Irrigation Performance Assessment Abadiska and UAAIE Irrigation Scheme

Service developed for Upper Awash Agro Industry Enterprise (UAAIE)

January 2023

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Water Productivity Improvement in Practice

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by

Mekonnen, K., ECDSWCo

Prepared by Kirbubel Mekonnen, EDCSWCo

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1 Background

The Awash River basin is the most intensively developed river basin in Ethiopia. The highest economic value and assets of the country are predominantly located in this basin. Despite this fact, among other challenges, water shortage is a critical problem in the Awash Basin due to the excessive withdrawal of water for irrigation purposes. To deal with this problem, the Awash Basin Water Allocation Strategic Plan (ABWAP) was developed in 2017 to improve water allocation in the basin. However, there is still a water scarcity issue in the basin, and this issue is exacerbated in the future as a result of climate change.

Along the whole stretch of the river, both commercial and non-commercial irrigation farming has been practiced. One of these is the Upper Awash Agro Industry Enterprise (UAAIE), which is located on the upper bank of the Awash River. UAAIE is the biggest producer of oranges, mandarins, and other tropical fruits like mango and papaya in Ethiopia. It uses a lot of water for irrigation according to ABWAP (2017). The company is also the main producer and supplier of tomato paste, tomato juice, orange marmalade, and guava nectar in the country. Therefore, understanding the performance of this irrigation scheme is of great importance for evaluating the productivity of schemes. Such understanding could help to design possible intervention mechanisms that could be made to improve the performance of the schemes. In this view, the Ethiopian Construction Design and Supervision Works Cooperation (ECDSWC) has developed a service for UAAIE which aims to assess the performance of the Abadiska and UAAIE irrigation scheme and to provide recommendations for improvement.

2 Description of the project area

The Upper Awash Basin, Ethiopia, is geographically located between 8° 4' to 9° 19' N latitude and 37° 57' to 39°10' E longitude (Figure 2-1). The Upper Awash basin covers an area of 11,620 km^2 with a reach length of 192 km. The basin has a complex topography with elevation ranging from 1,558 to 3,568 m.a.s.l as extracted from the Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM) of 30 by 30m resolution. The rainfall in the Upper Awash Basin exhibits a bimodal behavior: the primary rainy season occurs from June to September and the secondary rainy season from March to April. These rainy seasons are usually controlled by the movement of the Inter-Tropical Convergence Zone (Seleshi and Zanke, 2004). On average, about 91% of the annual rainfall occurs in the primary and secondary rainy seasons.

This study was undertaken in the Abdiska and UAAIE irrigation scheme which covers an area of 441 ha (Figure 2-1). The study area lies in Arsi zone Jelu Wereda and is located 150 km from Addis Ababa. Surface water is the major source of water in the Abadiska and UAAIE irrigation scheme. Pumps are used to withdraw water from the Awash River and deliver it to the unlined canals. Citrus and papaya are the main fruits grown in the study site, and furrow irrigation is the most commonly used irrigation type in the scheme (Figure 2-2). The Abadiska and UAAIE irrigation scheme comprises 26 Blocks of which 19 blocks have consistent planting date and the remaining blocks do not. Out of 19 blocks, 11 blocks are covered with citrus fruit and the remaining blocks are covered with Papaya. The fruit type and the area coverage for each block are presented in Table 2-1. The present study aimed to assess the performance of the irrigation scheme in 11 blocks of citrus crop. However, we did not include the irrigation performance assessment in 8 blocks covered with papaya because of the availability of in-situ data.

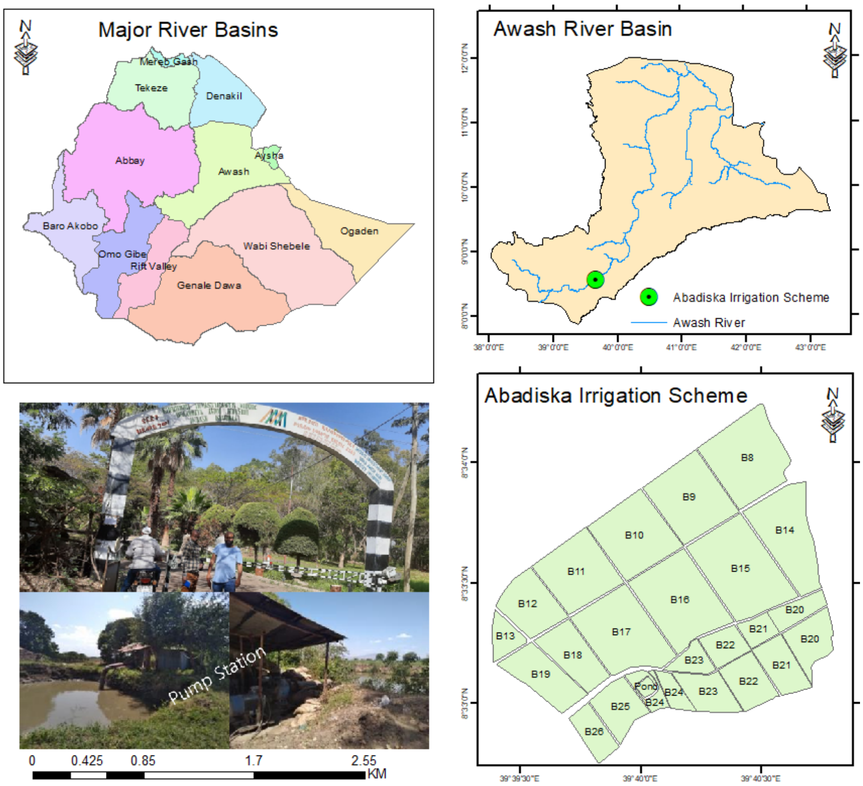

Figure 2-1: Location map of the study area

Figure 2-2: Unlined main canal, night storage and the major crops in Abadiska and UAAIE irrigation scheme

Table 2-1: Summary of crop type in each block and their area coverage. Blocks covered with Citrus Fruit were selected for the analysis.

Farm Name	Irrigation Scheme	Block Number	Area (ha)	Crop Name	Remark
Mert Jeju	Abadiska and UAAIE	B 8	32.2	Orange Valencia	Selected
Mert Jeju	Abadiska and UAAIE	B 9	28.3	Orange Valencia	Selected
Mert Jeju	Abadiska and UAAIE	B 10	26.9	Papaya	
Mert Jeju	Abadiska and UAAIE	B 11	24.7	Orange Valencia	Selected
Mert Jeju	Abadiska and UAAIE	B 12	16.4	Orange Valencia	Selected
Mert Jeju	Abadiska and UAAIE	B 13	5.7	Papaya	
Mert Jeju	Abadiska and UAAIE	B 14	27.8	Orange Valencia	Selected
Mert Jeju	Abadiska and UAAIE	B 15	37.3	Orange Valencia	Selected
Mert Jeju	Abadiska and UAAIE	B 16	33.3	Orange Valencia	Selected
Mert Jeju	Abadiska and UAAIE	B 17	31.0	Orange Valencia	Selected
Mert Jeju	Abadiska and UAAIE	B 18	14.6	Orange Valencia	Selected
Mert Jeju	Abadiska and UAAIE	B 19	16.0	Papaya	
Mert Jeju	Abadiska and UAAIE	B 20	18.2	Orange Valencia	Selected
Mert Jeju	Abadiska and UAAIE	B 21	16.1	Orange Valencia	Selected
Mert Jeju	Abadiska and UAAIE	B 22	18.9	Papaya	
Mert Jeju	Abadiska and UAAIE	B 23	15.9	Papaya	
Mert Jeju	Abadiska and UAAIE	B 24	8.2	Papaya	
Mert Jeju	Abadiska and UAAIE	B 25	11.7	Papaya	
Mert Jeju	Abadiska and UAAIE	B 26	8.3	Papaya	

3 Irrigation Performance Assessment Indicators

Four irrigation performance indicators were used to assess the performance of the irrigation scheme for the period 2015 to 2019. These indicators include Equity (Eq. 3-1), beneficial fraction (Eq. 3-2), adequacy (Eq. 3-3), and relative water deficit (Eq. 3-4) (Chukalla et al., 2022). Equity is defined as the coefficients of variation (CV) of seasonal ETa in the study area. It measures the water consumption between fields/blocks within an irrigation scheme with a homogenous crop, which could be a proxy for an even distribution of water to the different irrigated blocks. It is calculated as the CV of the average ET of each block, which is an indication of equity in the scheme. According to Bastiaanssen et al. (1996), CV of 0 to 10% is good, 10 to 25% is fair and CV > 25% is poor uniformity. The beneficial fraction (BF) is the ratio of the water that is consumed as transpiration compared to overall field water consumption (ETa) whereas the adequacy measures the relative evapotranspiration.

$$\boldsymbol{CV = \frac{ET_{sd}}{ET_m}}$$

Equation 3-1

$$\boldsymbol{BF = \frac{T_a}{ET_a}}$$

Equation 3-2

$$\boldsymbol{A = \frac{ET_a}{ET_p}}$$

Equation 3-3

$$RWD = 1 - \frac{ET_a}{ET_x}$$

Equation 3-4

ET_x can be ET_p or 99 percentile of the actual evapotranspiration.

For this analysis, both primary and secondary data were collected. Primary data were collected from the UAAIE and include planting date, harvesting date, and yield data of citrus fruits. According to UAAIE, the harvesting time for citrus is March each year, the seasons were therefore defined as starting the first of April and ending at the end of March the following year. For this study we analysed the data for four growing seasons in consecutive years from 2015 to 2019 (see Table 3-1).

Table 3-1: Specific periods defined for each of the four seasons analysed

Season	Dates
2016 season	2015-04-01 to 2016-03-31
2017 season	2016-04-01 to 2017-03-31
2018 season	2017-04-01 to 2018-03-31
2019 season	2018-04-01 to 2019-03-31

In addition, the yield data obtained from a citrus crop for Block 8 is 5.6 ton/ha. Secondary data such as Actual Evapotranspiration and Interception (AETI), Transpiration (T), Net Primary Production (NPP), Land Cover Classification (LCC), Precipitation (PCP) and Reference Evapotranspiration (RET) were collected from WaPOR data portal. These data were downloaded and processed using **WAPORWP** in python environment (Chukalla et al. 2020)[1]. The spatial and temporal resolutions of the data used in this study are presented in Table 3-2.

Table 3-2: Data used in this study

No.	WaPOR Data	Description	Spatial resolution	Temporal resolution	Coverage
1	AETI	Actual evapotranspiration	30 m	Dekadal	2015-2019
2	T	Transpiration	30 m	Dekadal	2015-2019
3	NPP	Net Primary Production	30 m	Dekadal	2015-2019
4	LCC	Land cover classification	100 m	Annual	2015-2019
5	PCP	Precipitation	5 km	Dekadal	2015-2019
6	RET	Reference ET	20 km	Dekadal	2015-2019

The crop coefficient (Kc) of the citrus crop was obtained from the Food and Agricultural Organization (FAO) of the United Nations (FAO. 1998). The Kc value for each stage is summarized in Table 3-3.

Table 3-3: The Kc of citrus fruit-based on FAO (1998)

Months	Kc	Stage	Months	Kc	Stage
April	0.7	Initial	October	0.65	Mid
May	0.7	Initial	November	0.65	Mid
June	0.65	Development	December	0.65	Mid
July	0.65	Development	January	0.7	Late
August	0.65	Development	February	0.7	Late
September	0.65	Development	March	0.7	Late

[1] https://github.com/wateraccounting/WAPORWP

Moreover, efforts were also made to compare WaPOR-based yield with the in-situ yield for citrus fruit planted in Block 8. This allows to understand the accuracy and reliability of remotely sensed (WaPOR) datasets in estimating yield.

4 Results

In this section, we present the irrigation performance of the Abadiska and UAAIE irrigation scheme using four performance indicators. In addition, WaPOR-based yield, biomass and water productivity yield gap for 2015-2019 are presented in subsequent sub-sections.

4.1 Estimating Actual Evapotranspiration (AETI)

The estimated seasonal AETI at block and pixel level are presented in Figures 4-1 and 4-2. Results show that AETI varies in space (Blocks) and time (season). The seasonal AETI of the study area ranges from 1200 to 2200 mm. On average, the highest AETI was estimated in Block 12 whereas the lowest were observed in Block 14 (Table 4-1).

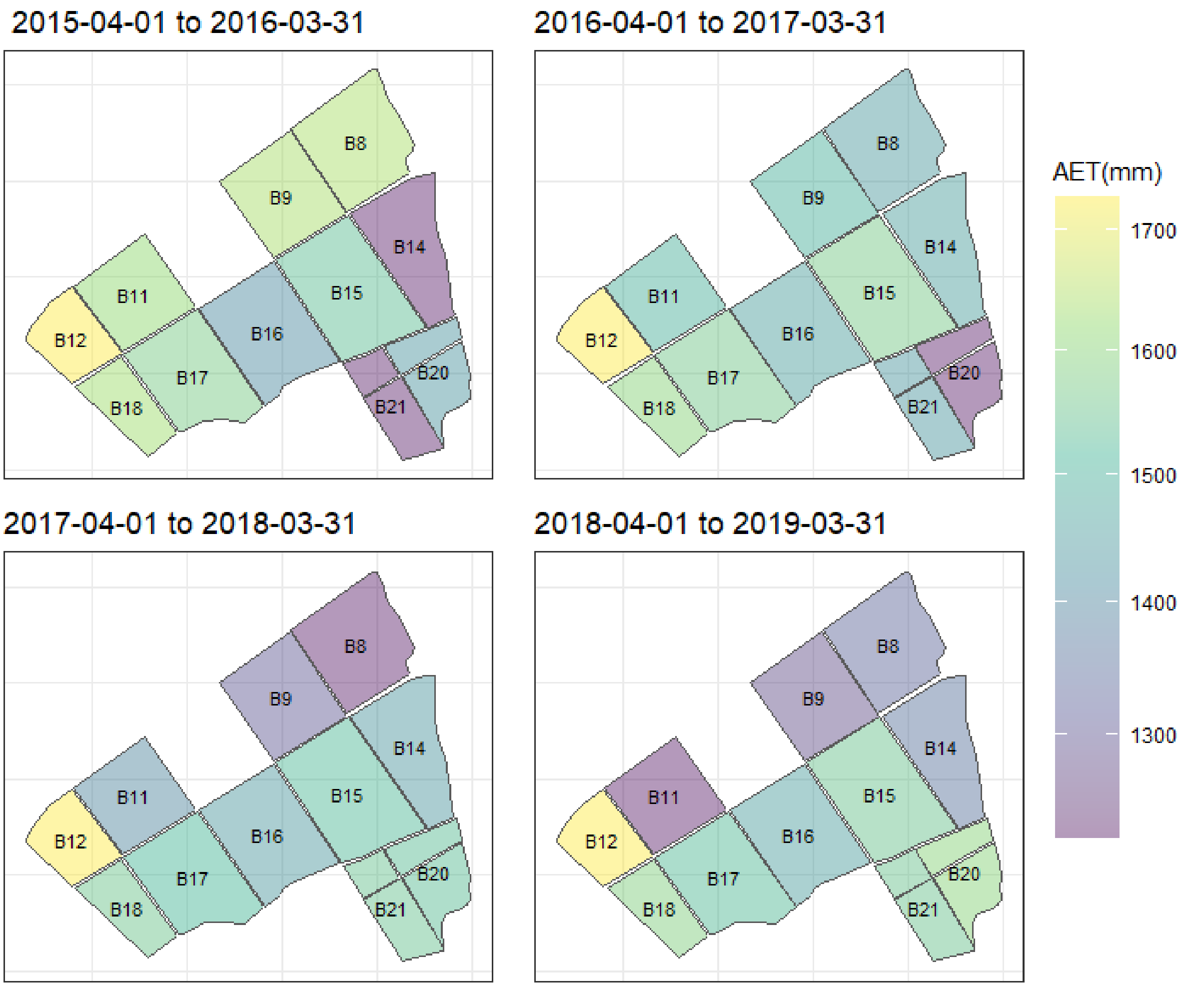

Figure 4-1: Spatial distributions of AETI at block level for 2015-2019. The description of each block is presented in Table 2-1.

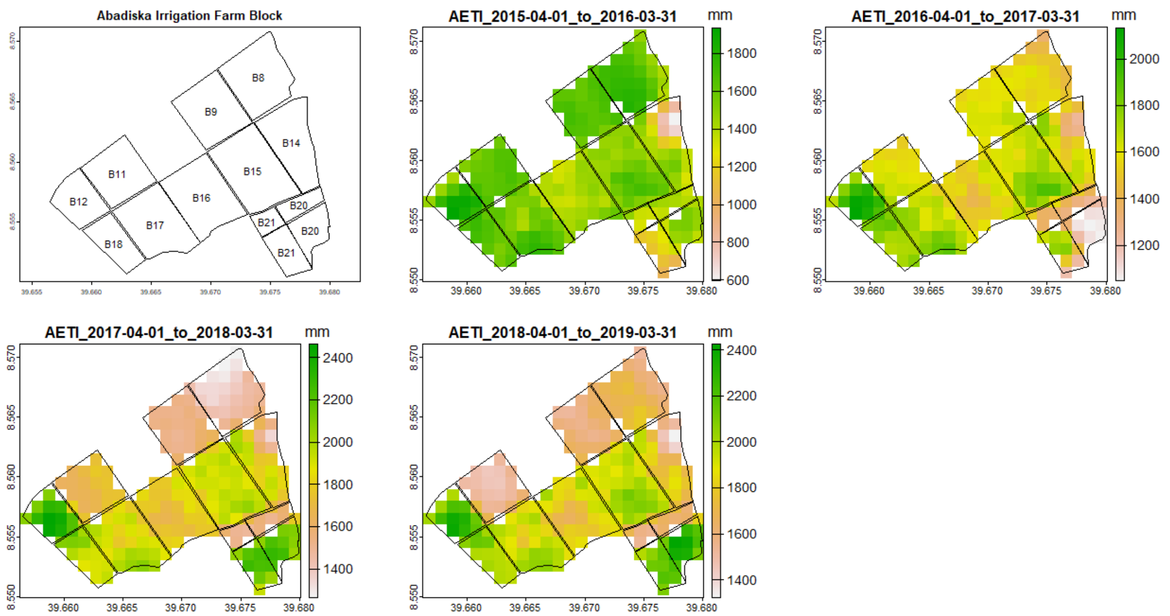

Figure 4-2: Spatial distributions of AETI at pixel level for the period 2015-2019

Table 4-1: Summaries of seasonal AETI (mm/season) estimated in the selected citrus farm blocks.

Block	2016 season	2017 season	2018 season	2019 season	Average
B11	1,618	1,602	1,702	1,527	1,612
B12	1,728	1,952	2,276	2,195	2,038
B14	1,225	1,538	1,769	1,701	1,558
B15	1,535	1,704	1,914	1,959	1,778
B16	1,412	1,544	1,770	1,831	1,639
B17	1,572	1,694	1,904	1,925	1,774
B18	1,631	1,756	1,964	2,008	1,840
B20	1,431	1,197	1,925	2,025	1,645
B21	1,226	1,504	1,955	1,958	1,661
B8	1,642	1,522	1,404	1,667	1,559
B9	1,639	1,603	1,540	1,602	1,596

4.2 Comparing WaPOR-based yield and observed yield

According to the UAAIE farm manager, the yield of citrus fruit in Block 8 is 5.6 ton/ha for the year 2019. Efforts were then made to compare WaPOR-based yield against the observed one. Results show that WaPOR overestimates the observed yield for this specific block (Table 4-2). The possible reasons for overestimation are associated with the certainty in parameters used for estimating citrus yield using remotely sensed datasets. These parameters include harvest index (HI), moisture content, dry matter over fresh biomass (MC), light use efficiency correction factor (fc) and above ground over total biomass production ratio (AOT). The corresponding crop parameters used for this study are 0.3, 0.8, 1.6 and 0.6. This study suggests that further studies could be needed to accurately quantify these parameters for orchard crop in general and citrus crop in particular. The citrus yield estimated from WaPOR datasets at field (block) and pixel levels are presented in Figures 4-3 and 4-4. Block 12 produced the highest yield compared to other blocks covered with citrus fruit whereas Block 8 had the lowest yield.

Table 4-2: Yield in ton/ha estimated from citrus blocks using WaPOR dataset

Block	2016 season	2017 season	2018 season	2019 season	Average
B11	9.62	10.24	9.43	8.60	9.47
B12	10.59	14.02	14.22	14.78	13.40
B14	6.58	10.73	10.05	10.58	9.48
B15	9.02	12.02	11.24	12.66	11.23
B16	8.09	10.75	10.12	11.64	10.15
B17	9.48	12.01	11.26	12.43	11.30
B18	9.83	12.49	11.74	13.20	11.82
B20	8.25	8.19	11.79	13.49	10.43
B21	6.56	10.23	11.91	12.93	10.41
B8	9.60	10.65	7.06	9.91	9.31
B9	9.62	10.79	8.09	9.24	9.44

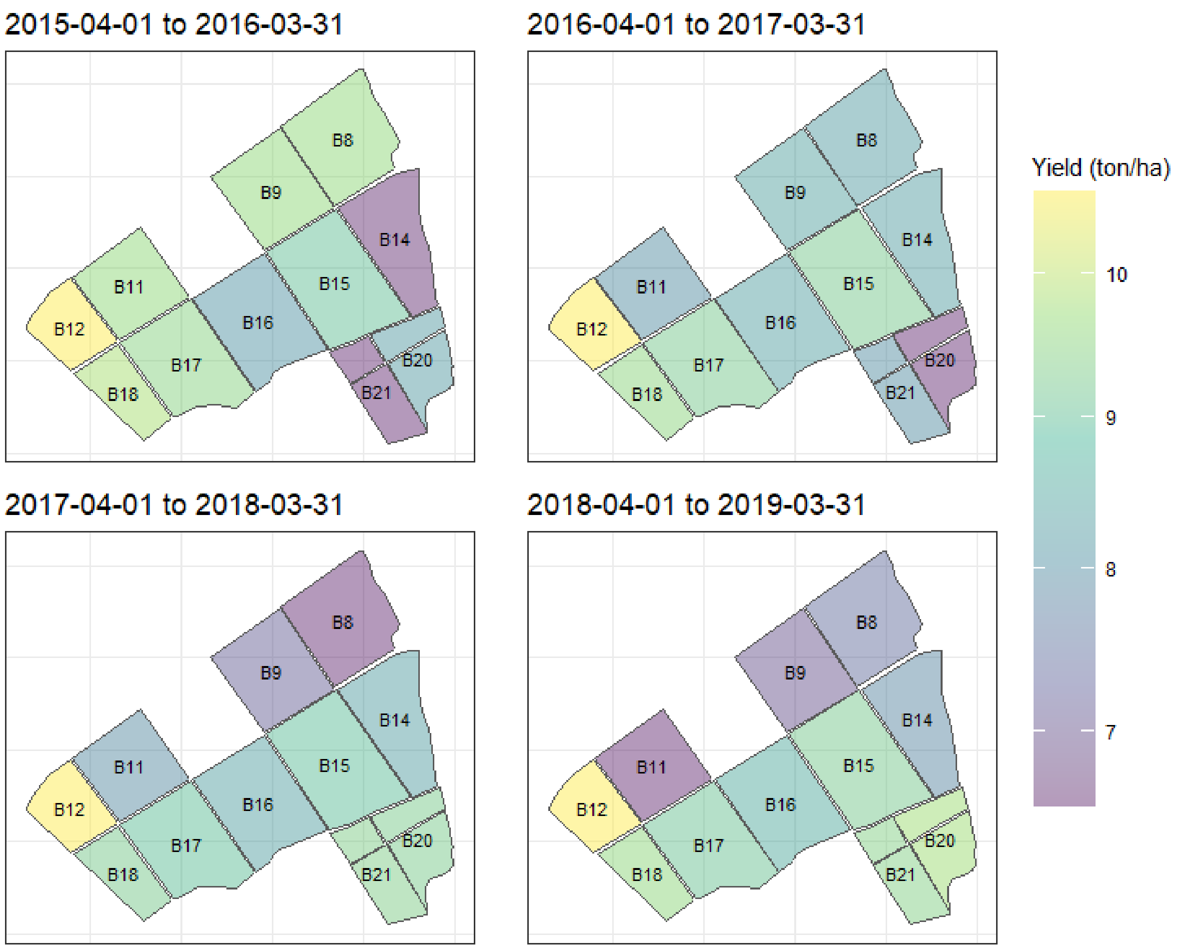

Figure 4-3: Spatial distribution of WaPOR-based yield estimated in the selected citrus farm blocks

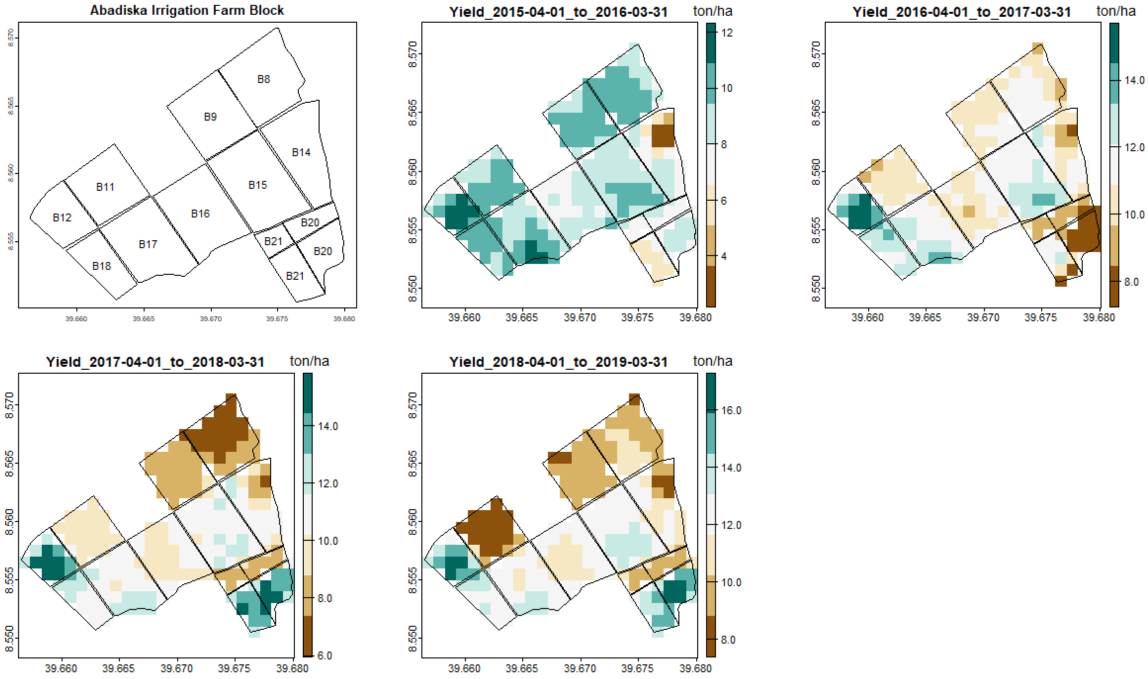

Figure 4-4: Spatial distribution of WaPOR-yield at pixel level for the period 2015-2019.

4.3 Crop water productivity gaps

The crop water productivity gaps estimated at field and pixel levels are shown in Figure 4-6 and 4-7. Results show that the water productivity yield gap is lower in the 2016 season than in other years. On average, the water productivity yield gap in the study site is 0.41 kg/ m^3/season (Table 4-3). Among the citrus blocks, a high crop water productivity gaps were evident in Blocks 12, 17,and 18 and it is thus important to improve the water productivity in those blocks using the following measures;

- Reducing unproductive water losses
- Maintaining healthy, vigorously growing crops through optimized water, nutrient and agronomic management.

The target yield and target water productivity yield results are shown in Figure 4-5. The target yield and target water productivity yield for 2019 season is 16 ton/ha and 2.3 kg/m^3, respectively.

	Season	Target_yield	Target_WPy
0	2015-04-01 to 2016-03-31	11.0	2.1
1	2016-04-01 to 2017-03-31	14.0	2.5
2	2017-04-01 to 2018-03-31	15.0	2.2
3	2018-04-01 to 2019-03-31	16.0	2.3

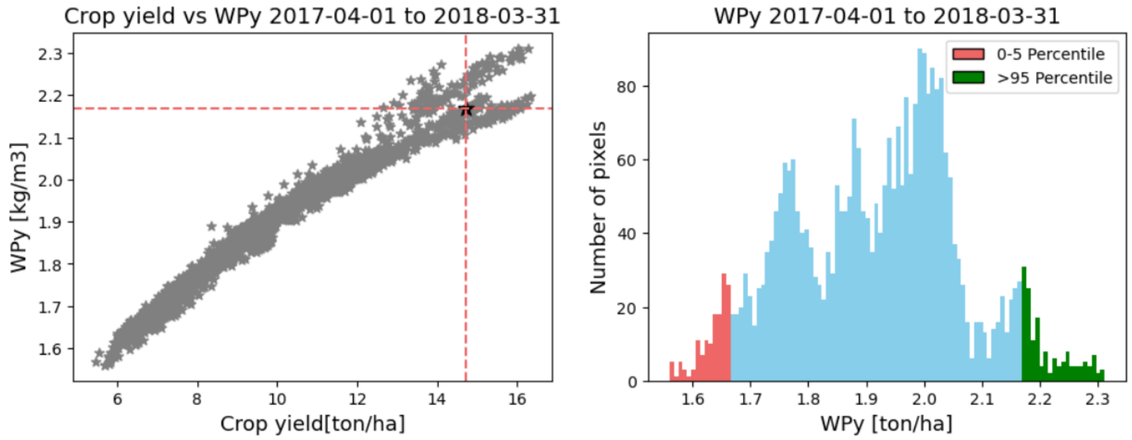

Figure 4-5: Target yield and target water productivity for different seasons

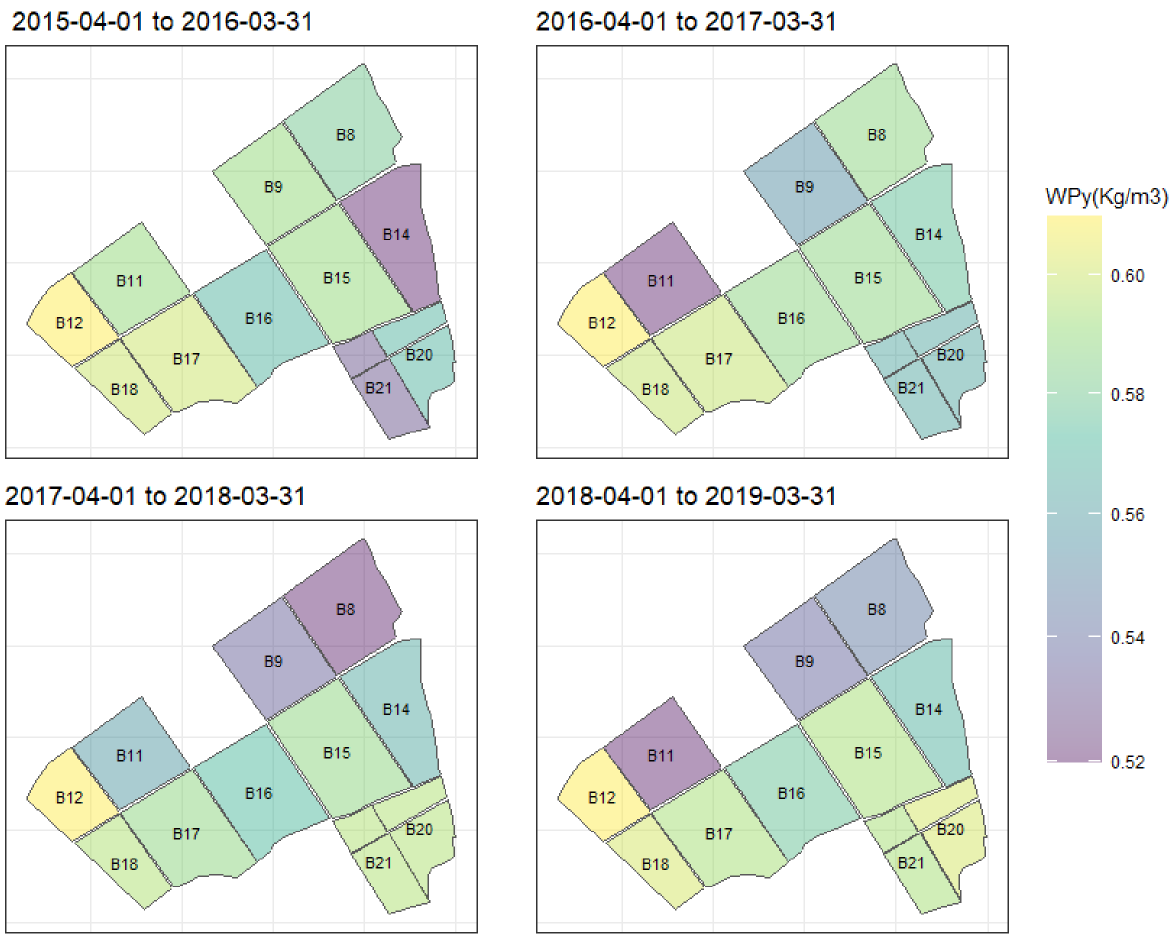

Figure 4-6: Seasonal water productivity gaps at field level for the selected citrus blocks

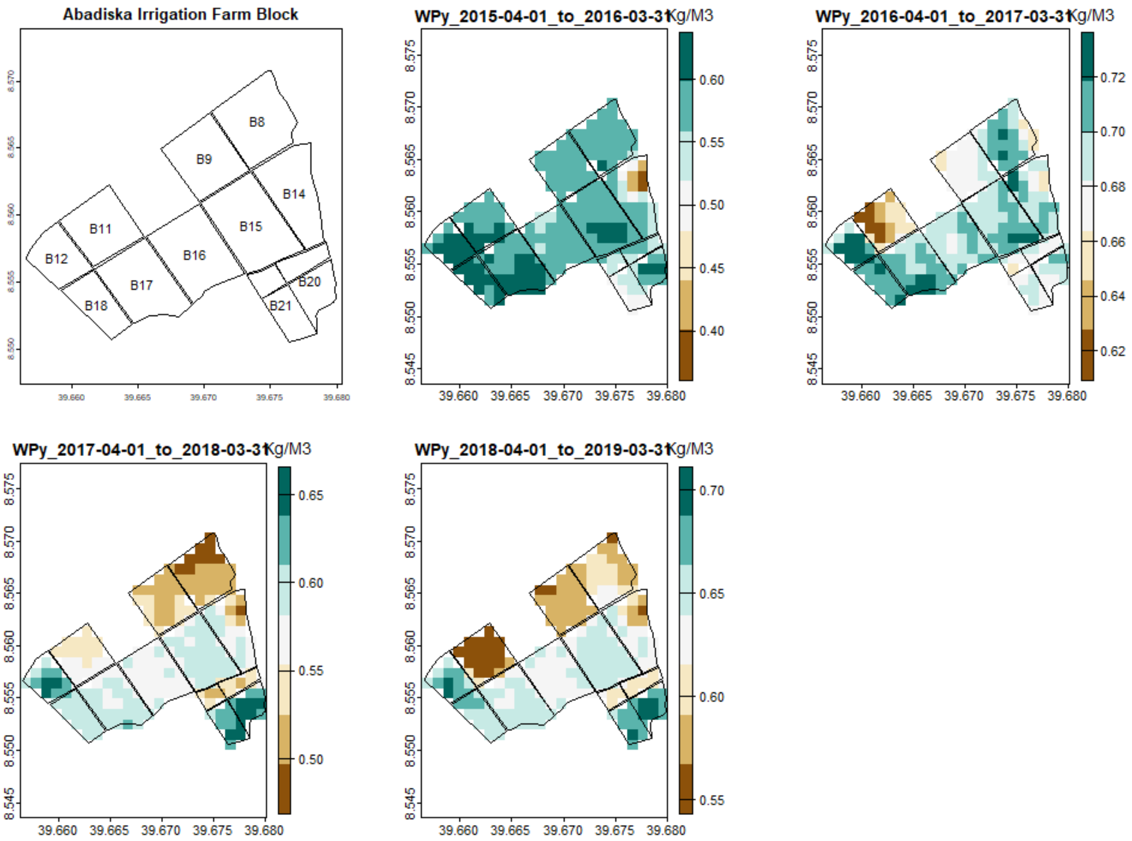

Figure 4-7: Seasonal water productivity gaps at pixel level for the selected citrus blocks

Table 4-3: Water Productivity gaps in kg/m^3 in the selected citrus block for different seasons

Block	2016 season	2017 season	2018 season	2019 season	Average
B11	0.59	0.64	0.55	0.56	0.59
B12	0.61	0.72	0.62	0.67	0.65
B14	0.52	0.69	0.56	0.62	0.60
B15	0.59	0.70	0.59	0.65	0.63
B16	0.57	0.70	0.57	0.63	0.62
B17	0.60	0.71	0.59	0.65	0.64
B18	0.60	0.71	0.60	0.66	0.64
B20	0.57	0.68	0.60	0.66	0.63
B21	0.53	0.68	0.60	0.65	0.62
B8	0.58	0.70	0.50	0.59	0.59
B9	0.59	0.67	0.52	0.58	0.59
Average	0.58	0.69	0.57	0.63	0.62

4.4 Irrigation Performance Assessment

4.4.1 Uniformity and relative water deficit

The evenness of water consumption within an irrigated field was estimated and results are presented in Table 4-4 and Figure 4-8. Results show that on average, the evenness of the water consumption is better in B12 than other fields whereas we found poor uniformity in Blocks 8,9, 11 and 20 (Table 4-4).

Table 4-4: The evenness of water consumption within in the selected irrigated fields. The numbers in block represent poor uniformity

Block	2016 season	2017 season	2018 season	2019 season	Average
B11	36.03	36.68	35.07	40.78	37.14
B12	19.81	18.31	18.03	16.73	18.22
B14	34.71	23.32	30.91	31.60	30.14
B15	26.22	18.84	25.57	19.70	22.58
B16	28.83	21.57	27.34	16.87	23.65
B17	27.74	18.21	22.62	15.97	21.14
B18	27.05	17.08	22.74	14.65	20.38
B20	42.72	49.86	28.60	19.45	35.16
B21	44.26	27.29	27.16	20.73	29.86
B8	44.48	34.20	45.10	33.51	39.32
B9	34.23	21.36	37.70	34.50	31.95
Average	33.28	26.07	29.17	24.04	

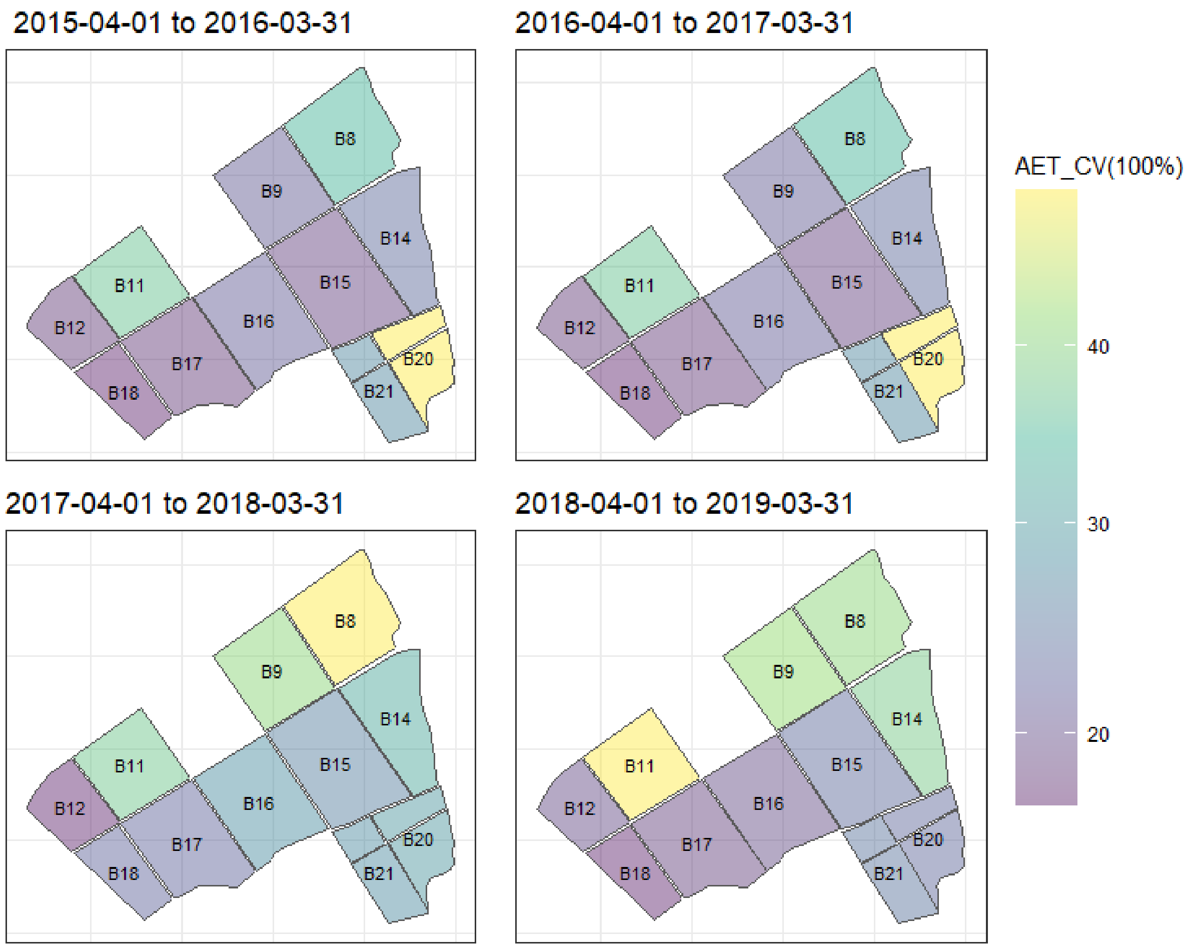

Figure 4-8: The evenness of water consumption within the irrigated field of citrus crop for the period 2015 to 2019.

The overall uniformity of water distribution in the selected irrigated field of Abadiska and UAAIE irrigation scheme is presented in Table 4-5 and we found fair uniformity of water distribution within the irrigation field since the coefficient of variation of AETI ranges from 10 to 20%. The seasons with the highest and lowest uniformity were 2018/19 and 2017/18, respectively. At the beginning of the crop season (2015/16) the highest CV of AETI was estimated but these values tend to decrease at the harvesting stage. Overall, the CV of AET varies in space and time may be attributed to the agronomic and management practices implemented in these blocks.

Table 4-5: Overall uniformity for different seasons

S.No	Season	CVs of AETI (%)	Remark
1	2016 season	14.4	Fair Equity
2	2017 season	12.6	Fair Equity
3	2018 season	15.1	Fair Equity
4	2019 season	13.7	Fair Equity

The relative water deficit in the selected irrigation field for different seasons results show that RWD ranges from 0.22 to 0.27 with the highest RWD estimated in 2017-04-01 to 2018-03-31 and the lowest in 2015-04-01 to 2016-03-31 (Table 4-6).

Table 4-6: Relative Water Deficit (RWD) in the selected irrigation field from 2015 to 2019

S.No	Season	RWD
1	2016 season	0.22
2	2017 season	0.25
3	2018 season	0.27
4	2019 season	0.25

4.4.2 Adequacy and Beneficial Fractions

Irrigation adequacy is a measure of the amount of water supplied to the crop relative to crop water requirement. Accordingly, on average, the adequacy of irrigation water in the Abadiska and UAAIE irrigation scheme ranges from 0.7 to 1.2 for the period 2015-2019 (Figures 4-9 and 4-10). The highest adequacy was recorded in the year 2018/19 and this indicates excess water was delivered beyond the crop water requirement and the soil moisture deficit (Table 4-7). On the other hand, in the year 2015/16, the adequacy of irrigation water is below the need for the crop irrigation water requirement. Moreover, the adequacy of irrigation water varies in space and time. Based on this performance measure, Block 8, 9, and 11 had lower adequacy compared to other blocks. Therefore, care should be given to these blocks to improve the application of water in these fields.

Table 4-7: Summary of irrigation adequacy in the irrigated fields of Abadiska and UAAIE irrigation scheme.

Block	2016 season	2017 season	2018 season	2019 season	Average
B11	0.95	0.96	0.98	0.89	0.95
B12	1.02	1.17	1.31	1.29	1.20
B14	0.72	0.92	1.02	1.00	0.91
B15	0.90	1.02	1.10	1.15	1.04
B16	0.83	0.93	1.02	1.07	0.96
B17	0.92	1.02	1.09	1.13	1.04
B18	0.96	1.06	1.13	1.18	1.08
B20	0.84	0.72	1.11	1.19	0.96
B21	0.72	0.90	1.12	1.15	0.97
B8	0.96	0.92	0.81	0.98	0.92
B9	0.96	0.96	0.89	0.94	0.94
Average	**0.89**	**0.96**	**1.05**	**1.09**	

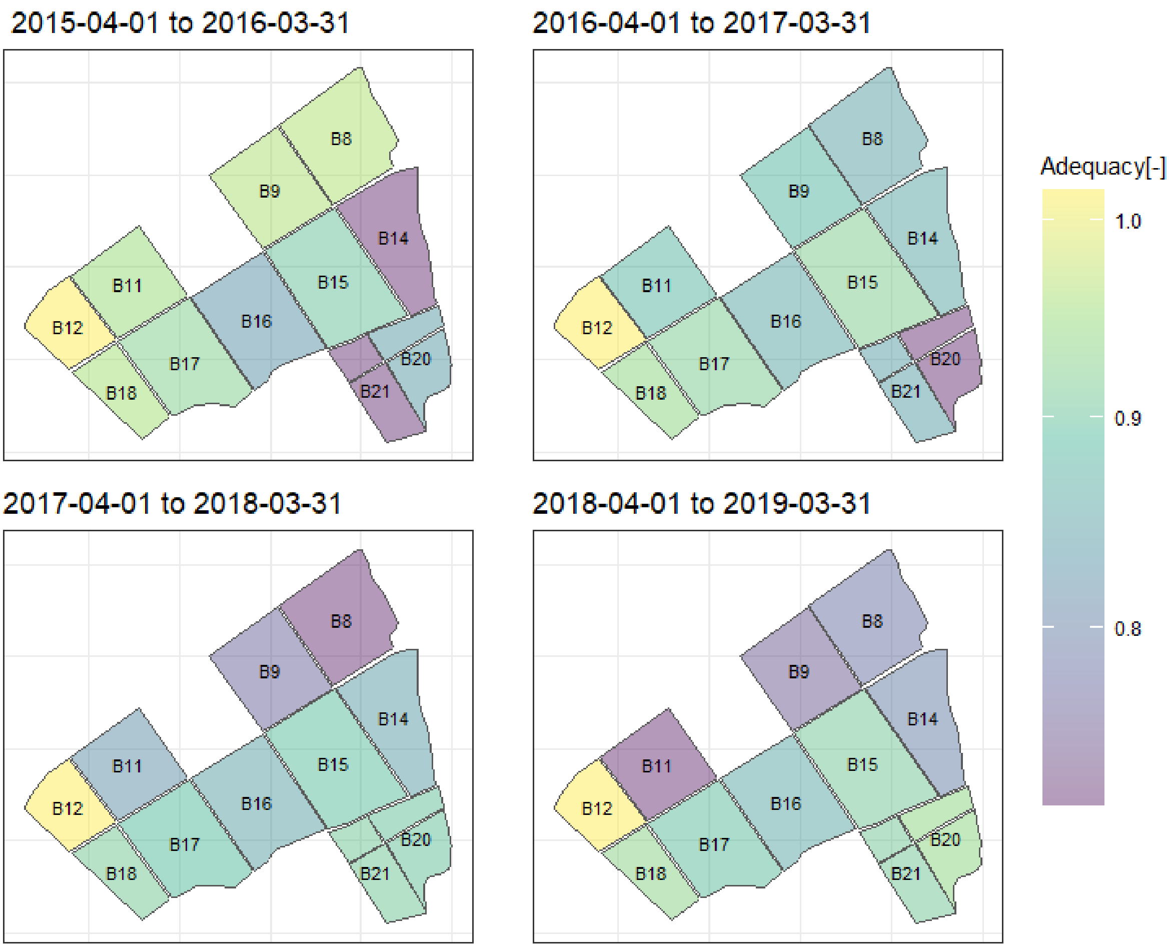

Figure 4-9: Irrigation Adequacy in the selected blocks covered with citrus for the period 2015 to 2019.

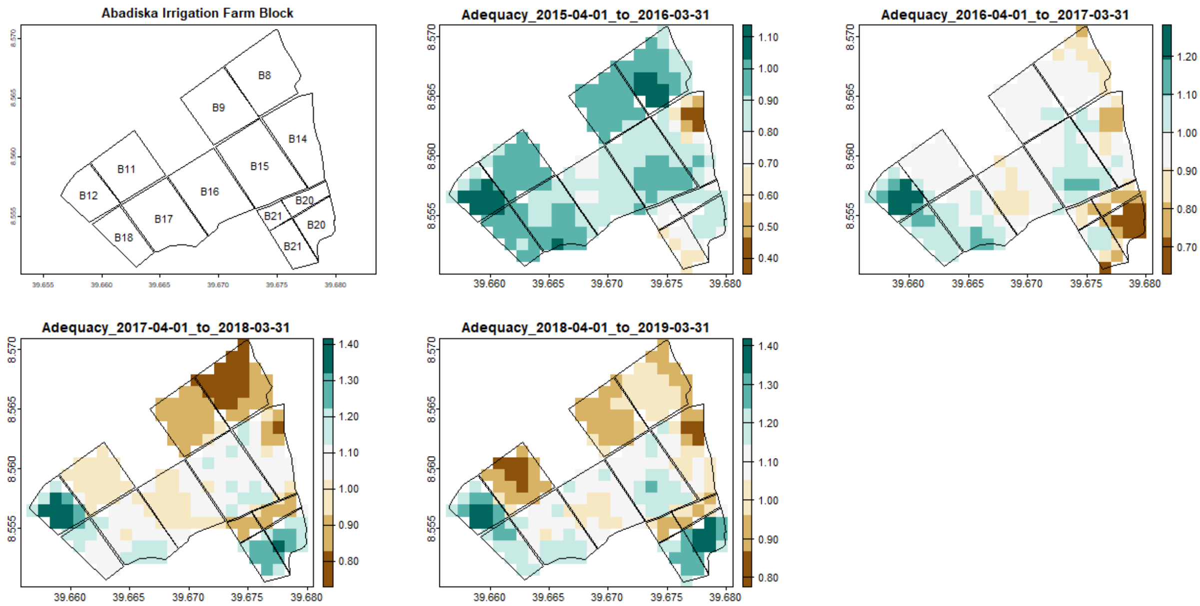

Figure 4-10: Spatial distributions of Adequacy of irrigation water at pixel level for the selected blocks of Abadiska and UAAIE irrigation scheme for 2015-2019.

The beneficial fraction (efficiency) that measures the efficiency of on-farm water and agronomic practices was estimated and results are shown in Figures 4-11 and 4-12, and Table 4-8. Based on the WaPOR dataset, on average, the efficacy of the efficiency of on-farm water and agronomic practices is greater than 80 %, which is acceptable. Among the citrus crop field, block 9 and 11 had the lowest BF whereas block 12 and 18.

Table 4-8: Summaries of beneficial fraction at each block

Block	2016 season	2017 season	2018 season	2019 season	Average
B11	0.80	0.80	0.82	0.82	0.81
B12	0.83	0.85	0.86	0.86	0.85
B14	0.77	0.83	0.84	0.84	0.82
B15	0.82	0.84	0.85	0.86	0.84
B16	0.80	0.83	0.84	0.85	0.83
B17	0.82	0.84	0.85	0.86	0.84
B18	0.83	0.84	0.85	0.86	0.85
B20	0.80	0.80	0.84	0.86	0.83
B21	0.78	0.81	0.85	0.86	0.83
B8	0.82	0.82	0.80	0.83	0.82
B9	0.81	0.80	0.81	0.82	0.81
Average	0.81	0.82	0.84	0.85	0.83

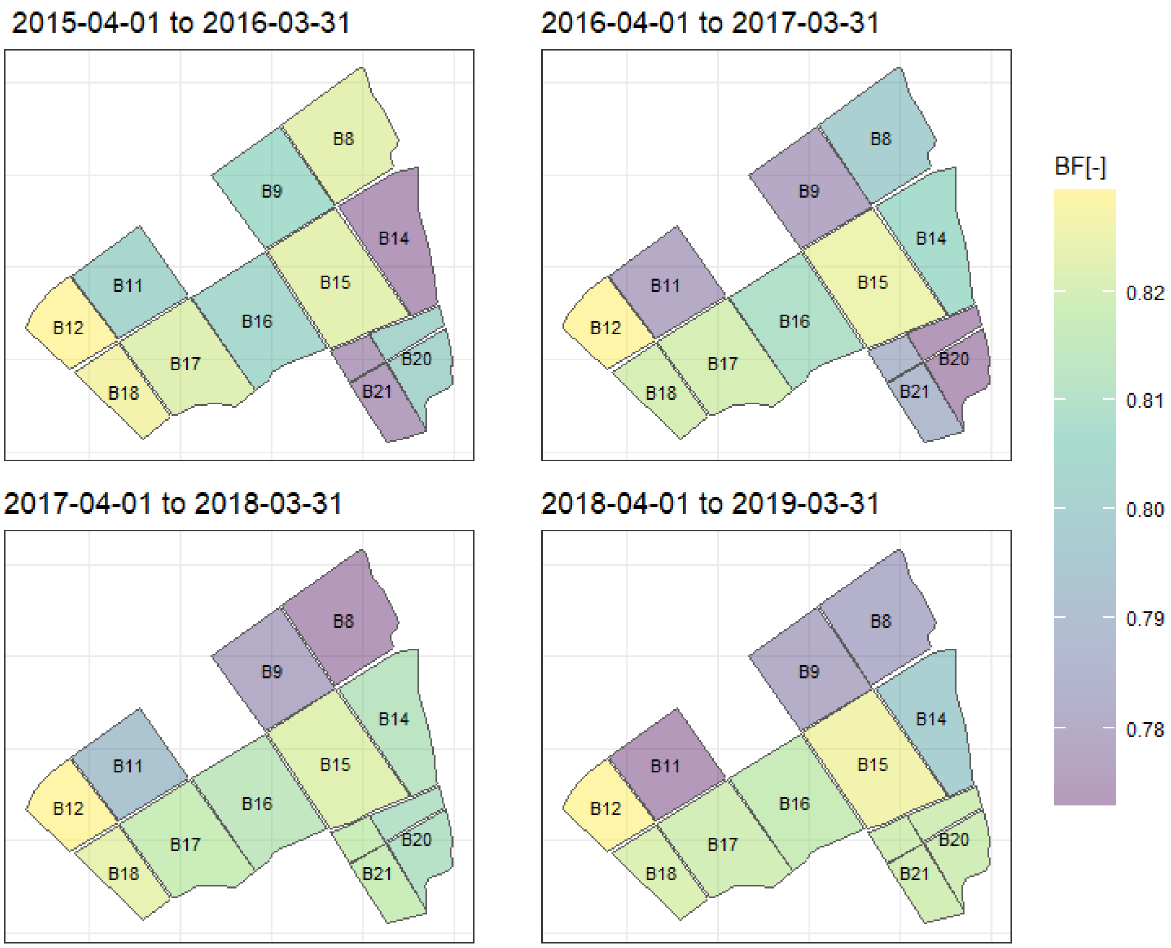

Figure 4-11: Spatial distribution of beneficial fraction in the selected citrus blocks for the period 2015 to 2019.

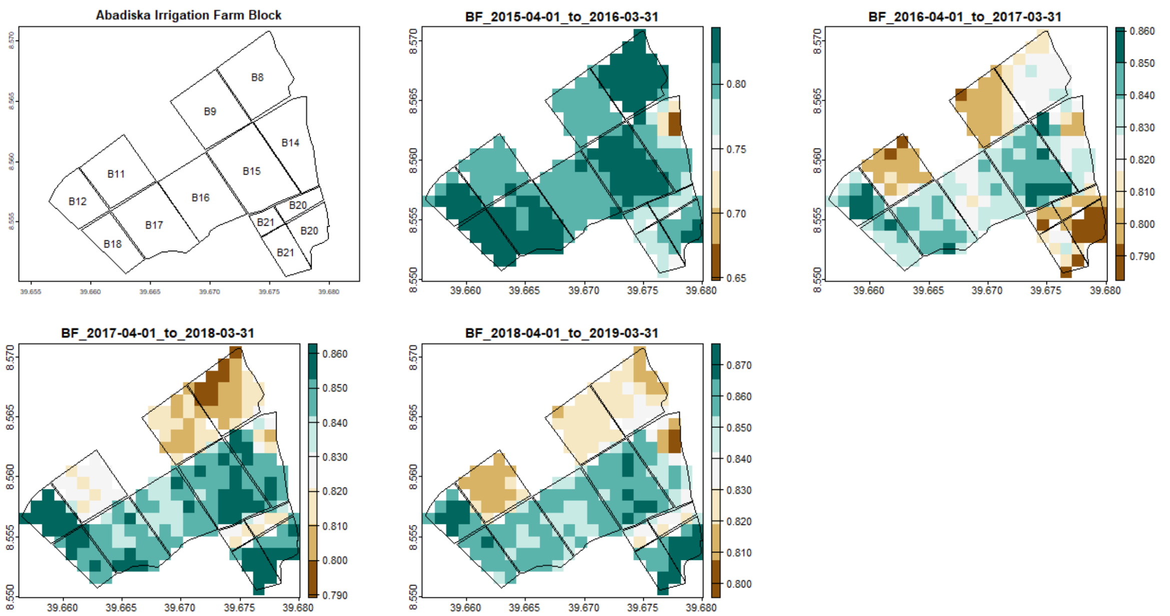

Figure 4-12: Spatial distribution of beneficial fraction at pixel level for the period 2015 to 2019

5 Conclusion

This service was developed for the UAAIE under the Ministry of Irrigation and Lowlands (MILLs) which aims to assess the performance of the Abadiska and UAAIE irrigation scheme using four irrigation performance indicators namely Uniformity, Relative Water deficit (RWD), Adequacy, and Beneficial Fraction. Both primary and secondary data were collected to perform this analysis. We used WAPORWP packages to download and analyze WaPOR data for the period 2015 to 2019. Efforts were also made to compare the WaPOR-yield and in-situ yield data for the citrus fruits planted in Block 8. Based on the findings of this study, the following conclusions are drawn;

- The seasonal AETI of the study area ranges from 1200 to 2200 mm. On average, the highest AETI was estimated in Block 12 whereas the lowest were observed in Block 14.
- WaPOR overestimates the yield of citrus fruit. The possible reasons for overestimation are associated with the certainty in parameters (HI, MC, fc, AOT) used for estimating citrus yield using remotely sensed datasets. Further studies could be needed to optimize these parameters for Orchard crops using field-experiment.
- The water productivity yield gaps estimated at field and pixel levels show that the crop water productivity gap is lower in the 2015 and 2018 seasons than in others. On average, the water productivity yield gap in the study site is 0.41 kg/m^3/season.
- The target yield and target water productivity yield for 2018-04-01 to 2019-03-31 season is 16 ton/ha and 2.3 kg/m^3, respectively.
- The performance of the irrigation scheme is better in the year 2018/19 .On the other hand, in the year 2015/16, the adequacy of irrigation water is below the need for the crop irrigation water requirement. The average beneficial fraction (efficiency) that measures the efficiency of on-farm water and agronomic practices was higher than 80%.
- Overall, all the irrigation performance indicator results revealed that the performance varies in space (blocks) and time (season). Based on the crop water productivity gaps, the highest crop water productivity gaps were evident in Blocks 12, 17, and 18 and it is thus important to improve their productivity through reducing unproductive water losses, maintain healthy, vigorously growing crops through optimized water, nutrient and agronomic management.

6 Reference

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