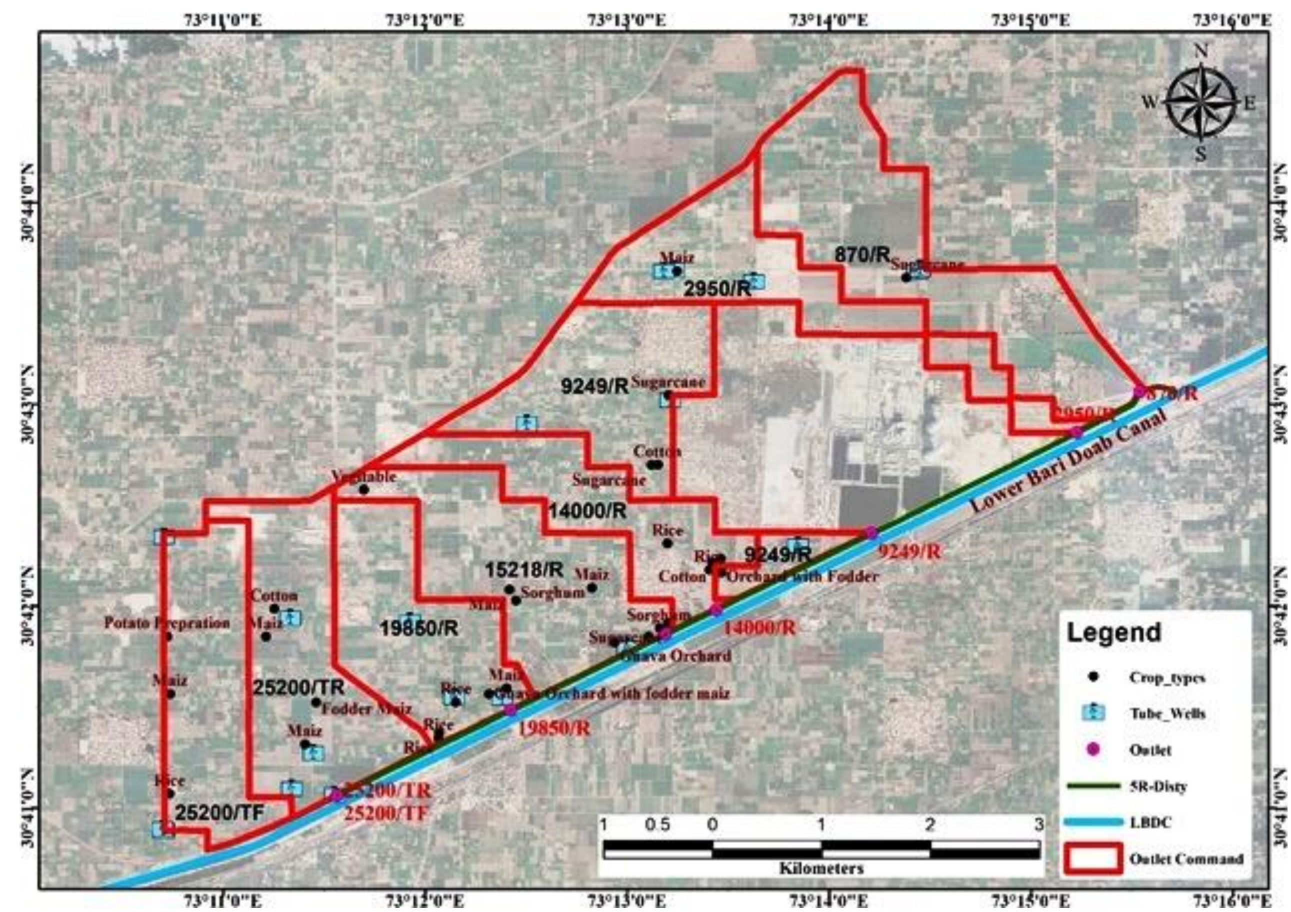

Figure 2: Field collected data

Data Processing: In this section the complete data processing strategy is described how the data is processed to achieve the objectives. The representation of all the methods, techniques and all steps of inputs f0r the further procedure to extract our results is oriented in a specific order.

Demarcation of 5R-Disty Canal Command Area: First of all, canal command area was developed in ARCGIS from Planned Cadastral map of Irrigation department. After that corrected it by Satellite based Google map then field survey was also conducted for ground truthing and finally demarked it according to the existing land use. (El-Magd & Tanton, 2005)

Model Selection: There are a number of methods used to estimate the evapotranspiration like Penman-Monteith (FAO56PM), Hamon equation, Hargreaves equation, CROPWAT model but in the present research the model "Surface Energy Balance Algorithm for Land" (SEBAL) is selected on the basis of available data, required accuracy and terrain of study area.

Surface Energy Balance Algorithm for Land (SEBAL): The model is designed on programming-based script which works in a systematic way according to the surface energy balance equation for computation of evapotranspiration.

Theoretical Basis of SEBAL: SEBAL works on the basis of surface energy balance equation to compute evapotranspiration by utilizing satellite images and weather parameters. As satellite image provide surface information at the overpass time of the satellite and SEBAL calculate an instantaneous ET Flux for each pixel of the image. The surface energy budget equation is as under:

Equation 3. 1

Here

λET = Latent heat flux (w/m^2)

= Net radiation flux at the surface (w/m^2)

G = Soil heat flux (w/m^2)

H = Sensible heat flux to the air (w/m^2)

The ET flux is calculating for each pixel of the image as a "residual" of the surface energy budget equation. (Jaber, et al.,2016)

The determination of two "anchor" pixels (the hot and cold), over the region of intrigued is a significant point in SEBAL model. This set of pixels are utilized to decide the contrast in temperature between the surface temperature (Ts) and air temperature (dT). A straight relationship is expected between both in the frame of

Equation 3. 2

Where a and b are the linear relationship constants. To determine these constants, SEBAL uses the two "anchor" pixels for which a value for H can be reliably calculated. The values of both surface and air temperature is calculated from the land surface temperature for all pixels. Surface and air temperature are estimated for both hot and cold pixels utilizing the following relationship.

Equation 3. 3

Where H can be estimated for the anchor pixels utilizing climatological data, *r* is the air density (kg/m3), cp is the particular heat of air (1004 J/kgK), dT is the temperature distinction between two statures (K), and the is the stramlined resistance to heat transport (s/m) for both type of pixels. The over straight relationship between dT and Ts is may be a major assumption in SEBAL. Previous research in this regard show that, this is helpful in region level.

Equation is formulated by utilizing dT values for both pixels and surface temperature. The cold pixels are utilized to characterize the sum of evapotranspiration through H, happening from the foremost vegetated and irrigated areas within the satellite images. A full surface covered crop farming or water reservoirs is usually utilized to recognize the cold pixels with in the zone of intrigued. In this investigation the automatic selection algorithm is used.

So, for this purpose a surface temperature that is utilized needs to be consistently balanced to a common reference height for precise expectation of dT. In on another way differences in elevation, become a reason for distortion in the results. Hence SEBAL examine a Lapsed surface temperature map to calculate surface to air temperature contrasts by accepting that the rate of diminish in surface temperature by topographic effect. For this purpose, DEM information is utilized for these calculations. Following equation is utilized for this.

Equation 3. 4

where Δz is the alterations of the pixel's height from the sea level, and that is constructive if the height of the pixels is greater than the datum. 6.5 c is a constant value founded on the universal account that air temperature declines 6.5 C when elevation rises by 1km. From the residual in the instantaneous energy-balance equation and the evaporative fraction (EF), the daily ET (ET24, mm/day) was calculated. Therefor its instant values can be taken as mean daily values. so that the spatial inconsistency in daily ET can be expected over large scales.

Equation 3. 5

Equation 3. 6

where $Rn,_{24}$ is daily net radiation; G_{24} is daily soil heat flux; 86,400 is the number of seconds in a 24 h period; and is the latent heat of vaporization (J/kg). The latent heat of vaporization permits the expression of ET_{24} in mm/day. The indicator G_{24} can be expressed for vegetative and upper surface as zero at the soil surface. Reason behind this is, as soil released the energy in night time occupied in the day time.

The latent heat vaporization and $Rn,_{24}$ are defined as:

where is 24 h incoming solar radiation; is albedo; a is a regression coefficient of relationship between net long wave radiation and atmospheric transmissivity at daily scale; and is the one-way transmittance in calm conditions and also forecasted for calm and dry weather conditions by utilizing the height above sea level. Coefficient depends upon the region. In dry regions, the coefficient an approximately 143 with R2 = 0.80.

Net Radiation Flux (Rn): The net radiation flux can be calculated by subtracting reflected radiations from all incident radiations.

It can be computed by surface radiation balance equation:

Equation 3. 7

Here; $R_{S\downarrow}$ is the receiving shortwave radiations (W/m^2), α is the surface albedo, $R_{L\downarrow}$ is the incoming longwave radiation (W/m^2), $R_{L\uparrow}$ is the outgoing longwave radiation (W/m^2), and ε_o is the surface thermal emissivity.

SEBAL Inputs and Processing: SEBAL model requires a satellite image and some weather parameters in computing evapotranspiration. The following flow chart in the Figure 5 is also depicting the all process of SEBAL from inputs to outputs. (Lee & Kim,2016)

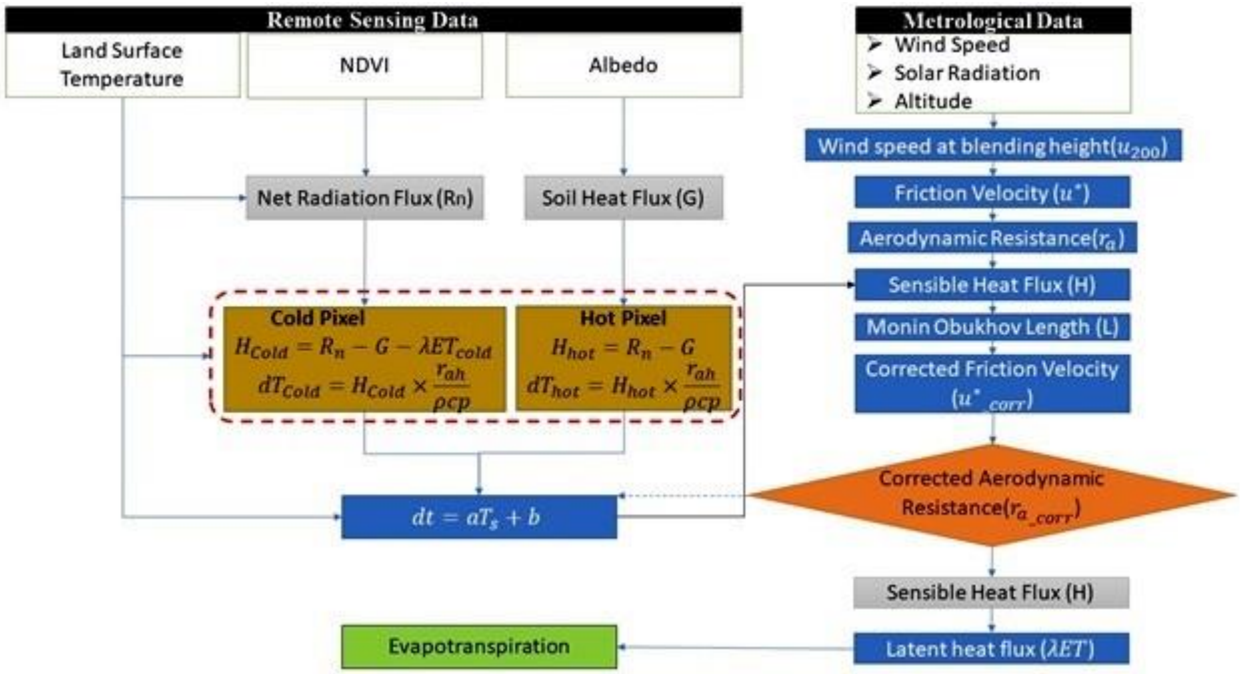

Figure 5: SEBAL Implementation Flow Chart

Cloud free images: Satellite Images should be cloud free with a clear sky because SEBAL could not work efficiently in the presence of clouds.

Weather Parameters: For SEBAL processing following weather parameters are required:

Solar Radiation, Air Temperature, Humidity, Precipitation, Wind Speed and Sunshine Hours are required. The solar radiations are beneficial to estimate the cloud cover of the image and for the adjustment of the atmospheric transmissivity. Humidity data is essential for the estimation of reference evapotranspiration (ET0). ET0 is the estimated evapotranspiration for a specific reference crop. Precipitation data is used to check the "wetness" of areas that have received rain within four or five days before the image date. It is used to calculate H at the "cold" anchor pixel and to compute the ET0 fraction (ET0F) that is used to predict 24-hour and seasonal ET. The speed of wind (u) at the time of the satellite overpass is required to estimate the sensible heat flux (H) and for the ET0 calculation.

SEBAL Outputs: After the systematic processing by inputs, surface energy balance algorithm for land model evaluated evapotranspiration in raster form. As per required objectives two different types of evapotranspiration acquired as actual evapotranspiration (ET_{act}), and potential evapotranspiration (ET_{pot}). ETact claims as crop water consumption and ET_{pot} is equal to crop water requirement.

SEBAL Outputs Processing in ARCGIS: The obtained SEBAL raster results converted in to tabular form for mean calculation according to the outlets command by using three different models step by step in the model builder. Firstly, all the raster images extracted according to the study area. Secondly, extracted raster was processed for statistics calculation and converted in to data base files (dbf). Thirdly, all the dbfs converted in to excel format as per requirement. The following models portrays the all processing.

Study Area Extraction: In this phase model was developed in the model builder for the extraction of AOI. As shown in the figure 6 First of all iterate rasters tool was applied to compile multiple rasters in a single folder. After that the tool Extract by mask was applied according to the study area boundary to propagate the study.

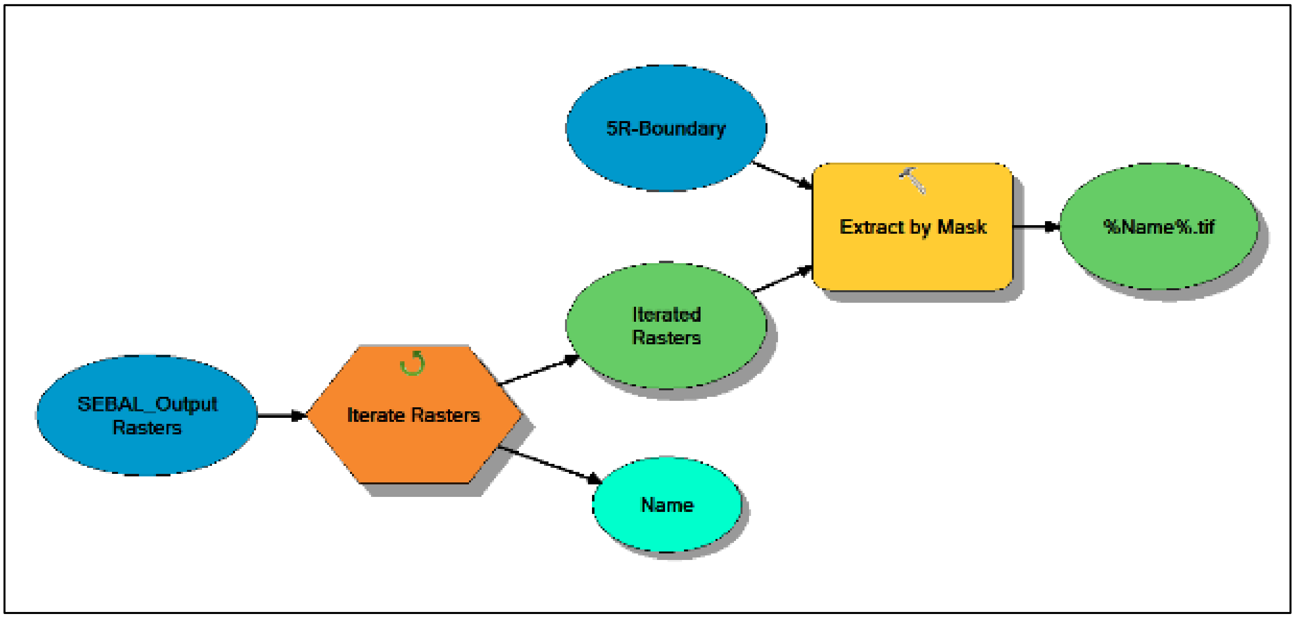

Figure 6: Study Area Extraction Flow

Mean Calculation: In the second phase all the extracted rasters iterated for the implementation of zonal statistics according to outlet command as shown in the Figure 7. By the application of zonal statistics tool mean evapotranspiration computed in data base format.

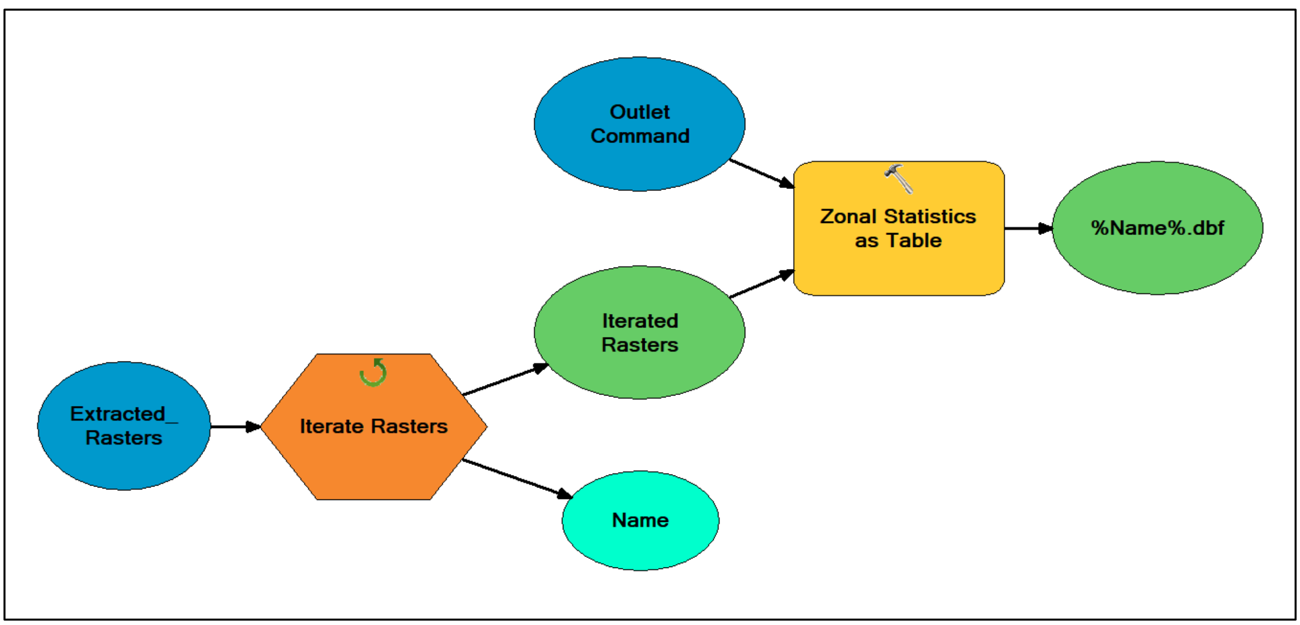

Figure 7: Raster to Data Base File Conversion

Data Base File to MS Excel File: As shown in the figure 8 multiple dbf files iterated to compile in single folder than table to excel tool applied for further results compiling according to the required objectives.

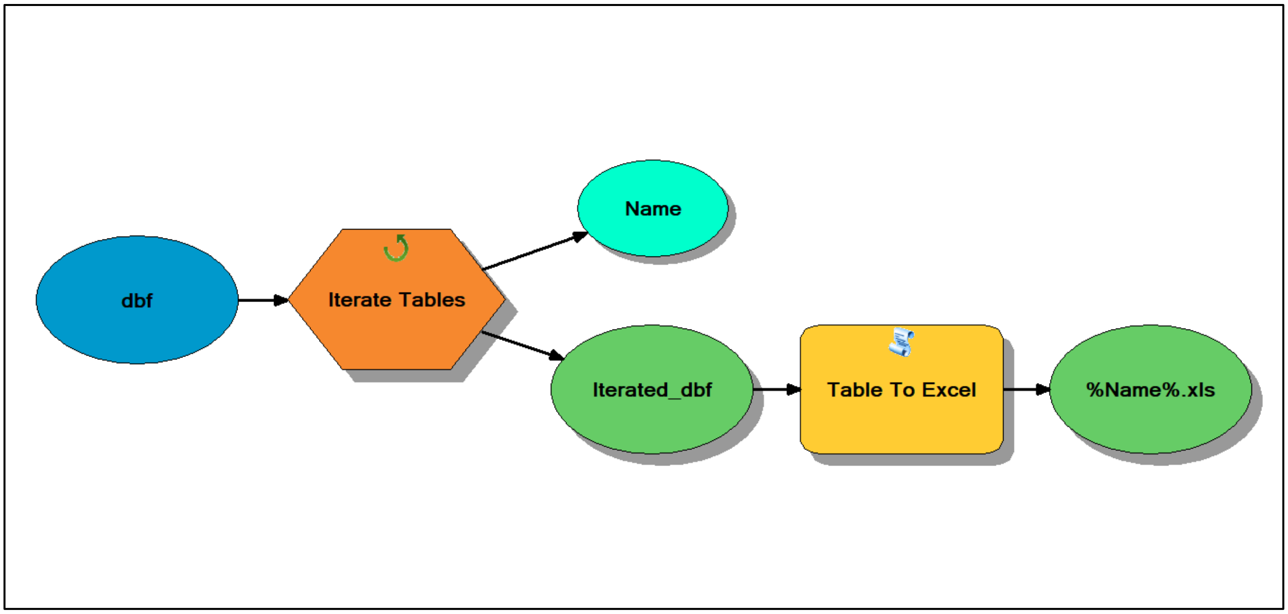

Figure 8: Data Base File to MS Excel File Flow

Crop water Budgeting: The crop water budget computed by the equation:
Equation 3. 8
Here,
is the total water amount which is provided to crop or it receives in the form of rainfall
Out Flow is the amount of water which the crop is utilized that is computed by SEBAL as actual evapotranspiration
Equation 3. 9
Here
= Irrigation Supply by PMIU Punjab Irrigation Department
= Ground water Consumption by tube wells discharge
For the effective rainfall the precipitation amount multiplied by 0.75
All the data implemented on daily basis throughout the both seasons Rabi and kharif.

Measurement of Ground water discharge flow:
In crop water budgeting after evaluation of irrigation supply and precipitation share from crop water consumption, ground water consumption can be abstracted. As well ground water consumption is also verified by Trajectory method. In this method to measure the tube well discharge some calculations are done in the field visit. The formula is as under:
Equation 3. 10
Here
Q = Water Discharge in lps (liter per second)
D = Pipe diameter in cm
X = X-coordinate of flow in cm (horizontal distance measured from the end of the pipe)
Y = Y-coordinate of flow in cm (vertical distance measured down from the horizontal point to the top of the water jet)

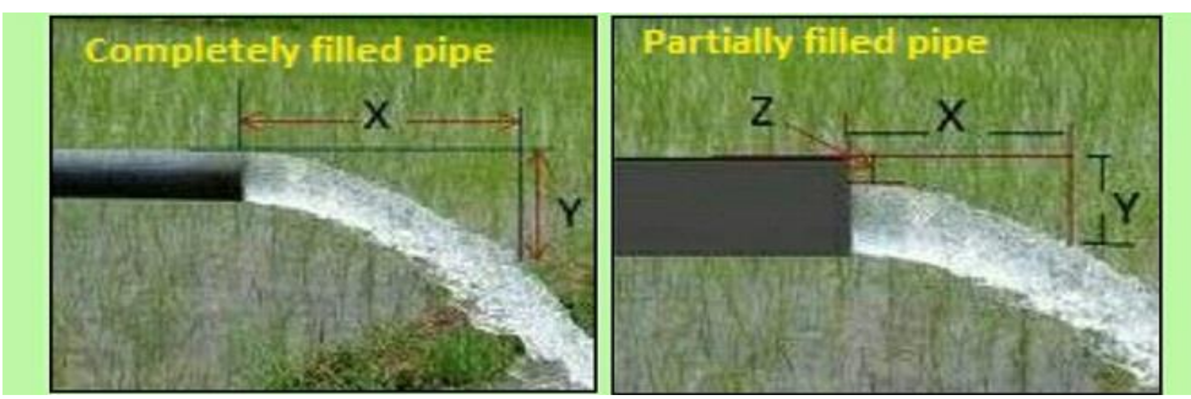

Figure 9: Trajectory calculation

Crop water Deficit: Crop water deficit mean the amount of water short fall by a specific required amount of water according to every crop water requirement which is also computed by the formula

Where

Crop water requirement (CWR) is equal to ET_{pot} and crop water consumption is equal to $_{ETact}$ So:

Equation 3. 11

RESULTS AND DISCUSSION

The study results are discussed in this chapter according to the objectives as per requirement. All the results are presented in the appropriate format as maps, tables and graphs.

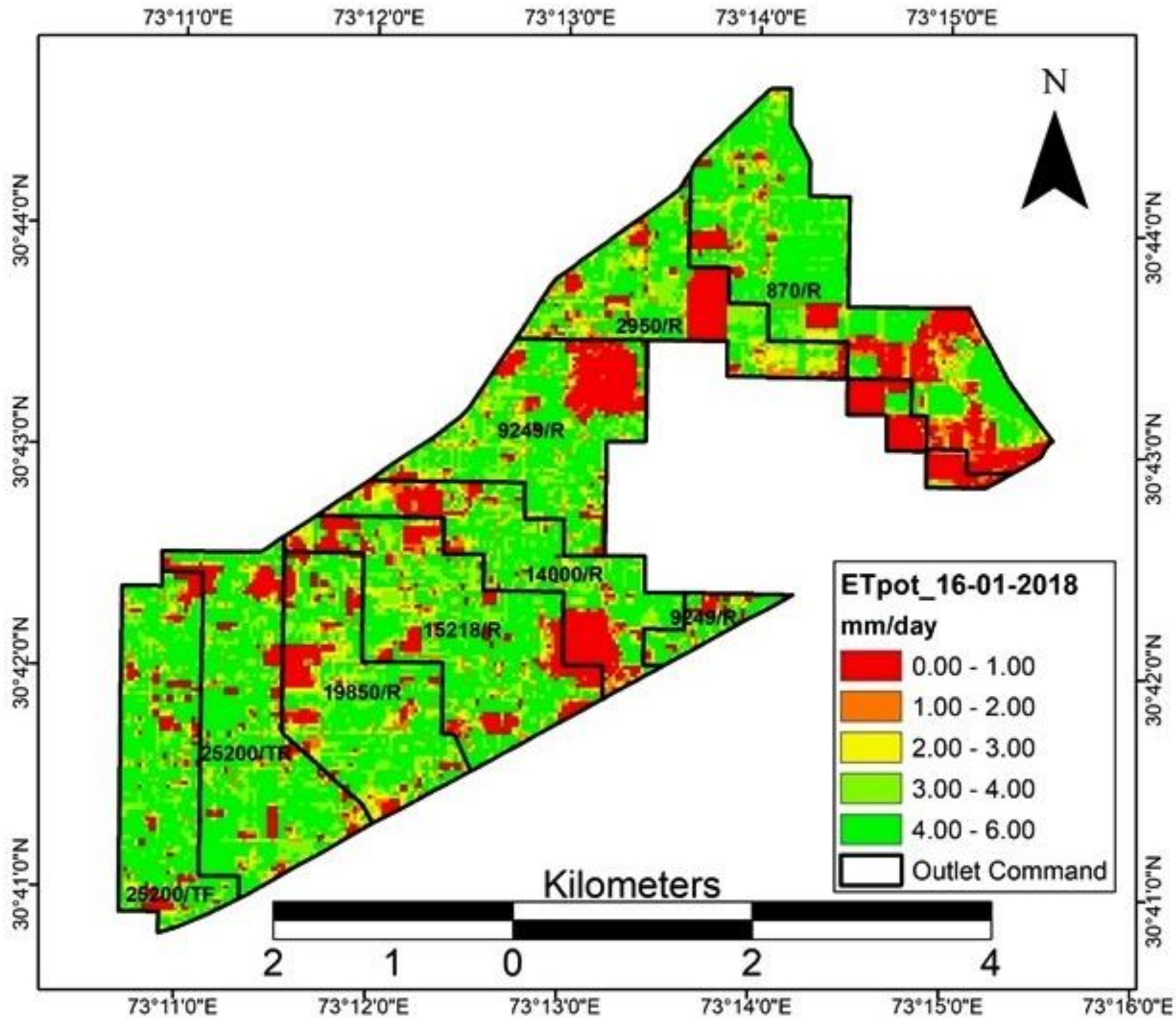

Figure 10. All the irrigation department assigned turnouts (Nakka) are shown with Black arrow sign along watercourses. The total Growth command area of the developed disty is 4595 acres while Growth Command area (GCA) of the disty is 4214 acres.

Digital Outlet Command 5R-Distributry Canal LBDC Sahiwal Division: In the ditsy command area map the detailed irrigation network is developed along with main canal LBDC, 5R-Distributary canal, Outlets (Moga) existing positions, Outlets Command boundaries, Murabba Boundaries and watercourses till farm level including Nakkas as shown in the Figure 10. All the irrigation department assigned turnouts (Nakka) are shown with Black arrow sign along watercourses. The total Growth command area of the developed disty is 4595 acres while Growth Command area (GCA) of the disty is 4214 acres.

Resultant map of SEBAL output of crop water requirement is shown in the Figure 11. This image was taken from rabi season on Jan.16, 2018. Wheat is a major crop of rabi season in the whole Distributary canal command area. From November to January crop reaches till development stage so mean crop water requirement in maximum area is 3 to 6 mm/day. Red colour in map is showing zero crop water requirement in non-Vegetated area.

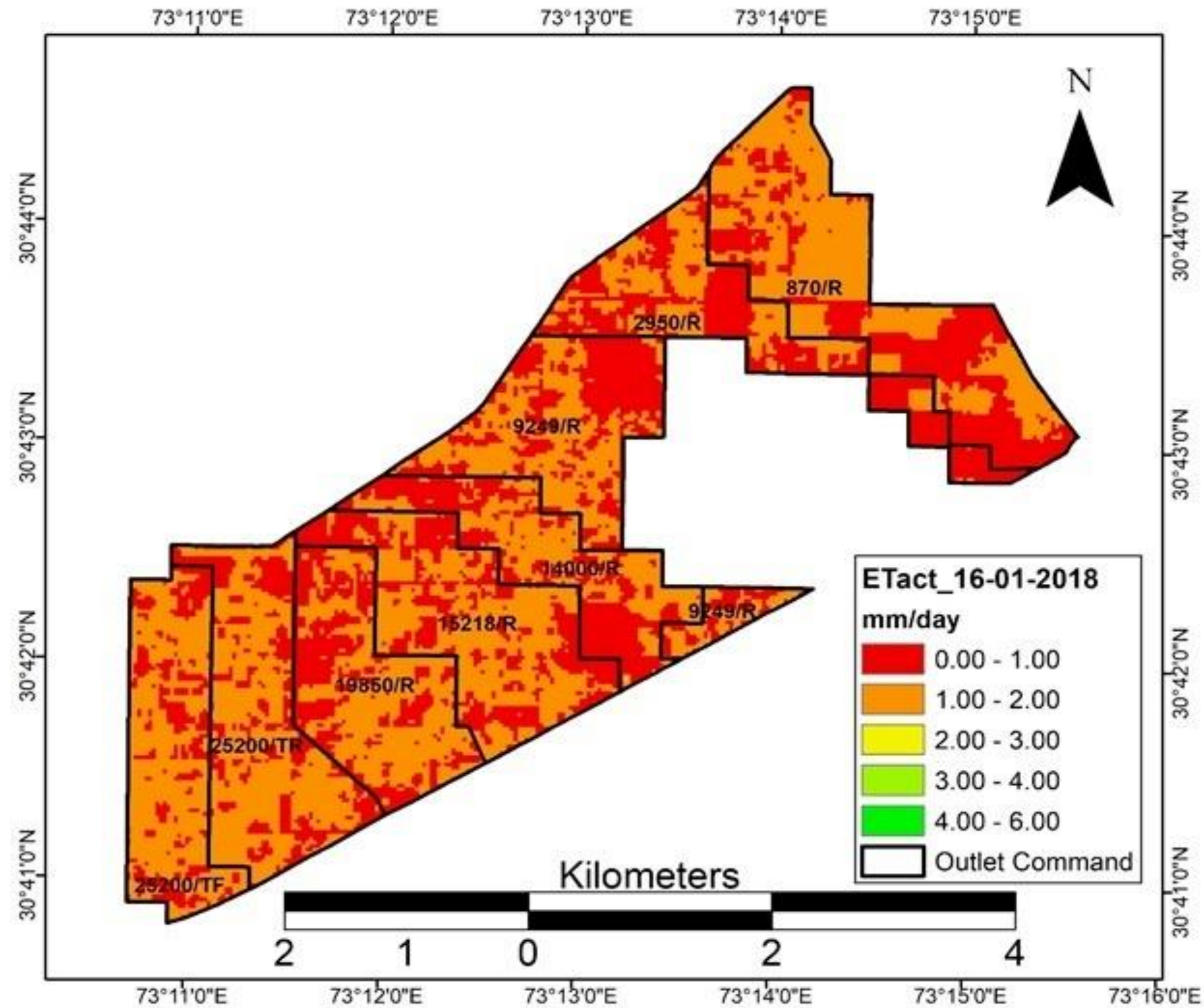

Figure 31: SEBAL Output Crop Water Requirement on January 16, 2018.

In the Figure 12 crop water consumption is shown after processing in SEBAL. ET_{act} values were showing in every outlet command uniformly from 1 to 2 mm/day in the vegetated cover. The overall deficit was meanly 2 to 3 mm because in January 2018 there was no precipitation on that day and canal supply was also was also zero which is verified by daily discharge of irrigation supply. According to rotation plan of PID 5R Distributary canal remain closed from 25th December 2017 to 15th February 2018. So, in this season ground water is only source for irrigation in the absence of rainfall and canal supply which is not enough to fulfill the crop demand.

Crop water Requirement and Consumption of Outlet (870/R) in Rabi: The total mean crop water requirement estimated 557.28 mm in Rabi and mean crop water consumption evaluated 342 mm of this outlet. This outlet utilized 10.15 mm less water from the total mean volume of 5R-Distributary Canal consumption contribution which is 2.88% less according to mean volume of the 5R-Disty. ET_{pot} and ET_{act} become up and down with the growing stages of the crops as shown in the Figure 4.5 from season start both have low values and gradually increases some fluctuations are also occurred in both due to Irrigation supply and rainfall events. The total deficit of the outlet is 215.28mm in Rabi which is 39 % in relate to demand.

Figure 42: SEBAL Output Crop Water Consumption on January 16, 2018

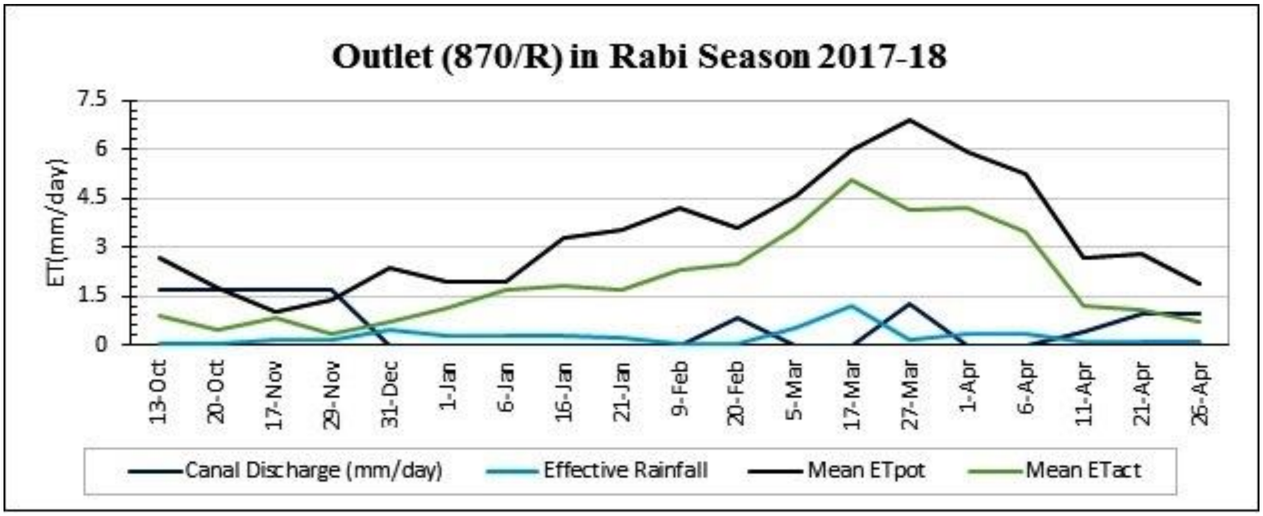

Figure 13: Crop Water Requirement and Consumption of Outlet (870/R) in Rabi 2017-18

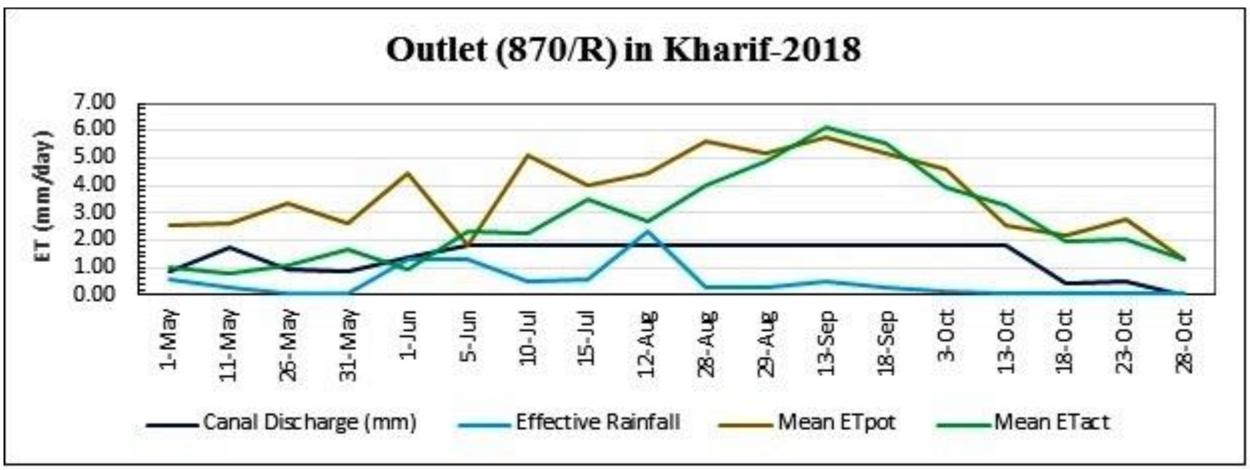

Figure 54: Crop water requirement and Consumption in Outlet (870/R) in Kharif 2018

Crop Water Requirement and Consumption of Outlet (870/R) in Kharif: In kharif, total mean crop water requirement evaluated 588.11 mm in and mean crop water consumption assessed 441.01 mm of this outlet. This outlet consumed 17.01 mm more water than the total mean volume of 5R-Distributary Canal consumption contribution which is 4.01% more according to mean volume of the 5R-Disty. In the Kharif season rice is major crop of this outlet which utilized maximum water greater than the mean volume of the outlet because rice needs water from growing to harvesting throughout the season. As shown in the Figure 14 from start of June to end July remain moon soon season which cause low values of ETpot and ETact on rainy day. In September kharif crops are at full mature stage that's why the CWR and consumption is maximum in those days. In October harvesting of kharif starts so CWR and CWC are also navigates. The total deficit of this outlet resultant 117.1 mm in Kharif.

Crop Water Requirement and Consumption of Outlet (2950/R) in Rabi: The total mean crop water requirement assessed 455.93 mm in Rabi and mean crop water consumption estimated 294.40 mm of this outlet. This outlet utilized 57.76 mm less water from the total mean volume of 5R-Distributary Canal consumption contribution which is 16.40% less according to mean volume of the 5R-Disty. The deficit of the outlet is 161.53 mm in rabi season that was 35 % in relation to demand. ETpot and ETact become up and down with the growing stages of the crops as shown in the Figure 15 from season start both have low values and gradually increases some fluctuations are also occurred in both due to Irrigation supply discharge ups and downs and also due to rainfall events.

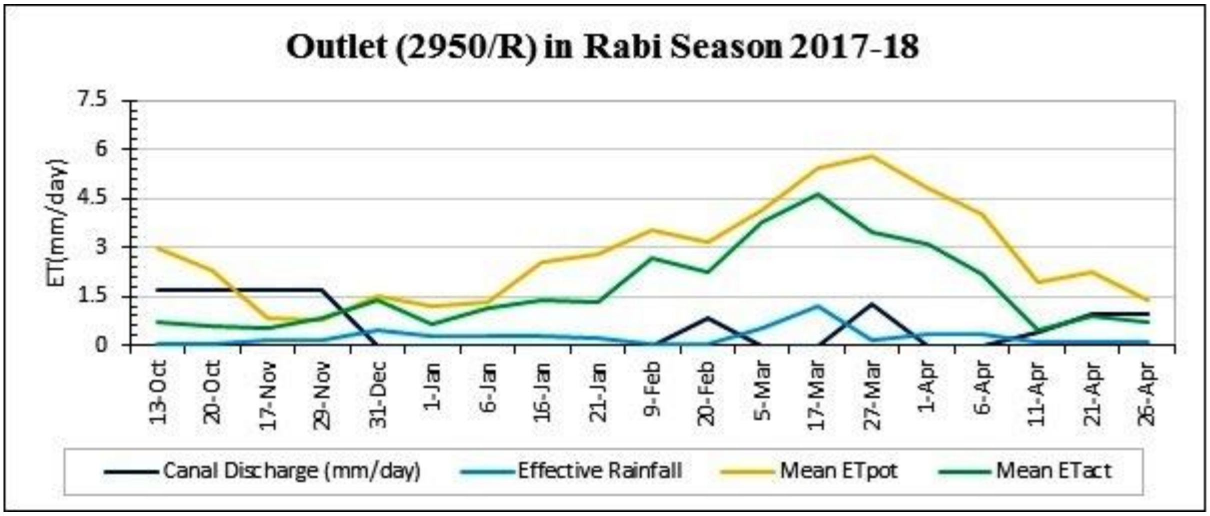

Figure 15: Crop water Requirement and Consumption of Outlet (2950/R) in Rabi 2017-18

Crop water Requirement and Consumption of Outlet (2950/R) in Kharif 2018: The total mean crop water requirement evaluated 474.62 mm in Kharif and mean crop water consumption evaluated 248.71mm of this outlet. This outlet used 175.29 mm less water according to the total mean volume of 5R-Distributary Canal consumption contribution which is 41.34% less according to mean volume of the 5R-Disty. The total mean deficit of the season estimated 225.91mm that was 90 %. As shown in the Figure 16 from start of June to end July remain moon soon season which cause low values of ETpot and ETact on rainy day. In September kharif crops are at full mature stage that's why the CWR and consumption is maximum in those days. In Oct. start harvesting as start so CWR and CWC are also navigates.

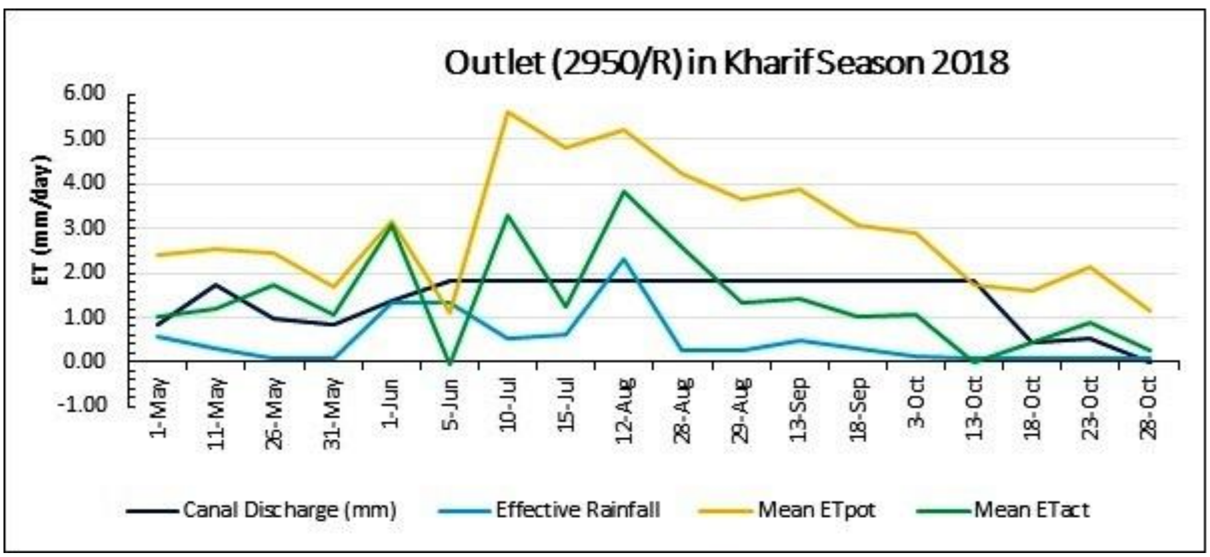

Figure 16: Crop water Requirement and Consumption of Outlet (2950/R) in Kharif Season 2018

Crop water Requirement and Consumption of Outlet (9249/R) in Rabi 2017-18: The total mean crop water requirement estimated 541.10 mm in Rabi and mean crop water consumption calculated 333.95 mm of this outlet. This outlet employed 18.20 mm less water from the total mean volume of 5R-Distributary Canal consumption contribution which is 5.17% less according to mean volume of the 5R-Disty. The total deficit of the outlet is 207.14mm in Rabi. ETpot and ETact become up and down with the growing stages of the crops as shown in the Figure-17 from season start both have low values and gradually increases some fluctuations are also occurred in both due to Irrigation supply and rainfall events.

Crop water Requirement and Consumption of Outlet (9249/R) in Kharif 2018: Total mean crop water requirement expected 628.76 mm in Kharif and mean crop water consumption estimated 337.48 mm of this outlet. This outlet used 46.52 mm less water according to the total mean volume of 5R-Distributary Canal consumption contribution which is 10.97% less according to mean volume of the 5R-Disty. The total mean deficit of the season is 251.27mm. As shown in the Figure 18 from start of June to end July remain moon soon season which cause low values of ETpot and ETact on rainy day. In September kharif crops are at full mature stage that's why the CWR and consumption is maximum in those days. As in October harvesting starts so CWR and CWC are also navigates.

Crop water Requirement and Consumption of Outlet (14000/R) in Rabi 2017-18: The total mean crop water requirement estimated 525.78 mm in Rabi and mean crop water consumption evaluated 345.24 mm of this outlet. This outlet consumed 6.92 mm less water from the total mean volume of 5R-Distributary Canal consumption contribution which is 1.96% less according to mean volume of the 5R-Disty. The total deficit of the outlet is 180.54mm in Rabi. ETpot and ETact become impetuous with the growing stages of the crops as shown in the Figure 19 from season start both have low values and gradually increases, some fluctuations are also occurred in both due to Irrigation supply and rainfall events.

Crop Water Requirement and Consumption of Outlet (14000/R) in Kharif 2018: The total mean crop water requirement assessed 589.42 mm in Kharif and mean crop water consumption evaluated 403.78 mm of this outlet. This outlet used 20.22 mm less water according to the total mean volume of 5R-Distributary Canal consumption contribution which is 4.77% less according to mean volume of the 5R-Disty. The total mean deficit of the season is 185.64mm. As shown in the Figure 20 moon soon season starts in June and remains till July which cause low values of ETpot and ETact on rainy day. In September kharif crops are at full mature stage that's why the CWR and consumption is maximum in those days. In October CWR and CWC are also navigate because harvesting starts.

Crop Water Requirement and Consumption of Outlet (15218/R) in Rabi 2017-18: The total mean crop water requirement estimated 575.51mm in Rabi and mean crop water consumption assessed 370.32 mm of this outlet. This outlet used 18.16 mm more water than the total mean volume of 5R-Distributary Canal consumption contribution which is 5.16% greater than mean volume of the 5R-Disty. The total deficit of the outlet is 205.20mm in Rabi. ETpot and ETact become up and down with the growing stages of the crops as shown in the Figure 21 from season start both have low values and gradually increases some fluctuations are also occurred in both due to Irrigation supply and rainfall events.

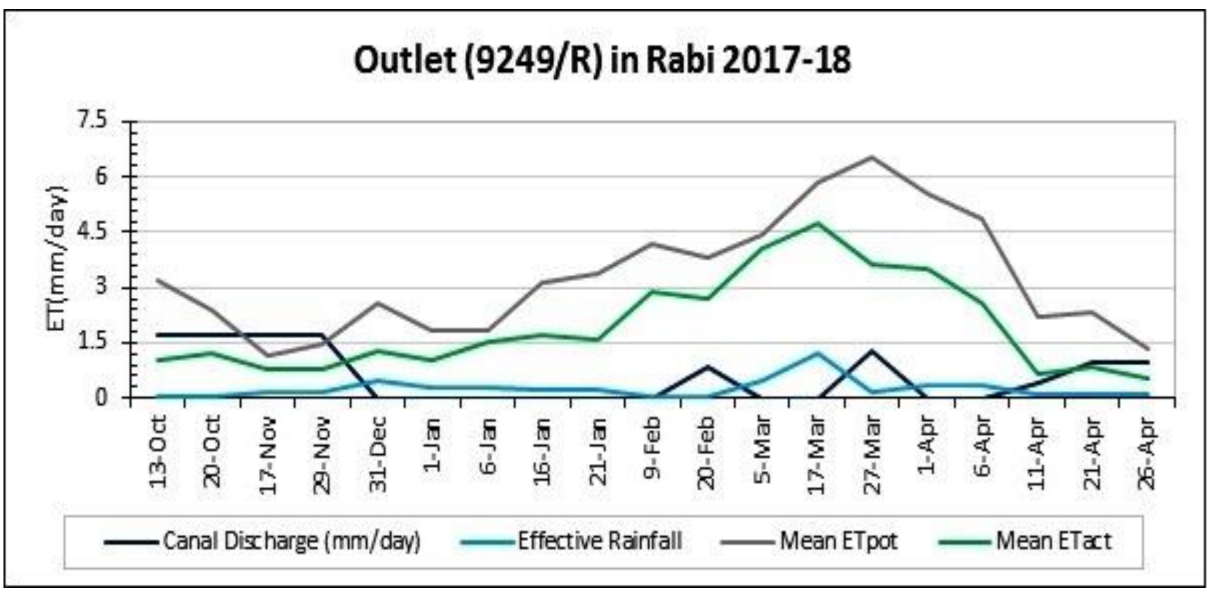

Figure 17: Crop water Requirement and Consumption of Outlet (9249/R) in Rabi

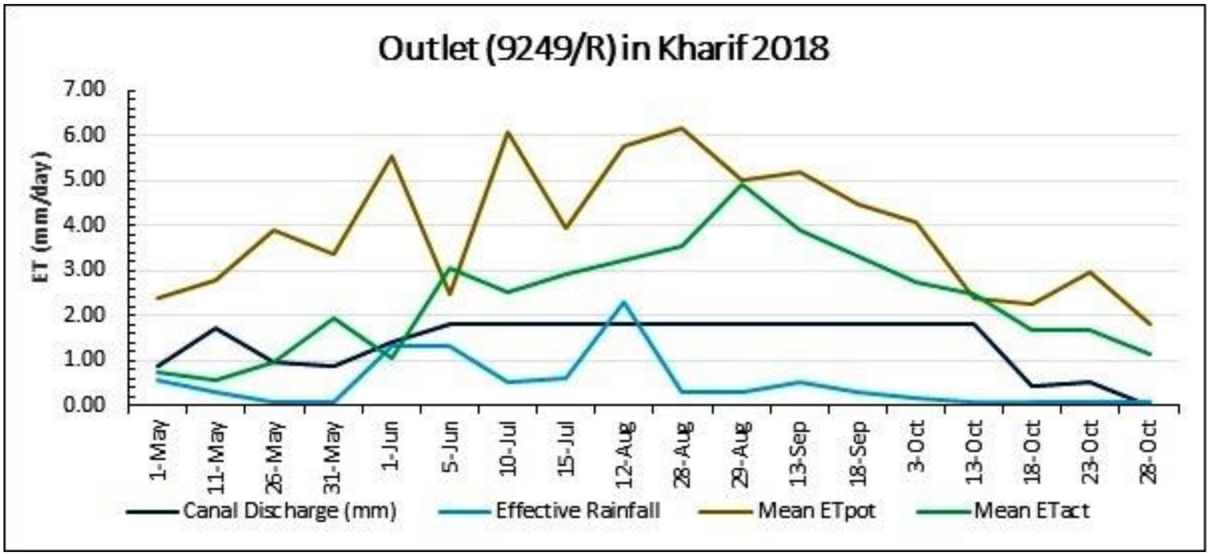

Figure 18: Crop water Requirement and Consumption of Outlet (9249/R) in Kharif -2018

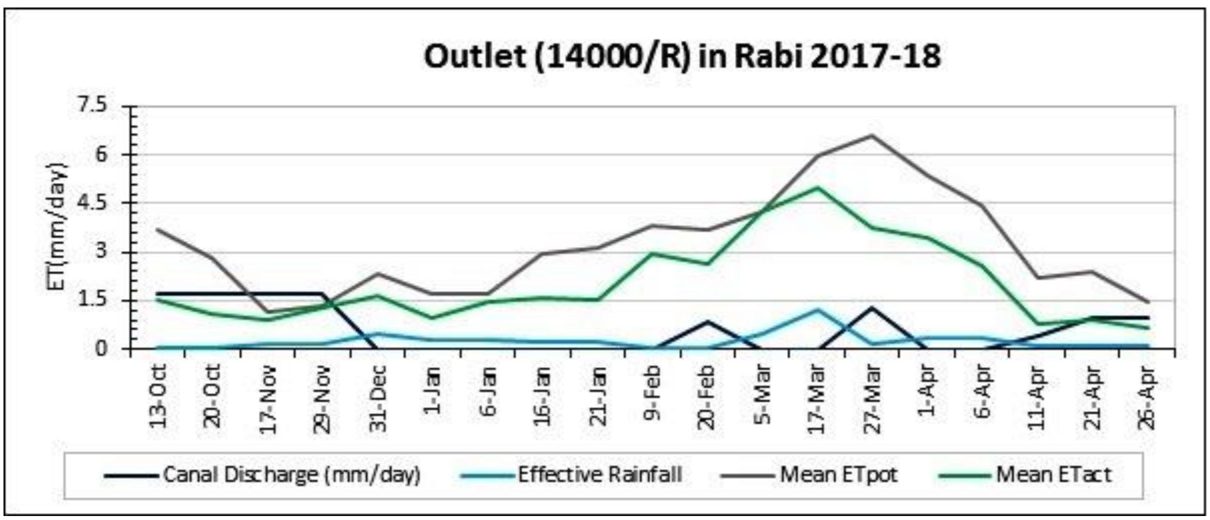

Figure 19: Crop Water Requirement and Consumption of Outlet (14000/R) in Rabi 2017-18

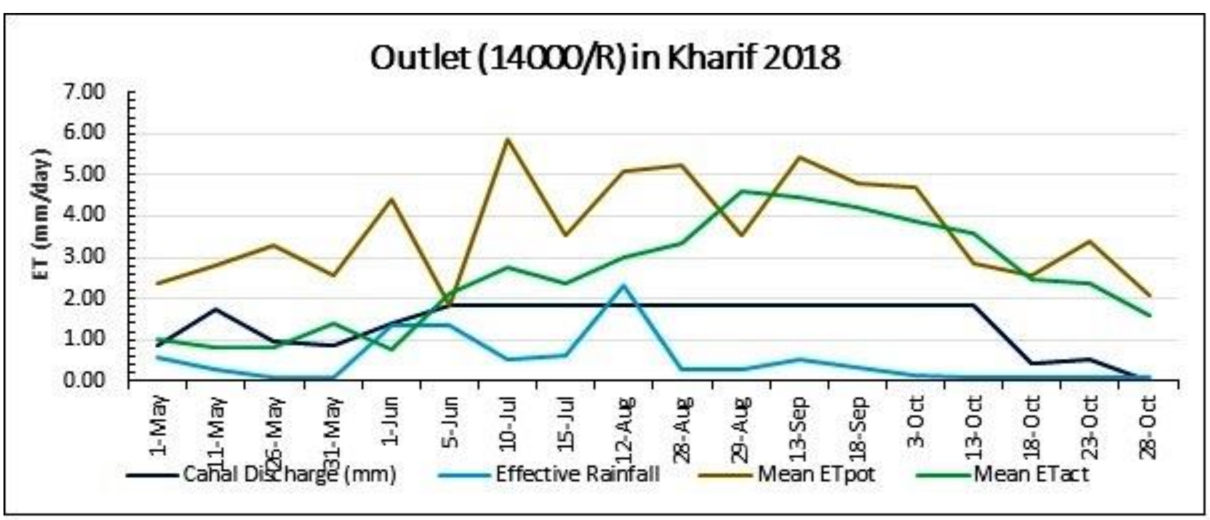

Figure 21: Crop Water Requirement and Consumption of Outlet (15218/R) in Rabi 2017-18

Crop Water Requirement and Consumption of Outlet (15218/R) in Kharif 2018: The total mean crop water requirement estimated 668.43mm in Kharif and mean crop water consumption evaluated 523.99mm of this outlet. This outlet utilized 99.99 mm more water according to the total mean volume of 5R-Distributary Canal consumption contribution which is 23.58% greater than mean volume of the 5R-Disty. The total mean deficit of the season is 144.44mm. As shown in the Figure 22 from start of June to end July remain moon soon season which cause low values of ETpot and ETact on rainy day. In September kharif crops are at full mature stage that's why the CWR and consumption is maximum in those days. Due to harvesting CWR and CWC found negative.

Crop Water Requirement and Consumption of Outlet (19850/R) in Rabi 2017-18: The total mean crop water requirement assessed 548.76mm in Rabi and mean crop water consumption evaluated 358.26mm of this outlet. This outlet utilized 6.10mm more water than the total mean volume of 5R-Distributary Canal consumption contribution which is 1.73% greater than mean volume of the 5R-Disty. The total deficit of the outlet is 190.50mm in Rabi. ETpot and ETact become irregular with the growing stages of the crops as shown in the Figure 23 from Values are low when the season starts and gradually increases, whereas irrigation supply and rainfall events also plays an important part.

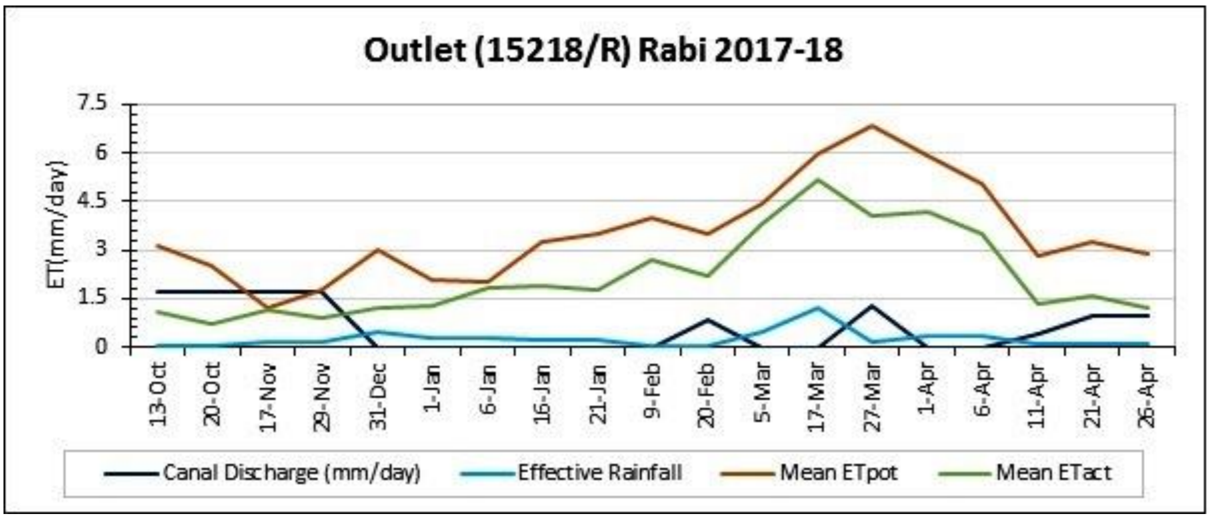

Figure 20: Crop Water Requirement and Consumption of Outlet (14000/R) in Kharif 2018

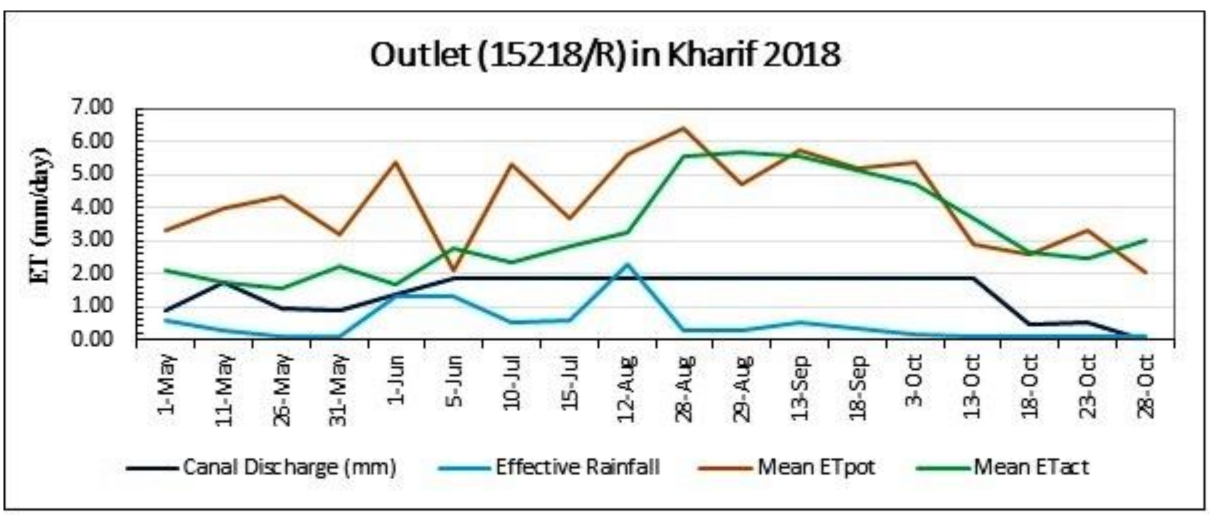

Figure 22: Crop Water Requirement and Consumption of Outlet (15218/R) in Kharif 2018

Crop Water Requirement and Consumption of Outlet (19850/R) in Kharif 2018: The total mean crop water requirement estimated 579.26mm in Kharif and mean crop water consumption evaluated 399mm of this outlet. This outlet utilized 25mm less water according to the total mean volume of 5R-Distributary Canal consumption contribution which is 5.90% less than mean volume of the 5R-Disty. The total mean deficit of the season is

180.26mm. As shown in the Figure 24 from start of June to end July remain moon soon season which cause low values of ETpot and ETact on rainy day. In September kharif crops are at full mature stage that's why the CWR and consumption is maximum in those days. As in October harvesting starts so CWR and CWC are also navigates.

Crop Water Requirement and Consumption of Outlet (25200/TR) in Rabi 2017-18: The total mean crop water requirement estimated 565.82mm in Rabi and mean crop water consumption calculated 368.53mm of this outlet. This outlet utilized 16.37mm more water than the total mean volume of 5R-Distributary Canal consumption contribution which is 4.65% greater than mean volume of the 5R-Disty. The total deficit of the outlet is 197.29mm in Rabi. ETpot and ETact become unbalanced with the growing stages of the crops as shown in the Figure 25 from values of both increased with the growing stage of crop. Rainfall events and irrigation supply are also responsible for some variations.

Crop Water Requirement and Consumption of Outlet (15218/TR) in Kharif 2018: The total mean crop water requirement estimated 626.89mm in Kharif and mean crop water consumption evaluated 470.84mm of this outlet. This outlet utilized 46.84 mm more water according to the total mean volume of 5R-Distributary Canal consumption contribution which is 11.05% greater than mean volume of the 5R-Disty. The total mean deficit of the season is 156.06mm. As shown in the Figure 26 from start of June to end July remain moon soon season which cause low values of ETpot and ETact on rainy day. In September kharif crops are at full mature stage that's why the CWR and consumption is maximum in those days. In October harvesting season starts so CWR and CWC are also navigates.

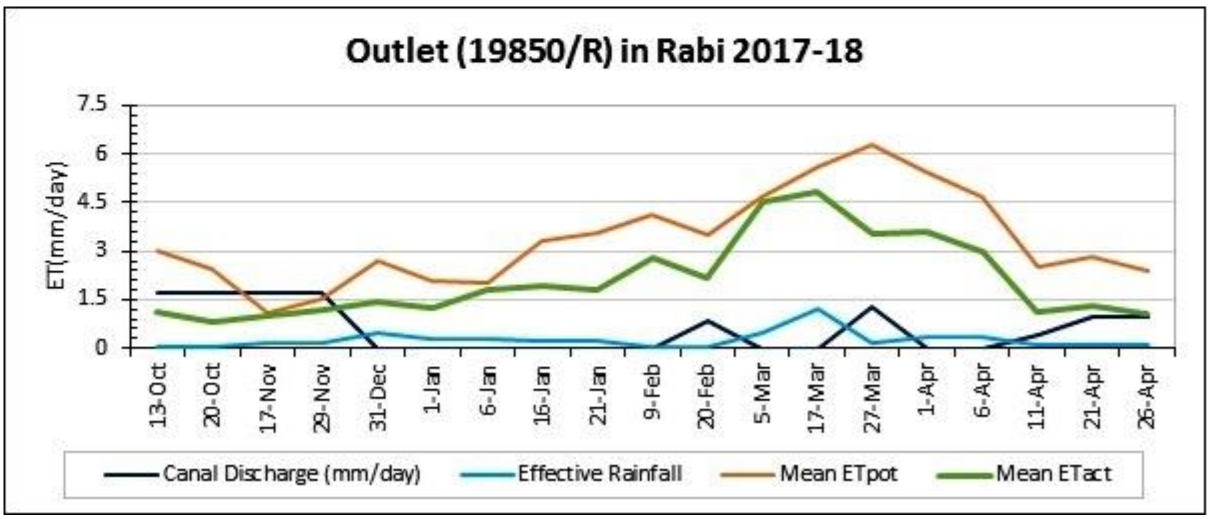

Figure 23: Crop Water Requirement and Consumption of Outlet (19850/R) in Rabi 2017-18

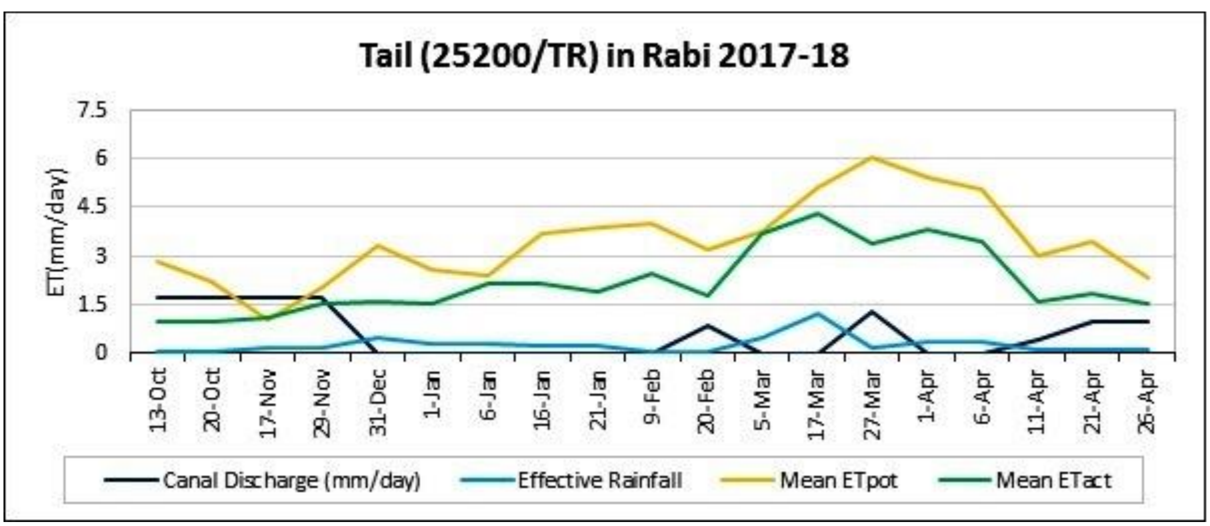

Figure 6: Crop Water Requirement and Consumption of Outlet (19850/R) in Kharif 2018

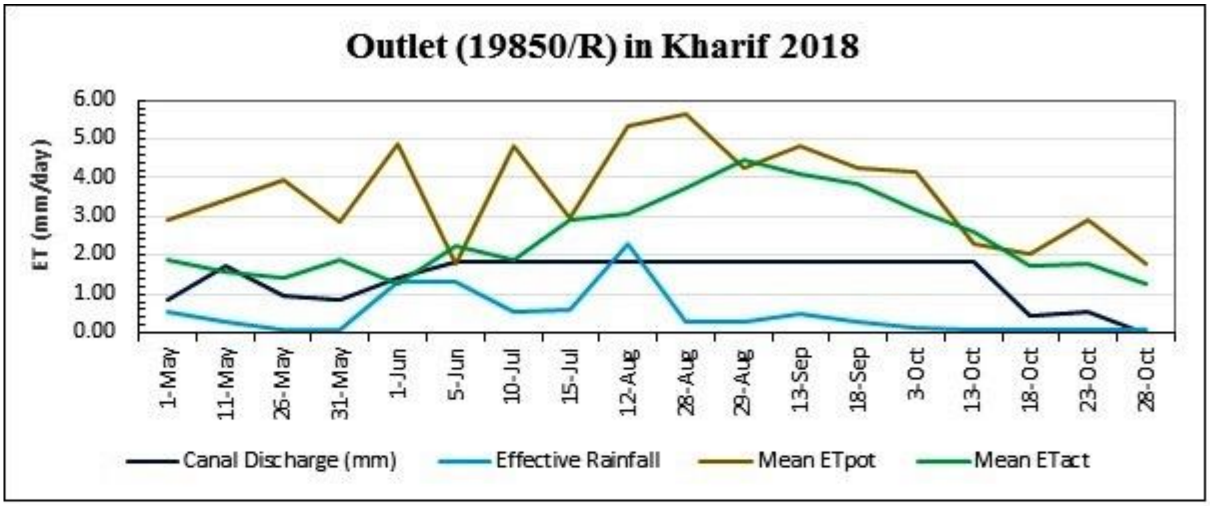

Figure 25: Crop Water Requirement and Consumption of Outlet (25200/TR) in Rabi 2017-18

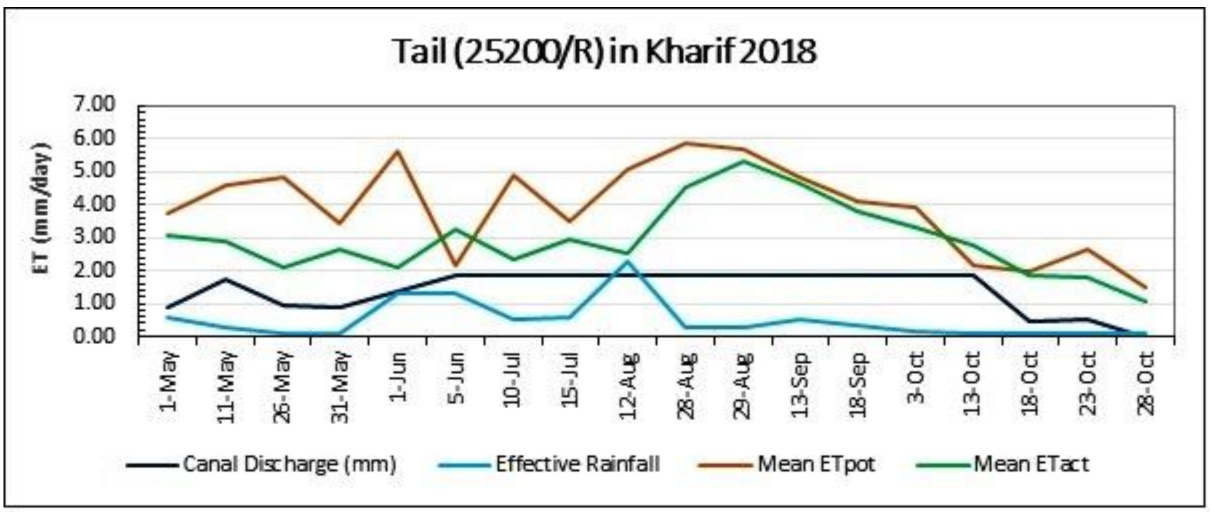

Figure 26: Crop Water Requirement and Consumption of Outlet (25200/TR) in Kharif 2018

Crop Water Requirement and Consumption of Outlet (25200/TF) in Rabi 2017-18: The total mean crop water requirement estimated 606.54mm in Rabi and mean crop water consumption evaluated 404.55mm of this outlet. This outlet utilized 52.39mm more water than the total mean volume of 5R-Distributary Canal consumption contribution which is 14.88% greater than mean volume of the 5R-Disty. The total deficit of the outlet is 202mm in Rabi. ETpot and ETact become uneven with the growing stages of the crops as shown in the Figure 27 from as season starts both have low values and gradually increase, some fluctuations are also occurred in both due to Irrigation supply and rainfall events.

Crop Water Requirement and Consumption of Outlet (25200/TF) in Kharif: The total mean crop water requirement assessed 710.63mm in Kharif and mean crop water consumption evaluated 532.22mm of this outlet. This outlet consumed 108.22mm more water according to the total mean volume of 5R-Distributary Canal consumption contribution which is 25.52% greater than mean volume of the 5R-Disty. The total mean deficit of the season is 156.06mm. As shown in the Figure 28 from start of June to end July remain moon soon season which cause low values of ETpot and ETact on rainy day. In September kharif crops are at full mature stage that's why the CWR and consumption is maximum in those days. In October harvesting starts so CWR and CWC also navigates.

Overall Crop Water Requirement and Consumption in Rabi season 2017-18: Wheat, Fodder and Potato are major crops of the rabi season in the study area. As in October the Kharif season ends and rabi starts so crop water requirement (CWR) as ET potential in the Figure 29 and Crop water consumption as ETact in the Figure 30 have low scale. With the passage of time, as crops grow ET increased that ultimately affect the canal discharge.

Great fluctuation can be seen in rainfall in the graph. In the 5R-Distributary canal command the total mean volume of CWR evaluated 547.09 mm and mean volume of Crop water consumption is 352.16 mm. The irrigation supply evaluated by mean daily discharge that is 129.6 mm that is 37 % of total mean crop water consumption. Total mean rainfall is 33.6 mm that is 9 % and the remaining is ground water consumption that is 188.8 mm that is 54 % of total consumption. Overall water budget of rabi season 2017-18 also shown in the Figure 31. The total mean deficit estimated was 195 mm that was 36 % accordingly.

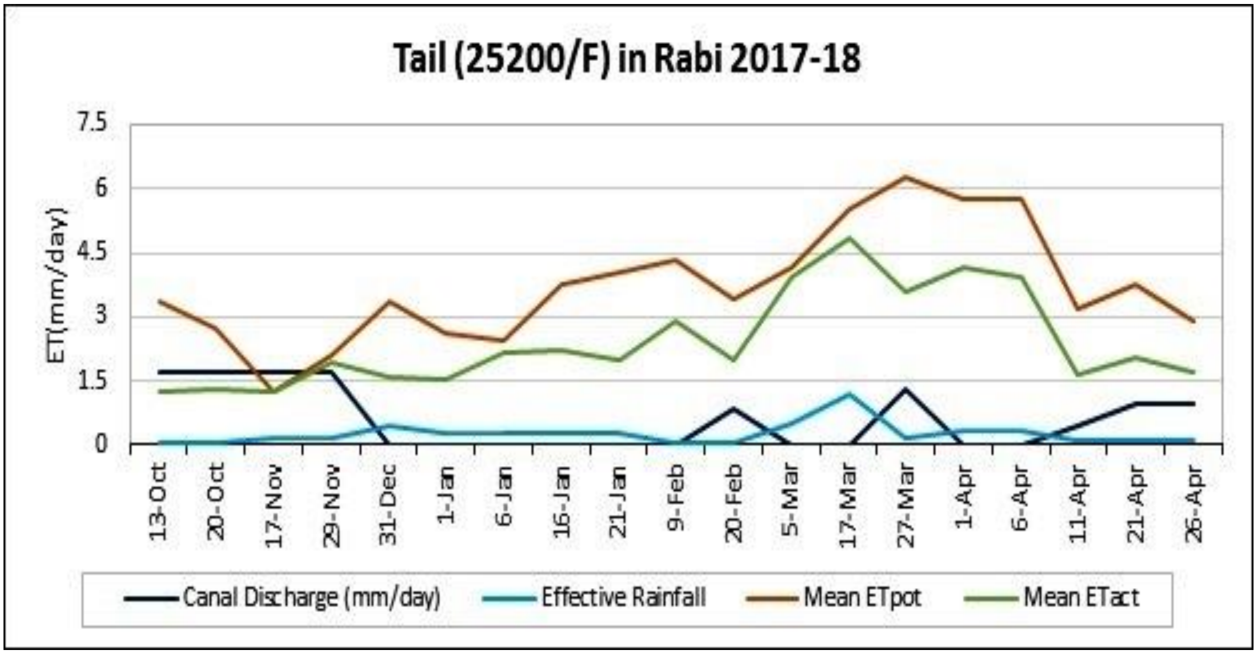

Figure 27: Crop Water Requirement and Consumption of Outlet (25200/TF) in Rabi 2017-18

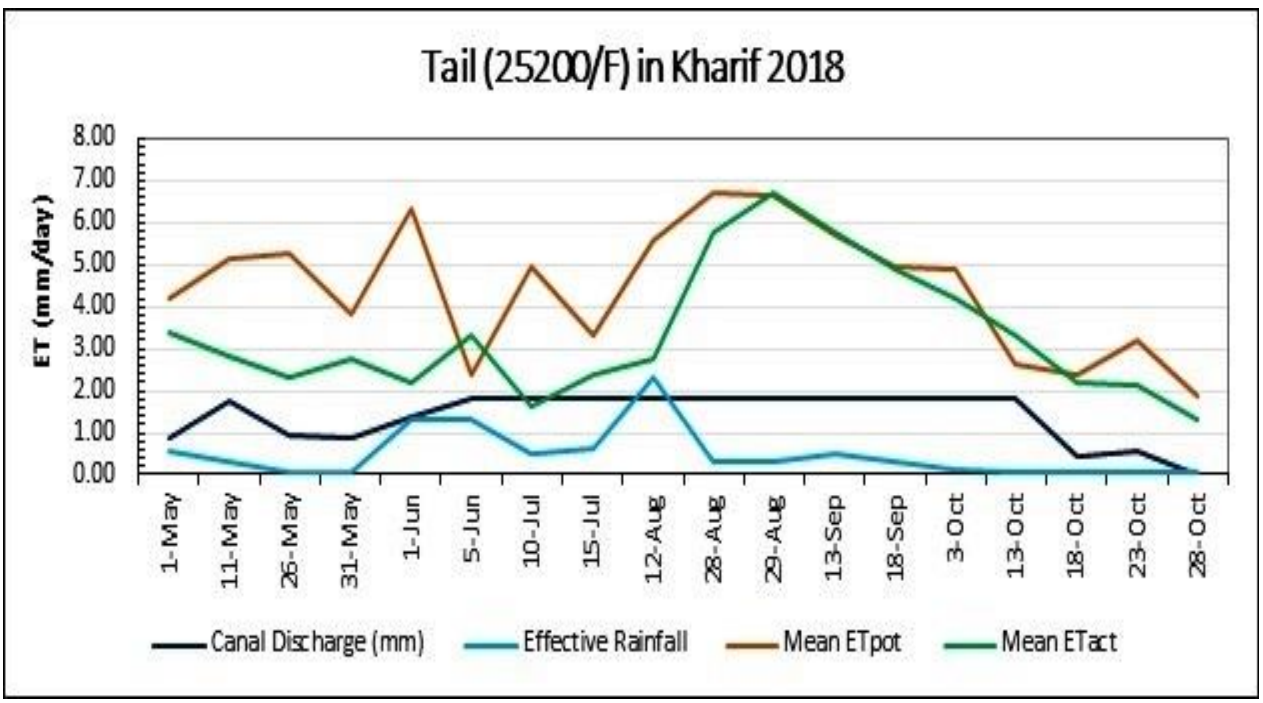

Figure 29: Overall Outlets Crop Water Requirement in Rabi 2017-18

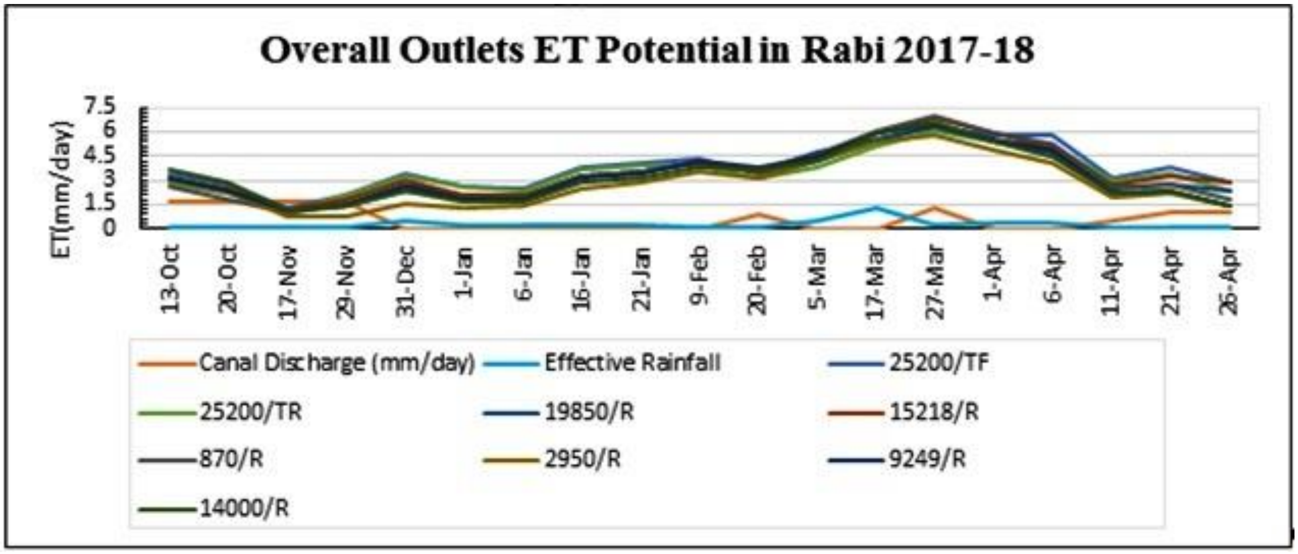

Figure 28: Crop Water Requirement and Consumption of Outlet (25200/TF) in Kharif 2018

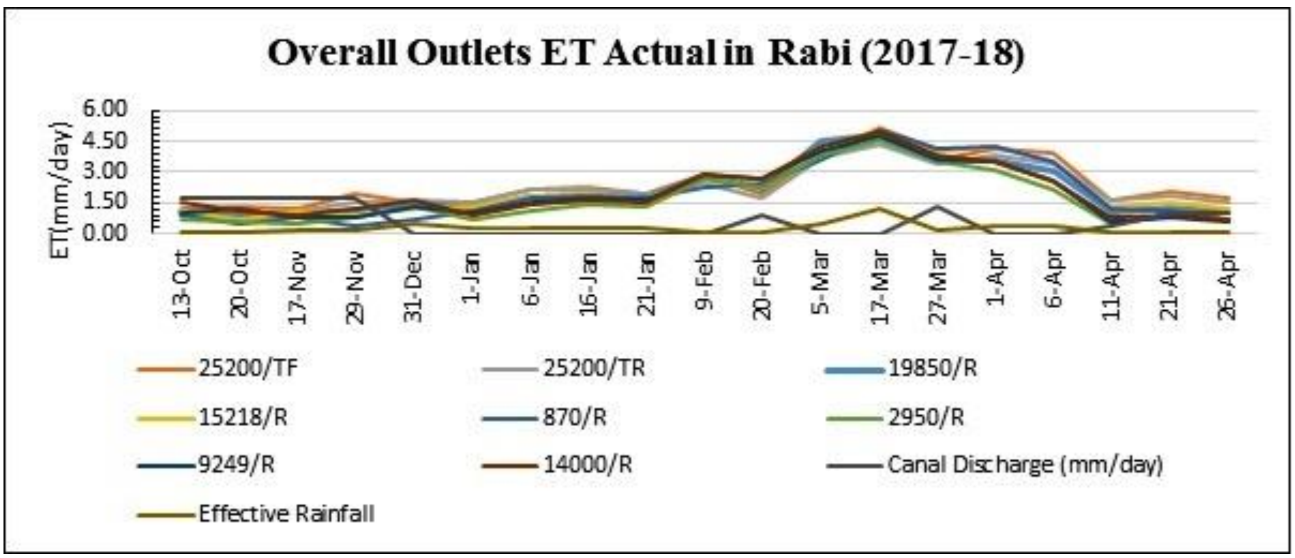

Figure 30: Overall Outlets Crop Water Consumption in Rabi 2017-18

Descriptive Statistics of all Outlets in Rabi 2017-18: The detailed description about all outlets the Table 3 is showing mean crop water demand, consumption and deficit in rabi season 2017-18.

Table 3: Descriptive Statistics of all Outlets in Rabi Season 2017-18.

Outlet No	Mean ET_{pot} in Rabi(mm)	Mean ET_{act} in Rabi(mm)	Mean Deficit in Rabi (mm)
870/R	557.28	342.00	215.28
2950/R	455.93	294.40	161.53
9249/R	541.10	333.95	207.14
14000/R	525.78	345.24	180.54
15218/R	575.51	370.32	205.20
19850/R	548.76	358.26	190.50
25200/TR	565.82	368.53	197.29
25200/TF	606.54	404.55	202.00
Overall Mean	547.09	352.16	194.94

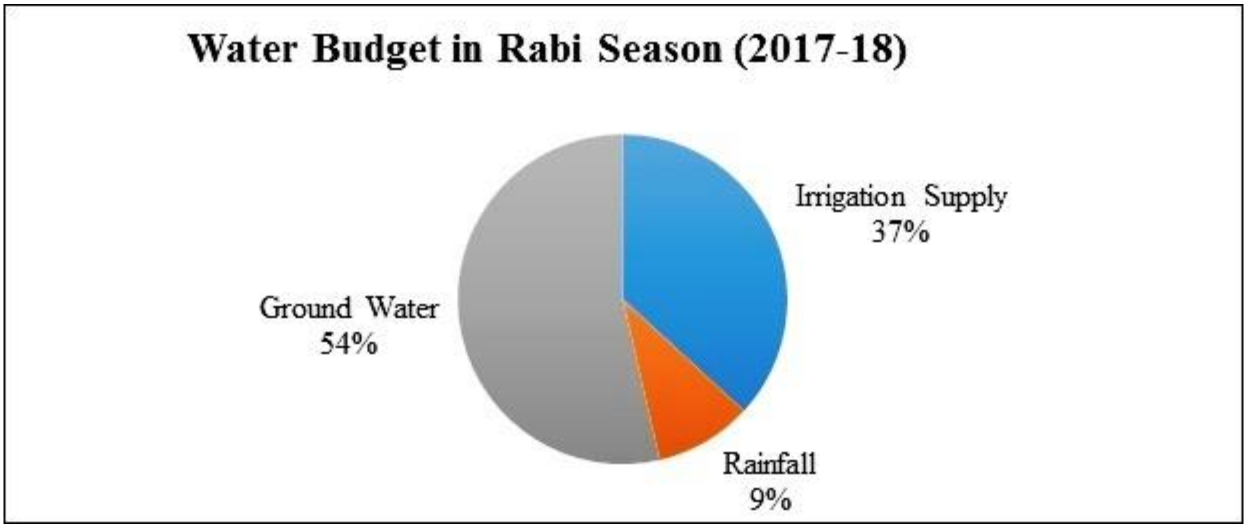

Figure 31: Water Budget in Rabi Season (2017-18).

Overall Crop Water Requirement and Consumption in Kharif Season 2018: Crop water requirement and consumption varies according to the crop growing time till mature stage and also depends upon area of outlet command included cultivated crops there. Rice is dominant Kharif crop, cultivated in the whole study area and it requires a great amount of water throughout the season. So, graph depicts high values in both CWR and consumption as compare to rabi season as shown in the Figure 32 and Figure 33. The total mean CWR volume for kharif was required 608 mm while crop water consumption is 425 mm. The canal supply was 201.6 mm from total consumption which is 48 % of total consumption from remaining. The total rainfall was 129 mm in the whole season which is 30 % of total consumption remaining 22 % is utilized from ground water pumping. The Figure 34 is also showing overall water budget in kharif season 2018. he total deficit was 184 mm in the whole season which effected the yield production.

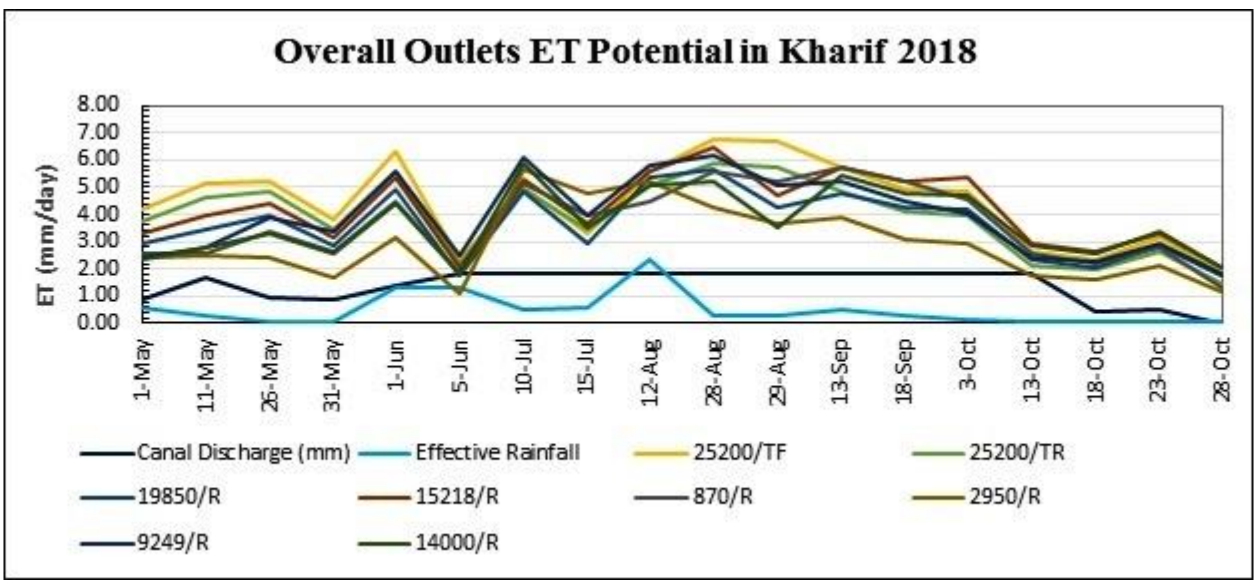

Figure 32: Overall Outlets Crop water requirement in Kharif 2018

Descriptive Statistics of all Outlets in Kharif Season 2018: The detailed description about all outlets the Table 4 is showing mean crop water requirement, consumption and deficit in rabi kharif season 2018.

Table 4: Descriptive Statistics of all Outlets in Kharif Season 2018.

Outlet No	Mean ETpot in Kharif(mm)	Mean ETact in Kharif (mm)	Mean Deficit in Kharif (mm)
870/R	588.11	441.01	147.10
2950/R	474.62	248.71	225.91
9249/R	628.76	377.48	251.27
14000/R	589.42	403.78	185.64
15218/R	668.43	523.99	144.44
19850/R	579.26	399.00	180.26
25200/TR	626.89	470.84	156.06
25200/TF	710.63	532.22	178.41
Overall Mean	608.27	424.63	183.64

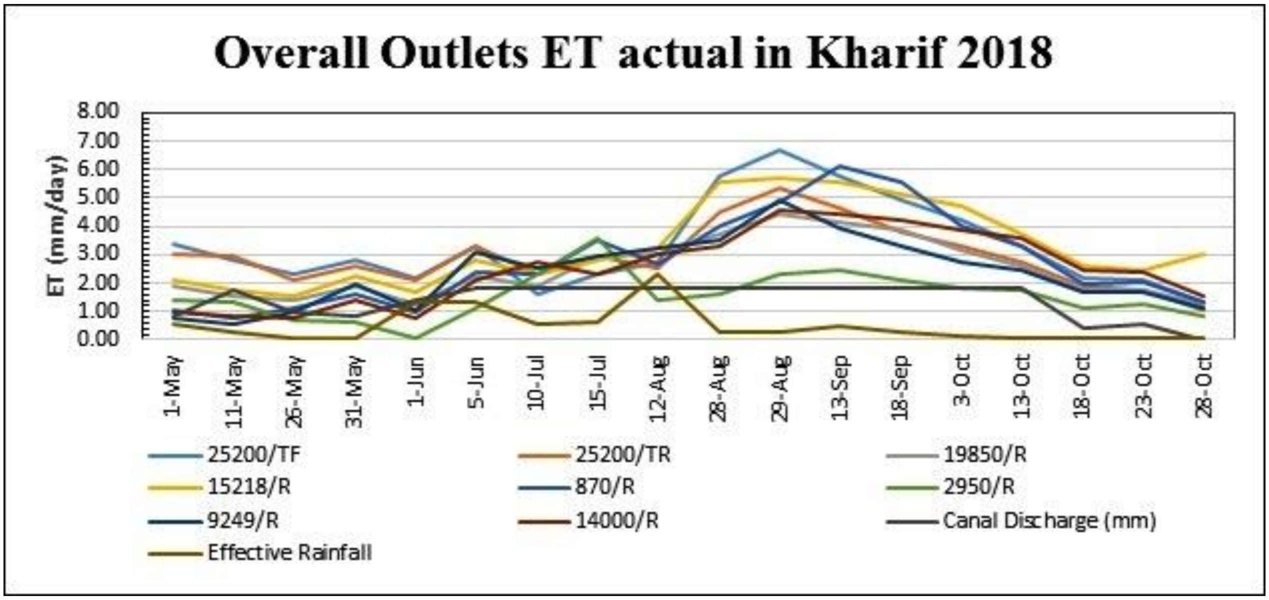

Figure 33: Overall Outlets Crop Water Consumption in Kharif 2018

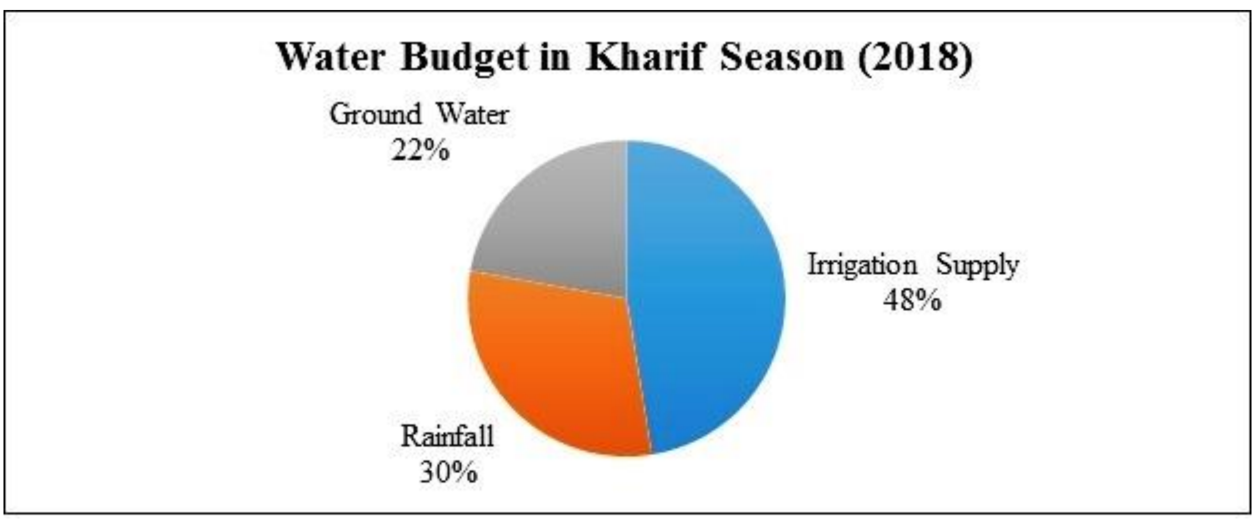

Figure 34: Water Budget in Kharif Season 2018

Conclusions and Suggestions for Future Work

Conclusion: This part of the research elaborates the findings of this research that were accomplished for the sustainable management of water within distributary command level with the help of remote sensing and GIS. For this purpose, 5-R distributary canal was selected in Sahiwal district, which was investigated at outlet command level. In the contemporary research, crop water budget was calculated by using remote sensing techniques based on SEBAL model. The conversion of the analogue maps of outlet command area to digital georeferenced format was necessary to achieve results at farm level. Watercourse network and Murabba boundaries were delineated after detailed field survey to develop decision support system for farm level monitoring of irrigation supplies. Crop classification provided by Punjab Irrigation Department was verified during field verification and was found 85% accurate in rabi season and 75% true in kharif season. Major crops identified for Rabi season were Wheat, Spring Maize and Fodder, while Rice and Cotton were found major crops of the kharif season. The results showed that crop water requirement and consumption were low at initial stage and gradually increased with crop development stage and attained peak level at mid stage, which eventually started to decease towards mature stage. The resultant crop water deficit values varied throughout the season and it attained highest level during mid stage when crop required maximum water in both rabi and kharif seasons. In this study it is revealed that the higher crop water requirement and consumption is observed at tail outlet command in comparison with head reach outlets. It is concluded that Remote sensing and GIS is of great help to observe crop water consumption at regular intervals at farm level scale. Results can be utilized to increase or alter irrigation supply at particular outlet by observing crop growth, crop demand and climate conditions.

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