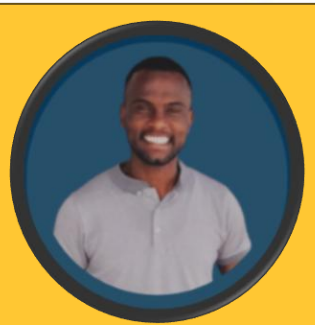
Karadeniz Technical University

The Graduate School of Natural and Applied Sciences

Geomatics Engineering Graduate Program

Application of Remote Sensing and Machine Learning for Estimating Crops Areas, Yield, and Water Productivity of Wheat in the Gezira Irrigation Scheme



Presented by:

Osman O. Ahmed Ibrahim

Sep. 20, 2024 @ 03:00 P.M.

supervisor:

(Assoc. Prof. VOLKAN YILMAZ)

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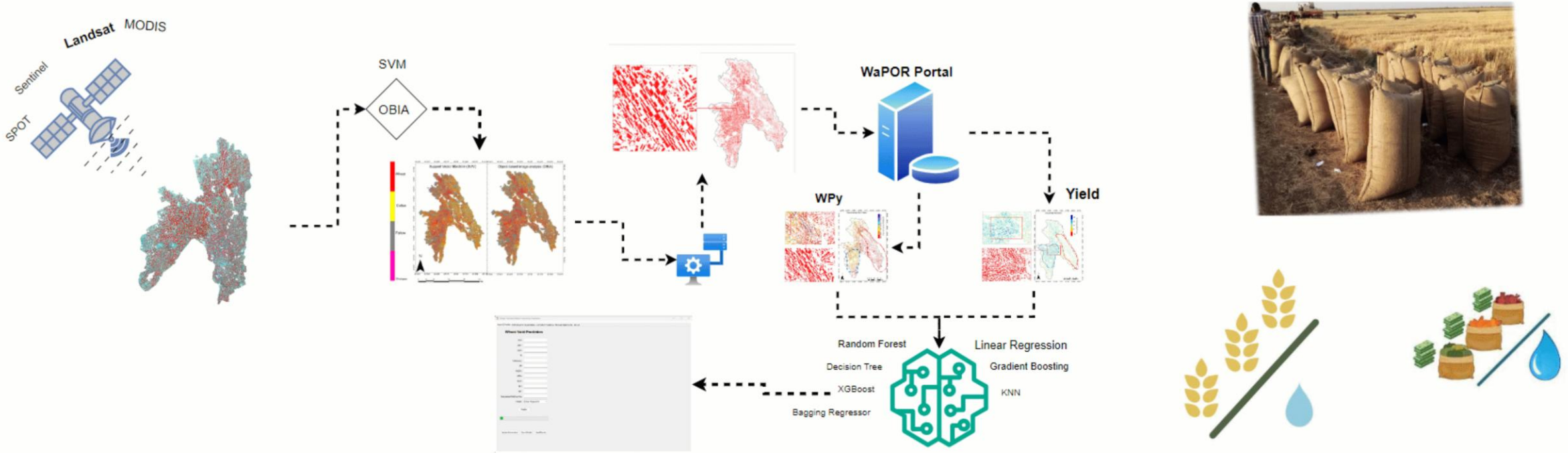
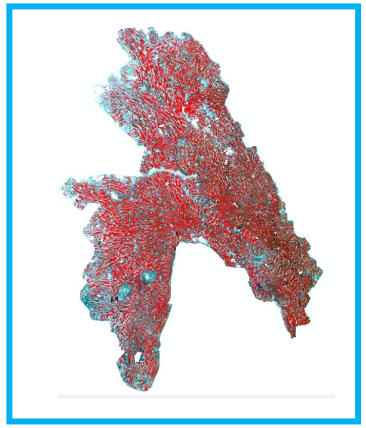
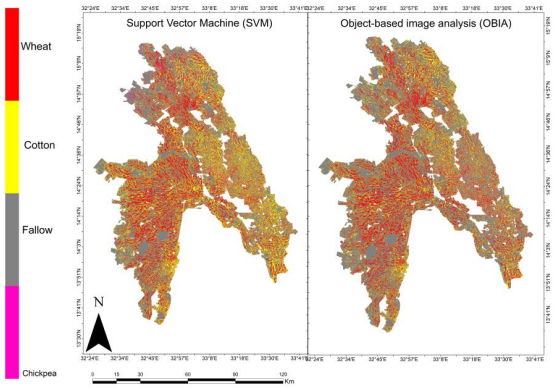
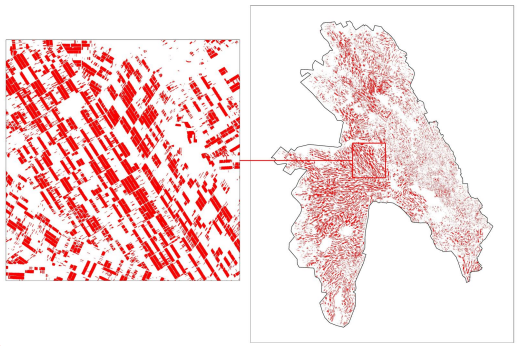


Sentinel-2A (02/02/2020)

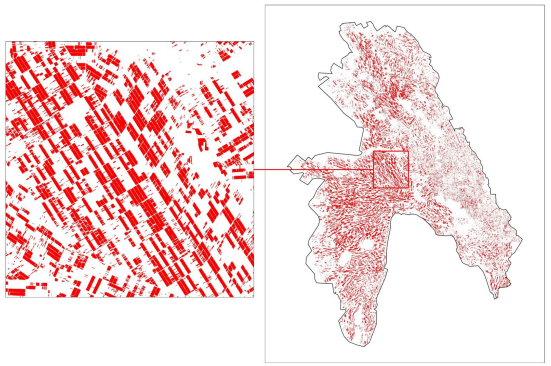


SVM and OBIA

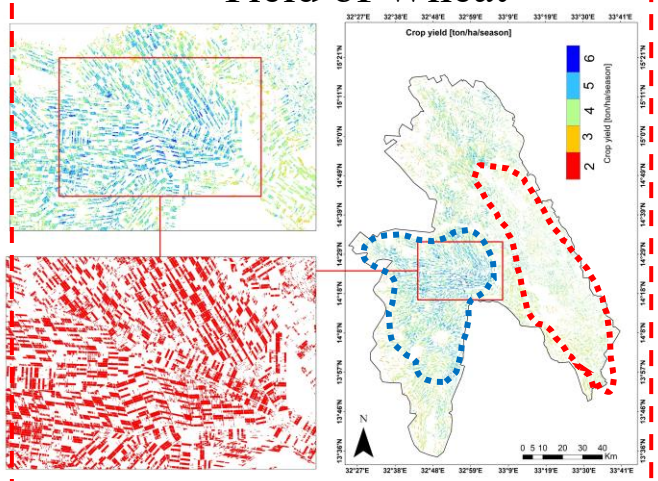




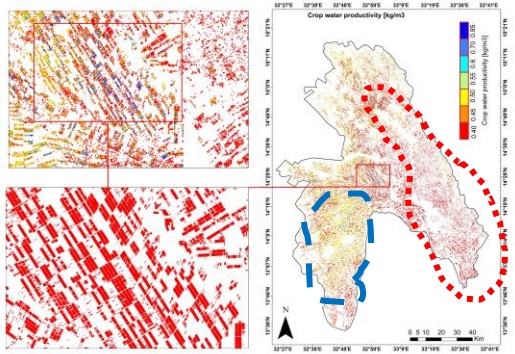
WaPOR Portal +Python



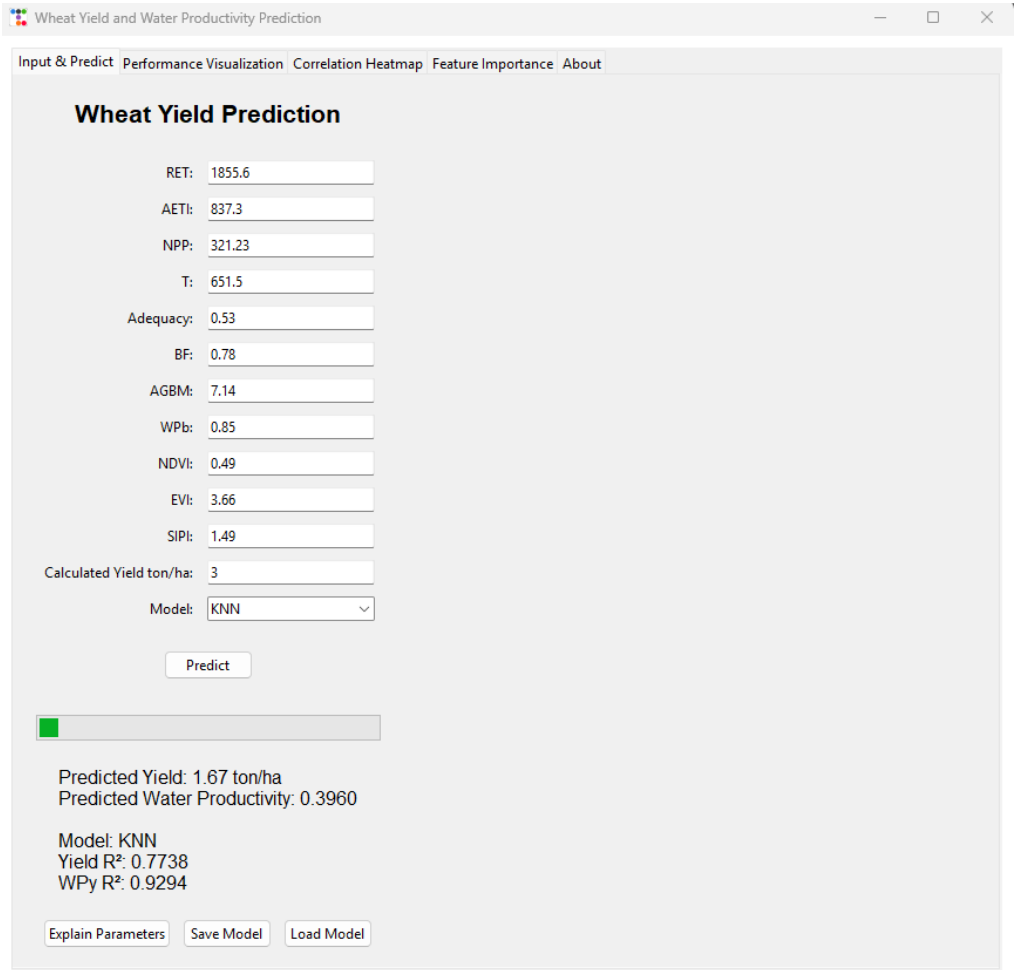
Yield of Wheat



Yield of Wheat



Result from WaPOR Portal +Python+field Data+Data from Google Eearth Engine

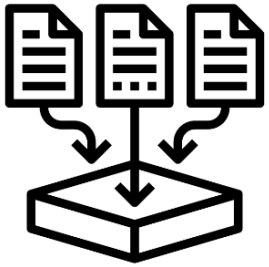


CONTENT


1- Problem Statement, Research Objectives
2- Stuy Area and Data Collection
3- Classification Crops Method
Compute Yield Water Productivity Methods-WaPOR
5- Machine Learning Models
6- Analysis & Results
7- Recommendations

PROBLEM STATEMENT:

The Gezira Irrigation Scheme, despite its vast potential, faces significant challenges in optimizing wheat production and water use efficiency. **Current wheat yields (3.18-4.02 t/ha) fall substantially short of the optimal range (6-9 t/ha) (FAO, 2020), while water productivity (0.32-0.45 kg/m³) remains below target levels (0.58 kg/m³) (Adam et al., 2021).** These inefficiencies, coupled with water scarcity concerns, **threaten food security and agricultural sustainability in Sudan** (Al Zayed et al., 2015). **Traditional methods of crop monitoring and yield estimation are often time-consuming, costly, and lack the spatial resolution needed for targeted interventions** (Lobell, 2013). There is a critical need for innovative approaches to accurately assess crop areas, predict yields, and optimize water use across this large-scale irrigation scheme (Bastiaanssen and Steduto, 2017).



Research Objectives:

1.Develop and validate an accurate method for estimating wheat crop areas in the Gezira Irrigation Scheme using high-resolution satellite imagery and advanced classification techniques.

2.Assess the spatial variability of key productivity indicators across the scheme, including:

1. Actual Evapotranspiration (AETI)
2. Reference Evapotranspiration (RET)
3. Net Primary Production (NPP)
4. Above Ground Biomass (AGB)
5. Crop Yield
6. Water Productivity (WP)

3.Identify and analyze 'bright spots' of high performance within the scheme to understand factors contributing to superior wheat productivity and water use efficiency.

4.Develop and compare multiple machine learning models for predicting wheat yield and water productivity, integrating remote sensing data with ground-truth information.

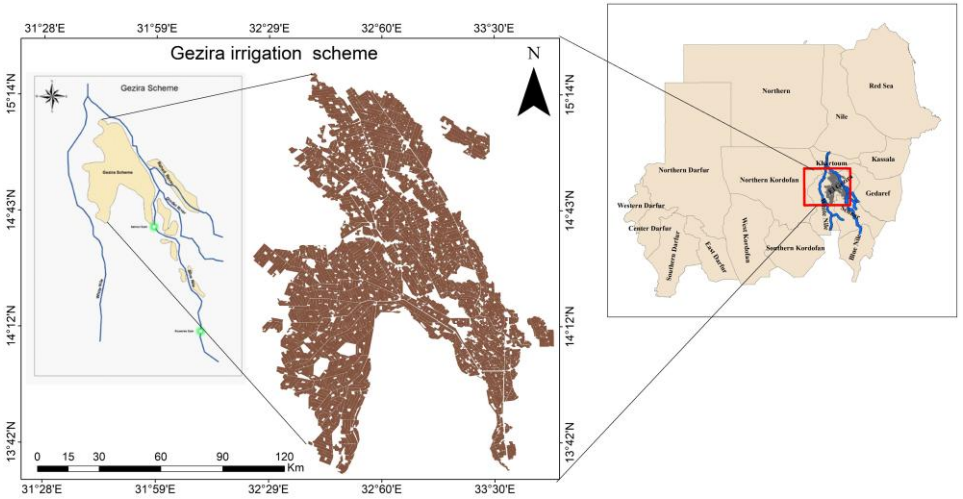
5.Quantify yield gaps and water productivity gaps across different irrigation divisions of the Gezira Scheme to prioritize areas for intervention.

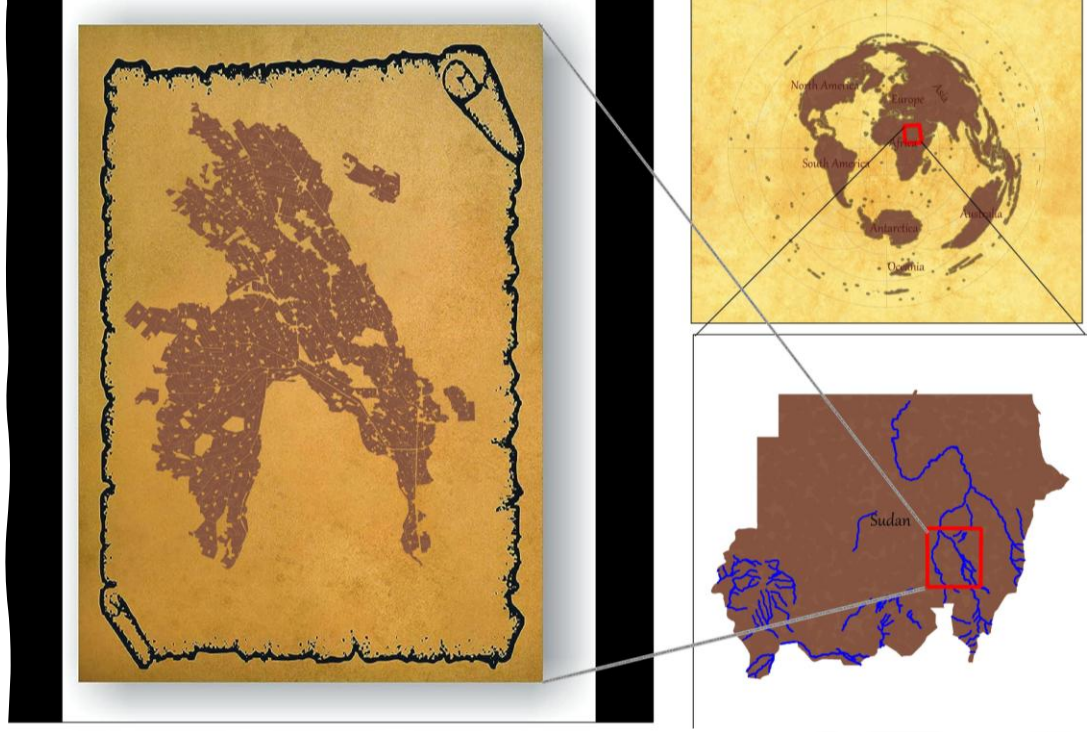
6.Investigate the relationship between management practices and productivity outcomes through analysis of farmer survey data from high-performing areas.

7.Evaluate the effectiveness of integrating remote sensing data (WaPOR) with ground-based measurements for agricultural monitoring in large irrigation schemes.

8.Develop evidence-based recommendations for improving wheat productivity and water use efficiency across the Gezira Irrigation Scheme.

OVERVIEW OF THE GEZIRA IRRIGATION SCHEME





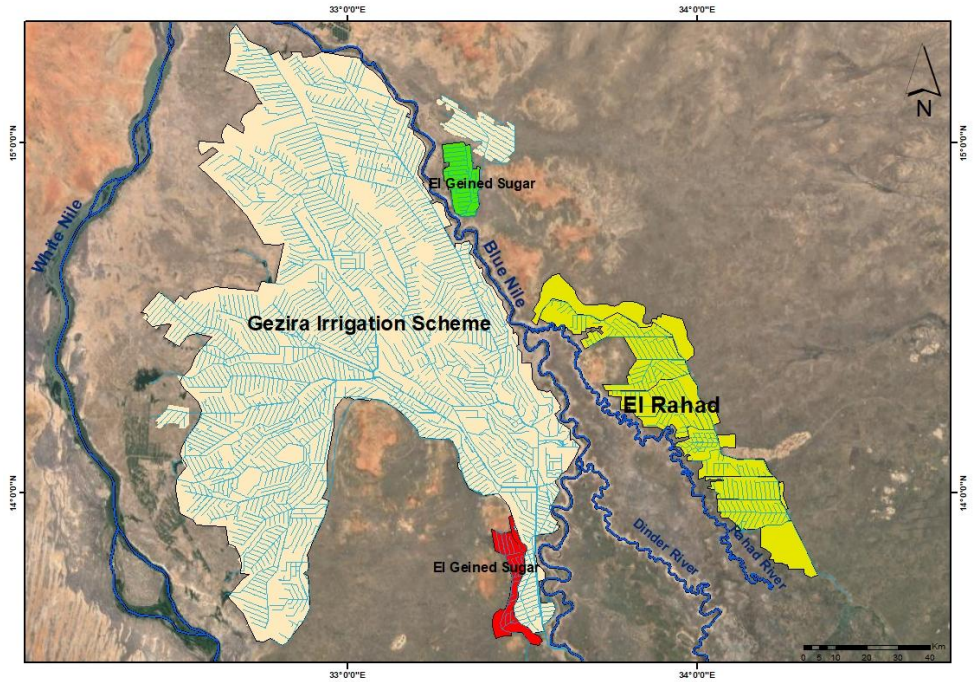
Coordinate System: WGS 1984 UTM Zone 36N
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 33.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meters

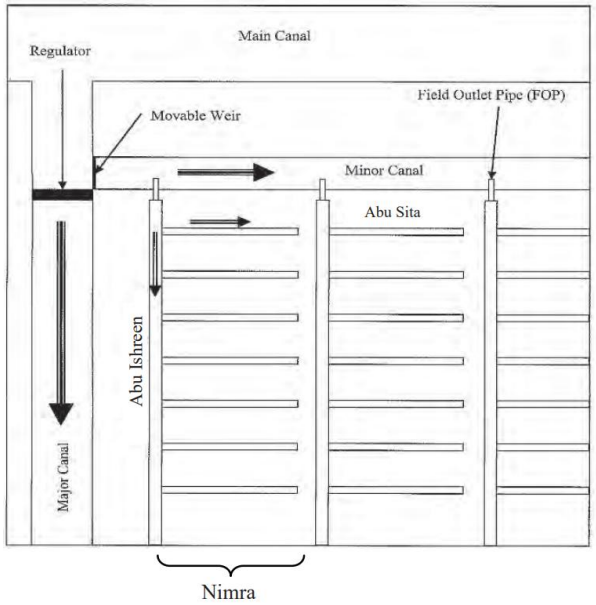
Study Area

Aspect	Details
Location	Central Sudan, between the Blue and White Nile rivers.
Size	2.1 million feddans (approximately 882,000 hectares).
Established	1925, initially for cotton cultivation.
Climate	Semi-arid with significant reliance on seasonal flooding of the Blue Nile for irrigation.
Soil Type	Heavy cracking clay soils (Vertisols), fertile but challenging due to moisture-related expansion and contraction.
Irrigation Source	Sennar Dam on the Blue Nile, providing regulated water flow.
Main Crops	Cotton, wheat, sorghum, and groundnuts, Chickpea, vegetables
Water Management	Network of canals distributing Nile water, critical for overcoming the semi-arid climate challenges.
Challenges	Soil salinity, water management, aging infrastructure, and maintaining economic viability.
Recent Developments	Adoption of modern irrigation techniques and crop diversification to enhance sustainability.

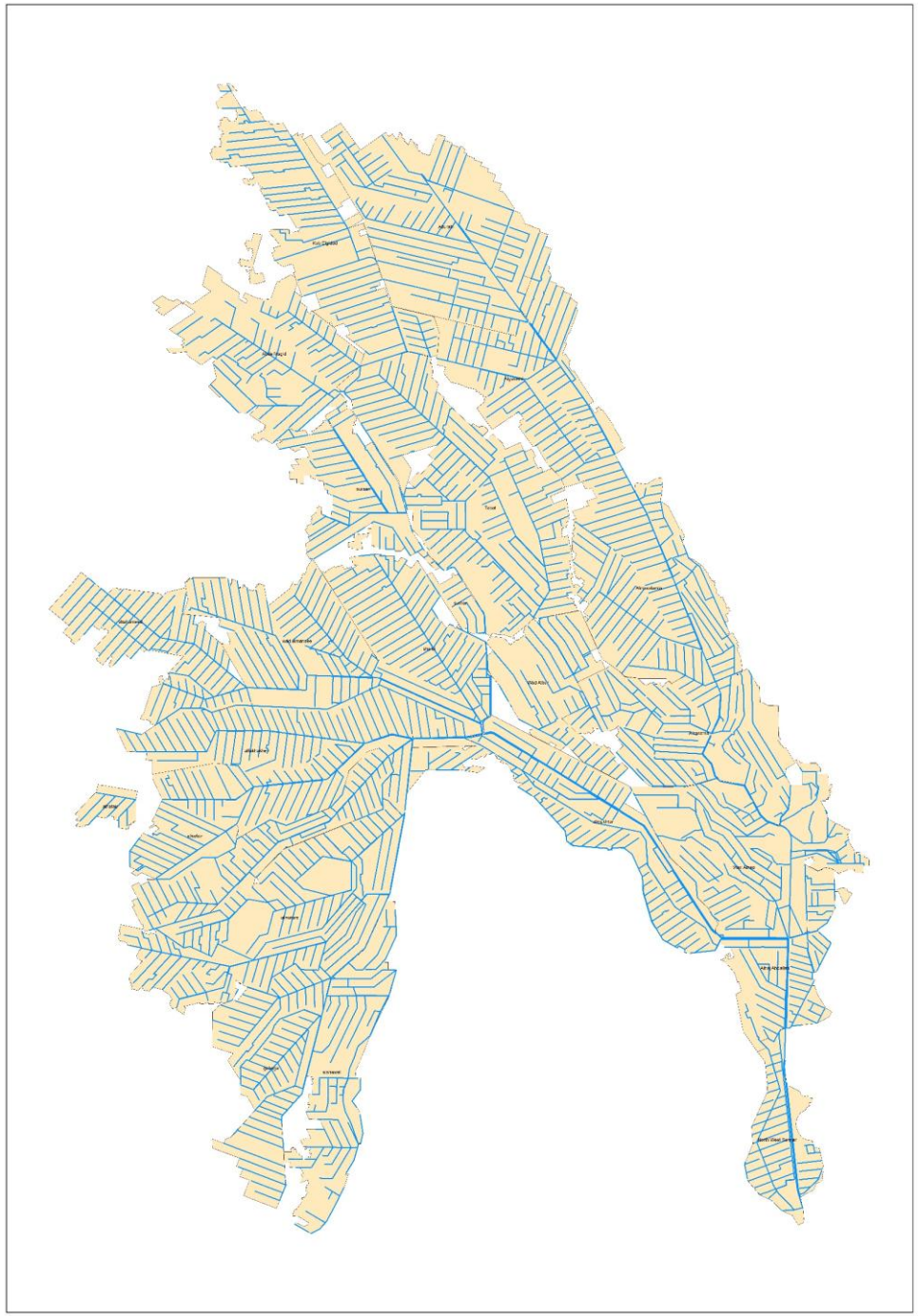
overview of the Gezira Irrigation Scheme

Irrigation system:





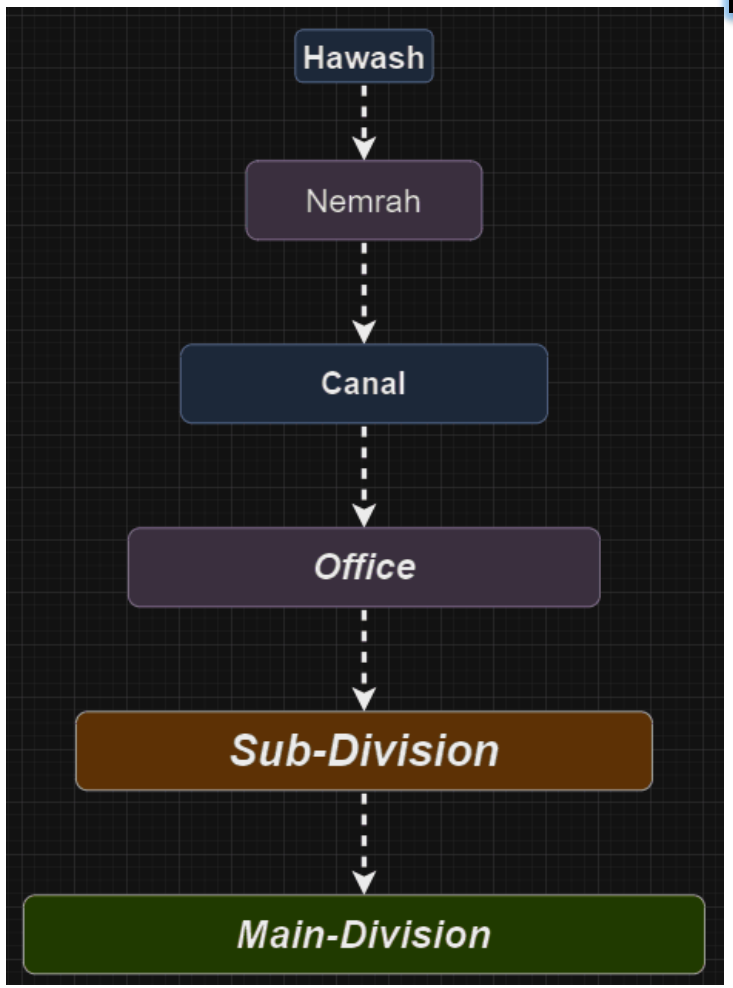
- The scheme's irrigation system, fueled by the Sennar Dam, consists of two main canals – the Gezira and Managil – with capacities of 168 m³/s and 186 m³/s, respectively. Water is efficiently distributed through a network of major and minor canals to support equitable field irrigation.

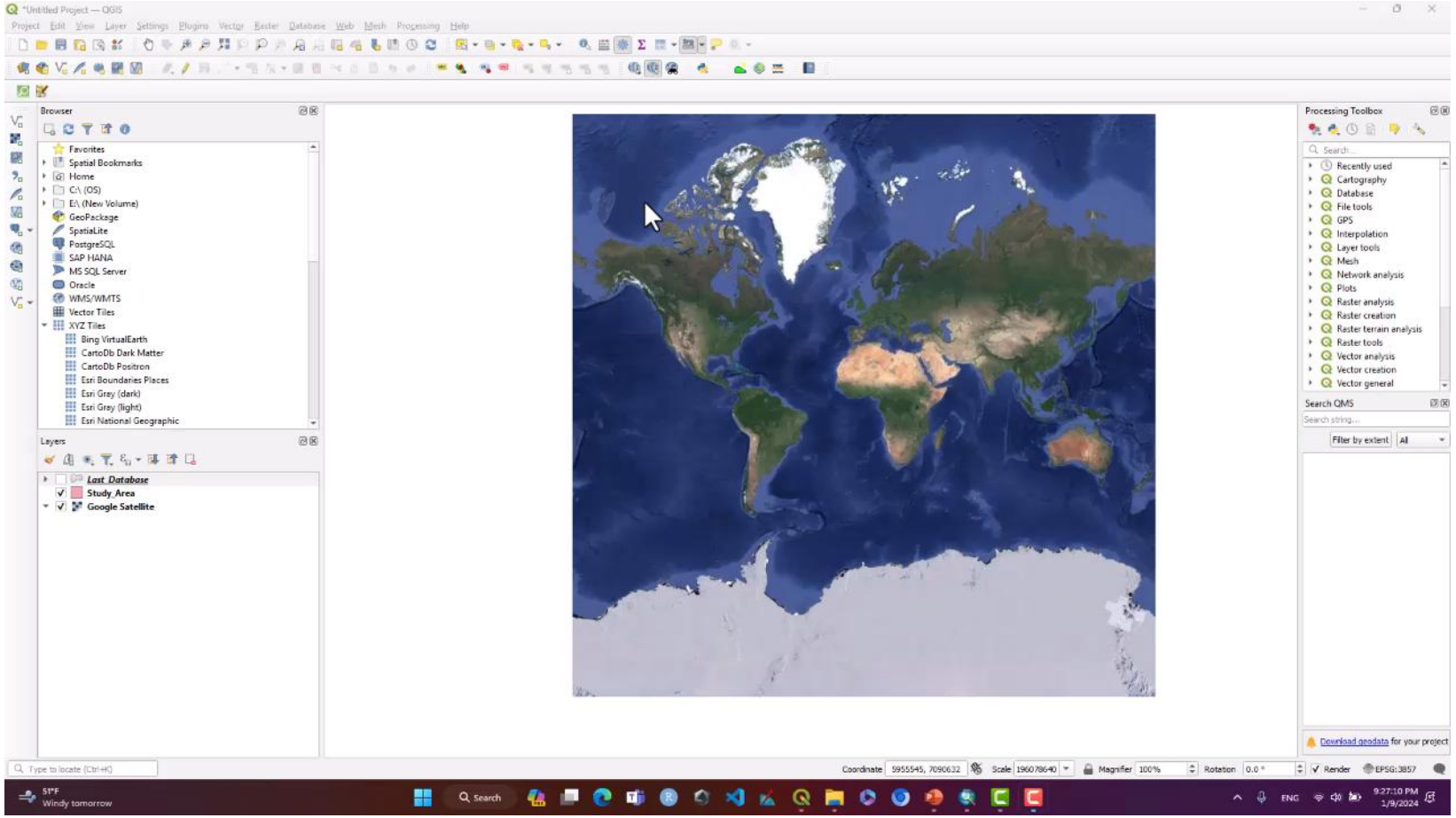


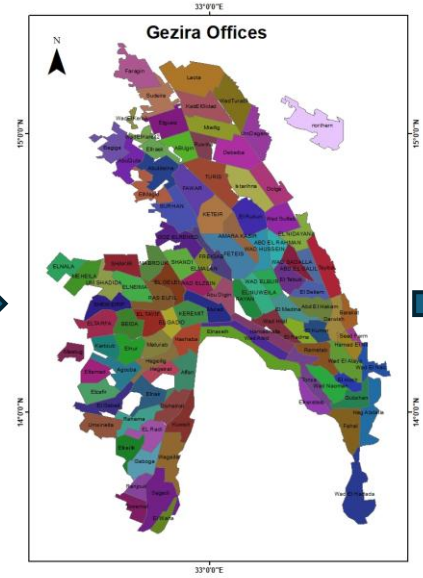
Canalization characteristics of the Gezira Scheme:

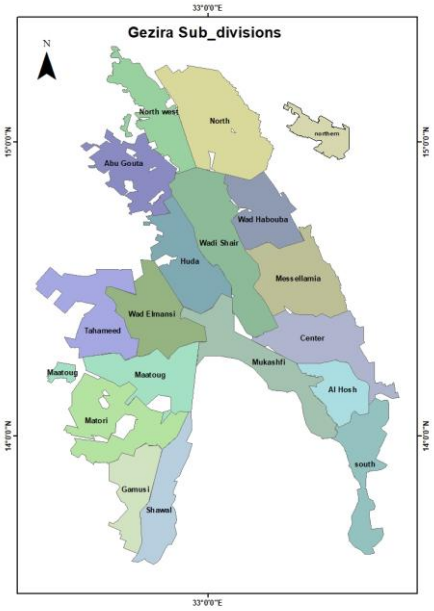
Canal	Number	Capacity (m^3/s)	Average width (m)	Length (km)
Main	2	354	50	261
Branch	11	25-120	30	651
Major	107	1.2-15	20	1,650
Minor	1,700	0.5-1.5	6	8,120
Abu Ishreen	29,000	0.116	1	40,000
Abu Sitta	350,000	0.05	0.5	100,000

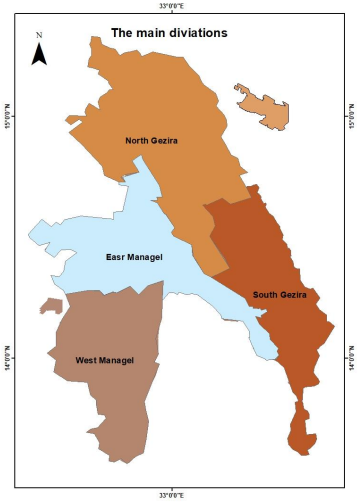
Administrative Division of the Gezira Irrigation scheme :

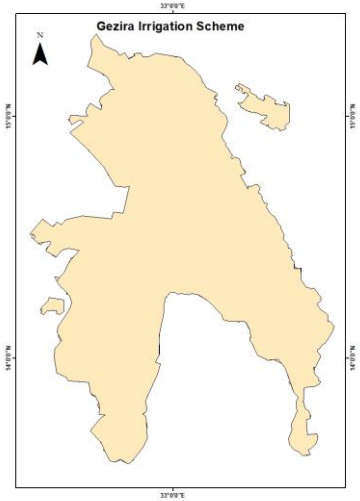





Gezira Offices
N
33°0'0"E


Gezira Sub_divisions
N
33°0'0"E
North west
North
northern
Abu Gouta
Wad Habouba
Wadi Shair
Huda
Mossellamia
Wad Elmansi
Tahameed
Center
Mukashfi
Maatoug
Maatoug
Al Hosh
Matori
south
Gamus I
Shawal


The main diviations
N
33°0'0"E
North Gezira
Easr Managel
South Gezira
West Managel


Gezira Irrigation Scheme
N
33°0'0"E

Winter Crop Cultivation Schedule in the Gezira Irrigation Scheme

Chickpea

Crop	Planting Date	Harvest Date
Wheat	Early November	Mid-March
Barley	Mid-November	Late April
Pigeon pea	Late October	Early May
Chickpea	Early December	Late March
Vegetables	Late November	Throughout season
Cotton	Early October	Late March

Cotton

Vegetables

Summer Crop Cultivation Schedule in the Gezira Irrigation Scheme

Crop	Planting Date	Harvest Date
Maize	Early May	Late August
Sorghum	Mid-May	Early September
Cotton	Early October	Late March
Groundnut	Early June	Late October
Vegetables	Various dates	Various dates

Sorghum

Groundnut

Maize

Crop Name	Planting Month	Germination Stage (days)	Growth Stage (days)	Maturity Stage (days)	Harvest Month
Wheat	November	5-8	30-40	90-120	March
Barley	November	5-7	30-45	90-110	April
Chickpea	December	7-14	40-60	90-120	March
Cotton	October	7-10	50-70	150-180	March

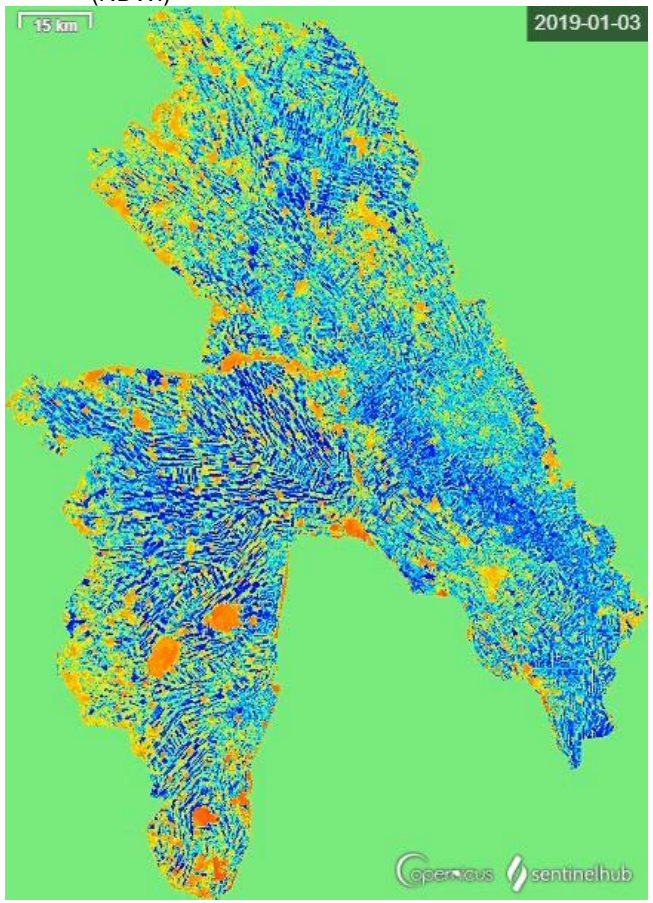
Crop Name	Planting Month	Germination Stage (days)	Growth Stage (days)	Maturity Stage (days)	Harvest Month
Sorghum	May	3-5	35-50	95-110	September
Maize	May	4-7	45-60	80-100	August
Groundnut	June	10-14	40-60	120-150	October
Cotton	October	7-10	50-70	150-180	March

Summer & Winter Crop Cultivation Schedule in the Gezira Irrigation Scheme :

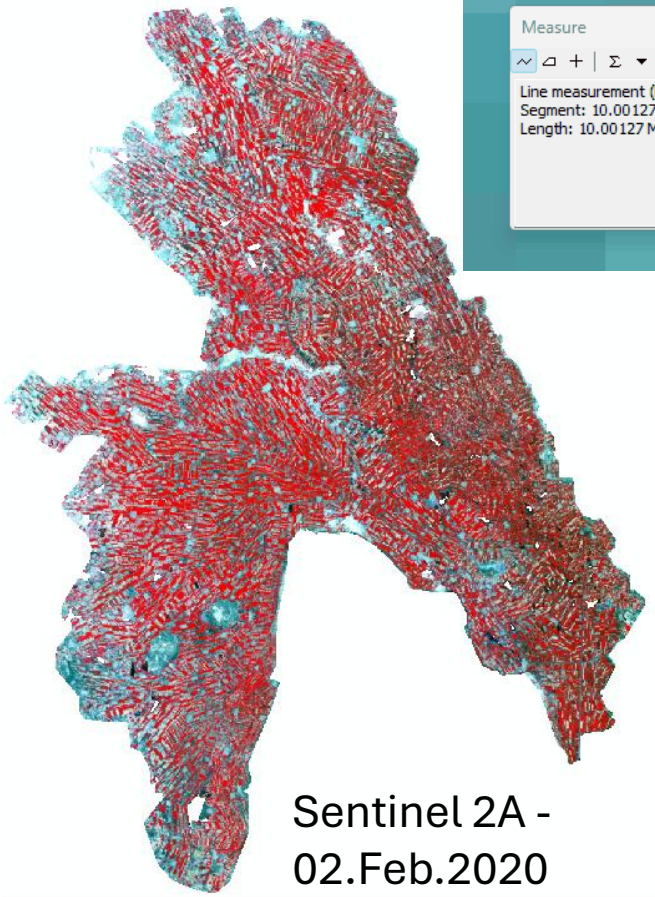
Normalized difference vegetation index (NDVI)

Sentinel image

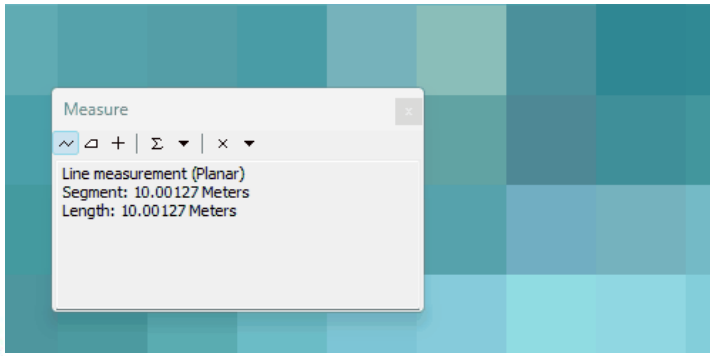
Normalized Difference Water Index (NDWI)



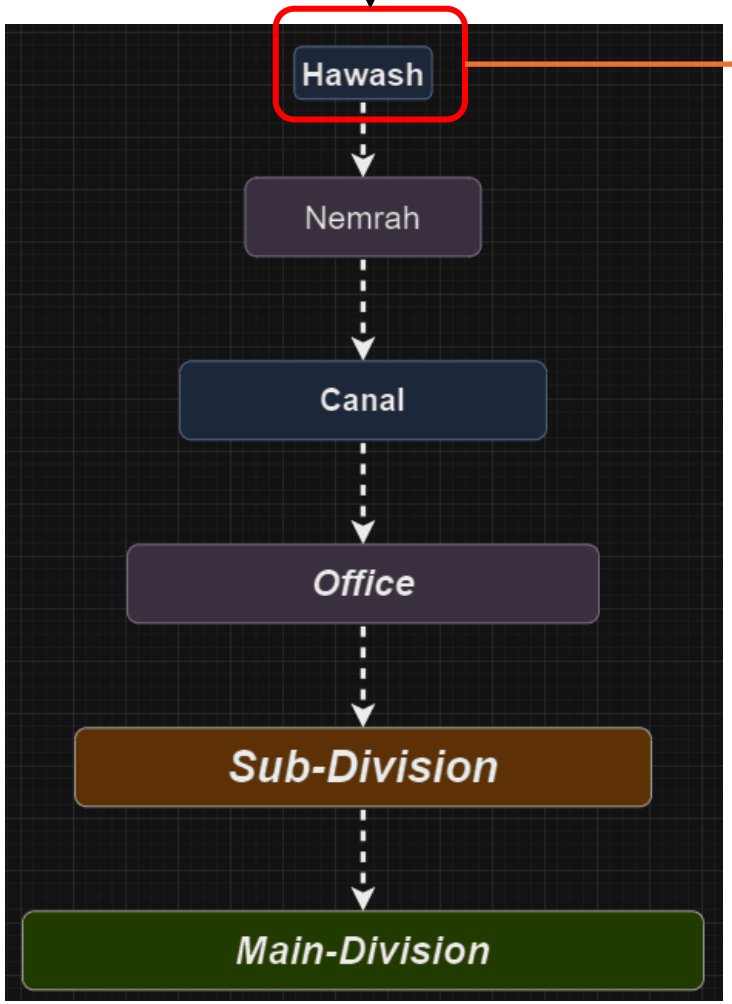
Is It Possible to Utilize Satellite Imagery for Monitoring Crops in the Gezira irrigation scheme?

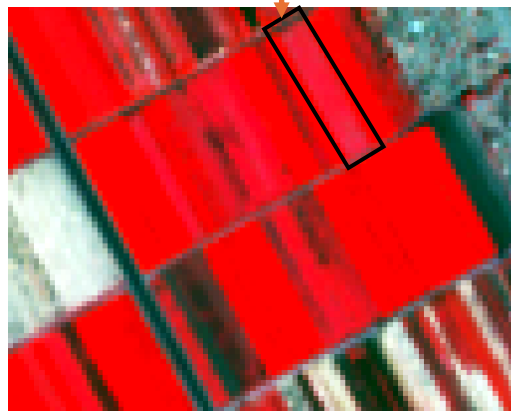


Sentinel 2A - 02.Feb.2020



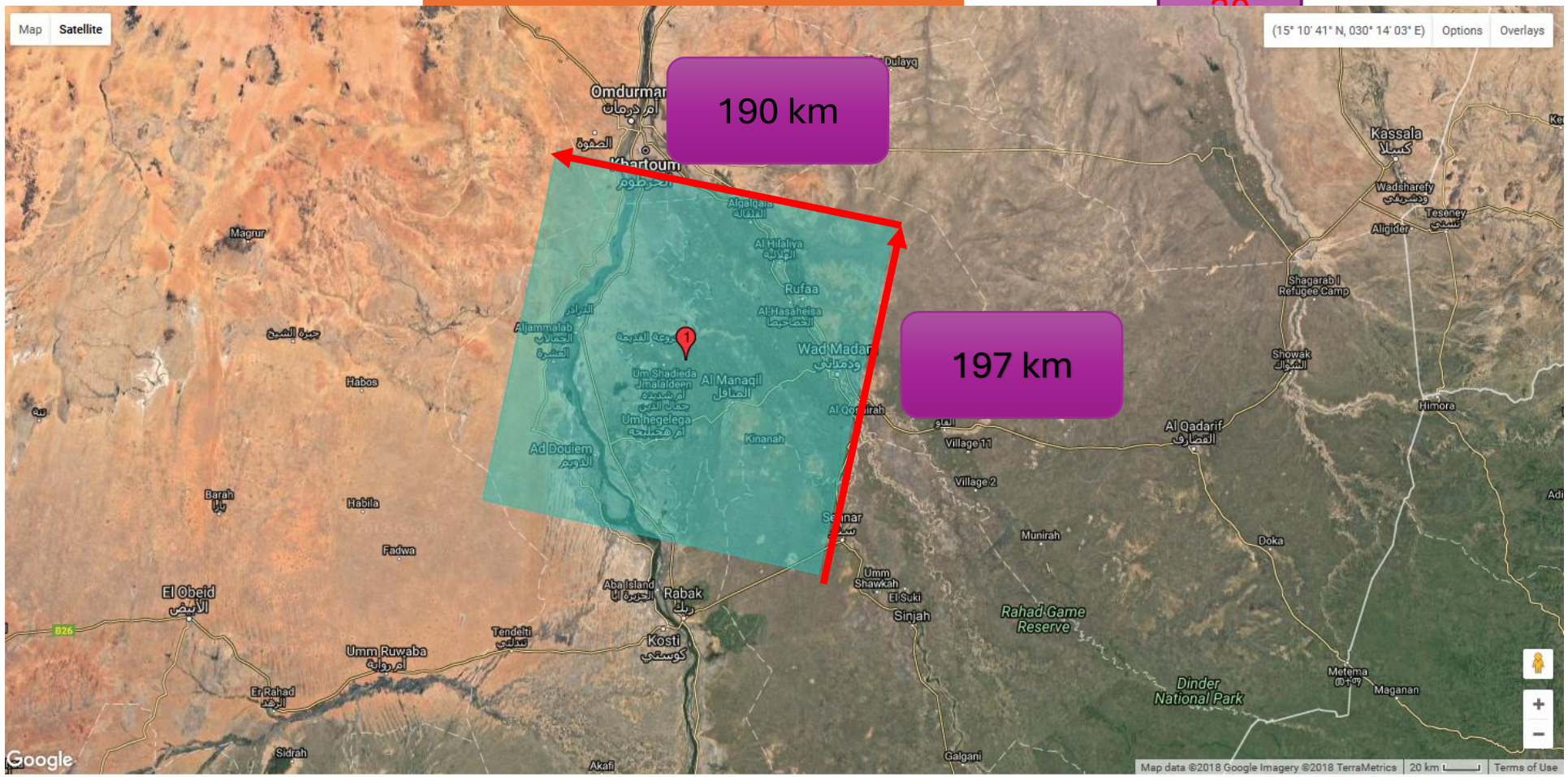
1 feddan = 0.42 ha
Hawash = (2 , 4) Feddan
Feddan = 4200 m2
2*4200 = 8400

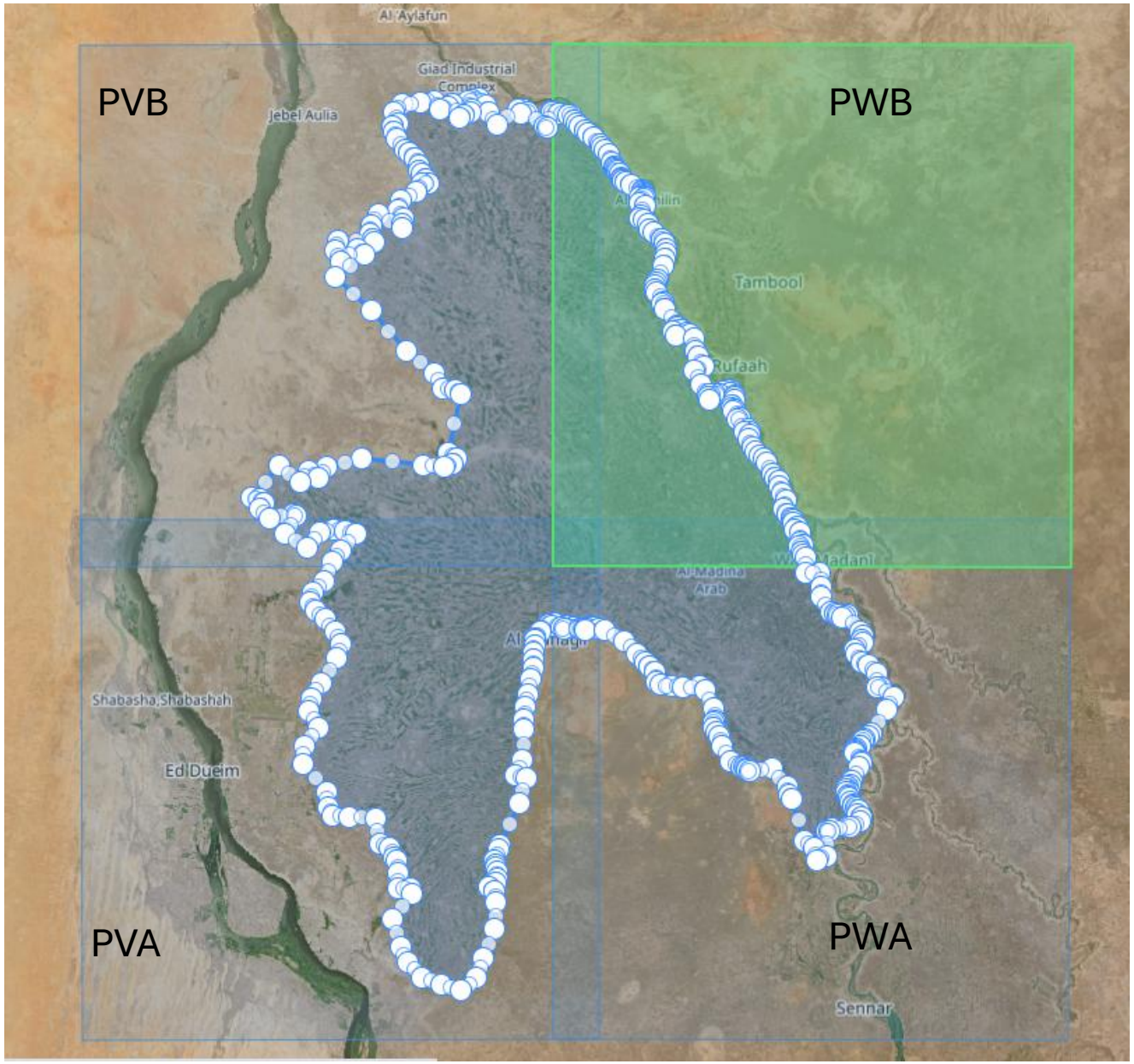


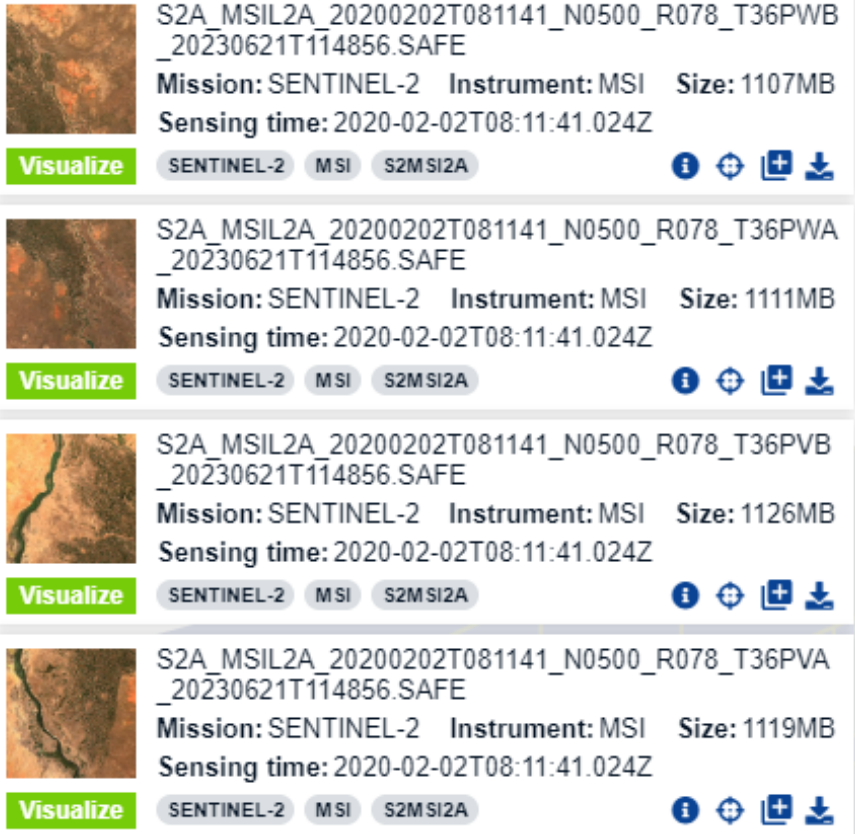


Is It Possible To Utilize Satellite Imagery For Monitoring Crops In The Gezira Irrigation Scheme?

Landsat 8 Satellite




PVB
PWB
PVA
PWA
Al Aylafun
Giad Industrial Complex
Jebel Aulia
Tambool
Rufaah
Al Madina Arab
Shabasha,Shabashah
Ed Dueim
Sennar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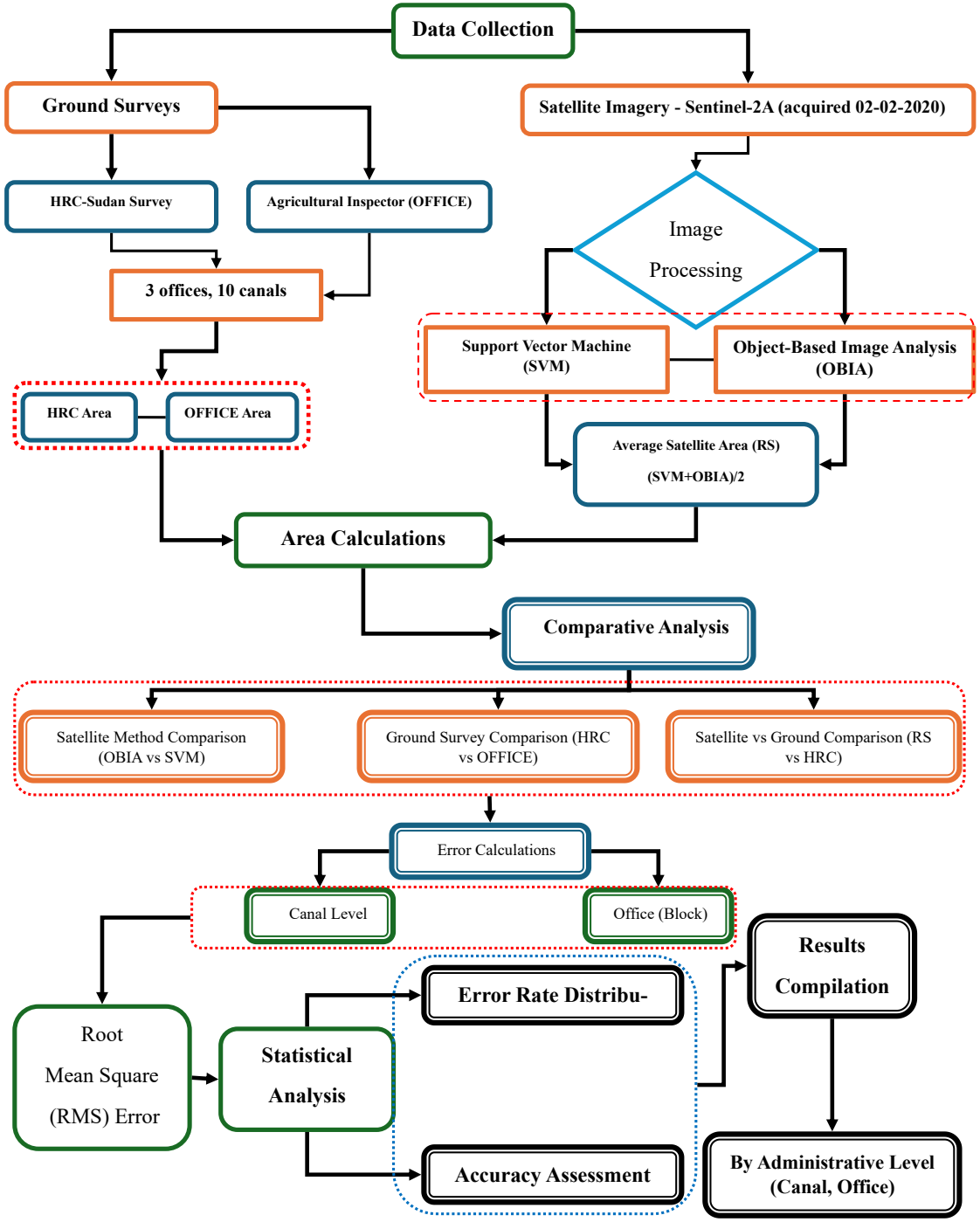
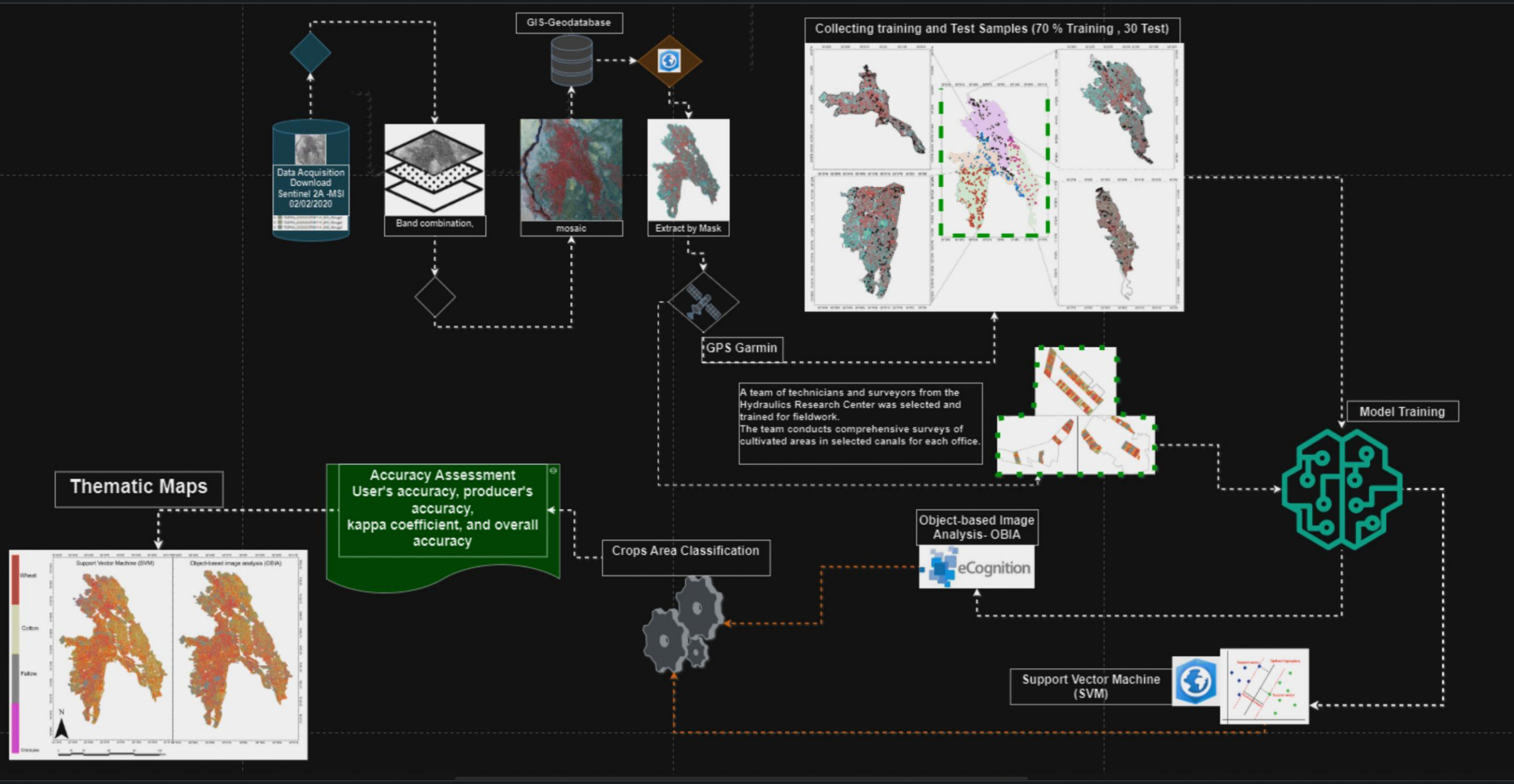
Mission: SENTINEL-2 Instrument: MSI Size: 1107MB
Sensing time: 2020-02-02T08:11:41.024Z
Visualize
SENTINEL-2 MSI S2MSI2A
S2A_MSIL2A_20200202T081141_N0500_R078_T36PWA_20230621T114856.SAFE
Mission: SENTINEL-2 Instrument: MSI Size: 1111MB
Sensing time: 2020-02-02T08:11:41.024Z
Visualize
SENTINEL-2 MSI S2MSI2A
S2A_MSIL2A_20200202T081141_N0500_R078_T36PVB_20230621T114856.SAFE
Mission: SENTINEL-2 Instrument: MSI Size: 1126MB
Sensing time: 2020-02-02T08:11:41.024Z
Visualize
SENTINEL-2 MSI S2MSI2A
S2A_MSIL2A_20200202T081141_N0500_R078_T36PVA_20230621T114856.SAFE
Mission: SENTINEL-2 Instrument: MSI Size: 1119MB
Sensing time: 2020-02-02T08:11:41.024Z
Visualize
SENTINEL-2 MSI S2MSI2A

Link

Importance of Wheat Production in Sudan

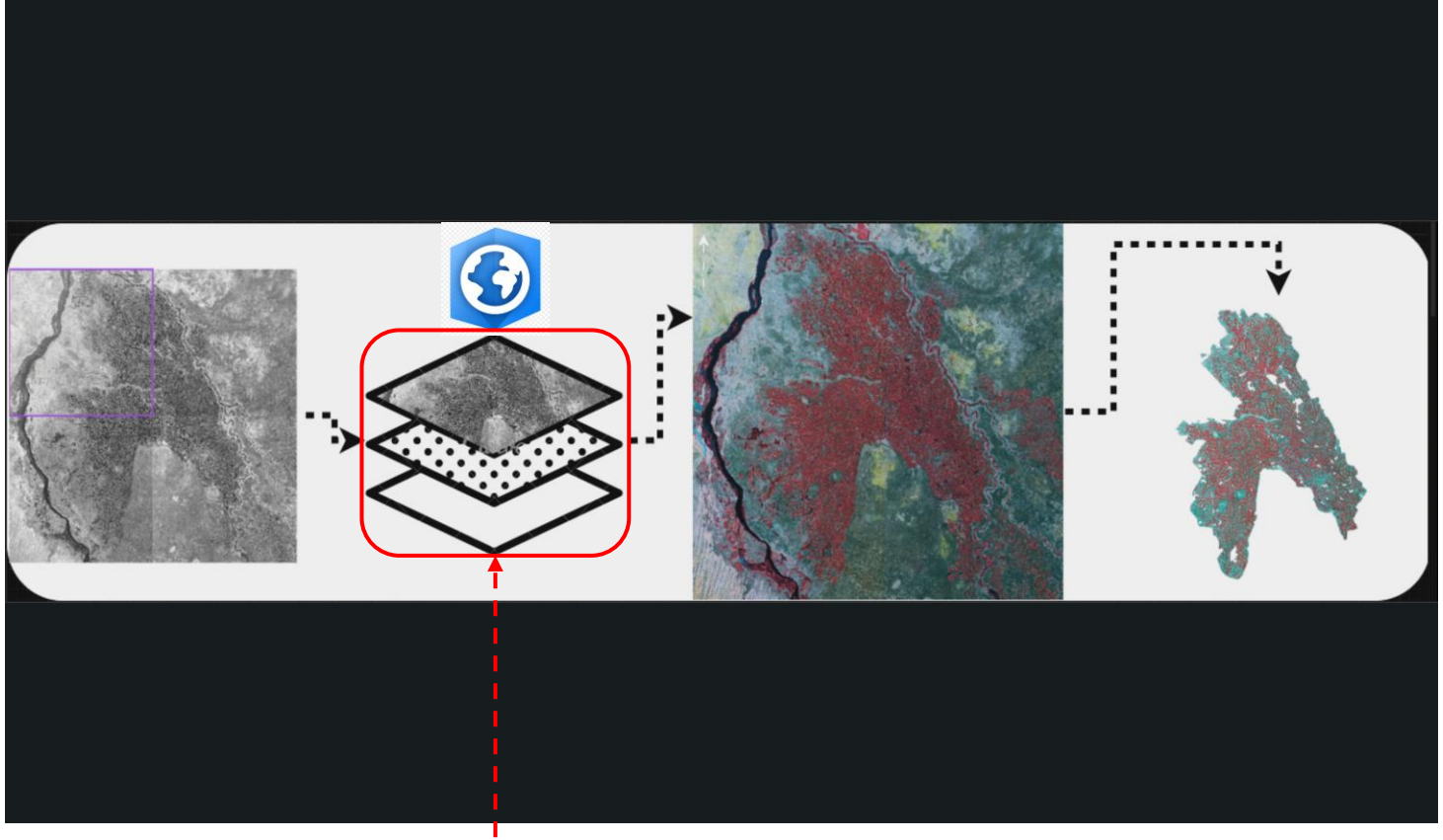
1. Food Security and Import Reduction
2. Economic Impact and Rural Livelihoods
3. Strategic Crop for Agricultural Development
4. Climate Adaptation and Crop Diversification

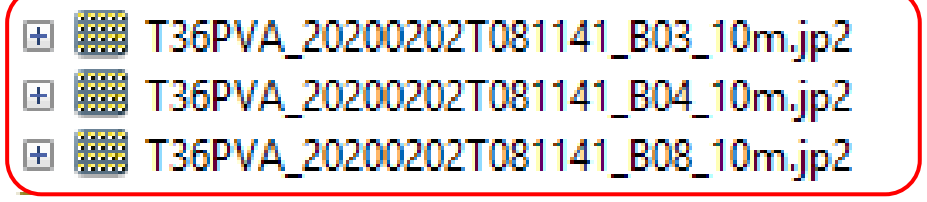

Data Collection
Ground Surveys
Satellite Imagery - Sentinel-2A (acquired 02-02-2020)
HRC-Sudan Survey
Agricultural Inspector (OFFICE)
Image Processing
3 offices, 10 canals
Support Vector Machine (SVM)
Object-Based Image Analysis (OBIA)
HRC Area
OFFICE Area
Average Satellite Area (RS) (SVM+OBIA)/2
Area Calculations
Comparative Analysis
Satellite Method Comparison (OBIA vs SVM)
Ground Survey Comparison (HRC vs OFFICE)
Satellite vs Ground Comparison (RS vs HRC)
Error Calculations
Canal Level
Office (Block)
Root Mean Square (RMS) Error
Statistical Analysis
Error Rate Distribu-
Accuracy Assessment
Results Compilation
By Administrative Level (Canal, Office)


GIS-Geodatabase
Collecting training and Test Samples (70 % Training , 30 Test)
Data Acquisition
Download
Sentinel 2A -MSI
02/02/2020
Band combination,
mosaic
Extract by Mask
GPS Garmin
A team of technicians and surveyors from the Hydraulics Research Center was selected and trained for fieldwork.
The team conducts comprehensive surveys of cultivated areas in selected canals for each office.
Model Training
Thematic Maps
Accuracy Assessment
User's accuracy, producer's accuracy,
kappa coefficient, and overall accuracy
Crops Area Classification
Object-based Image Analysis- OBIA
eCognition
Support Vector Machine (SVM)
Support Vector Machine (SVM)
Object-based image analysis (OBIA)
Wheat
Cotton
Fallow
Orchard
N

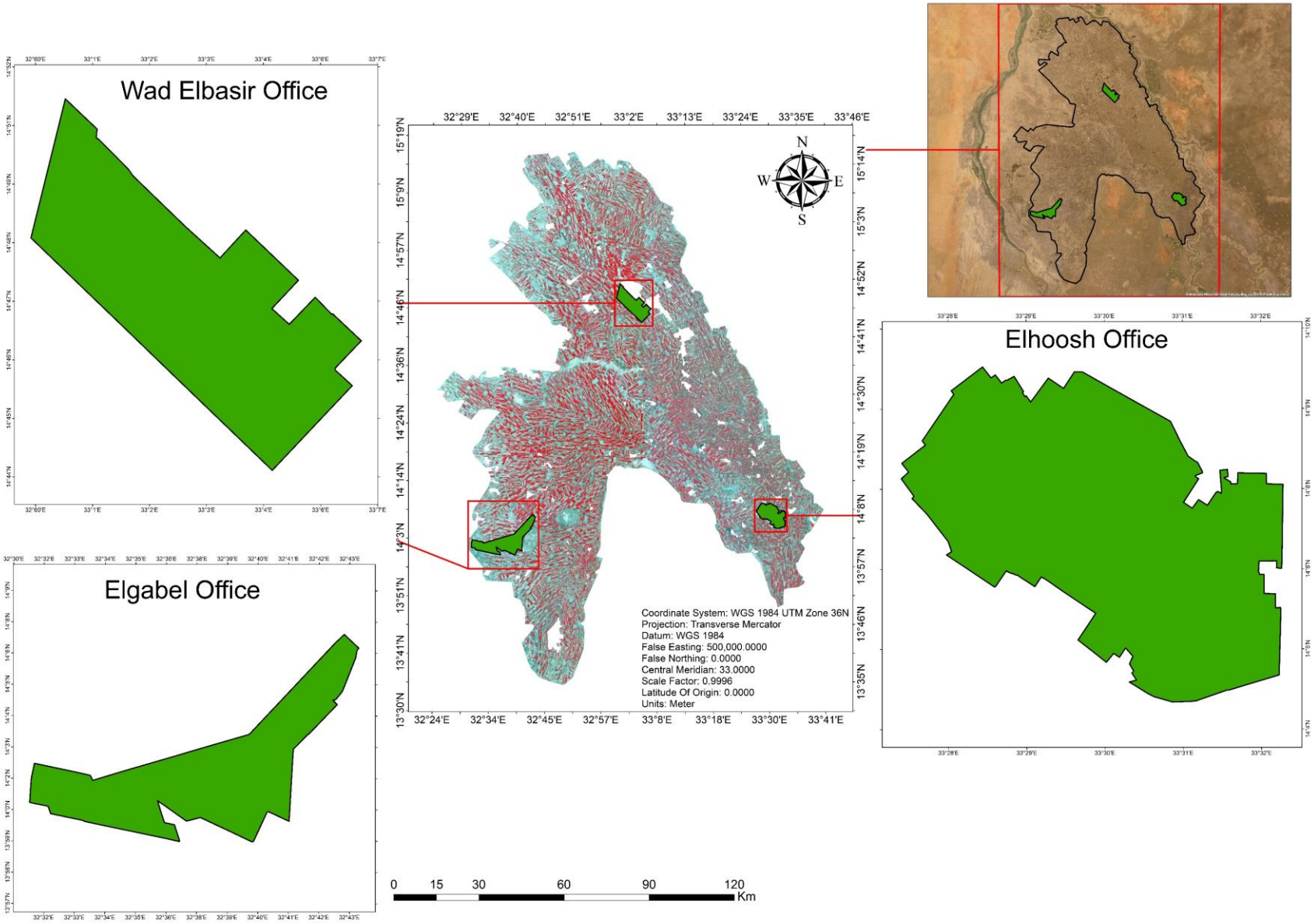
Attribute	Description
Satellite Name	Sentinel-2
Mission	Earth observation
Launch Dates	Sentinel-2A: 23 June 2015 Sentinel-2B: 7 March 2017
Spatial Resolution	10 meters (VNIR), 20 meters (Red Edge and SWIR), 60 meters (Coastal/Aerosol, Water Vapor, Cirrus)
Spectral Bands	13 bands covering visible, near-infrared, short-wave infrared, and atmospheric content
Temporal Resolution	5 days at the equator (with both satellites operating)
Swath Width	290 km
Data Accessibility	Open access through the Copernicus Open Access Hub
Applications	Land cover classification, agriculture monitoring, forestry, disaster management, water quality assessment
Processing Levels	Level-1C (Top-of-Atmosphere Reflectance), Level-2A (Bottom-of-Atmosphere Reflectance)
Revisit Time	5 days
Data Format	GeoTIFF
Orbit Altitude	786 km
Inclination	98.62°

Sentinel-2 Bands	Central Wavelength (µm)	Resolution (m)
Band 1 - Coastal aerosol	0.443	60
Band 2 - Blue	0.490	10
Band 3 - Green	0.560	10
Band 4 - Red	0.665	10
Band 5 - Vegetation Red Edge	0.705	20
Band 6 - Vegetation Red Edge	0.740	20
Band 7 - Vegetation Red Edge	0.783	20
Band 8 - NIR	0.842	10
Band 8A - Vegetation Red Edge	0.865	20
Band 9 - Water vapour	0.945	60
Band 10 - SWIR - Cirrus	1.375	60
Band 11 - SWIR	1.610	20
Band 12 - SWIR	2.190	20





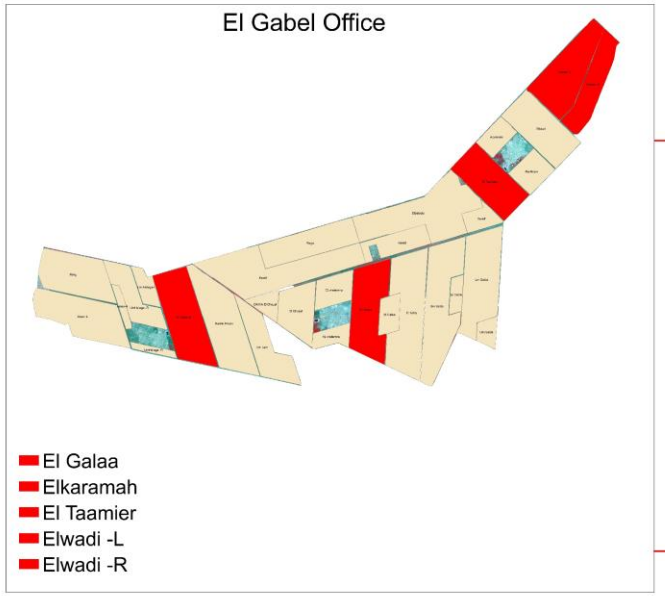
- Three offices within the Gezira Scheme were selected based on their semi-geographical distribution within the Scheme area. We assumed that these three offices approximately represent the entire Gezira Scheme. The selected offices are Elhoosh, Wad Elbasir, and Elgabel.

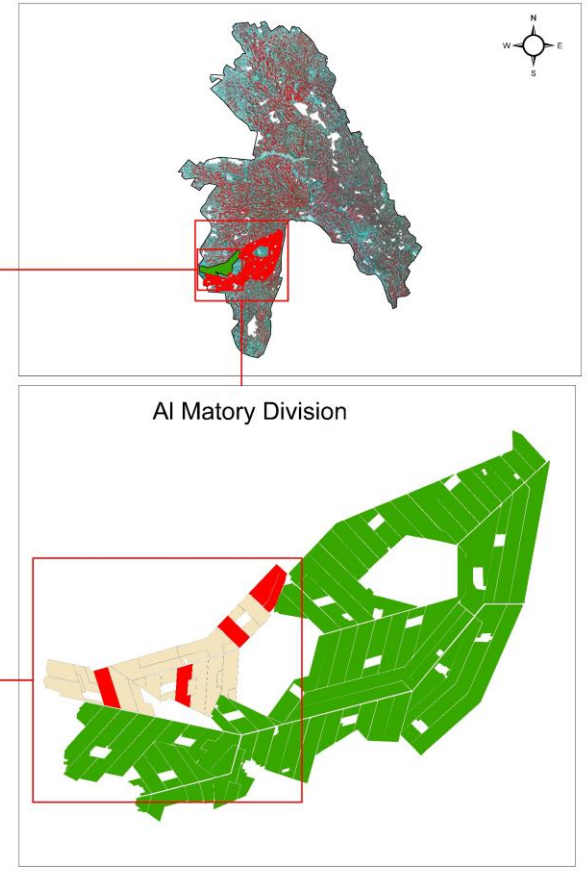


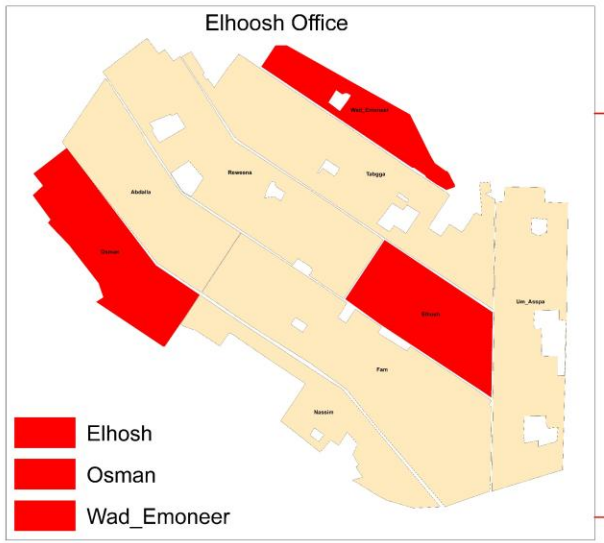
Elgabel Office:

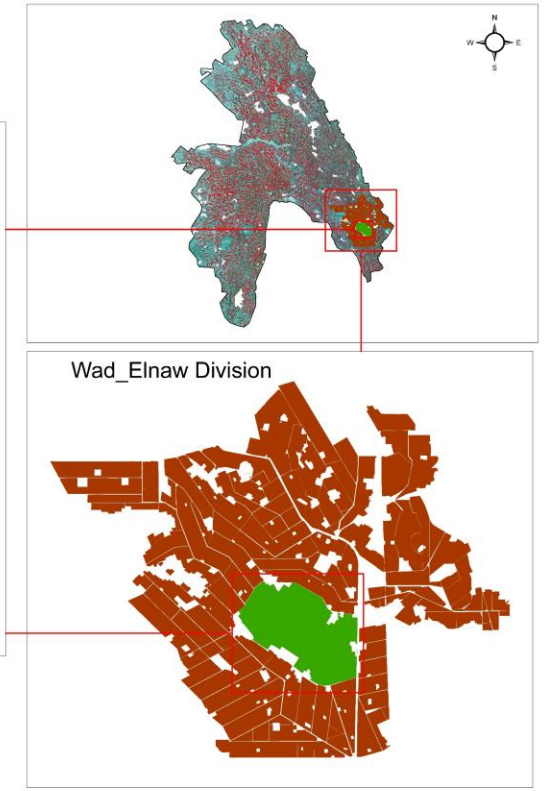
Elgabel Office 74 is located within the Al Matory Division . area of Elgabel Office is approximately 18,939 Feddan and consists of 18 canals . Table (...) lists the names of the canals in Elgabel Office and the number of Nemra for each canal includes .Elgabel Office is irrigated by the Dawrah and Alazozab Major. The administrative boundaries of Elgabel Office were determined in collaboration with the Division inspector and the office inspector (Division Inspector: Eng. Jamal Al Nouri, Office Inspector: Eng. Al Tijani) on 12/06/2016.

No. canal	Cana Name	No. of Nemra	Canal Area/ Feddan
1	ElWadi-R	13	1586
	ElWadi-L	13	
2	Elbilad	10	888
3	Abulkram	10	625
4	ElTaamier	10	891
5	Elbaladia	16	1430
6	Kereif	36	2714
7	Um Sabla	15	1138
8	El Gaba	17	1374
9	El Ndra	16	1272
10	El Galaa	13	1083
11	EL metemira	9	560
12	El Chazal	8	1083
13	DXX/A El Chazal	3	
14	Um Laot	10	671
15	Bashir Elzein	14	1135
16	ElKaramah	13	1106
17	Um Halaga	13	741
18	Ussar	10	1044
	Rizig	10	
Total Area			18939





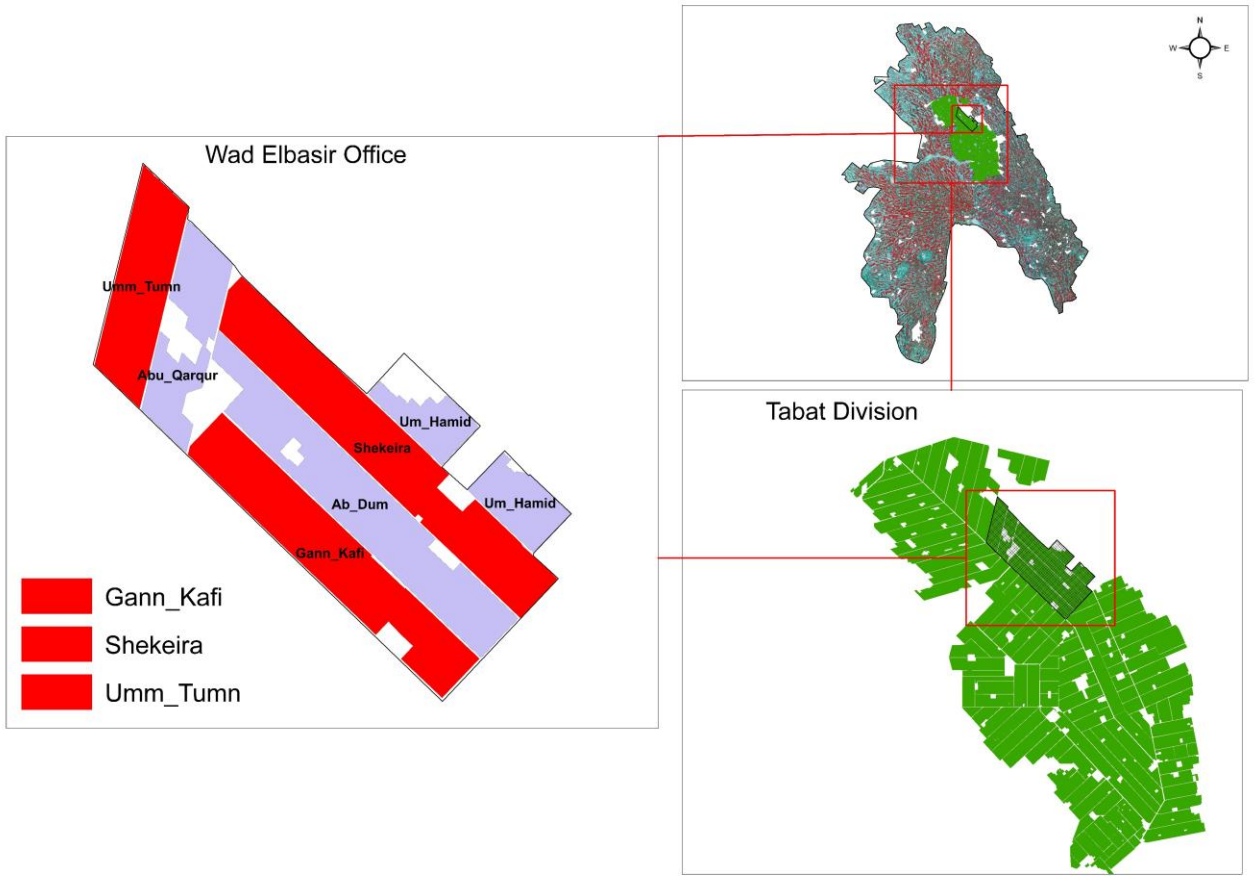




- ***Elhoosh Office :***

Elhoosh Office is located in the southern part of the Gezira Scheme . within Wad Elnaw Division . area of Elhoosh Office is approximately 14,440 Feddan and consists of 9 canals . lists the names of the canals in Elhoosh Office and the number of Nemra each canal includes. Elhoosh Office is irrigated by the Al-Hayawan and Nasim Major, which takes water from the 57 Weir. The administrative boundaries of Elhoosh Office were determined in collaboration with the office inspector (Inspector: Salah Hamdan) on 22/02/2016.

No. canal	Cana Name	No. of Nemra	Canal Area/ Feddan
1	Nassim	19	884
2	Osman	18	1072
3	Fam	21	2316
4	Abdalla	16	1235
5	Elhosh	12	961
6	Reweena	21	1858
7	Tabgga	24	1954
8	Wad_Emoneer	14	618
9	Um_Asspa	20	1593
Total Area			12491



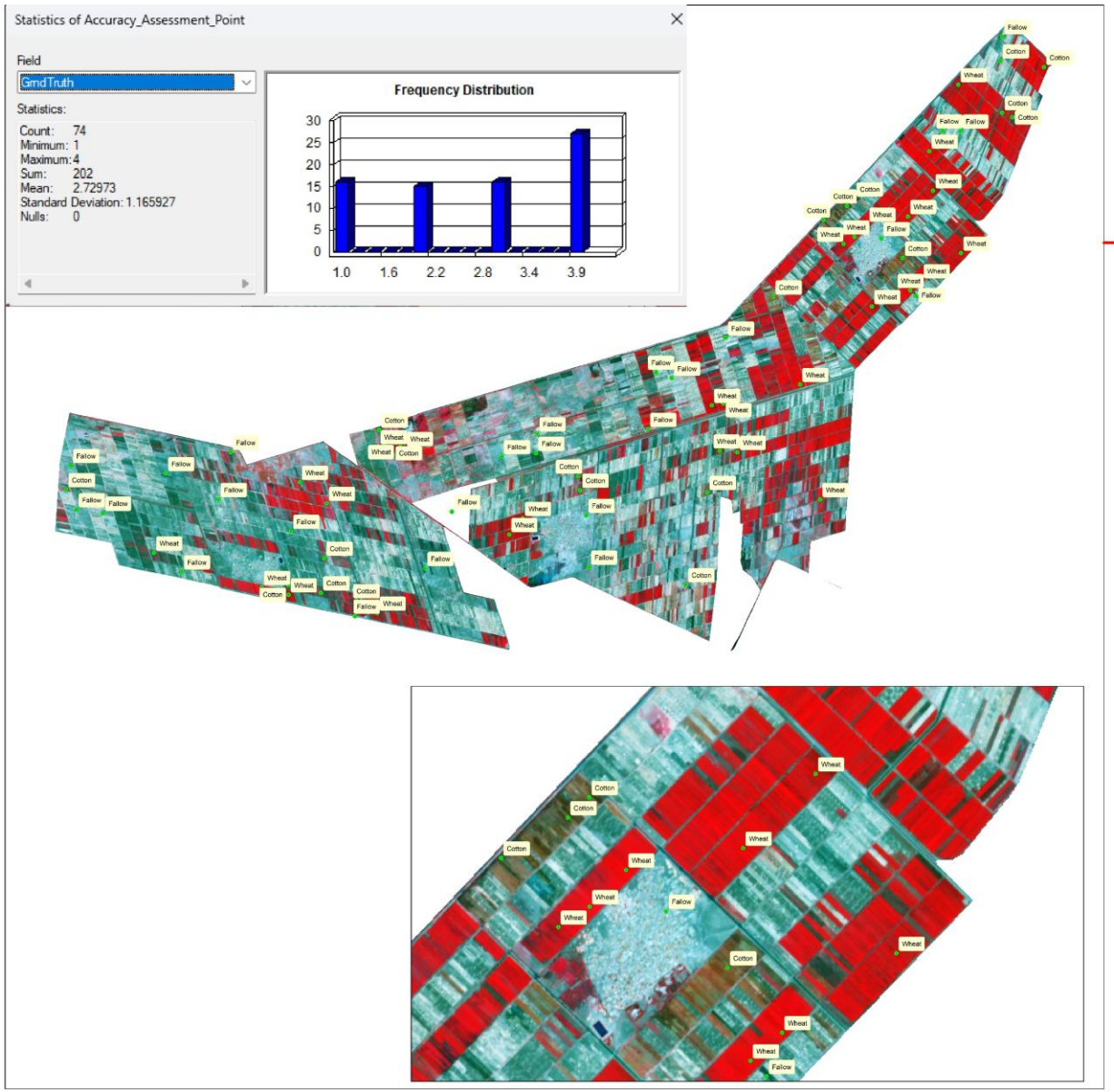
- ***Wad EL Basir Office***

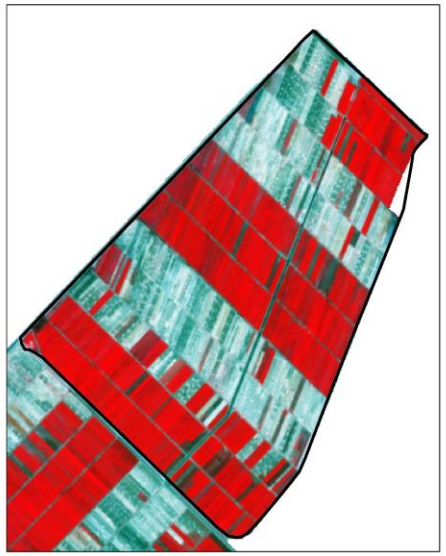
Wad Al Basir Office is located in the northern part of the Gezira Scheme. within Tabat Division and covers an area of approximately 16,000 Feddan. The office consists of 6 canals. and is irrigated by the Major of Al-Muraibiya.

No canal	Cana Name	No of Nemra	Canal Area/ Feddan
1	Gann_Kafi	31	2714
2	Ab_Dum	36	2912
3	Shekeira	39	3264
4	Um_Hamid	17	1281
5	Abu_Qarqur	17	1276
6	Umm_Tumn	18	144
Total Area			**11591**

Code	Equation Name	Equation	Description
HRC	HRC Area	HRC	Area surveyed by the Hydraulics Research Center
OFFICE	Office Area	OFFICE	Area surveyed by the agricultural inspector
SVM	Satellite Area (Method 1)	SVM	Area obtained from the satellite (Method 1)
OBIA	Satellite Area (Method 2)	OBIA	Area obtained from the satellite (Method 2)
RS	Average Satellite Area	(SVM + OBIA) / 2	Average area obtained from the satellite using both methods
Diff OBIA SVM	Difference OBIA SVM	(OBIA - SVM) / OBIA * 100	Percentage difference between OBIA and SVM areas
Avg. SVM OBIA	Average SVM OBIA	(SVM + OBIA) / 2	Average area between SVM and OBIA
Diff HRC Office	Difference HRC Office	(HRC - OFFICE) / HRC * 100	Percentage difference between HRC and Office areas
Diff RS HRC	Difference RS HRC	(RS - HRC) / RS * 100	Percentage difference between RS and HRC areas
Diff C (Gardens/Chickpea/Cotton/Other)	Cotton Difference	(HRC - RS) / 2 * 100	Percentage difference for cotton crop
Diff W (Wheat)	Wheat Difference	(HRC - RS) / 2 * 100	Percentage difference for wheat crop

Percentage Difference or Relative Difference





Area surveyed by the Hydraulics Research Center

	Elwadi_L		
Nemrah	Wheat (F)	Onion (F)	pigeo pea(F)
1	100	3	
2	106	8.5	
3	36	7.5	
4	13.5	0	
5	1.5	0	
6	100	0	
7	81	6	
8	56	4.5	
9	0	3	3
10	6	0	3
11	6	0	0
12	9	0	0
13	0	0	0
Total	515	32.5	6

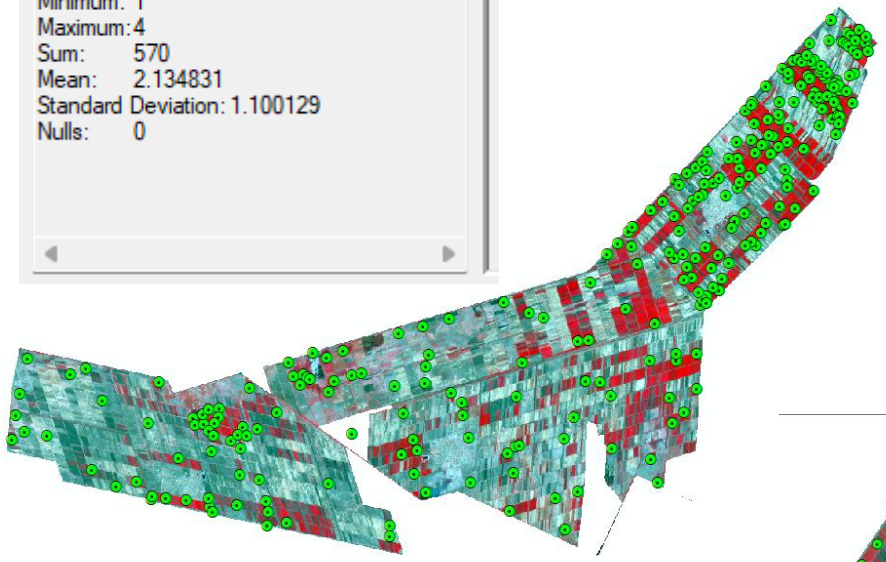
Statistics of Accuracy_Assessment_Point

Field

Classified

Statistics:

Count: 267
Minimum: 1
Maximum: 4
Sum: 570
Mean: 2.134831
Standard Deviation: 1.100129
Nulls: 0



Statistics of Samples

Field

Classified

Statistics:

Count: 297
Minimum: 1
Maximum: 5
Sum: 883
Mean: 2.973064
Standard Deviation: 1.186036
Nulls: 0

Statistics of ACAS_Point

Field

Classified

Statistics:

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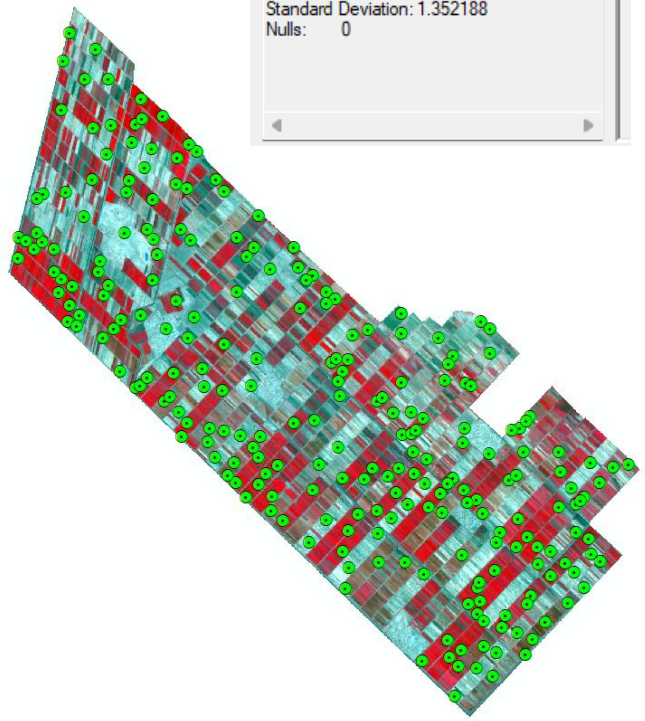
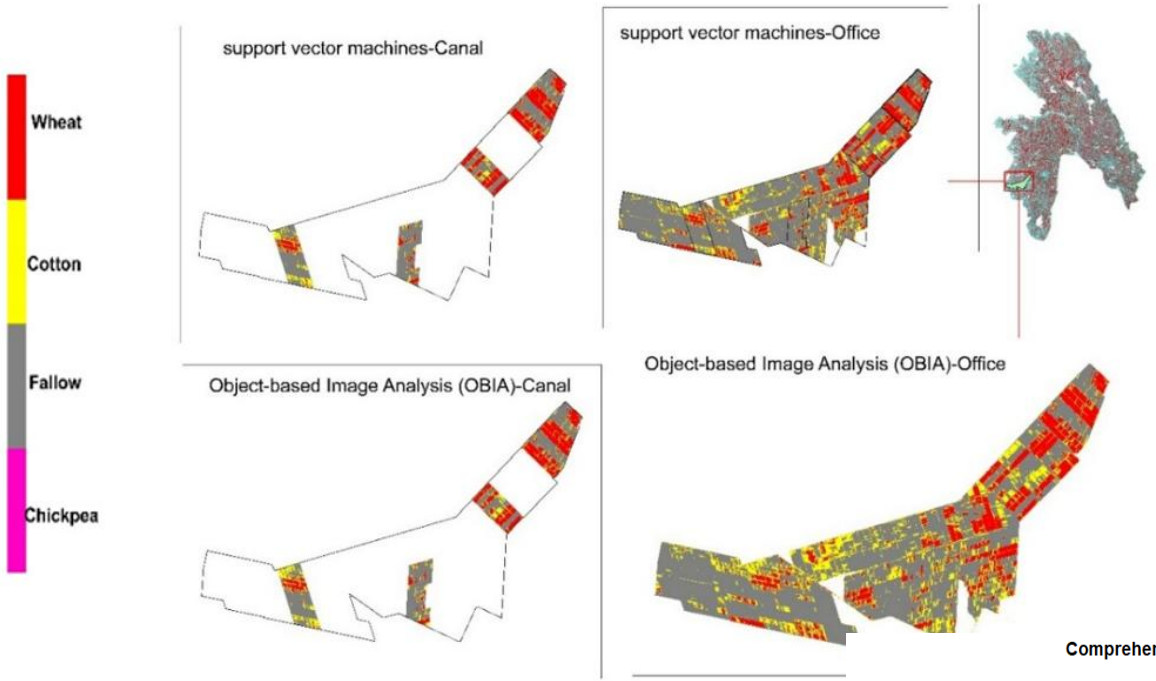
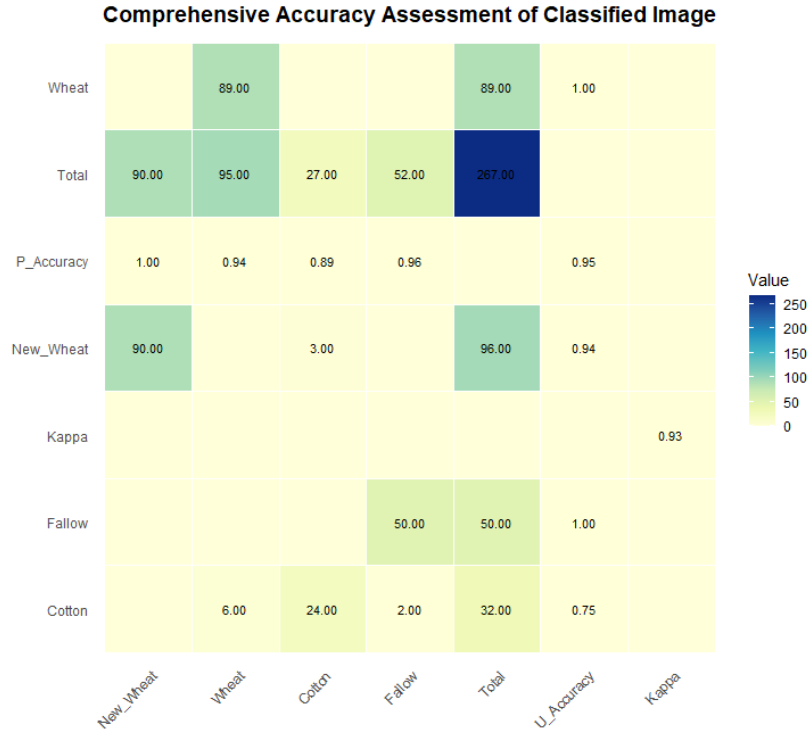
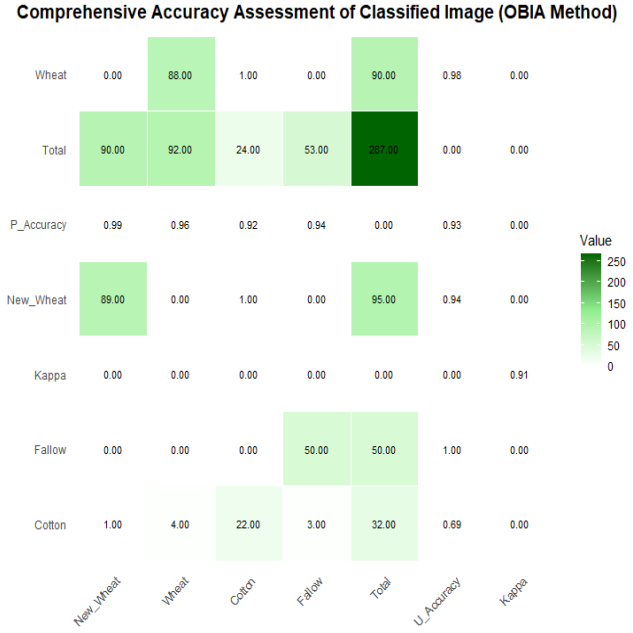
Maximum: 5
Sum: 742
Mean: 3.053498
Standard Deviation: 1.352188
Nulls: 0



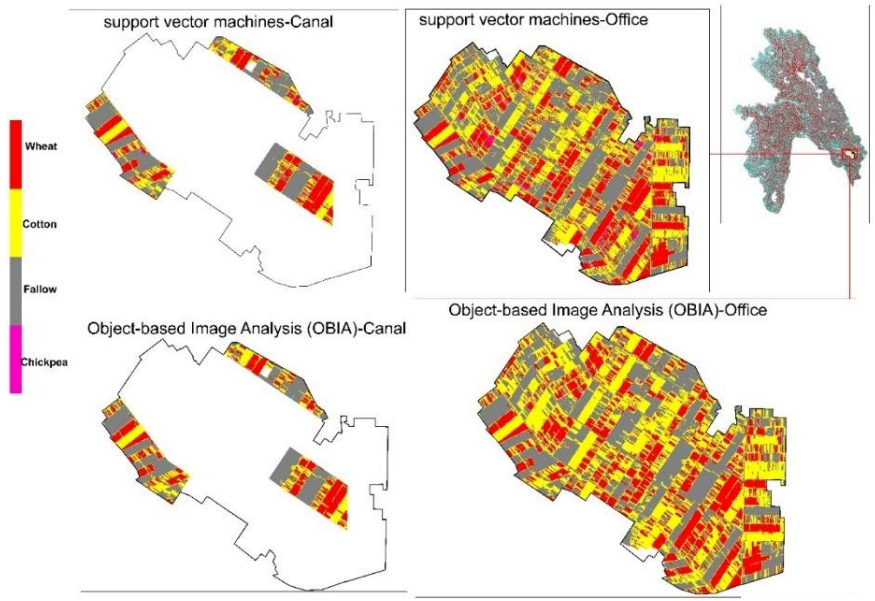
Results: Crop Classification with Accuracy assessment

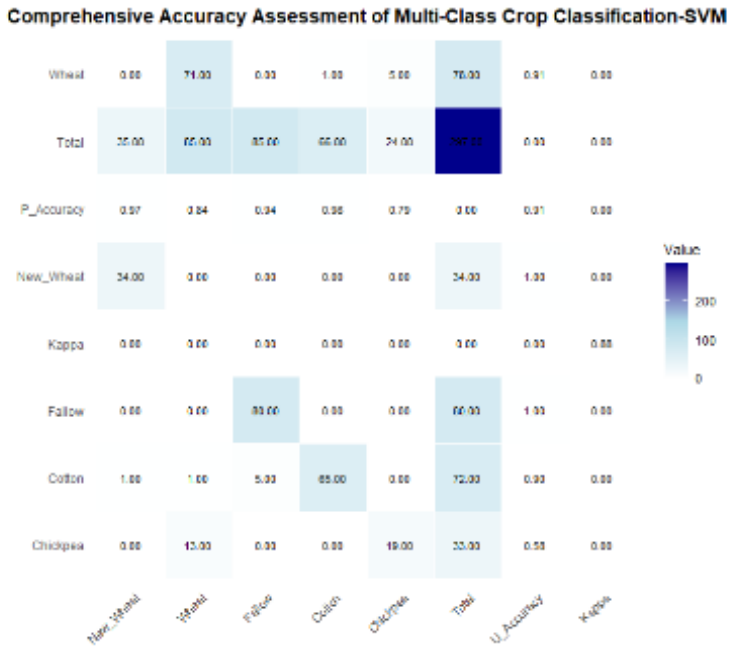


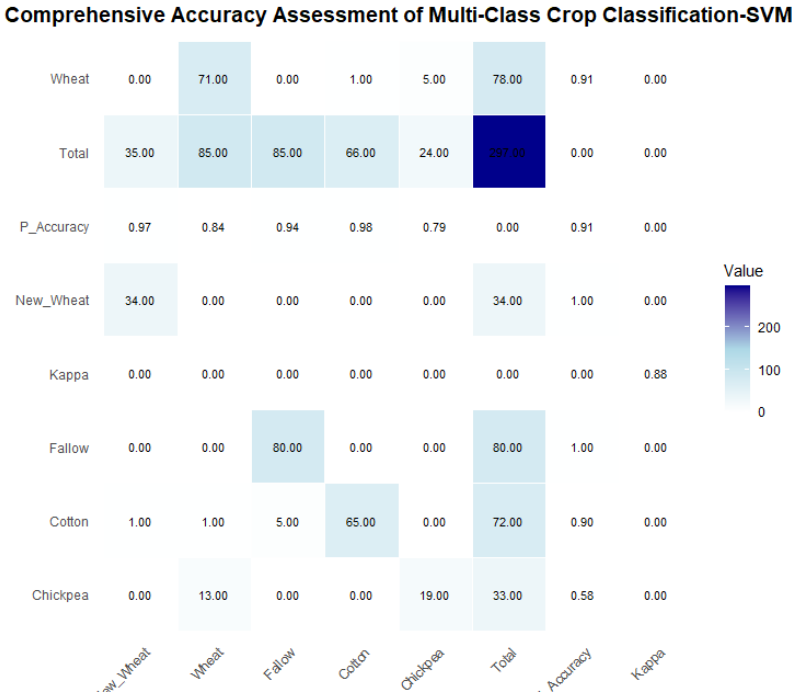




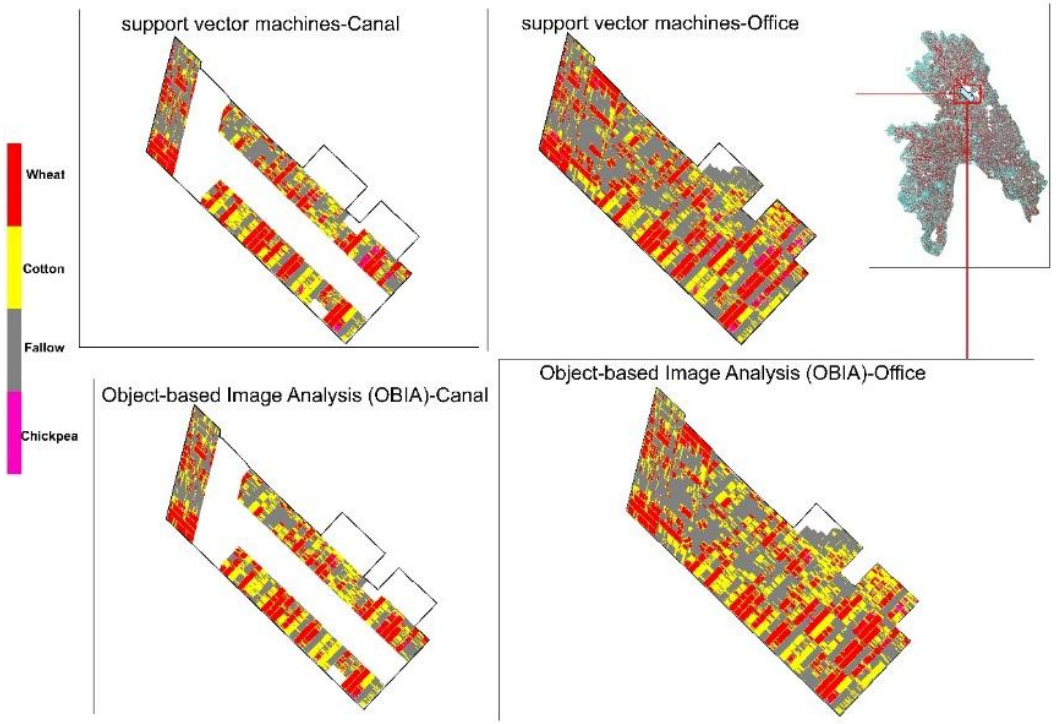
Results: Crop Classification with Accuracy assessment







Results: Crop Classification with Accuracy assessment



Revised Comprehensive Accuracy Assessment of Multi-Class Crop Classification-SVM

	New_Wheat	Wheat	Cotton	Fallow	Chickpea	Total	U_Accuracy	Kappa
Wheat	0.00	33.00	0.00	0.00	0.00	33.00	1.00	0.00
Total	2.00	49.00	47.00	70.00	28.00	243.00	0.00	0.00
P_Accuracy	0.00	0.98	0.70	1.00	1.00	0.00	0.91	0.00
New_Wheat	48.00	0.00	0.00	0.00	0.00	48.00	1.00	0.00
Kappa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.88
Fallow	0.00	0.00	0.00	64.00	0.00	64.00	1.00	0.00
Cotton	1.00	5.00	47.00	6.00	0.00	59.00	0.80	0.00
Chickpea	0.00	9.00	0.00	0.00	28.00	39.00	0.72	0.00

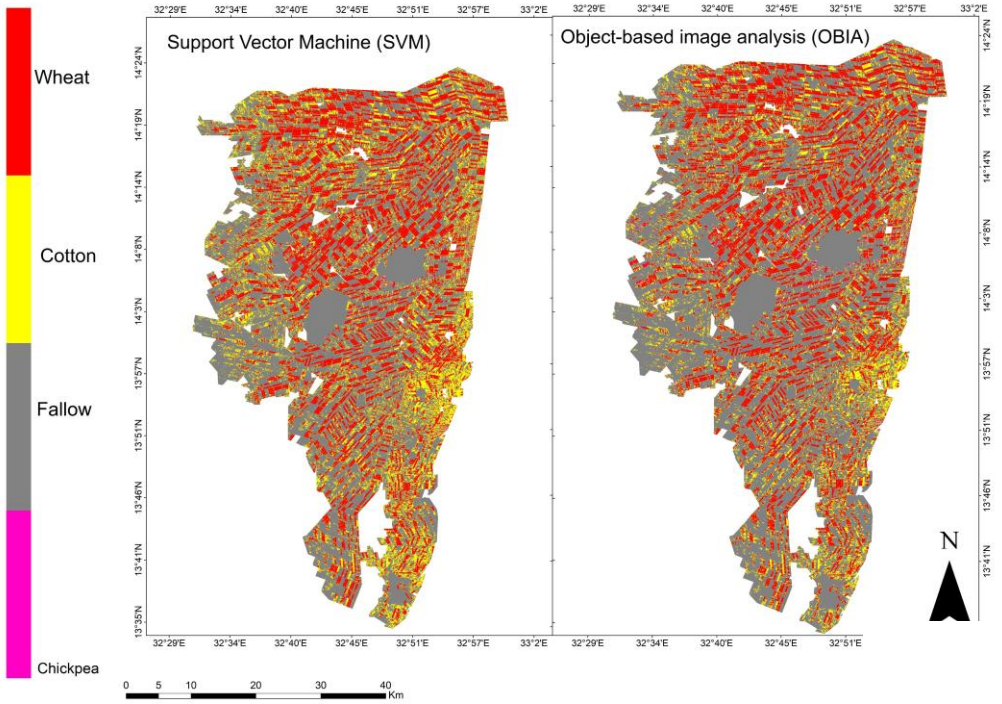
Value: 200, 150, 100, 50, 0

Comprehensive Accuracy Assessment of Multi-Class Crop Classification-OBIA

	New_Wheat	Wheat	Cotton	Fallow	Chickpea	Total	U_Accuracy	Kappa
Wheat	0.00	38.00	0.00	0.00	15.00	54.00	0.70	0.00
Total	49.00	47.00	47.00	70.00	28.00	243.00	0.00	0.00
P_Accuracy	0.98	0.81	1.00	0.91	0.46	0.00	0.86	0.00
New_Wheat	48.00	0.00	0.00	0.00	0.00	48.00	1.00	0.00
Kappa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83
Fallow	0.00	0.00	0.00	64.00	0.00	64.00	1.00	0.00
Cotton	1.00	5.00	47.00	6.00	0.00	59.00	0.80	0.00
Chickpea	0.00	4.00	0.00	0.00	13.00	18.00	0.72	0.00

Value: 200, 150, 100, 50, 0

Results: Crop Classification with Accuracy assessment



Weast of Managil Division

Comprehensive Accuracy Assessment of Multi-Class Crop Classification-SVm

	New_Wheat	Wheat	Cotton	Fallow	Chickpea	Total	U_Accuracy	Kappa
Wheat	0.000	102.000	0.000	0.000	0.000	102.000	1.000	0.000
Total	111.000	109.000	29.000	91.000	45.000	385.000	0.000	0.000
P_Accuracy	0.991	0.936	1.000	0.989	1.000	0.000	0.977	0.000
New_Wheat	110.000	0.000	0.000	0.000	0.000	110.000	1.000	0.000
Kappa	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.969
Fallow	0.000	0.000	0.000	90.000	0.000	90.000	1.000	0.000
Cotton	1.000	3.000	29.000	1.000	0.000	34.000	0.853	0.000
Chickpea	0.000	4.000	0.000	0.000	45.000	49.000	0.918	0.000

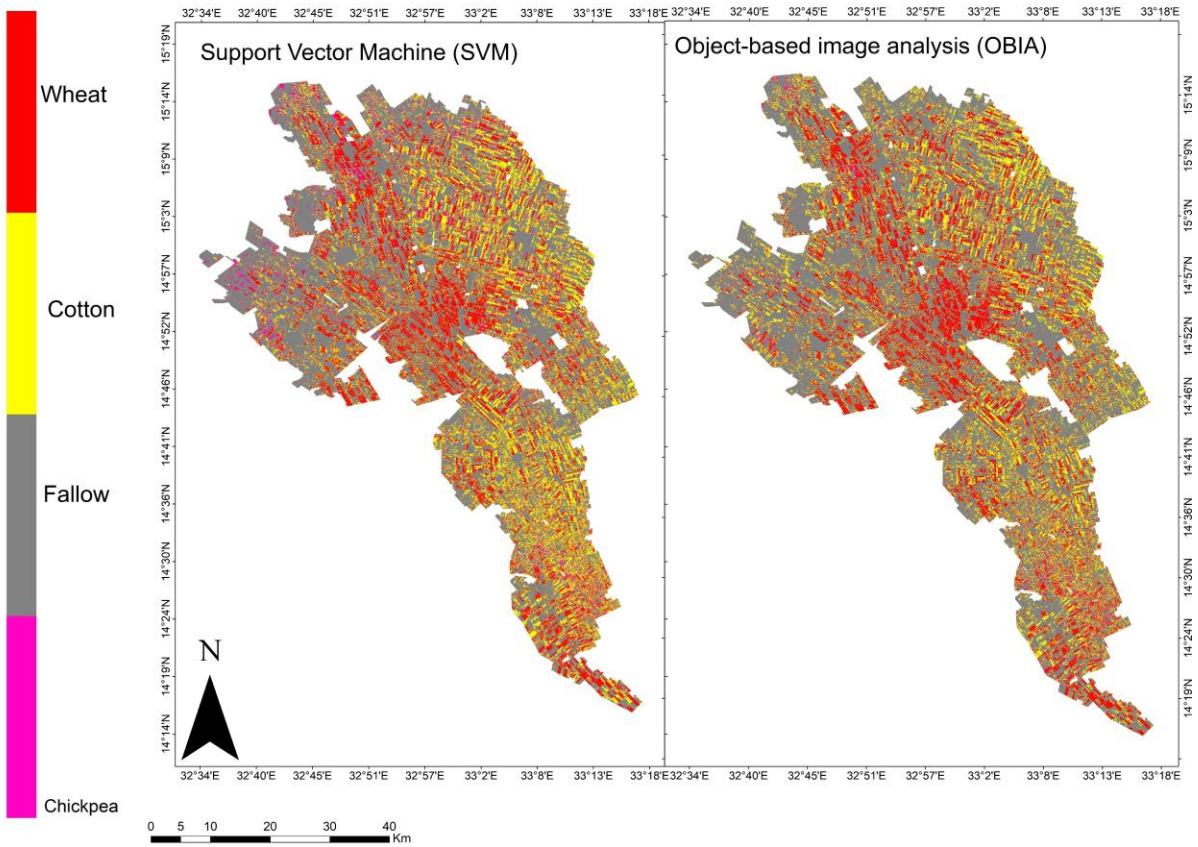
Value: 300, 200, 100, 0

Comprehensive Accuracy Assessment of Multi-Class Crop Classification-OBIA

	New_Wheat	Wheat	Cotton	Fallow	Chickpea	Total	U_Accuracy	Kappa
Wheat	0.00	102.00	0.00	0.00	0.00	102.00	1.00	0.00
Total	111.00	112.00	29.00	91.00	42.00	385.00	0.00	0.00
P_Accuracy	0.99	0.91	1.00	0.99	1.00	0.00	0.97	0.00
New_Wheat	110.00	0.00	0.00	0.00	0.00	110.00	1.00	0.00
Kappa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96
Fallow	0.00	0.00	0.00	90.00	0.00	90.00	1.00	0.00
Cotton	1.00	3.00	29.00	1.00	0.00	34.00	0.85	0.00
Chickpea	0.00	7.00	0.00	0.00	42.00	49.00	0.86	0.00

Value: 300, 200, 100, 0

Results: Crop Classification with Accuracy assessment



North of Gezira Division

Comprehensive Accuracy Assessment of Multi-Class Crop Classification-SVM

	New_Wheat	Wheat	Cotton	Fallow	Chickpea	Total	U_Accuracy	Kappa
Wheat	0.00	51.00	0.00	0.00	0.00	51.00	1.00	0.00
Total	58.00	55.00	40.00	73.00	51.00	278.00	0.00	0.00
P_Accuracy	0.91	0.93	0.85	0.96	1.00	0.00	0.93	0.00
New_Wheat	53.00	0.00	0.00	0.00	0.00	53.00	1.00	0.00
Kappa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.91
Fallow	0.00	0.00	0.00	70.00	0.00	70.00	1.00	0.00
Cotton	2.00	0.00	34.00	3.00	0.00	39.00	0.87	0.00
Chickpea	3.00	4.00	6.00	0.00	51.00	65.00	0.78	0.00

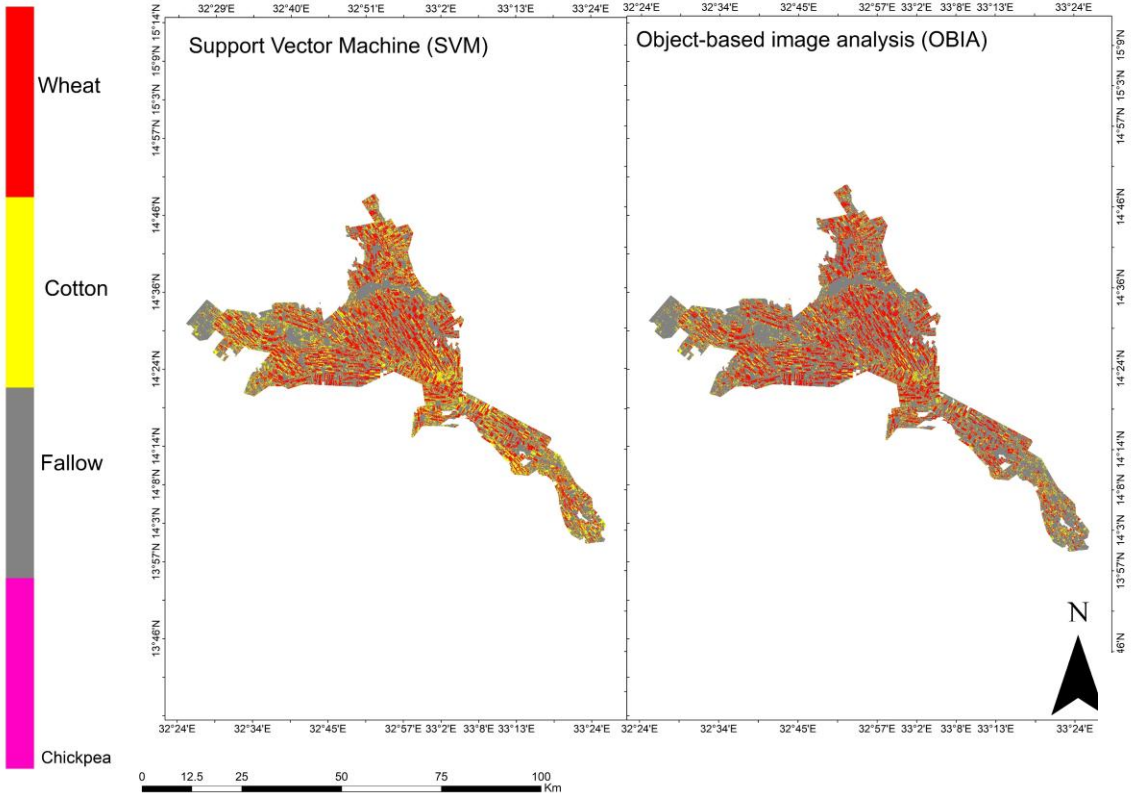
Value: 200, 100, 0

Comprehensive Accuracy Assessment of Multi-Class Crop Classification-OBIA

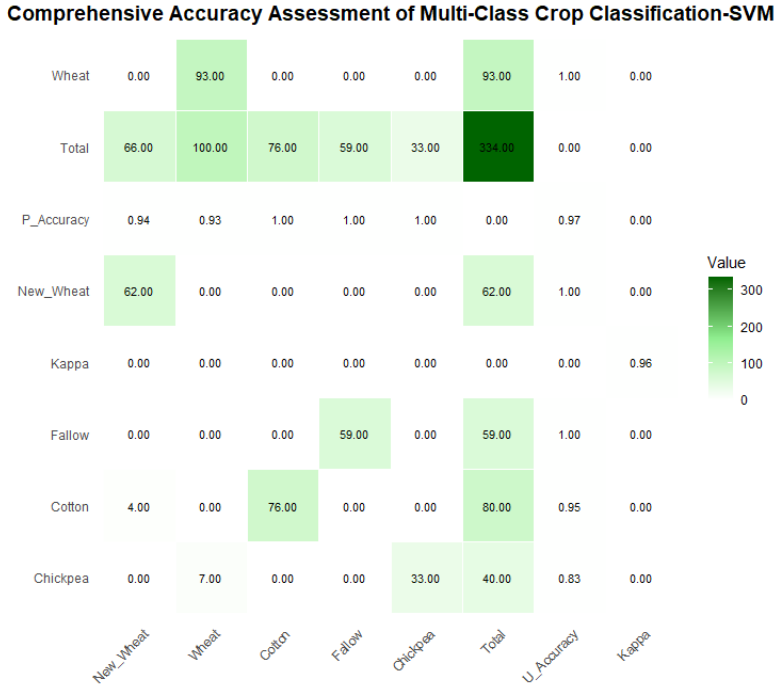
	New_Wheat	Wheat	Cotton	Fallow	Chickpea	Total	U_Accuracy	Kappa
Wheat	0.00	53.00	0.00	0.00	5.00	58.00	0.91	0.00
Total	58.00	55.00	40.00	73.00	51.00	278.00	0.00	0.00
P_Accuracy	0.93	0.96	0.90	0.96	0.80	0.00	0.91	0.00
New_Wheat	54.00	0.00	0.00	0.00	0.00	54.00	1.00	0.00
Kappa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89
Fallow	0.00	0.00	0.00	70.00	0.00	70.00	1.00	0.00
Cotton	3.00	0.00	36.00	3.00	5.00	47.00	0.77	0.00
Chickpea	1.00	2.00	4.00	0.00	41.00	49.00	0.84	0.00

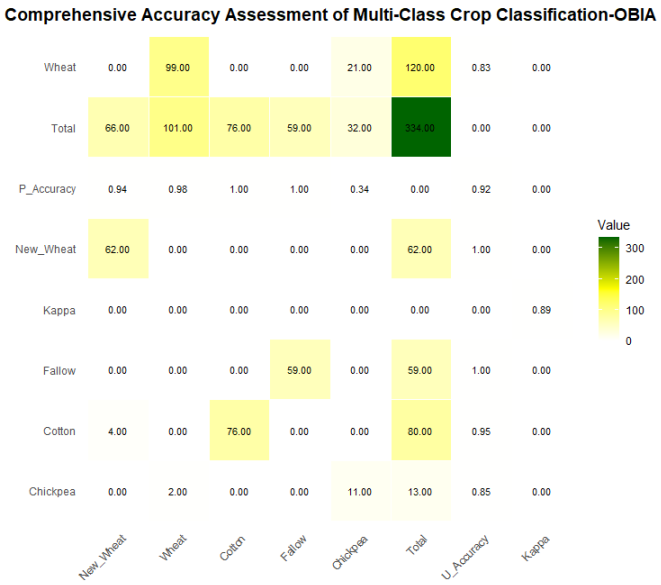
Value: 200, 100, 0

Results: Crop Classification with Accuracy assessment

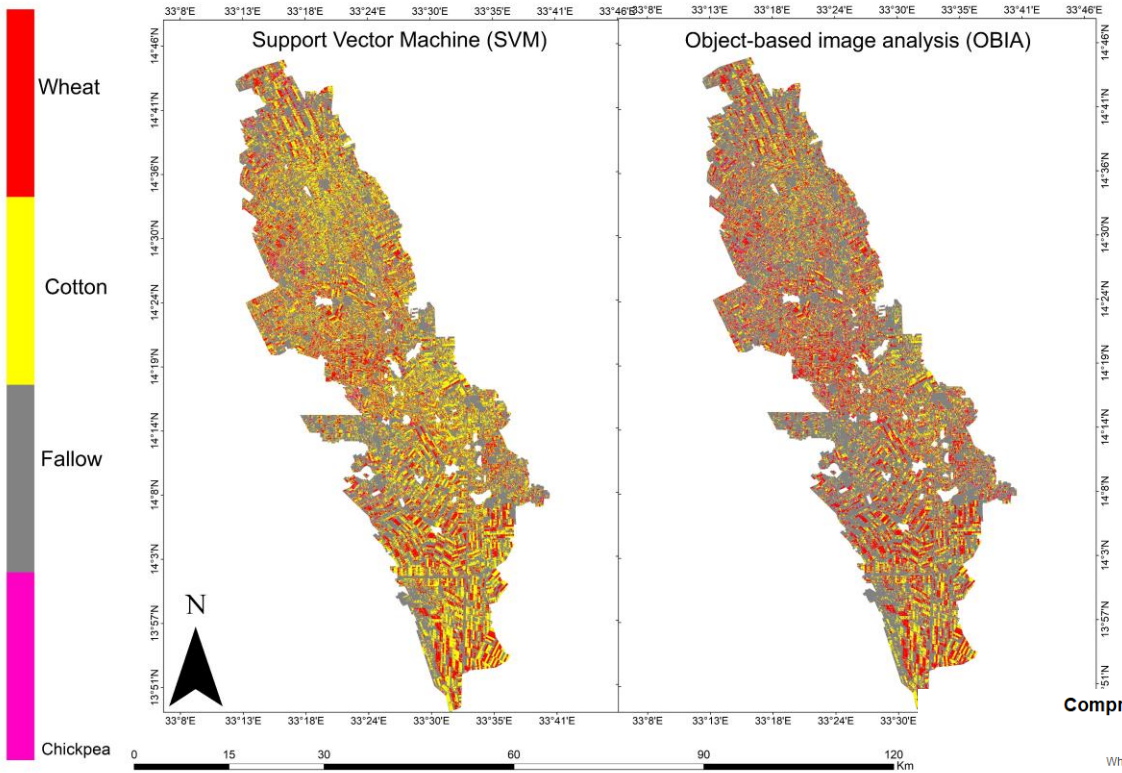


East of Managil Division





Results: Crop Classification with Accuracy assessment



South of Gezira Division

Comprehensive Accuracy Assessment of Multi-Class Crop Classification-SVM

	New_Wheat	Wheat	Cotton	Fallow	Chickpea	Total	U_Accuracy	Kappa
Wheat	0.00	27.00	0.00	0.00	0.00	27.00	1.00	0.00
Total	82.00	35.00	49.00	49.00	35.00	250.00	0.00	0.00
P_Accuracy	1.00	0.77	0.96	0.98	1.00	0.00	0.96	0.00
New_Wheat	82.00	0.00	0.00	0.00	0.00	82.00	1.00	0.00
Kappa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94
Fallow	0.00	0.00	0.00	48.00	0.00	48.00	1.00	0.00
Cotton	0.00	3.00	47.00	0.00	0.00	50.00	0.94	0.00
Chickpea	0.00	5.00	2.00	1.00	35.00	43.00	0.81	0.00

Value: 250, 200, 150, 100, 50, 0

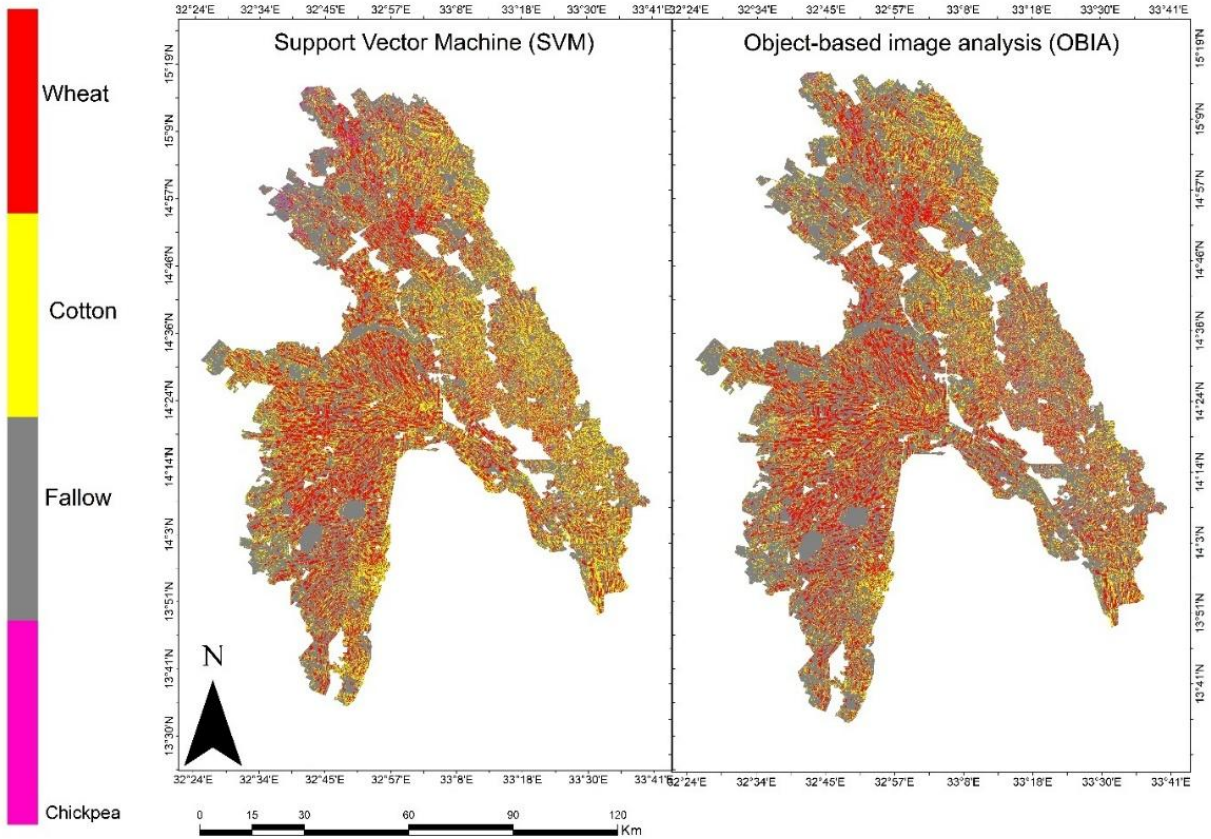
Comprehensive Accuracy Assessment of Multi-Class Crop Classification-OBIA

	New_Wheat	Wheat	Cotton	Fallow	Chickpea	Total	U_Accuracy	Kappa
Wheat	0.00	27.00	0.00	1.00	1.00	29.00	0.93	0.00
Total	82.00	35.00	52.00	49.00	32.00	250.00	0.00	0.00
P_Accuracy	1.00	0.77	1.00	0.98	0.88	0.00	0.95	0.00
New_Wheat	82.00	0.00	0.00	0.00	0.00	82.00	1.00	0.00
Kappa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.93
Fallow	0.00	0.00	0.00	48.00	0.00	48.00	1.00	0.00
Cotton	0.00	3.00	52.00	0.00	3.00	58.00	0.90	0.00
Chickpea	0.00	5.00	0.00	0.00	28.00	33.00	0.85	0.00

Value: 250, 200, 150, 100, 50, 0

West of Managil	SVM (Feddan)	OBIA (Feddan)	Average area calculated by satellite imagery ("SVM+OBIA"/2)
Wheat	176863.286	164323.200	170593.243
Gardens/Chickpea/Cotton/Other	142239.452	115788.310	129013.881
East Of Mangil			
Wheat	140993.619	130827.766	135910.693
Gardens/Chickpea/Cotton/Other	122679.738	79971.611	101325.675
South of Gezira			
Wheat	75547.786	70655.049	73101.417
Gardens/Chickpea/Cotton/Other	176346.952	134895.531	155621.242
North of Gezira			
Wheat	147262.024	150789.025	149025.525
Gardens/Chickpea/Cotton/Other	259932.738	216676.545	238304.642
Total			
Wheat	528630.877		
Gardens/Chickpea/Cotton/Other	624265.439		

Results: Crop Classification for All Scheme



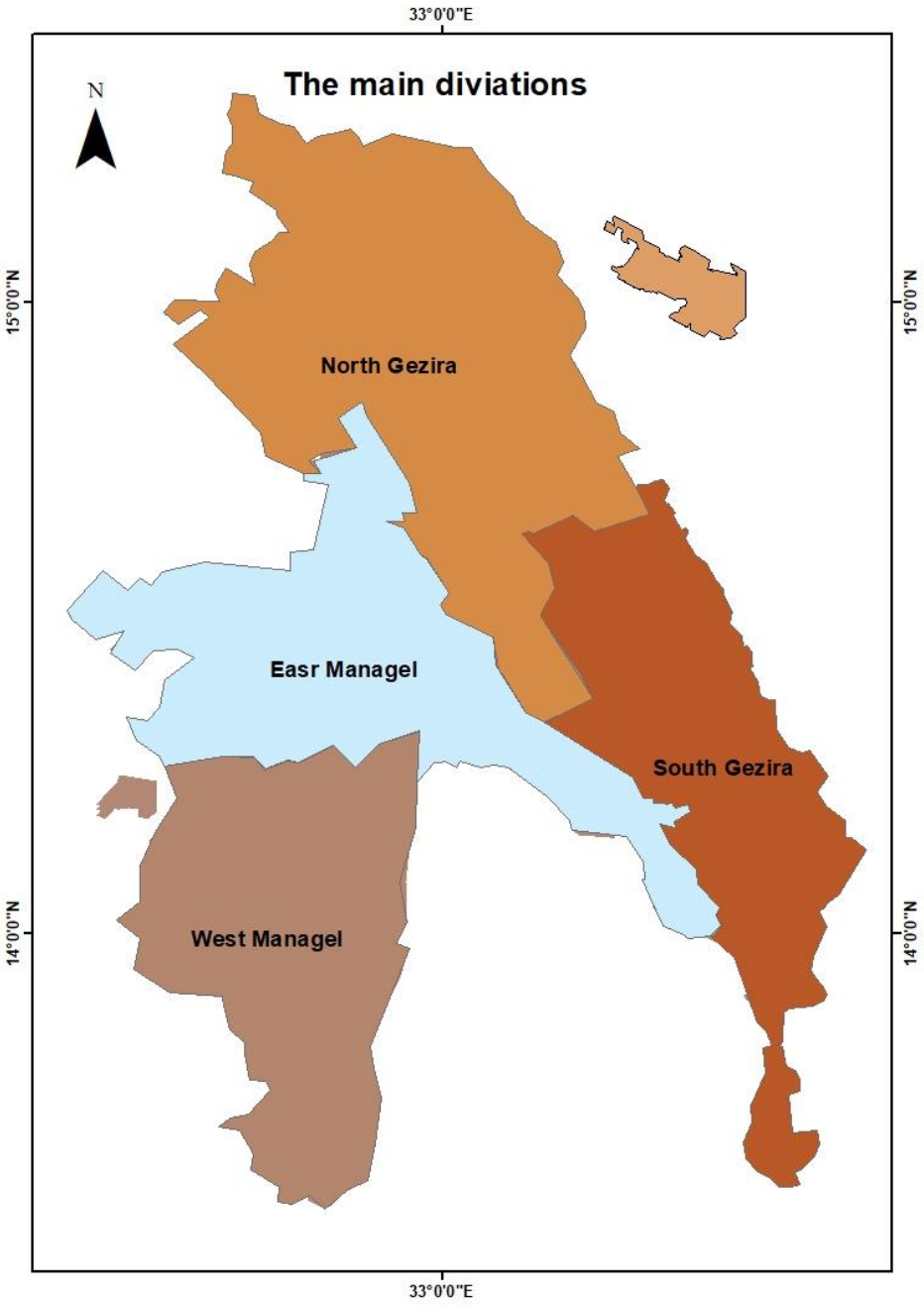
Crop Category	Office Gezira (Feddan)	RS Estimate (Feddan)
Wheat	495,132	528,630.877
Gardens/Chickpea/Cotton/Other	595,419	624,265.439
Total Cultivated Lands	1,090,551	1,152,896.32

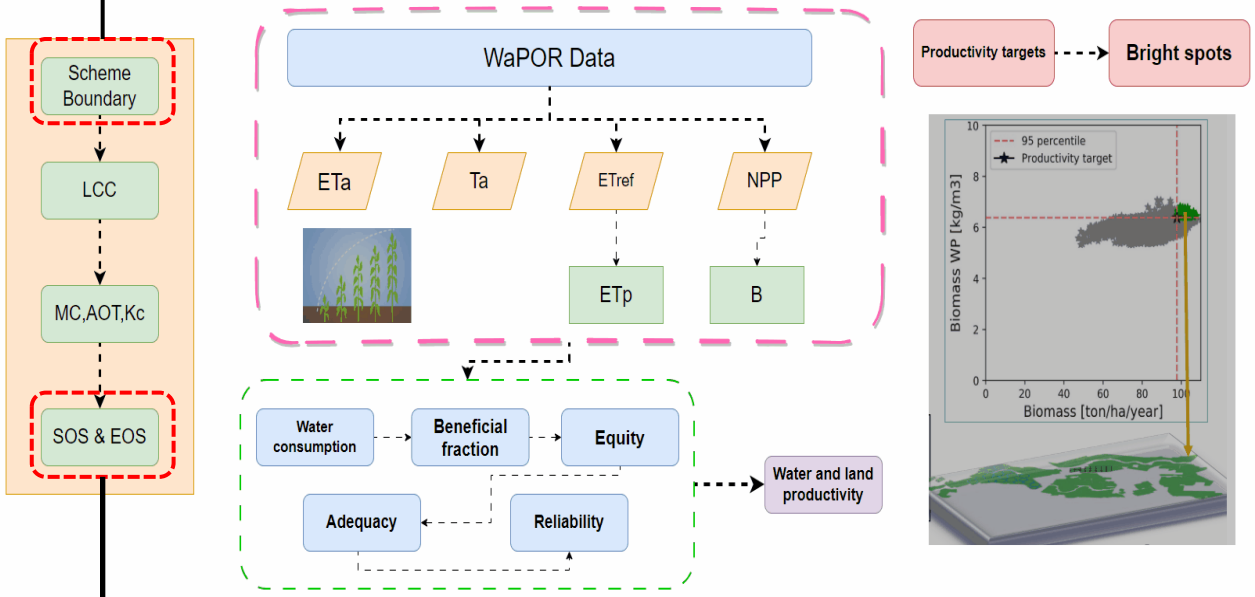
WaPOR Data Downloading Data

https://colab.research.google.com/drive/1o7OGTvTn7NB_LN5vBvZ9LKzSbT0k7sg0

No.	WaPOR Data	Definition	Spatial resolution	Temporal resolution	Units	Temporal coverage	Reference
1	Evapotranspiration	Total water consumed through evaporation, transpiration, and interception	100 m	10-day	mm/dekad	2009 - present	WaPOR Database Methodology (2020)
2	Transpiration (T)	Water consumed by plants and released as vapor	100 m	10-day	mm/dekad	2009 - present	WaPOR Database Methodology (2020)
3	Net Primary Production (NPP)	Rate of biomass production by plants	100 m		$gC/m^2/day$	2009 - present	Running et al. (2004)
4	Land cover classification (LCC)	Categorization of land surface cover types	100 m	Annual	N/A	2009 - present	WaPOR Database Methodology (2020)
5	Precipitation (PCP)	Amount of water falling as rain or snow	5 km		mm/dekad	2009 - present	WaPOR Database Methodology (2020)
6	Reference Evapotranspiration (RET)	ET from a hypothetical grass reference crop	20 km	Daily	mm/day	2009 - present	Allen et al. (1998)

What Information is Required to Compute Water Productivity (WP)?

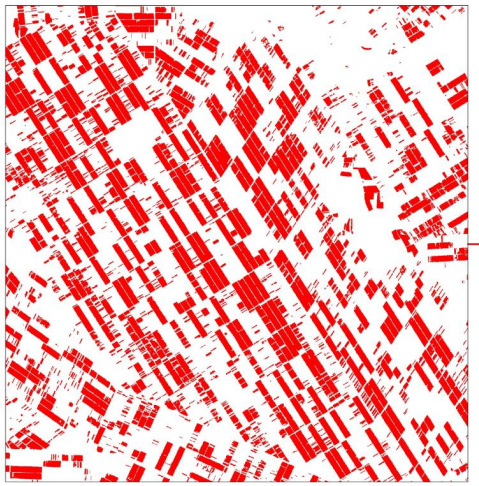


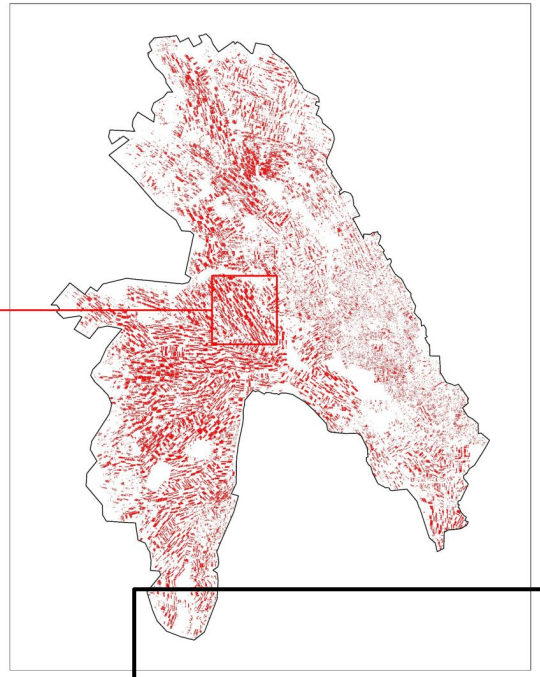


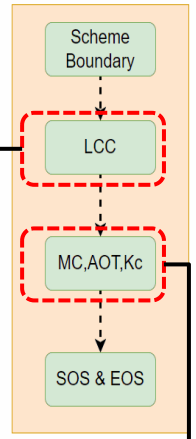

```
In [18]: df_dates = pd.read_excel('../Data/df_SosEos.xlsx')
         df_dates
```

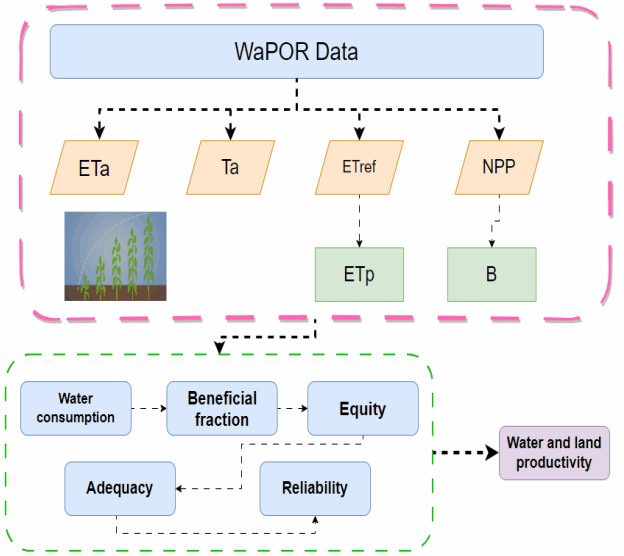
Out[18]:

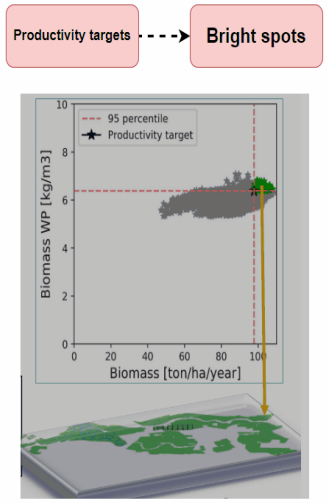
	Seasons	SOS	EOS
0	1	2019-10-07	2020-04-26











SOS: Start of season= (07/10/2019)	AOI: above ground over total biomass= (0.85)
EOS: End of season = (26/04/2020)	MC: Moisture content ratio= (0.15)
Avg_Kc: crop factor = 0.85	
HI: harvest index= (0.36)	

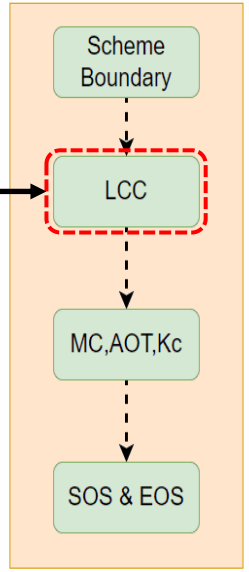
•**AOI: Above Ground Over Total Biomass** Definition: The ratio of above-ground biomass (stems, leaves, and grains) to the total plant biomass, including roots, Value: 0.85 (85% of total biomass is above ground)

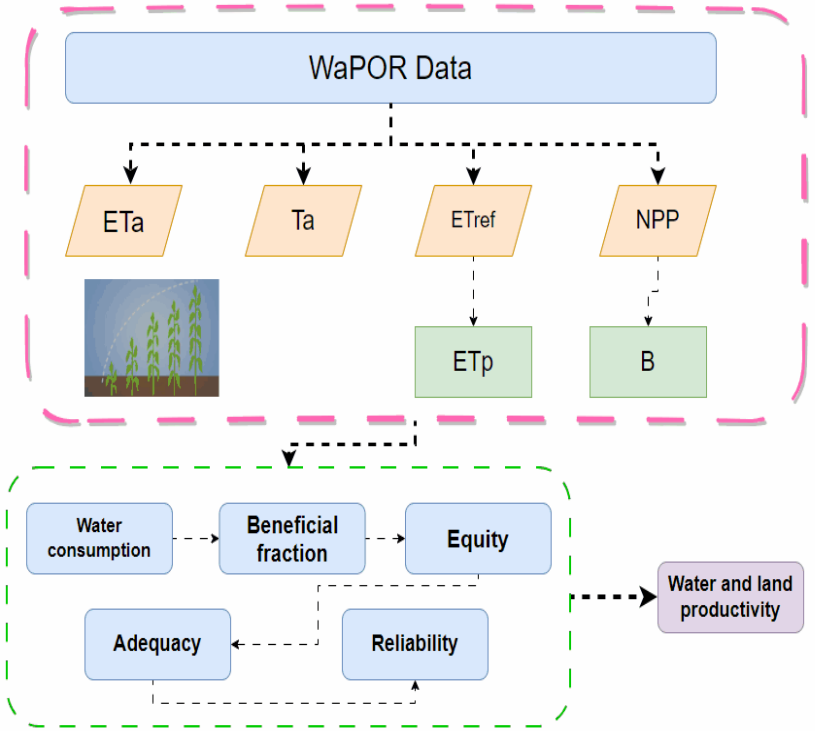
•**MC: Moisture Content Ratio:** Definition: The proportion of water in the harvested wheat, expressed as a fraction of the total weight,Value: 0.15 (15% of the harvested weight is water)

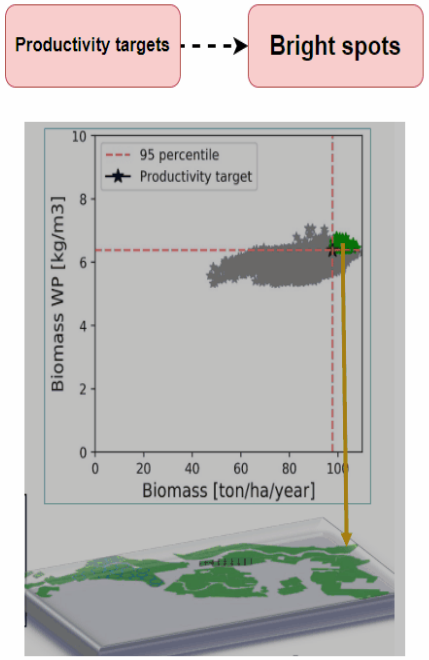
•**HI: Harvest Index** Definition: The ratio of grain yield to total above-ground biomass, indicating the efficiency of converting biomass into harvestable yield, Value: 0.36 (36% of above-ground biomass is harvestable grain)

•**Avg_Kc: Average Crop Coefficient** Definition: A factor that relates the reference evapotranspiration to crop evapotranspiration, representing the integrated effects of crop characteristics on water use ,Value: 0.85

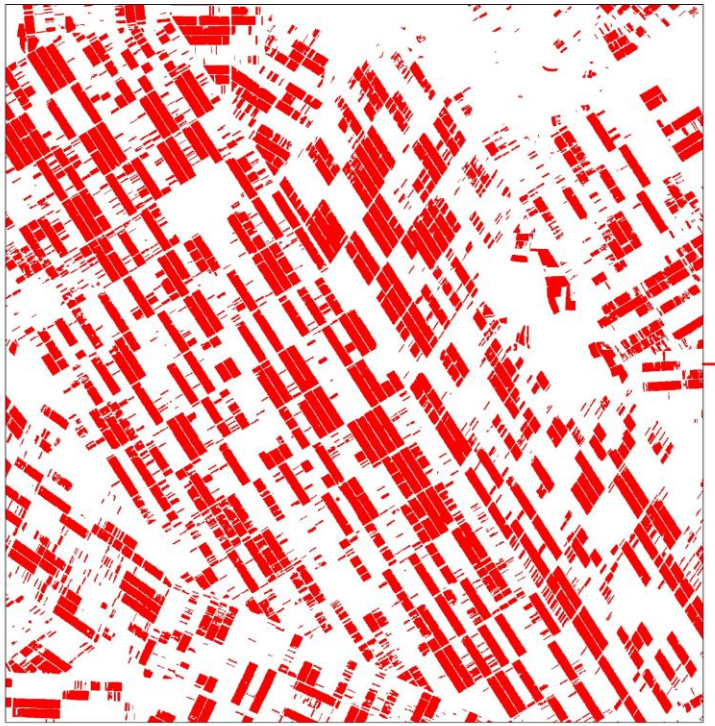
How?

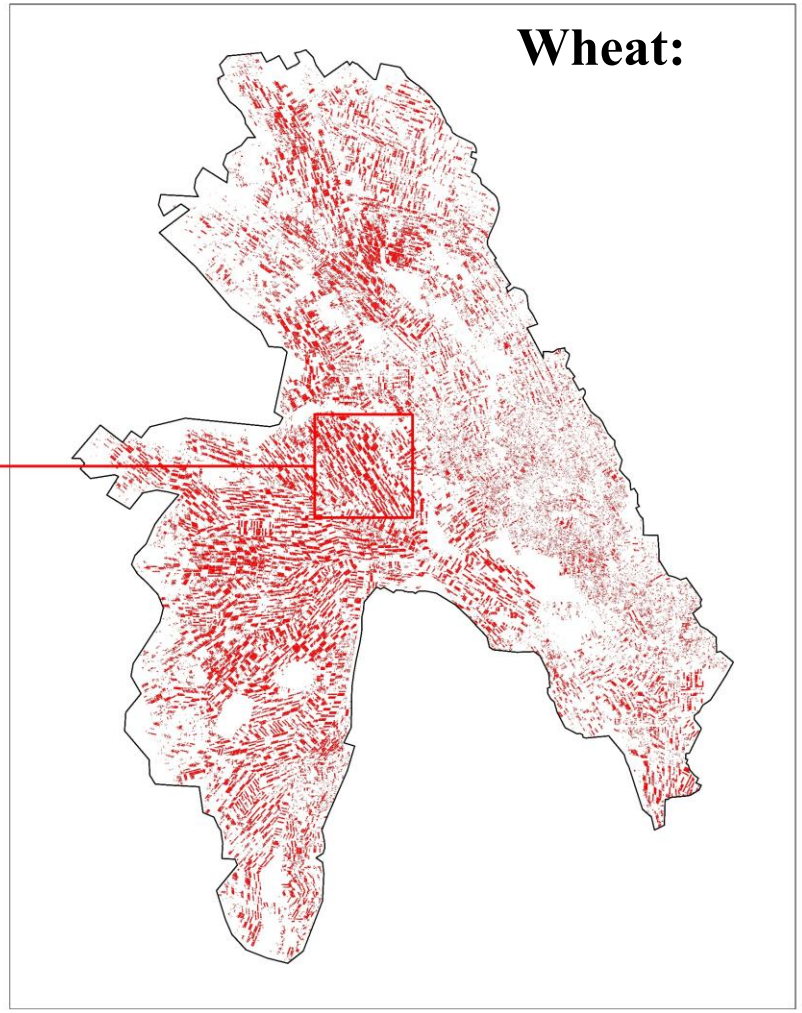

Scheme Boundary
LCC
MC,AOT,Kc
SOS & EOS

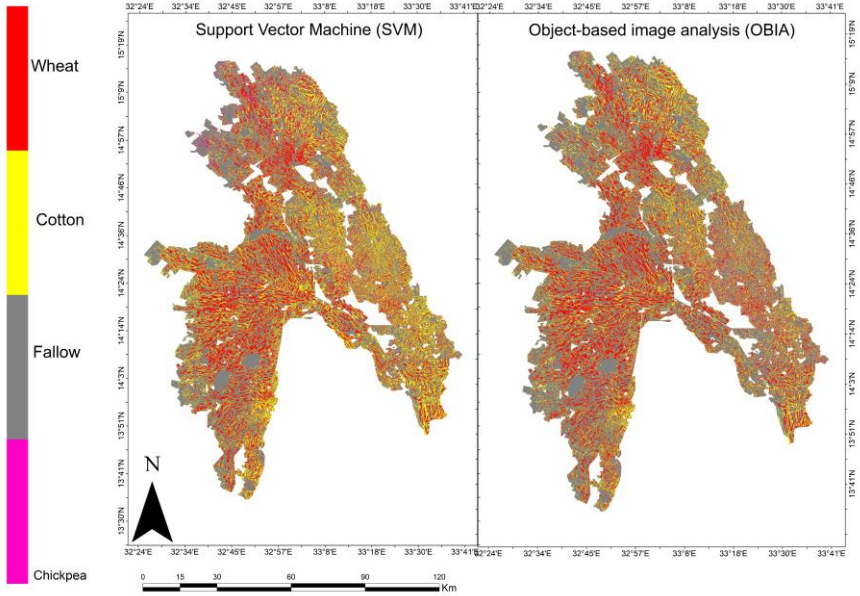

WaPOR Data
ETa
Ta
ETref
NPP
ETp
B
Water consumption
Beneficial fraction
Equity
Adequacy
Reliability
Water and land productivity


Productivity targets
Bright spots
95 percentile
Productivity target
Biomass WP [kg/m3]
Biomass [ton/ha/year]

LCLU:

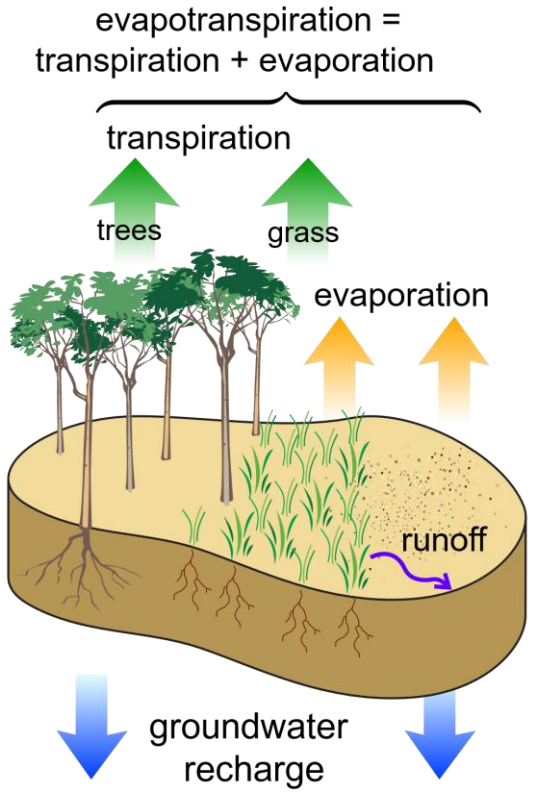






All Crops:

2-Water management indicators -Seasonal Actual Evapotranspiration (ETa,s)



Seasonal Actual Evapotranspiration (ETa,s) is the cumulative amount of water that is transferred from the land surface to the atmosphere through evaporation from the soil and transpiration from plants over the course of a growing season. It represents the actual water consumption by crops and the surrounding soil under real-world conditions.

Seasonal Actual Evapotranspiration $ET_{a,s} = \sum_{SOS}^{EOS} ET_a$

Potential Evapotranspiration $ETc = ETo * Kc$

Where:

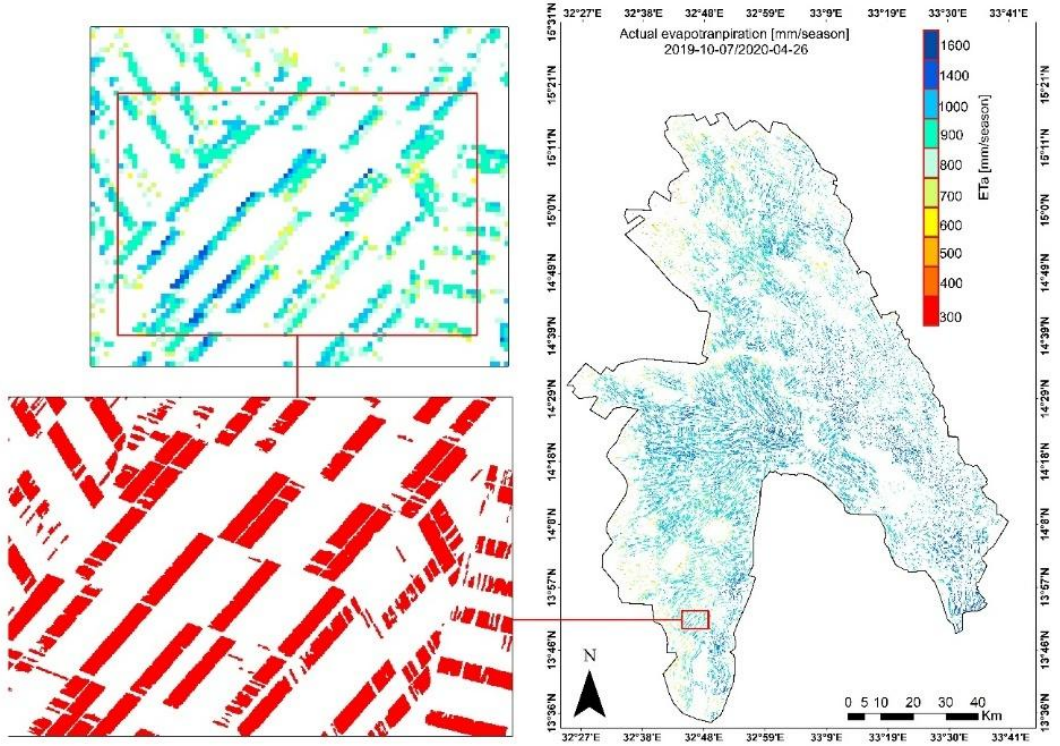
ETa,s = Actual evapotranspiration

SOS = Start of season

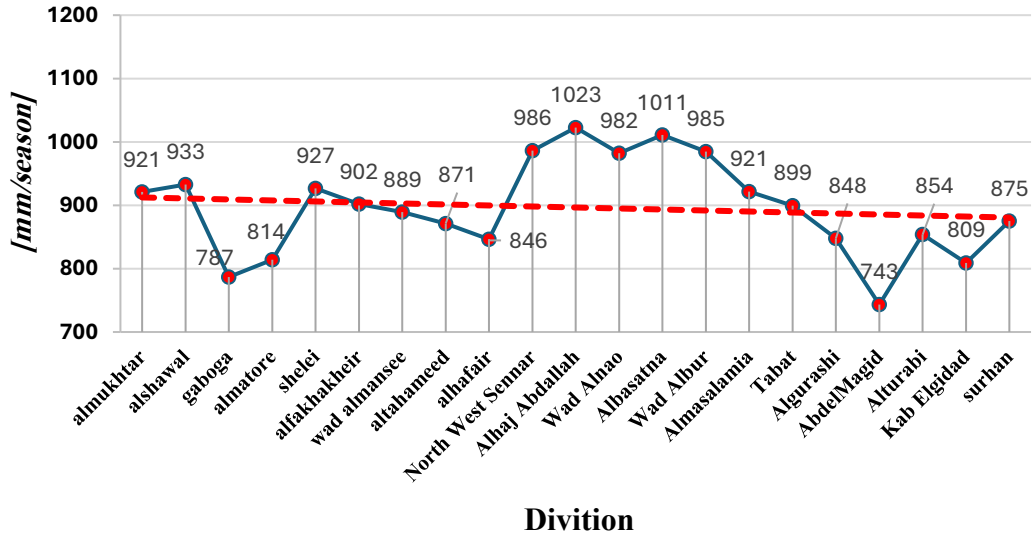
EOS = End of season

ETo = Reference evapotranspiration

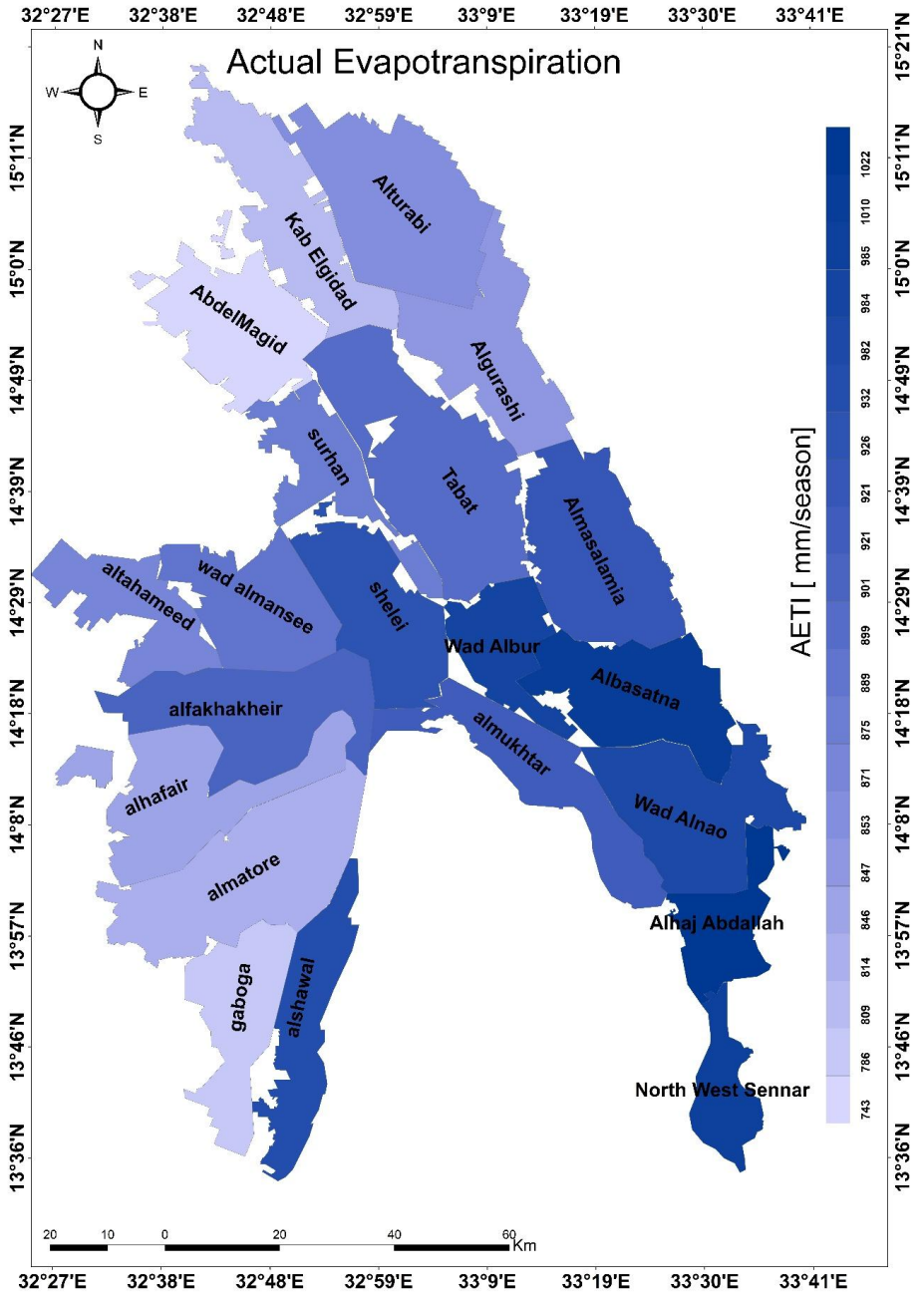
Kc = Crop coefficient



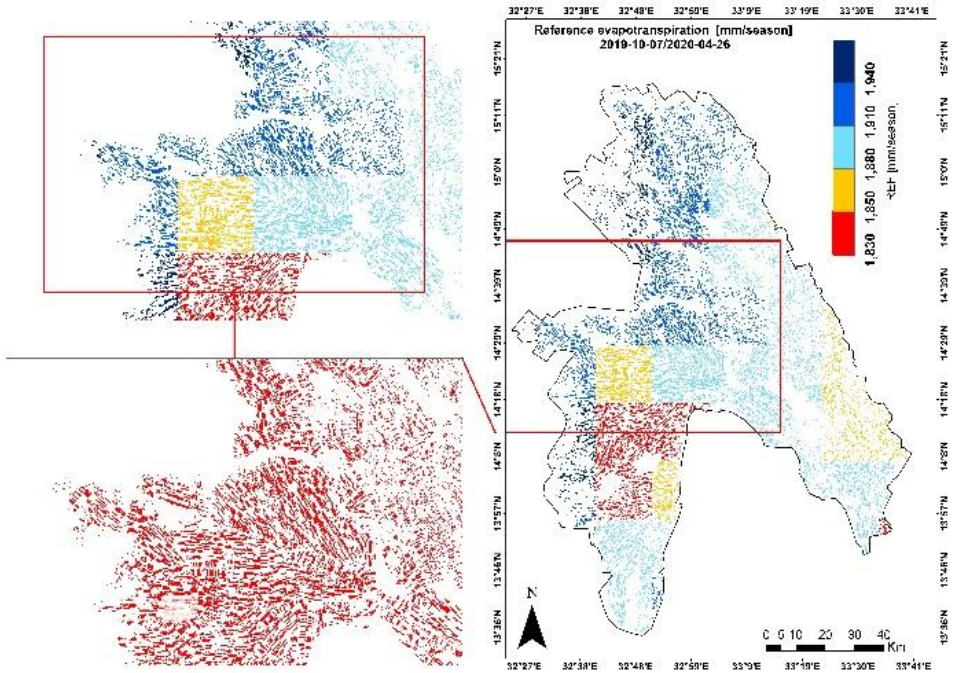
Actual Evapotranspiration

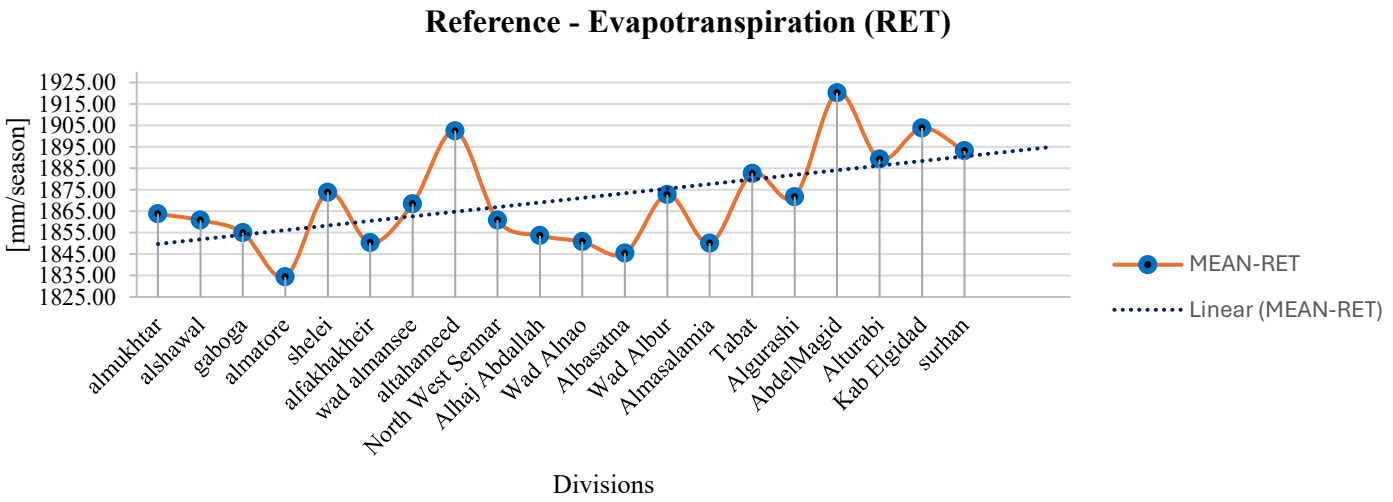


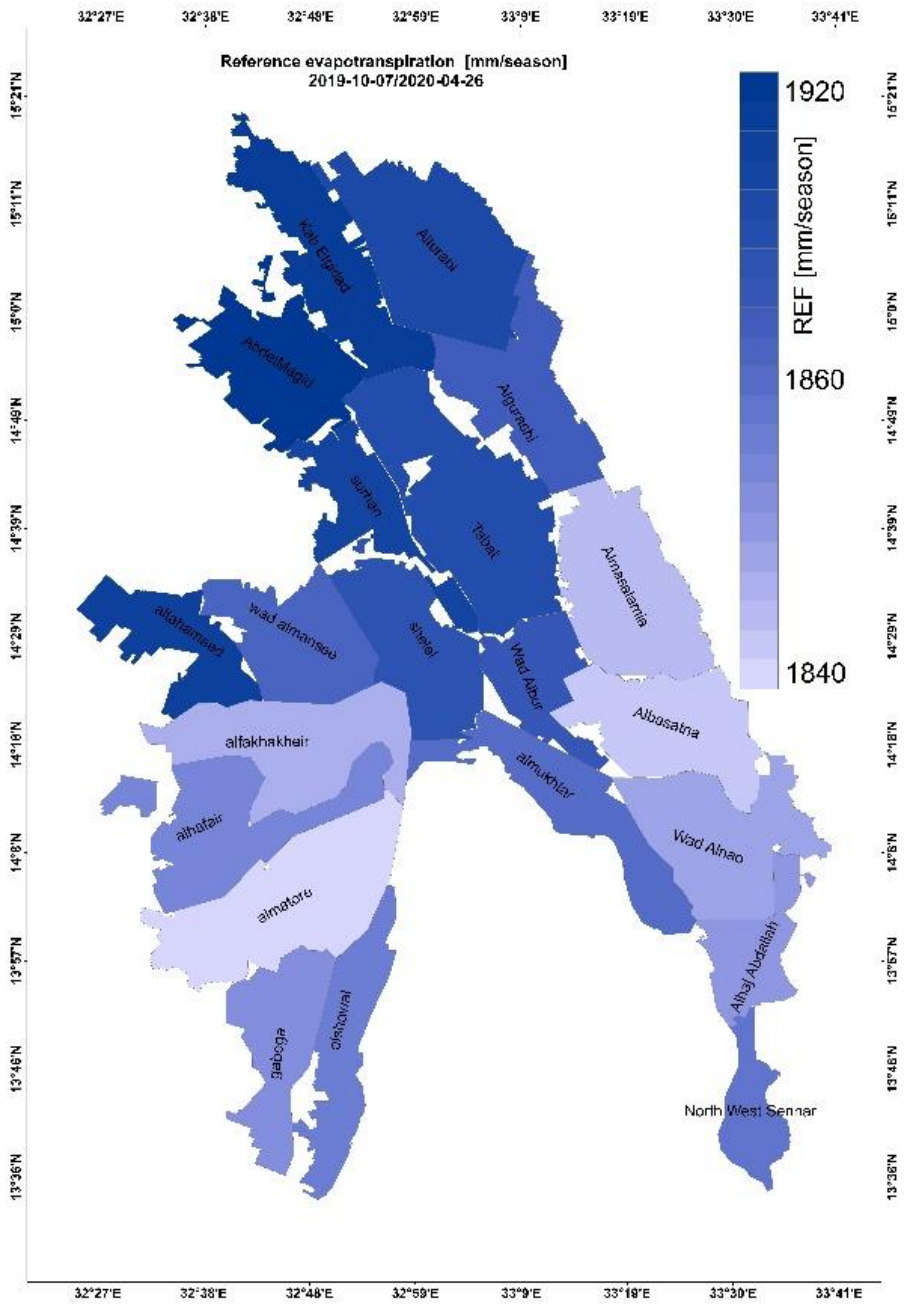
Divition



3-Water management indicators Reference Evapotranspiration (RET) :







4-Water management indicators - Beneficial Fraction

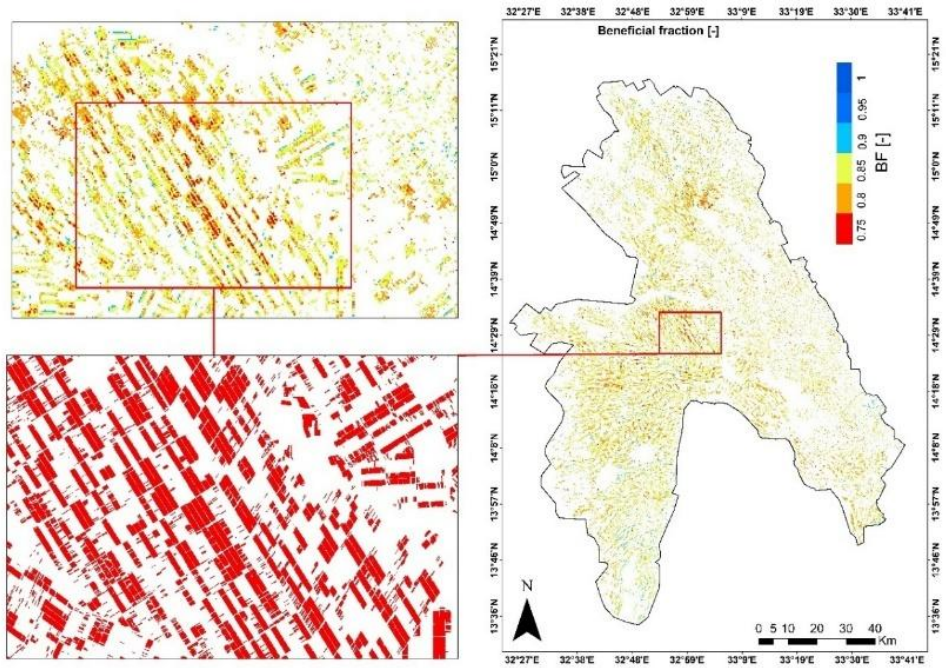
$$BF = Ta/ETa$$

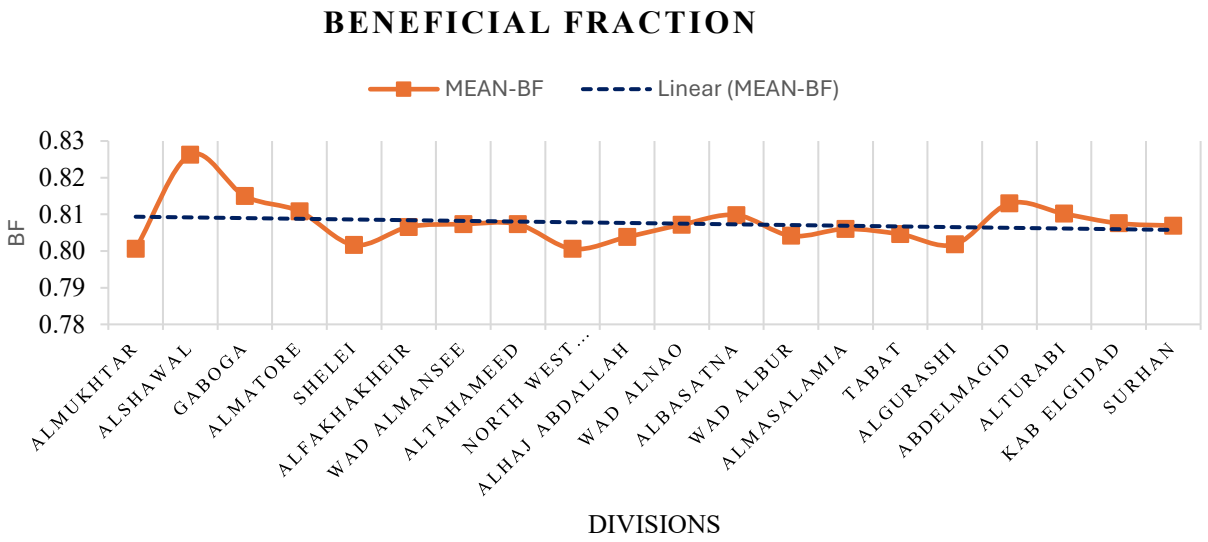
Where:

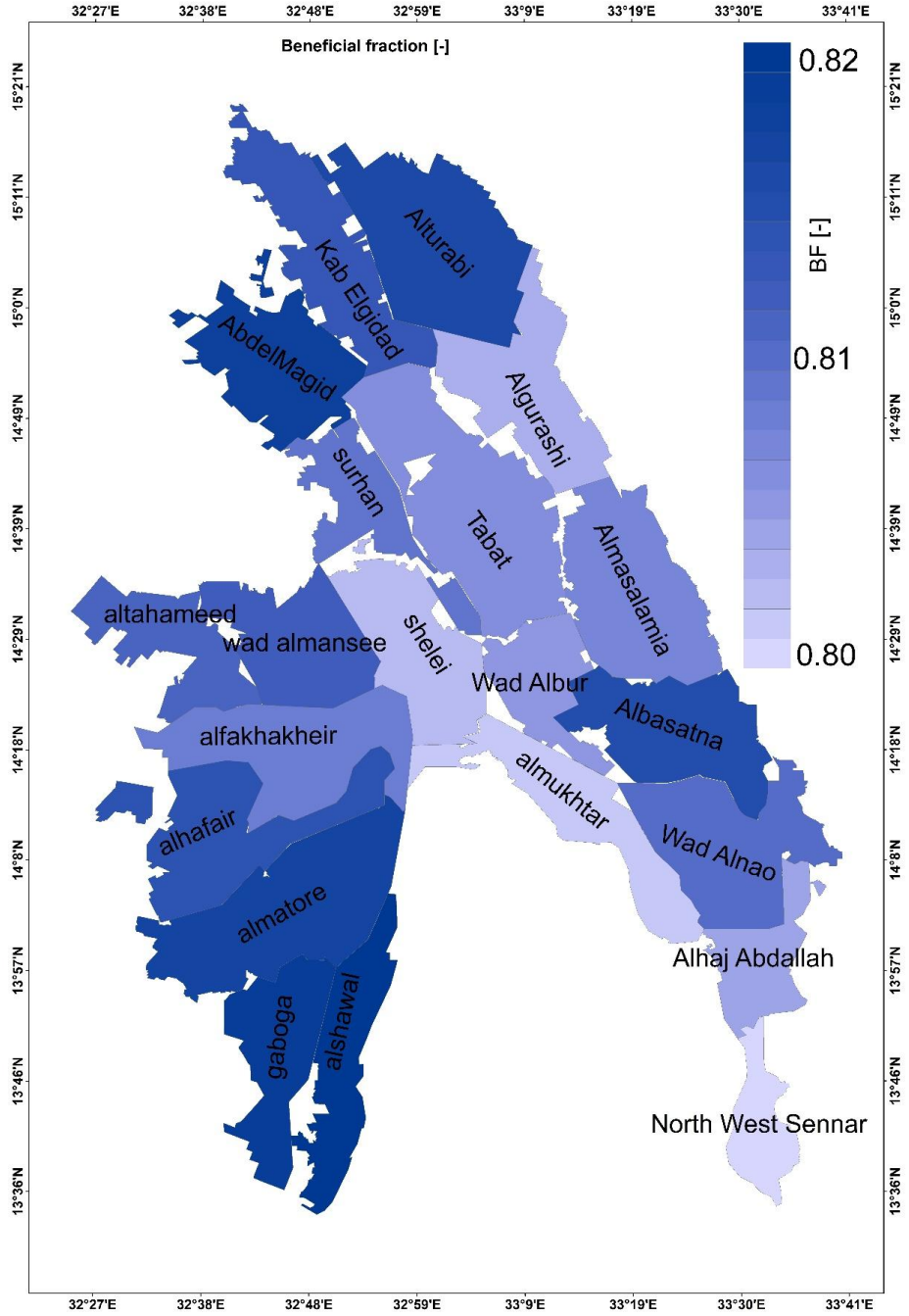
BF = Beneficial Fraction

Ta = Actual Transpiration

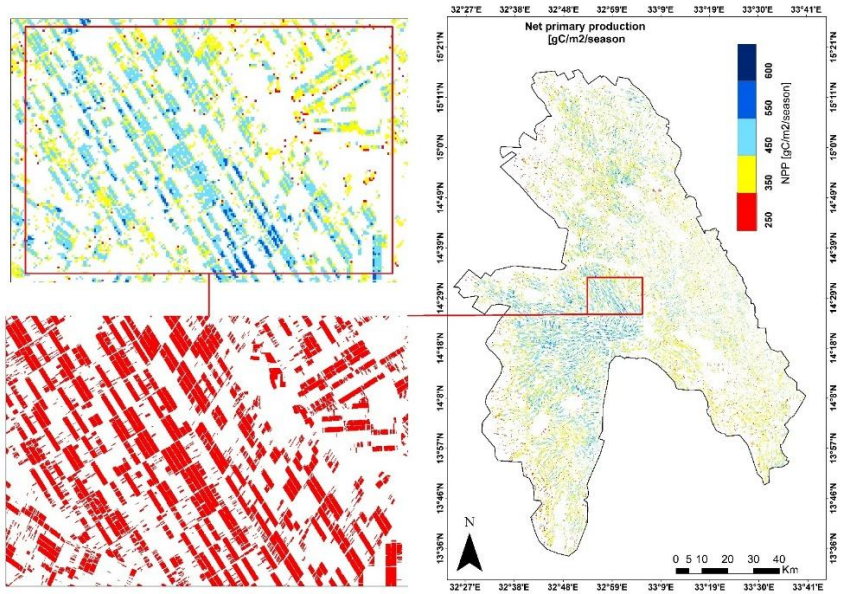
ETa = Actual Evapotranspiration

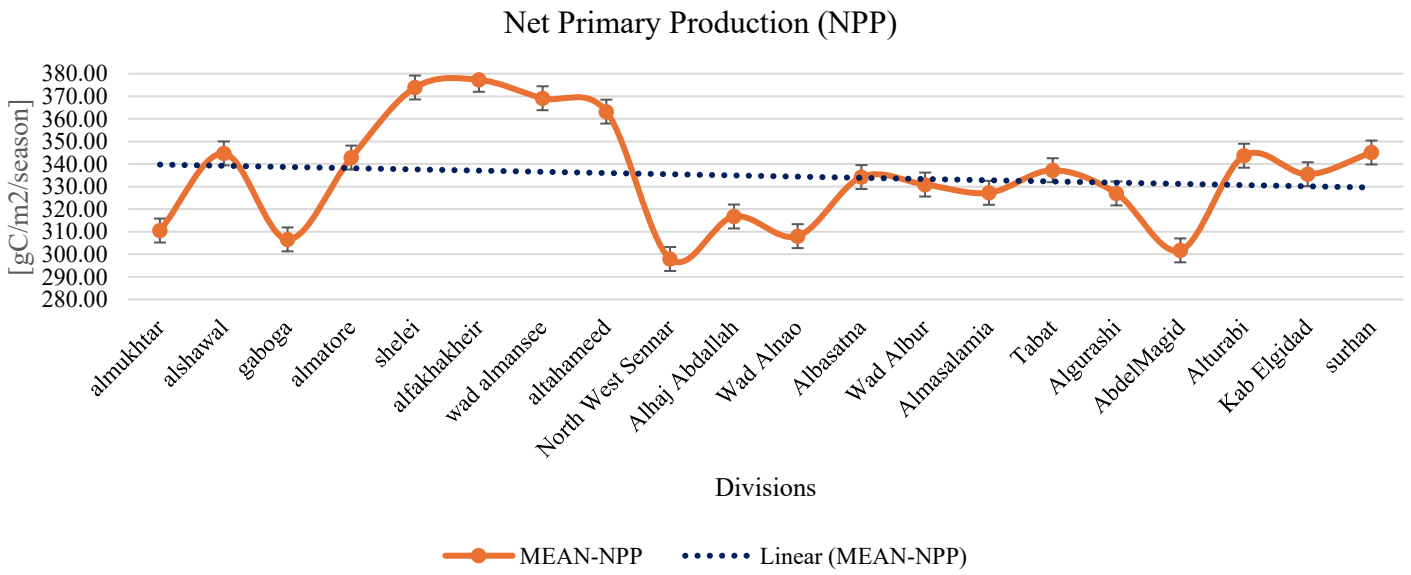


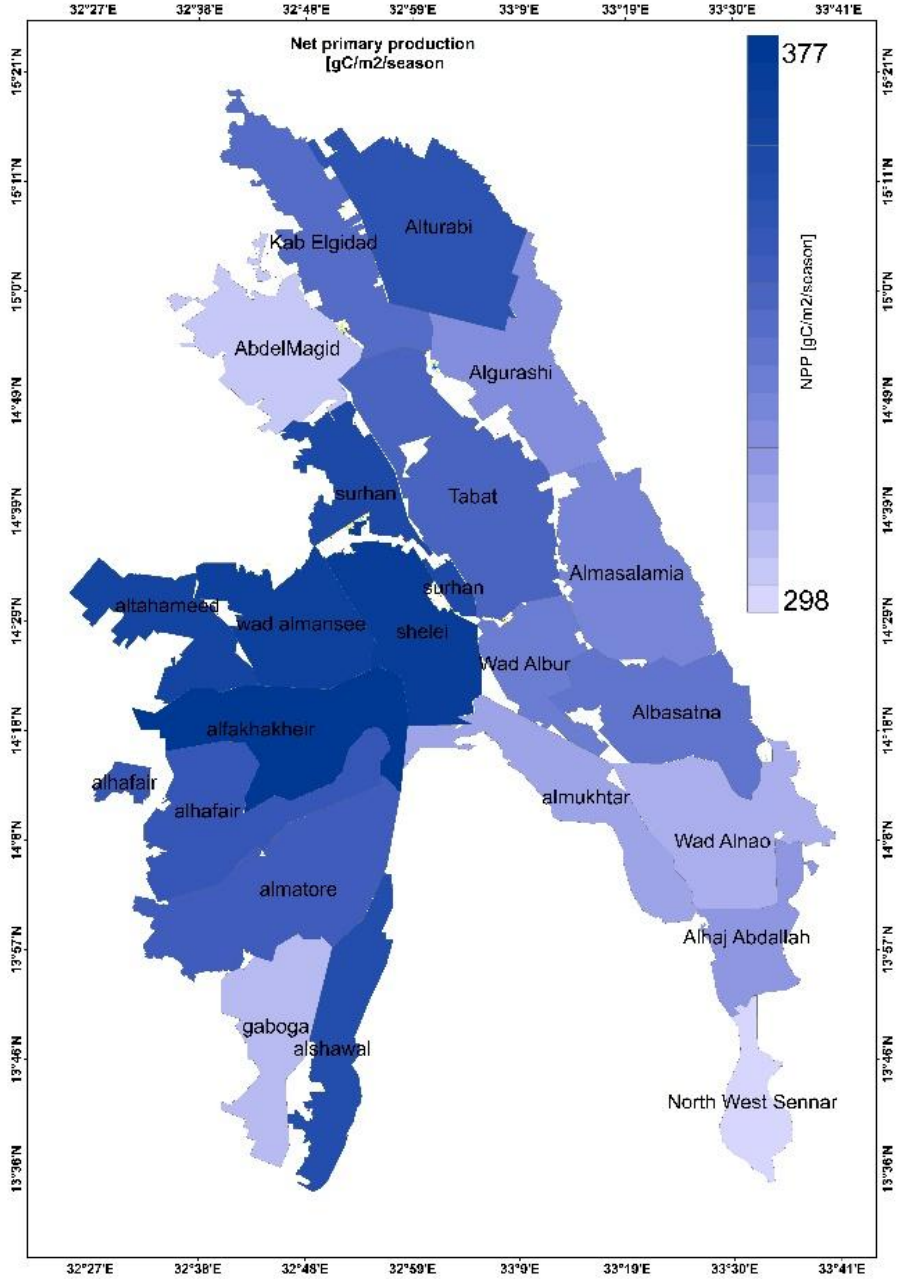




1-Productivity indicators - Net Primary Production (NPP) :







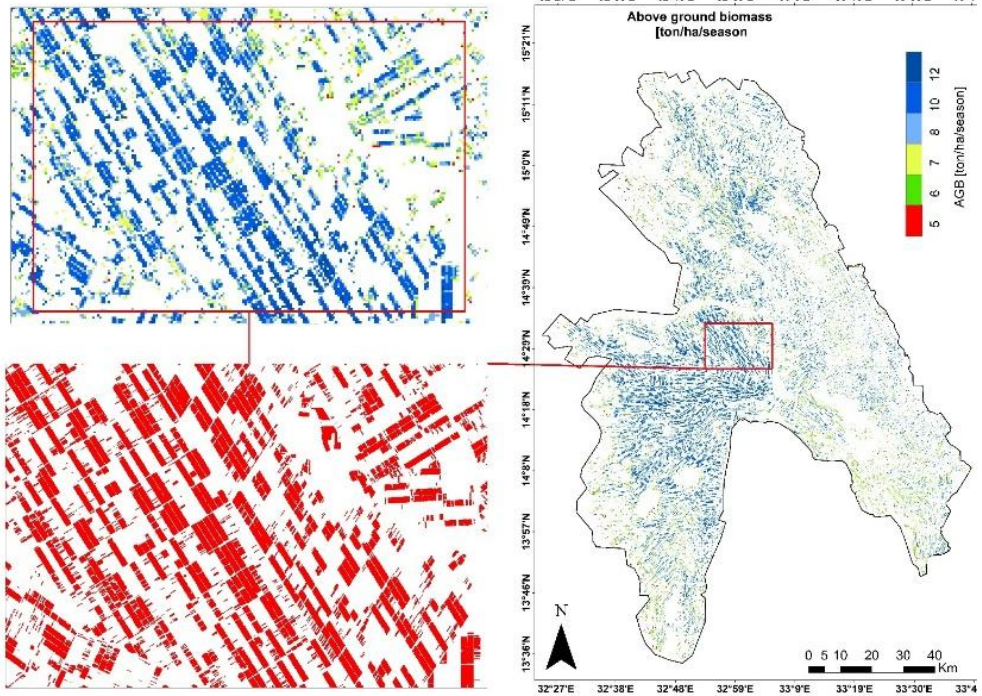
2-Productivity indicators - Above Ground Biomass (AGB):

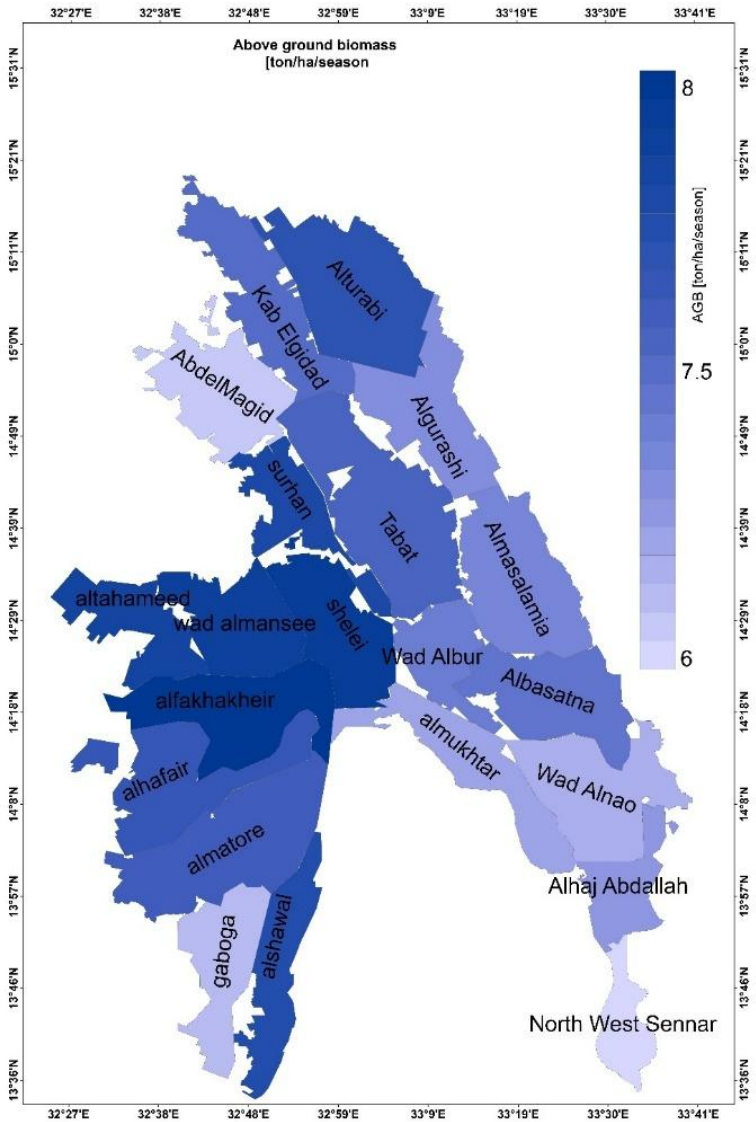
$$\text{Biomass } B = \text{AOT} \cdot f_c \cdot \frac{\text{NPP}_s \cdot 22.222}{(1-\text{MC})}$$

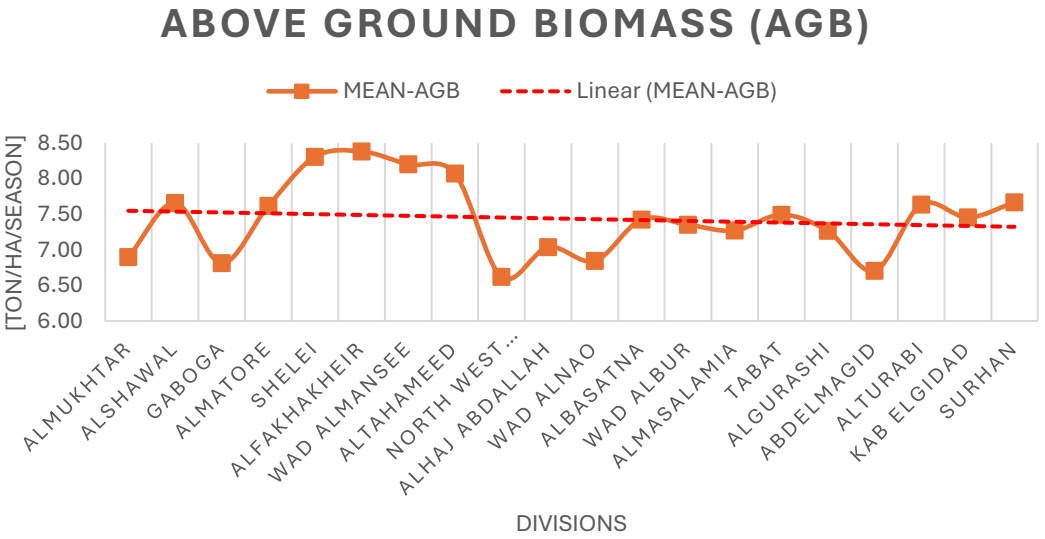
AOT = Above-ground over total biomass ratio

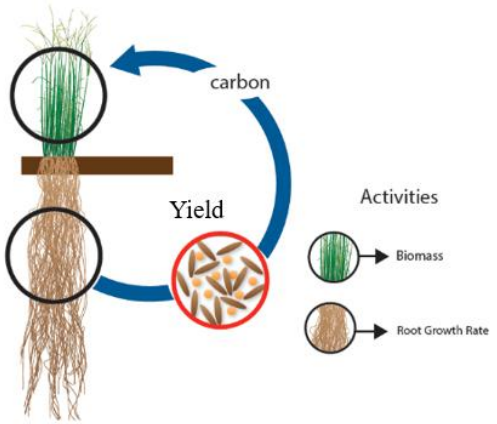
fc = Light use efficiency correction factor

mc = Moisture content of fresh biomass





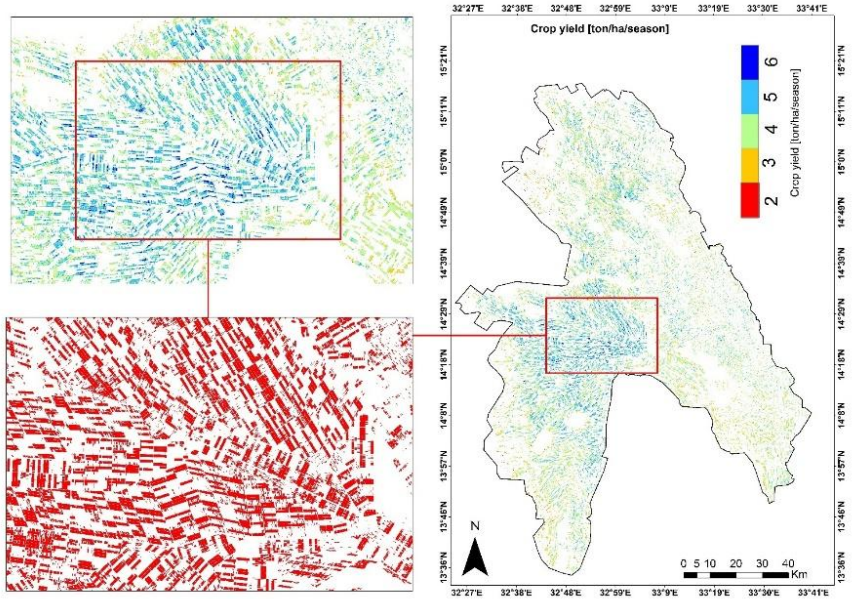


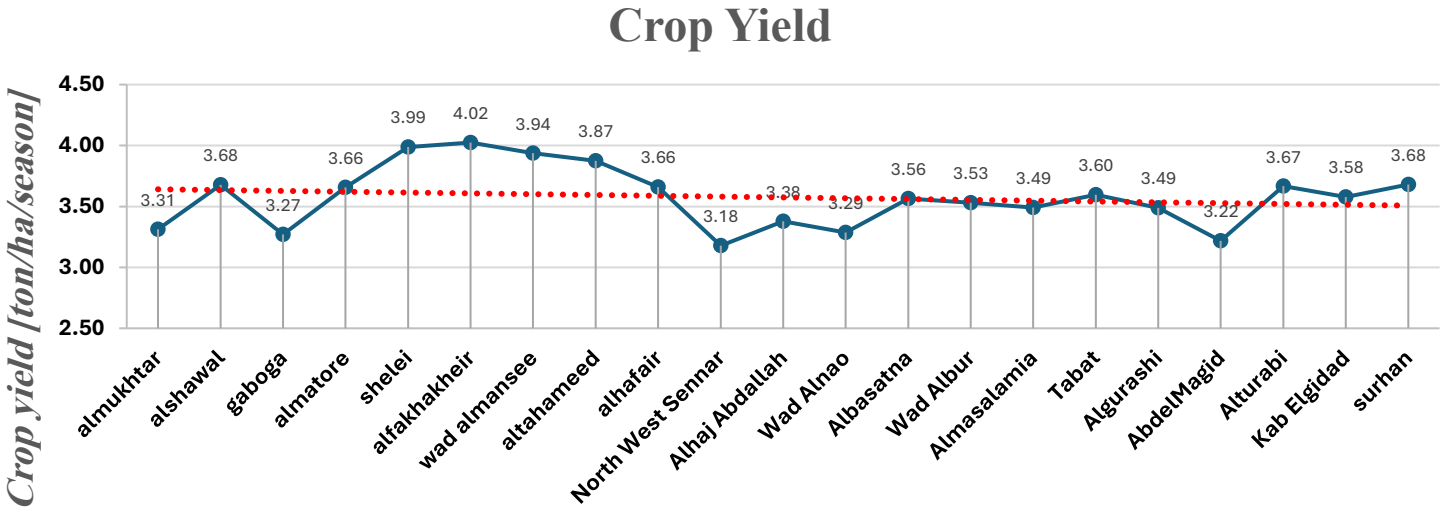


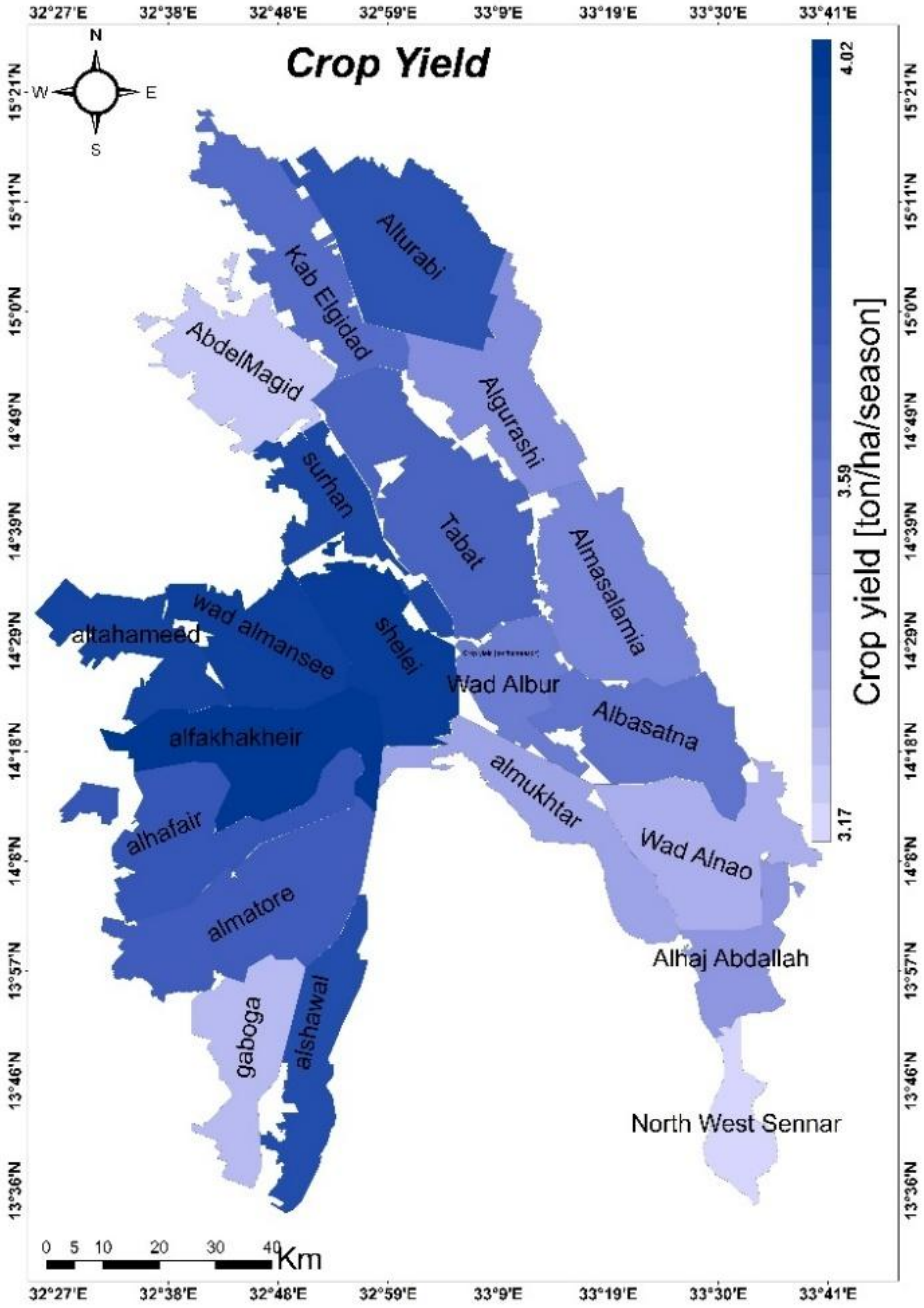
3-Productivity indicators - Crop Yield:

$$\text{Yield} = B \cdot \text{HI}$$

HI = Harvest Index (Wheat = 0.84)







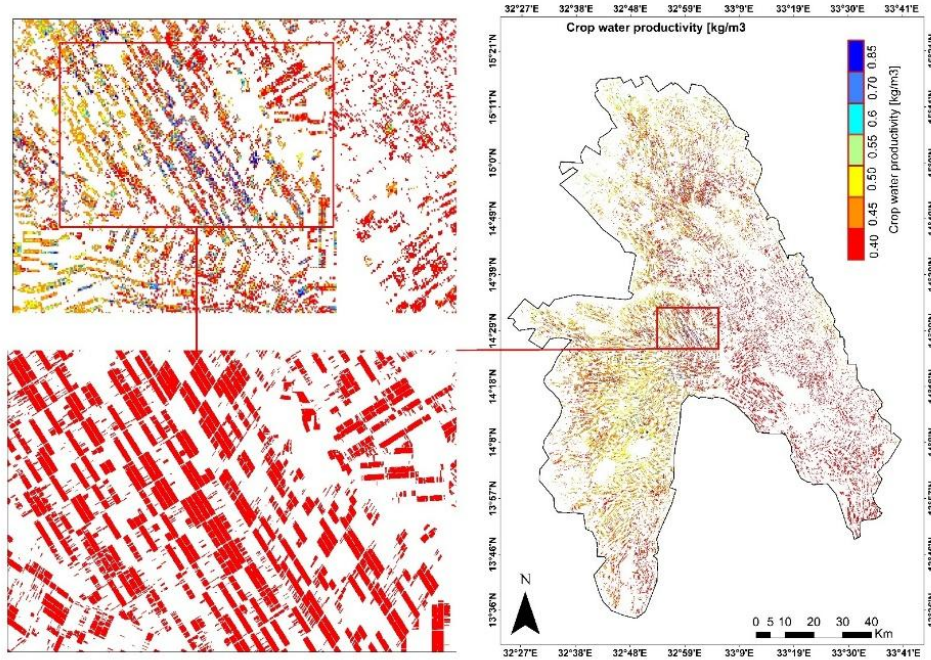
4-Productivity indicators - Crop Water Productivity:

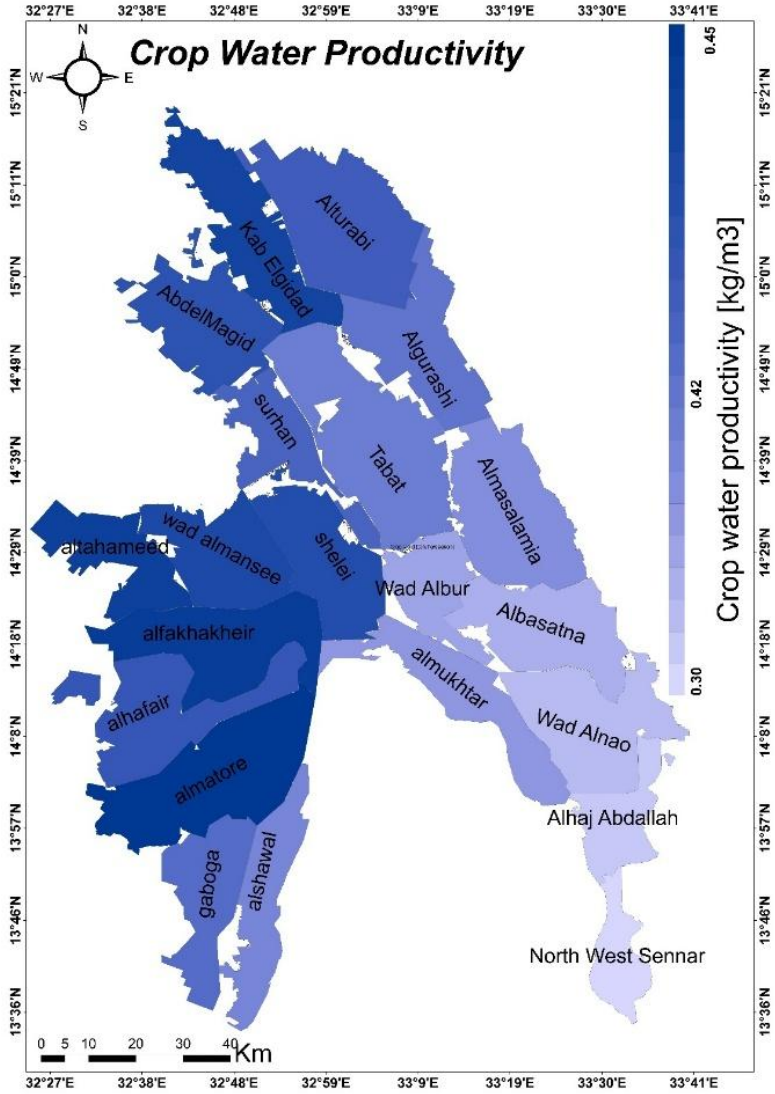
$$WP = \frac{Y}{ET_{a,s}}$$

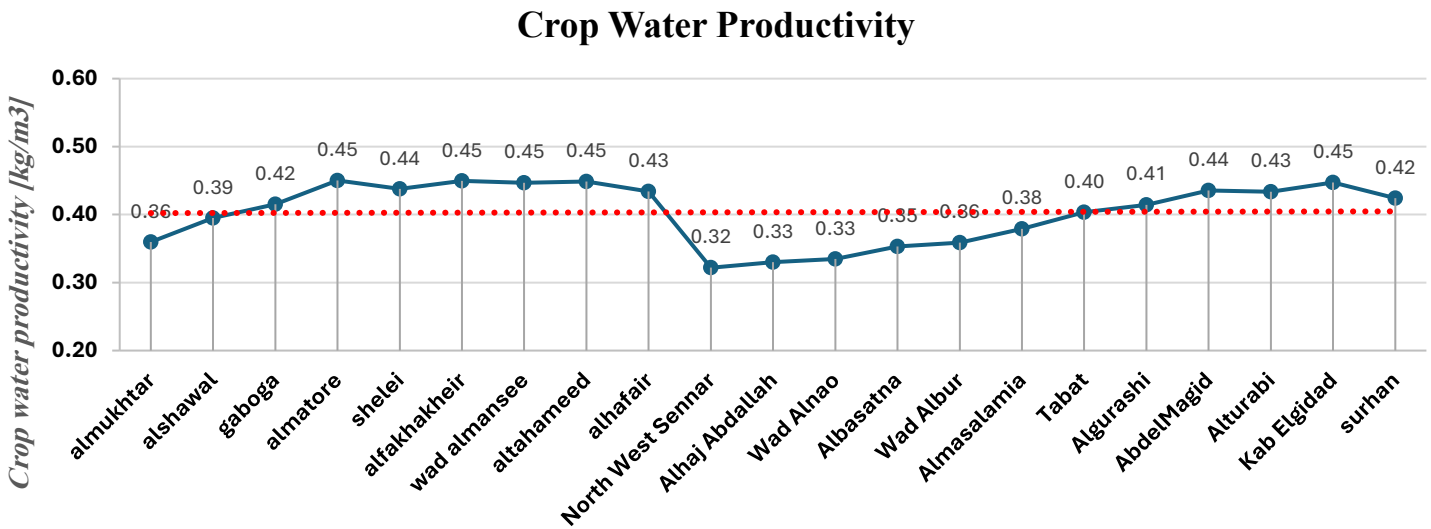
Y = Yield

$ET_{a,s}$ = actual evapotranspiration

Units: kg/m³

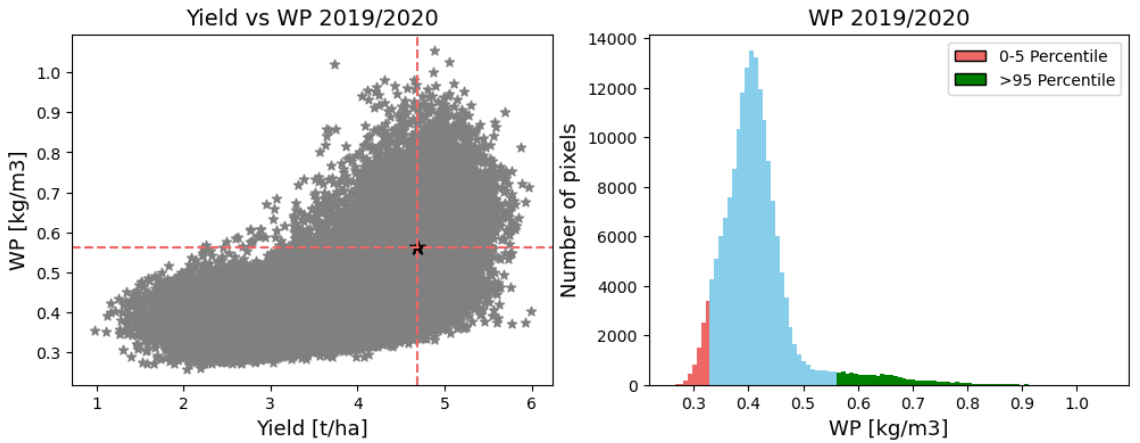


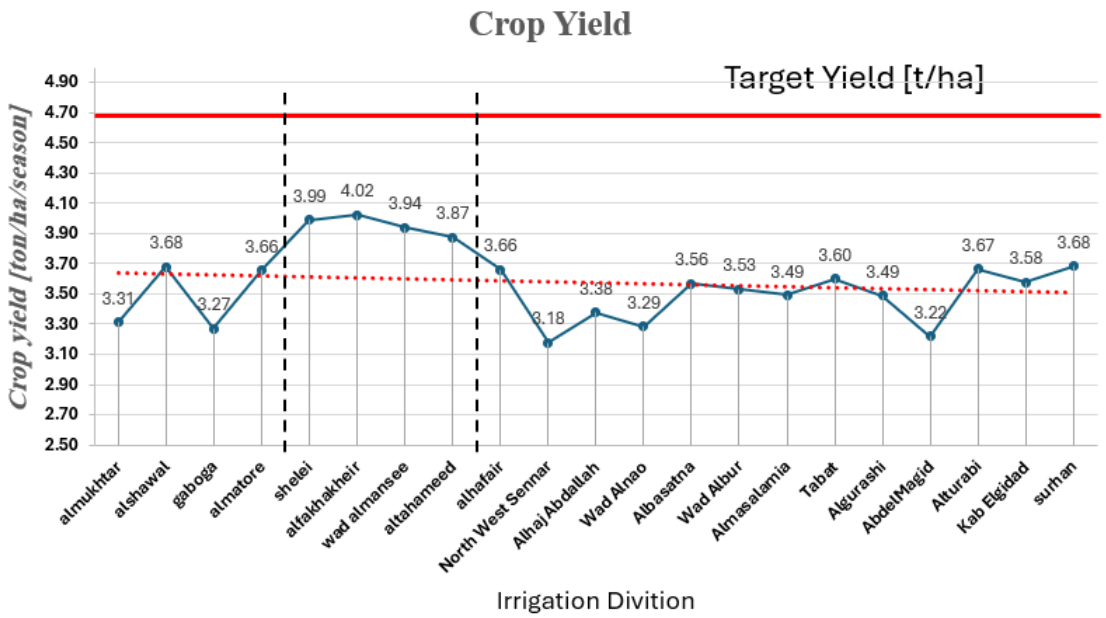


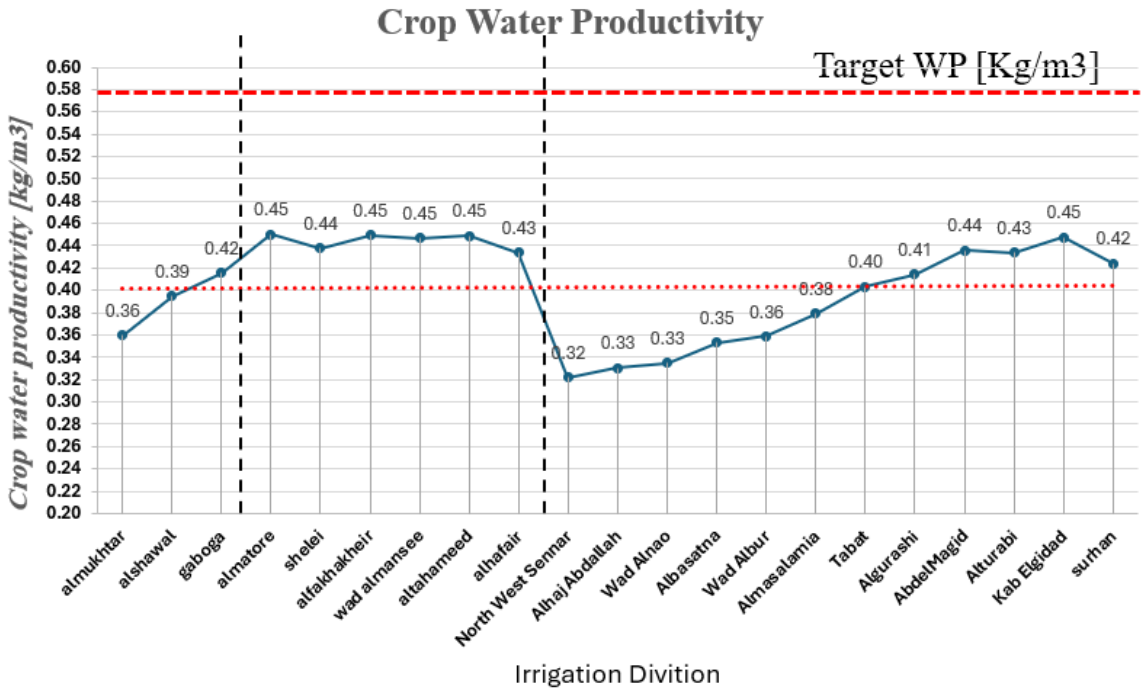


Crop Yield and WPy Analysis for Wheat in the Gezira Scheme

Season	Target Yield [t/ha]	Target WP [Kg/m3]
2019-10-07 to 2020-04-26	4.7	0.58







1-Efficiency indicators-Equity:

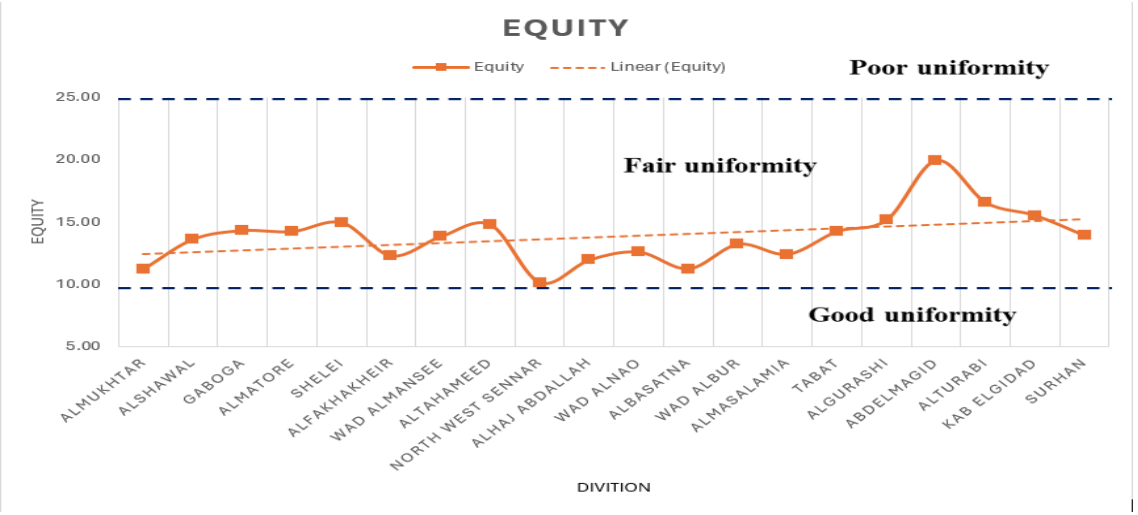
Equity: in irrigation systems refers to the degree to which water deliveries or crop water use are considered fair across all users or areas within the system. It is a crucial indicator of irrigation performance and system management effectiveness.

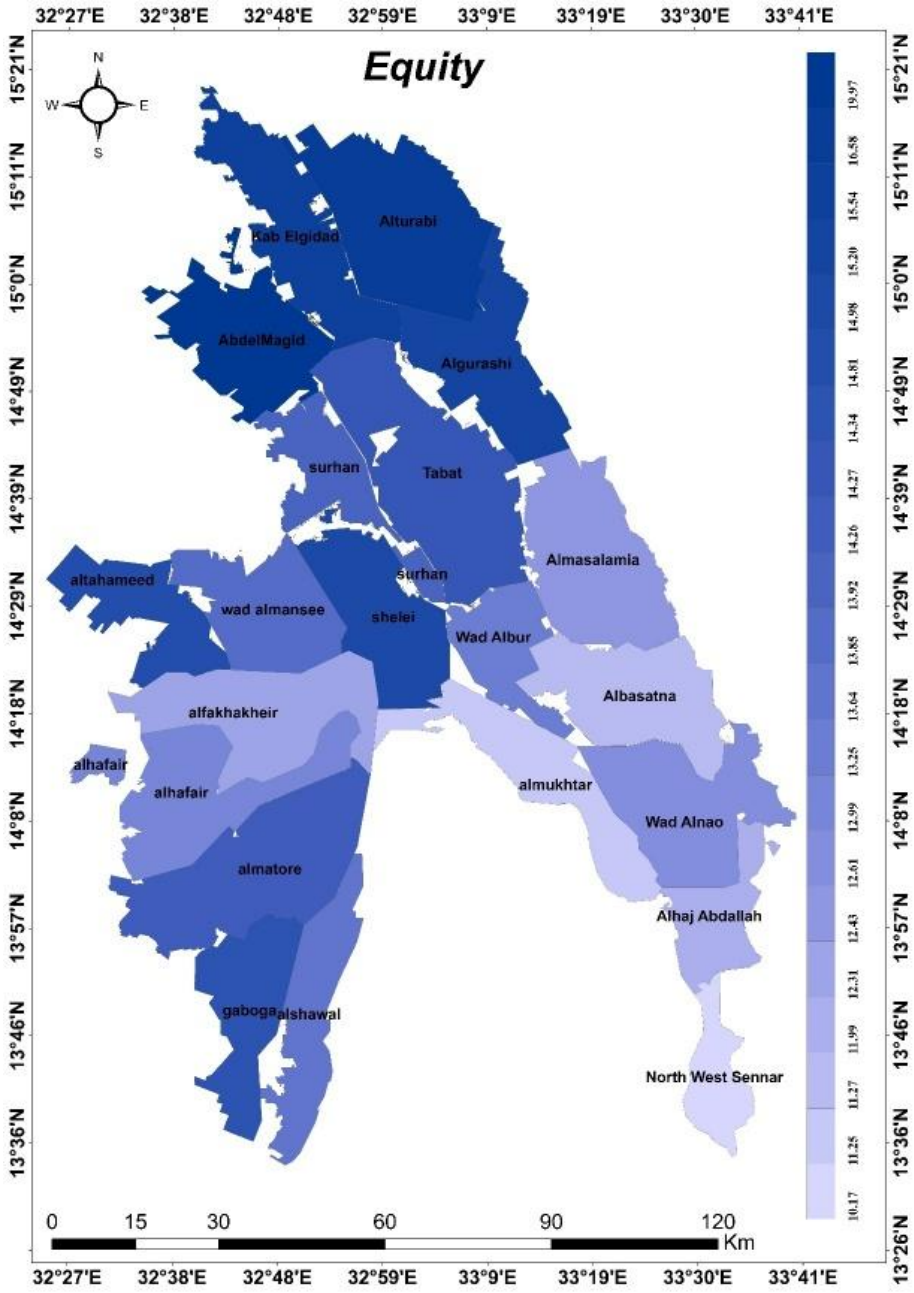
$$\text{Equity} = CV(ETa)$$

Calculate Coefficient of Variation (CV): CV = (Standard Deviation / Mean) * 100

The CV value represents your Equity measure.

Performance Indicator	Reference Range
Equity	▪ 0 < E < 10% Good ▪ 10 < E < 25% Fair ▪ E > 25% Poor performance



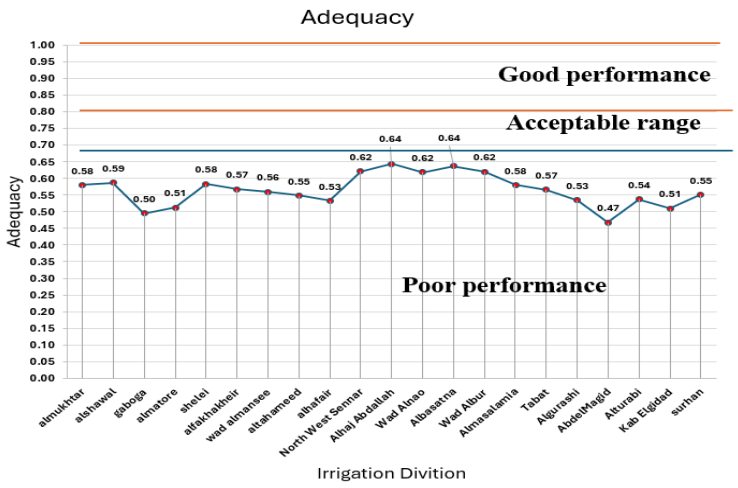


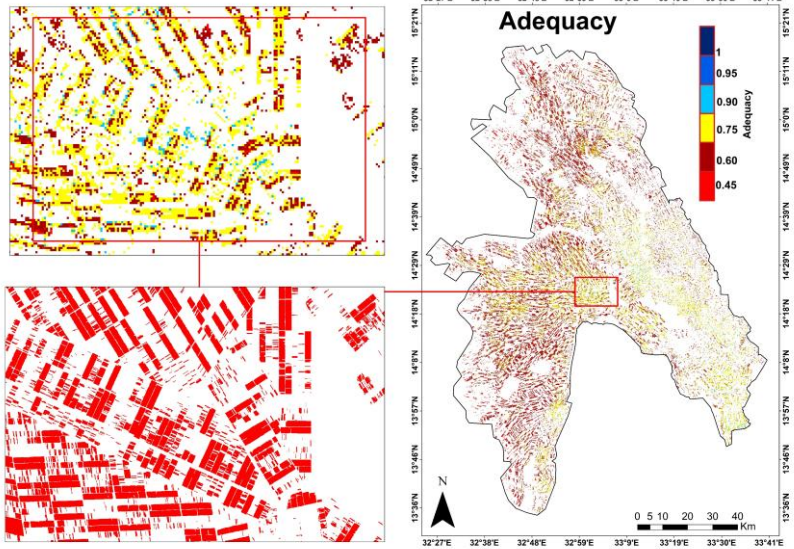
2-Efficiency indicators- Adequacy:

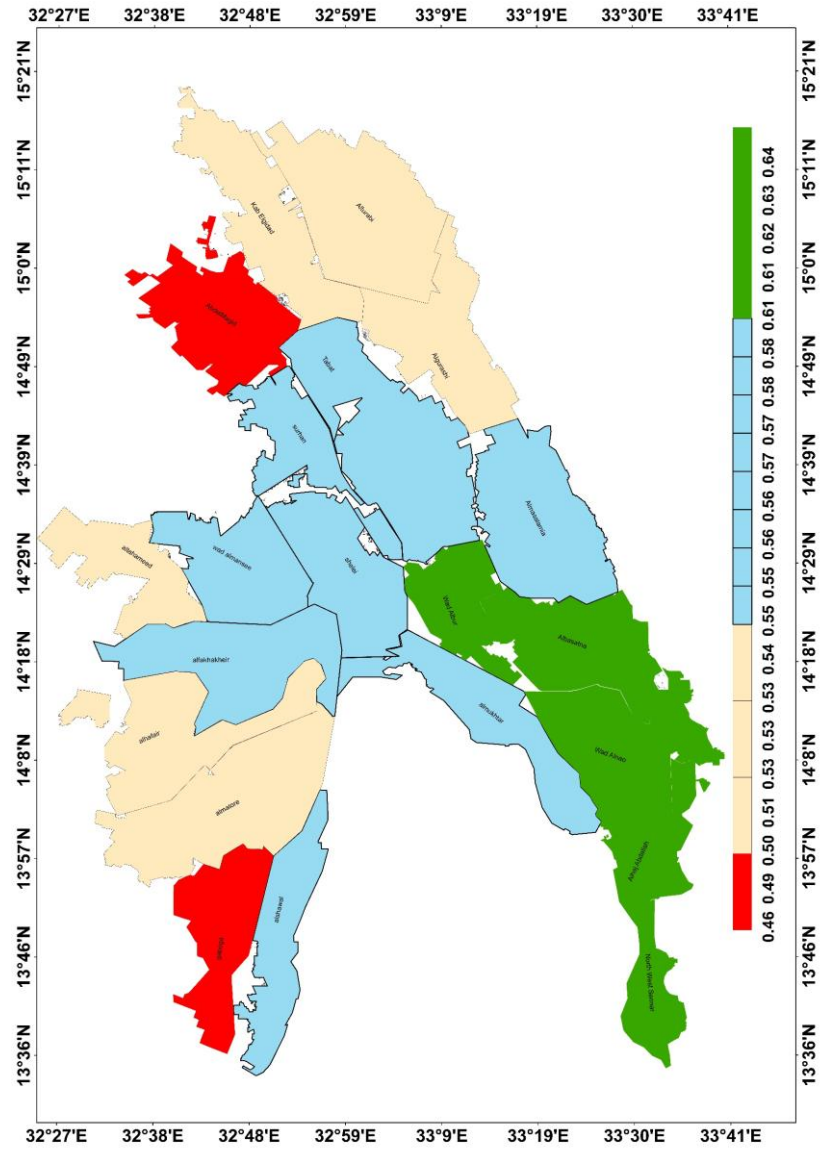
Adequacy: is a critical efficiency indicator in irrigation systems, quantifying the extent to which crop water requirements are met. It is defined as the ratio of actual evapotranspiration (ETa) to potential evapotranspiration (ETp) over a growing season.

$$\text{Adequacy} = \frac{\text{Seasonal ETa}}{\text{Seasonal ETp}}$$

Performance Indicator	Reference Range
Adequacy	- 0.8 < A <= 1 Good performance / operational range - 0.68 < A <= 0.8 Acceptable range - A <=0.68 Poor performance







3-Efficiency indicators- Relative water deficit:

Relative Water Deficit (RWD): is a crucial physiological indicator that quantifies the degree of water stress experienced by crops.

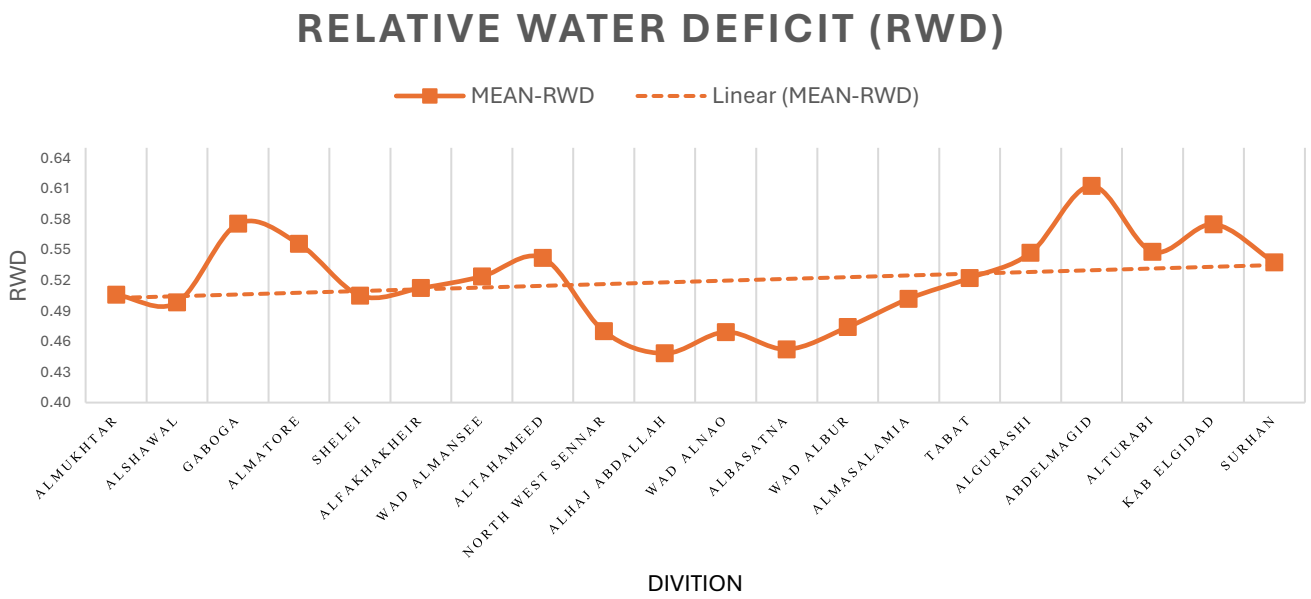
$$\text{Relative Water Deficit (RWD)} = 1 - (\text{AETI} / \text{REF})$$

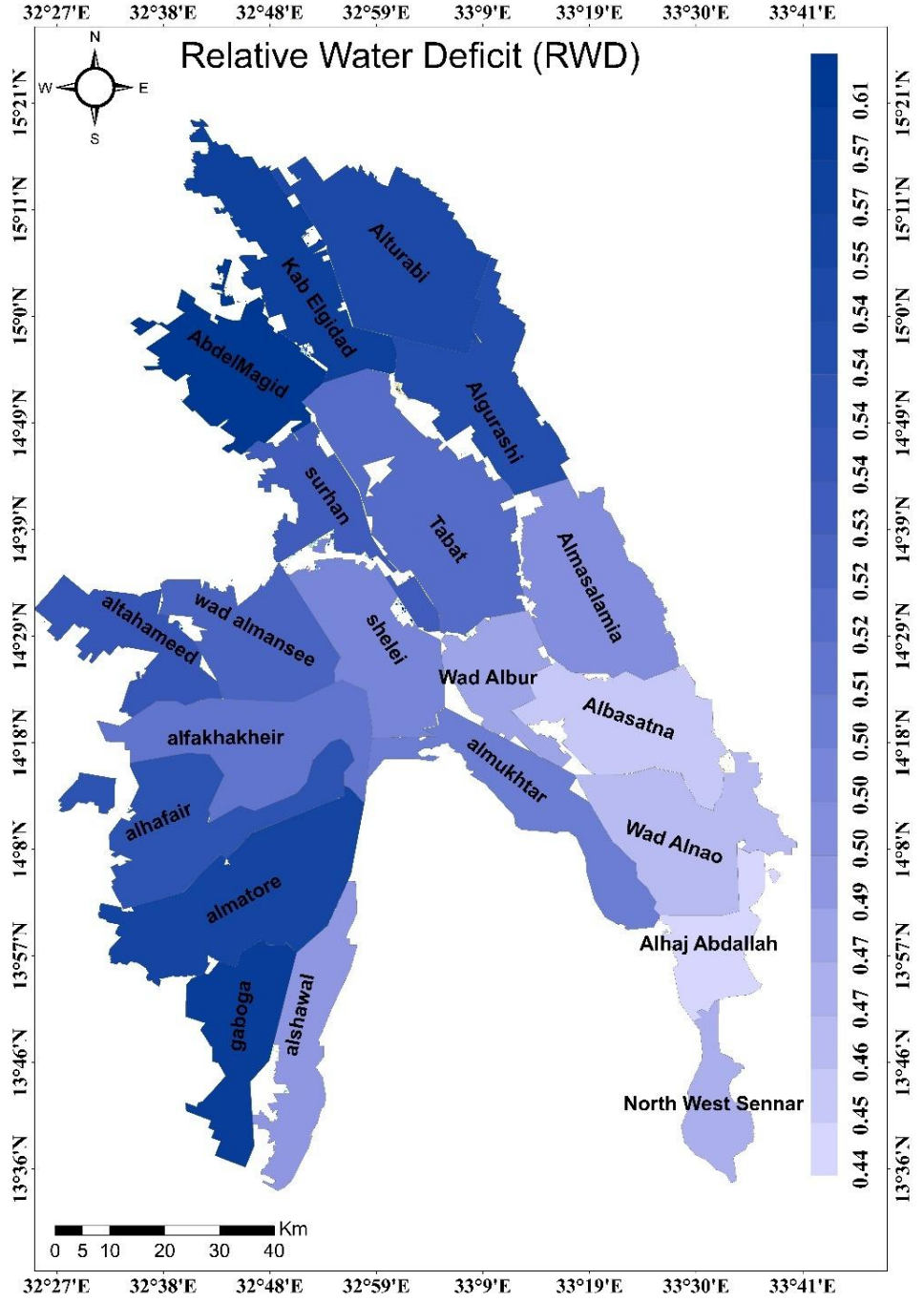
Where:

AETI: Actual Evapotranspiration

REF: Reference Evapotranspiration

Relative Water Deficit for all Scheme Season2019/2020 = (27%) crops in the scheme received only 73% of their optimal water requirements

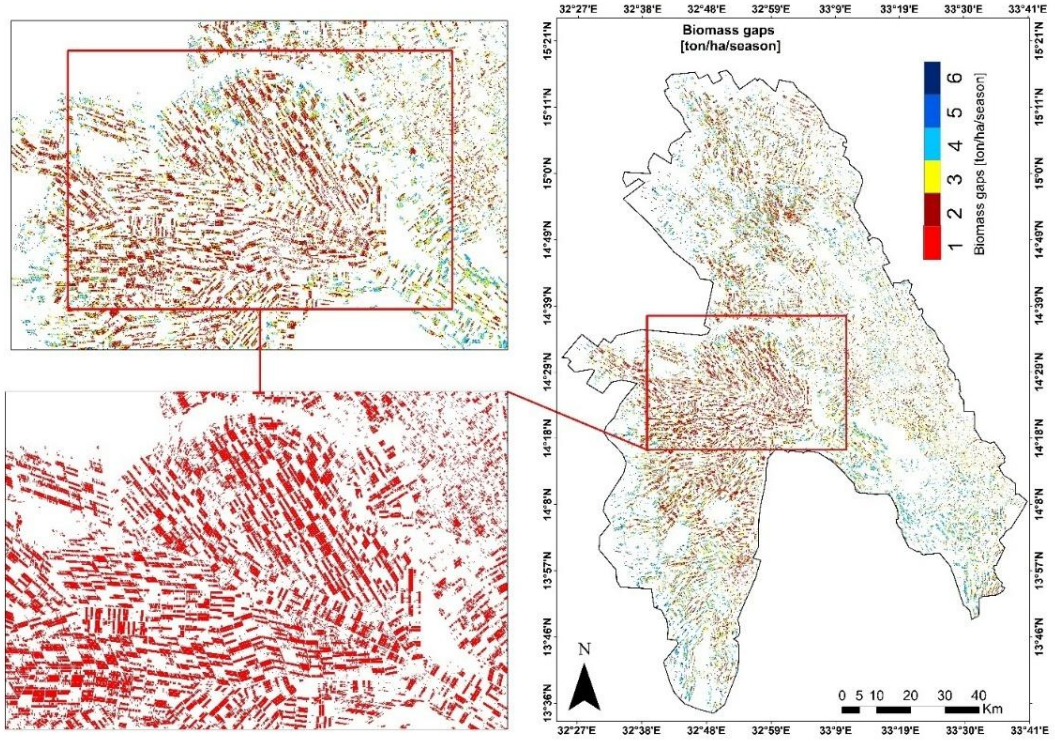


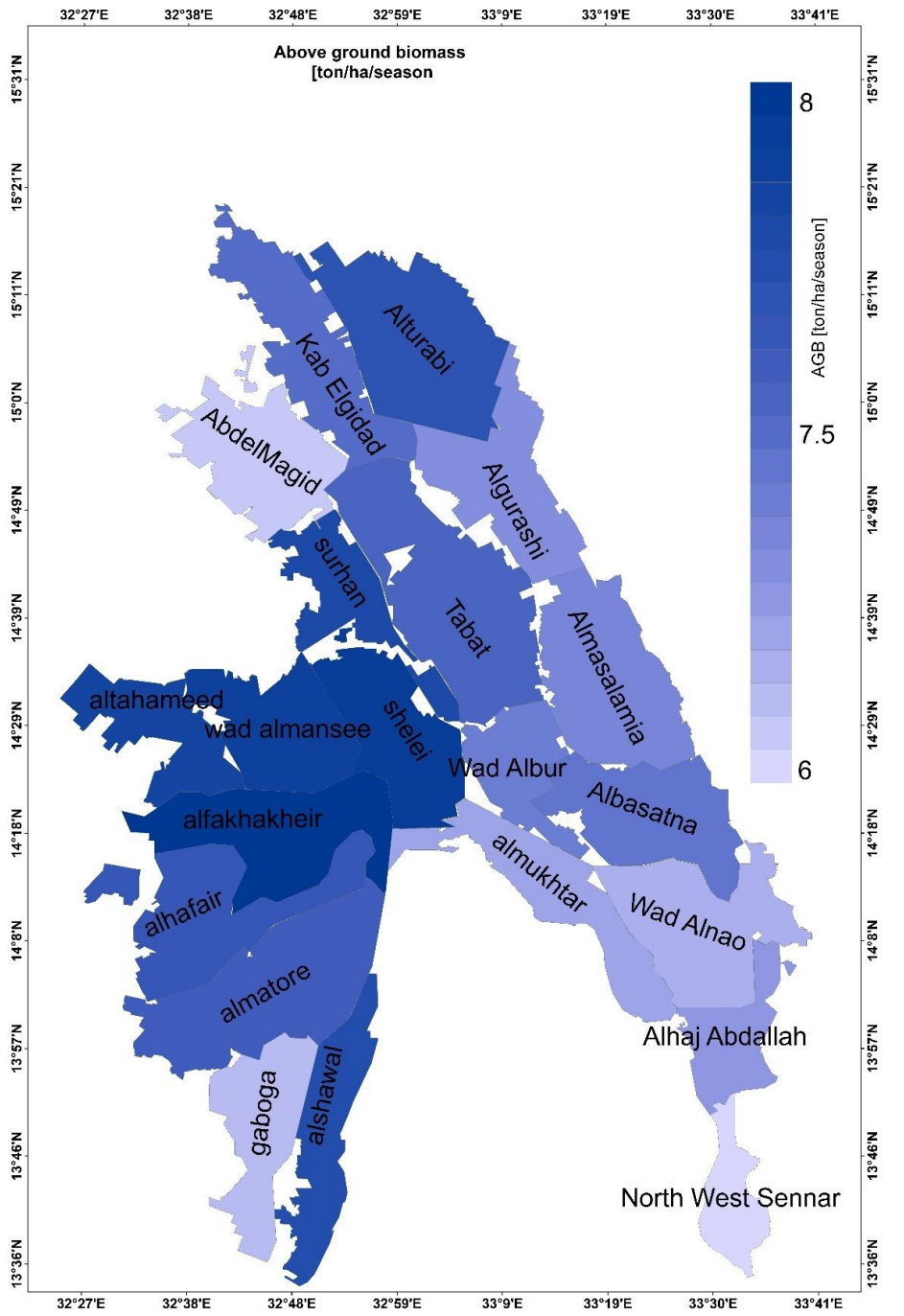


1-Gaps Analysis Biomass Gaps:

Biomass Gap: The difference between the target biomass and the actual biomass in areas where the actual biomass is below the target.

$$Biomass\ gap = \text{Target Biomass} - \text{Actual Biomass}$$

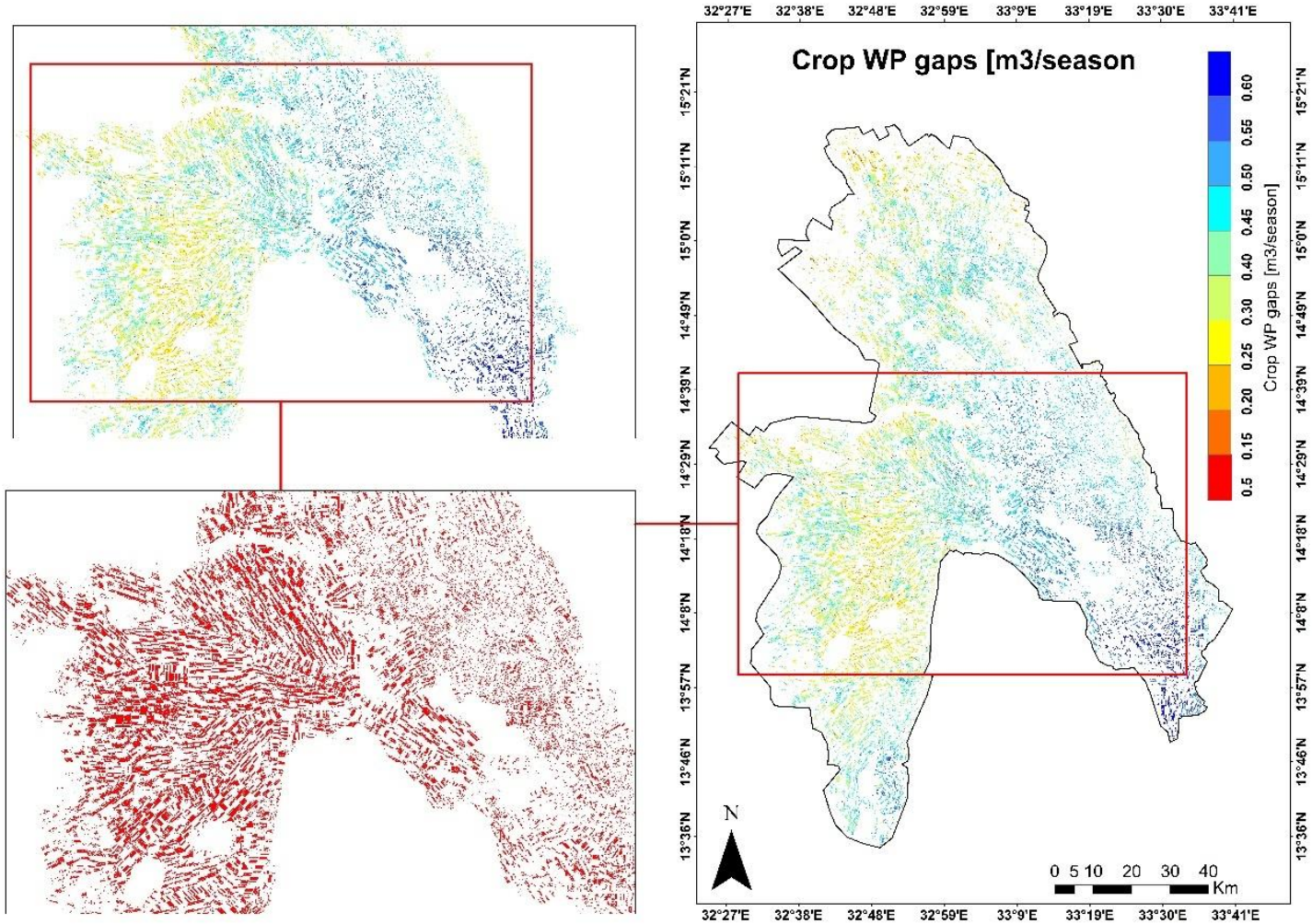




Biomass Water Productivity Gaps" (Biomass WP Gaps):

The difference between the target biomass water productivity and the actual biomass water productivity in areas where the actual WPb is below the target.

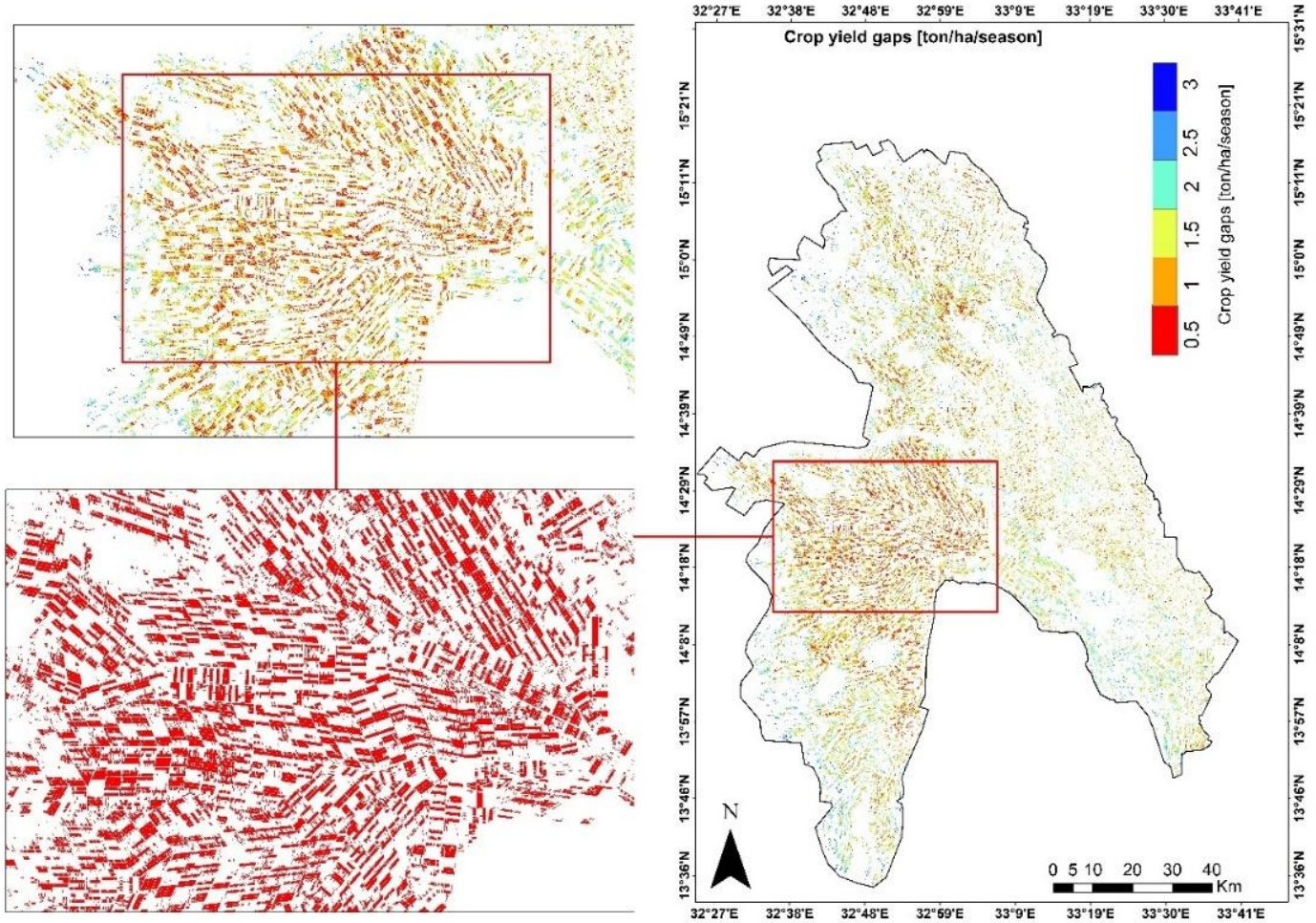
$$\text{WPb Gap} = \text{Target WPb} - \text{Actual WPb}$$



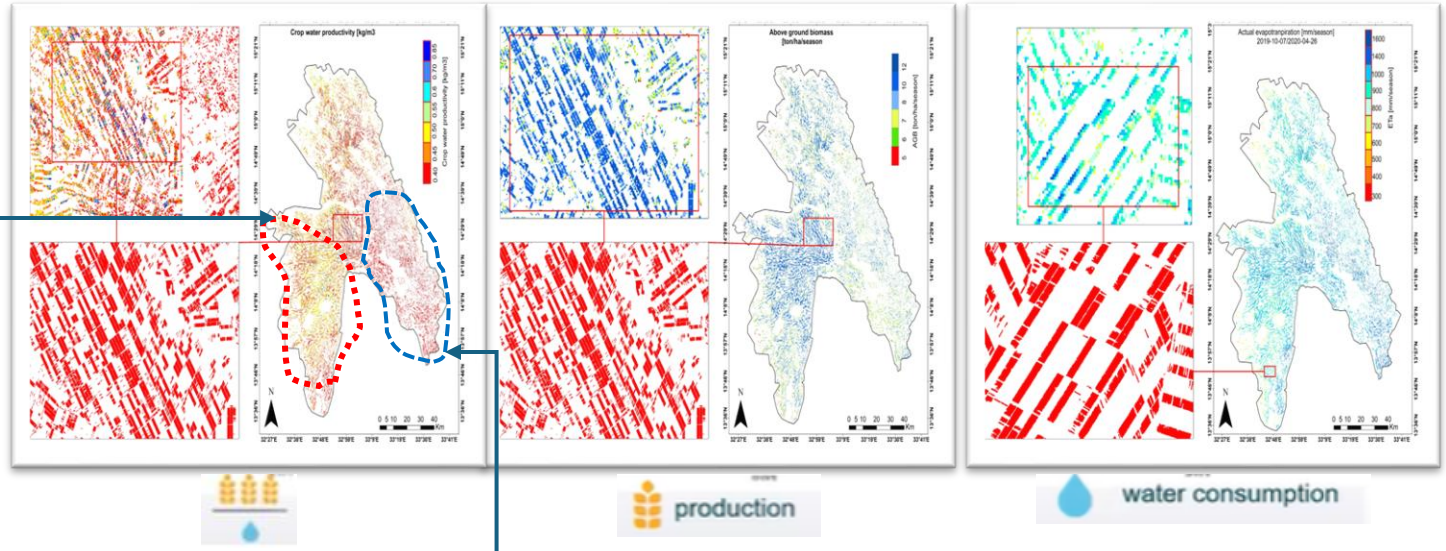
Crop Yield Gaps:

Crop Yield Gap: The difference between the target crop yield and the actual crop yield in areas where the actual yield is below the target.

$$\text{Yield Gap} = \text{Target Yield} - \text{Actual Yield}$$



Calculating Yield Water Productivity: Maximizing Efficiency in Agricultural Outputs :



Managil Zone:

Yield Range:

The wheat yield in the Managil zone varies between **4 to 5 tons per hectare (tons/ha).** However, this is below the optimum yield range, which should ideally be between **6 to 9 tons/ha.** This indicates that the current yields are lower than the potential yield that could be achieved under ideal conditions.

Water Productivity:

The water productivity in this zone is approximately **0.55 kilograms per cubic meter** (kg/m^3). This value is less than 50% of the **optimum water productivity range, which is between 0.8 to 1.6 kg/m^3.** This suggests that the current usage of water in the Managil zone is not efficient, as the crops are producing less than half the yield they could potentially produce per unit of water used.

South and North Gezira Zone:

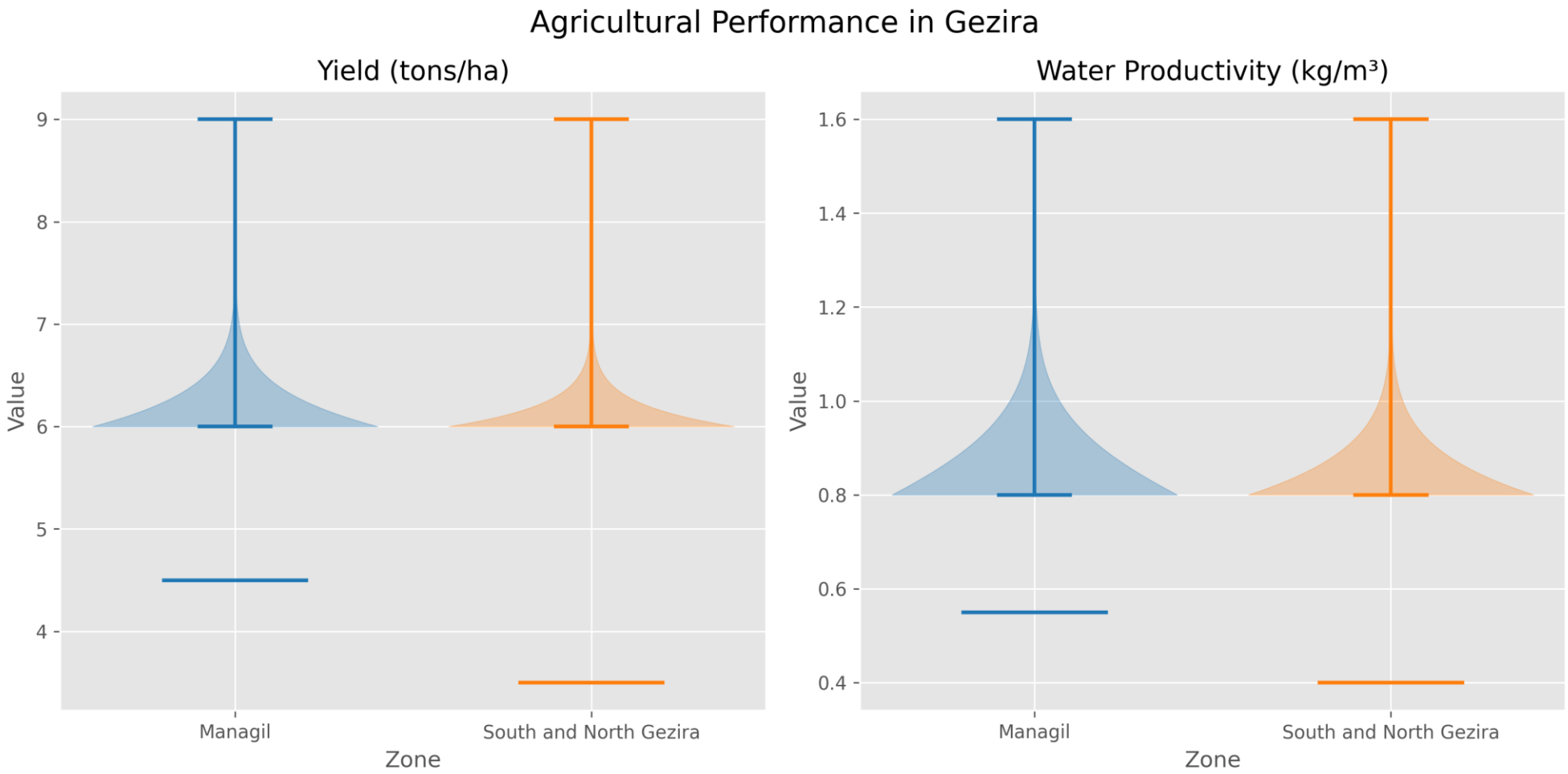
Yield:

In these zones, the majority of the wheat harvest is **less than 3.5 tons/ha.** This yield is significantly lower than in the Managil zone and far below the optimum yield range, indicating major issues in crop productivity.

Water Productivity:

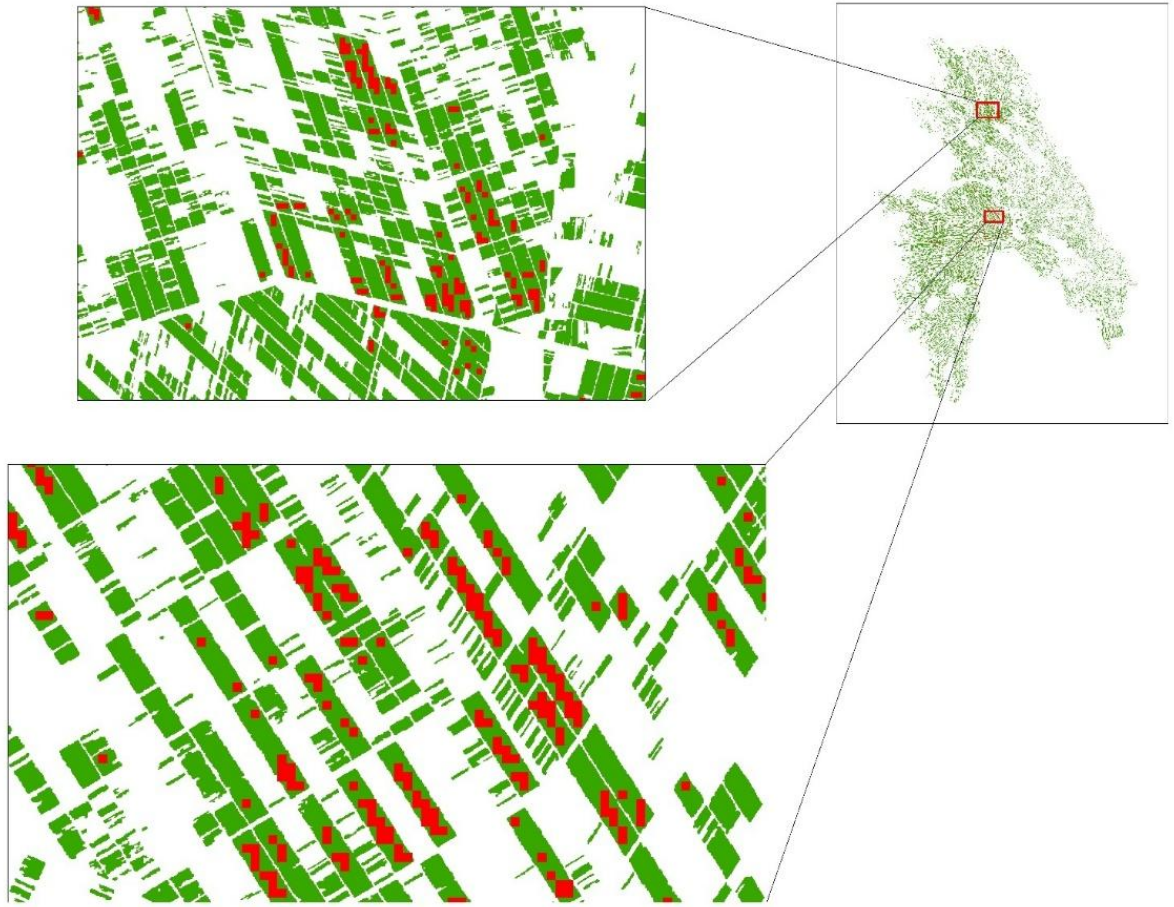
The water productivity here is **below 0.4 kg/m^3**. This is even lower than the already suboptimal productivity in the Managil zone and well below the optimum range. It implies an even less efficient use of water in these zones, with the crops producing a very small amount of yield per unit of water used.

In summary, both zones are experiencing suboptimal wheat yields and poor water productivity. The yields are lower than the ideal targets, and the amount of wheat produced per unit of water is significantly less than the optimal values. This indicates a need for improved agricultural practices, better water management, and potentially the integration of advanced technologies to enhance both yield and water productivity in these areas.


Agricultural Performance in Gezira
Yield (tons/ha)
Water Productivity (kg/m³)
Value
Zone
Managil
South and North Gezira
9
8
7
6
5
4
1.6
1.4
1.2
1.0
0.8
0.6
0.4

Bright Spots Analysis:

The Bright Spots analysis for the Gezira Scheme, based on remote sensing data from October 7, 2019, to April 26, 2020, revealed significant insights into high-performing areas of wheat cultivation.



$$\text{Bright Spot} = (\text{Actual Biomass} \geq \text{Target Biomass}) \text{AND } (\text{Actual WPb} \geq \text{Target WPb})$$

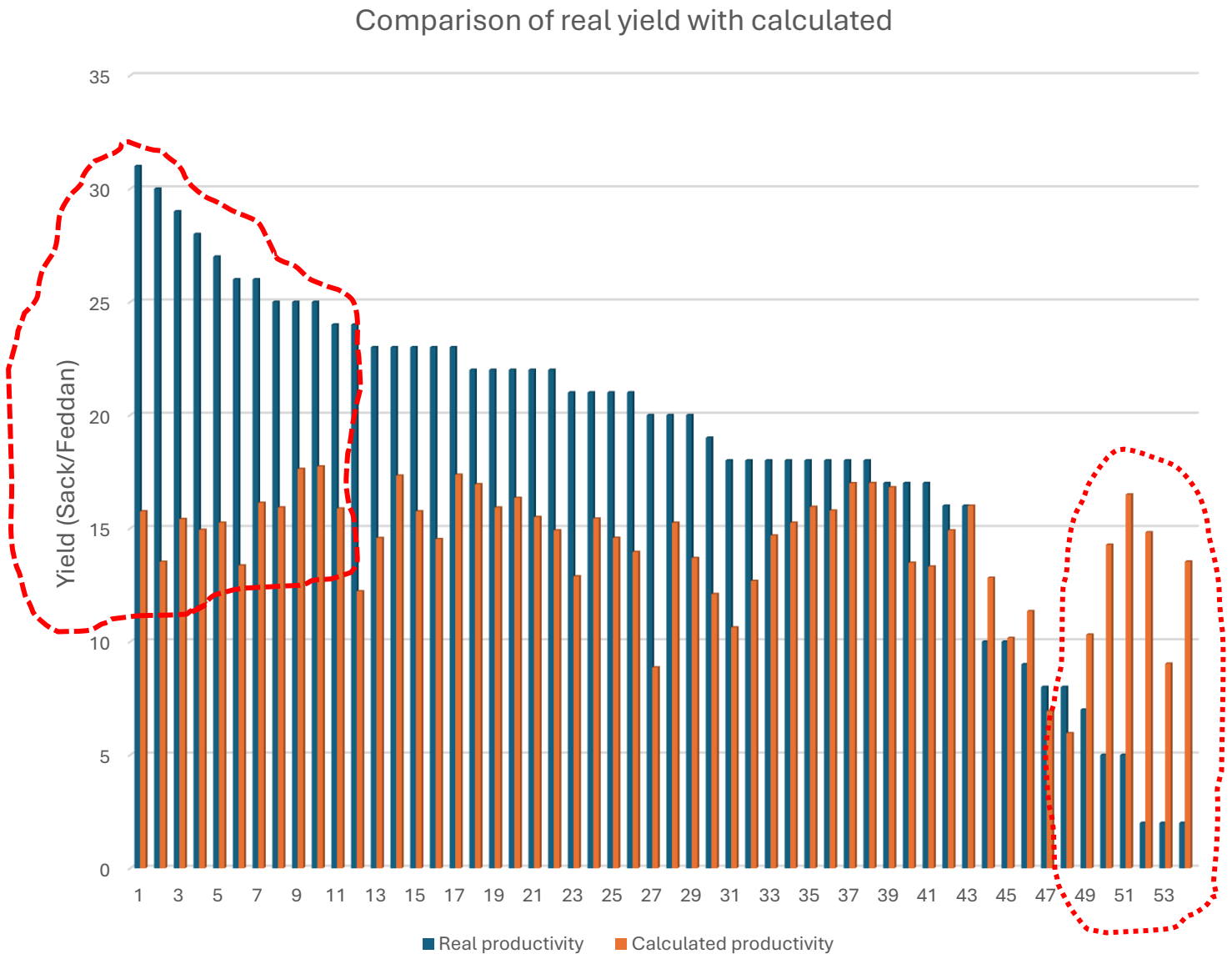
$$\text{Bright Spot} = (\text{Actual Yield} \geq \text{Target Yield}) \text{AND } (\text{Actual WPy} \geq \text{Target WPy})$$

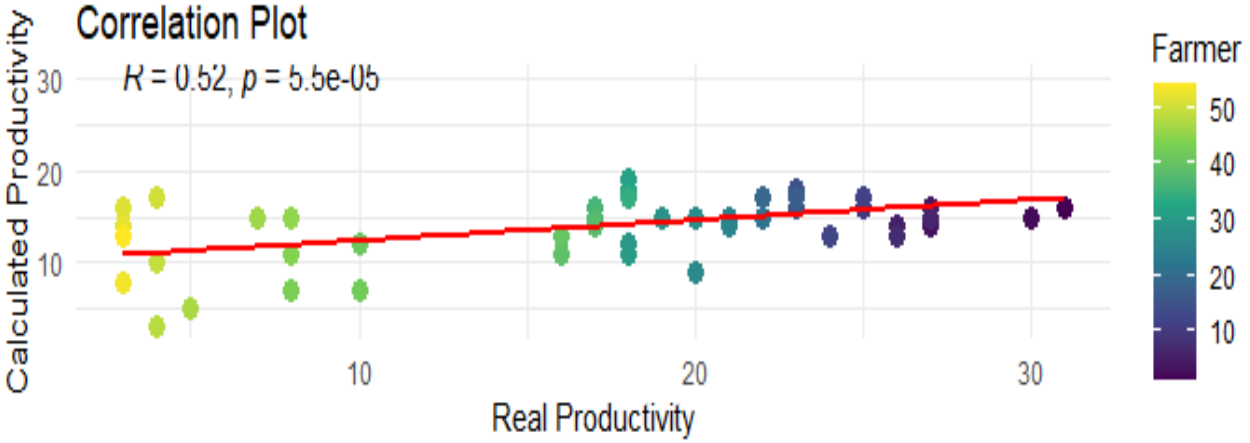
Fieldwork

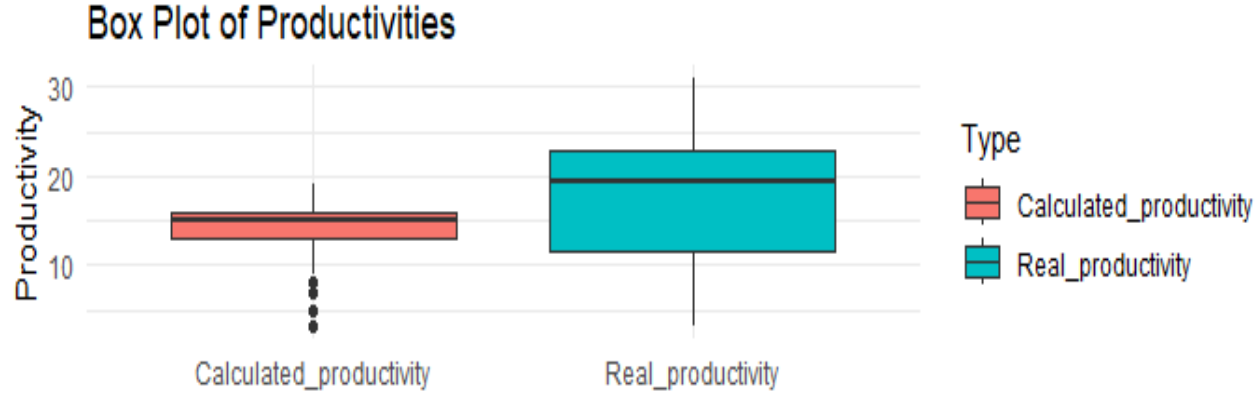
NO.	Farmer Name	Area	Yield	Land Prepration							Chemical fertilizers							Additional problems				Type of Seed	seed rate (Kg/feddan)	Average	Sowing Date	1st Irrigation	2nd Irrigation	Irrigation during season	Are weed and silt problems a major issue in you
				Chezel (Khalkhal	Disk (3-Disk	Plough	Harrow	Kharbash	Leveling (Disck_harrow		Dap	Dap/fddan	Avarge	Urea	Urea/fddan	Average	Amonium Phosphate	NPK	Irrigation	Finance	Harvest	pests							
1																													
2																													
3	1		3	20	19		1	5			1	7	2.3	1.7	8	2.7	2.5	0	0	√			Imam	60	71.6	2019-11-15	2019-11-20	2019-12-05	8	Yes
4	2		3	18	19		1	2			2	6	2.0	1.7	7	2.3	2.5	0	0	√		√	Imam	60	71.6	2019-11-15	2019-11-20	2019-12-05	8	Yes
5	3		6	20	19	1		5		1	2	6	2.0	1.7	9	3.0	2.5	0	0	√	√	√	Imam	60	71.6	2019-11-10	2019-11-15	2019-12-03	6	Yes
6	4		6	22	19			5			1	3	1.0	1.7	10	3.3	2.5	0	0	√		√	Imam	60	71.6	2019-11-18	2019-11-25	2019-12-10	6	Yes
7	5		3	23	19	1		4			1	6	2.0	1.7	7	2.3	2.5	0	0		√	√	Imam	60	71.6	2019-11-20	2019-11-25	2019-12-10	8	Yes
8	6		3	18	19		1	2			2	7	2.3	1.7	10	3.3	2.5	0	0			√	Imam	60	71.6	2019-11-15	2019-10-20	2019-12-03	8	Yes
9	7		6	18	19	1		3			1	4	1.3	1.7	6	2.0	2.5	0	0	√			Imam	60	71.6	2019-11-12	2019-11-18	2019-12-06	6	Yes
10	8		3	23	19							4	1.3	1.7	7	2.3	2.5	0	0	√			Imam	60	71.6	2019-11-18	2019-11-21	2019-11-11	7	Yes
11	9		3	21	19		1	4			1	5	1.7	1.7	6	2.0	2.5	0	0	√	√	√	Imam	67	71.6	2019-11-15	2019-11-17	2019-12-03	7	Yes
12	10		3	20	19	1	1	3			2	4	1.3	1.7	10	3.3	2.5	0	0	√			Imam	67	71.6	2019-11-18	2019-12-06	2019-12-28	6	Yes
13	11		3	21	19	1		4			1	4	1.3	1.7	7	2.3	2.5	0	0	√			Imam	60	71.6	2019-11-13	2019-11-14	2019-11-30	7	Yes
14	12		3	16	19		1	3			1	4	1.3	1.7	7	2.3	2.5	0	0	√		√	Imam	60	71.6	2019-11-06	2019-12-18	2019-11-28	8	Yes
15	13		3	22	19	1	1	5			1	4	1.3	1.7	8	2.7	2.5	0	0	√	√		Imam	80	71.6	2019-11-15	2019-11-17	2019-12-05	7	Yes
16	14		3	25	19		2	3			1	5	1.7	1.7	8	2.7	2.5	0	0		√		Imam	80	71.6	2019-11-15	2019-11-20	2019-12-06	9	Yes
17	15		3	21	19		2	4			1	4	1.3	1.7	10	3.3	2.5	0	0			√	Imam	83	71.6	2019-11-04	2019-11-11	2019-12-03	9	Yes
18	16		3	21	19		1	3			2	5	1.7	1.7	7	2.3	2.5	0	0				√	Imam	100	71.6	2019-11-24	2019-11-24	2019-10-15	7	Yes
19	17		3	28	19	2		4			1	5	1.5	1.7	6	2.0	2.5	0	0			√	√	Imam	90	71.6	2019-11-15	2019-11-22	2019-12-03	8	Yes
20	18		3	30	19	2		4			2	6	2.0	1.7	9	3.0	2.5	0	0			√	Imam	80	71.6	2019-11-16	2019-11-25	2019-12-10	8	Yes
21	19		3	26	19	2		4			2	5	1.7	1.7	7	2.3	2.5	0	0			√	Imam	65	71.6	2019-11-14	2019-11-20	2019-12-04	6	Yes
22	20		3	21	19			4			2	5	1.7	1.7	6	2.0	2.5	0	0			√	Imam	60	71.6	2019-11-09	2019-11-07	2019-11-20	7	Yes
23	21		3	16	19		1				1	3	2.0	1.7	6	2.0	2.5	0	0		√	√	Imam	106	71.6	2019-11-15	2019-11-15	2019-11-30	8	Yes
24	22		3	17	19			3	1			4	1.3	1.7	6	2.0	2.5	0	0	√	√		Imam	70	71.6	2019-11-20	2019-11-27	2019-12-10	8	Yes
25	23	Alemam Mohamed Mustafa Mohamed	3	23	19	1		1	1		1	4	1.3	1.7	8	2.7	2.5	0	0	√			Imam	80	71.6	2020-11-01	2020-11-05	2020-10-20	8	Yes
26	24	Mustafa Ali Mustafa Mohamed	4	31	19			8			3	10	3.3	1.7	12	4.0	2.5	0	0	√		√	Imam	125	71.6	2020-11-05	2020-11-07	2020-11-20	12	Yes
27	25	AlTayieb Elemam Mohamed Almustafa	6	22	19			1			2	4	1.3	1.7	8	2.7	2.5	0	1			√	Imam	80	71.6	2020-11-01	2020-11-05	2020-11-20	8	Yes
28	26	Ali Edress Mohamed	3	18	19			2			1	6	2.0	1.7	12	4.0	2.5	0	0	√			Imam	80	71.6	2020-11-05	2020-11-11	2020-11-30	8	Yes
29	27	Ibrahim Abo Alkiram Ali	6	17	19			1			1	6	2.0	1.7	8	2.7	2.5	0	0	√	√		Imam	60	71.6	2020-11-20	2020-11-21	2020-12-05	8	Yes
30	28	Abo Dogana Alshikh Alaebaid	9	23	19		1	6			2	6	2.0	1.7	7	2.3	2.5	0	0				Imam	60	71.6	2020-11-13	2020-11-27	2020-12-12	8	Yes
31	29	Abdalla Gareeballah Mohamed	9	26	19			4			1	6	2.0	1.7	7	2.3	2.5	0	0				Imam	66	71.6	2020-11-15	2020-11-29	2020-12-15	8	Yes
32	30	Mohamed Khaier Ali Alnyar Alemam	9	24	19		1	8			1	4	1.3	1.7	8	2.7	2.5	0	1				Imam	73	71.6	2020-11-10	2020-11-10	2020-11-25	9	No
33	31	Alfadil Ali Mustafa	40	24	19	1		3	1		1	6	2.0	1.7	9	3.0	2.5	0	1	√			Imam	60	71.6	2020-11-10	2020-11-12	2020-12-04	6	Yes
34	32	Abdalla Ibrahim Hamdan Ibrahim	15	23	19	1	1	4			2	6	2.0	1.7	10	3.3	2.5	0	1		√		Imam	60	71.6	2020-11-05	2020-11-05	2020-11-20	9	Yes
35	33	Ahmed Abdalazim	30	18	19	1		1			1	6	2.0	1.7	6	2.0	2.5	0	0				Imam	63	71.6	2020-11-10	2020-11-15	2020-11-25	7	Yes
36	34	Rafea Alrayah Abdalla	12	18	19	1		4			1	6	2.0	1.7	6	2.0	2.5	0	1	√		√	Imam	60	71.6	2020-11-24	2020-12-01	2020-12-15	6	Yes
37	35	Modather Yousif Mohamed Abdalla	3	22	19	1	1	3				8	2.7	1.7	6	2.0	2.5	0	1	√			Imam	100	71.6	2020-11-15	2020-11-16	2020-11-26	8	Yes
38	36	Mohamed Noor Ahmed Gdal	90	20	19	1		2			1	4	1.3	1.7	8	2.7	2.5	0	0	√		√	Imam	60	71.6	2020-11-20	2020-11-20	2020-12-05	7	Yes
39	37	Ammar Alamin Ahmed	3	27	19	1		6			2	3	1.0	1.7	6	2.0	2.5	0	0	√	√		Imam	60	71.6	2020-12-06	2020-12-07	2020-12-21	7	Yes
40	38	Khalid Alrayah Abdalla	15	25	19	1	1	4			2	6	2.0	1.7	6	2.0	2.5	0	0	√			Imam	60	71.6	2020-11-13	2020-11-17	2020-12-05	7	Yes
41	39	Abdeen Ahmed Mohamed	42	22	19		1	4			1	4	1.3	1.7	7	2.3	2.5	0	1	√			Imam	60	71.6	2020-11-05	2020-11-07	2020-11-22	7	Yes
42	40	Hago Alhady Mohamed	6	17	19		1	2			1	3	1.0	1.7	6	2.0	2.5	0	0			√	By self	60	71.6	2020-12-01	2020-12-05	2020-12-20	8	Yes
43	41	Fkhar Aldeen Mohamed Yousif Omer	9	25	19	1	2	4			1	5	1.7	1.7	9	3.0	2.5	0	0				Al ragieh	67	71.6	2020-11-15	2020-11-15	2020-12-03	10	Yes
44	42	Abdalla Alnagy Yagoub Abdalla	9	29	19		1	3			1	4	1.3	1.7	7	2.3	2.5	0	0			√	Imam	80	71.6	2020-11-25	2020-11-26	2020-12-15	8	Yes
45	43	Azhary Mohamed Alamin	9	18	19		1	3			2	4	1.3	1.7	6	2.0	2.5	0	0	√		√	Imam	80	71.6	2020-12-07	2020-12-07	2020-12-22	7	Yes
46	44	Abdalmahmood Ahmed Mosa	30	26	19		2	6			1	5	1.7	1.7	7	2.3	2.5	0	0				Imam	60	71.6	2020-11-15	2020-11-15	2020-12-05	8	Yes
47	45	Sir Alkhatim Ahmed Alhaj	9	18	19		1	4			1	4	1.3	1.7	6	2.0	2.5	0	0			√	Imam	60	71.6	2020-11-15	2020-11-15	2020-11-30	8	Yes
48	46	Abdallaleif mansor Alebaied	60	30	19	1		5		1	1	6	2.0	1.7	6	2.0	2.5	0	0	√			Al motafe Erada company	80	71.6	2020-11-10	2020-11-11	2020-11-26	8	No
49	47	Omer Hassan Abdalhameed	6	22	19	1		4		1	1	4	1.3	1.7	7	2.3	2.5	0	0	√		√	Almotafy Erada company	70	71.6	2020-11-12	2020-11-20	2020-12-03	6	Yes
50	48	Ali Mansor Alebaied	12	27	19	1		5			1	6	2.0	1.7	6	2.0	2.5	0	0	√			Al motafe Erada company	90	71.6	2020-11-10	2020-11-25	2020-12-10	7	Yes
51	49	Nour Aldaiem Mosa Ahmed Alrady	6	19	19			4			1	5	1.7	1.7	8	2.7	2.5	0	1	√			Imam	80	71.6	2020-11-05	2020-11-10	2020-11-25	7	Yes
52	50	Faroug Bakhet Mohamed	21	16	19		1	2			1	4	1.3	1.7	8	2.7	2.5	0	1		√		Imam	90	71.6	2020-11-01	2020-11-07	2020-11-15	8	Yes
53	51	Imam Fadl Almola Imam	9	21	19			4		3	1	4	1.3	1.7	6	2.0	2.5	1	1				Zakia	80	71.6	2020-11-13	2020-11-13	2020-11-28	7	Yes
54	52	بلال العبيد محمد	3	7				1	3		1	3	1	1	6	2		0	0	√			Imam	60		2019-11-20	2019-10-25	2019-12-10	4	Yes
55	53	نور الدين جبارة	3	10				1	1		1	3	1	1	6	2		0	0	√			Imam	60		2019-11-20	2019-11-25	2019-12-10	4	Yes
56	54	سعيد عبد الحي وطنجت	6	8				1	1		1	3	1		6	2		0	0	√			Imam	60		2019-11-15	2019-11-25	2019-10-15	6	Yes
57	55	معاذ اصباح الخير محمد المكي	3	9				1	3		1	3	1		6	2		0	0	√			Imam	60		2019-11-15	2019-11-20	2019-12-05	5	Yes

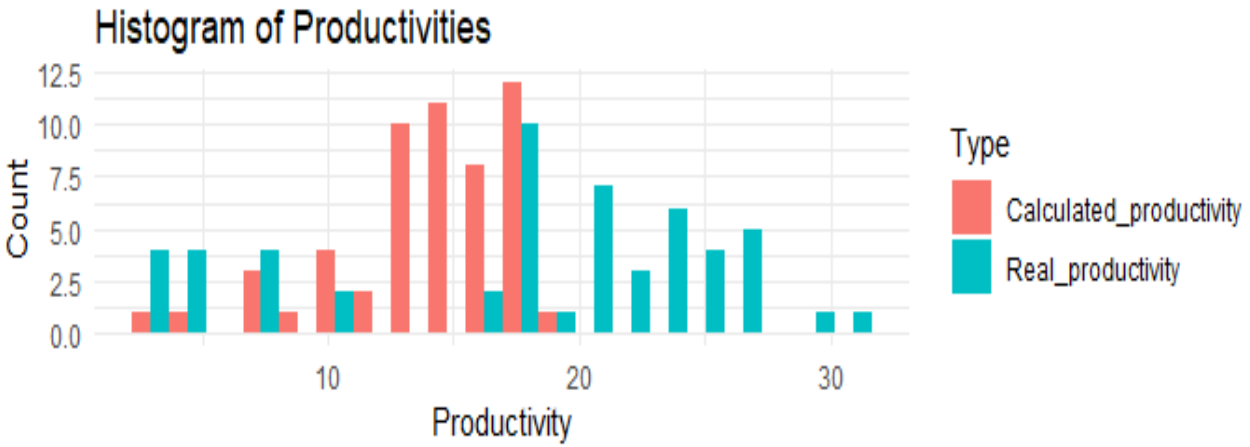
Comparing between Real Productivity Yield and Calculate Productivity from WaPOR:

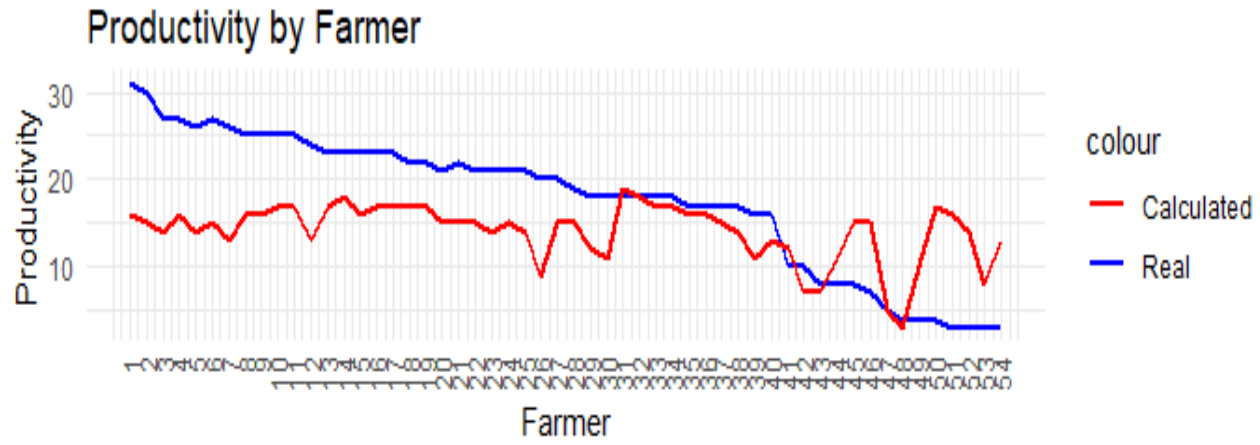
According to the figure bellow it is noticed that the accuracy of the WaPOR increases when the Productivity value is moderate between (15-25) sack/feddan ,and Data accuracy is also reduced in the case of very high and very low Productivity the WaPOR results over estimate the lower yield and underestimates the higher yield.

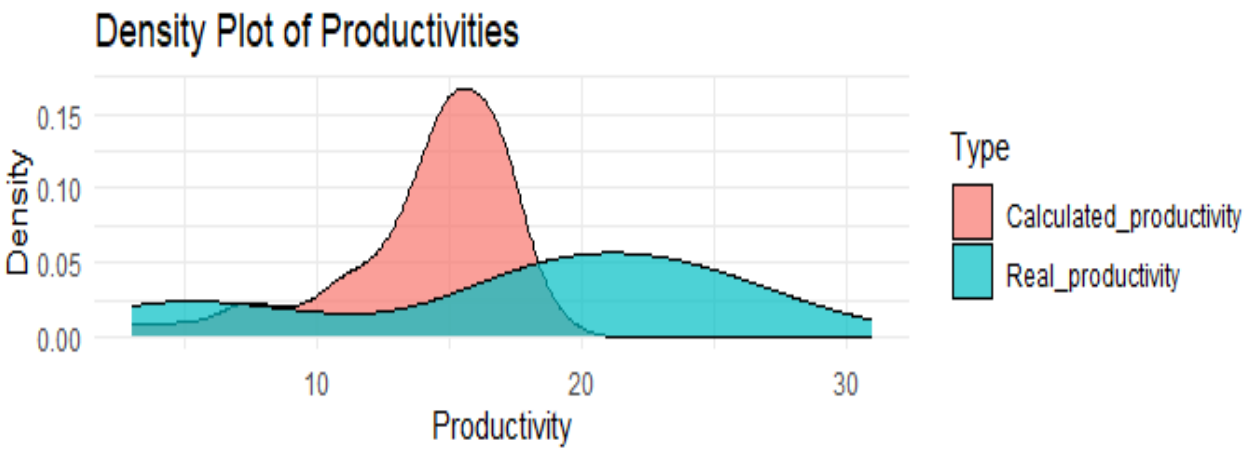


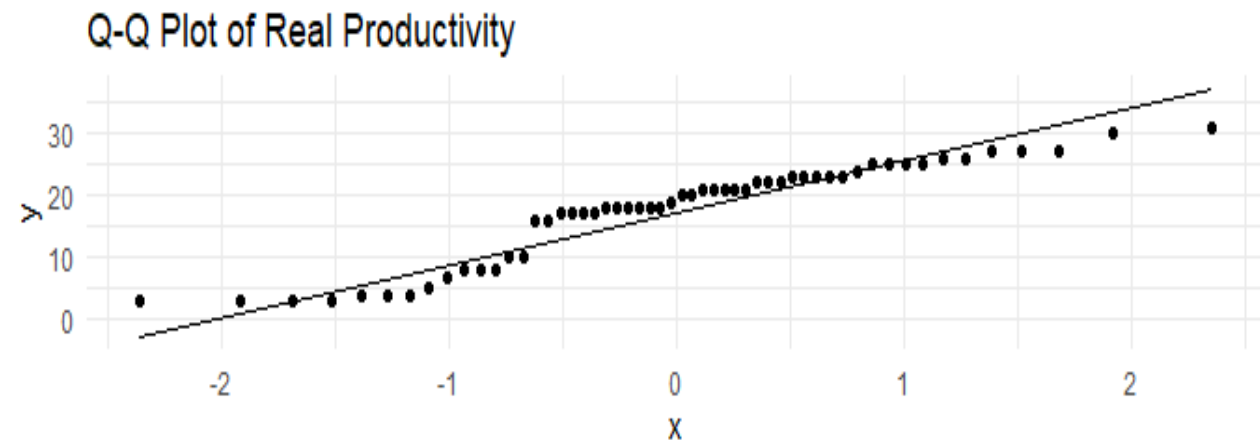

Correlation Plot
R = 0.52, p = 5.5e-05
Calculated Productivity
Real Productivity
Farmer


Box Plot of Productivities
Productivity
Calculated_productivity
Real_productivity
Type


Histogram of Productivities
Count
Productivity
Type
Calculated_productivity
Real_productivity


Productivity by Farmer
Productivity
Farmer
colour
Calculated
Real


Density Plot of Productivities
Density
Productivity
Type
Calculated_productivity
Real_productivity


Q-Q Plot of Real Productivity
y
x

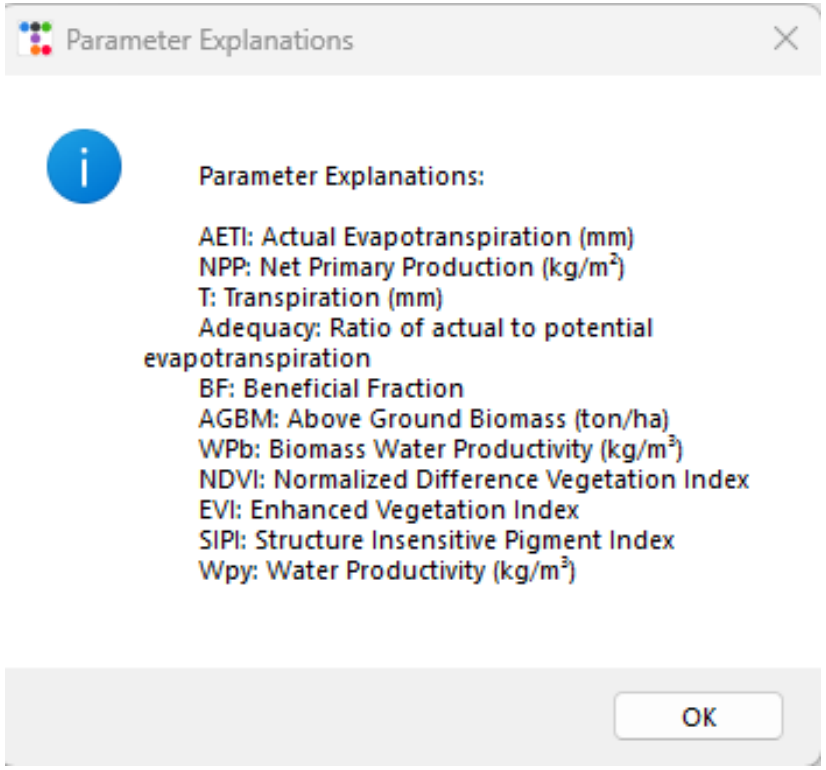

Weeds &
silt control
Seed
variety
Fertilizers
Seed
Preparatio
n
productivity
Planting
method
Land
preparation
Irrigation
scheduling

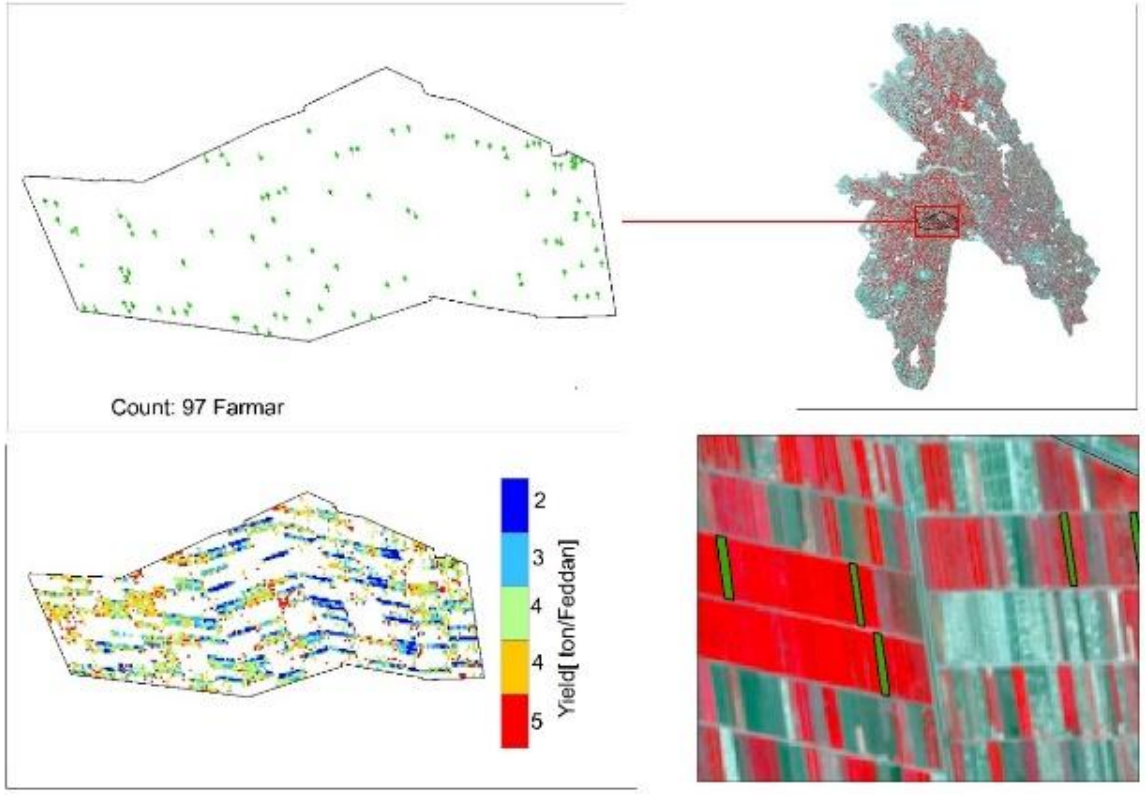
- **Results:**

The questionnaire has been conducted with 185 farmers based in the yield of wheat, 16 Sack/Feddan or more has been considered as high yield 15 Sack/Feddan or less has been considered as low yield the following table summaries the average practices of the farmers according to the high and low yield

No.	Activity	Suitable Practice
1	Seed rate	60 - 70 kg / Feddan
2	Seed preparation	It should be done according to the agricultural inspector or use the ready prepared type
4	Land preparation	Plough 3-4 times according to the rain , leveling 1-2 times
5	Sowing Date	10th – 20th of November
6	First irrigation	10th – 25th of November
7	Second irrigation	Should not be after the end of December
8	Irrigation intervals	12 - 15 days
9	Irrigation time	12 hours
10	Chemical Fertilizers	Dap 60 - 80 kg/feddan – urea 100 - 150kg / feddan
11	Weeds control	Used when its need it
12	Pests control	Used when its need it (Jet spray is enough)
13	Number of Irrigations during the season	7 – 8 times
14	Organic Fertilizers	Not significant

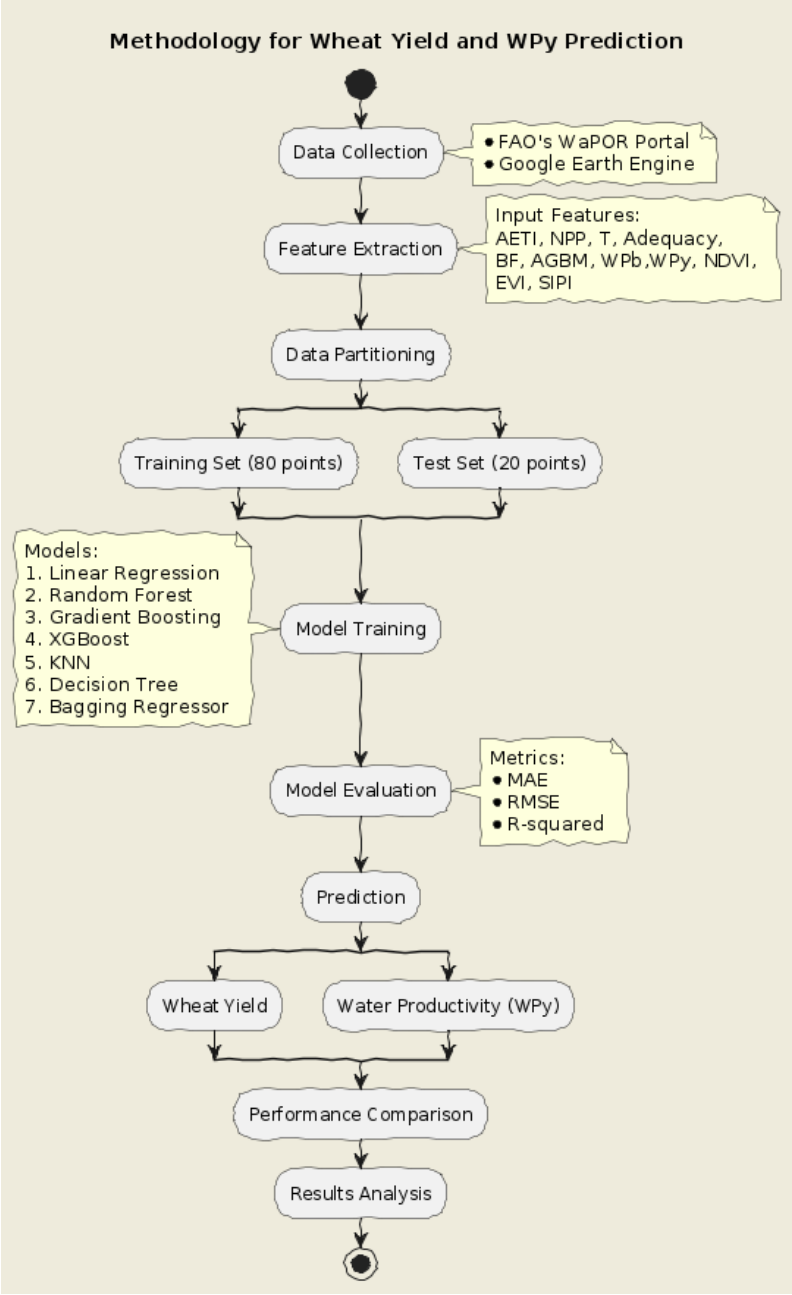
Predicting Wheat Yield and Water Productivity in The Gezira Scheme Using Machine Learning Approach

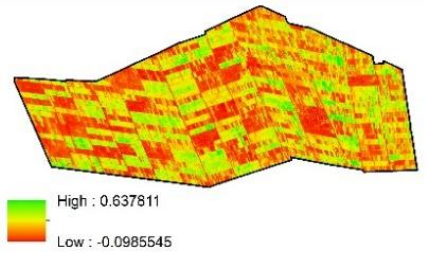




RET	AETI	NPP	T	Adequacy	BF	AGBM	WPb	Wpy	NDVI	EVI	SIPI	Calculated Yield ton/ha	Real Yield ton/ha
1855.6	791.2	277.37	615	0.5	0.78	6.16	0.78	0.37	0.35	3.86	1.45	3	1.15
1855.6	798.5	282.44	616.2	0.5	0.77	6.28	0.79	0.38	0.44	3.92	1.37	3	1.28
1849.3	815.2	317.2	643.1	0.51	0.79	7.05	0.86	0.42	0.52	3.72	1.19	3	1.75

Methodology:





Enhanced Vegetation Index (EVI):

EVI is an optimized vegetation index designed to enhance the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmosphere influences.

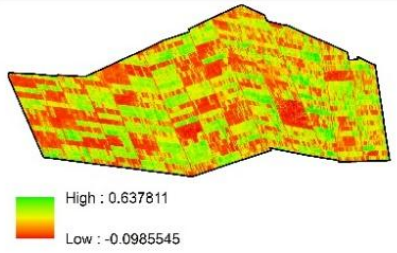
Range: -1 to 1

Purpose: Improved vegetation index that corrects for soil background and atmospheric influences.

Equation for Sentinel-2:

EVI = 2.5 * ((NIR - Red) / (NIR + 6 * Red - 7.5 * Blue + 1))

Where:
NIR = Band 8 (Near Infrared)
Red = Band 4 (Red)
Blue = Band 2 (Blue)



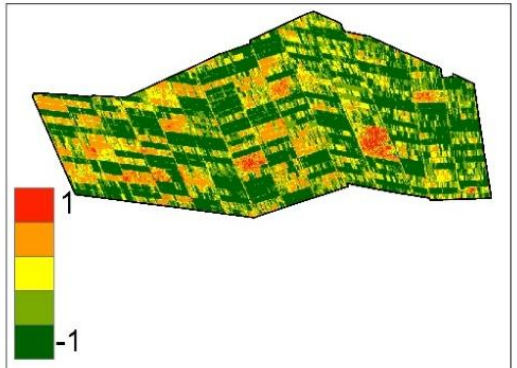
Normalized Difference Vegetation Index (NDVI):

NDVI is a widely used vegetation index that quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs).

Range: -1 to 1

Purpose: Measures vegetation health and density. Higher values indicate healthier vegetation.

Equation for Sentinel-2:
NDVI = (NIR - Red) / (NIR + Red)
Where:
NIR = Band 8 (Near Infrared)
Red = Band 4 (Red)



Structure Insensitive Pigment Index (SIPI):

SIPI is designed to maximize the sensitivity to the ratio of bulk carotenoids (for example, alpha-carotene and beta-carotene) to chlorophyll while decreasing sensitivity to variation in canopy structure (leaf area index).

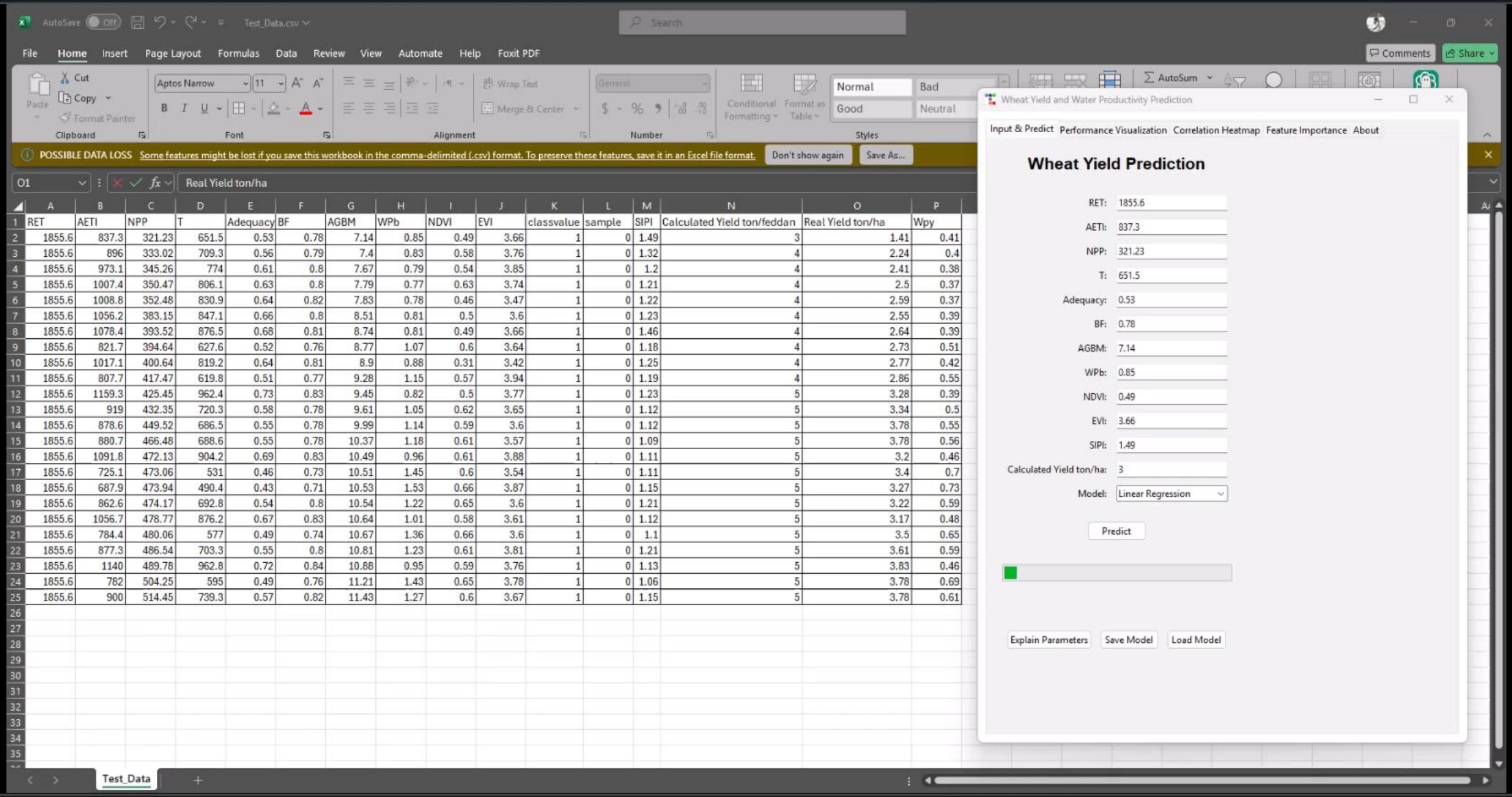
Range: 0 to 2

Purpose: Estimates the ratio of carotenoids to chlorophyll.

Equation for Sentinel-2:
SIPI = (NIR - Blue) / (NIR - Red)
Where:
NIR = Band 8 (Near Infrared)
Red = Band 4 (Red)
Blue = Band 2 (Blue)

Performance metrics of machine learning models for wheat yield and WPy estimation in the Gezira Irrigation Scheme

Target	Model	MAE	RMSE	R-squared
Yield	Linear Regression	0.245	0.322	0.708
Yield	Random Forest	0.167	0.228	0.854
Yield	Gradient Boosting	0.177	0.244	0.832
Yield	XGBoost	0.170	0.245	0.831
Yield	KNN	0.236	0.290	0.763
Yield	Decision Tree	0.170	0.223	0.860
Yield	Bagging Regressor	0.163	0.226	0.857
Wpy	Linear Regression	0.003	0.003	0.999
Wpy	Random Forest	0.006	0.007	0.996
Wpy	Gradient Boosting	0.004	0.008	0.995
Wpy	XGBoost	0.004	0.007	0.996
Wpy	KNN	0.018	0.026	0.945
Wpy	Decision Tree	0.010	0.013	0.986
Wpy	Bagging Regressor	0.005	0.007	0.996



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	RET	AETI	NPP	T	Adequacy	BF	AGBM	WPb	NDVI	EVI	classvalue	sample	SIPI	Calculated Yield ton/feddan	Real Yield ton/ha	Wpy
2	1855.6	837.3	321.23	651.5	0.53	0.78	7.14	0.85	0.49	3.66	1	0	1.49	3	1.41	0.41
3	1855.6	896	333.02	709.3	0.56	0.79	7.4	0.83	0.58	3.76	1	0	1.32	4	2.24	0.4
4	1855.6	973.1	345.26	774	0.61	0.8	7.67	0.79	0.54	3.85	1	0	1.2	4	2.41	0.38
5	1855.6	1007.4	350.47	806.1	0.63	0.8	7.79	0.77	0.63	3.74	1	0	1.21	4	2.5	0.37
6	1855.6	1008.8	352.48	830.9	0.64	0.82	7.83	0.78	0.46	3.47	1	0	1.22	4	2.59	0.37
7	1855.6	1056.2	383.15	847.1	0.66	0.8	8.51	0.81	0.5	3.6	1	0	1.23	4	2.55	0.39
8	1855.6	1078.4	393.52	876.5	0.68	0.81	8.74	0.81	0.49	3.66	1	0	1.46	4	2.64	0.39
9	1855.6	821.7	394.64	627.6	0.52	0.76	8.77	1.07	0.6	3.64	1	0	1.18	4	2.73	0.51
10	1855.6	1017.1	400.64	819.2	0.64	0.81	8.9	0.88	0.31	3.42	1	0	1.25	4	2.77	0.42
11	1855.6	807.7	417.47	619.8	0.51	0.77	9.28	1.15	0.57	3.94	1	0	1.19	4	2.86	0.55
12	1855.6	1159.3	425.45	962.4	0.73	0.83	9.45	0.82	0.5	3.77	1	0	1.23	5	3.28	0.39
13	1855.6	919	432.35	720.3	0.58	0.78	9.61	1.05	0.62	3.65	1	0	1.12	5	3.34	0.5
14	1855.6	878.6	449.52	686.5	0.55	0.78	9.99	1.14	0.59	3.6	1	0	1.12	5	3.78	0.55
15	1855.6	880.7	466.48	688.6	0.55	0.78	10.37	1.18	0.61	3.57	1	0	1.09	5	3.78	0.56
16	1855.6	1091.8	472.13	904.2	0.69	0.83	10.49	0.96	0.61	3.88	1	0	1.11	5	3.2	0.46
17	1855.6	725.1	473.06	531	0.46	0.73	10.51	1.45	0.6	3.54	1	0	1.11	5	3.4	0.7
18	1855.6	687.9	473.94	490.4	0.43	0.71	10.53	1.53	0.66	3.87	1	0	1.15	5	3.27	0.73
19	1855.6	862.6	474.17	692.8	0.54	0.8	10.54	1.22	0.65	3.6	1	0	1.21	5	3.22	0.59
20	1855.6	1056.7	478.77	876.2	0.67	0.83	10.64	1.01	0.58	3.61	1	0	1.12	5	3.17	0.48
21	1855.6	784.4	480.06	577	0.49	0.74	10.67	1.36	0.66	3.6	1	0	1.1	5	3.5	0.65
22	1855.6	877.3	486.54	703.3	0.55	0.8	10.81	1.23	0.61	3.81	1	0	1.21	5	3.61	0.59
23	1855.6	1140	489.78	962.8	0.72	0.84	10.88	0.95	0.59	3.76	1	0	1.13	5	3.83	0.46
24	1855.6	782	504.25	595	0.49	0.76	11.21	1.43	0.65	3.78	1	0	1.06	5	3.78	0.69
25	1855.6	900	514.45	739.3	0.57	0.82	11.43	1.27	0.6	3.67	1	0	1.15	5	3.78	0.61

Recommendations:

1. Targeted Water Management Interventions:

- Implement precision irrigation techniques in divisions with low adequacy values (0.47-0.64).
- Develop a scheme-wide water monitoring system to address the 27% average relative water deficit.
- Promote the optimal irrigation schedule identified (7-8 times per season, 12-15 day intervals).

2. Agronomic Practice Optimization:

Widely disseminate and encourage adoption of best practices identified from high-yielding farmers:

- Optimal seed rates: 60-70 kg/feddan
- Timely sowing: 10th-20th November
- Appropriate fertilizer application: DAP 60-80 kg/feddan, urea 100-150 kg/feddan

3. Yield Gap Reduction Strategy:

- Focus on bridging the yield gap between current (3.18-4.02 t/ha) and optimal (6-9 t/ha) production levels.
- Implement targeted interventions in South and North Gezira zones, which show critical underperformance.

4. Water Productivity Enhancement:

- Set zone-specific targets to improve water productivity from the current 0.32-0.45 kg/m³ towards the optimal 0.8-1.6 kg/m³ range.
- Prioritize interventions in divisions with Water Productivity (WPy) values below 0.4 kg/m³.

5. Technology Integration and Capacity Building:

- Enhance the integration of remote sensing (WaPOR) data with ground-truth information for more accurate yield estimations.
- Provide training to farmers and extension workers on interpreting and utilizing remote sensing data for decision-making.

Recommendations:

6. Research and Innovation:
- Conduct in-depth studies on 'bright spots' to understand and replicate success factors.
- Investigate causes of low performance in specific divisions, particularly Northwest Sennar.
- Explore drought-resistant wheat varieties suitable for divisions with consistently low adequacy values.

8. Knowledge Dissemination:
- Create demonstration plots in 'bright spot' areas for farmer field schools and peer-to-peer learning.
- Develop and distribute region-specific best practice guides based on the findings of this study.

9. Infrastructure Improvement:
- Invest in upgrading irrigation infrastructure, particularly in divisions showing high Actual Evapotranspiration (AETI) values.
- Implement water-saving technologies in areas with low Beneficial Fraction (BF) values.

Thank You!

Questions and Discussion