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Some Design Considerations of Runoff Farming in Erbil Plain and Its Peripheral Areas

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Abstract: Water harvesting has been recognized as a proxy for ensuring water availability and improving crop production in regions with low rainfall and frequent drought. Therefore, the current study was initiated to obtain some design considerations for runoff harvesting through the generation of continuous surfaces for the ratio of catchment to cultivated area over Erbil and its peripheral regions. To target the above objectives, recorded data were obtained on rainfall quantities and other meteorological elements from 19 meteorological stations spread over the study area. The rainfall data covered a period of 25 years (1998-2022). The other requirements encompassed determination of hydrologic soil groups, runoff coefficient, crop water demand, and design rainfall at each station. A special formula was applied to determine the ratio of catchment to cultivated area (C: CA) at different locations under different land slopes. Thereafter, continuous surfaces were generated for C: CA using the best interpolation method. The results indicated that the annual rainfall varies greatly in space and is characterized by high spatial variability. The ratio of catchment to cultivated area varied from a minimum of 3.18:1 to a maximum of 28.73:1, and most of the subareas have a ratio of less than 5:1. Moreover, this ratio is significantly affected by land slope and tends to increase gradually from north to south and from east to west. It is recommended to practice the runoff farming on slopes in the range of 6-10% to lessen the sacrificed lands and to control erosion.

Keywords: *Design Rainfall; Erbil Plain; Ratio of Catchment to Cultivated Area; Runoff Farming*

1. Introduction

Water shortage has become a global challenge because of population growth, urbanization, and climate change [1, 2], and this is especially experienced in arid and semiarid regions. In these regions, potential evapotranspiration is characterized by being extreme due to intensive solar radiation, low relative humidity, and strong wind velocity [3]. The problem of water scarcity in these zones is not only due to low annual rainfall, but also includes unfavorable rainfall distribution over the time of the year [4]. In these regions, restricted and unreliable rainfall often gives rise to poor crop yields or crop failure in total [5]. Under these conditions, the agricultural production is facing numerous challenges in terms of a drop in crop productivity, besides natural resource degradation [6]. Accordingly, there must be a strategy to overcome such risks.

Previous research has revealed that some novel knowledge and methods can assist farmers in mitigating meteorological drought and increasing water use efficiency [7]. Under these circumstances, water harvesting can be regarded as a possible complement to irrigated agriculture [4]. Umukiza et al. [8] highlighted that water harvesting is a system of capturing and concentrating the runoff, followed by storage within the soil for direct use by plants or in pools for use during dry spells.

Rainwater harvesting systems include the collection and then storage of water directly in the form of rainfall and runoff, or indirectly in the form of surface springs, rivers, or groundwater [9]. On the other hand, runoff farming can be defined as the technique of directing water from uncultivated land to cultivated (cropped) areas [10].

The runoff area should have an adequately high runoff coefficient, while the cultivated area must possess a high infiltration rate, besides a high storage capacity [11]. Lalljee and Facknath [12] highlighted that the soil storage capacity is a function of soil texture, soil depth, and soil organic matter content.

The justification for applying runoff farming is to provide sufficient water for plant growth and alleviate soil water deficit during the growing season. Hence, runoff farming as a type of micro catchment rainwater harvesting system is the correct choice [11].

For water harvesting designers, the most complicated step is to select the proper design of rainfall as a prerequisite for defining the catchment cropping area ratio [13]. They defined this parameter as the annual rainfall depth, which supplies sufficient water for plant growth. When the rainfall depth becomes below or above this critical value, there will be soil moisture stress and structural damage, respectively.

The design of micro catchment water harvesting encompasses a catchment area that collects runoff and a cultivated area that captures and concentrates runoff from the catchment area [14]. Precise calculation of this relationship (ratio) demands data relevant to design rainfall, crop water requirement, runoff coefficient, and efficiency factor [15].

The catchment-to-field ratio can range from 1:1 to 1: many square kilometers. The higher the aridity of an area, the larger is the required catchment area in relation to the cropping area for the same water yield [16]. Dwiratna et al. [17] observed that the cropping index under dry farming can be increased to 300% with a catchment cultivation ratio of 6.2. This means that to ensure the water demand for 1000 m^2 of cropping land, 6200 m^2 of catchment area is required. Frezghi et al. [11] elucidated that the ratios of catchment to cultivated area of 0.8, 1.1, and 2.2 offered the highest grain yield of sorghum for land slopes of 35%, 10%, and 5%, respectively, under runoff farming at Hamelmalo, Eritrea.

Overall, agriculture in the study region is strongly affected by a host of factors such as low rainfall and its uneven distribution, repeated drought, marginal lands, etc. One of the central approaches or practices to cope with these constraints is runoff farming as a type of micro catchment water harvesting to overcome water deficit and sustain agricultural productivity [6]. Accordingly, the current study was initiated with the main objective of providing some design considerations of runoff farming, such as design rainfall and the ratio of catchment to cultivated area over Erbil plain and its peripheral areas for different hydrologic soil groups and land slopes.

2. Methodologies

2.1 Description of the Study Area

The majority of the study area covers Erbil plain, which is situated in the southern part of Erbil governorate with a nearly gentle slope. The study area also includes undulating lands surrounding the Erbil plain from all around. Overall, the study area is sandwiched between latitude 35.76810° ° and 36.74139° North and between longitude 43.48080° ° and 44.64806° East. The altitude ranges from a minimum of 225 m at Gwer to a maximum of 883 m amsl at Shaqlawa. The mean annual rainfall varies from a minimum of 232.98 mm at Altun Kupri to a maximum of 745.24 mm at Shaqlawa. It possesses a unimodal distribution with rainfall mainly concentrated from November to April. There is water surplus from about mid-November to mid-April. On the contrary, there is a water deficit over the remaining months of the year. January and July are the coldest and warmest months of the year, respectively. The climate regime of the area under investigation can be classified as semiarid (0.20 <

AI < 0.50) based on the aridity scheme proposed by [18]. Moreover, according to the scheme proposed by Koppen, its southern part can be put under Mediterranean climate, mild with dry, and hot summer (BSh), while the middle and northern parts can be put under temperate, dry summer, hot summer (CSa).

The area is under intensive dry farming, wheat being the primary winter crop, followed by barley, lentil, faba bean, and chickpea. The following system is practiced to a great extent. Vegetables and orchards can be found in the form of scattered spots adjacent to the main streams.

The dominant soil group at the middle part of the plain is Chromoxererts, whereas the soils adjacent to the main streams are categorized under Torrifluvents. On the other hand, Xerothents and Rendolls are overlying stony materials in the areas surrounding their upper part. The major soil types are silty clay loam, clay loam, and silty clay soils. Lighter soils can be found in the southern parts of the study area. All the existing soils are characterized by being calcareous, non-saline, with slightly to mildly alkaline in reactions.

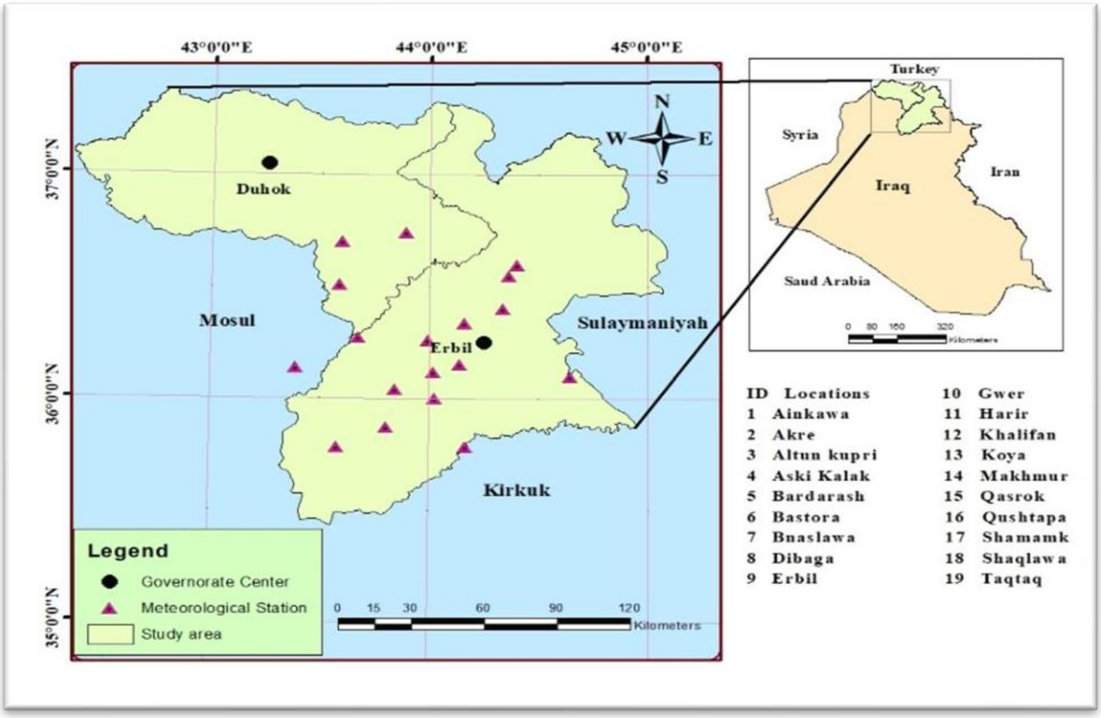

Figure 1: Location map showing the distribution of the meteorological stations over the study area.

2.2 Data Acquisition

The collected data sets cover monthly rainfall quantities and the related climatic variables for computing potential evapotranspiration records at 19 meteorological stations distributed over the Erbil plain and the surrounding areas (Fig.1). The recorded data covered a time span of 25 years (1998-2022). The obtained climatic variables encompassed the monthly average of each of the daily maximum temperature (Tmax), daily minimum temperature (Tmin), daily vapour pressure (e_a), daily wind speed (U_2), and daily sunshine duration (n). The above data were provided by the Ministry of Agriculture and Water Resources and the Directorate of Meteorology of Erbil. The annual time series for rainfall and evapotranspiration was obtained by summing up the monthly values of these two climatic input variables.

2.3 Calculation of Potential Evapotranspiration

Calculation of potential evapotranspiration was based on using the Penman-Monteith expression [19] and as follows:

(1) $$ET_o = \frac{0.408\Delta(R_n - G) + \frac{900\gamma U_2(e_s - e_a)900}{T+273}}{\Delta + (1 + 0.34U_2)\gamma}$$

Where ETo = potential evapotranspiration (mm/ day), Δ= slope of vapor pressure versus temperature (kPa/ °C), Rn= net radiation (MJ/ m^2 /day), G = heat flux density into and out of the soil (MJ/ m^2 /day), T= mean daily air temperature at 2 m above the ground surface [°C], U_2= wind speed at 2 m above the ground surface (m/s), es and ea are saturation and actual vapor pressure respectively (kPa), γ = psychrometric constant (kPa/°C). CROPWAT software version 8 [20] was applied for estimation of positional evapotranspiration according to (1).

The potential evapotranspiration (ETo) was converted to crop evapotranspiration (ETc) according to:

(2) $$ET_c = K_c \quad ET_o$$

Kc= average crop coefficient over the growing season.

2.4 Design Rainfall

The design rainfall was determined at each station by performing the following steps: 1) the total annual rainfall was obtained from each station for a length of record of 25 years; 2) the annual rainfall was ranked in descending order with rank (m) = 1 for the highest value and m = 25 for the lowest value; 3) the probability of occurrence of each ranked observation (P) was calculated according to the plotting position formula and as follows [13]:

(3) $$\mathrm{P} = \frac{1}{\mathrm{T}} = \left(\frac{\mathrm{m} - 0.375}{\mathrm{N} + 0.25}\right) \quad \mathrm{x}100$$

where: T= return period (years)

m = rank of observation

N= sample size

4) The annual rainfall was plotted versus the probability of occurrence, and the best fitting line was drawn; 5) the annual rainfall which corresponded to a probability of 66.67%. It represents the design depth or the total runoff depth of rainfall during the growing season at or above which the catchment area will offer the necessary water to satisfy the crop water demand.

2.5 Efficiency Factor

The efficiency factor is the fraction of runoff water utilized by the growing plants in the cultivated area. The source of water loss covers mainly evaporation and deep percolation. The value of this parameter ranges between 0.5 for macro catchment to 0.75 for micro catchment water harvesting [17]. A value of 0.75 was applied for the efficiency factor (E_F) as recommended by [21] for micro catchment water harvesting.

2.6 Runoff Coefficient

The runoff coefficient, Rc, represents the integrated effect of a host of factors such as land use/land cover, the nature of the surface, type of soil, antecedent soil moisture content, rainfall intensity, and rainfall duration etc. During the current study, the runoff coefficients were selected based on land use, land slope, and hydrologic soil group, the nature of the surface, surface slope, and rainfall intensity. Typical values of Rc were obtained for similar soil characteristics and land slope as outlined by [22].

2.7 Ratio of Catchment to Cultivated Area

The derivation of the equation for determining the catchment to cultivated area ratio (C: CA) was based on [11]:

$$V_h = V_a \tag{4}$$

where

Vh = Harvested volume of water

$$V_h = (DR * Rc * E_F)\ CA \tag{5}$$

$$V_a = (ET_c - DR)\ *\ C \tag{6}$$

Substituting (5) and (6) in (4) will give

$$(DR * R_c * E_F)\ CA = (ET_c - DR)C \tag{7}$$

By dividing both sides of (7) by CA (DR * RC* EF), the expression for C: CA becomes:

$$\frac{C}{CA} = \frac{(ET_c - DR)}{DR * R_c * E_F} \tag{8}$$

where

C = catchment area (L^2)

CA = Cultivated area (L^2)

ETc = Annual crop water demand (mm)

ETc = Annual crop water demand (mm)

DR = Design rainfall (mm)

Rc = Runoff coefficient (-)

E_F = Efficiency factor (-)

2.8 Spatial Distribution of the Input Variables and Ratio of Catchment to Cultivated Area Over the Study Area

A set of interpolation schemes has been applied to generate continuous surfaces for design rainfall and the ratio of catchment to cultivated area in a GIS environment by applying ArcMap version 10.8. The best interpolation scheme was selected among the applied schemes for preparing the final maps for the study parameters after ranking using the TOPSIS technique.

3. Results and Discussion

3.1 Characterization of the Climatic Variables across Erbil Plain and the Surrounding Areas

Table 1 shows the distribution of annual rainfall over the study area. As depicted in Table 1 and as mentioned earlier, the annual rainfall varies from as low as 232.98 mm in the southern part of the study area to as high as 745.24 mm in the northern part, and the annual rainfall for the remaining parts falls between these two extremes. It is also obvious from Table 1 that this parameter is characterized by being highly variable.

Table 1: Some statistical indices for spatial distribution of annual rainfall and annual potential evapotranspiration across Erbil plain and its peripheral areas

Parameter	Statistical Indices							
	Min	Max	Range	Mean	St. dev.	CV (%)	Skewness	Kurtosis
Annual rainfall	232.98	745.24	512.26	422.07	151.12	36.04	0.83	- 0.40
Annual potential evapotranspiration	1256.83	1843.38	586.54	1573.24	176.57	11.22	- 0.48	- 0.72

The coefficient of variation amounts to 36.04% (Table 1). Based on the classification scheme proposed by [23], the annual rainfall over the study area fell in the high variable class (CV > 30). These results are in concordance with the findings of [24] and [25] who observed that precipitation is characterized by a degree of variability over Duhok and Sinjar areas. It is also obvious from the above results that water availability tends to increase as one moves from south to north (Figure 2). Similar trends or spatial increases of water availability can be observed from west to east.

On the other hand, the potential evapotranspiration ranges from a minimum of 1256.83 mm at Khalifan station to a maximum of 1843.38 mm at Altun kupri location (Table 1). Unlike annual rainfall, annual potential evapotranspiration exhibited opposite trend. The evapotranspiration tended to decrease from south to north and from west to east. This parameter exhibited a lower spatial variability across the study area (11.22% versus 36.04%) (Table 1). Most of the variability potential evapotranspiration is due to variation in air temperature.

Not only rainfall is characterized by a high spatial variability but also characterized by high temporal variability with decreasing trends over most of the stations distributed over the study area. Investigation of the variability of rainfall and other climatic variables is important for decision makers for water management because rainfall is an essential factor controlling water availability in each area [26].

3.2 Runoff Coefficient Based on Hydrologic Soil Group and Land Slope

Table 2 displays the input factors required for calculating the ratio of catchment to cultivated area over three different land slopes, namely, 0 - 2%, 2 - 6 %, and > 6%, at different locations surrounding the stations within the study area. The soil surrounding the selected stations was put into different hydrologic groups based on soil texture, storage capacity, infiltration and water transmitting rates, degree of aggregation, and swelling potential. Most of the soils within the middle and upper parts were classified under soil hydrologic group C. The dominant soil texture of these parts is clay loam, silty clay loam, and silty clay. Conversely, most of the soils in the southern part of the study area fall within soil hydrologic group B with a lower runoff potential. The dominant soil textures of this part cover silt loam, sandy clay loam, and silty clay loam. The information about hydrologic groups over different subareas, along with the percent of slope, was utilized to identify runoff coefficients for different sites (Table 2) according to the procedure outlined by [22]. It is also obvious from Table 2 that the soils of group B offer a lower runoff potential compared to those of Group C for the same land slope. Furthermore, it can be noticed that the runoff coefficient tended to increase with an increase in land slope. The steeper slope gives rise to lower infiltration and consequently a higher runoff rate.

Table 2: Runoff coefficient based on hydrologic soil group and land slope

Hydrologic Soil Group	Land slope (%)		
	0 – 2	2 – 6	> 6
Soil group A	0.08	0.13	0.18
Soil group B	0.11	0.15	0.21
Soil group C	0.14	0.19	0.26
Soil group D	0.18	0.23	0.31

3.3 Crop Water Requirement (ETc)

Table 3 presents the average crop coefficients over the growing period from November 1st to June 1st for the upper and lower parts of the study area. The mean of these two values was used as the average crop coefficient for the central part of the area under investigation. The monthly potential evaporation was calculated at each station according to the Penman-Monteith method and was summed up during the indicated period to obtain the potential evapotranspiration during the winter growing season over different parts of the study area. The crop water demand was obtained after multiplying the potential crop evapotranspiration by the weighted crop coefficient during the indicated period.

Table 4 in section 3.5 exhibits the crop water demand for the principal winter crops, specifically for wheat. The results indicated that the crop water demand varied from a minimum of 373.27 mm at Akre to a maximum of 594.67 mm at Altun Kupri, and the values of these parameters at the remaining stations fell between these two extremes.

Table 3: Calculation of annual crop coefficient for the southern and northern parts of the study area

Part	**Variable**	**Month**							**Source of data**
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Nov**	**Dec**	
Southern	**Monthly crop coefficient (Kci)**	0.87	1.1	1.17	1.03	0.6	0.58	0.65	[23]
	Weight (Wi)	0.146	0.132	0.146	0.142	0.146	0.142	0.146	
	Ki* Wi	0.127	0.145	0.171	0.146	0.088	0.082	0.095	
	Annual Kc	**0.854**							
Northern	**Monthly crop coefficient (Kci)**	0.91	1.14	1.15	1.06	0.51	0.53	0.58	[24]
	Weight (Wi)	0.146	0.132	0.146	0.142	0.146	0.142	0.146	
	Kci * Wi	0.133	0.151	0.168	0.150	0.075	0.075	0.085	
	Annual Kc	**0.836**							

3.4 Design Rainfall

Another input factor for designing a micro catchment water harvesting design is design rainfall. Design rainfall (DR) refers to the total depth of rain during the growing season of crops at or above which the sacrificed area supplies enough runoff water to meet the crop water need [13]. The calculation of this parameter was based on rainfall records at the meteorological stations for a record length of 25 years. It is also apparent from Table 4 of section 3.5 that the design rainfall ranges from as low as 176.43 mm at Altun Kupri station to as high as 617.37 mm at Shaqlawa station. The obtained values of design rainfall at each station are the annual rainfall at a probability level of 67 percent. This implies that on average, in 67 percent of the time (two out of three years), the recorded values of annual rainfall in Table 4 would be equaled or exceeded. The results also indicated that at 4 stations, the design rainfall exceeded the crop evapotranspiration for cereal winter cropping. This implies that at Akre, Qasrok, Khalifan, and Shaqlawa, there is no need for runoff farming. It is interesting to note that there will be a risk of the failure of the grown crops when the rainfall is less than the design rainfall. Under this situation, the design rainfall must be based on a higher probability to increase the reliability of the runoff farming design [13].

3.5 Ratio of Catchment to Cultivated Area (C: CA)

Table 4 also illustrates the calculation of a universal parameter for designing a micro catchment. Water harvesting or the ratio of catchment to cultivated area at different sites within the study area, under three possible land slopes for the existing cultivated areas at each location. The calculation is based on the fact that the amount of harvested water must be equal to the additional water needed to ensure the wheat crop's water demand. The input variables for this ratio were crop water demand, design rainfall, runoff coefficient, and efficiency factor. The values of the variables were also available in Table 4. It is evident from Table 4 that this ratio varied from a minimum of -3.18 at Khalifan to a maximum of 28.73 at Altun kupri under the land slope of 0 - 2%, and from a minimum of -2.34 at Khalifan to a maximum of 21.07 at Altun kupri under the land slope of 2 - 6%, and from -1.71 at Khalifan to 15.05 at Altun kupri under the land slope of > 6%. It is noteworthy to note that irrespective of land slope, the minimum and maximum values of C: CA were found at Khalifan and Altun Kupri, respectively. The negative values of this parameter at some locations, such as Akre, Khalifan, Qasrok, and Shaqlawa, reflect that there is no need to sacrifice additional land for harvesting water due to the fact that the design rainfall exceeded the crop water demand. Moreover, the results indicated that the value of this ratio converges to zero at the Harir location. At this location, the average annual rainfall amounted to about 570 mm over the last two decades. These results approximately indicate that extra water is not needed for locations with annual rainfall of 570 mm or more.

It is also obvious from Table 4 that the ratio is significantly affected by land slope. The increase in land slope gave rise to a significant reduction in the value of this parameter.

As shown in Table 4, the majority of the locations possess a C: CA ratio in the range of 2-20. These results are in concordance with the findings of [29], who observed that in general, the ratio can vary between 1:1 to 20:1 depending upon several factors such as the site conditions, rainfall amount, and crop water requirement. Additionally, it can be noticed that the majority of the ratio values are less than 4:1 over land slopes of > 6%

It is recommended to practice the runoff farming on slopes in the range of 6-10% to lessen the area of sacrificed lands on one hand and to reduce the rate of soil erosion in case of practicing this activity on steeper slopes on the other hand.

Table 4: Ratio of catchment to cultivated area over different land slopes surrounding different stations over Erbil plain and its peripheral areas

No.	**Station**	**Design rainfall (mm)**	**Crop water demand, ETc (mm)**	**Efficiency factor**	**Hydrologic Soil Group for the area surrounding the stations**	**Runoff Coefficient for the area with land slope percents of**			**Ratio of catchment to cultivated area, C: CA, over land slope percents of**		
						0.0 -2.0	**2.0 - 6.0**	**> 6.0**	**0.0 -2.0**	**2.0 - 6.0**	**> 6.0**
1	Ainkawa	288.69	457.21	0.75	C	0.14	0.19	0.26	5.56	4.10	2.99
2	Akre	485.36	373.27	0.75	C	0.14	0.19	0.26	-2.20	-1.62	-1.18
3	Altun kupri	176.43	594.67	0.75	B	0.11	0.15	0.21	28.73	21.07	15.05
4	Aski Kalak	255.78	511.80	0.75	B	0.11	0.15	0.21	12.13	8.90	6.35
5	Bardarash	308.86	450.60	0.75	C	0.14	0.19	0.26	4.37	3.22	2.35
6	Bastora	355.96	507.18	0.75	C	0.14	0.19	0.26	4.05	2.98	2.18
7	Bnaslawa	276.20	454.00	0.75	C	0.14	0.19	0.26	6.13	4.52	3.30
8	Dibaga	236.16	562.07	0.75	B	0.11	0.15	0.21	16.73	12.27	8.76
9	Erbil	261.26	459.11	0.75	B	0.11	0.15	0.21	9.18	6.73	4.81
10	Gwer	233.91	528.20	0.75	B	0.11	0.15	0.21	15.25	11.18	7.99
11	Harir	419.87	423.16	0.75	C	0.14	0.19	0.26	0.07	0.06	0.04
12	Khalifan	562.69	374.77	0.75	C	0.14	0.19	0.26	-3.18	-2.34	-1.71
13	Koya	439.50	492.64	0.75	B	0.11	0.15	0.21	1.47	1.07	0.77
14	Makhmur	199.81	571.15	0.75	B	0.11	0.15	0.21	22.53	16.52	11.80
15	Qasrok	500.45	410.02	0.75	C	0.14	0.19	0.26	-1.72	-1.27	-0.93
16	Qushtapa	262.60	545.81	0.75	B	0.11	0.15	0.21	13.07	9.59	6.85
17	Shamamk	254.34	535.85	0.75	B	0.11	0.15	0.21	13.42	9.84	7.03
18	Shaqlawa	617.37	431.65	0.75	C	0.14	0.19	0.26	-2.87	-2.11	-1.54
19	Taqtaq	333.58	537.81	0.75	B	0.11	0.15	0.21	7.42	5.44	3.89

3.6 Spatial Distribution Catchment to Cultivated Area Ratio and Some Related Climatic Variables

Figures 2 through 4 portray the spatial distribution of the ratio of catchment to cultivated area as affected by land slope over the study area, with the main objective of determining C: CA at unsampled locations. The IDW technique was selected to generate continuous surfaces in a GIS environment after examining several polynomial methods, including the Kriging method.

As can be noticed in Figures 2 through 4, the ratio at given land slope tended to decrease progressively from south to north and to some extent from west to east. It is interesting to note that the spatial distribution under different land slopes exhibited similar trends. It is also evident from Figure 5 that the annual rainfall exhibited opposite trends. On the other hand, it was noticed that the spatial distribution of annual evapotranspiration was in par with that of the ratio (Fig. 6). Moreover, it can be concluded that these trends are closely related to geographical coordinates, mainly latitude. Similar results were obtained for the spatial distribution of climatic variables by other researchers over some parts of the Iraqi Kurdistan region [24] and [30]. It is also commendable to mention that the displayed results are reliable for application over the Erbil plain, but not over areas bordering this plain, because limited stations were used for generating continuous surfaces.

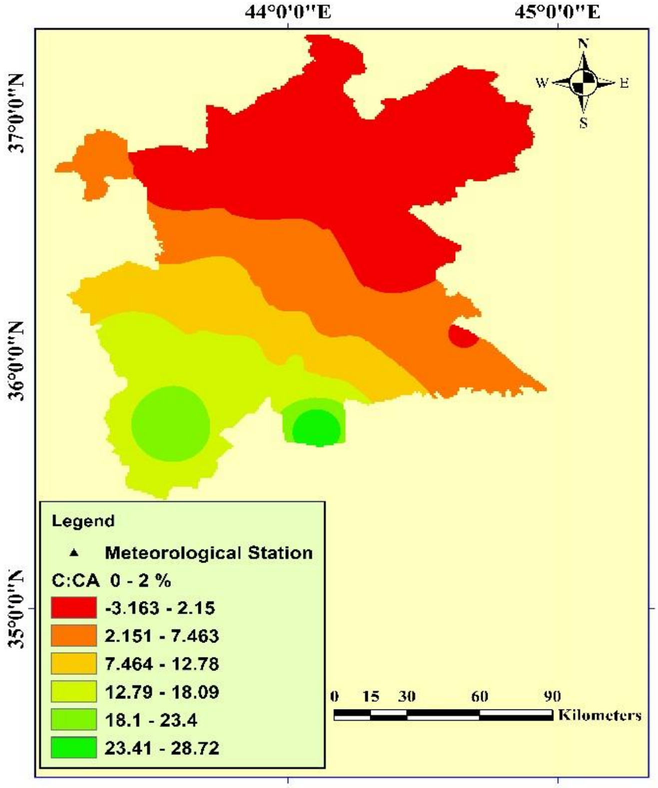

Figure 2: Spatial distribution of the ratio of catchment to cultivated area for sites with land slopes of 0 – 2% over the study area

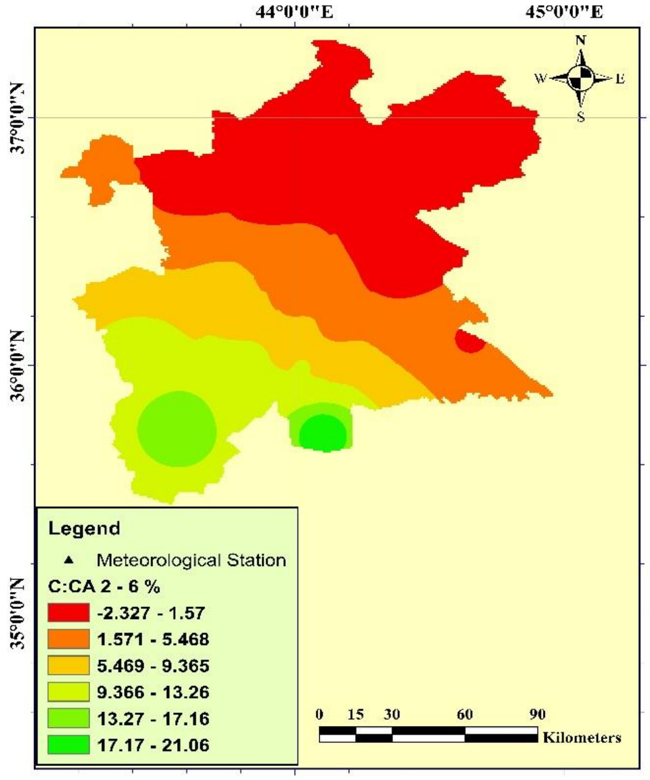

Figure 3: Spatial distribution of the ratio of catchment to cultivated area for sites with land slopes of 2 – 6% over the study area

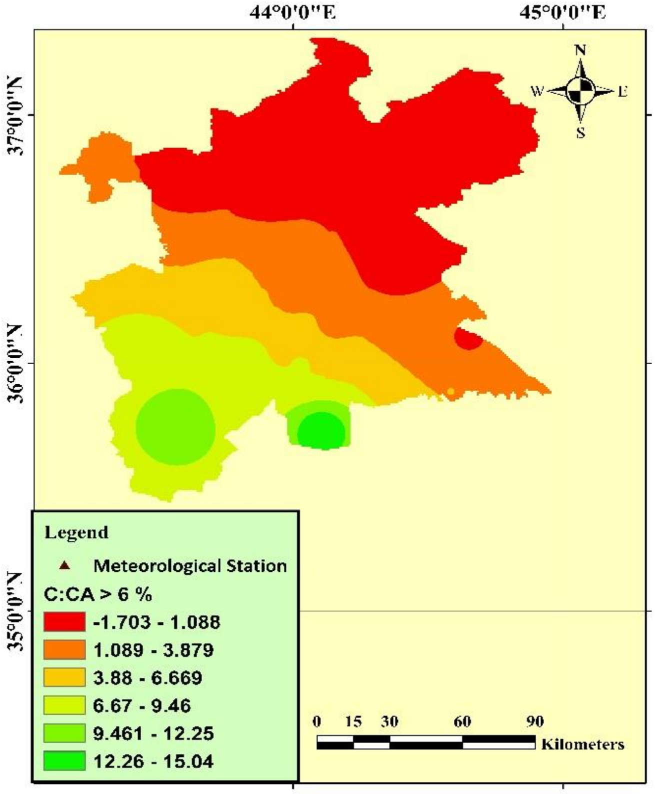

Figure 4: Spatial distribution of the ratio of catchment to cultivated area for sites with land slopes of > 6% over the study area

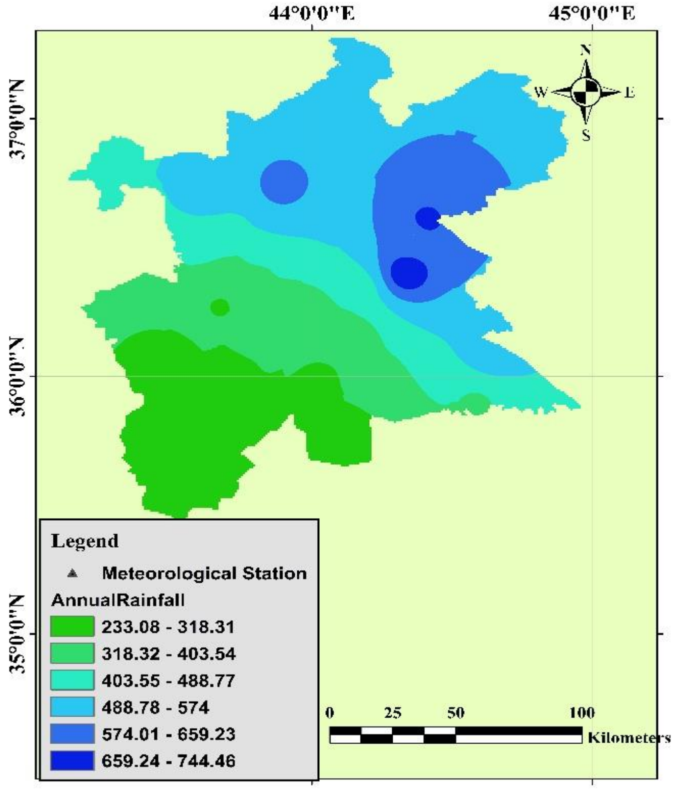

Figure 5: Spatial distribution of annual rainfall over the study area

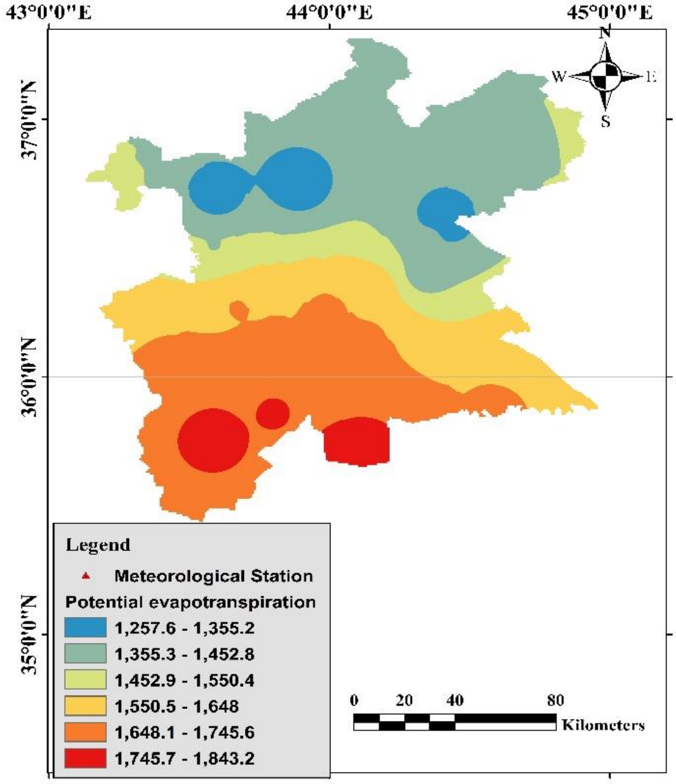

Figure 6: Spatial distribution of annual evapotranspiration over the study area

3.7 Pearson's Correlation Coefficients for the Relationship Between Ratio of Catchment to Cultivated Area

Table 5 exhibits the correlation between the ratio of catchment to cultivated area over different land slopes and each of longitude, latitude, altitude, design rainfall, seasonal crop evapotranspiration, annual rainfall, and annual potential evapotranspiration. As can be seen in Table 5, the ratio at a given slope is negatively and highly significantly correlated ($P < 0.05$) with each of longitude, latitude, altitude, design rainfall, and annual rainfall. Conversely, it was positively correlated with seasonal crop evapotranspiration and annual potential evapotranspiration. The seasonal crop evapotranspiration (ETc) exhibited the strongest positive correlation with C: CA ($r = 0.893$). On the contrary, the longitude exhibited the poorest negative correlation with C: CA ($r = - 0.449$). Linear multiple regression analysis showed that 84% of the variation in C: CA can be attributed to variation in latitude and annual rainfall (Fig. 7). on average the error of prediction, represented by mean absolute error was 1.26 when the runoff farming is practiced on slopes in the range of 6 -10%.

$$(9) \qquad C{:}CA = 344.27 - 9.25\,\text{Latitude} - 0.011\,\text{Annual rainfall} \qquad N= 19, \qquad R^2= 0.84$$

Table 5: Pearson's correlation coefficient for the relationship between each of the ratios of catchment to cultivated area with geographical coordinates and some climatic variables over the study area

Ratio of catchment to cultivated area for different slopes	Longitude (Degree decimal)	Latitude (Degree decimal)	Altitude (m)	Design rainfall (mm)	Seasonal ETc (mm)	Annual ETo (mm)	Annual rainfall (mm)
CA: C on slope of 0-2%	- 0.435	- 0.590	- 0.778	- 0.880	0.893	0.879	- 0.884
CA: C on slope of 2-6%	- 0.434	- 0.589	- 0.778	- 0.877	0.893	0.877	- 0.882
CA: C on slope of > 6%	- 0.434	- 0.589	- 0.777	- 0.877	0.893	0.877	- 0.882

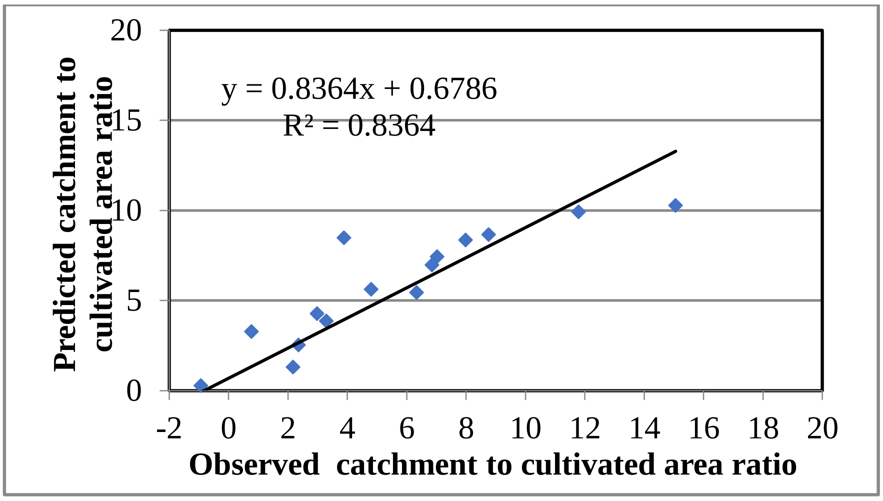

Figure 7: Plot of observed catchment to cultivated area ratio versus predicted value from a multiple linear model

4. Conclusions

The annual rainfall is an effective factor influencing winter crop productivity over the study area and is characterized by being highly variable in space and time. The average annual rainfall tends to increase gradually from south to north and from west to east. Runoff farming is a useful technique for enhancing crop production for sites with an average annual rainfall of less than 500 mm. The ratio of catchment to cultivated area ranges from a minimum of -3.18 to a maximum of 28.73. More than 60% of the investigated sites are in need of a ratio of less than 5:1 over land slopes of 6-10%.

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