Using remote sensing datasets (WaPOR) and crop coefficients to estimate actual crop evapotranspiration

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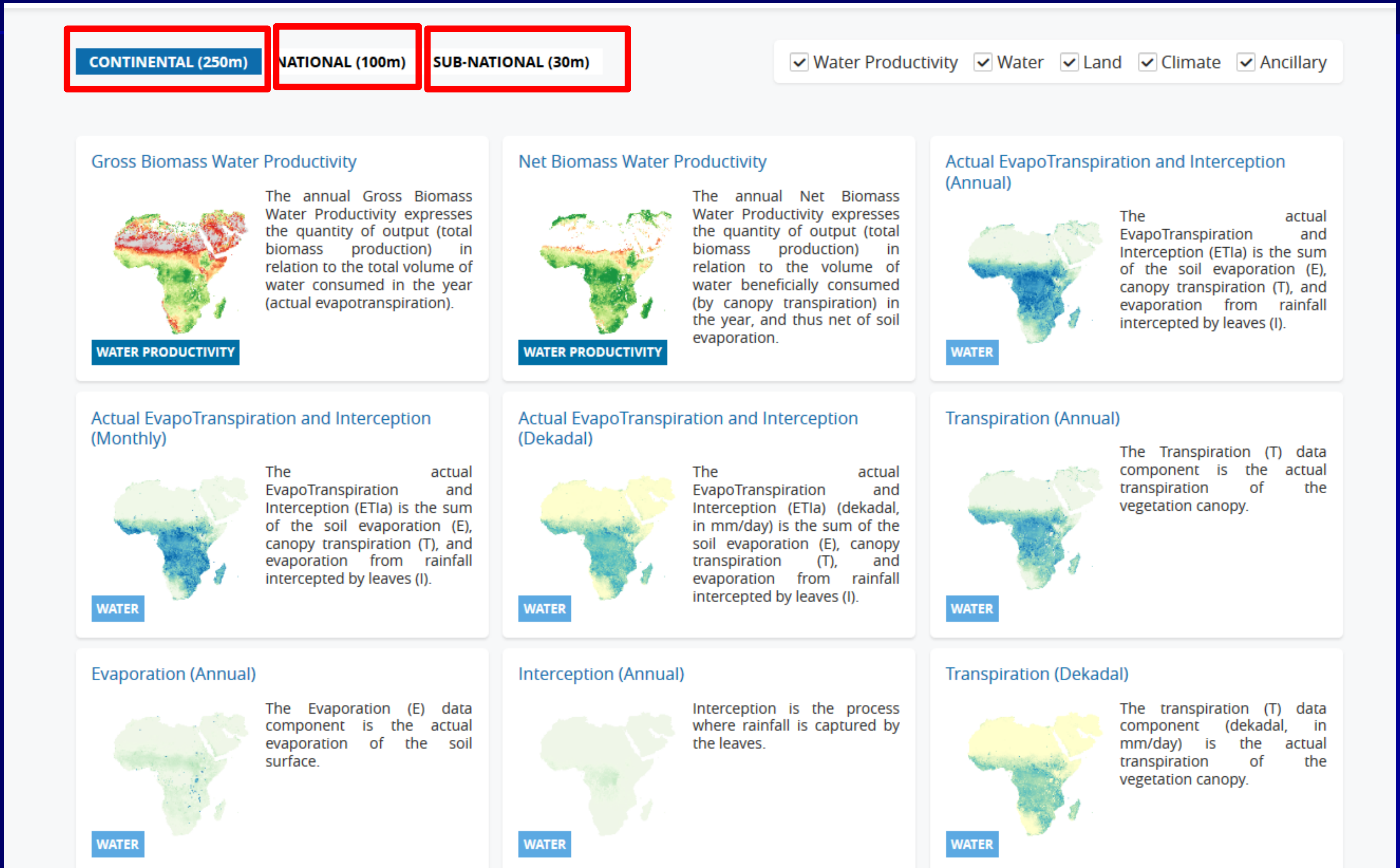
المركز العربي لدراسات المناطق الجافه و الأراضي القاحلة

(ACSAD)

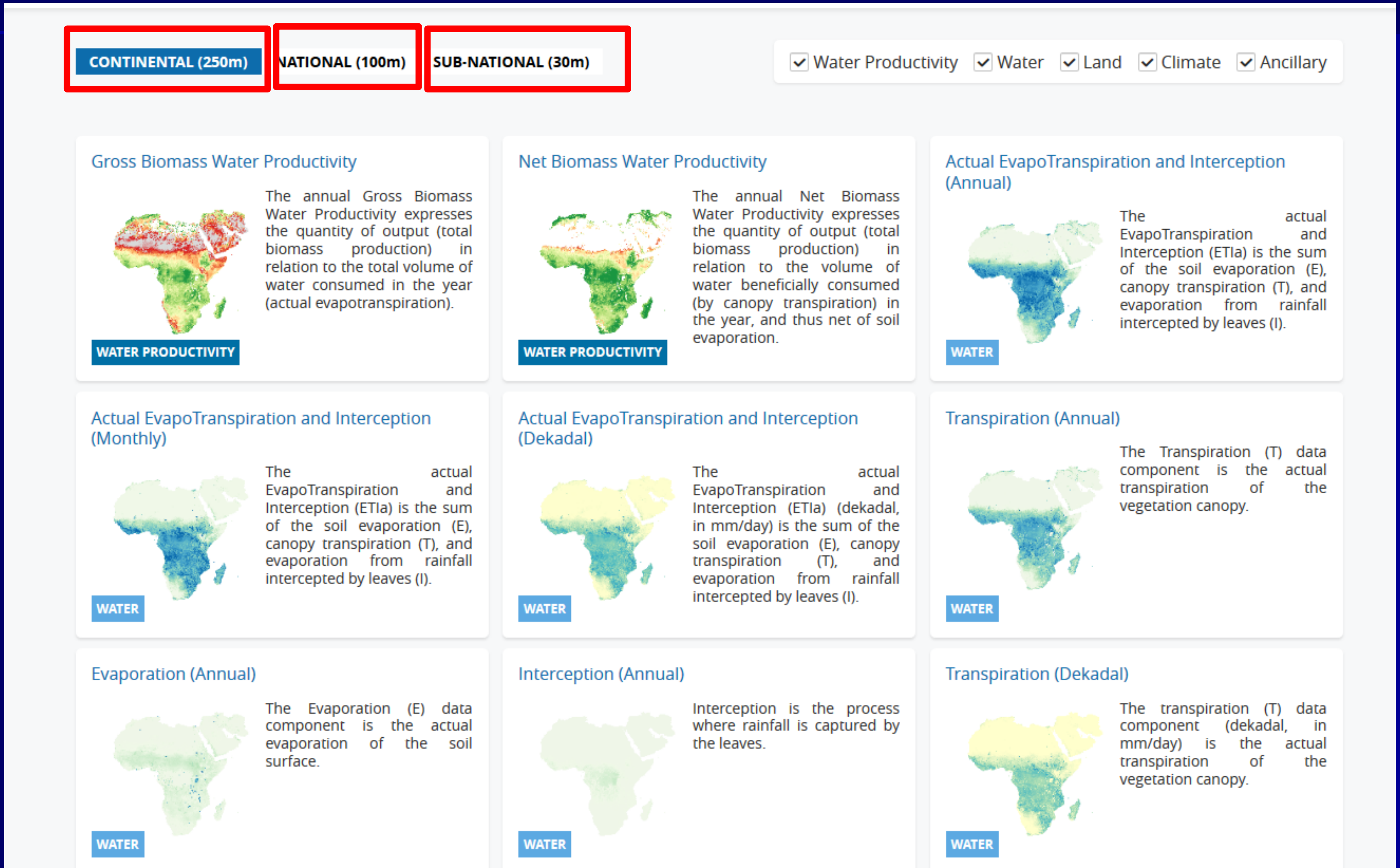
WaPOR database
https://wapor.apps.fao.org

- The WaPOR data portal, developed by the Food and Agricultural Organisation of the United Nations (FAO) is a tool that uses satellite data to monitor agricultural land- and water productivity throughout Africa and the Near East.

WaPOR database

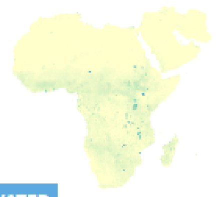


WaPOR database



WaPOR database

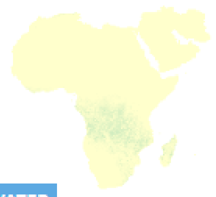
Evaporation (Dekadal)



The Evaporation (E) data component (dekadal, in mm/day) is the actual evaporation of the soil surface.

WATER

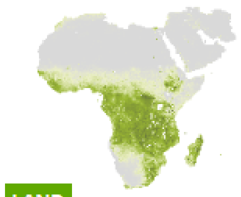
Interception (Dekadal)



The Interception (I) data component (dekadal, in mm/day) represents the evaporation of intercepted rainfall from the vegetation canopy.

WATER

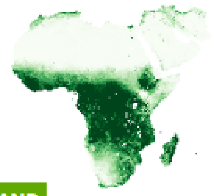
Net Primary Production



Net Primary Production (NPP) is a fundamental characteristic of an ecosystem, expressing the conversion of carbon dioxide into biomass driven by photosynthesis.

LAND

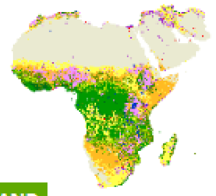
Total Biomass Production (Annual)



The annual Total Biomass Production expresses the total amount of dry matter produced over the year.

LAND

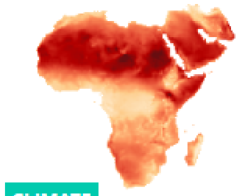
Land Cover Classification



This land cover dataset at continental scale is based on the Copernicus Global Land cover map.

LAND

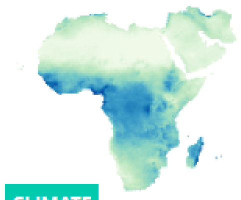
Reference EvapoTranspiration (Annual)



Reference EvapoTranspiration (RET) is defined as the evapotranspiration from a hypothetical reference crop and it simulates the behaviour of a well-watered grass surface.

CLIMATE

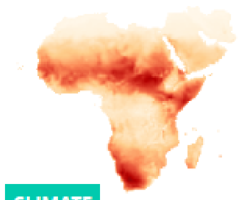
Precipitation (Annual)



Precipitation data is delivered on a daily basis. The source of this dataset is CHIRPS (Climate Hazards Group InfraRed Precipitation with Station) quasi-global rainfall dataset, starting from 1981 up to near present.

CLIMATE

Reference EvapoTranspiration (Monthly)



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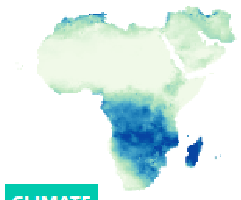
CLIMATE

Precipitation (Monthly)



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CLIMATE

WaPOR database

Reference EvapoTranspiration (Dekadal)

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CLIMATE

Precipitation (Dekadal)

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CLIMATE

Reference EvapoTranspiration (Daily)

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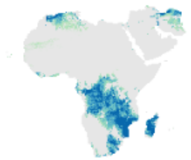
CLIMATE

Precipitation (Daily)



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CLIMATE

Quality of Normalized Difference Vegetation Index (Dekadal)

The layer gives an indication of the quality of the NDVI input data.

ANCILLARY

Quality Land Surface Temperature (Dekadal)

The quality layer gives an indication on the quality of the Land Surface Temperature (LST) input data.

ANCILLARY

Quality of Normalized Difference Vegetation Index (Long Term)

The long-term NDVI quality layer is produced as a summary of the quality for the entire time period (2009 to date).

ANCILLARY

Calculation of Actual EvapoTranspiration

- Actual EvapoTranspiration, is derived using the Penman-Monteith equation, The following data is used to calculate ET: daily incoming solar radiation and weather data (temperature, humidity, wind speed).
- The calculation of the ETIa is based on the ETLook model described in Bastiaanssen et al. (2012

Calculation of Actual EvapoTranspiration

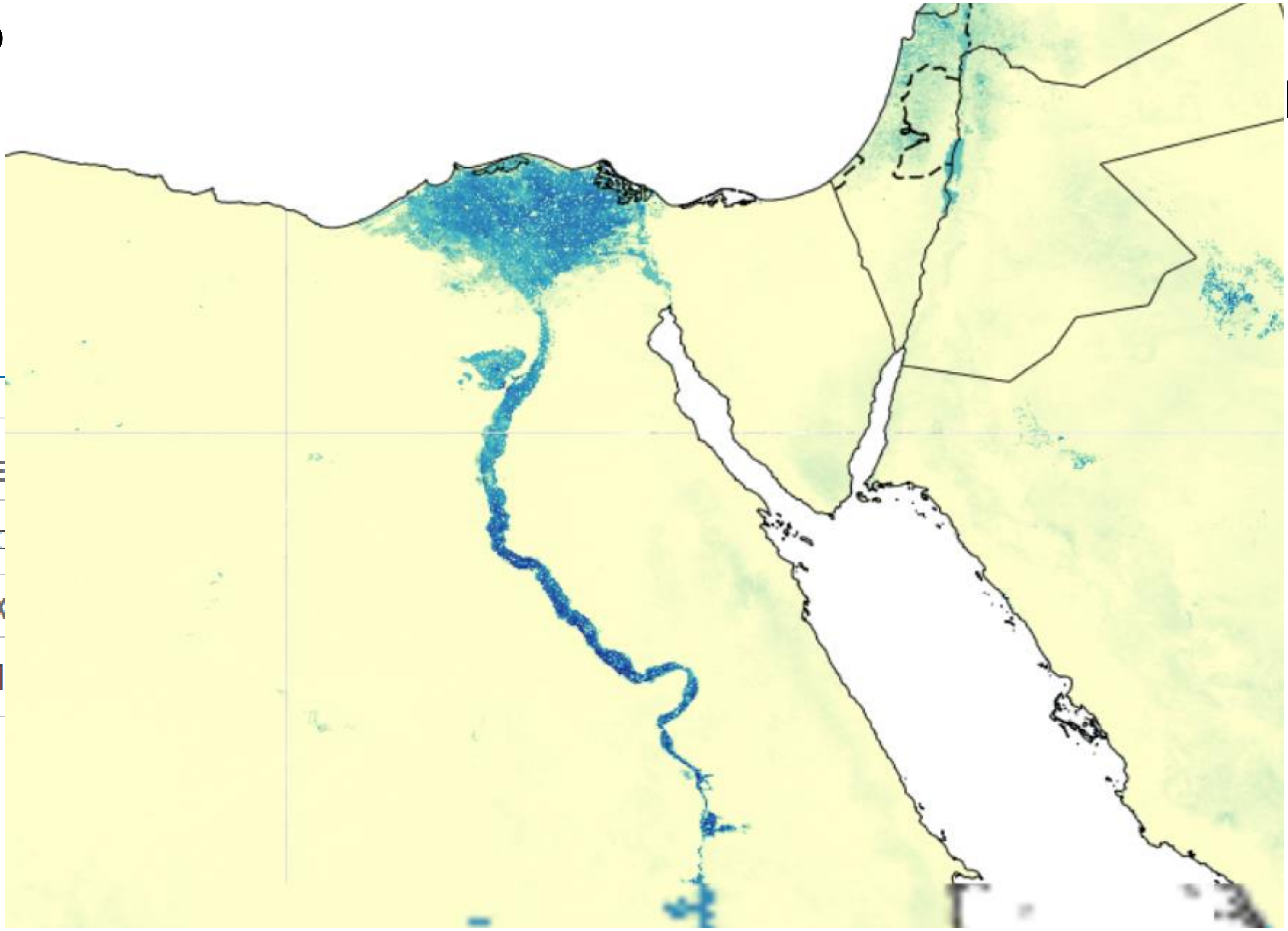
- ETLook model uses moderate resolution visible and near infrared data from the MODIS sensor for determining surface albedo and vegetation cover. Routine meteorological measurements (wind speed, air temperature and relative humidity) at a number of stations within the area are used to infer the current meteorological conditions

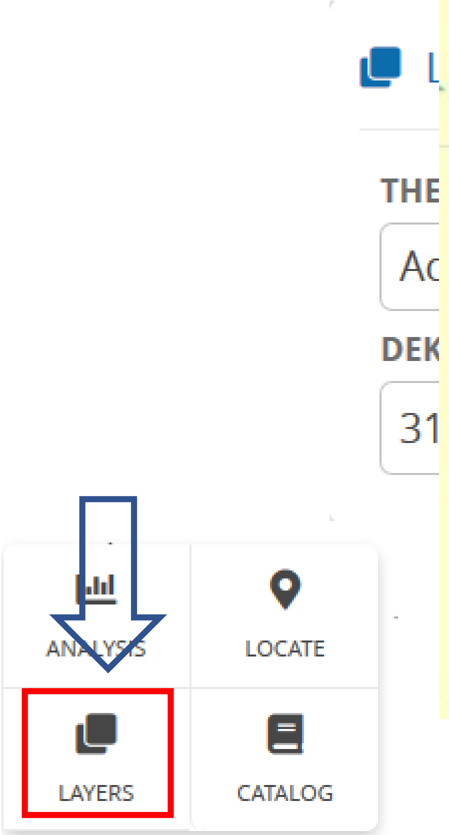
Example

- Determine actual evapotranspiration in Kafr El Sheikh at Nile Delta –Egypt
- Lat : 31.3275
- Lon : 30.9224

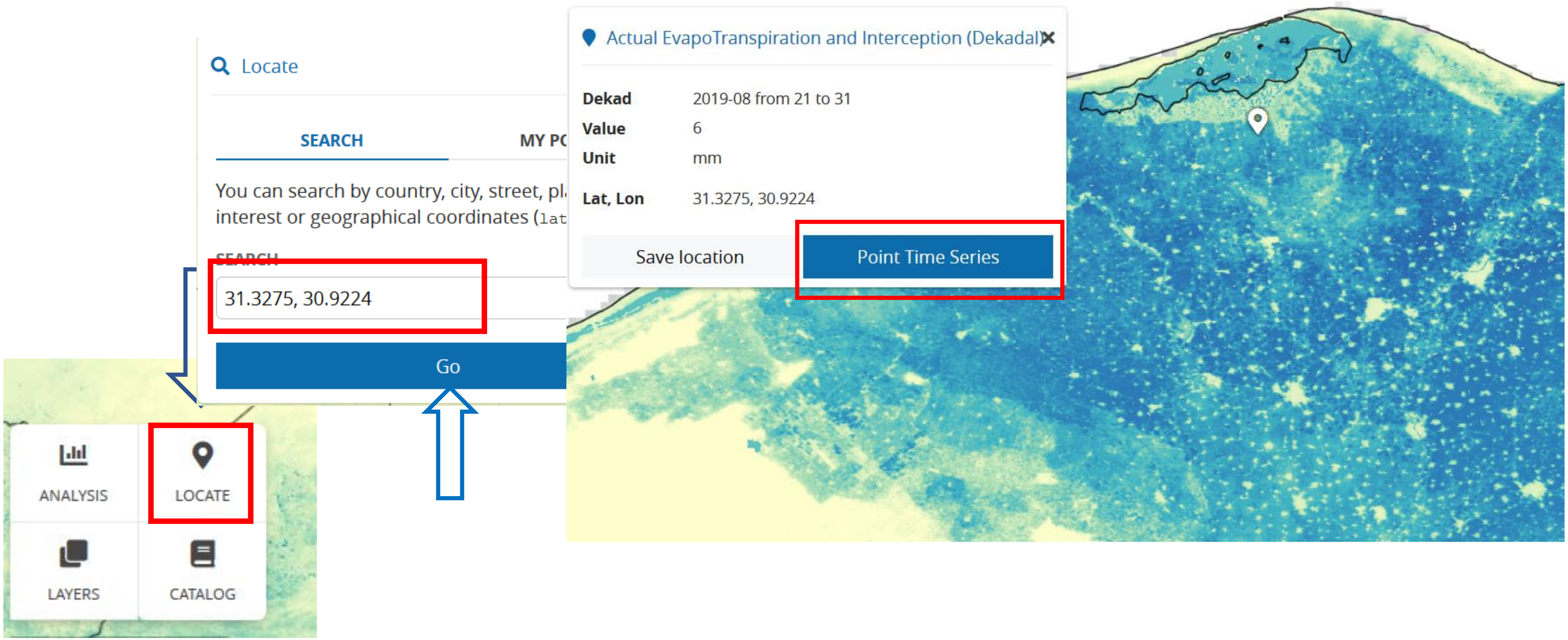
1: Click the Layers tool and select from Level I (250 m) data the layer Actual EvapoTransp

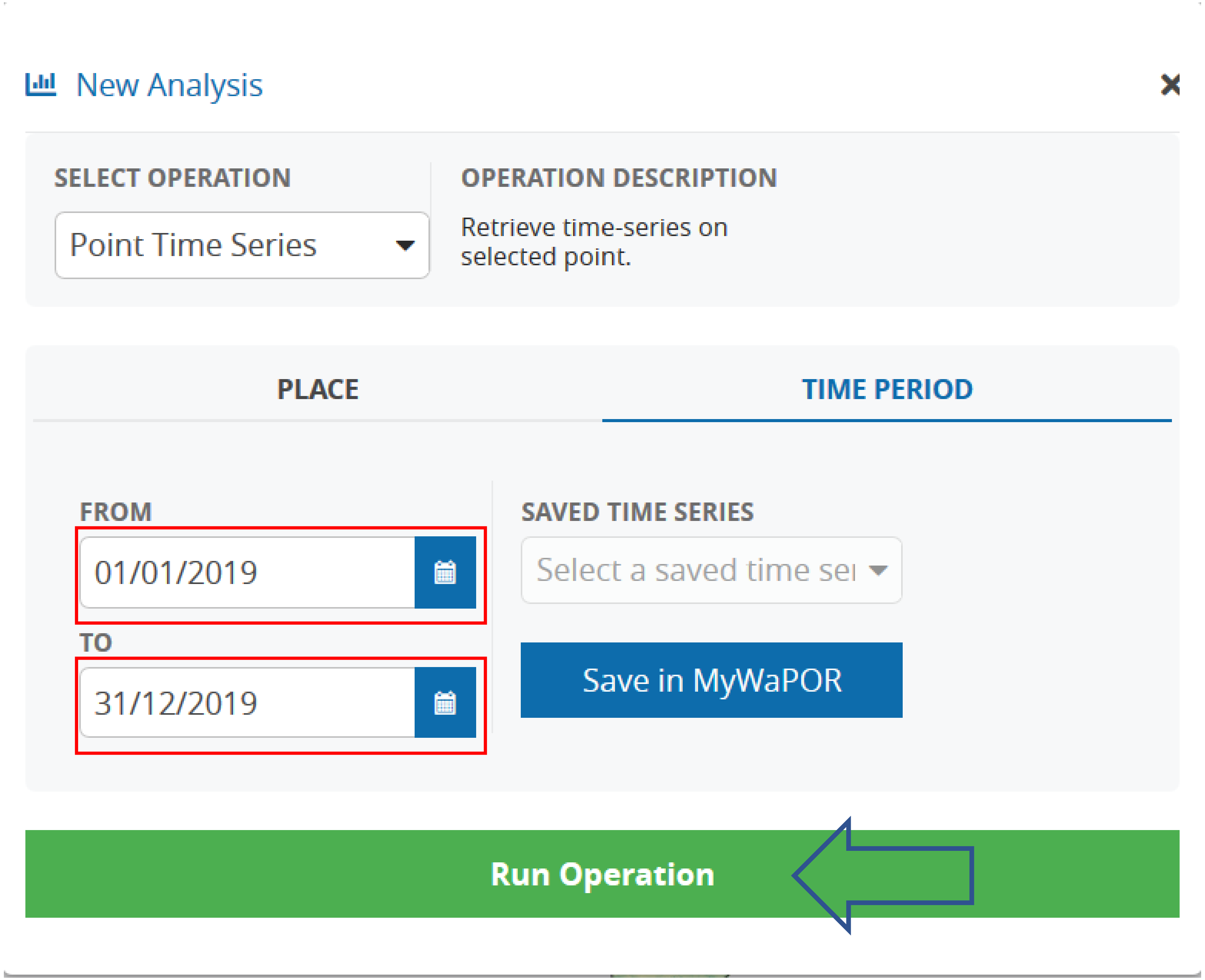
Change Laye l)

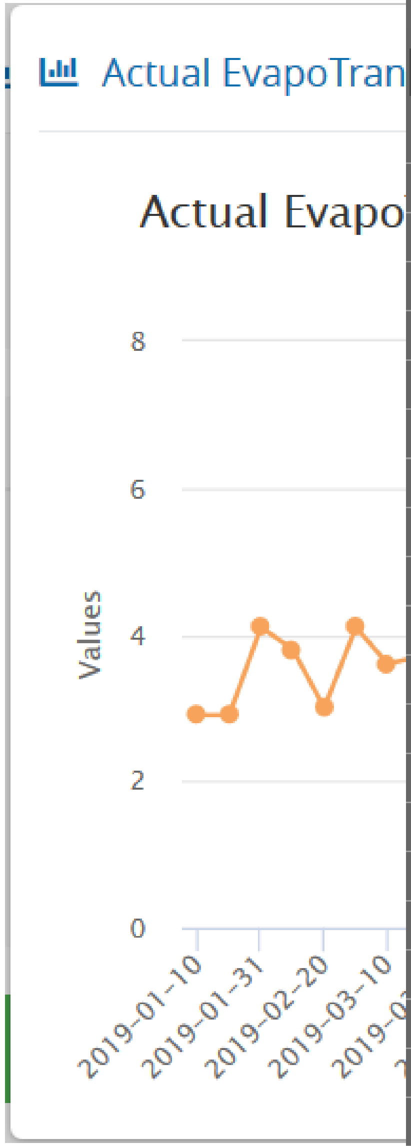


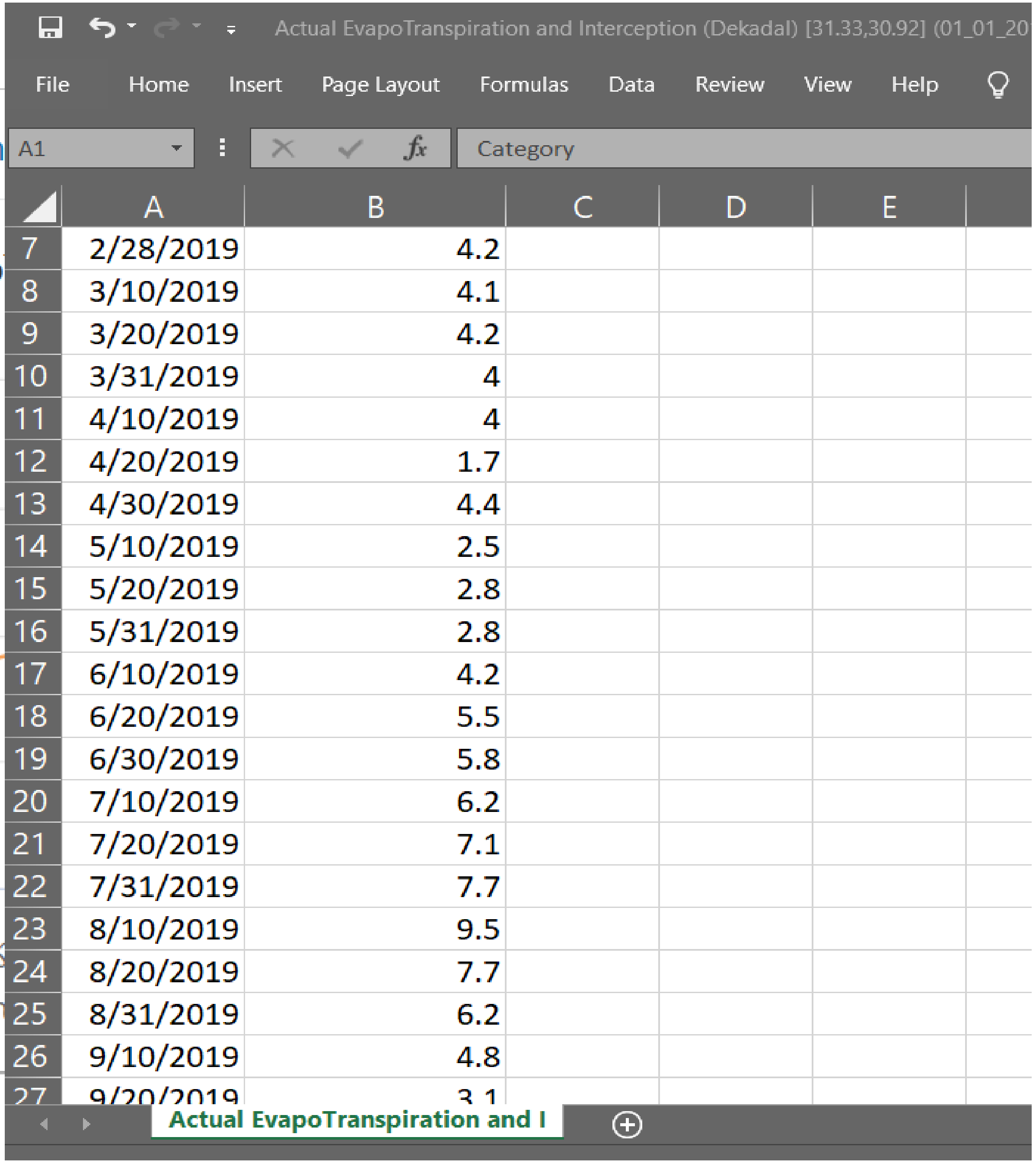


2 - Use the locate tool to navigate to the Kafr El Sheikh **area enter POINT OF INTREST: at Kafr Esahikh lat :** 31.3275, lon: 30.9224)




New Analysis
SELECT OPERATION
Point Time Series
OPERATION DESCRIPTION
Retrieve time-series on selected point.
PLACE
TIME PERIOD
FROM
01/01/2019
TO
31/12/2019
SAVED TIME SERIES
Select a saved time sei
Save in MyWaPOR
Run Operation

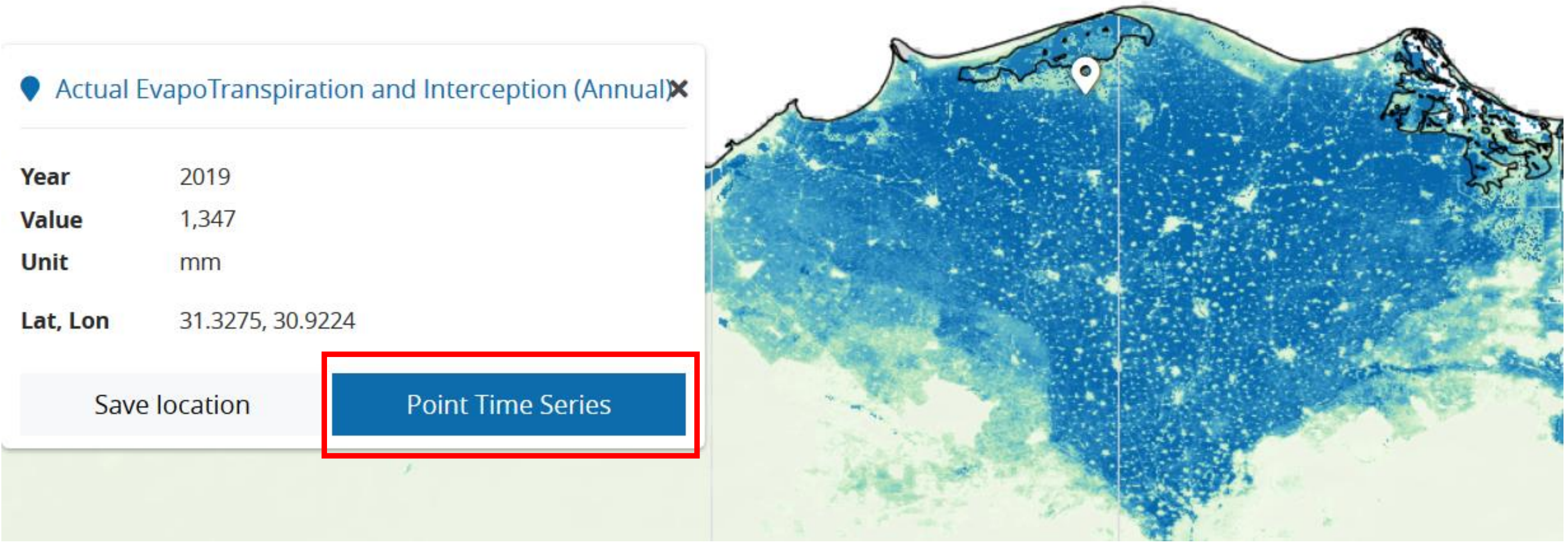


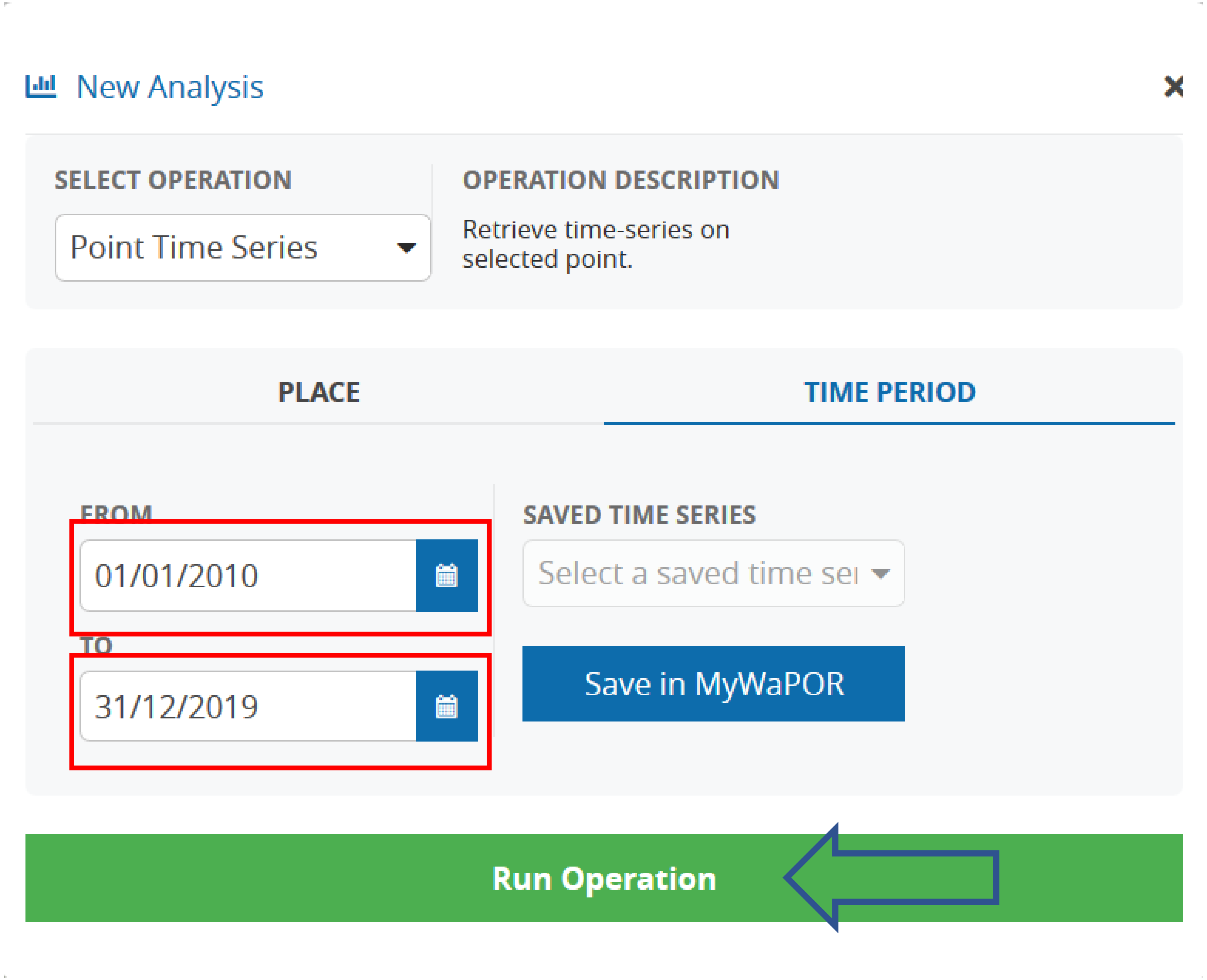


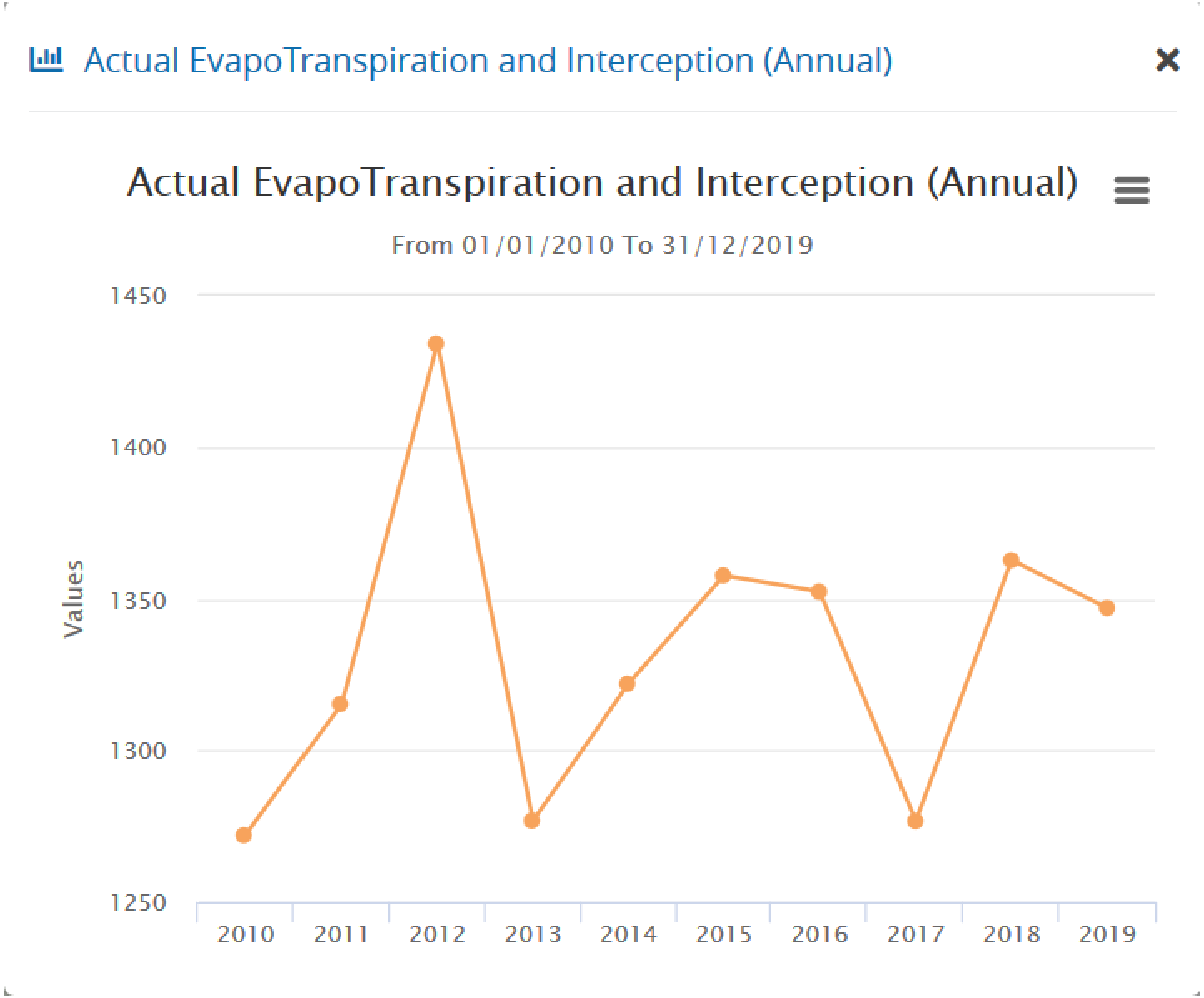
	A	B	C	D	E
7	2/28/2019	4.2			
8	3/10/2019	4.1			
9	3/20/2019	4.2			
10	3/31/2019	4			
11	4/10/2019	4			
12	4/20/2019	1.7			
13	4/30/2019	4.4			
14	5/10/2019	2.5			
15	5/20/2019	2.8			
16	5/31/2019	2.8			
17	6/10/2019	4.2			
18	6/20/2019	5.5			
19	6/30/2019	5.8			
20	7/10/2019	6.2			
21	7/20/2019	7.1			
22	7/31/2019	7.7			
23	8/10/2019	9.5			
24	8/20/2019	7.7			
25	8/31/2019	6.2			
26	9/10/2019	4.8			
27	9/20/2019	3.1			

Estimating Annual Actual EvapoTranspiration

1. Choose layer: Actual Evapo Transpiration (Annual) as before.
2. Choose Point of interest (Kafr Eshakh: 31.3275, 30.9224).

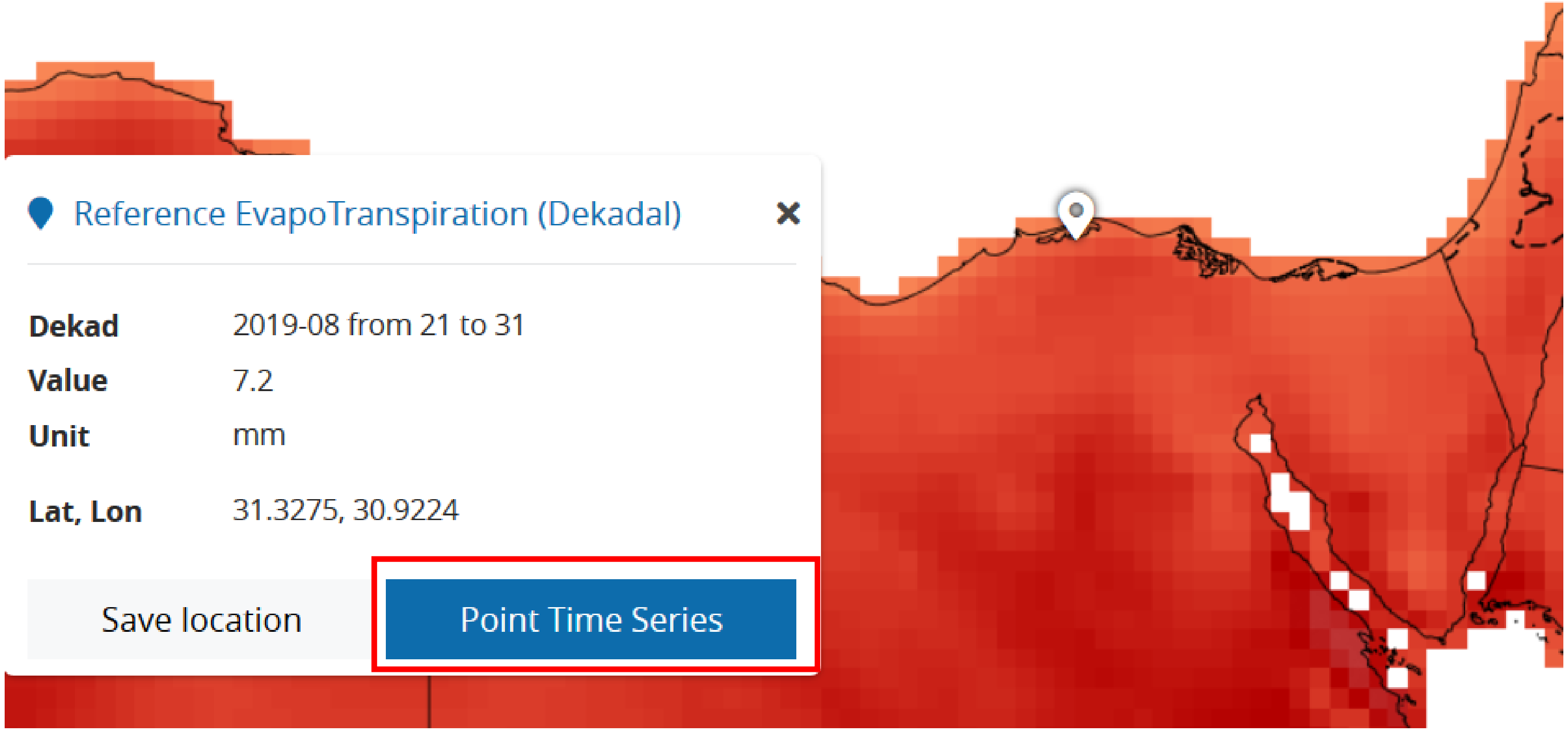


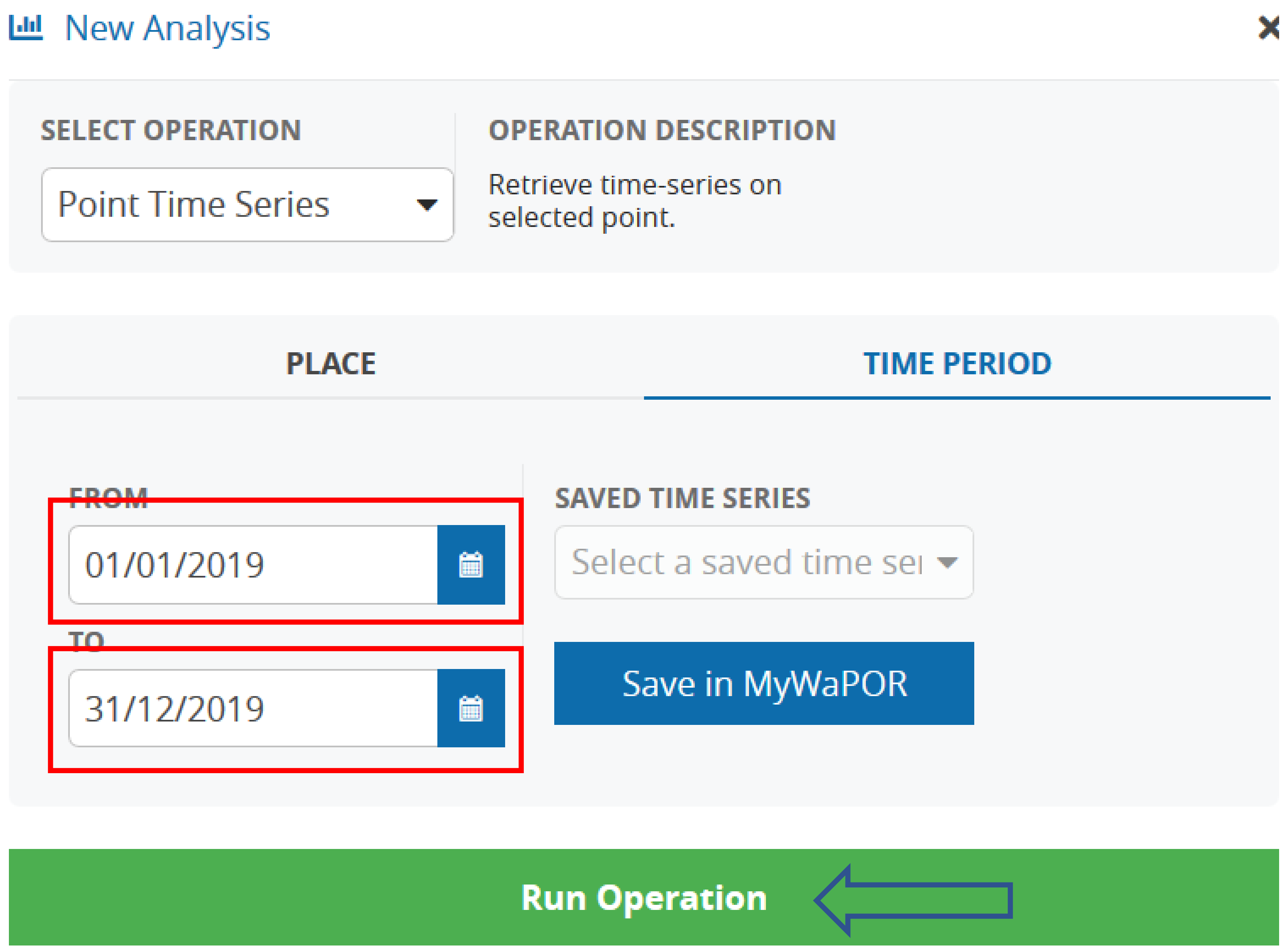

New Analysis
SELECT OPERATION
Point Time Series
OPERATION DESCRIPTION
Retrieve time-series on selected point.
PLACE
TIME PERIOD
FROM
01/01/2010
TO
31/12/2019
SAVED TIME SERIES
Select a saved time ser
Save in MyWaPOR
Run Operation

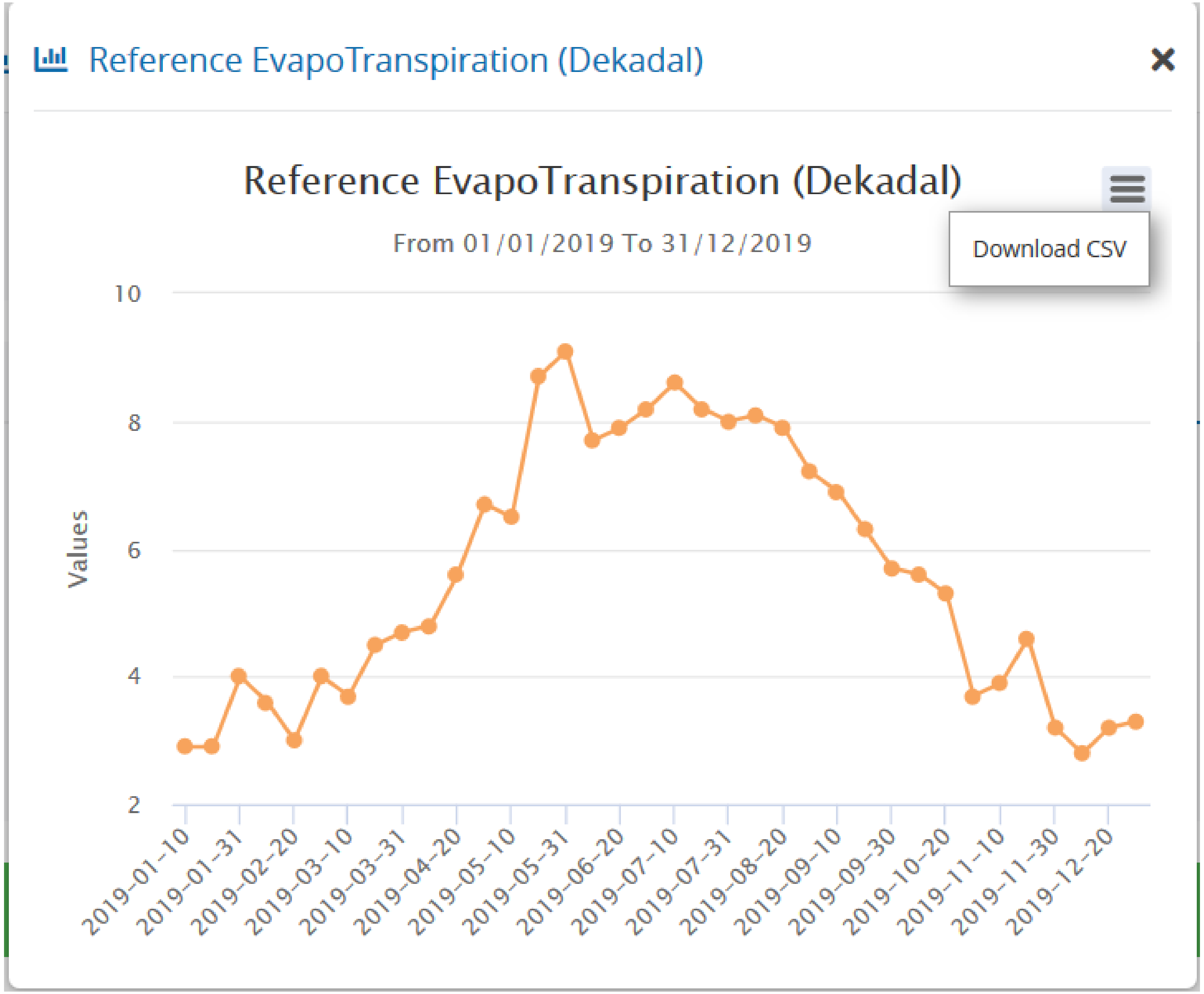

Actual EvapoTranspiration and Interception (Annual)
Actual EvapoTranspiration and Interception (Annual)
From 01/01/2010 To 31/12/2019
Values
1450
1400
1350
1300
1250
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Estimating Dekadal Reference EvapoTranspiration

1. Choose layer: Reference Evapo Transpiration (Dekadal) as before.
2. Choose Point of interest (Kafr Eshakh: 31.3275, 30.9224).
3. Hit poit time series.

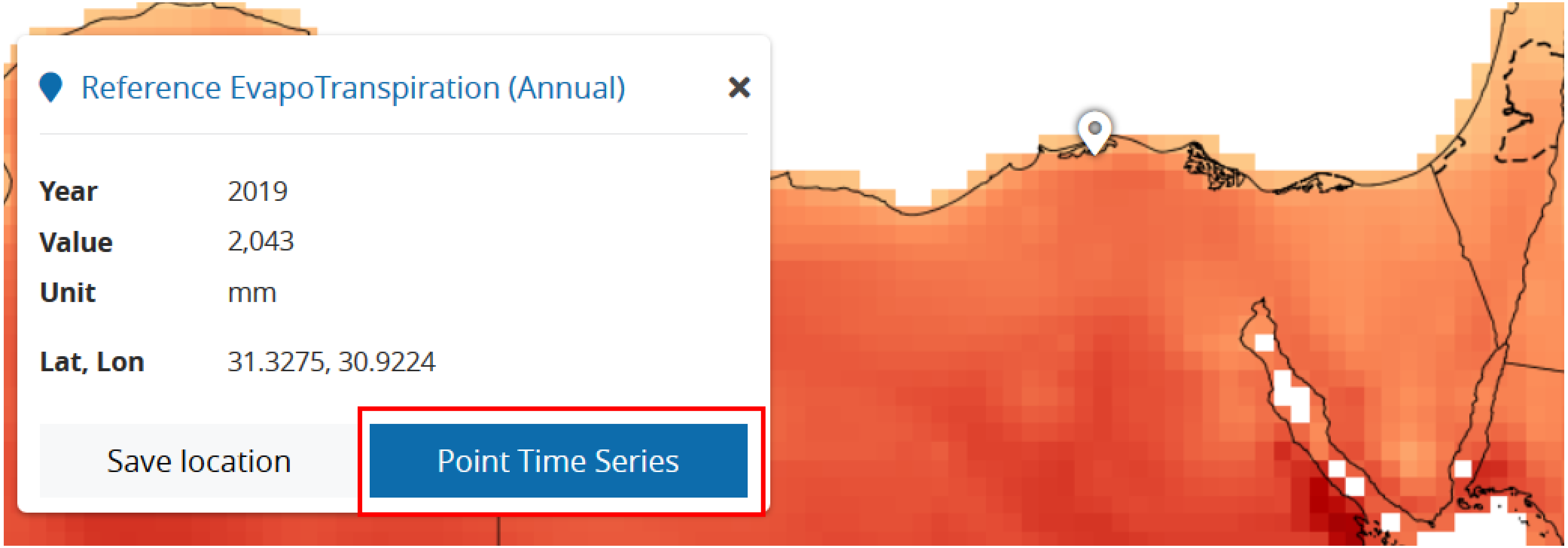


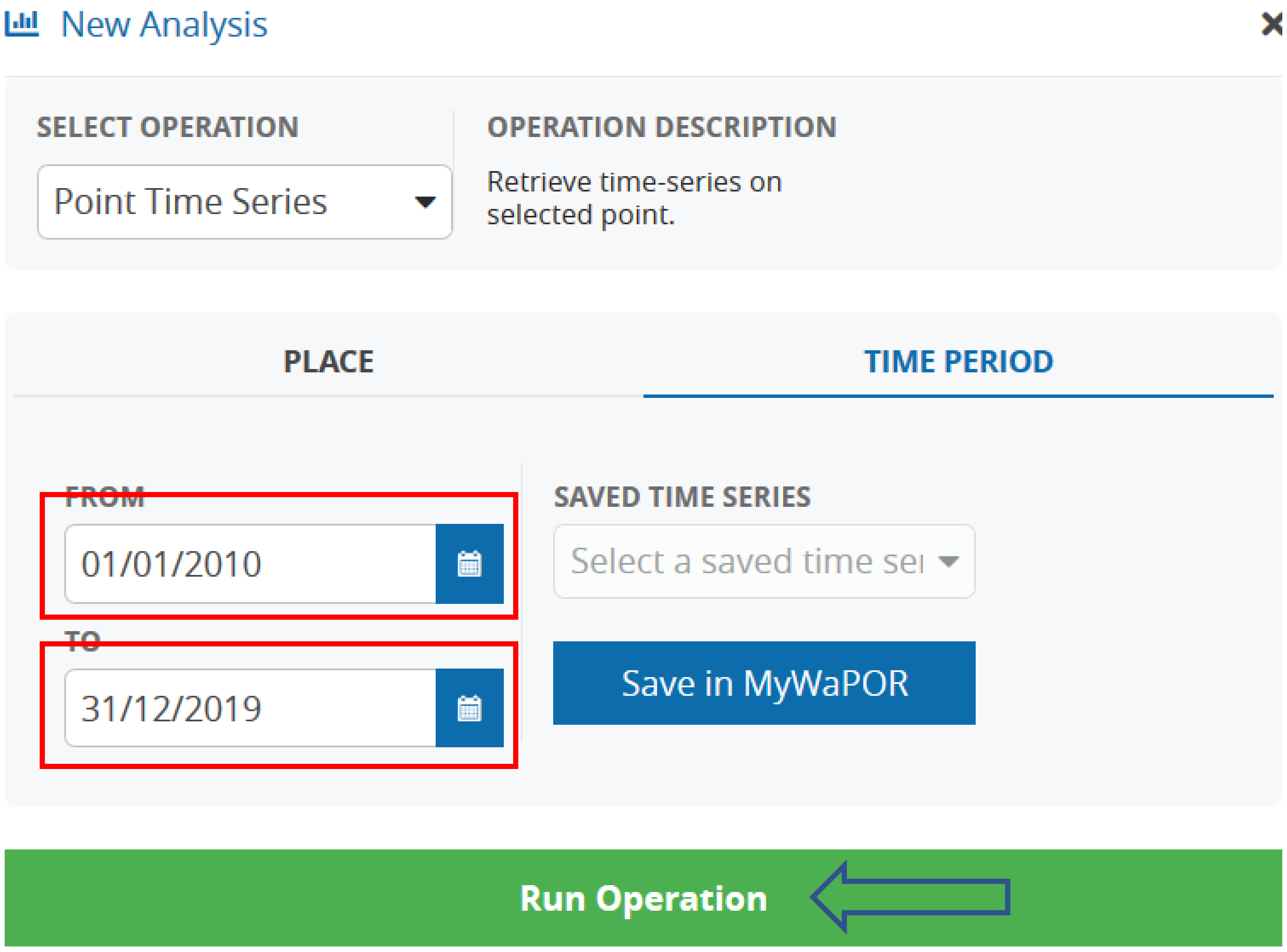

New Analysis
SELECT OPERATION
Point Time Series
OPERATION DESCRIPTION
Retrieve time-series on selected point.
PLACE
TIME PERIOD
FROM
01/01/2019
TO
31/12/2019
SAVED TIME SERIES
Select a saved time sei
Save in MyWaPOR
Run Operation


Reference EvapoTranspiration (Dekadal)
Reference EvapoTranspiration (Dekadal)
From 01/01/2019 To 31/12/2019
Download CSV
Values
10
8
6
4
2
2019-01-10
2019-01-31
2019-02-20
2019-03-10
2019-03-31
2019-04-20
2019-05-10
2019-05-31
2019-06-20
2019-07-10
2019-07-31
2019-08-20
2019-09-10
2019-09-30
2019-10-20
2019-11-10
2019-11-30
2019-12-20

Estimating annual Reference EvapoTranspiration

1. Choose layer: Reference Evapo Transpiration (Annual) as before.
2. Choose Point of interest (Kafr Eshakh: 31.3275, 30.9224).
3. Hit point time series.




New Analysis
SELECT OPERATION
Point Time Series
OPERATION DESCRIPTION
Retrieve time-series on selected point.
PLACE
TIME PERIOD
FROM
01/01/2010
TO
31/12/2019
SAVED TIME SERIES
Select a saved time sei
Save in MyWaPOR
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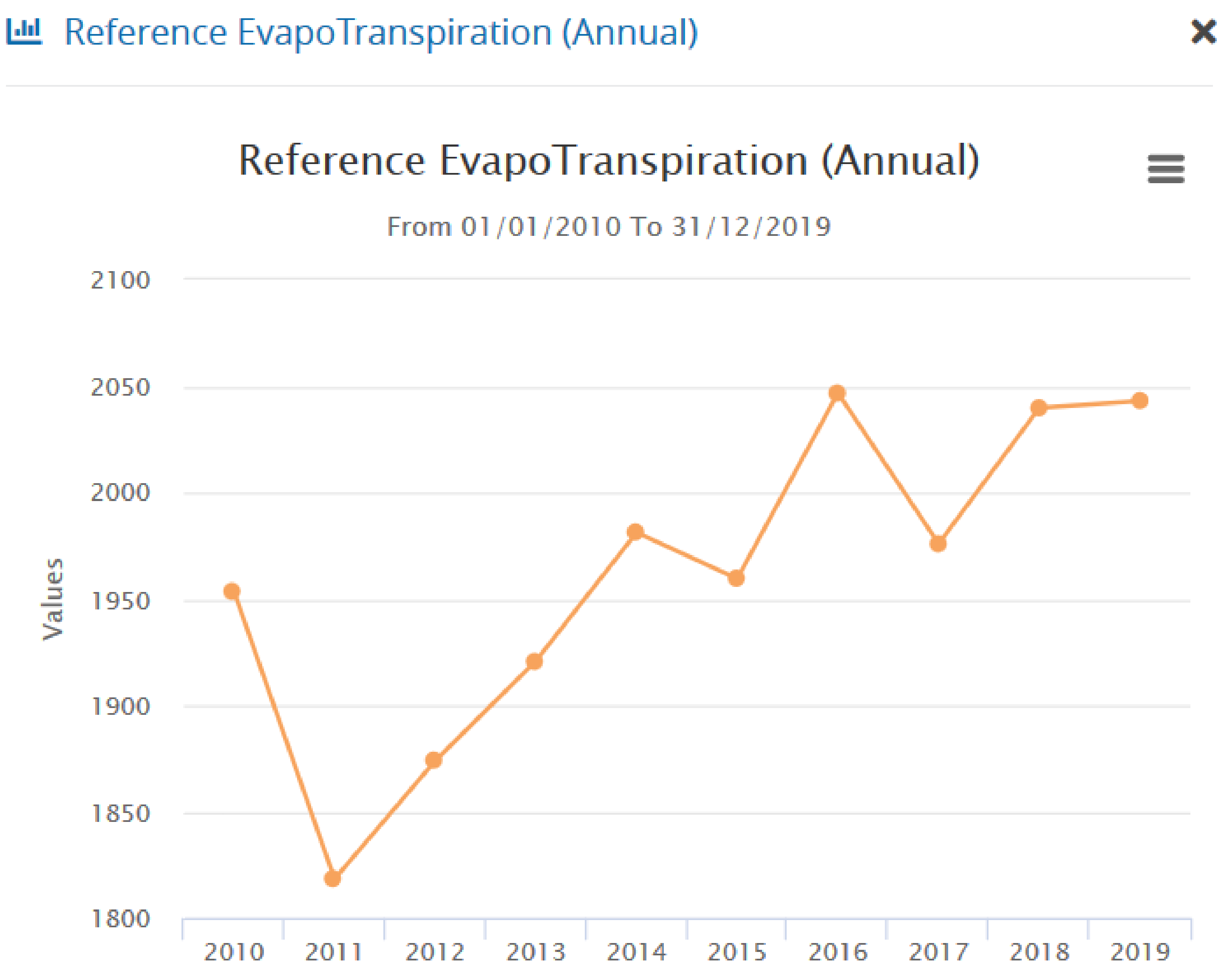
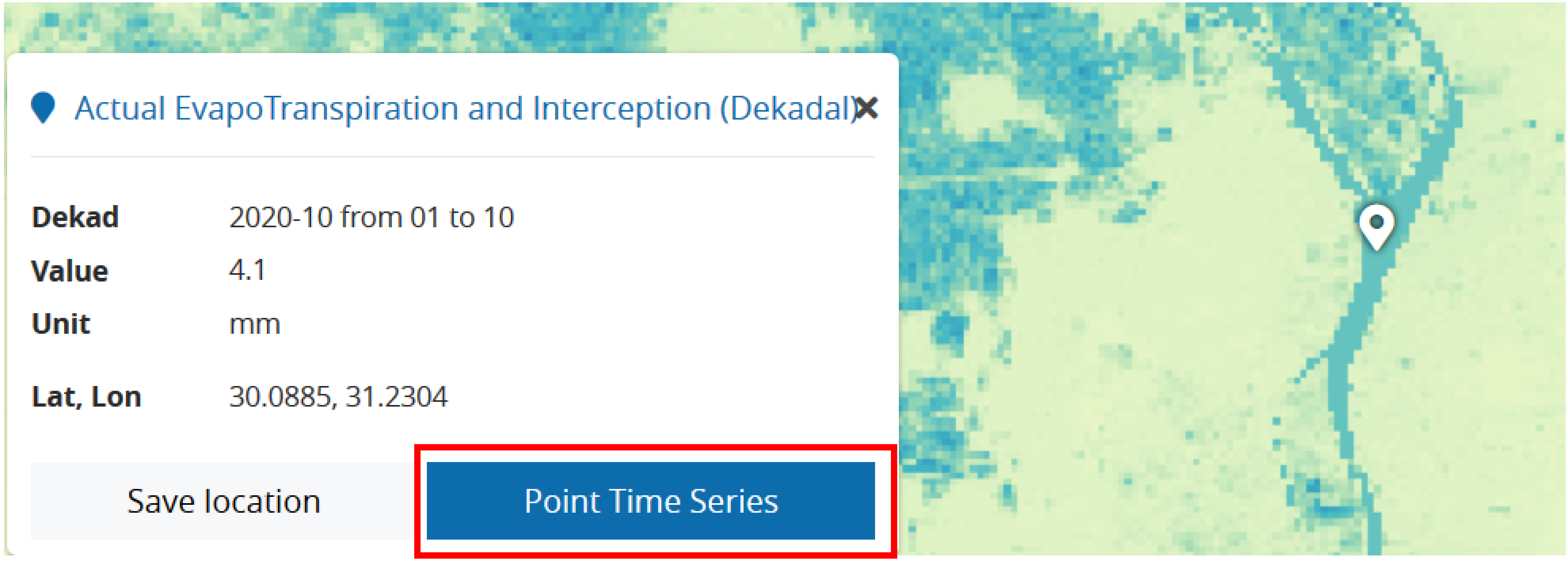
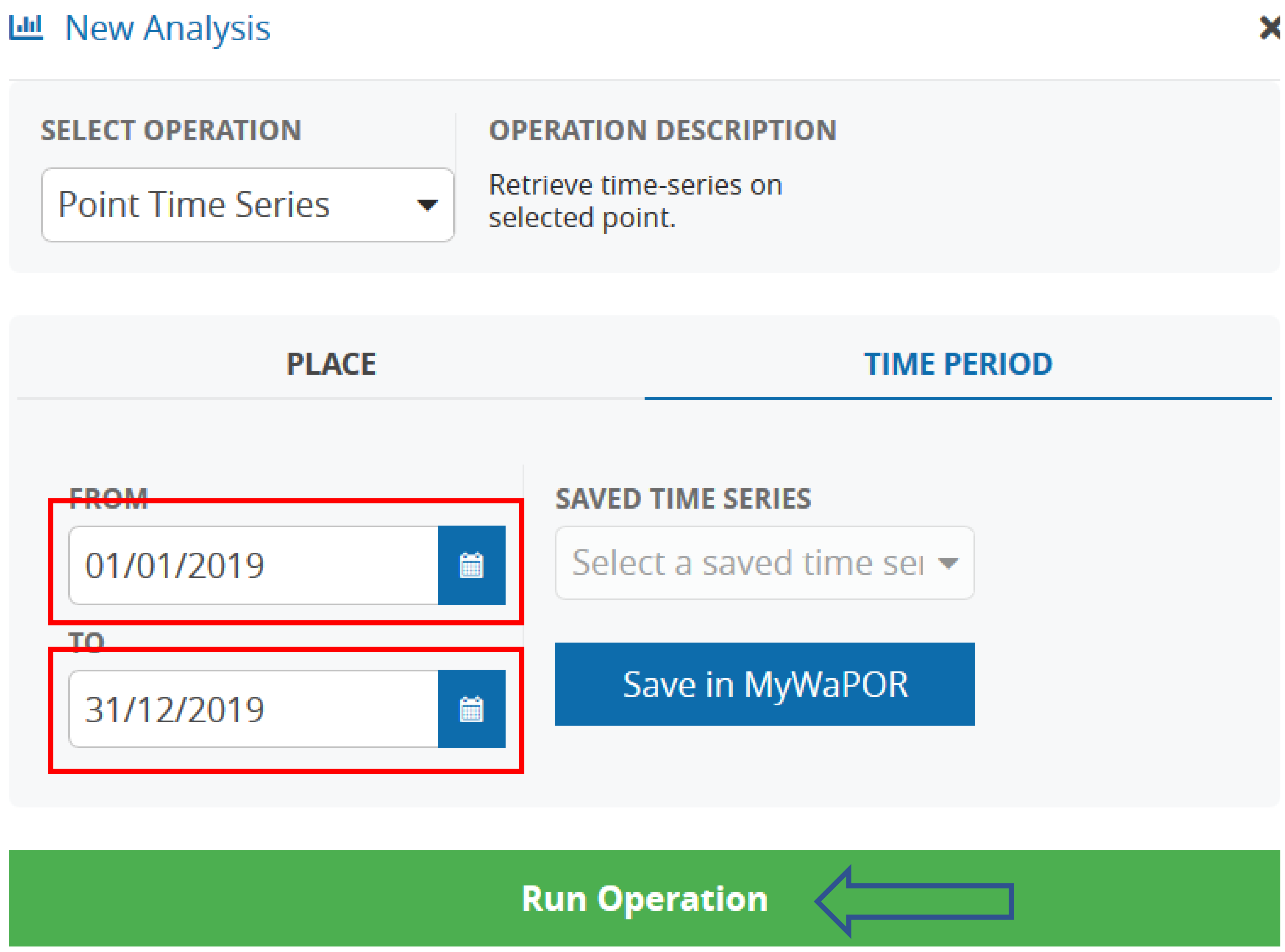

Reference EvapoTranspiration (Annual)
Reference EvapoTranspiration (Annual)
From 01/01/2010 To 31/12/2019
Values
2100
2050
2000
1950
1900
1850
1800
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Analysis of Actual Evapo Transpiration (Dekadal) for Water body e.g. Nile River

1. Choose layer: Actual Evapo Transpiration (Dekadal) as before.
2. Choose Point of interest (Any location of within Nile).
3. Hit point time series.




New Analysis
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TO
31/12/2019
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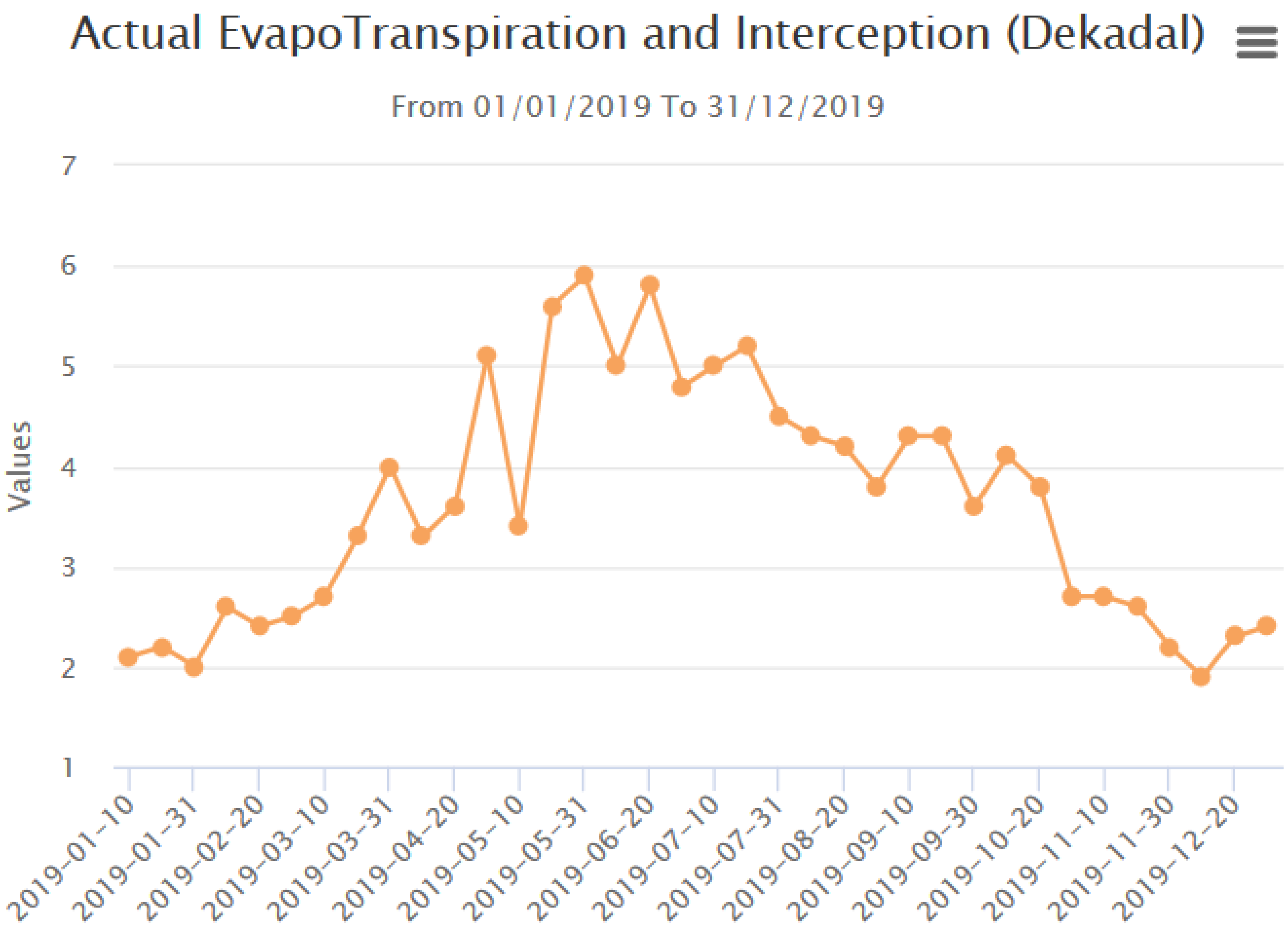
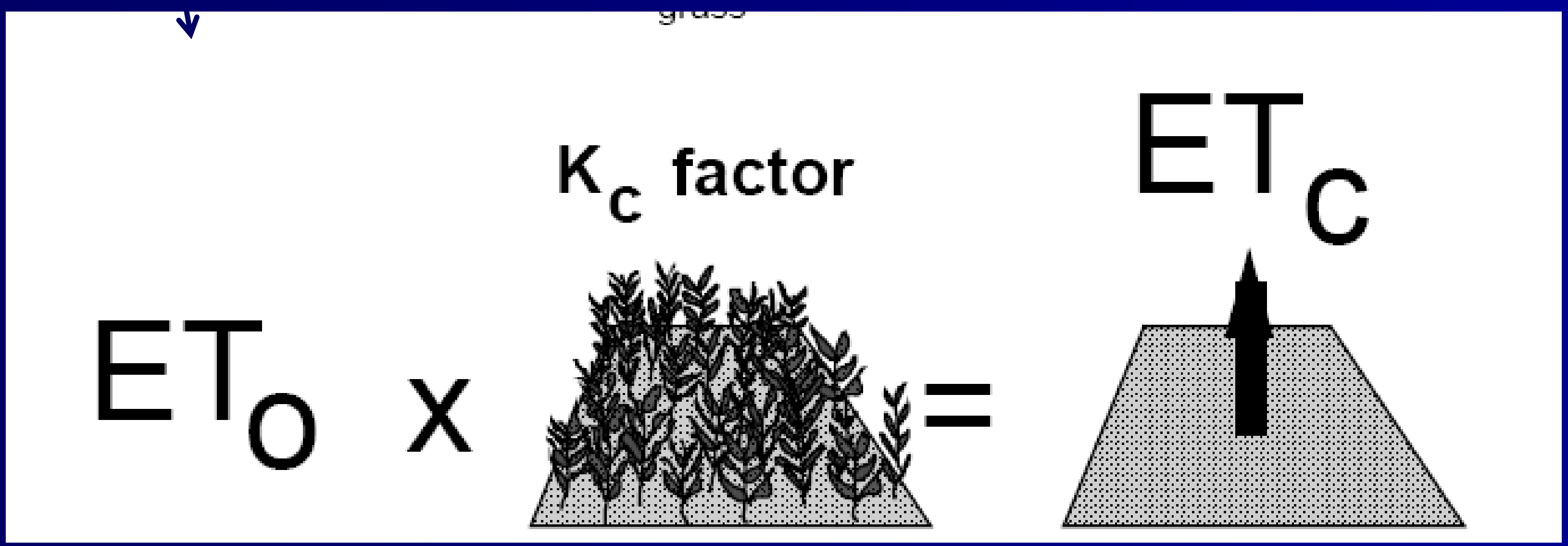
Run Operation

Actual EvapoTranspiration and Interception (Dekadal)



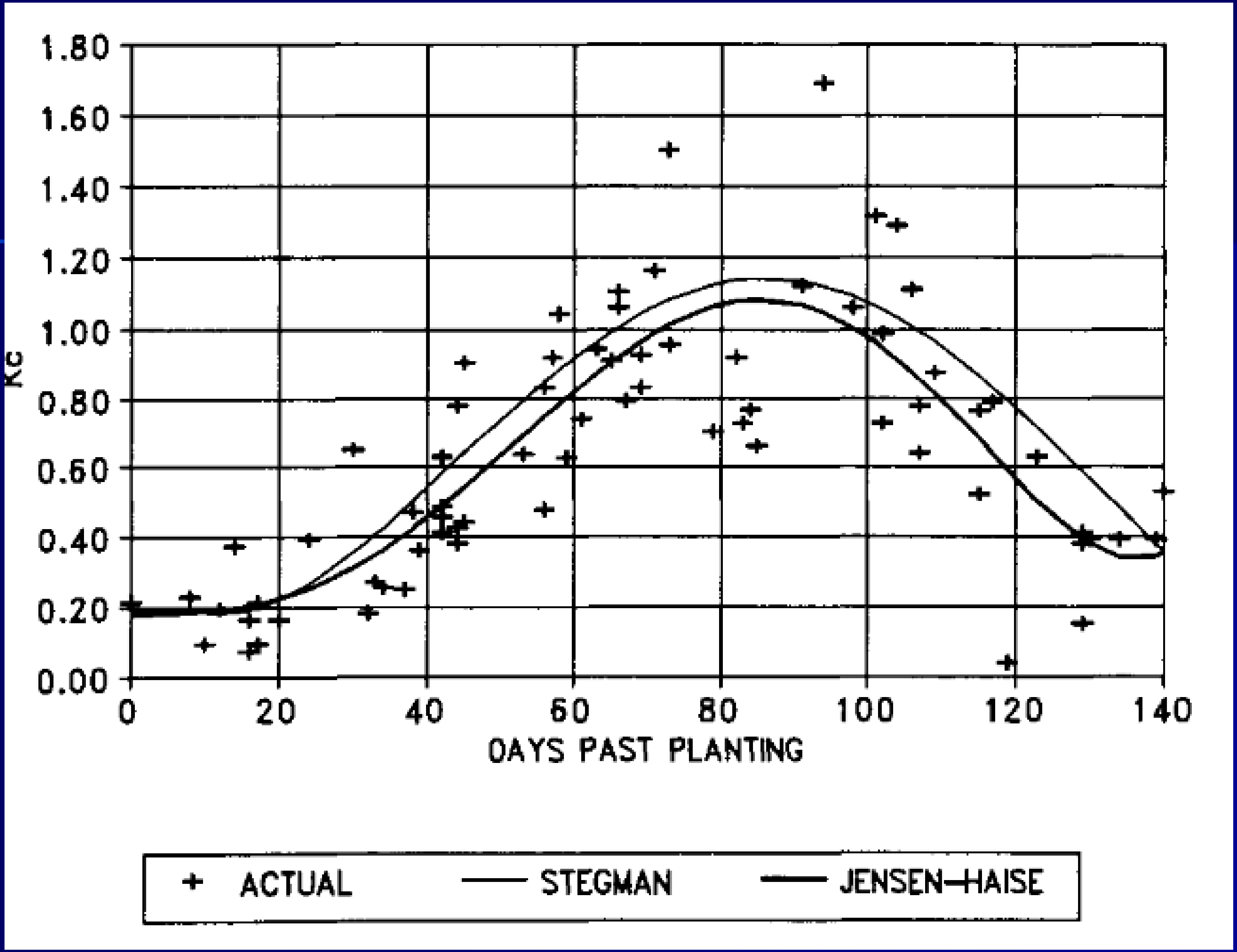
Estimating actual EvapoTranspiration using crop coefficient and Reference EvapoTranspiration

Estimating actual EvapoTranspiration using crop coefficient and Reference EvapoTranspiration

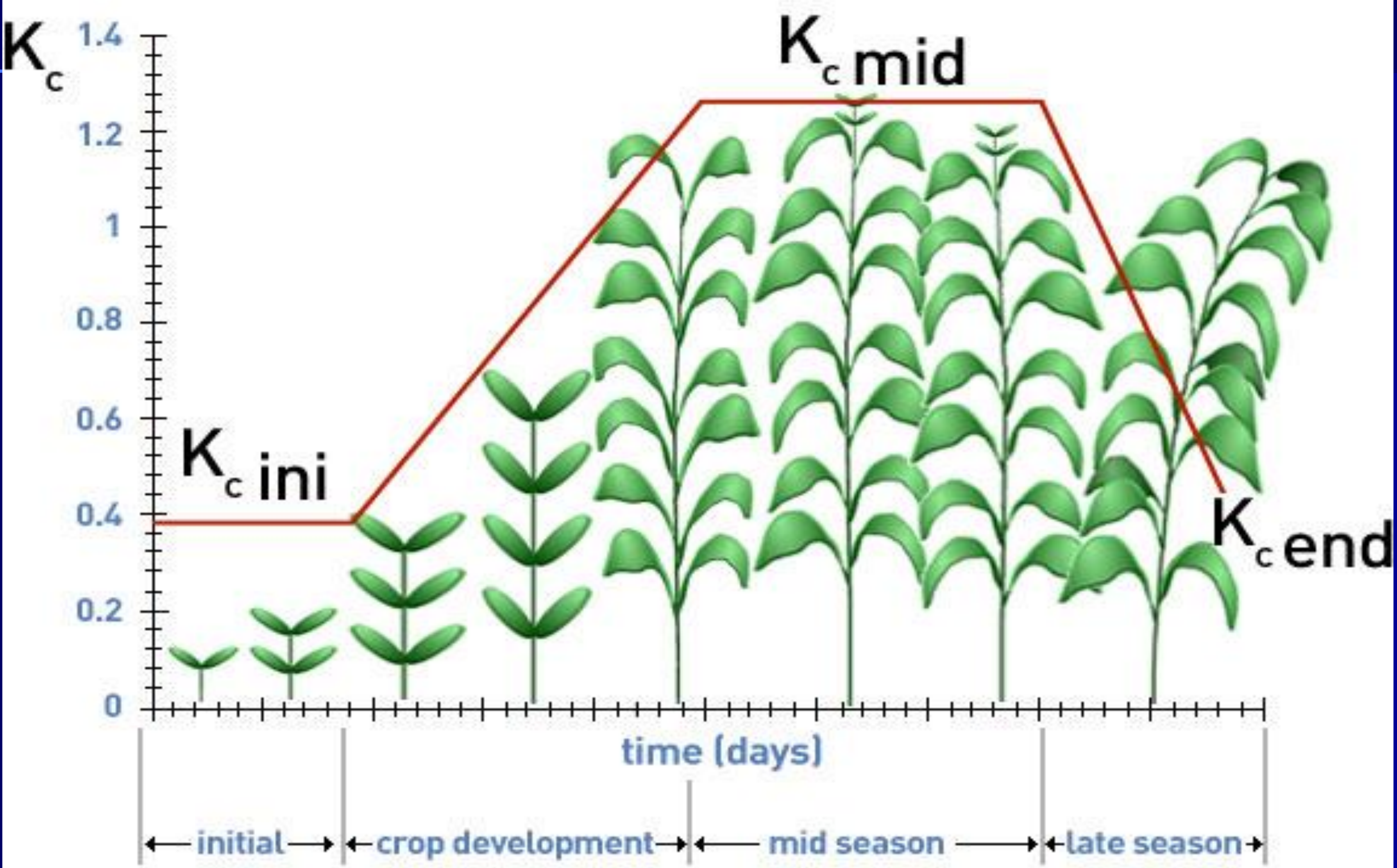


crop coefficient

$Kc = ETc/ETo$


1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Kc
0
20
40
60
80
100
120
140
DAYS PAST PLANTING
ACTUAL
STEGMAN
JENSEN–HAISE

Crop growth stages



Initial stage

- The initial stage runs from planting date to approximately 10% ground cover. The length of the initial period is highly dependent on the crop, the crop variety, the planting date and the climate.
- During the initial period, the leaf area is small, and evapotranspiration is predominately in the form of soil evaporation. Therefore, the Kc during the initial period (Kc ini) is large when the soil is wet from irrigation and rainfall and is low when the soil surface is dry

Crop development stage

- The crop development stage runs from 10% ground cover to effective full cover. Effective full cover for many crops occurs at the initiation of flowering.

Mid-season stage

- The mid-season stage runs from effective full cover to the start of maturity.
- The start of maturity is often indicated by the beginning of the ageing, yellowing or senescence of leaves, leaf drop, or the browning of fruit to the degree that the crop evapotranspiration is reduced relative to the reference ETo.

Late season stage

- The late season stage runs from the start of maturity to harvest or full senescence.

Lengths of crop development stages

TABLE 11
Lengths of crop development stages* for various planting periods and climatic regions (days)

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
a. Small Vegetables							
Broccoli	35	45	40	15	135	Sept	Calif. Desert, USA
Cabbage	40	60	50	15	165	Sept	Calif. Desert, USA
Carrots	20	30	50/30	20	100	Oct/Jan	Arid climate
	30	40	60	20	150	Feb/Mar	Mediterranean
	30	50	90	30	200	Oct	Calif. Desert, USA
Cauliflower	35	50	40	15	140	Sept	Calif. Desert, USA
Celery	25	40	95	20	180	Oct	(Semi)Arid
	25	40	45	15	125	April	Mediterranean
	30	55	105	20	210	Jan	(Semi)Arid
Crucifers[1]	20	30	20	10	80	April	Mediterranean
	25	35	25	10	95	February	Mediterranean
	30	35	90	40	195	Oct/Nov	Mediterranean
Lettuce	20	30	15	10	75	April	Mediterranean
	30	40	25	10	105	Nov/Jan	Mediterranean
	25	35	30	10	100	Oct/Nov	Arid Region
	35	50	45	10	140	Feb	Mediterranean
Onion (dry)	15	25	70	40	150	April	Mediterranean
	20	35	110	45	210	Oct; Jan.	Arid Region; Calif.
Onion (green)	25	30	10	5	70	April/May	Mediterranean
	20	45	20	10	95	October	Arid Region
	30	55	55	40	180	March	Calif., USA
Onion (seed)	20	45	165	45	275	Sept	Calif. Desert, USA
Spinach	20	20	15/25	5	60/70	Apr; Sep/Oct	Mediterranean
	20	30	40	10	100	November	Arid Region

Lengths of crop development stages

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	30	35	90	40	195	Oct/Nov	Mediterranean
Lettuce	20	30	15	10	75	April	Mediterranean
	30	40	25	10	105	Nov/Jan	Mediterranean
	25	35	30	10	100	Oct/Nov	Arid Region
	35	50	45	10	140	Feb	Mediterranean
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	20	35	110	45	210	Oct; Jan.	Arid Region; Calif.
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Onion (green)	25	30	10	5	70	April/May	Mediterranean
	20	45	20	10	95	October	Arid Region
	30	55	55	40	180	March	Calif., USA
Onion (seed)	20	45	165	45	275	Sept	Calif. Desert, USA
Spinach	20	20	15/25	5	60/70	Apr; Sep/Oct	Mediterranean
	20	30	40	10	100	November	Arid Region

Lengths of crop development stages

TABLE 11

Lengths of crop development stages* for various planting periods and climatic regions (days)

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
a. Small Vegetables							
Broccoli	35	45	40	15	135	Sept	Calif. Desert, USA
Cabbage	40	60	50	15	165	Sept	Calif. Desert, USA
Carrots	20	30	50/30	20	100	Oct/Jan	Arid climate
	30	40	60	20	150	Feb/Mar	Mediterranean
	30	50	90	30	200	Oct	Calif. Desert, USA
Cauliflower	35	50	40	15	140	Sept	Calif. Desert, USA
Celery	25	40	95	20	180	Oct	(Semi)Arid
	25	40	45	15	125	April	Mediterranean
	30	55	105	20	210	Jan	(Semi)Arid
Crucifers[1]	20	30	20	10	80	April	Mediterranean
	25	35	25	10	95	February	Mediterranean
	30	35	90	40	195	Oct/Nov	Mediterranean
Lettuce	20	30	15	10	75	April	Mediterranean
	30	40	25	10	105	Nov/Jan	Mediterranean
	25	35	30	10	100	Oct/Nov	Arid Region
	35	50	45	10	140	Feb	Mediterranean
Onion (dry)	15	25	70	40	150	April	Mediterranean
	20	35	110	45	210	Oct; Jan.	Arid Region; Calif.
Onion (green)	25	30	10	5	70	April/May	Mediterranean
	20	45	20	10	95	October	Arid Region
	30	55	55	40	180	March	Calif., USA
Onion (seed)	20	45	165	45	275	Sept	Calif. Desert, USA
Spinach	20	20	15/25	5	60/70	Apr; Sep/Oct	Mediterranean
	20	30	40	10	100	November	Arid Region

Lengths of crop development stages

Table 11 continued

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
Sweet melons	25	35	40	20	120	May	Mediterranean
	30	30	50	30	140	March	Calif., USA
	15	40	65	15	135	Aug	Calif. Desert, USA
	30	45	65	20	160	Dec/Jan	Arid Region
Water melons	20	30	30	30	110	April	Italy
	10	20	20	30	80	Mat/Aug	Near East (desert)
d. Roots and Tubers							
Beets, table	15	25	20	10	70	Apr/May	Mediterranean
	25	30	25	10	90	Feb/Mar	Mediterranean & Arid
Cassava: year 1	20	40	90	60	210	Rainy	Tropical regions
year 2	150	40	110	60	360	season	
Potato	25	30	30/45	30	115/130	Jan/Nov	(Semi)Arid Climate
	25	30	45	30	130	May	Continental Climate
	30	35	50	30	145	April	Europe
	45	30	70	20	165	Apr/May	Idaho, USA
	30	35	50	25	140	Dec	Calif. Desert, USA
Sweet potato	20	30	60	40	150	April	Mediterranean
	15	30	50	30	125	Rainy seas.	Tropical regions
Sugarbeet	30	45	90	15	180	March	Calif., USA
	25	30	90	10	155	June	Calif., USA
	25	65	100	65	255	Sept	Calif. Desert, USA
	50	40	50	40	180	April	Idaho, USA
	25	35	50	50	160	May	Mediterranean
	45	75	80	30	230	November	Mediterranean
	35	60	70	40	205	November	Arid Regions
e. Legumes (*Leguminosae*)							
Beans (green)	20	30	30	10	90	Feb/Mar	Calif., Mediterranean
	15	25	25	10	75	Aug/Sep	Calif., Egypt, Lebanon
Beans (dry)	20	30	40	20	110	May/June	Continental Climates
	15	25	35	20	95	June	Pakistan, Calif.
	25	25	30	20	100	June	Idaho, USA
Faba bean,	15	25	35	15	90	May	Europe
broad bean	20	30	35	15	100	Mar/Apr	Mediterranean
- dry	90	45	40	60	235	Nov	Europe
- green	90	45	40	0	175	Nov	Europe
Green gram, cowpeas	20	30	30	20	110	March	Mediterranean

Lengths of crop development stages

Table 11 continued.

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
f. Perennial Vegetables (with winter dormancy and initially bare or mulched soil)							
Artichoke	40 20	40 25	250 250	30 30	360 325	Apr (1st yr) May (2nd yr)	California (cut in May)
Asparagus	50 90	30 30	100 200	50 45	230 365	Feb Feb	Warm Winter Mediterranean
g. Fibre Crops							
Cotton	30 45 30 30	50 90 50 50	60 45 60 55	55 45 55 45	195 225 195 180	Mar-May Mar Sept April	Egypt; Pakistan; Calif. Calif. Desert, USA Yemen Texas
Flax	25 30	35 40	50 100	40 50	150 220	April October	Europe Arizona
h. Oil Crops							
Castor beans	25 20	40 40	65 50	50 25	180 135	March Nov.	(Semi)Arid Climates Indonesia
Safflower	20 25 35	35 35 55	45 55 60	25 30 40	125 145 190	April Mar Oct/Nov	California, USA High Latitudes Arid Region
Sesame	20	30	40	20	100	June	China
Sunflower	25	35	45	25	130	April/May	Medit.; California
i. Cereals							
Barley/Oats/ Wheat	15 20 15 40 40 20	25 25 30 30 60 50	50 60 65 40 60 60	30 30 40 20 40 30	120 135 150 130 200 160	November March/Apr July Apr Nov Dec	Central India 35-45 °L East Africa Calif. Desert, USA
Winter Wheat	20[2] 30	60[2] 140	70 40	30 30	180 240	December November	Calif., USA Mediterranean

Lengths of crop development stages

b. Vegetables – Solanum Family *(Solanaceae)*							
Egg plant	30 30	40 45	40 40	20 25	130\140	October May/June	Arid Region Mediterranean
Sweet peppers (bell)	25/30 30	35 40	40 110	20 30	125 210	April/June October	Europe and Medit. Arid Region
Tomato	30 35 25 35 30	40 40 40 45 40	40 50 60 70 45	25 30 30 30 30	135 155 155 180 145	January Apr/May Jan Oct/Nov April/May	Arid Region Calif., USA Calif. Desert, USA Arid Region Mediterranean
c. Vegetables - Cucumber Family *(Cucurbitaceae)*							
Cantaloupe	30 10	45 60	35 25	10 25	120 120	Jan Aug	Calif., USA Calif., USA
Cucumber	20 25	30 35	40 50	15 20	105 130	June/Aug Nov; Feb	Arid Region Arid Region
Pumpkin, Winter squash	20 25	30 35	30 35	20 25	100 120	Mar, Aug June	Mediterranean Europe
Squash, Zucchini	25 20	35 30	25 25	15 15	100 90	Apr; Dec. May/June	Medit.; Arid Reg. Medit.; Europe

Lengths of crop development stages

Table 11 continued

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
Sorghum	20 20	35 35	40 45	30 30	130 140	May/June Mar/April	USA, Pakis., Med. Arid Region
Rice	30 30	30 30	60 80	30 40	150 180	Dec; May May	Tropics; Mediterranean Tropics
j. Forages							
Alfalfa, total season[4]	10	30	var.	var.	var.		last -4°C in spring until first -4°C in fall
Alfalfa[4] 1st cutting cycle	10 10	20 30	20 25	10 10	60 75	Jan Apr (last -4° C)	Calif., USA. Idaho, USA.
Alfalfa[4], other cutting cycles	5 5	10 20	10 10	5 10	30 45	Mar Jun	Calif., USA. Idaho, USA.
Bermuda for seed	10	25	35	35	105	March	Calif. Desert, USA
Bermuda for hay (several cuttings)	10	15	75	35	135	---	Calif. Desert, USA
Grass Pasture[4]	10	20	--	--	--		7 days before last -4°C in spring until 7 days after first -4°C in fall
Sudan, 1st cutting cycle	25	25	15	10	75	Apr	Calif. Desert, USA
Sudan, other cutting cycles	3	15	12	7	37	June	Calif. Desert, USA
k. Sugar Cane							
Sugarcane, virgin	35 50 75	60 70 105	190 220 330	120 140 210	405 480 720		Low Latitudes Tropics Hawaii, USA
Sugarcane, ratoon	25 30 35	70 50 105	135 180 210	50 60 70	280 320 420		Low Latitudes Tropics Hawaii, USA
l. Tropical Fruits and Trees							
Banana, 1st yr	120	90	120	60	390	Mar	Mediterranean
Banana, 2nd yr	120	60	180	5	365	Feb	Mediterranean
Pineapple	60	120	600	10	790		Hawaii, USA
m. Grapes and Berries							
Grapes	20 20 20 30	40 50 50 60	120 75 90 40	60 60 20 80	240 205 180 210	April Mar May April	Low Latitudes Calif., USA High Latitudes Mid Latitudes (wine)
Hops	25	40	80	10	155	April	Idaho, USA
n. Fruit Trees							
Citrus	60	90	120	95	365	Jan	Mediterranean
Deciduous Orchard	20 20 30	70 70 50	90 120 130	30 60 30	210 270 240	March March March	High Latitudes Low Latitudes Calif., USA

continued...

Lengths of crop development stages

Table 11 continued

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
Olives	30	90	60	90	270[5]	March	Mediterranean
Pistachios	20	60	30	40	150	Feb	Mediterranean
Walnuts	20	10	130	30	190	April	Utah, USA
o. Wetlands - Temperate Climate							
Wetlands (Cattails, Bulrush)	10 180	30 60	80 90	20 35	140 365	May November	Utah, USA; killing frost Florida, USA
Wetlands (short veg.)	180	60	90	35	365	November	frost-free climate

crop coefficients, Kc

Crop	$K_{c\ ini}$[1]	$K_{c\ mid}$	$K_{c\ end}$	Maximum Crop Height (h) (m)
a. Small Vegetables	0.7	1.05	0.95	
Broccoli		1.05	0.95	0.3
Brussel Sprouts		1.05	0.95	0.4
Cabbage		1.05	0.95	0.4
Carrots		1.05	0.95	0.3
Cauliflower		1.05	0.95	0.4
Celery		1.05	1.00	0.6
Garlic		1.00	0.70	0.3
Lettuce		1.00	0.95	0.3
Onions - dry		1.05	0.75	0.4
- green		1.00	1.00	0.3
- seed		1.05	0.80	0.5
Spinach		1.00	0.95	0.3
Radish		0.90	0.85	0.3
b. Vegetables – Solanum Family (*Solanaceae*)	0.6	1.15	0.80	
Egg Plant		1.05	0.90	0.8
Sweet Peppers (bell)		1.05[2]	0.90	0.7
Tomato		1.15[2]	0.70-0.90	0.6
c. Vegetables – Cucumber Family (*Cucurbitaceae*)	0.5	1.00	0.80	
Cantaloupe	0.5	0.85	0.60	0.3
Cucumber – Fresh Market	0.6	1.00[2]	0.75	0.3
– Machine harvest	0.5	1.00	0.90	0.3
Pumpkin, Winter Squash		1.00	0.80	0.4
Squash, Zucchini		0.95	0.75	0.3
Sweet Melons		1.05	0.75	0.4
Watermelon	0.4	1.00	0.75	0.4
d. Roots and Tubers	0.5	1.10	0.95	
Beets, table		1.05	0.95	0.4
Cassava – year 1	0.3	0.80[3]	0.30	1.0
– year 2	0.3	1.10	0.50	1.5
Parsnip	0.5	1.05	0.95	0.4
Potato		1.15	0.75[4]	0.6
Sweet Potato		1.15	0.65	0.4
Turnip (and Rutabaga)		1.10	0.95	0.6
Sugar Beet	0.35	1.20	0.70[5]	0.5

crop coefficients, Kc

Crop	$K_{c\ ini}$ [1]	$K_{c\ mid}$	$K_{c\ end}$	Maximum Crop Height (h) (m)
a. Small Vegetables	0.7	1.05	0.95	
Broccoli		1.05	0.95	0.3
Brussel Sprouts		1.05	0.95	0.4
Cabbage		1.05	0.95	0.4
Carrots		1.05	0.95	0.3
Cauliflower		1.05	0.95	0.4
Celery		1.05	1.00	0.6
Garlic		1.00	0.70	0.3
Lettuce		1.00	0.95	0.3
Onions - dry		1.05	0.75	0.4
- green		1.00	1.00	0.3
- seed		1.05	0.80	0.5
Spinach		1.00	0.95	0.3
Radish		0.90	0.85	0.3
b. Vegetables – Solanum Family (*Solanaceae*)	0.6	1.15	0.80	
Egg Plant		1.05	0.90	0.8
Sweet Peppers (bell)		1.05[2]	0.90	0.7
Tomato		1.15[2]	0.70-0.90	0.6
c. Vegetables – Cucumber Family (*Cucurbitaceae*)	0.5	1.00	0.80	
Cantaloupe	0.5	0.85	0.60	0.3
Cucumber – Fresh Market	0.6	1.00[2]	0.75	0.3
– Machine harvest	0.5	1.00	0.90	0.3
Pumpkin, Winter Squash		1.00	0.80	0.4
Squash, Zucchini		0.95	0.75	0.3
Sweet Melons		1.05	0.75	0.4
Watermelon	0.4	1.00	0.75	0.4
d. Roots and Tubers	0.5	1.10	0.95	
Beets, table		1.05	0.95	0.4
Cassava – year 1	0.3	0.80[3]	0.30	1.0
– year 2	0.3	1.10	0.50	1.5
Parsnip	0.5	1.05	0.95	0.4
Potato		1.15	0.75[4]	0.6
Sweet Potato		1.15	0.65	0.4
Turnip (and Rutabaga)		1.10	0.95	0.6
Sugar Beet	0.35	1.20	0.70[5]	0.5

crop coefficients, Kc

Table 12 continued

Crop	$K_{c\ ini}$[1]	$K_{c\ mid}$	$K_{c\ end}$	Maximum Crop Height (h) (m)
e. Legumes (*Leguminosae*)	0.4	1.15	0.55	
Beans, green	0.5	1.05[2]	0.90	0.4
Beans, dry and Pulses	0.4	1.15[2]	0.35	0.4
Chick pea		1.00	0.35	0.4
Fababean (broad bean) – Fresh	0.5	1.15[2]	1.10	0.8
– Dry/Seed	0.5	1.15[2]	0.30	0.8
Grabanzo	0.4	1.15	0.35	0.8
Green Gram and Cowpeas		1.05	0.60-0.35[6]	0.4
Groundnut (Peanut)		1.15	0.60	0.4
Lentil		1.10	0.30	0.5
Peas – Fresh	0.5	1.15[2]	1.10	0.5
– Dry/Seed		1.15	0.30	0.5
Soybeans		1.15	0.50	0.5-1.0
f. Perennial Vegetables (with winter dormancy and initially bare or mulched soil)	0.5	1.00	0.80	
Artichokes	0.5	1.00	0.95	0.7
Asparagus	0.5	0.95[7]	0.30	0.2-0.8
Mint	0.60	1.15	1.10	0.6-0.8
Strawberries	0.40	0.85	0.75	0.2
g. Fibre Crops	0.35			
Cotton		1.15-1.20	0.70-0.50	1.2-1.5
Flax		1.10	0.25	1.2
Sisal[8]		0.4-0.7	0.4-0.7	1.5

crop coefficients, Kc

h. Oil Crops	0.35	1.15	0.35	
Castorbean (*Ricinus*)		1.15	0.55	0.3
Rapeseed, Canola		1.0-1.15[9]	0.35	0.6
Safflower		1.0-1.15[9]	0.25	0.8
Sesame		1.10	0.25	1.0
Sunflower		1.0-1.15[9]	0.35	2.0
i. Cereals	0.3	1.15	0.4	
Barley		1.15	0.25	1
Oats		1.15	0.25	1
Spring Wheat		1.15	0.25-0.4[10]	1
Winter Wheat - with frozen soils	0.4	1.15	0.25-0.4[10]	1
- with non-frozen soils	0.7	1.15	0.25-0.4[10]	
Maize, Field (grain) *(field corn)*		1.20	0.60,0.35[11]	2
Maize, Sweet *(sweet corn)*		1.15	1.05[12]	1.5
Millet		1.00	0.30	1.5
Sorghum – grain		1.00-1.10	0.55	1-2
– sweet		1.20	1.05	2-4
Rice	1.05	1.20	0.90-0.60	1

continued

crop coefficients, Kc

k. Sugar Cane	0.40	1.25	0.75	3
l. Tropical Fruits and Trees				
Banana – 1st year – 2nd year	0.50 1.00	1.10 1.20	1.00 1.10	3 4
Cacao	1.00	1.05	1.05	3
Coffee – bare ground cover – with weeds	0.90 1.05	0.95 1.10	0.95 1.10	2-3 2-3
Date Palms	0.90	0.95	0.95	8
Palm Trees	0.95	1.00	1.00	8
Pineapple[16] – bare soil – with grass cover	0.50 0.50	0.30 0.50	0.30 0.50	0.6-1.2 0.6-1.2
Rubber Trees	0.95	1.00	1.00	10
Tea – non-shaded – shaded[17]	0.95 1.10	1.00 1.15	1.00 1.15	1.5 2
m. Grapes and Berries				
Berries (bushes)	0.30	1.05	0.50	1.5
Grapes – Table or Raisin – Wine	0.30 0.30	0.85 0.70	0.45 0.45	2 1.5-2
Hops	0.3	1.05	0.85	5

Crop coefficient for the initial stage (Kc ini)

FIGURE 29
Average $K_{c\ ini}$ as related to the level of ET_o and the interval between irrigations and/or significant rain during the initial growth stage for all soil types when wetting events are light to medium (3-10 mm per event)

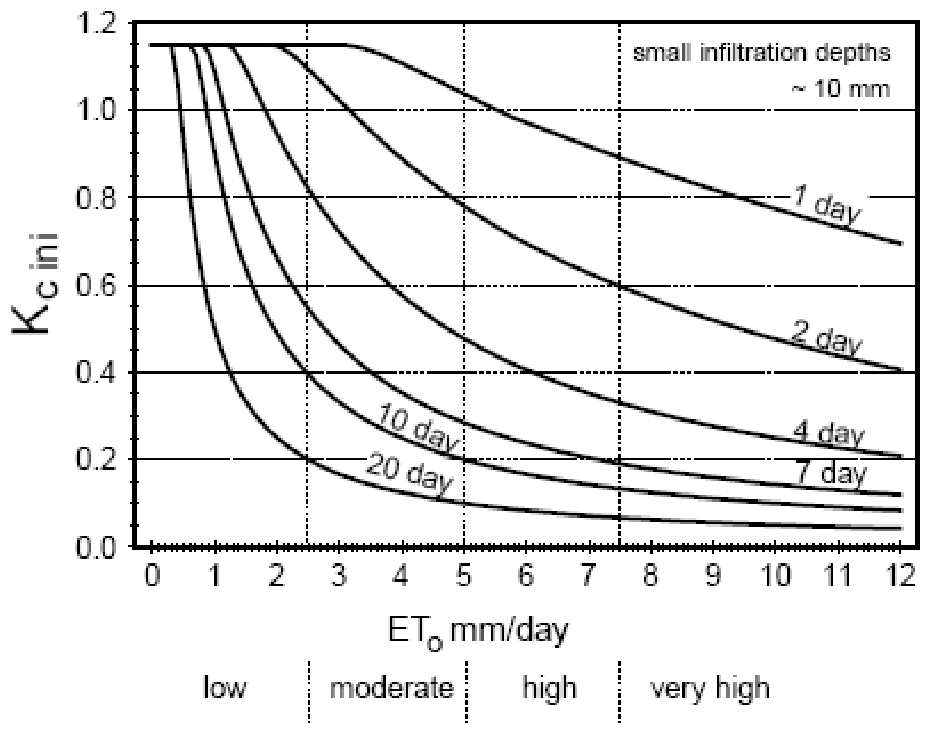


FIGURE 30

Average $K_{c\ ini}$ as related to the level of ET_o and the interval between irrigations greater than or equal to 40 mm per wetting event, during the initial growth stage for a) coarse textured soils; b) medium and fine textured soils

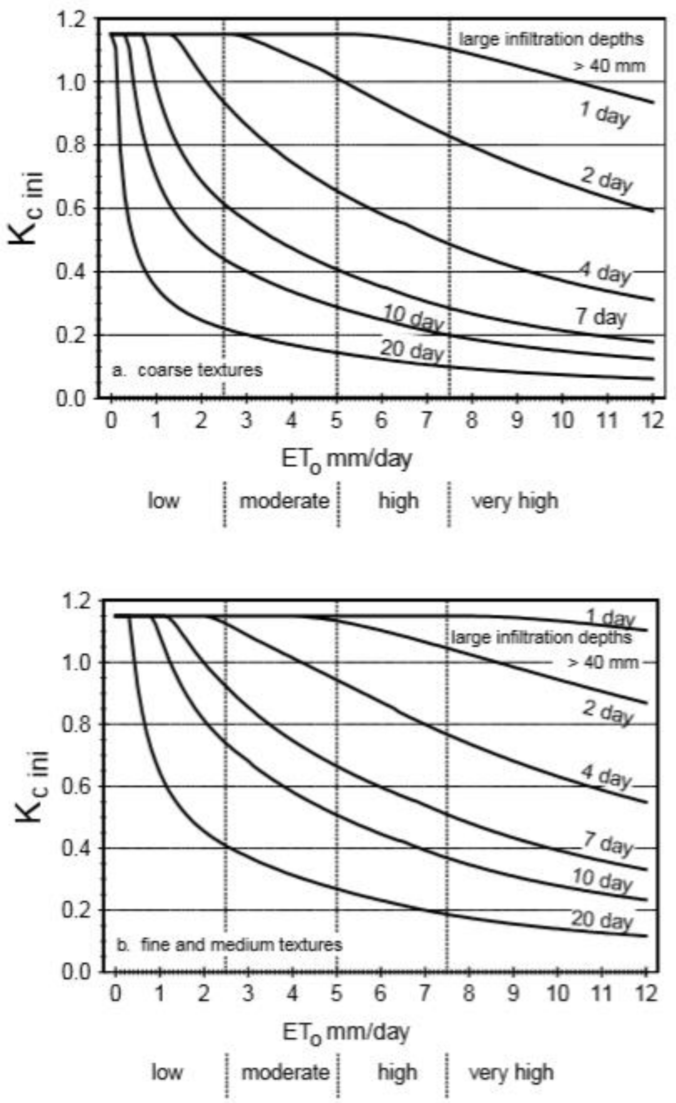
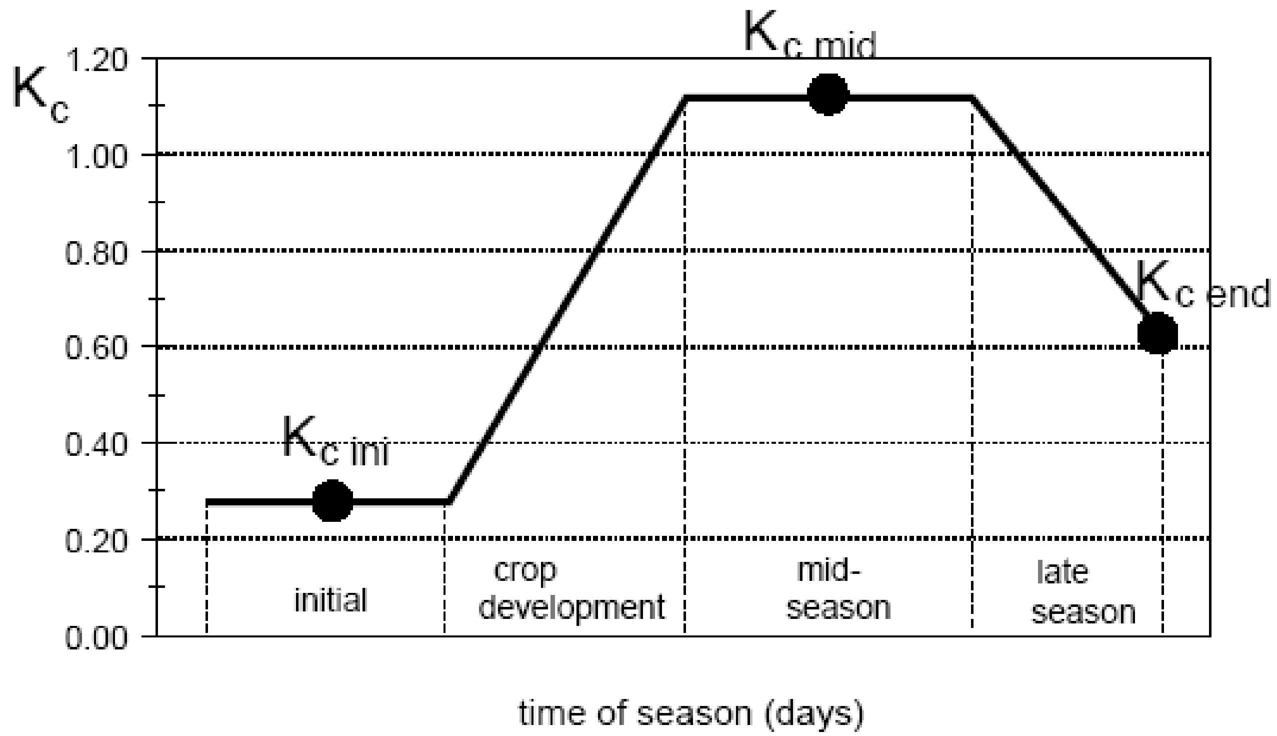


FIGURE 34
Crop coefficient curve



Adjustment of kc value

For specific adjustment in climates where RH_{min} differs from 45% or where u_2 is larger or smaller than 2.0 m/s, the $K_{c\ mid}$ values from Table 12 are adjusted as:

$$K_{c\ mid} = K_{c\ mid\ (Tab)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \quad (62)$$

where
- $K_{c\ mid\ (Tab)}$ value for $K_{c\ mid}$ taken from Table 12,
- u_2 mean value for daily wind speed at 2 m height over grass during the mid-season growth stage [m s^{-1}], for 1 m $s^{-1} \le u_2 \le 6$ m s^{-1},
- RH_{min} mean value for daily minimum relative humidity during the mid-season growth stage [%], for $20\% \le RH_{min} \le 80\%$,
- h mean plant height during the mid-season stage [m] for $0.1\ m < h < 10\ m$.

Adjustment of kc value

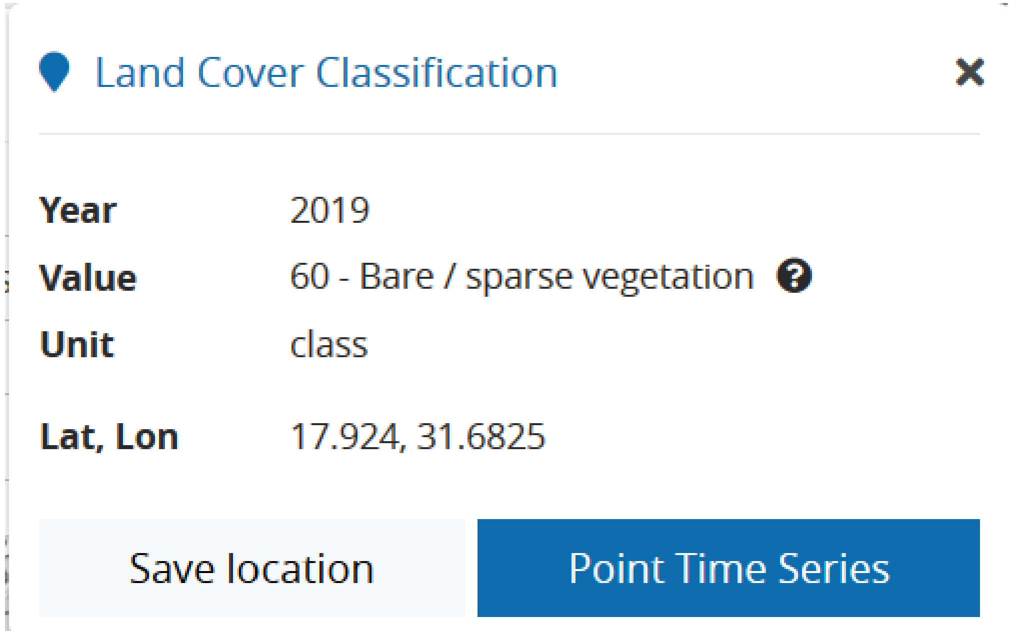
- Kc_{end} adjusted as following

$$K_{c\ end} = K_{c\ end\ (Tab)} + \left[0.04\,(u_2 - 2) - 0.004\,(RH_{min} - 45)\right]\left(\frac{h}{3}\right)^{0.3}$$

Example

- Determine crop water requirement for wheat at Sudan Marawi –Area
- Irrigation method : center pivot
- Irrigation interval : 1day

RHmin =15%
U2=4.5 m/s
h = 1 m

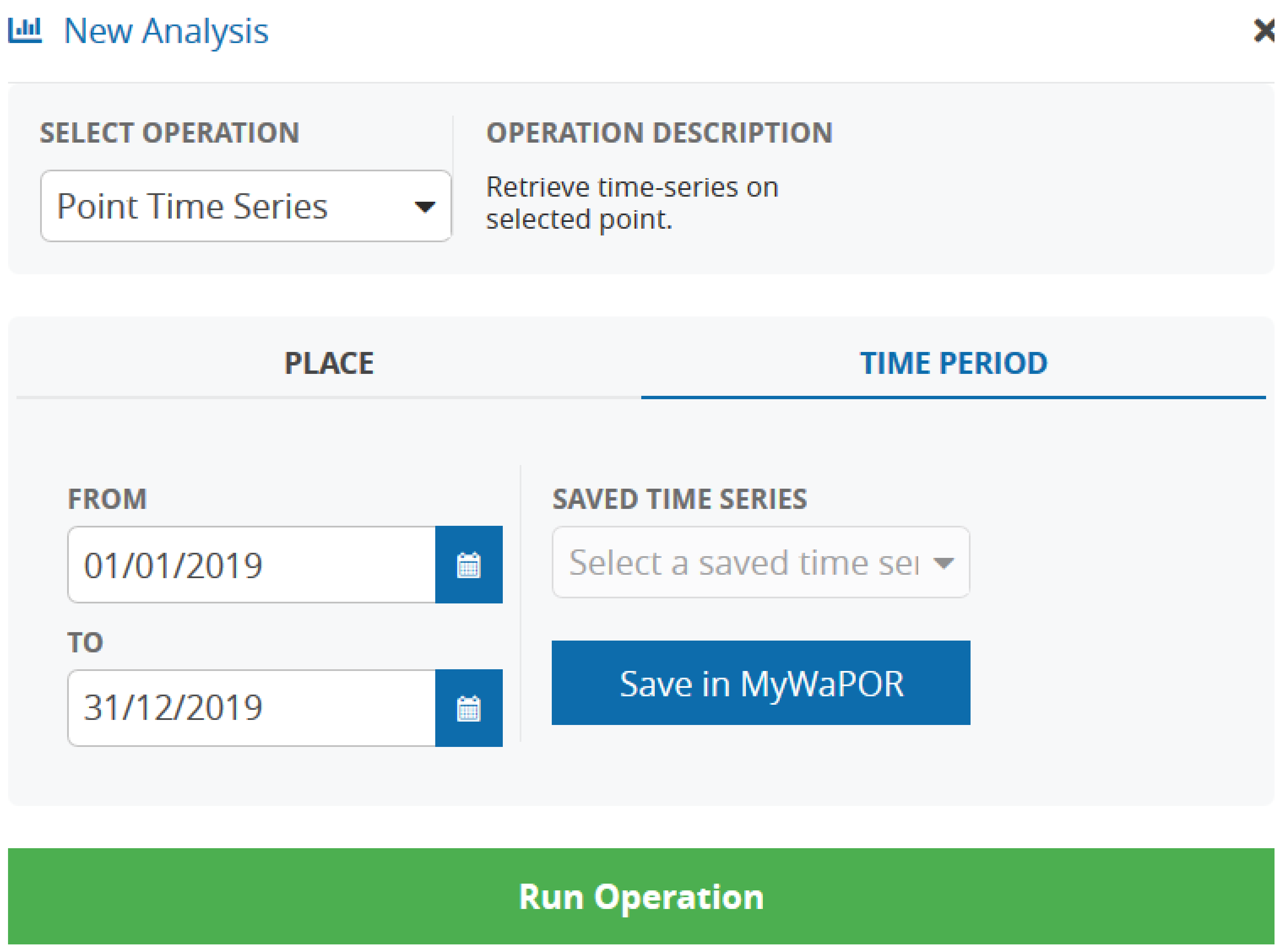

Land Cover Classification
Year
2019
Value
60 - Bare / sparse vegetation
Unit
class
Lat, Lon
17.924, 31.6825
Save location
Point Time Series

Actual EvapoTranspiration and Interception (Dekadal)

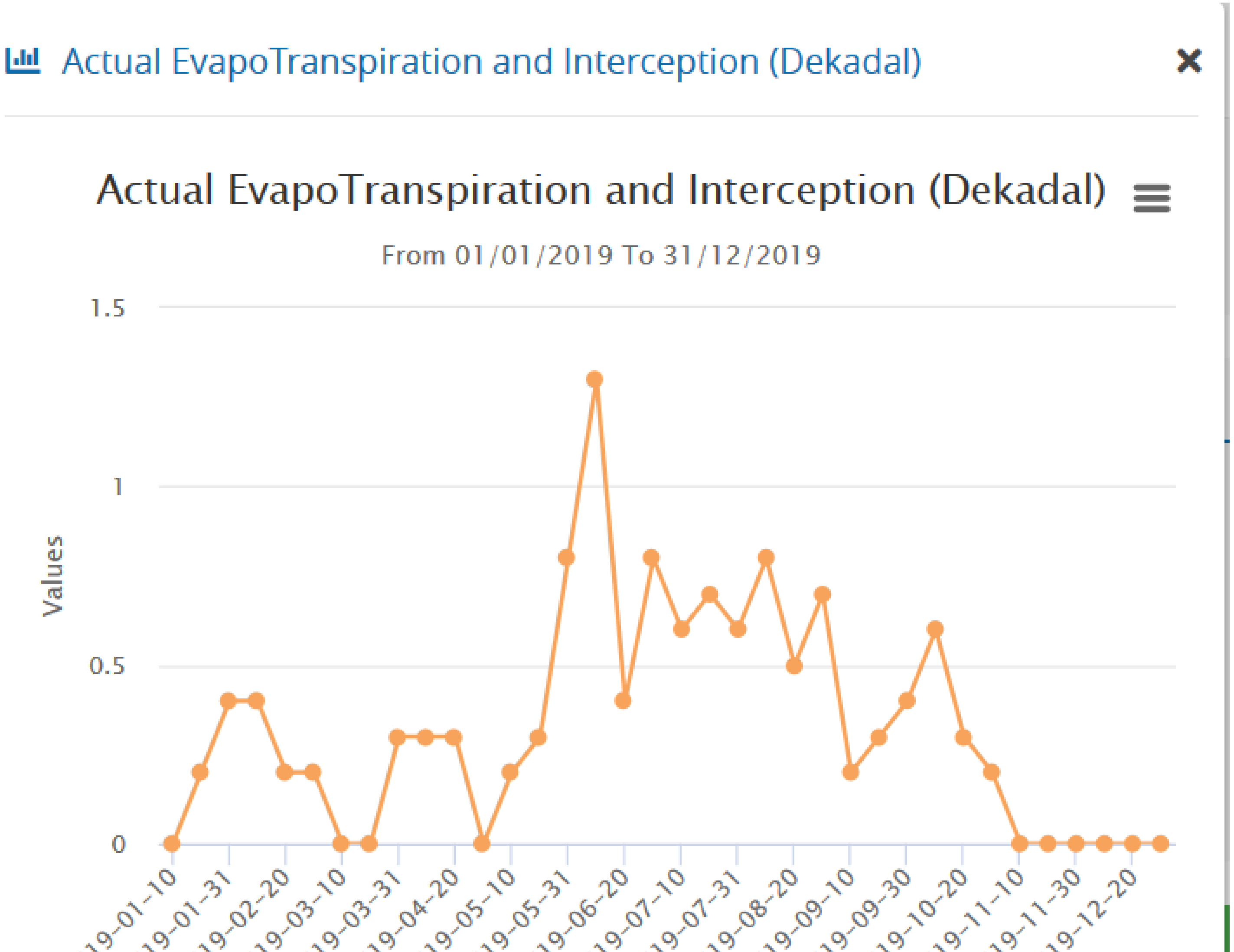
Dekad	2020-09 from 21 to 30
Value	1.6
Unit	mm
Lat, Lon	17.924, 31.6825

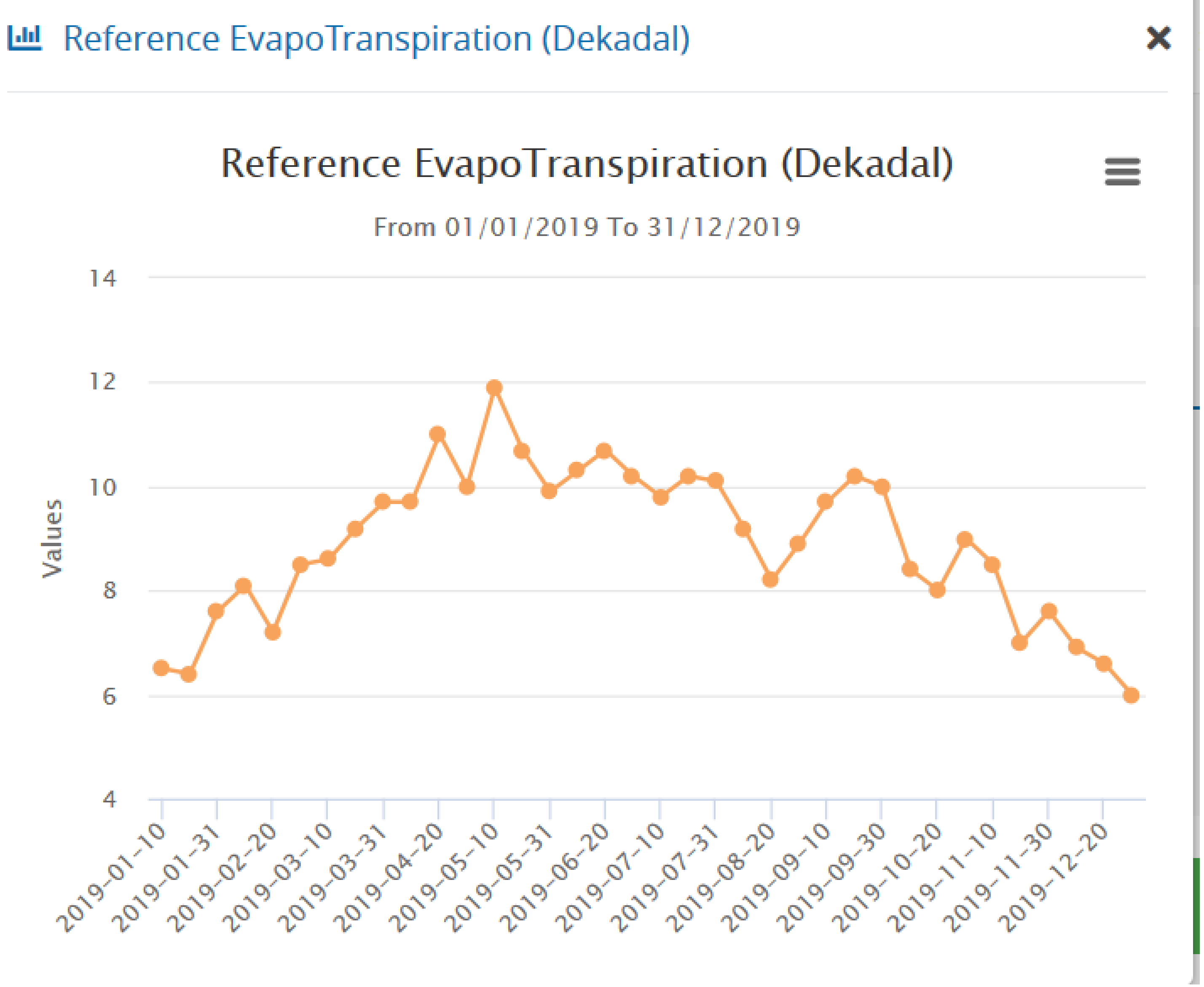
Save location

Point Time Series


New Analysis
SELECT OPERATION
Point Time Series
OPERATION DESCRIPTION
Retrieve time-series on selected point.
PLACE
TIME PERIOD
FROM
01/01/2019
TO
31/12/2019
SAVED TIME SERIES
Select a saved time sei
Save in MyWaPOR
Run Operation

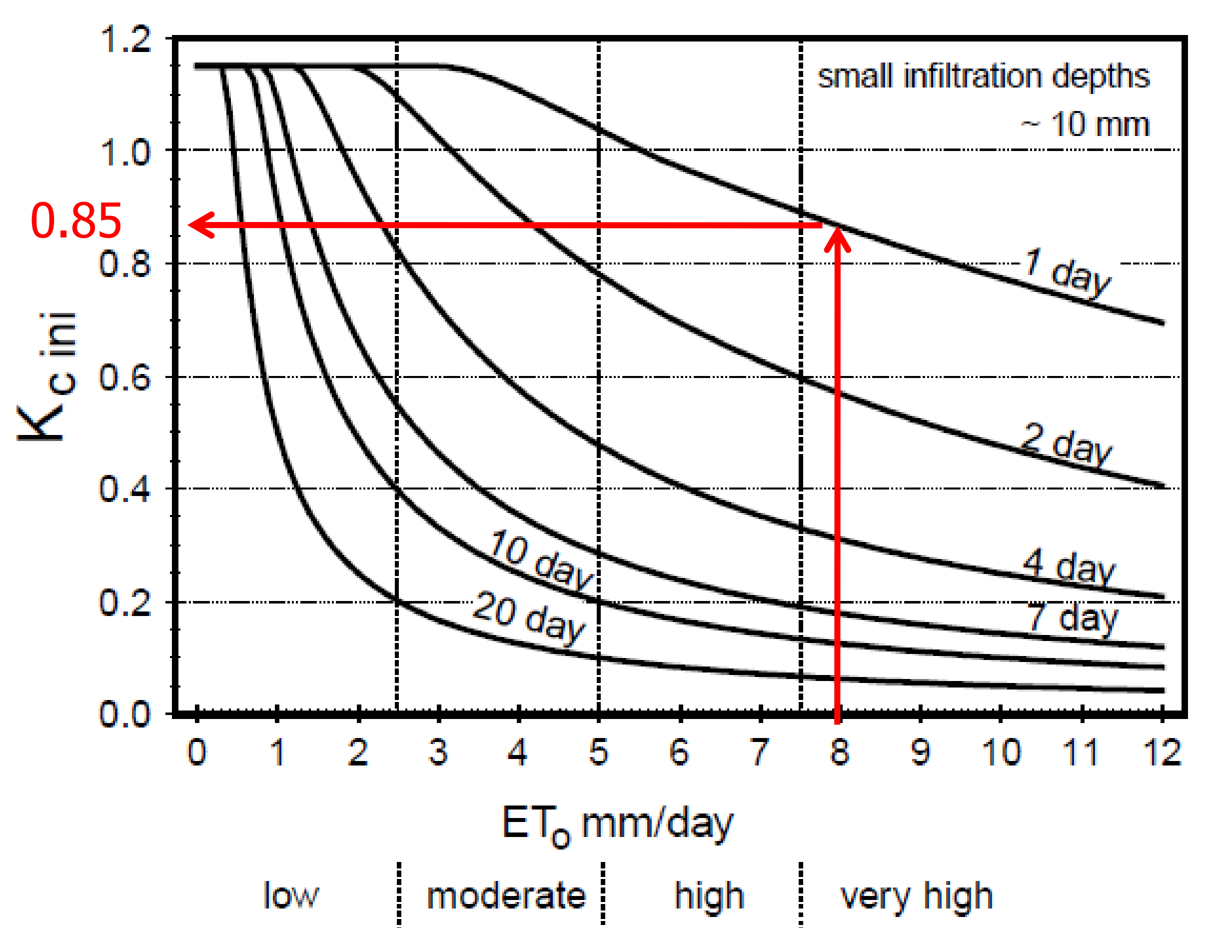
sudan


Actual EvapoTranspiration and Interception (Dekadal)
Actual EvapoTranspiration and Interception (Dekadal)
From 01/01/2019 To 31/12/2019
Values
1.5
1
0.5
0


Reference EvapoTranspiration (Dekadal)
Reference EvapoTranspiration (Dekadal)
From 01/01/2019 To 31/12/2019
Values
14
12
10
8
6
4
2019-01-10
2019-01-31
2019-02-20
2019-03-10
2019-03-31
2019-04-20
2019-05-10
2019-05-31
2019-06-20
2019-07-10
2019-07-31
2019-08-20
2019-09-10
2019-09-30
2019-10-20
2019-11-10
2019-11-30
2019-12-20

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
f. Perennial Vegetables (with winter dormancy and initially bare or mulched soil)							
Artichoke	40	40	250	30	360	Apr (1st yr)	California
	20	25	250	30	325	May (2nd yr)	(cut in May)
Asparagus	50	30	100	50	230	Feb	Warm Winter
	90	30	200	45	365	Feb	Mediterranean
g. Fibre Crops							
Cotton	30	50	60	55	195	Mar-May	Egypt; Pakistan; Calif.
	45	90	45	45	225	Mar	Calif. Desert, USA
	30	50	60	55	195	Sept	Yemen
	30	50	55	45	180	April	Texas
Flax	25	35	50	40	150	April	Europe
	30	40	100	50	220	October	Arizona
h. Oil Crops							
Castor beans	25	40	65	50	180	March	(Semi)Arid Climates
	20	40	50	25	135	Nov.	Indonesia
Safflower	20	35	45	25	125	April	California, USA
	25	35	55	30	145	Mar	High Latitudes
	35	55	60	40	190	Oct/Nov	Arid Region
Sesame	20	30	40	20	100	June	China
Sunflower	25	35	45	25	130	April/May	Medit.; California
i. Cereals							
Barley/Oats/ Wheat	15	25	50	30	120	November	Central India
	20	25	60	30	135	March/Apr	35-45 °L
	15	30	65	40	150	July	East Africa
	40	30	40	20	130	Apr	
	40	60	60	40	200	Nov	
	20	50	60	30	160	Dec	Calif. Desert, USA
Winter Wheat	20[2]	60[2]	70	30	180	December	Calif., USA
	30	140	40	30	240	November	Mediterranean
	160	75	75	25	335	October	Idaho, USA
Grains (small)	20	30	60	40	150	April	Mediterranean
	25	35	65	40	165	Oct/Nov	Pakistan; Arid Reg.
Maize (grain)	30	50	60	40	180	April	East Africa (alt.)
	25	40	45	30	140	Dec/Jan	Arid Climate
	20	35	40	30	125	June	Nigeria (humid)
	20	35	40	30	125	October	India (dry, cool)
	30	40	50	30	150	April	Spain (spr, sum.); Calif.
	30	40	50	50	170	April	Idaho, USA
Maize (sweet)	20	20	30	10	80	March	Philippines
	20	25	25	10	80	May/June	Mediterranean
	20	30	50/30	10	90	Oct/Dec	Arid Climate
	30	30	30	10[3]	110	April	Idaho, USA
	20	40	70	10	140	Jan	Calif. Desert, USA
Millet	15	25	40	25	105	June	Pakistan
	20	30	55	35	140	April	Central USA

تحديد Kcini



0.85
$K_{c\ ini}$
1.2
1.0
0.8
0.6
0.4
0.2
0.0
small infiltration depths
~ 10 mm
1 day
2 day
4 day
7 day
10 day
20 day
0 1 2 3 4 5 6 7 8 9 10 11 12
ET_o mm/day
low
moderate
high
very high

Crop	$K_{c\ ini}$[1]	$K_{c\ mid}$	$K_{c\ end}$	Maximum Crop Height (h) (m)
h. Oil Crops	**0.35**	**1.15**	**0.35**	
Castorbean (*Ricinus*)		1.15	0.55	0.3
Rapeseed, Canola		1.0-1.15[9]	0.35	0.6
Safflower		1.0-1.15[9]	0.25	0.8
Sesame		1.10	0.25	1.0
Sunflower		1.0-1.15[9]	0.35	2.0
i. Cereals	**0.3**	**1.15**	**0.4**	
Barley		1.15	0.25	1
Rice	1.05	1.20	0.90-0.60	1

continued...

6 The first $K_{c\ end}$ is for harvested fresh. The second value is for harvested dry.

7 The K_c for asparagus usually remains at $K_{c\ ini}$ during harvest of the spears, due to sparse ground cover. The $K_{c\ mid}$ value is for following regrowth of plant vegetation following termination of harvest of spears.

8 K_c for sisal depends on the planting density and water management (e.g., intentional moisture stress).

9 The lower values are for rainfed crops having less dense plant populations.

10 The higher value is for hand-harvested crops.

11 The first $K_{c\ end}$ value is for harvest at high grain moisture. The second $K_{c\ end}$ value is for harvest after complete field drying of the grain (to about 18% moisture, wet mass basis).

12 If harvested fresh for human consumption. Use $K_{c\ end}$ for field maize if the sweet maize is allowed to mature and dry in the field.

Kcini = 0.85

Kcmid(tab) = 1.15

Kcend(tab) = 0.4

Adjustment of kc value

$$K_{c\ mid} = K_{c\ mid\ (Tab)} + [0.04\,(u_2 - 2) - 0.004\,(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3}$$

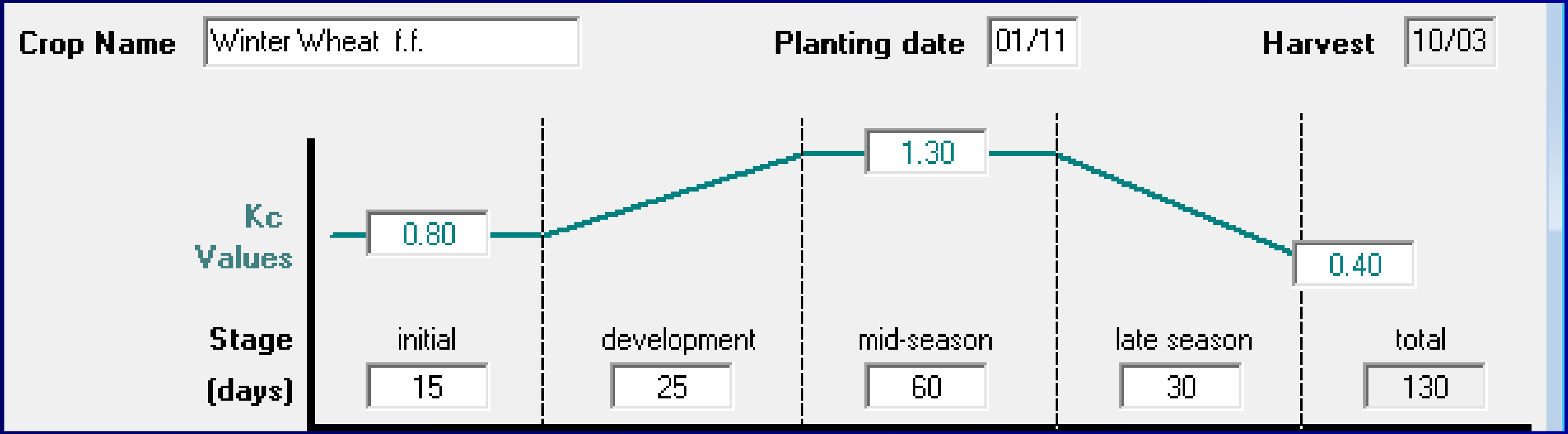
RHmin =15%
U2=4.5 m/s
h = 1 m

$$Kc_{mid} = 1.15 + [0.04(4.5 - 2) - 0.004(15 - 45)]\left(\frac{1}{3}\right)^{0.3} = 1.31$$

$$K_{c\ end} = K_{c\ end\ (Tab)} + \left[0.04\,(u_2 - 2) - 0.004\,(RH_{min} - 45)\right]\left(\frac{h}{3}\right)^{0.3}$$

$$Kc_{end} = 0.4 + \left[0.04(4.5 - 2) - 0.004(15 - 45)\right]\left(\frac{1}{3}\right)^{0.3} = 0.56$$

Crop coefficient curve for wheat – Sudan-Marawi



Crop water requirement for wheat – Sudan-Marawi

Month	ET0 (mm/day)	KC	ETC (mm/day)	ETC decadal (mm)
11	0.8	8.5	6.8	68
11	0.84	7	5.88	58.8
11	1.05	7.6	7.98	79.8
12	1.29	6.9	8.901	89.01
12	1.4	6.6	9.24	92.4
12	1.4	6	8.4	84
1	1.4	6.5	9.1	91
1	1.4	6.4	8.96	89.6
1	1.4	7.6	10.64	106.4
2	1.39	8.1	11.259	112.59
2	1.15	7.2	8.28	82.8
2	0.85	8.5	7.225	72.25
3	0.55	8.6		47.3
sum				1073.95

Jordan valley