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RESEARCH PAPER

Hydrometeorological Data Analysis and Drought Indices of Rawandoz Area, Iraqi-Kurdistan Region

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A B S T R A C T:
Water balancing techniques are strategies for resolving key theoretic and applied hydrologic challenges. The primary goals of the study are to examine the climatic characteristics and conditions that will be utilized in the water balancing approach used in the Rawandoz located in northeastern Iraq. The meteorological data from Soran meteorological station's 2000 to 2020 were applied to analyze the climate patterns of the research region. The mean for annual rainfall and evaporation were 550.50 and 1490.80 mm respectively. The average monthly humidity, temperature, and sunshine remained 73.8 percent, 18.50 °C, and 8 hours/day, respectively. The Kharrufa technique has been calculated the potential evapotranspiration (PET), water deficit and surplus and the Soil Conservation Service method (SCS) has been used to calculate surface runoff (Rs). The annual potential evapotranspiration, water surplus, and deficit are calculated to be 1900.27 mm, 430.10 mm, and 1579.90 mm, respectively, with an annual runoff of 376 mm. The rainfall index (SPI) was developed to quantify climatic dryness across a range of time; the average value is 0.562, indicating that the area is wet. The results of many climate classification reveal that the study area in humid to moist climate classification.

KEY WORDS: Evapotranspiration; Surface Runoff; Drought Indices; Rawanduz area.
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1.INTRODUCTION:

Climate is among the most essential environmental components in which humans live, owing to its effect on human health and comfort, as well as the economic effects, agricultural challenges, and all other human activities (Marius Lungu et al., 2011). There are numerous characteristics that determine the qualities of the climate system, such as air temperature, precipitation, sunshine, relative humidity percentage, and evaporation. The hydrological conditions and climate are influenced by morphology, soil type, and other variables (Vu et al. 2018). According to Koppen classification, the Kurdistan region's climate is dry and semi-arid. Summers are hot and dry, while winters are cold and wet, with spring and autumn seasons being shorter than summer and winter (Keller et al., 2019).

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Using the water balance technique, a quantitative study of water supplies and their changes is possible. Understanding water balance is crucial in the hydrological cycle because it allows the connection between rainfalls and total loss of water in various forms to be calculated. Climate variance in any area has become more interesting all around the world, because to its impact on human everyday activities (Ghahraman, 2007).

The autonomous area of Iraqi Kurdistan is mostly dependent on climatic conditions in agriculture, architecture, road constructions, building design, and other industries. This study will determine the meteorological drought conditions, and it is hoped that this will help agriculture, livestock, water resource sectors, and engineers understand better the region's climate and recognize the past and future status of climatic parameters, particularly those related to droughts, and which will help agriculture, livestock, water resource segments, and engineers improve planning and mitigation of drought hazards (Tadesse et al., 2004).

In the studied area the climatic data are being compiled by using the Agro-meteorological data about Soran station. The Soran meteorological station located at (36° 39' N) and (44° 32' E) and an elevation of (680 m a.s.l). The data of the period (2000-2020) used to determine the meteorological parameters for the study region.

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2. THE STUDY AREA

The study area is located around 110 kilometers northeast of Erbil. Longitudes and latitudes of (44°30'E and 45°0'E) and (36°20'N and 36°50'N) were used to define the region. The total area of the region is 977.68 km2 (Fig. 1). The research area is divided into three major tectonic zones (High Folded Zone to Imbricate Zone and Zagros Suture Zone). The study region is bordered by four mountains: Korek mountain in the southern, Handreen mountain in the eastern, Zozik mountain in the northern, and Bradost mountain in the western. (Jassim and Goff, 2006).

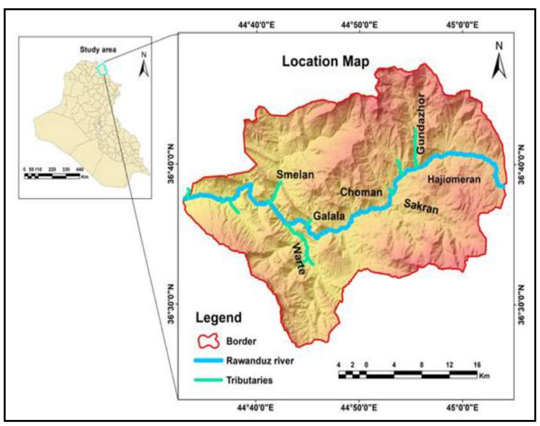
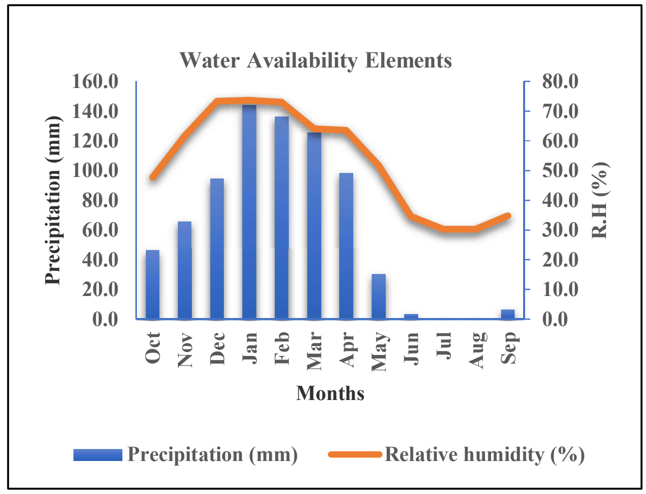


Figure 1: location map of study area.

3. MATERIALS AND METHODS

3.1 Water Availability Parameters

Climatic data have been used to compute the average monthly, seasonal, and annually rainfall, standard deviation, and coefficient of determination of the studied region. The most critical characteristics determining water availability are rainfall and relative humidity. Meteorological data from the Soran meteorological station in duration of (2000-2020) show that the highest and lowest average monthly relative humidity of 73.8 and 33.9% were recorded in January and July, respectively (Table 1 & Fig. 3). The highest and lowest annual rainfall



(1010 and 540mm) were recorded in 2002 and 2008 respectively. The average annual rainfall is about (750.50 mm) (Fig. 2 & 3).

Figure 2: Association between average monthly rainfall (mm) and R.H% during (2000-2020) in the area.

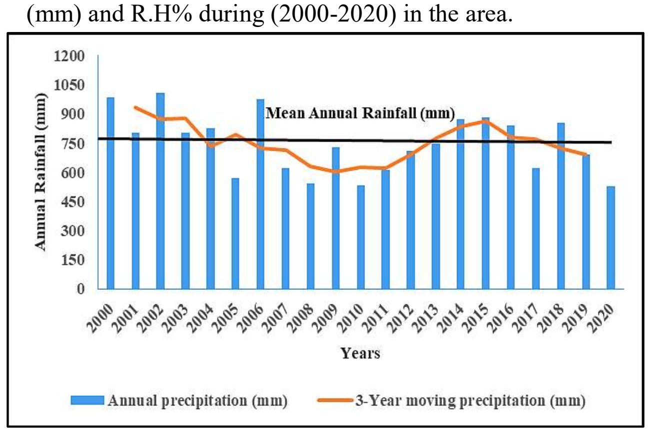


Figure 3: Three year moving precipitation and mean annual precipitation during (2000-2020) in the area.

Table (1) Average monthly rainfall and relative humidity during (2000-2020) in the area.

Months	**Oct.**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Rainfall (mm)	46.21	65.52	94.28	143.97	136.20	125.24	98.23	30.06	3.51	0.33	0.40	6.52
R.H %	47.72	61.68	73.33	73.71	73.02	64.06	63.53	51.78	34.66	30.24	30.26	34.86

Generally, we can calculate the consistency or uniformly of the rainfall data specially depending on the main seasons. In overall, a set of data with a high coefficient of variation suggests that the group is more variable, less stable, and less uniform. A low coefficient of variation shows that the group is less changeable and more stable or homogenous. The coefficient of determination has been used to assess data consistency. According to (Table 2 and Fig 4), the coefficient of determination of three main seasons such as (Autumn, Winter, and Spring) suggesting that the C.V values of winter and spring are less and the precipitation of winter and spring months were practically consistent and steady in their quantities. Winter and spring precipitation seems to be the most efficient for generating flow in the Rawandoz stream, which implies also that river discharge would have the same uniformity and consistency.

Table (2) Mean, Standard Deviation, and Coefficient of Seasonal Rainfall Variation during (2000-2020) in the area.

Years/Seasons	**Months**	**Mean**	**Standard Deviation**	**Coefficient variation (%)**
Autumn				
2000-2020	Sep	118	91	79
	Oct			
	Nov			
Winter				
2000-2020	Des	375	85	23
	Jan			
	Feb			
Spring				
2000-2020	Mar	254	71	28
	Apr			
	May			

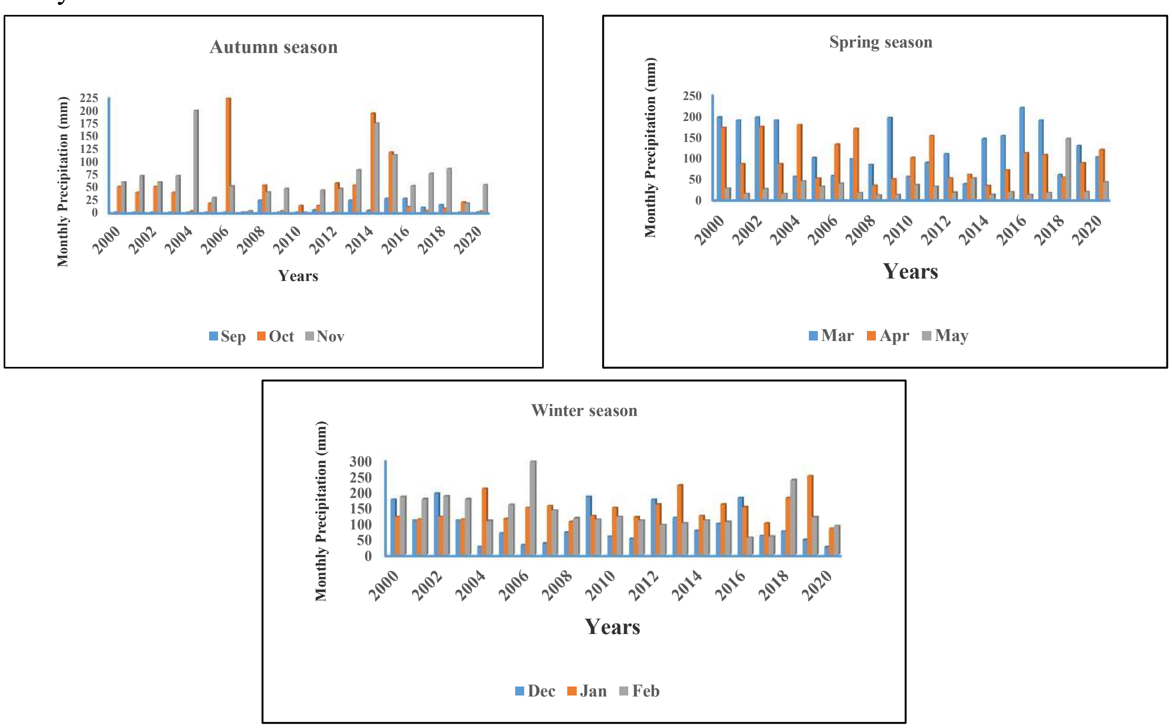


Figure 4: Seasonal Rainfall variation for the period (2000-2020) in the study area.

3.2 Water Losses Parameters

This characteristic includes temperature (T°C), wind speed (m/sec), sunshine (hr/day), and evaporation (mm). Temperature has a considerable influence on both evaporation and evapotranspiration. Plant growth and temperature have a strong relationship, with plants reacting to temperature limits that allow them to perform their activities (Thornthwaite, 1944). The highest and lowest average monthly temperatures in the study area are 32.07 °C and 4.86 °C in August and January, individually, although, the average annual temperature is 18.50 °C. The study region has a maximum average monthly sunshine of 12.40 hours/day in July and a minimum average monthly sunshine of 3.89 hours/day in February, with an average annual sunshine of 8 hours/day. The maximum monthly evaporation is 285 mm in July, while the minimum monthly evaporation is 16.50 mm in January, with an overall annual evaporation of 1497.80 mm (Table 3 and Fig 5).

Table (3) Mean monthly water losses element for the period (2000-2020) in the study area

Months	Oct.	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Temperature (℃)	20.51	12.97	7.18	4.86	7.00	11.95	16.35	21.90	28.28	31.67	32.07	27.33
Sunshine (m/day)	6.92	6.53	4.64	4.65	3.89	5.77	5.55	10.33	12.15	12.40	11.86	10.78
Wind speed (m/sec)	1.85	1.38	1.37	1.53	1.58	2.70	2.62	2.34	2.41	2.36	2.38	2.27
Evaporation (mm)	112.63	38.30	17.69	16.50	25.66	61.42	93.44	147.52	245.16	284.97	265.60	188.89

depending on the known meteorological data information to analyze the area (Aqrawi, 2003)

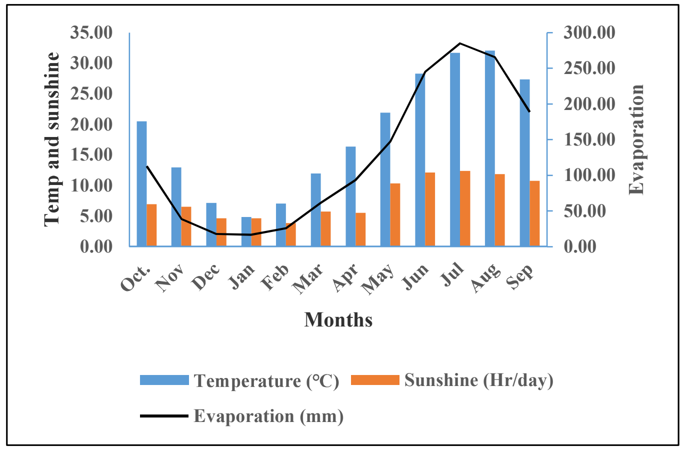


Figure 5: Association between mean monthly Temperature (℃), Sunshine (hr/day) and Evaporation (mm) during (2000-2020) in the area.

3.3 Water Balance Techniques

3.3.1 Evapotranspiration

Evaporation is the process by which liquid or solid precipitation that reaching the surface is converting to in to the water vapor and returned to the atmosphere. Transpiration is the process by which plants lose water. Due of the difficulty in distinguishing these two functions, the name evapotranspiration is widely used to explain the two major related processes. PET could be estimated utilizing temperature-based methodologies for evaluating evapotranspiration

PET could be estimated utilizing temperature-based methodologies for evaluating evapotranspiration depending on the known meteorological data information to analyze the area (Aqrawi, 2003). Kharrufa developed a modest formula for calculating PET values according to the correlation between temperature and sunshine duration (Kharrufa, 1985), and the equation is as follows:

$$\mathbf{PET = 0.34\, \rho\, T^{1.31}} \qquad \ldots\ldots\ldots\ldots\ldots (1)$$

Where T: is the average monthly temperature in °C, and ρ: is the percentage of overall sunshine hours in each month to overall sunshine hours in the year.

3.3.2 Water Surplus and Water Deficit

The areas with a water surplus (WS) have precipitation volume more than potential evapotranspiration over a specific period, and conversely in situation of a water deficit (WS), and the following equations were established:

WS = P - PET if P > PET …... (2)
WD = PET – P if PET > P ……… (3)
WS% = (WS / P) * 100 ……...... (4)
WD% = 100 – WS% ……….. (5)

Where WS: is water surplus, WD: is water deficit, P: is rainfall, and PE: is potential evapotranspiration.

3.3.3 Surface Runoff (Rs)

Surface runoff, often known as overland flow, is the discharge of precipitation from a watershed via its natural drainage system (Anderson and Mc Donnell, 2005). It is one of the most important hydrologic parameters used in the large majority of water resource uses. Surface runoff is computed from known precipitation data and the soil conservation system (SCS) method (Jawad and Washeed, 1986). The empirical rainfall-runoff relationship is as follows:

Q = (P – 0.2S)2 / P + 0.8 S ……… (6)

Where; Q: is runoff surface (mm); P: is monthly precipitation (mm); S: is retention including the initial abstraction [S = 1000/CN – 10]; CN: is Curve number.

Given the fact that detailed info on the vegetation cover and soil is available, this method is utilized. The approach developed from a large number of monthly precipitation records, besides various soil and cover combination. (Fig 6). The SCS technique was used with four soil classifications (hydrologic soil groups) (Table 4).

Table (4) Hydrologic soil classifications depending on infiltration rates (Maidment, 1993).

Group types	Infiltration rate cm/h	Runoff rate	Soil description
A	≥ 0.76	Low	Sands or gravels
B	0.38 – 0.76	Moderate – Fine	Silt loam and loam
C	0.13 – 0.38	Fine – High	Sandy clay loam
D	0.0 – 0.13	High	Clay loam, silty clay loam, sandy clay, silty clay and clay

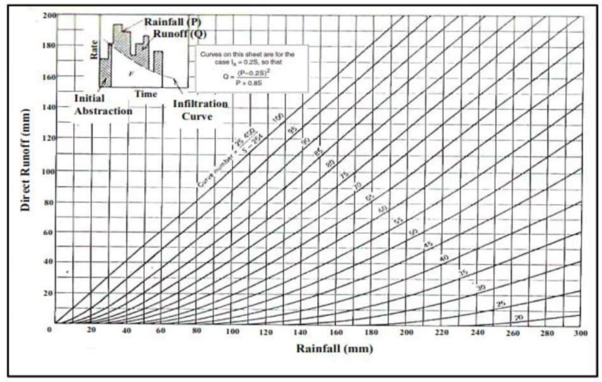


Figure 6: Graph representing the association of surface runoff-precipitation (after SCS, 1971, in Hammer and Mackiehan, 1981).

4. Climate Classification

Many climatic index classifications would be analyzed to evaluate the type of climate in the research region, according to Kharrufa result value, the following climatic index are:

4.1 De Martonne's (1970)

This method depending on rainfall and temperature elements to determine the aridity index (A) (Serhat and Mesut, 2010). This method which could be calculated as follows (Peguy, 1970, p.331):

A = P / T + 10 …………………. (7)

Where; P: the annual mean of precipitation in (mm). T: the annual mean of temperature (°C).

4.2 N.N. Ivanove (1985)

Ivanove developed a climatic categorization based on evapotranspiration, from which we may compute evapotranspiration (PET) as shown:

$$PET = 0.0018*(25 + T)^2 (100 - Rh) \quad ……(8)$$

Where T is the daily average air temperature (°C), and Rh is relative humidity (%).

Then, we can estimate the moisture Factor (Mi) which Ivanove put it as shown:

MI = P / PET .... **(9)**

4.3 Bailey (1960)

We may estimate the moisture index (Mi) from this method as follows:

Mi = P / (1.025) t ....**(10)**

Where: P: the accumulation of the monthly precipitation (inches).t: Monthly temperature average.

4.4 Al-Kubaisi (2004)

This method represent an annual dryness technique depended on rainfall and temperature. Also, to determine climatic type using the following equation:

AI-1= (1*P) / (11.525*t) ....**(11)**

AI-2 = 2 √P / t ....**(12)**

Where: AI: is aridity index; P: is annual precipitation (mm); t: is temperature (C°).

5. Drought Analysis

Climate change and variability seem to be the most important environmental and worldwide hazards of the twenty-first century (Edame et al., 2011). The global climate is changing with incredible rate in recent human history (Thornton et al., 2006). The average worldwide surface temperature has risen by 0.6°C (0.4°C to 0.8°C) over the last 100 years, according to Houghton (2001) study. The main reason for droughts occurring is complex because they focus not only on the environment, but also on hydrological processes (Mishra and Singh, 2010). Drought monitoring is typically done using indices. The Standardized Precipitation Index (SPI) was used to assessment drought analysis in the study area during (2000-2020). The SPI is calculated for any area based on the long-term precipitation data for an objective time (3 months, 6 months, etc.). This important element is assigned to a probability distribution and then transformed into a normal distribution with the goal of achieving a mean SPI of zero for the location and time specified. The SPI equation is the following below used to calculate the yearly (12-months) for the period (2000-2020) from the following formula:

SPI = (P-P⁻) / S.D .... **(13)**

Where: SPI: Standardized precipitation index; P: Annual rainfall (mm); P-: Mean annual rainfall (mm); S.D: Standard deviation.

6. RESULTS AND DISCUSSION

6.1 Evapotranspiration

Water flow from the cultivation of crops to the atmosphere. Actual evapotranspiration (AE or AET) and prospective evapotranspiration are the two forms of evapotranspiration. In AE, the variables that cause real water to be discharged from a surface are evaporation and transpiration. PET, on the other hand, is a measurement of the climate's tendency to evacuate water from the surface through transpiration and evaporative disintegration while assuming without influence over water supply. According to Kharrufa (1985), the evapotranspiration statistics are representing in the Table 5 and Fig 7. The annual overall evapotranspiration is 1900.27 mm. The water surplus and water deficit estimation show in the Table 6.

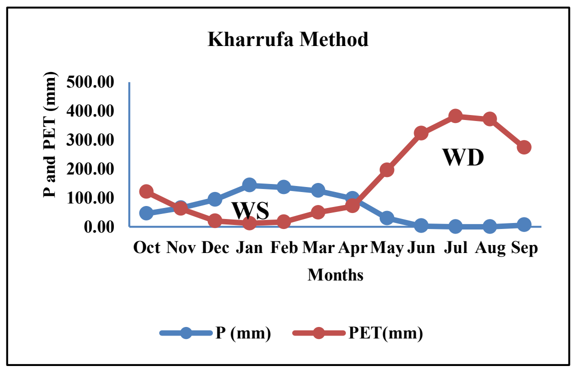


Figure 7: average monthly water surplus and water deficit as a result of Kharrufa (1985) method.

Months	T (°C)	ρ	P (mm)	PET (mm)
Oct	20.51	6.92	46.21	120.64
Nov	12.97	6.53	65.52	62.45
Dec	7.18	4.64	94.28	20.47
Jan	4.86	4.65	143.97	12.30
Feb	7.00	3.89	136.20	16.62
Mar	11.95	5.77	125.24	49.58
Apr	16.35	5.55	98.23	71.98
May	21.90	10.33	30.06	196.29
Jun	28.28	12.15	3.51	322.82
Jul	31.67	12.40	0.33	381.90
Aug	32.07	11.86	0.40	371.49
Sep	27.33	10.78	6.52	273.73
Average	**18.51**			
Total			**750.47**	**1900.27**

Table (5) Potential evapotranspiration values considered by

Months	P(mm)	PET (mm)	APE	WS	WD
Oct	46.2	120.6	46.2		74.4
Nov	65.5	62.4	62.4	3.1	
Dec	94.3	20.5	20.5	73.8	
Jan	144.0	12.3	12.3	131.7	
Feb	136.2	16.6	16.6	119.6	
Mar	125.2	49.6	49.6	75.7	
Apr	98.2	72.0	72.0	26.2	
May	30.1	196.3	30.1		166.2
Jun	3.5	322.8	3.5		319.3
Jul	0.3	381.9	0.3		381.6
Aug	0.4	371.5	0.4		371.1
Sep	6.5	273.7	6.5		267.2
Total	**750.50**	**1900.30**	**320.40**	**430.10**	**1579.90**
				WS% = 57.31%	**WD% = 42.69%**

Kharrufa method during (2000-2020) in the area.

Table (6) calculated the water deficit and water surplus from Kharrufa method result values.

6.2 Surface Runoff (Rs)

Surface runoff, also known as overland flow, is the discharge of rainwater from a watershed into its natural drainage system (Anderson, 2005). According to soil classification map from Ministry of Agriculture-Iraq, the soil of study area is clay to clay-loam and the vegetation cover during rainy season consist of higher coverage of grassland, then according to these conditions, the soil is in class D type and the annual surface runoff is 376 mm/year (Table 7 and Fig 8).

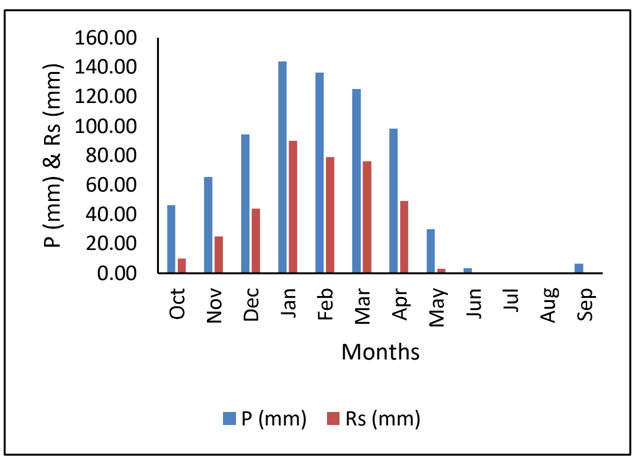


Figure 8: Graph shows the relation between rainfall and surface runoff (Rs) in the area.

6.3 Climate Classification

To establish the kind of climate in the Rawandoz region, climate has been classified using several approaches such as H. Bailey (1960), De Martonne's (1925), N.N. Ivanove (1985) and Al-Kubaisi (2004). The calculation of climate which is summarized in the (Table 8, 9, 10 and 11).

Table (8) Type of climate classification according to H. Bailey (1960) in the area for during (2000-2020).

Moisture Factor (Mi)	Climate Types	Category	Dry index in the study area
<2.5	Dry	E	18.71
2.5-4.7	Semi dry	D	
4.7-8.7	Semi humid	C	
8.7-16.2	Humid	B	
>16.2	Very humid	A	

Table (9) Type of climate classification according to De Martonne's (1925) in the area during (2000-2020).

Dry Index (A)	Climate Types	Dry index in the study area
>5	Dry	26.32
5-10	Semi dry	
10-20	Semi humid	
20-30	Humid	
>30	Very humid	

Table (10) Type of climate classification according to N.N. Ivanove (1985) in the area during (2000-2020).

Moisture Factor (Mi)	Climate Types	Dry index in the study area
>0.12	Very dry	4.71
0.12-0.30	Dry	
0.30-0.60	Semi dry	
0.60-1	Semi humid	
1-1.50	Humid	
>1.50	Very humid	

Table (7) Surface runoff calculation in the study area due to curve number for the period (2000-2020).

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
P (mm)	46.21	65.52	94.28	143.97	136.20	125.24	98.23	30.06	3.51	0.33	0.40	6.52	750.47
Rs (mm)	10	25	44	90	79	76	49	3	0	0	0	0	376.00

Table (11) Type of climate classification according to Al-Kubaisi (2004) in the area during (2000-2020).

Climate Type-1	Evaluation	Climatic Type -2	Evaluation
AI-1 > 1.0	Humid to Moist	AI-2 > 4.5	Humid
		2.5 < AI-2 < 4.0	Humid to Moist
		1.85 < AI-2 < 2.5	Moist
		1. 5 < AI-2 < 1.85	Moist to Sub-Arid
AI-1 < 1.0	Sub-Arid to Arid	1.0 < AI-2 < 1.5	Sub-Arid
		AI < 1.0	Arid
In study area= 3.52		In study area= 2.84	

6.4 Drought Analysis

The SPI is calculated for any location depended on the long-term precipitation data for an objective time (3 months, 6 months, etc.). The SPI equation is the following below used to calculate the yearly (12-months) for the period (2000-2020) (Table 12 &13 and Fig 9):

Table (13) Frequency of drought classification based on the SPI value (McKee et al. 1993)

SPI rang values	Category	Frequency	%
>2	Extremely wet	----	----
1.5 to 2	Severely wet	----	----
1 to 1.5	Moderately wet	1	5
0.5 to 1	Wet	3	15
0 to 0.5	Normal	9	45
0 to -0.5	Normal		
-0.5 to -1	Moderately dry	4	20
-1 to -1.5	Dry	2	10
-1.5 to -1.99	Severely dry	1	5
≤ -2	Extremely dry	----	------

Table (12) SPI value result in the study area for the period (2000-2020).

Years	Annual Rainfall (mm)	SPI	Standard interpretation	Years	Annual Rainfall (mm)	SPI	Standard interpretation
2000	498.5	-1.04	Dry	2016	840	0.42	Normal
2001	565.8	-0.75	Moderately Dry	2017	619.5	-0.52	Normal
2002	811.2	0.29	Normal	2018	856.3	0.49	Wet
2003	991.6	1.06	Moderately Wet	2019	691.6	-0.22	Normal
2004	580.8	-0.69	Moderately Dry	2020	529	-0.91	Moderately Dry
2005	716.3	-0.11	Normal				
2006	563.3	-0.76	Moderately Dry				
2007	765.1	0.10	Normal				
2008	337	-1.73	Severely Dry				
2009	490.1	-1.08	Dry				
2010	640.9	-0.43	Normal				
2011	612.6	-0.55	Moderately Dry				
2012	711.6	-0.13	Normal				
2013	748	0.02	Normal				
2014	871.2	0.55	Wet				
2015	882.8	0.60	Wet				

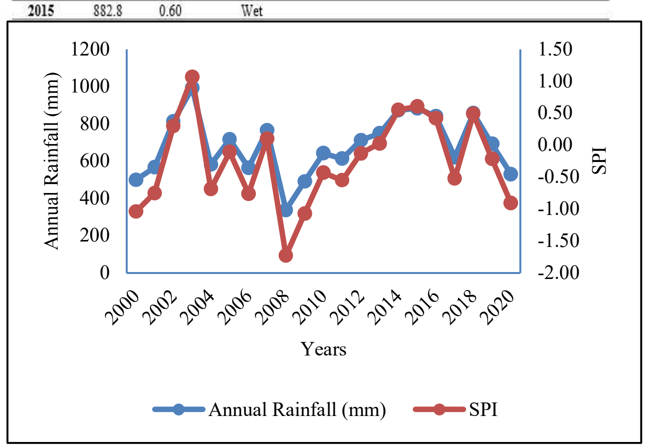


Figure 9: Relations between Annual Rainfall and SPI during (2000-2020) in the area.

7. CONCLUSION

This study showed that there is a water surplus about (430.10 mm and equal to 57.31%) of the total rainfall (750.47 mm) based on the water balance. The water deficit represents (1579 mm is equal to 42.69%) of the potential evapotranspiration. The climate of the study area is diversity between the wet climates in winter to the dry climate in summer and in most cases, it can be considered that the climate of the study area is Humid to moist.

8. ACKNOWLEDGMENTS

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