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ASSIGNMENT PART III

Scheme Performance Assessment at ROI02 (2015/2016)

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Assignment Part III:
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1. INTRODUCTION

The second-largest endorheic lake is in northwest Iran, called Lake Urmia and is discharged from Lake Urmia basin – a closed drainage basin with an area of around 51800 km2. However, there is the shrinkage of the lake and a dramatic decrease in water level from 1278.5 m to 1271.58, starting in 1995, due to uncontrolled increase of the irrigated area, combining with poor agricultural water use efficiency(*Schulz et al.*, 2020). For the restoration of the Urmia Lake, the Iran government announced Urmia Lake Restoration Program (ULRP), which mandated the reduction of 40% of water consumption and the promotion of water efficiency within five years in agriculture sectors, especially in Maindoad area, called Maindoad Irrigation Scheme (MIS)(*Michel*, 2017). Therefore, **it is crucial to conduct a thorough study in MIS to assess the MIS performance to help the government in devising informed strategies for increasing the water efficiency and reducing the water consumption**, which is the aim of this assignment.

This part of the assignment analyzed the crop water consumption and land and water productivity for two main crops at a region of interest of 02 (ROI 02), as shown in fig.1. Also, the assessment of irrigation service delivery performance is the significant part, including Adequacy, Equity, Uniformity, Productivity and Efficiency. According to the evaluation, **the reflections and recommendations for improving the water efficiency and the reduction of agriculture water consumption in ROI 02 in 2015/2016 crop year** were proposed by the researcher.

Many studies focus on the estimation of the crop water parameters (evapotranspiration, biomass production and soil moisture) using remote sensing technology(*Calera et al.*, 2017; *Er-Raki et al.*, 2007; *Li et al.*, 2008; *Prasad et al.*, 2006). Importantly, *Bastiaanssen et al.*, (1998) proposed a remote sensing algorithm, called the Surface Energy Balance Algorithm for Land (SEBAL), for estimating crop water parameters. **In this case study, the actual evapotranspiration, transpiration, evaporation and biomass production were estimated by this approach.** Moreover, the reason for remote sensing technology widespread in irrigation management is the associated low cost and lack of transferred technology, compared with in-situ measurement(*Bandara*, 2006).

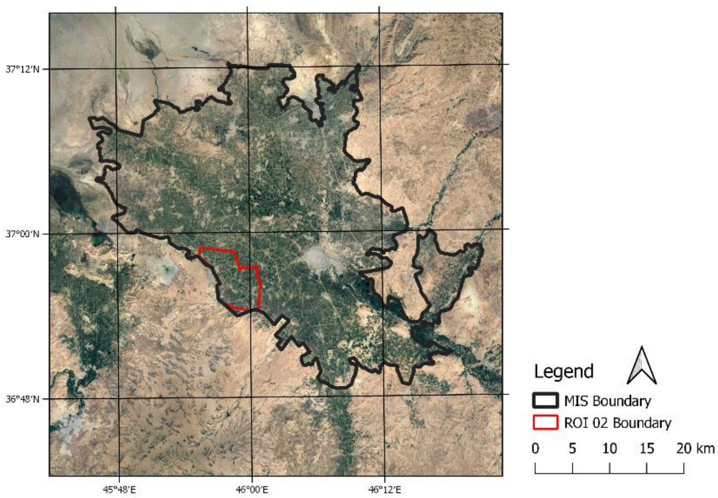

Figure 1 Boundary of ROI02 (red line) and Miandoab (black line)

2. DATA AND METHODOLOGY

2.1 Data

2.1.1 Requirement of PySEBAL

Actual evapotranspiration, Biomass production, Actual transpiration and Actual transpiration were estimated by PySEBAL, which is the program of the SEBAL model ran by python. The data for running PySEBAL could be divided into followed four parts: 1. Satellite data; 2. Meteorological data; 3. Topography; 4. Soil hydraulic properties.

Primary information was collected by remote sensing technique, including electromagnetic waves, and topography. Landsat 8 L1TP imageries were used, consisting of 12 bands in visible, near-infrared, short wave infrared and thermal infrared portion of the spectrum of the electromagnetic waves for estimating crop water parameters by SEBAL. And the monthly images from Oct 2015 to Sep 2016, were downloaded from earth explorer in United States Geological Survey (USGS) (retrieved from https://earthexplorer.usgs.gov/). Also, the digital elevation model (DEM) was downloaded on this website.

Moreover, the three hourly Meteo data were obtained from the global model - GLDAS (retrieved from https://hydro1.gesdisc.eosdis.nasa.gov/data/GLDAS/GLDAS_NOAH025_3H.2.1/). The instantaneous and daily averaged data containing the wind speed, air temperature, pressure and relative humidity, were computed by GDAL library and GRASS GIS, referring to https://pysebal-doc.readthedocs.io/en/version3.7.3/data.html#meteo-data.

Soil hydraulic properties, including saturated water content, residual water content, field capacity and wilting point, are important for the estimation of crop water parameters. There are free data available from HiHydroSoil in Futurewater (retrieved from https://www.futurewater.eu/)

2.1.2 Other data and explanation

The boundaries of the Maiondoad and ROI02 and fields in ROI02 were provided from Dr.Karimi and Dr. Pareeth. Moreover, the background of maps was obtained by google satellite. The main crops in ROI02 were identified by crop type map, which was classified by the classification program in google earth engine (GEE), and Dr.Pareeth programmed the code.

However, different crops have different crop seasons. In this case study, the two main crops are Wheat and Barley and Alfalfa. The crop season of Alfalfa in 2015/2016 crop years is from Oct 2015 to Sep 2016, and the crop season of Wheat and Barley is from Oct 2015 to July 2016, according to a typical crop calendar (Fig.2). Therefore, the definition of the season in the unit is different.

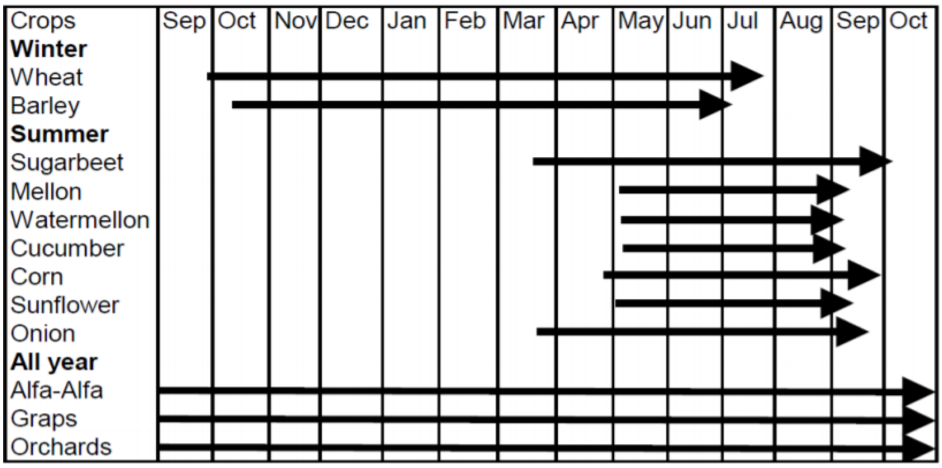

Figure 2 A typical crop calendar in Miandoab (Source: from slides in class)

2.2 Methodology

2.2.1 Principle of SEABL

The crop water parameters include the evapotranspiration (ET) related to the vapour water loss, and it cannot be seen. But a lysimeter could measure ET, which is located on the ground. However, the data, obtained from the lysimeters, are point values and cannot be analyzed the spatial and temporal effects of different combinations of atmospheric, plant and ground components. Fortunately, the remote sensing data processing by SEBAL can present the spatiotemporal variation of ET.

SEBAL *(Bastiaanssen et al.,* 1998) is a remote sensing algorithm that uses satellite images in the visible and thermal infrared portion of the spectrum of the electromagnetic waves to calculate the Latent heat flux at the basin level. It uses the following formula to calculate the residual ET in the flux of the surface energy budget equation at the pixel image resolution:

$$\lambda ET = R_n - G - H$$

Where:

λET: *Latent heat flux (W/m^2)*

R_n: *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)*

2.2.2 Irrigation Performance Assessment with Indicators

The irrigation performance assessment is that the irrigated agriculture is observed, documented and interpreted systematically for the objective of continuous improvement. There have several irrigation performance parameters, using for this assignment, as shown in following: 1) Adequacy; 2) Equity; 3) Uniformity; 4) Productivity; 5) Efficiency(*Bos et al.*, 2005). Service Performance Criteria and indicators with the remark are presented in figure 3.

1) Adequacy: the ability which targeted irrigation water deliver to a specific, represented by two indicators of the dimensionless ratio. The ratios are defined as:

$$Relative\ evapotranspiration = \frac{seasonal\ ET_{actual}}{seasonal\ ET_{potential}}$$

$$Relative\ water\ deficit = 1 - \frac{ET_{actual}}{ET_{potential}}$$

2) Equity: the degree of fairness to irrigation water delivery by all. The coefficient of variation of the averaged evapotranspiration per field in the scheme gives valuable information to the water manager. The indicator is defined as:

$$Equity = CV(ET_{actual}\ per\ field)$$

3) Uniformity: the even degree to the spatial distribution of irrigation application in the field. The indicator is the coefficient of variation of averaged evapotranspiration per pixels in a field, as shown in the following:

$$uniformity = CV(ET_{actual}\ per\ pixel)$$

4) Productivity: to estimate the efficiency of production. Outputting the water productivity of biomass production and yield are important for this service performance, computed by

$$WP_b = \frac{Biomass\ production}{ET_{actual}}$$

$$Fresh\ yield = \frac{Harvest\ index \times Biomass\ production}{Dry\ matter\ content} \qquad WP_y = \frac{Fresh\ yield}{ET_{actual}}$$

5) Efficiency: system's ability to minimize water losses due to oversupply. The dimensionless ratio of actual transpiration over evapotranspiration is the indicator to present the irrigation efficiency for water management, called beneficial fraction, as written by:

$$\text{Beneficial Fraction} = \frac{T_{actual}}{ET_{actual}}$$

Criteria	Indicator	Remark
Adequacy	RET	Accumulated seasonal average ETa and ETp per field*
	RWD	Accumulated seasonal average ETa and ETp per field*
Reliability	Temporal variation of RET	Accumulated average ETa and ETp per field at smaller time intervals (e.g. 10 day, monthly) *
Equity	CV of ET	Accumulated seasonal average ETa per field inside the shceme/block*
Uniformity	CV of ET	Accumulated seasonal average ETa per pixel inside a field
Productivity	Biomass production	Accumulated seasonal average B production per unit of area per field*
	Yield	Average yield per unit of area per field*
	WP_B	Biomass Water productivity per field*
	WP_Y	Yield Water productivity per field*
Efficiency	Beneficial fraction	Accumulated seasonal average Ta and ETa per field*

Figure 3 Service Performance Criteria and indicators (Source: from slides in class)

3. RESULTS

The two main crops at ROI02 in Maindoab in 2015/2016 crop year are Alfalfa and Wheat and Barley. The spatial distribution of seasonal water consumption and water productivity of the two crops were analyzed in areas, which were classified in crop type map, as shown in figure 4. Moreover, fields in ROI02 with irrigation canal network were used for irrigation performance assessment. The determination of the main crops in fields were evaluated by QGIS, and the fields of Alfalfa and Wheat and barley in crop type are shown in figure 5. Importantly, the values of pixels averaged in each field for comparison.

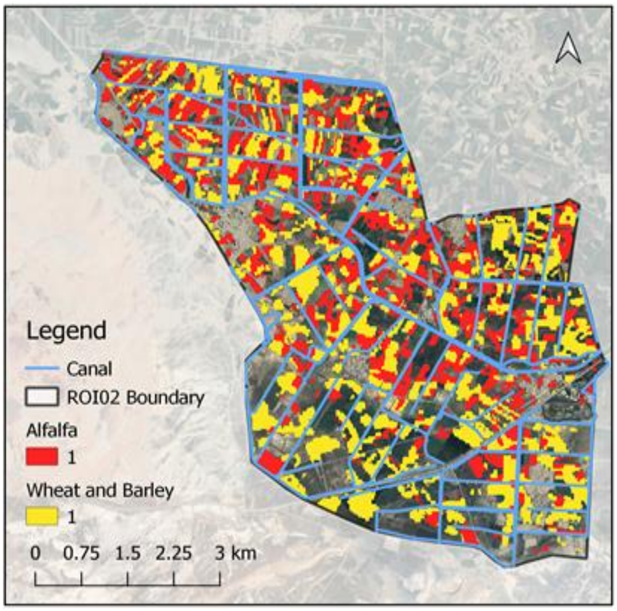

Figure 4 Profile of Alfalfa (red) and Wheat and Barley (yellow) in ROI02 in 2015/2016 crop year

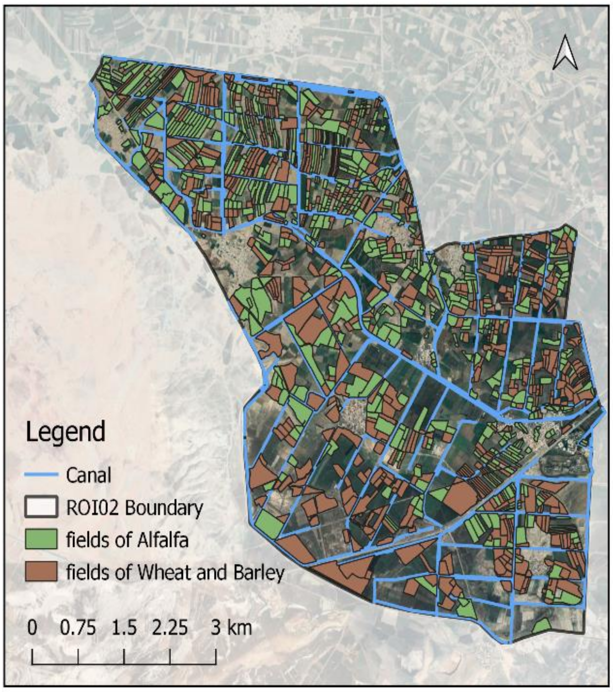

Figure 5 Fields with majority crop of Alfalfa (green) and Wheat and Barley (brown)

3.1 Seasonal crop water consumption

3.1.1 Alfalfa

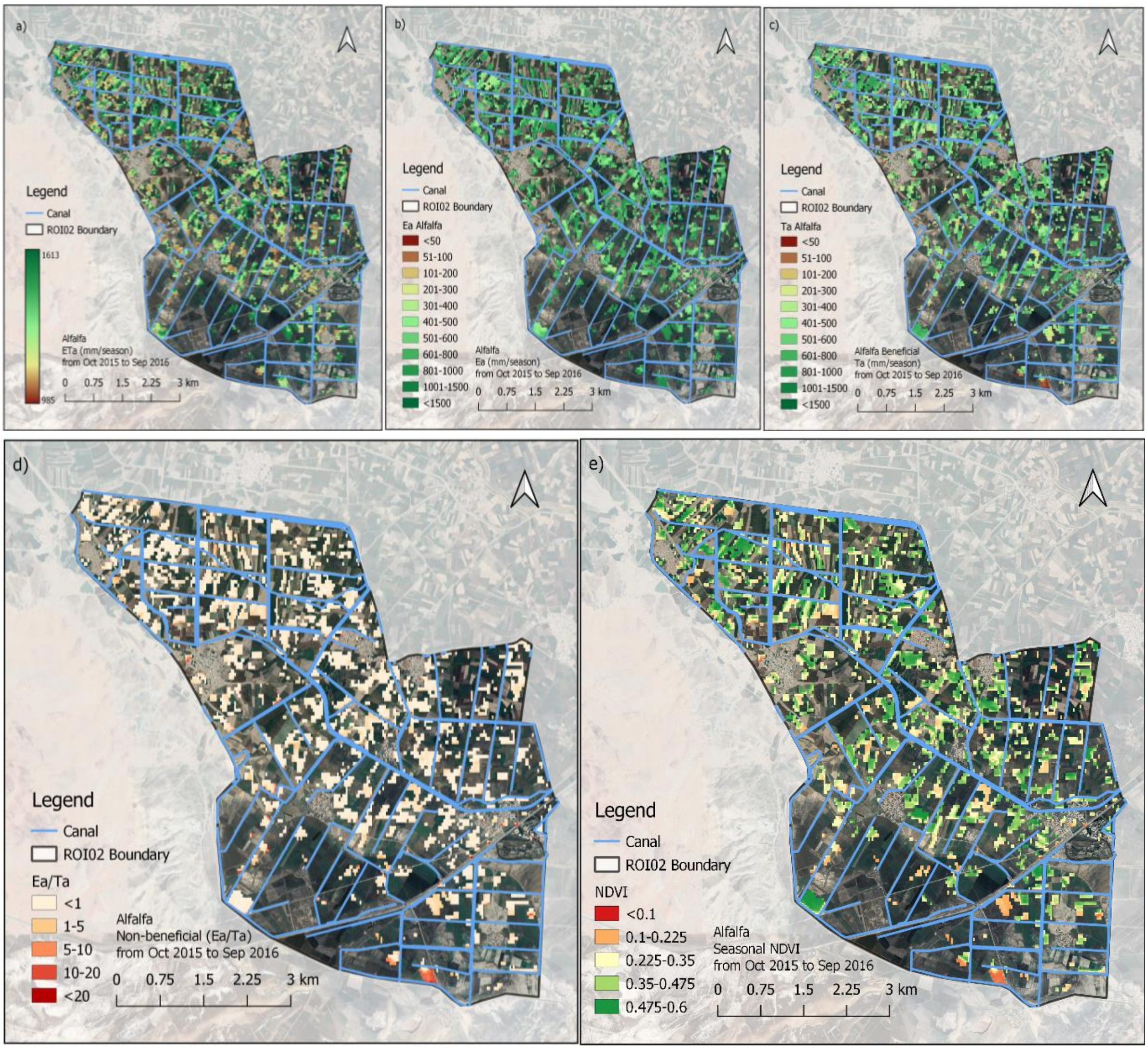

Figure 6 Seasonal water consumption of Alfalfa in 2015/2016 crop year: a) Seasonal Actual Evapotranspiration (mm/season); b) Seasonal Actual Evaporation (mm/season); c) Seasonal Actual Transpiration (mm/season) [Beneficial]; d) Ratio of actual evaporation over transpiration [Non-beneficial]; e) NDVI. Note that the crop season of Alfalfa is from Oct 2015 to Sep 2016.

Figure 6 presents seasonal water consumption of Wheat and Barley in 2015/2016 crop year, including seasonal ETa, seasonal Ta, seasonal Ea, Non-beneficial parameter and NDVI. Apparently, the agriculture area of alfalfas was concentrated in the central and north of the ROI 02 and the southwest of ROI has little Alfalfa. As for the evapotranspiration, the maximum of the ETa is 1613 mm/season, compared with the minimum ETa of 985 mm/season, and it is irregularly distributed of high ETa in ROI02 (fig.6a). Interestingly, the spatial distribution of the NDVI is inversed similar to the ETa that the area with low ETa has high NDVI value. Meanwhile, actual evaporation and actual transpiration are shown in fig.6 b & c where the crop area of Ea is greener than that of Ta, indicating that the Ea is generally higher than Ta. Hence to estimate the water efficiency, the dimensionless ration of actual evaporation over transpiration was used, represented the degree of non-beneficial water consumption. It is clearly shown that most areas in ROI 02 have a low ratio of non-beneficial water consumption, except in the south of ROI02.

3.1.2 Wheat and Barley

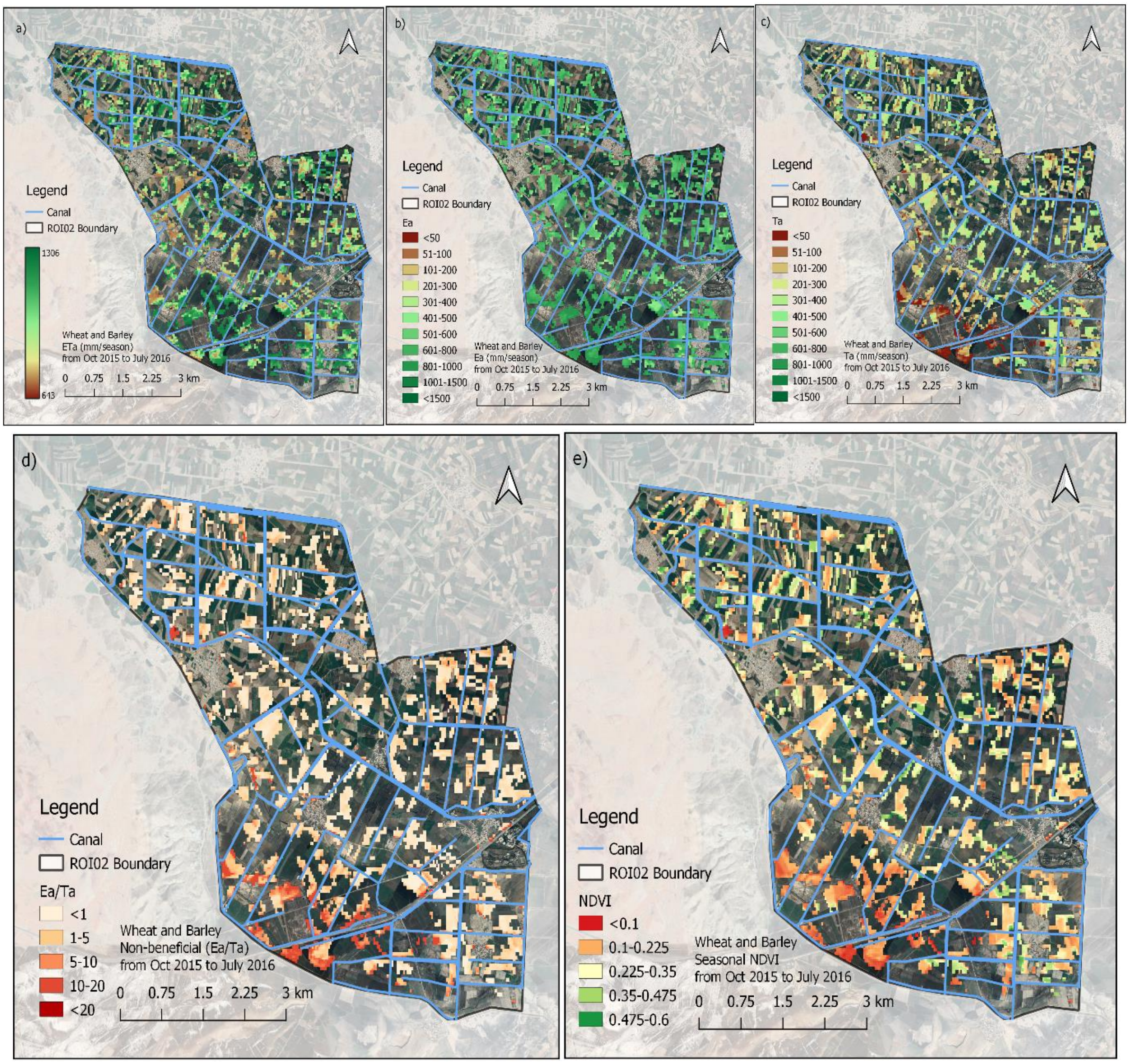

Figure 7 Seasonal water consumption of Wheat and Barley in 2015/2016 crop year: a) Seasonal Actual Evapotranspiration (mm/season); b) Seasonal Actual Evaporation (mm/season); c) Seasonal Actual Transpiration (mm/season) [Beneficial]; d) Ratio of actual evaporation over transpiration [Non-beneficial]; e) NDVI. Note that the crop season of Wheat and Barley is from Oct 2015 to July 2016.

Seasonal water consumption of Wheat and Barley in 2015/2016 crop year, including seasonal ETa, seasonal Ta, seasonal Ea, Non-beneficial parameter and NDVI, are shown in figure 7. The agriculture area of Wheat and Barley distributed in the whole ROI02 and the evapotranspiration of Wheat and Barley is slightly less than that of Alfalfa by around 300 mm/season, with the maximum ETa of 1313 mm/season and the minimum ETa of 643 mm/season. Moreover, the area with high ETa was concentrated in the southwest of ROI02 (fig.7a). Apparently, Ea is much higher than Ta due to that the crop area of Ea is greener than that of Ta, as shown in fig.7 b & c, and the values of Ta in Alfalfa overtake the Ta of Wheat and Barley. Hence to estimate the water efficiency, the dimensionless ration of actual evaporation over transpiration was used, represented the degree of non-beneficial water consumption (fig.7d). It is clearly shown that most areas in ROI 02 have a low ratio of non-beneficial water consumption, except in the south of ROI02. The water efficiency of Alfalfa is better than that of Wheat and Barley.

3.2 Water productivity and Seasonal Biomass production

3.2.1 Alfalfa

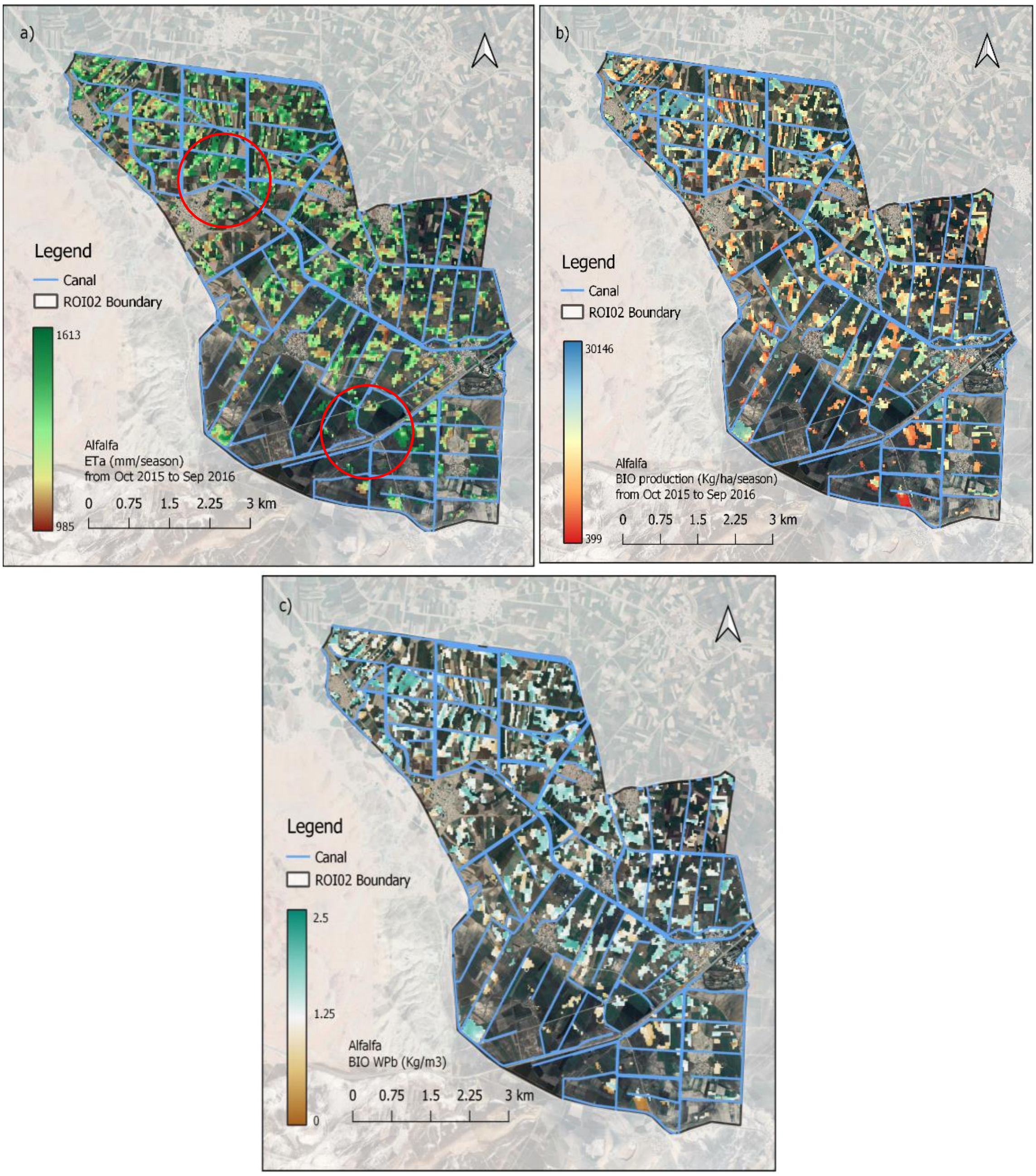

Figure 8 Crop water parameters of Alfalfa: a) Seasonal Actual Evapotranspiration (mm/season); b) Seasonal Biomass Production (kg/ha/season); c) BIO Water Productivity (kg/m3). Note that the crop season of Alfalfa is from Oct 2015 to Sep 2016.

Figure 8 presents the water productivity of Alfalfa in 2015/2016 crop year, with seasonal ETa and BIO. It shows that the agriculture area of Alfalfa located in the southwest and northwest of ROI02 with red circles has high evapotranspiration and low biomass production. Therefore, water productivity is relatively lower than in other areas, which is the ratio of biomass production to actual evapotranspiration. The difference in spatial BIO production in ROI 02 is huge, with the maximum difference of around 30000 kg/ha/season. Interestingly, the spatial distribution of the BIO is inversed similar to the ETa that the area with low ETa has high biomass production and water productivity, and the maximum of water productivity per pixels is 2.5 kg/m3.

3.2.2 Wheat and Barley

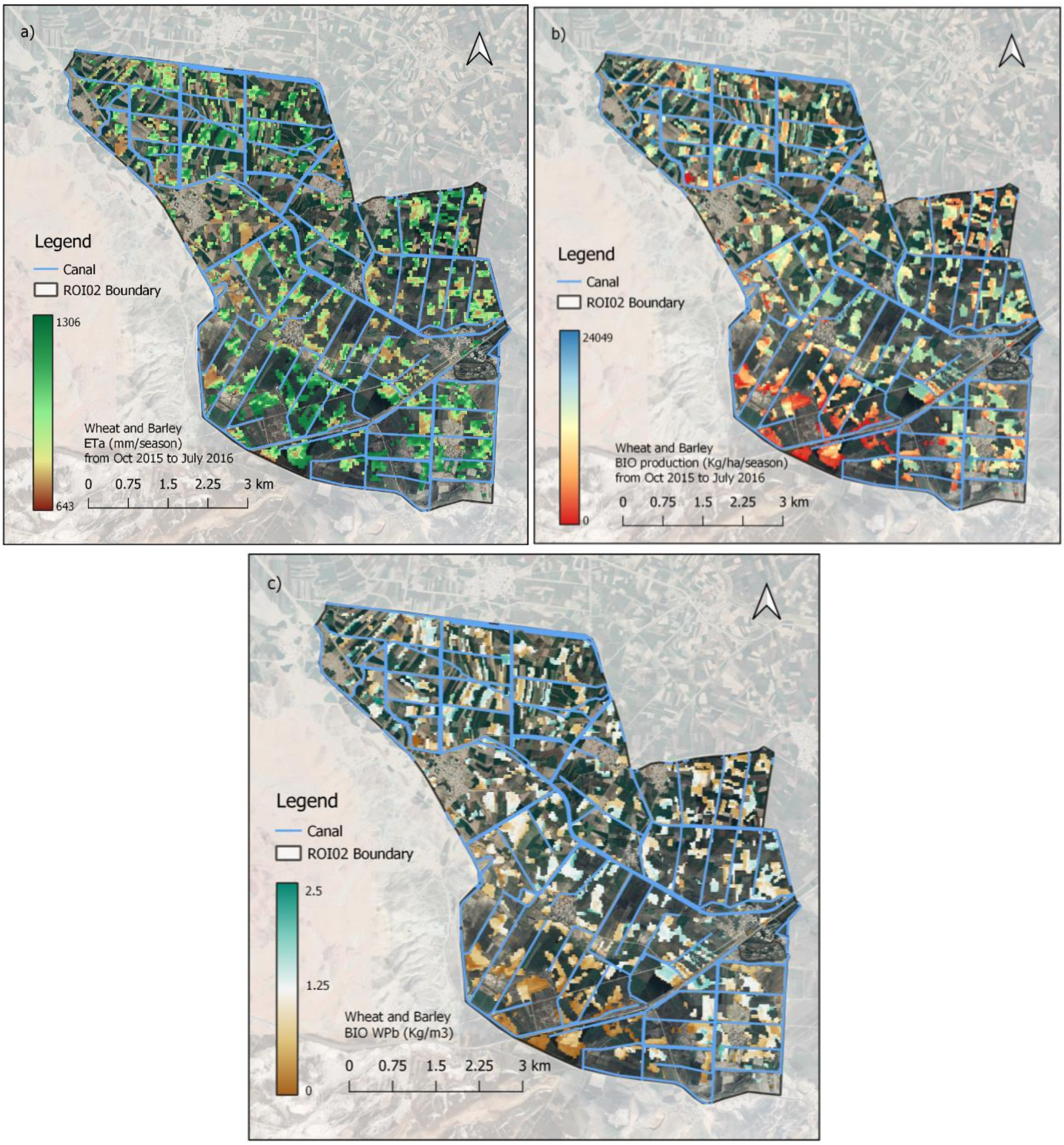

Figure 9 Crop water parameters of Wheat and Barley: a) Seasonal Actual Evapotranspiration (mm/season); b) Seasonal Biomass Production (kg/ha/season); c) BIO Water Productivity (kg/m3). Note that the crop season of Wheat and Barley is from Oct 2015 to July 2016.

Water productivity of Wheat and barley in 2015/2016 crop year, with seasonal ETa and BIO, is shown in figure 9. The spatial distribution of the BIO is inversed similar to the ETa that the area with low ETa has high biomass production and water productivity. Compared with the water productivity of Alfalfa, the Wheat and Barley's WPb is relatively low. Apparently, the water productivity of Wheat and Barley in the southwest of ROI02 is low, with high ETa and low BIO. Therefore, high water productivity appears in a single crop area with relatively low ETa value and high BIO value.

3.3 Bright spots for WP at the MIS level in ROI02

3.3.1 Alfalfa

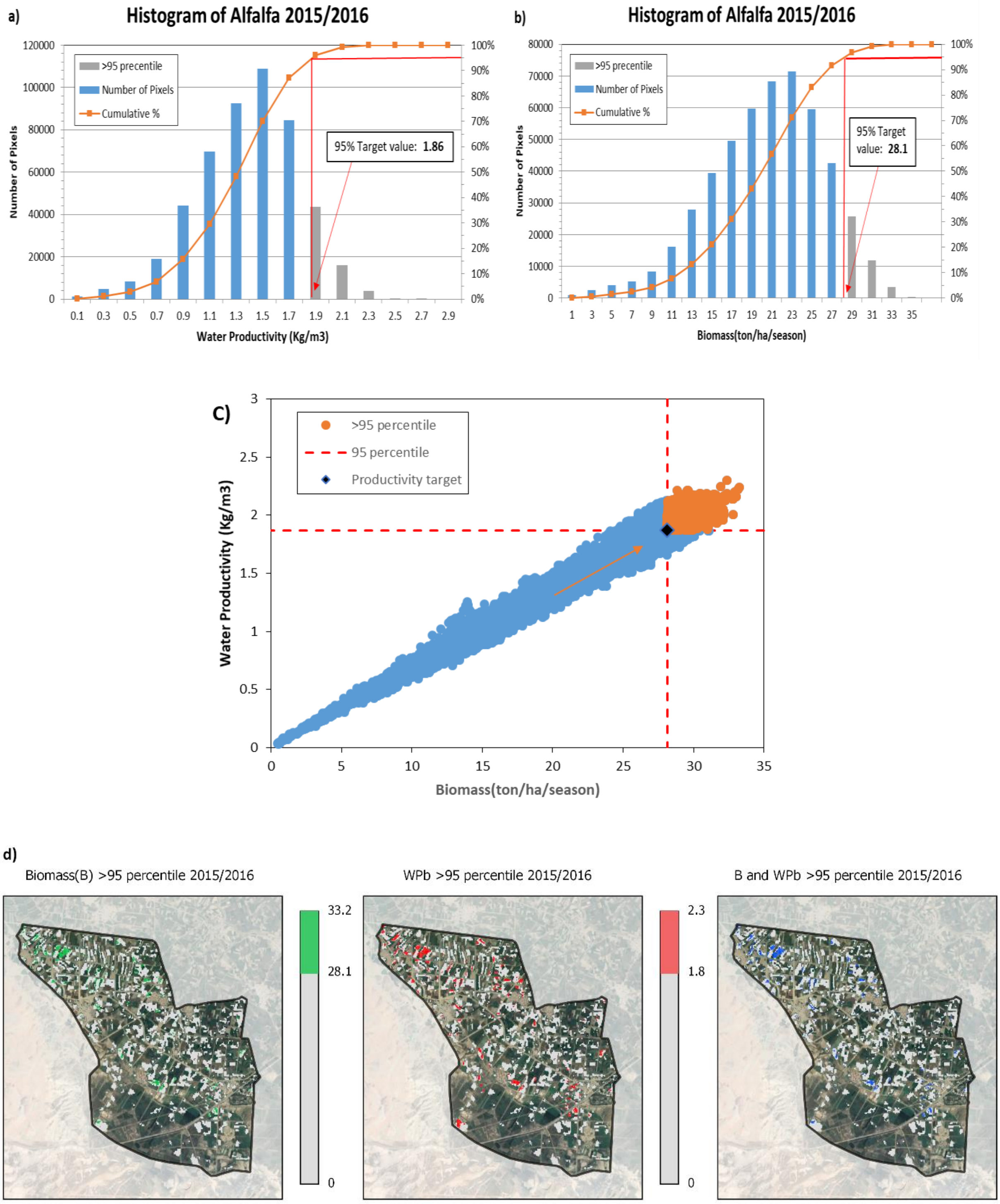

Figure 10 Bright spots of Alfalfa in 2015/2016 crop year: a) Water Productivity Histogram at MIS level; b) Biomass production Histogram at MIS level; c) determination of bright spots (organ points) by target level; d) Bright spots profile in ROI02.

The target values of water productivity and biomass production were obtained from whole Maindoab area, as shown in figure 10a and 10b, with 1.86 kg/m3 and 28.1 ton/ha /season (> 95%) respectively. The points above the thresholds are bright spots (figure 10c), which means that the biomass production and water productivity are large than 95 percentile for reaching the ideal water productivity and biomass production in ROI02. Figure 10d presents the spatial distribution of bright spots in ROI02. The spatial distribution of bright spots in BIO and WPb are similar, mainly concentrated in the middle and northwest of ROI02.

3.2.2 Wheat and Barley

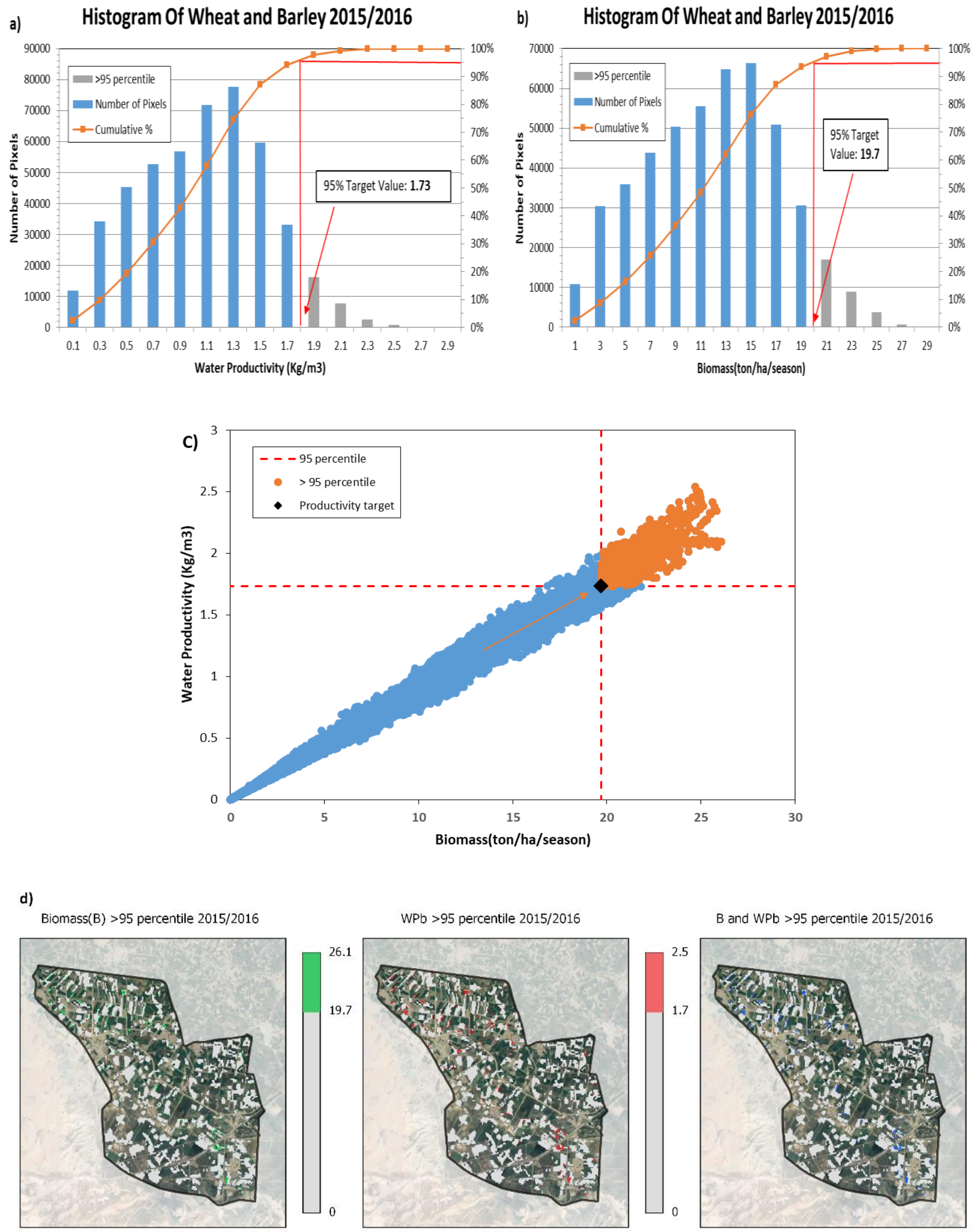

Figure 11 Bright spots of Wheat and Barley in 2015/2016 crop year: a) Water Productivity Histogram at MIS level; b) Biomass production Histogram at MIS level; c) determination of bright spots (organ points) by target level; d) Bright spots profile in ROI02.

The productivity target of water productivity and biomass production were obtained from whole Maindoab area, as shown in figure 11a and 11b, with 1.73 kg/m3 and 19.7 ton/ha /season (> 95%) respectively. The points above the threshold are bright spots (figure 11c), which means that the biomass production and water productivity are large than 95 percentile for reaching the ideal water productivity and biomass production in ROI02. Figure 10d presents the spatial distribution of bright spots in ROI02. Compared with bright spots in Alfalfa, the bright spots of Wheat and Barley are less and irregularly distribute in ROI area.

3.4 Irrigation Performance Assessment

3.4.1 Adequacy

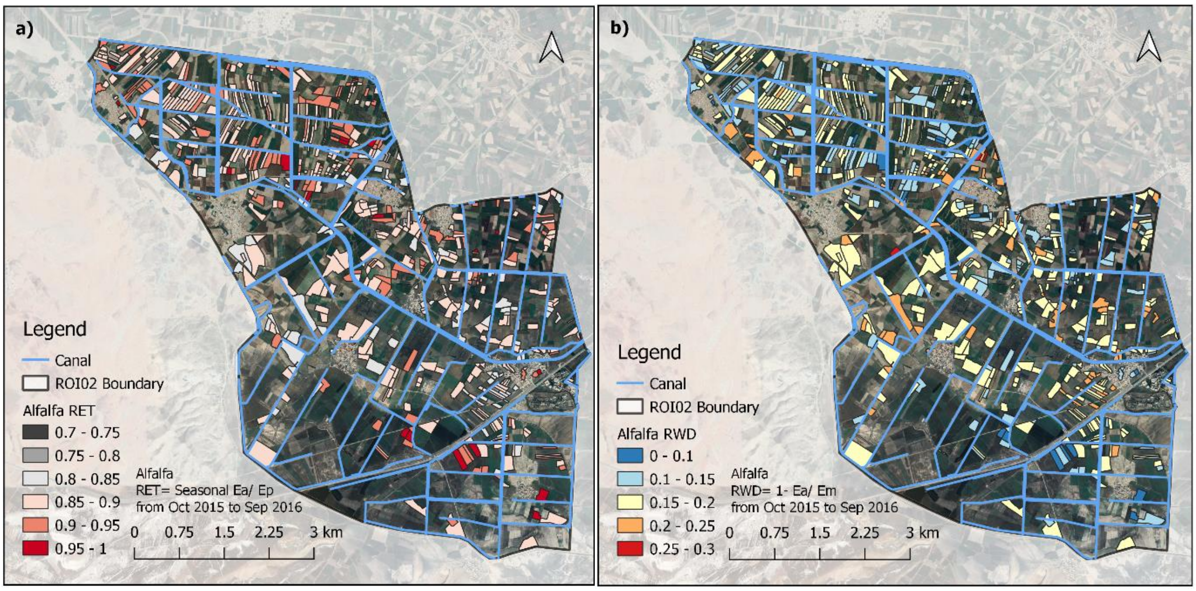

Figure 12 a) Relative evapotranspiration of Alfalfa in 2015/2016 crop year; b) Relative Water Deficit of Alfalfa

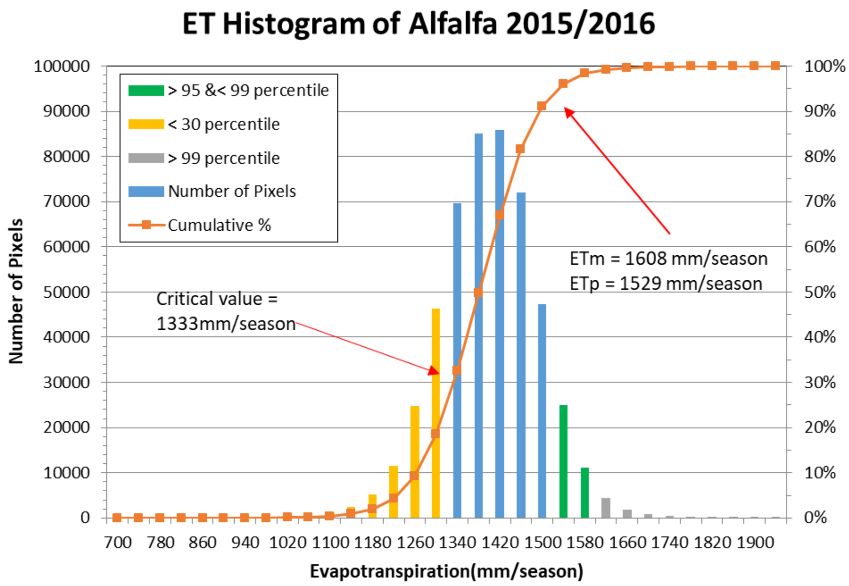

Figure 13 ETa Histogram of Alfalfa 2015/2016

Figure 13 presents the histogram of actual evapotranspiration in Alfalfa crop with a critical value of 1333 mm/season, maximum ETa of 1608 mm/season and potential ETa of 1529 mm/season. The value of potential ET equal to 95% of ETa, and the value, which overtakes 99% ETa, is the maximum ET. Moreover, ETa of 30% is defined as Critical value. Relative evapotranspiration (RET) is the ratio of seasonal ETa over potential ET, and the value, obtained by one minus the ratio of seasonal ETa over maximum ET, is relative water deficit (RWD), as shown in figure 12a and 12b. The higher value of RET, and the lower value of RWD, the stronger ability of targeted irrigated water delivery performed. In figure 12a and 12b, the adequacy of irrigated water in the center of ROI02 is relatively lower than other areas, and the area in the north presents a bad performance of Adequacy with blue or light blue in figure 12b.

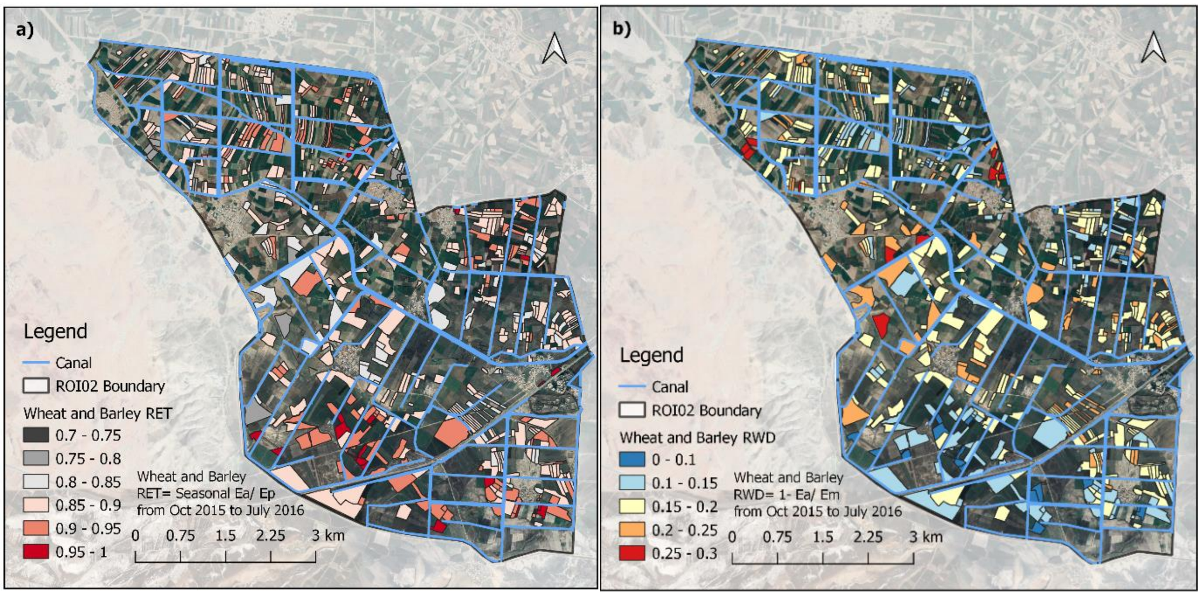

Figure 14 a) Relative evapotranspiration of Wheat and Barley in 2015/2016 crop year; b) Relative Water Deficit of Wheat and Barley

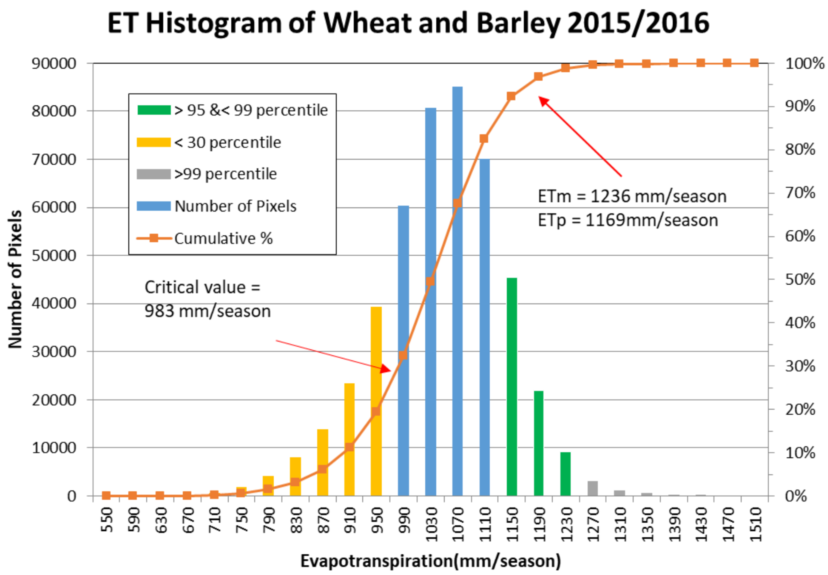

Figure 15 ETa Histogram of Wheat and Barley 2015/2016

Figure 15 presents the histogram of actual evapotranspiration in Wheat and barley with a critical value of 1333 mm/season, maximum ETa of 1608 mm/season and potential ETa of 1529 mm/season. And the adequacy of irrigated water delivery in the southwest of ROI02 is stronger than other areas, with blue or light blue in figure 14b. However, in the centre of ROI02, the RWD values are high, with red in figure 14b, which means that the Adequacy is weak.

3.4.2 Uniformity

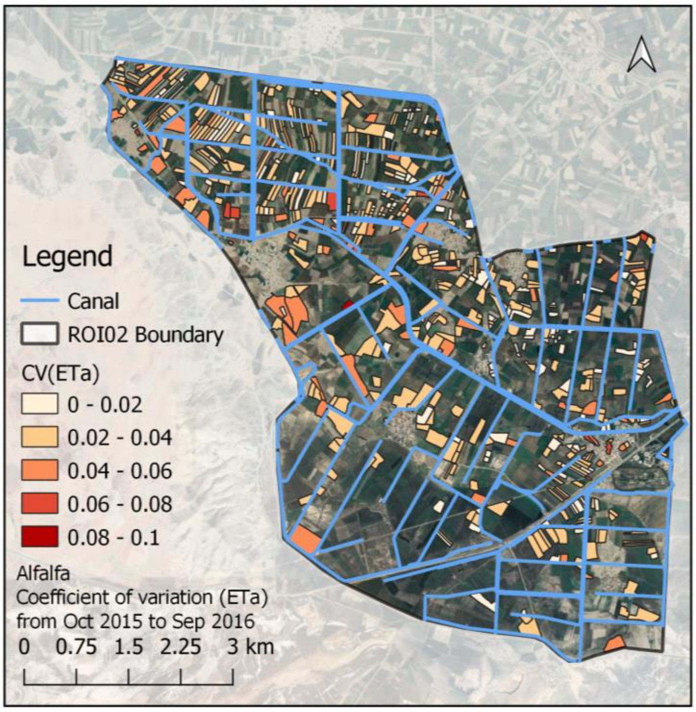

Figure 16 Coefficient of variation in ETa per field for Alfalfa

Figure 16 and 17 present the coefficient of variation in Eta per field in Alfalfa and Wheat and Barley in2015/2016 crop year. The CV(ETa) is the ratio of the standard deviation over mean actual evapotranspiration per pixel in each field. It represents the even degree of the spatial distribution of irrigated water in the field, called uniformity. The uniformity performance is better, with the decrease of the CV values. Therefore, the colour of fields of Alfalfa is redder in figure 14, the performance is bad, especially the fields in the west of ROI02. As for Wheat and barley, the irrigated water in fields was not evenly in the southwest of ROI02.

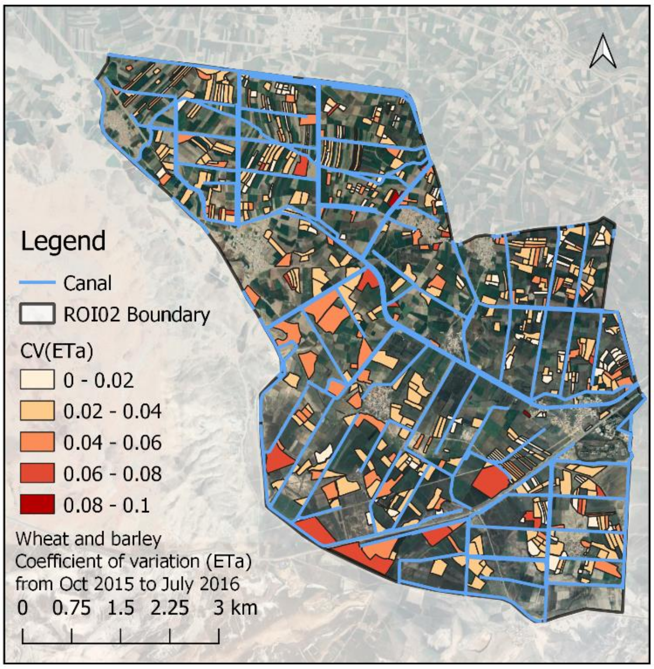

Figure 17 Coefficient of variation in ETa per field for Wheat and Barley

3.4.3 Productivity

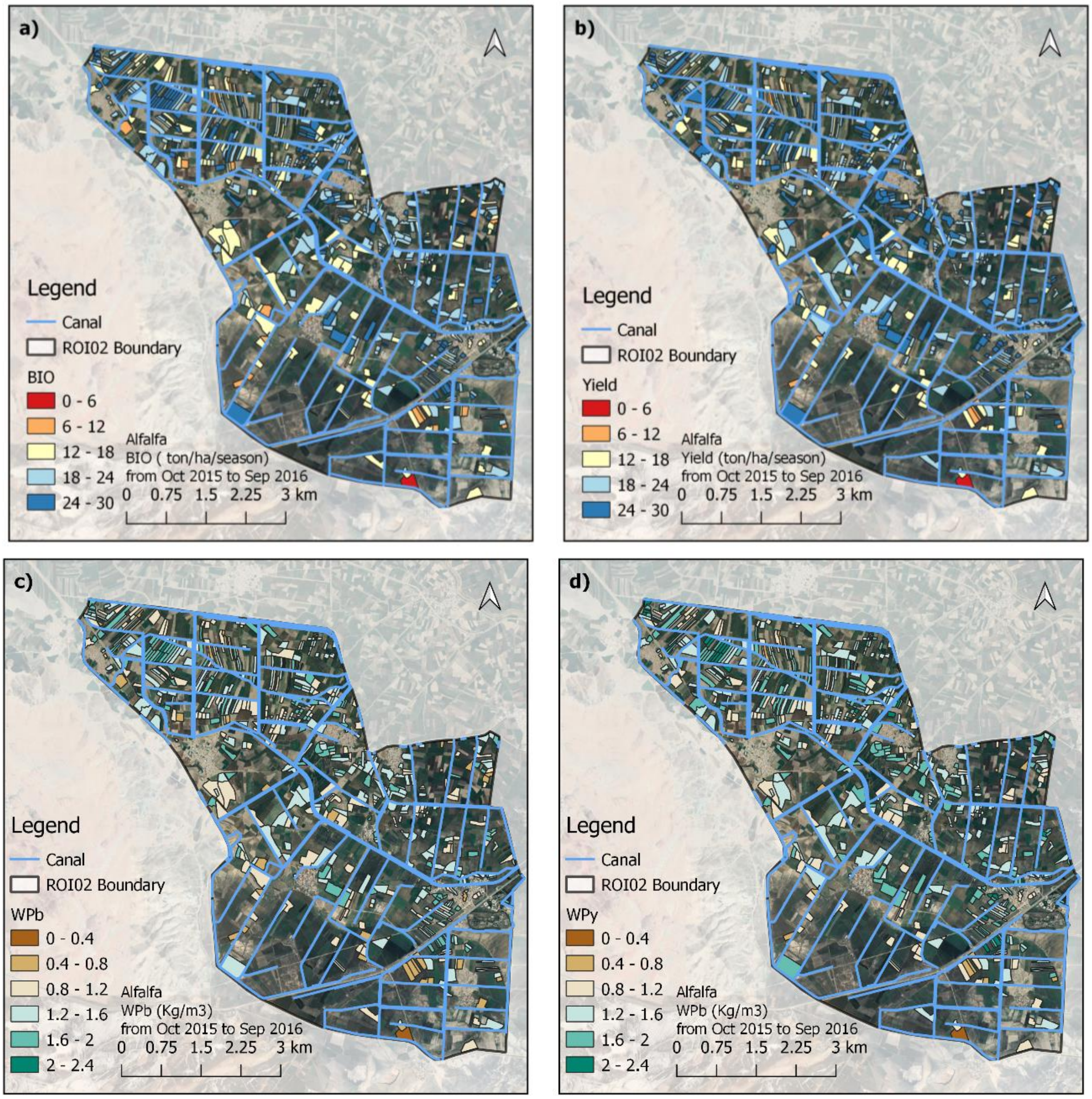

Figure 18 Productivity of Alfalfa in 2015/2016 crop year: a) Biomass production b) Fresh yield; c) BIO Water productivity; d) Fresh Yield Water productivity

Figure 18 presents the significant parameters for the estimation of yield and water productivity in Alfalfa. The fresh yields of Alfalfa were computed by dry biomass production with harvest index of 0.95 and dry matter content of 0.87(*Eve*, 2014). And fresh yield water productivity is the ratio of the yields to evapotranspiration. In figure 18, fresh yields were a slight increase, compared with the biomass production, and some fields changed colour from yellow to blue. Therefore, the water productivity of dry Biomass productions is lower than that of fresh yield.

As for Wheat and Barley, the fresh yields were obtained by dry biomass production with harvest index of 0.39 and dry matter content of 0.865(*Eve*, 2014), as shown in figure 19b. It is not difficult to find that dry biomass production is much higher than fresh yield, according to the equation of fresh yield. Hence, the water productivity of fresh yield is relatively low, compared with that of biomass production.

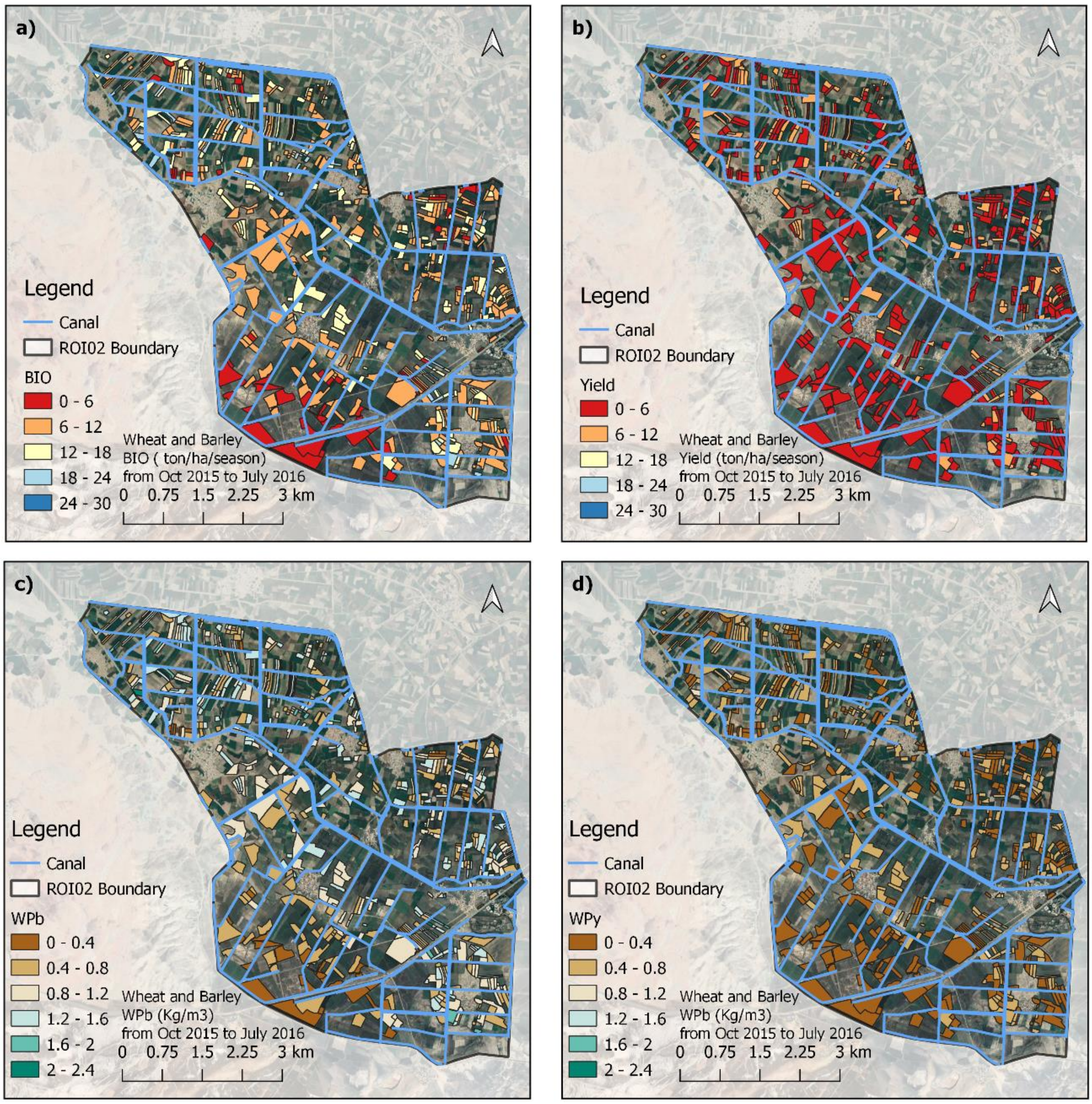

Figure 19Productivity of Wheat and Barley in 2015/2016 crop year: a) Biomass production b) Fresh yield; c) BIO Water productivity; d) Fresh Yield Water productivity

3.4.4 Equity

Table 1 CV(ETa per field) of Alfalfa and Wheat and Barley in ROI02

ETa	Mean	Standard deviation	Coefficient of Variation
Alfalfa	1346	54	0.04
Wheat and Barley	1025	49	0.05

The coefficients of variation of Alfalfa and Wheat and Barley in ROI02 is shown in the table, with 0.04 and 0.05 respectively. This parameter represents the degree of fairness for irrigation water delivery by all. According to the table, the irrigated water delivery performance well for equity.

3.4.5 Efficiency

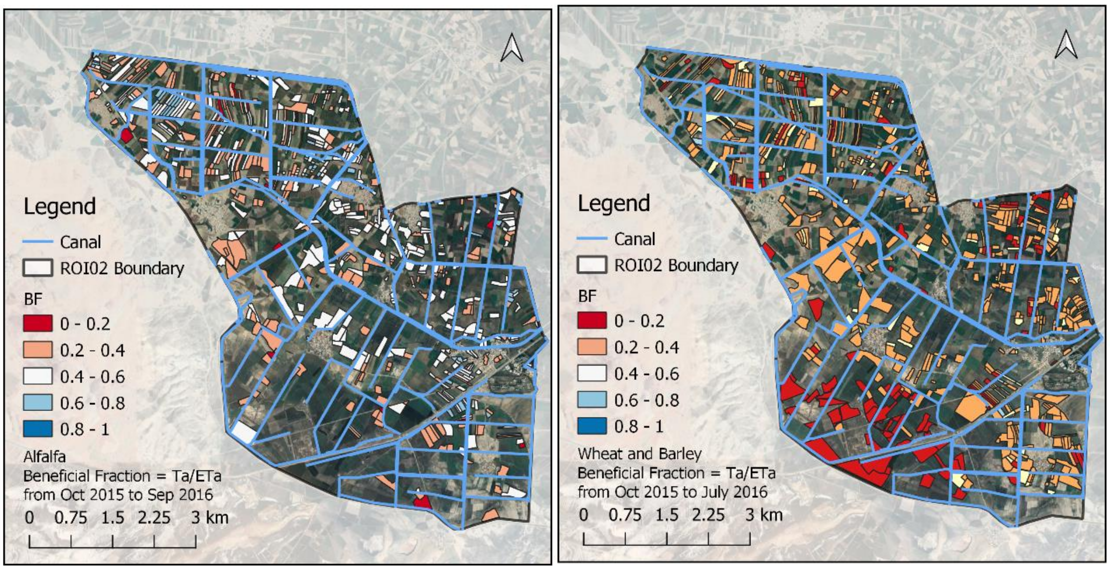

Figure 20 Beneficial Fraction in Alfalfa (left) and Wheat and Barley (right)

The beneficial fraction is the dimensionless ratio of actual transpiration over evapotranspiration which represents the irrigation efficiency in each field. The BF value more closed to 1, the higher beneficial water consumption is got. Therefore, the water efficiency of Alfalfa is better than that of Wheat and Barley, while the number of red or light red fields in Alfalfa is larger, compared with that in Wheat and barley, as shown in figure 20.

4. CONCLUSION and DISCUSSION

4.1 Conclusion

For achieving the goal of ULRP about the reduction of water consumption, this research assesses several aspects of irrigation performance and analyses the crop water consumption and yield or water productivity.

On the one hand, according to the analysis of seasonal crop water consumption, the water efficiency of Alfalfa, which is the ratio of actual transpiration to evapotranspiration, is better than that of Wheat and Barley. As for water productivity, the values of water productivity of Wheat and Barley in the southeast of ROI02 is low, compared with other areas. Moreover, the bright spots of Wheat and barley in ROI02 are apparently smaller than that of Alfalfa in ROI02, which is a significant parameter for irrigation efficiency in a single crop.

On the other hand, the irrigation performance assessment also indicates some valuable information. First, irrigated water delivery performance well for equity in the whole ROI02 in both two main crops, according to the coefficient of variation (CV) in Alfalfa and Wheat and Barley in ROI02, with 0.04 and 0.05 respectively. Meanwhile, to increase the scale, the CV values in fields related to ETa value per pixel are generally low, which means a great uniformity performance, expect the fields of Wheat and Barley in the southwest of ROI02. As for efficiency, similarly, the fields of Wheat and Barley in the southwest of ROI02 have relatively low. Furthermore, the adequacy of irrigated water delivery for Wheat and Barley in the southwest of ROI02 is stronger than other areas. Also, the water productivities of fresh yield in Wheat and Barley are much lower than that of Alfalfa, especially the fields in southwest of ROI02.

To sum up, the low water efficiency and high water consumption of Wheat and Barley in the southwest of ROI02 were identified. Therefore, we need to do some measures for reducing water consumption in this area.

4.2 Recommendation for reduction the water consumption

There are many ways to reduce water consumption.

First of all, the farmers can improve the irrigation technique or increase the density of the canal network for reduction the irrigated water. For example, the irrigation for the crop was changed from flood irrigation to drip irrigation. It can effectively reduce the evaporation for increasing water efficiency.

Secondly, the planting structure should be adjusted. According to the water use characteristics, difference of yield and difference of efficiency of crops, a reasonable crop planting structure and crop rotation method should be constructed to improve the utilization efficiency of water resources during the annual crop.

Last but not least, the farmer could upgrade Wheat and Barley varieties to increase the harvest index and fresh yield to rise the water productivity. This method indirectly reduces water consumption.

4.3 Recommendation for possible improvements with justification

4.3.1 Assessment of temporal variation of ETa

The indicators mentioned in this assignment are good parameters for irrigation performance assessment. However, this assignment mainly discussed the spatial variation of water efficiency and water consumption. Thus, the temporal variation in those two main crops in ROI02 should be analyzed. For instance, reliability is a good performance criterion for the evaluation of temporal variation of water efficiency, which is the degree of water delivery conforming to the prior expectations of users. Moreover, the more valuable information may come from the daily or monthly data due to the continuation of the evapotranspiration.

4.3.2 Errors caused by different resolution analysis

Accumulated seasonal ETa value in each field was averaged by pixel values in the field. However, it is possible missing values due to the different resolution of the raster layer and vector layer in QGIS, resulting in some errors in the estimation.

Moreover, whether the mean of ETa in each field is representative or not, we should do a deep research in the determination of ETa in each field.

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