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Water requirements for major crops in different agro-climatic zones of Iraqi Kurdistan using by CROPWAT 8.0

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ABSTRACT: *The study was performed by using FAO Penman-Monteith equation. Required parameters were set for 9 synoptic stations in Iraqi Kurdistan for a period from 2004 to 2012. Sangasar and Karkuk were selected as two different agro-climatic zones. Data were processed by (CROPWAT 8.0) program, and the values of ETo and effective rainfall were calculated. Several crops were selected in the study including alfalfa, barley, beans, cabbage, grapes, maize, potatoes, sunflower, melons, tomatoes and wheat. Crop coefficients (Kc) were taken from tables of FAO under medium soil conditions. The results show that potential evapotranspiration in Sangasar zone was 0.9 -8 mm/day, whereas in Karkuk zone was 1.5 to12 mm/day. The highest water requirement was estimated for grape in the Sangasar zone (Soran) 987.6mm/day and 1635.1 mm/day for Karkuk zone (Makhmur). In the same way, the minimum water requirement was estimated for alfalfa (first mowing) in Sangasar zone (Penjwen) 224.1mm/day and 269.7mm/day for Karkuk zone (Chamchamal).*

Keywords - *potential evapotranspiration, crop water requirement, Penman-Monteith method, CROPWAT, Iraqi Kurdistan*

I. INTRODUCTION

Water resources management has been a challenge in Iraqi Kurdistan due to precipitation shortage in recent years. Economically crops production has direct relationship with irrigation. However, irrigation scheduling has been based on the predicted crop water requirements (CWR), which is the total water needed for evapotranspiration from planting to harvest for a given crop in a specific climate regime. When adequate soil water is maintained by rainfall and/or irrigation, it does not limit plant growth and crop yield (Hess, 2005). CWR is calculated for a given crop under the different climatic conditions. (FAO, 2005) defined that CWR is the depth (or amount) of water needed to meet the water loss through evapotranspiration. In other words, it is the amount of needed water by the various crops to grow optimally. The crop water requirement always refers to a crop grown under optimal conditions, i.e. a uniform crop, actively growing, completely shading the ground, free of diseases, and favorable soil conditions (including fertility and water). The CWR mainly depends on the climate, the crop type and the growth stage of the crops. The effects of various climates on evapotranspiration are incorporated into reference evapotranspiration (ET_o). In this study, ET_o is calculated by using the FAO Penman-Monteith method (FAO, 1998):

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \dfrac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \dfrac{r_s}{r_a}\right)}$$

Where R_n is the net radiation, G is the soil heat flux, (e_s - e_a) represents the vapour pressure deficit of the air, ρ_a is the mean air density at constant pressure, c_p is the specific heat of the air, Δ represents the slope of the saturation vapour pressure temperature relationship, γ is the psychrometric constant, and r_s and ra are the (bulk) surface and aerodynamic resistances.

CWR or ET_c is calculated by multiplying the reference crop evapotranspiration, ET_o and a crop coefficient, Kc values. The effects of characteristics that distinguish field crops from grass are integrated into the crop coefficient. In order to, tabulated Kc values are used for initial, development, mid and late stages of crop growing (FAO, 1977).

II. MATERIALS AND METHODS

Iraqi Kurdistan region is located at latitude 35.00 to 37.30, longitude 42.20 to 46.20 and includes three governorates which are Erbil, Dohuk and Sulaymaniyah (Figure 1). Kurdistan region has been divided into Sangasar and Karkuk agro-climatic zones (FAO/UNESCO/WMO, 1962). Sangasar zone consists of hilly areas and high mountains with 600 to 1000 mm of rainfall per annum. The vegetation is mainly oak forest on slopes between 500 and 2000 meters altitude; whereas mostly grasses between 2000 to 4000 meters and alpine plants above 4000 meters. Karkuk zone includes the main dry farming area of the region with 200 to 600 mm rainfall. The summer is hot and dry but the winter is cold and rainy.

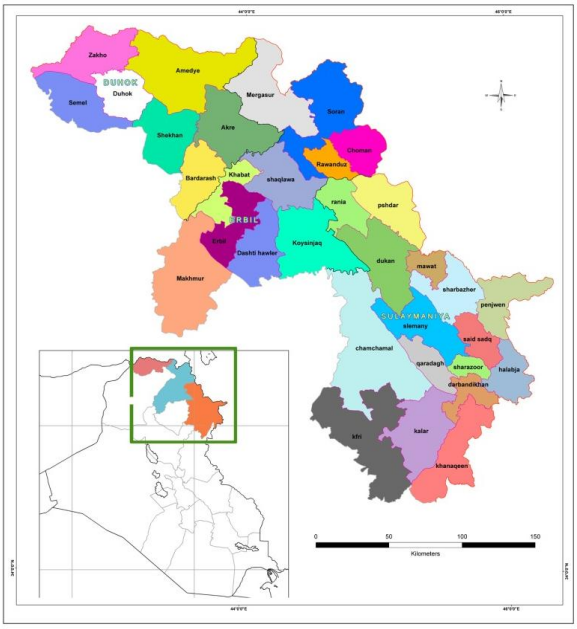

Figure 1. Map of the governorates of Kurdistan region

Estimation of ET_o: (FAO, 1992), (Smith et al., 1991) and (Smith, 1992) reported that CROPWAT is a practical tool (software) used to help agrometeorologists, agronomists and irrigation engineers to carry out standard calculations for evapotranspiration and crop water use studies, and more accurate design and management for irrigation schemes.

In order to, CROPWAT 8.0 was used to study of 9 meteorological stations. The respective climatic data were collected from the agro-meteorological department /Kurdistan ministry of agriculture and water resources and arranged by using Excel program. Table 1 shows summary statistics of meteorological stations.

Table1. Main meteorological data recorded in study areas (2004-2012)

Station	zone	Lat.	Log.	Alt., m	Annual average: Air temp. °C Min.	Air temp. °C Max.	Humidity, %	Wind Speed, m/s	Sunshine duration, h	Annual Rainfall, mm
Akre	Sangasar	36°50 ´N	43°51 ´E	636	14.6	23.2	42.0	1.6	7.6	477.7
Chamchamal	Karkuk	35°33´N	45°50´E	708	14.2	26.4	41.0	0.8	6.9	387.5
Duhok	Sangasar	36°50 ´N	43°00 ´E	569	15.0	26.2	44.9	1.1	7.6	488.5
Erbil	Karkuk	36°12 ´N	44°02 ´E	420	15.7	27.4	47.4	2.3	7.9	395.7
Makhmur	Karkuk	35°46 ´N	43°35 ´E	270	16.6	29.4	42.7	3.7	7.9	242.5
Penjwen	Sangasar	35°37´N	45°56´E	1302	7.6	17.8	59.9	3.8	7.4	1002.9
Soran	Sangasar	36°39 ´N	44°32 ´E	680	12.2	24.3	62.0	2.0	7.6	653.1
Sulaymaniyah	Sangasar	35°33´N	45°27´E	885	14.6	25.4	45.8	1.3	7.3	622.5
Zakho	Sangasar	37°80 ´N	42°41 ´E	444	14.7	26.7	38.6	1.1	6.8	528.6

Loamy soil was considered as a case study. Total available soil moisture (FC-WP) for this type of soil was equal to 180mm/meter and maximum rain infiltration rate was equal to 30mm/day.

III. RESULTS AND DISCUSSION

Annual potential evapotranspiration (ET_o) had estimate values between 1339 - 2382 mm for Zakho and Makhmur respectively. The highest and lowest values of ET_o were recorded in July and January which were 12 mm/day and 0.9 mm/ day for Makhmur and Soran, respectively (Table 2).

Table 2: Estimated monthly and annual ETo for studied stations

Station	Zone	ETo, mm/day Jan.	Feb.	Mar.	Apr.	may	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual mm
Akre	Sangasar	1.0	1.5	2.2	3.6	5.8	6.7	7.0	7.1	5.6	3.8	2.0	1.3	1451
Chamchamal	Karkuk	1.7	2.3	3.0	4.0	4.7	5.3	5.0	6.6	5.0	3.3	2.4	1.7	1361
Duhok	Sangasar	1.2	1.5	2.6	3.4	5.1	6.4	6.7	6.2	4.9	3.3	1.8	1.3	1352
Erbil	Karkuk	1.5	1.9	3.1	4.3	6.6	8.3	8.5	8.1	6.3	4.5	2.4	1.6	1738

Makhmur	Karkuk	1.9	2.5	3.9	5.8	8.7	11.5	12.0	11.4	9.0	6.1	3.3	2.1	2382
Penjwen	Sangasar	0.9	1.2	2.1	3.1	4.5	7.2	7.7	7.9	6.6	3.6	1.7	1.4	1458
Soran	Sangasar	0.9	1.2	2.5	3.3	5.2	7.5	8.0	7.7	6.0	3.3	1.8	1.1	1479
Sulaymaniyahh	Sangasar	1.1	1.6	2.6	3.4	4.5	6.8	7.1	6.8	5.1	3.3	1.8	1.3	1385
Zakho	Sangasar	1.2	1.5	2.5	3.4	5.1	6.4	6.7	6.2	4.9	3.2	1.8	1.2	1339

Crop water requirements (CWR) and irrigation requirement (IR): The CWR module includes calculations, producing the irrigation water requirement of the crop on a monthly basis and total growing season. Irrigation requirement is different between the crop evapotranspiration under standard conditions (ET_c) and the effective rainfall. A summary of the results, which explains the different CWR and IR calculation for selected crops, is showed in the tables 3 to 13.

Alfalfa

The highest CWR by alfalfa is 428.5mm at Makhmur, and the lowest at Penjwen is 224.1mm; whereas, the highest IR by alfalfa is 361.4mm at Makhmur and the lowest at Penjwen is 56.1mm (Table 3).

Table 3: Estimated CWR and IR for alfalfa (first cutting) in the studied stations

Station	Mar.		Apr.		May		Total	
	CWR	IR	CWR	IR	CWR	IR	CWR	IR
Akre	43.5	8.4	124	68.5	85	74.1	252.5	151.0
Chamchamal	55.9	21.2	138.6	78.9	75.2	66.2	269.7	166.3
Duhok	47.6	13.8	118	66.8	74.9	62.5	240.5	143.1
Erbil	59.7	14.8	154.6	113.5	100.7	92.2	315.0	220.5
Makhmur	78.4	54.4	213	176	137.1	131	428.5	361.4
Penjwen	41.1	0	113.5	13.6	69.5	42.5	224.1	56.1
Soran	46.6	0	116.8	30.7	77.9	62	241.3	92.7
Sulaymaniyah	48.3	0	117	36	66.5	43.2	231.8	79.2
Zakho	46.9	6.3	117	68.6	74.6	63.6	238.5	138.5

Barley

The highest CWR by barley is 702.8mm at Makhmur and the lowest at Penjwen 368.4mm; while, the highest IR by barley is 496.1mm at Makhmur and the lowest at Penjwen 49.8mm (Table 4).

Table 4: Estimated CWR and IR for barley in the studied stations

Station	Nov.		Des.		Jan.		Feb.		Mar.		Apr.		May		Total	
	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR
Akre	16.9	0	24.8	0	25.8	0	41	0	77.2	31.2	118.6	63.2	96.9	81.2	401.2	175.6
Chamchamal	21.9	6	33.1	4.3	29.6	0	46.6	0	104.8	64.3	136.6	76.9	85.1	73.7	457.7	225.2
Duhok	16.3	0	24.3	0	29.2	0	44.8	0	86.8	45	114.8	63.7	86.4	67.1	402.6	175.8
Erbil	20.2	1	30.6	0	36.4	0	57.2	1.3	111.1	55.7	150.7	109.5	115.6	102.9	521.8	270.4
Makhmur	27.7	16.6	39.7	14.3	48.2	6.7	73.8	14.2	148	124	208.4	171.3	157	149	702.8	496.1
Penjwen	15	0	25	0	23.4	0	36	0	77	0	111.3	11.5	80.7	38.3	368.4	49.8
Soran	15.6	0	20.8	0	23.4	0	36.2	0	86.4	8.3	113.8	27.7	90.6	67.9	386.8	103.9
Sulaymaniyah	15.4	0	24.5	0	28	0	46.1	0	88.6	13.8	114.2	33.3	77.7	40	394.5	87.1
Zakho	15.7	0	23.4	0	28.2	0	43.8	0	85.6	24.1	113.8	65.6	86	69.4	396.5	159.1

Beans

The highest CWR by beans is 657.7mm at Makhmur and the lowest at Penjwen 344.9mm; while, the highest IR by beans is 451.1mm at Makhmur and the lowest at Penjwen is 34mm (Table 5).

Table 5: Estimated CWR and IR for beans in the studied stations

Station	Nov.		Des.		Jan.		Feb.		Mar.		Apr.		May		Total	
	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR
Akre	11.3	0	19.8	0	27.9	0	44.4	0	78.1	32	109.6	54.2	89.8	74.1	380.9	160.3
Chamchamal	14.6	0.5	27	0	32.2	0	49.8	0	103.6	63.1	124.1	64.3	76.4	64.9	427.7	192.8
Duhok	10.9	0	19.7	0	31.8	0	48.7	0	87.7	45.9	106.3	55.2	79.8	60.4	384.9	161.5
Erbil	13.5	0	24.7	0	39.8	0	61.5	3.6	110.5	55.1	137.2	95.9	104.9	92.1	492.1	246.7
Makhmur	18.4	7.4	32.5	7	53	11.5	78.9	19.4	146	122	188	151	140.9	132.8	657.7	451.1
Penjwen	10	0	20.2	0	25.6	0	38.6	0	76.4	0	101	3.4	73.1	30.6	344.9	34

Soran	10.3	0	16.8	0	25.5	0	38.8	0	85.9	8	103.6	17.5	82.5	59.9	363.4	85.4
Sulaymaniyah	10.2	0	19.7	0	30.6	0	49.9	0	89.3	14.3	105.8	24.8	71.5	34	377	73.1
Zakho	10.5	0	18.8	0	30.6	0	47.3	0	86.4	24.9	105.4	57.2	79.4	62.8	378.4	144.9

Cabbage

The highest CWR by cabbage is 844.7mm at Makhmur and the lowest at Zakho 452.1mm; while, the highest IR by cabbage is 748.4mm at Makhmur and the lowest at Zakho 283.9mm (Table 6).

Table 6: Estimated CWR and IR for cabbage in the studied stations

Station	Aug.		Sep.		Oct.		Nov.		Des.		Jan.		Total	
	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR
Akre	150.7	150.5	122.3	120.2	103.9	77.6	61.2	17.9	41.5	0	28	0	507.6	366.2
Chamchamal	141.2	141.1	110.4	105.4	95.5	74.1	77.6	47	59	26.9	33	0	516.7	394.5
Duhok	132.7	132.6	107.9	106.3	89.6	64.2	57.5	10.6	40.8	0	31.8	0	460.3	313.7
Erbil	173.9	173.6	140.2	137.6	123.6	105.2	74.4	32.3	52.2	0	39.8	0	604.1	448.7
Makhmur	245.2	245.1	198.5	195.1	172.4	165	104.8	84.7	70.1	44.7	53.7	13.8	844.7	748.4
Penjwen	169.2	169	146.2	143.8	101.9	49.3	57.1	1.5	43.9	0	26.3	0	544.6	363.6
Soran	165.2	164.5	132.5	128.6	92	45.6	56.8	9.4	35.5	0	25.5	0	507.5	348.1
Sulaymaniyah	145.3	145.2	112.9	111	91.4	44.1	54.8	4.6	41.1	0	30.3	0	475.8	304.9
Zakho	132	131.4	106.6	102.8	87.8	41.4	55.7	8.3	39.3	0	30.7	0	452.1	283.9

Grape

The highest CWR by grape is 1635.1mm at Makhmur and the lowest at Chamchamal 798.5mm; while, the highest total IR by grape is 1553.7mm at Makhmur and the lowest at Chamchamal 682mm (Table 7).

Table 7: Estimated CWR and IR for grape in the studied stations

Station	Feb.		Mar.		Apr.		may		Jun.		Jul.		Aug.		Sep.		Total	
	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR
Akre	6.7	0	32.9	1.9	96	40.6	177.6	161.9	198.9	198.8	200.3	200.3	141.5	141.4	20.5	20.5	874.4	765.4
Chamchamal	10	0	44.2	10.8	107.7	47.9	153.7	142.1	164.4	163.6	153.3	153.3	144.3	144.2	20.9	20.1	798.5	682
Duhok	7.3	0	36.4	4.9	92.6	41.5	159.8	140.5	194.6	193.7	194.3	194.2	127.6	127.4	18.5	18.5	831.1	720.7
Erbil	8.9	0	45.7	6.2	121.3	80.1	216.1	203.4	262	260.2	257.7	257.4	177.8	177.4	25.9	25.8	1115.4	1010.5
Makhmur	11.1	0	60.5	36.5	170.6	133.5	302.8	294.8	384.4	384.1	390.3	390.2	274	273.9	41.4	40.7	1635.1	1553.7
Penjwen	5.6	0	31.8	0	91.1	8.8	157.4	115	234.3	232.6	243.2	241.1	183.5	183.4	29.3	29.3	976.2	810.2
Soran	5.9	0	35.9	0	92.7	16.8	173.3	150.6	238.1	236.9	244.5	243.9	171.5	171	25.7	25.7	987.6	844.9
Sulaymaniyah	7.5	0	36.9	0	91	14.9	144	106.5	205.5	204.3	204.7	204.6	140.1	140	19.8	19.8	849.5	690.1
Zakho	7.1	0	35.9	0	91.8	43.6	159.1	142.6	194.3	192.7	193.9	193.8	127	126.7	18.4	18.3	827.5	717.7

Maize

The highest total CWR by maize is 1404.4mm at Makhmur and the lowest at Chamchamal 635.8mm; while, the highest IR by maize is 1358.6mm at Makhmur and the lowest at Chamchamal 588.1mm (Table 8).

Table 8: Estimated CWR and IR for maize in the studied stations

Station	Apr.		May		Jun.		Jul.		Aug.		Total	
	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR
Akre	33	0	115.2	99.5	221.8	221.6	245.8	245.8	138.6	138.5	754.4	705.4

Chamchamal	35.3	0	96.9	85.4	182.5	181.7	187.1	187.1	134	133.9	635.8	588.1
Duhok	31.4	0	103.9	84.6	218.4	217.5	239.9	239.8	125.2	125.1	718.8	667
Erbil	39.4	4	138.1	125.4	291.9	290.1	315.1	314.9	168.3	168.1	952.8	902.5
Makhmur	52.6	15.4	192.5	184.5	431.9	431.4	478.5	478.5	248.9	248.8	1404.4	1358.6
Penjwen	28.6	0	100.8	61.6	260.9	259.3	296.2	294	166.8	166.7	853.3	781.6
Soran	30	0	112.2	89.5	267.7	266.5	300.9	300.3	161.3	160.6	872.1	816.9
Sulaymaniyah	30.9	0	94.7	57.2	232.4	231.3	254.5	254.4	137.4	137.2	749.9	680.1
Zakho	31.1	0	103.5	86.9	218.1	216.5	239.3	239.1	124.7	124.4	716.7	666.9

Potato

The highest CWR by potato is 704.1mm at Makhmur and the lowest at Chamchamal 491.2mm; while, the highest IR by potato is 621.7mm at Makhmur and the lowest at Chamchamal 401mm (Table 9).

Table 9: Estimated CWR and IR for potato in the studied stations

Station	Mar.		Apr.		May		Jun.		Jul.		Total	
	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR
Akre	21.4	0	76.1	23.9	195.2	179.5	206.2	206.1	65	65	563.9	474.5
Chamchamal	27.4	8	81.7	23.5	165.5	153.8	167.9	167.1	48.7	48.6	491.2	401
Duhok	23.3	4.1	72.3	22.6	174.1	155	200.4	199.5	63.9	63.8	534	445
Erbil	28.6	2.1	92.2	51.1	232.4	219.6	266.7	264.9	84.2	84	704.1	621.7
Makhmur	36.9	26.2	125.6	88.4	319.2	311.2	385.5	385.2	127.1	127.1	994.3	938.1
Penjwen	19.7	0	67.7	2.2	167.6	125.1	236.3	234.7	78	77.2	569.3	439.2
Soran	22.5	0	70.4	10.4	185.8	163.1	241.7	240.4	79.5	79.3	599.9	493.2
Sulaymaniyah	23.5	0	70.9	8.9	156.5	119	211.2	210.1	67.4	67.3	529.5	405.3
Zakho	22.9	0	71.7	26	173.5	157	200.1	198.5	63.8	63.7	532	445.2

Sunflower

The highest CWR by sunflower is 704.1mm at Makhmur and the lowest at Chamchamal 491.2mm; while, the highest IR by sunflower is 621.7mm at Makhmur and the lowest at Chamchamal 401mm (Table 10).

Table 10: Estimated CWR and IR for sunflower in the studied stations

Station	Mar.		Apr.		May		Jun.		Jul.		Total	
	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR
Akre	15	0	58.9	14.4	177.7	161.9	206.6	206.5	89.2	89.2	547.4	472
Chamchamal	19.2	0.9	63.8	13.9	153.5	142	171.2	170.5	65.9	65.8	473.6	393.1
Duhok	16.3	0	56.3	13.3	160.5	141.1	203	202.1	87	87	523.1	443.5
Erbil	20	0	72.4	33.2	216.8	204.1	273.2	271.4	113.8	113.6	696.2	622.3
Makhmur	25.9	15	99.9	62.7	304.5	296.5	402.3	401.8	169.7	169.7	1002.3	945.7
Penjwen	13.8	0	53.7	0	158.8	116.3	245.5	243.9	105.3	103.7	577.1	463.9
Soran	15.8	0	55.4	4.6	174.4	151.8	248.9	247.7	107.3	106.9	601.8	511
Sulaymaniyah	16.4	0	55.1	3.1	144.5	107	214.2	213.1	91.5	91.4	521.7	414.6
Zakho	16.1	0	55.8	14.7	159.9	143.2	202.6	201	86.9	86.7	521.3	445.6

Sweet Melon

The highest CWR by sweet melon is 936mm at Makhmur and the lowest at Chamchamal 460.9mm; while, the highest IR by sweet melon is 879.5mm at Makhmur and the lowest at Chamchamal 371.1mm (Table 11).

Table 11: Estimated CWR and IR for sweet melon in the studied stations

Station	Mar.		Apr.		May		Jun.		Jul.		Total	
	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR
Akre	21.4	0	70.3	18.1	174.8	159.1	198.8	198.6	66.1	66.1	531.4	441.9
Chamchamal	27.4	8	75.4	17.3	147.7	136.2	161.2	160.5	49.2	49.1	460.9	371.1
Duhok	23.3	4.1	66.8	17.3	156.3	137	193.3	192.4	64.7	64.6	504.4	415.4
Erbil	28.6	2.1	85	43.8	207.9	195.1	256.2	254.5	84.8	84.6	662.5	580.1
Makhmur	36.9	26.2	115.4	78.2	286.1	278	370.2	369.7	127.4	127.4	936	879.5
Penjwen	19.7	0	62.4	0	150	107.6	227	225.4	78.2	77.5	537.3	410.5
Soran	22.5	0	64.8	6.4	166.8	144.1	233	231.7	80.1	79.9	567.2	462.1
Sulaymaniyah	23.5	0	65.5	5.2	140.9	103.4	204.2	203.1	68.4	68.3	502.5	380
Zakho	22.9	0	66.2	20.5	155.6	139.1	193	191.4	64.6	64.5	502.3	415.5

Tomato

The highest CWR by tomato is 1229mm at Makhmur and the lowest at Chamchamal 604.2mm; while, the highest IR by tomato is 1159.3mm at Makhmur and the lowest at Chamchamal 491.6mm (Table 12).

Table 12: Estimated CWR and IR for tomato in the studied stations

Station	Mar.		Apr.		May		Jun.		Jul.		Total	
	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR
Akre	42.9	2.5	90.8	35.5	195.5	179.7	219.3	219.2	142.2	142.2	690.7	579.1
Chamchamal	56.7	16.1	98.6	38.8	165.7	154.3	177.9	177.2	105.3	105.2	604.2	491.6
Duhok	47.3	9	86.6	35.5	174.7	155.5	213.3	212.4	138.7	138.6	660.6	551
Erbil	57.8	6	110.8	69.5	232.9	220.1	283	281.3	181.6	181.4	866.1	758.3
Makhmur	74.4	50.5	151.5	114.3	320.8	312.7	408.9	408.5	273.4	273.3	1229	1159.3
Penjwen	39.5	0	81.6	5.5	168.2	125.6	250.9	249.3	168.7	166.9	708.9	547.3
Soran	45.4	0	84.5	13.8	186.7	164.1	257.1	255.9	172.3	171.9	746	605.7
Sulaymaniyah	47.9	0	85.2	12.1	157.5	120	225.2	224	146.5	146.4	662.3	502.5
Zakho	46.6	0.1	85.9	37.7	174.1	157.5	213	211.3	138.5	138.4	658.1	545

Wheat

The highest CWR by wheat is 832mm at Makhmur and the lowest at Penjwen 440.4mm; while, the highest IR by wheat is 625.2mm at Makhmur and the lowest at Penjwen 119mm (Table 13).

Table 13: Estimated CWR and IR for wheat in the studied stations

Station	Nov.		Des.		Jan.		Feb.		Mar.		Apr.		May		Jun.		Total	
	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR	CWR	IR
Akre	16.4	0	24	0	25.5	0	41.5	0	78.6	32.6	120.9	65.5	138.4	122.7	32.1	32	477.4	252.8
Chamchamal	20.9	5	31.5	2.4	41.1	0	67.3	0.2	112.2	71.7	139.7	79.9	121	109.5	26.1	25.4	559.8	294.1
Duhok	15.7	0	23.5	0	28.8	0	45.3	0	88.3	46.5	117.1	65.9	123.7	104.4	30.6	29.7	473	246.5
Erbil	19.5	0.7	29.5	0	36	0	57.9	2	113	57.6	153.5	112.3	166	153.3	40	38.5	615.4	364.4
Makhmur	26.8	16	38.3	13	47.7	6.2	74.6	15.1	150.5	126.4	212.2	175.1	226.3	218.2	55.6	55.2	832	625.2
Penjwen	14.5	0	24.1	0	23.1	0	36.5	0	78.2	0	113.3	12.3	117.3	74.9	33.4	31.8	440.4	119
Soran	15	0	20.1	0	23.1	0	36.6	0	87.9	9.4	115.9	29.9	131.1	108.4	35.2	34	464.9	181.7
Sulaymaniyah	14.9	0	23.7	0	27.7	0	46.7	0	90.2	14.9	116.5	35.5	111.9	74.4	31.6	30.5	463.2	155.3
Zakho	15.2	0	22.5	0	27.9	0	44.1	0	87.1	25.6	116.1	67.8	123.1	106.6	30.5	28.9	466.5	228.9

IV. CONCLUSION

Results of the study explain that the evapotranspiration (ET_o) was highest in July (12 mm/day) and lowest in January (0.9 mm/day). On the other hand, estimated CWR and IR show that the use of water and irrigation projects should be done in Kurdistan region, especially in Karkuk zone, with modern methods to increase efficiency and save water resources.

V. RECOMMENDATIONS

It is recommended that prepared a comprehensive plan to estimation CWR for all zones in Iraqi Kurdistan region. Such a plan can be used as a basis for agricultural projects. However, estimated CWR and IR must be confirmed by practical tests.

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Appendix

Table App. 1: Main features of the crops studied

Crop	Botanical Name	Planting time	Harvesting time	Kc, Crop coefficient		
				Inti.	Mid	End
Alfalfa	Medicago sativa L.	Mar-Apr	May-Jun	0.4	1.2	1.15
Barley	Hordeum vulgare L.	Mid Nov	May	0.6	1.15	0.25
Beans	Phaseolus coccineus L.	Oct-Nov	May	0.4	1.15	0.35
Vegetable(Cabbage)	Brassica oleracea	Agu	Mar	0.7	1.05	0.95
Grape	Vitis vinifera	Feb	Aug-Sep	0.3	1.05	0.5
Maize (Grain)	Zea mays L.	Mar-Apr	Jul	0.3	1.2	0.4
Potato (spring)	Solanum Tuberosum	Feb-Mar	Jun	0.5	1.15	0.75
Sunflower	Helian Thusannuus L.	Mar	Jul	0.35	1.1	0.25
Sweet Melon	Cucumis melo L.	Mar	Jun-Jul	0.5	1.05	0.75
Tomato	Solanum lycopersicum	Mar-Apr	Jul-Oct	0.6	1.15	0.8
Wheat	Triticum aestivum	Mid Nov	Jun	0.6	1.15	0.32`

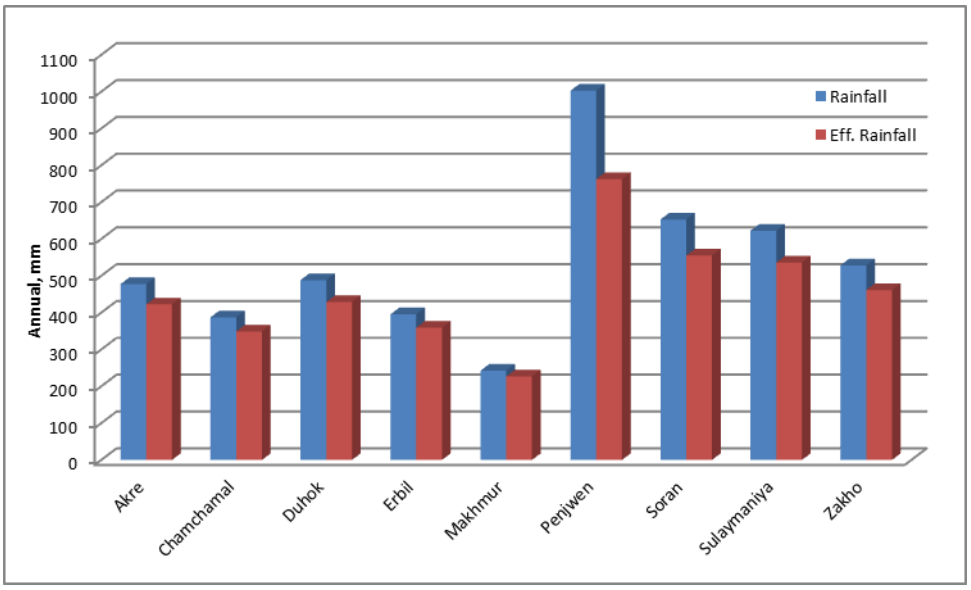

Figure App.1: Annual rainfall and effective rainfall by USDA S.C. Method for studied stations.