Comparative Analysis of the Water Balance of Drainage Basins in Arid regions:
A case study of Wadi Bishah and Wadi Itwad Basins Asir region (Kingdom of Saudi Arabia)

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Abstract

This research provides an estimate and analysis of the water balance in Wadi Bishah and Wadi Itwad basins in Asir region (KSA). The study is based on the integrated employment of maximum daily rain data for the period (1980-2017) in a total of 10 rain stations belonging to the Ministry of Agriculture, Water and Environment, the land resources map, and the NRCS-CN model. The study came up with that the daily average of maximum rainfall (1980-2017) in (10) rainfall precipitation stations under the study - (7) rainfall precipitation stations in the Wadi Bishah basin and (3) rainfall precipitation stations in the Wadi Itwad basin.-the statistical properties of the maximum daily rain data extracted were identified, analyzed and used in calculating the water balance components by applying the NRCS-CN model. The study managed to employ the land resources map for both Wadi Bishah and Wadi Itwad basins in extracting the weighted soil curve number in each basin. The weighted soil curve number in each basin was utilized in calculating the maximum energy for water retention in the soil and the initial extraction factor that both adopted in calculating the components of the water balance by applying the aforementioned model. In conclusion, the study managed to determine/identify the weighted soil curve number for Wadi Bishah and Wadi Itwad basins and made use of it to estimate the components of the water balance and representing its spatial distribution on a map.

***Keywords*:** Curve number, Land cover, Wadi Bishah Basin, Wadi Itwad Basin, Asir Region.

التحليل المقارن للميزانية المائية بأحواض التصريف في المناطق الجافة : دراسة حالة حوضي وادي بيشة ووادي عتود بمنطقة عسير (المملكة العربية السعودية)

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مستخلص

يقدم هذا البحث تقديراً وتحليلاً لعناصر الميزانية المائية بحوضي وادي بيشة ووادي عتود بمنطقة عسير بالاعتماد على التوظيف المتكامل لبيانات الأمطار اليومية القصوى للفترة 1980–2017 بمجموع 10 محطات مطرية تابعة لوزارة الزراعة والمياه والبيئة ولخريطة الموارد الأرضية ولنموذج NRCS-CN. توصلت هذه الدراسة إلى حساب المتوسطات اليومية للأمطار اليومية القصوى للفترة 1980–2017 بمجموع 10 محطات مطرية، منها 7 محطات بحوض وادي بيشة و 3 محطات بحوض وادي عتود. كما تم تحديد وتحليل الخصائص الاحصائية للبيانات المطرية اليومية القصوى المستخرجة من البيانات اليومية للأمطار بالمحطات المذكورة واستخدامها في حساب عناصر الميزانية المائية بتطبيق نموذج NRCS-CN. ولقد تمكنت هذه الدراسة من توظيف خريطة الموارد الأرضية لحوضي وادي بيشة ووادي عتود في استخلاص رقم منحنى التربة الموزون بكل حوض مائي واستخدامه في حساب الطاقة القصوى لاحتفاظ التربة بالماء وحساب معامل الاستخلاص الأولي المعتمدين في حساب عناصر الميزانية المائية بتطبيق النموذج المذكور. تمكنت هذه الدراسة من تحديد رقم منحنى التربة الموزون بحوضي وادي بيشة ووادي عتود واستخدامه في تقدير عناصر الميزانية المائية وتمثيل توزيعها المكاني بالحوضين على خريطة.

الكلمات المفتاحية: رقم منحنى التربة، الغطاءات الأرضية، حوض وادي بيشة، حوض وادي عتود، منطقة عسير.

1.0. Foreword

The accurate calculation of the water budget/ balance is a prerequisite for determining the water needs in different sectors of human activity in any state. The exact calculation of the water balance depends on knowing the extent of inputs and outputs from the available water resources. The available water resources are closely related to the rainfall system in the semi-arid and dry regions, which are characterized by a large extent of the total demand for water due to climatic conditions on the one hand and the steady increase in the population's needs for agriculture, industry and household and municipal uses on the other hand.

Therefore, water balance represents the correlation between the quantities of incoming water resources that are formed by rain water and the quantities of water losses through filtration and evaporation, in addition to the quantities of water discharged in the various needs of human activities.

The researchers' interest in studying the water balance varies from one country to another; so many scientific studies have analyzed the components of the water balance, especially with the increasing global interest in climate change.

In this regard, many studies touched upon the water balance analysis of drainage basins in different regions of the world. Kane & Yang (2004) conducted a study on the water budget in the drainage basins of the high Latitudes. Ghandhari & Moghadda (2011) carried out a study in determining the basics of the water budget in five river basins in Iran. Jiang et al. (2011) also, attempted to preface future modeling applications within a watershed in South Carolina, by assessing the performance of the Soil and Water Assessment Tool (SWAT) model in analyzing watershed hydrology and variability of stream flow in watershed. Furthermore, in 2014, the Development and Agriculture Bank presented a study on the water budget to achieve sustainable development through a plan to evaluate and manage water in the tribal areas under the Federal Administration of Pakistan (ADB, 2014).

In all, many studies have concerned with the influence of factors affecting the water budget: Hlásny et al. (2015) investigated the effect of deforestation on the water budget of drainage basins through a hydrological modeling methodology and the effect of pond water and surface runoff of water basins in the water budget in the Sahel region (Gal et al., 2015). Equally, Dhungal & Fielder (2016) studied the effect of using the water budget in the recovery process and its repercussions on the management of water basins using the dynamic approach. Also a study presented on assessing the effects of climate change on the water balance components of the Heaya drainage basin in Hawaii (Letaa et al., 2016). Recently, (Tang & Wang, 2017) published another study on assessing the effect of pond characteristics on a long-term water balance via Budyko Equation on the basis of two phases for rainfall precipitation. While (Ayivi & Jha, 2018) adopted a study on using (SWAT) program in estimating the water budget of the drainage basin of River Creek in North Carolina, while a study was adopted (Lu et al., 2018) on the spatial distribution of the runoff model in the evaluation of the water balance of a drainage basin of Lake Poyang.

Since the 1970s, few studies have emerged in the Arab World that have concerned with estimating the water budget and analyzing its components such as Musa's (1976) study on the regions of water sufficiency in Syria and Halimi's (1977) on the water balance in Algeria. Similarly, Al-Samani (2013) conducted a study on the water balance and the distribution of agricultural lands in the Sinai Peninsula, a study that relied on climatic rates for the period 1980-2000 with nine meteorological stations. Finally, Hussein and Ahmed's (2008) study that dealt with calculating the water budget in the Western Desert of Iraq using Data of six climate components in (1980-2000) within 7 rainfall precipitation stations.

1.1. Significance of the Study

No comprehensive and complete studies in the Kingdom of Saudi Arabia on the water balance at the national level except for individual studies available for some researchers: Al-Jarash (1988) on the climatic water balance in KSA. Atta's study (2001) on evaporation and water balance in Al- Abha ,(KSA). Another study by (Atta, 2005) on evaporation and water balance in Abha in KSA. There are few studies that dealt with the budget in the drainage basins, including a study of Al-Mudaiheem (2001) on the water budget of Wadi Hanifa basin, which relied on a map of the equal lines of the average rainfall for the period (1988-1994) in estimating the size of precipitation that reached (405.7m/ $km^{2)}$ with an annual average precipitation of (88.3 mm) over the drainage area of Wadi Hanifa Basin (4,590 km^2). Similarly, a study carried out by Al-Baroudi (1986) on the water budget of Wadi Fatimah Basin also showed the rainfall rate for this basin is 156 mm / year, with a size of (667.6 million m^3/ year) and surface runoff, which represents only(2%) of the amount of rain in the eastern region of the basin and (5 to 6%) of the rain in the western region of it, which is equivalent to about (13.4 million m^3 / year) and (40.0 million m^3 / year) in the two regions respectively.

On the other hand, governmental studies which came in the form of reports and discretionary calculations on the quantities of individual water consumption from various sources or on estimating the per capita water resources in urban centers. Since the 1970s, the water budget has started to register a clear deficit due to the high quantities of water consumed compared to the traditional water resources provided by the rain. At the beginning of the 1980s, the demand for water doubled due to the urban expansion on the one hand and the accompanying population increase on the other hand in conjunction with the various development plans. This situation has led to the trend of the state to desalination technologies to cover the double demand for water resources by producing the equivalent of 3million m3/day covering about (90%) of the daily water needs (Al-Dawan, 2011).

From what has been mentioned above, it became necessary to develop a complete visualization of the water budget at the national level, based on detailed scientific studies at water basins level. The Ministry of Water, Agriculture, and Environment can adopt the water budget studies in the Kingdom in a national water plan that provides a clear vision and specific goals to address the current water situation in volatile climate conditions accompanied by a steady increase in population and water needs afflicting various regions of the Kingdom.

1.2. Study area

The study area consists of Wadi Bishah and Wadi Itwad basins.

(A)- Wadi Bishah basin

Wadi Bishah is one of the most important wadi of Asir region, with its water resources and the number of population centers that have developed within its drainage area. The water basin of Wadi Bishah has a drainage area of 11,802.8 km^2. Astronomically located between latitudes 17˚ 56 and 19˚ 56 N, and longitude 41˚ 56˚ and 40˚ 42˚E.It is bounded on the northwest by the Wadi Raniyah basin, on the southwest by the Wadi Hali basin, on the east by the tributaries basins of Wadi Tathlith (Wadi Masarah, Wadi Marwah, Wadi At Thafin, Wadi Al Musayriq and Wadi Tarb), and on the south by Al Sarwat Heights from the cities of Abha and Khamis Mushayt (Figure 1).

From the western side, Wadi Bishah basin is surrounded by a series of mountainous heights exceeding 2000 meters extends west of the city of Abha in a southeast-northwest direction, with altitudes ranging between (2889) meters at Sha'af Rahmah and (3015) meters at the top of As Sudah that separates the Wadi Tanah Basin (the tributary of Wadi Bishah) and Wadi Wadi Hiswah basin. The elevation of the mountainous terrain gradually decreases to the north until it reaches (2062m) when the Wadi Bishah is combined with Wadi Iya at Jabal Dihya. On the east side, Wadi Bishah basin is surrounded by another series of mountains, whose heights reach (2720m) at Sarat Abidah, and then gradually decline towards the north to (2203 m) at Jabal Al Qarn and to (1949 m) where Wadi Bishah is combined with Wadi Tindahah. East of the basin extend a series of hills that separate the eastern and western mountainous heights (topographical map, 500000: 1, plate number NF38-SW).

Wadi Bishah stems from the heights of Sarat Abidah and runs northward over the Asir Plateau, breaking through Bilad Shahran and Rijal Al Hajr. This valley runs along a length of about (500 km).The course of Wadi Bishah is formed from the confluence of three main wadis north of the city of Khamis Mushayt, namely Wadi Itwad, which descends from Jabal As Sahn (2380 m) passing through the city center of Khamis Mushayt, and Wadi Abha, which descends from the highlands of Abha (2360m), as well as Wadi Al Jawf, that descends from the heights of Sarat Abidah (2720 m).

Geologically, Wadi Bishah basin is entirely within the southern Arabian Shield, most of which are composed of basic igneous rocks, surrounded by many faults that head from Khamis Mushayt in the south-northeast direction; to meet a group of faults cut by Wadi Tathlith, Wadi Bishah and Wadi Raniyah. On the northwest, a group of faults emerged, extending from An Namas to the northeast side. On the western side, a group of faults extends east of the city of Abha.

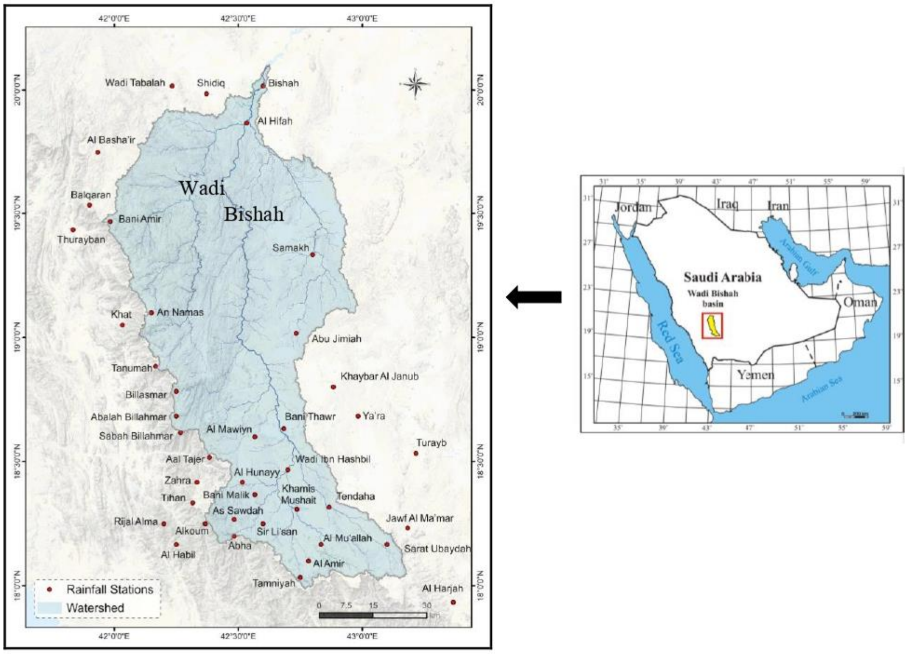
The rocks exposed on the surface are varied and differ in terms of geological age, structure and rock composition. These rocks are arranged as follows:

1. Quaternary Deposits:

It is loosened alluvium, sand pebble layers and gravel on limited areas in the north of Wadi Bisha basin.

2. Pre-Cambrian formations:

They are formed mainly from impulsive rocks accompanying the Cambrian and pre-Cambrian faults, and their lifespan is estimated between 500-600 million years, and they are formed mainly from granite- gneiss, granodiorite, and sericite schist. They are basically formed from granite rocks and are of alkaline calcareous origin formed after tectonic movements. Their age is estimated at 600-650 million years. And the granite rocks accompanied the tectonic movements, their age is estimated between 650-800 million years and granite rocks preceded by tectonic movements, their age is estimated to be about one billion years old and the dark green rocks that have an igneous origin. Pre-Cambrian formations are formed from metamorphic rocks, and they are of sedimentary and volcanic origin, green basalt rocks and alkaline gneiss rocks. Part of it dates back to before the Cambrian and the other part belongs to the Cambrian.



Source: topographic map, 500000: 1, Sheet NF38-SW, Air Survey Department, Ministry of Petroleum and Mineral Resources, Riyadh, 1st edition, 1404 AH (1983 AD).

Figure 1: The geographical location of the wadi Bishah basin

Wadi Bishah basin is part of a plateau that extends at the feet of the eastern slopes of Asir Mountains, with an average height of (1500) meters. It is very difficult, rugged and fragmented due to its rich water networks, channels and jagged rocks that developed during the ancient rainy climatic periods. The hikes range in wadi Bisha basin from the south to the north, and from the west and the east towards the main stream. On the surface of these plateaus, a sophisticated and active network of wadis developed from the

Pleistocene Period. The water network of Wadi Bishah basin is formed mainly from wadi Hirjab and its tributaries from the eastern side, and of Wadi Tarj and wadi Tabalah and their tributaries from the western side.

(B)- Wadi Itwad basin

Wadi Itwad mountainous basin is located between longitude 42° 15' and 42 ° 45' E and between latitude 17° 30' and 18o 15' N (Figure 2). It is bordered on the north by the Wadi Bishah and wadi Hali basins and by the coast line of the Red Sea from the south. On the east, by the wadi Baydh basin, and on the west by the Wadi Rim basin. wadi Itwad basin extends over a drainage area of (1853 km^2) of which (1362 km^2) located at heights between (345m) and (2976 m) (Bourouba, 2007).The drainage area of Wadi Itwad basin is composed of 3 sub-basins, which are wadi Maraba Basin, wadi Dili basin, and the Upper wadi Itwad Basin with discharge areas of (536 km^2) and (321 km^2) and (505 km^2) respectively. Also, it is equivalent to 39.3%, 23.6% and 37.1% of the total drainage area of the wadi Itwad basin respectively.

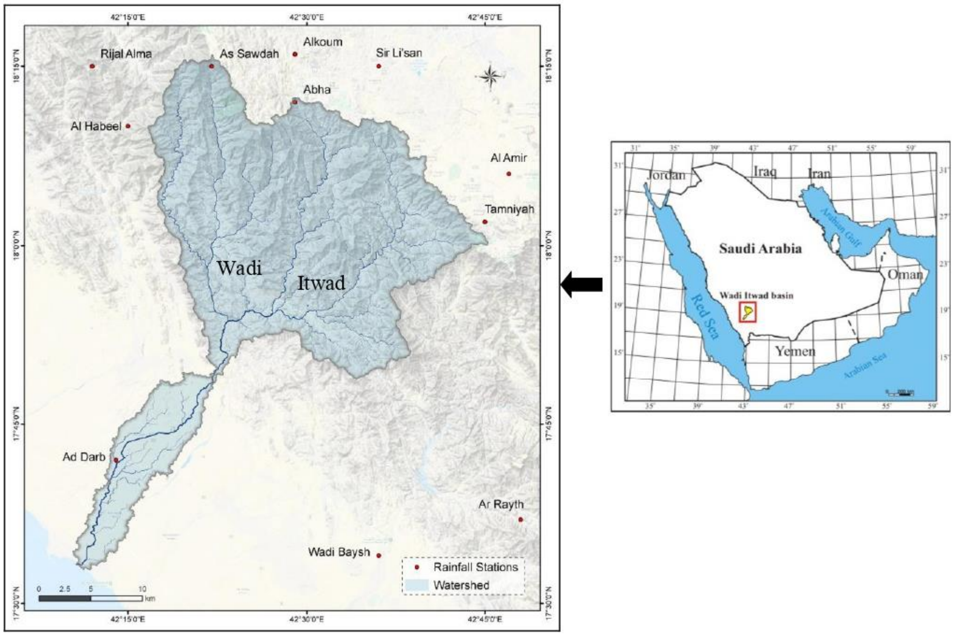
Wadi Itwad basin is formed from the tertiary formations and the pre-Cambrian formations, in addition to the quaternary deposits (Figure 4). These rocks are arranged as follows (Faucoult & Raoult, 1984):

1. **Quaternary deposits**:

These sediments/deposits consist of two types of sediments, which are surface Eolian sand formed by wind erosion about 1.8 million years ago, and alluvium and related surficial deposits and the main tributary streams.

2. **Tertiary formations:**

They are formed mainly from a geological unit formed about 65 million years ago by stratified gabbro applied by the inner magma processes.



Source: topographic map, 1: 500000, Sheet NF38-SW Air Survey Administration, Ministry of Petroleum and Mineral Resources, Riyadh, 1st edition, 1404 AH (1983 AD).

Figure 2: The geographic location of wadi Itwad basin

3. **Pre-Cambrian formations**:

Pre-Cambrian formations are mainly composed of a mixture of impulsive rocks and modern and ancient volcanic rocks. Wadi Itwad basin is characterized by mountainous terrain with steep slopes over which valleys run in directions commensurate with the nature of the geological structure and the type of rocky structure. So, it is found that the terrain that rises to more than (1200m) covers about (197.9 km^{2}), equivalent to (39.1%) of the total drainage area of the Wadi Itwad basin.

In general, the climate of wadi Bishah and Wadi Itwad is moderate, characterized by an annual average temperature of 18 to 20 ° C. While the winter is characterized by low temperatures that often reach below zero and lead to snowfall on the peaks of As Sudah, An Namas and Abha mountains. The annual average humidity ranges between 60 and 84%, which is accompanied by fog on many days of the year. The rain falls on the basin of Wadi Bishah and Wadi Itwad during the various seasons at rates ranging between 200 and 500 mm on mountain heights and western slopes often accompanied by the phenomenon of frost and local thunder.

3. Methodology of the study

The methodological procedure for calculating the water budget in Wadi Bishah and Wadi Itwad basins depend on NRCS-CN model outputs through the application of a series of related equations summarized in the following:

3.1. Data collection

The application of NRCS-CN model requires the following data:

1. Land Cover map to determine the soil curve number (CN).The study relies on the Kingdom's Land Resources Map issued in 1994 by the Ministry of Agriculture on a scale of 1: 500,000.The drainage area of the Wadi Bishah basin extends to plate number 69, while the drainage area of the Wadi Itwad basin extends to plate number 78.These two panels represent the different natural land cover of the two mentioned basins.
2. Collecting data for daily rainfall amounts. This study relies on the maximum daily rainfall data for the period 1980-2017 with a total of 10 rain stations belonging to the Ministry of Agriculture, Water and Environment. Including (3) stations at Wadi Itwad basin and (7) stations at Wadi Bishah basin (Table 1) and (Figures 4 and 5).

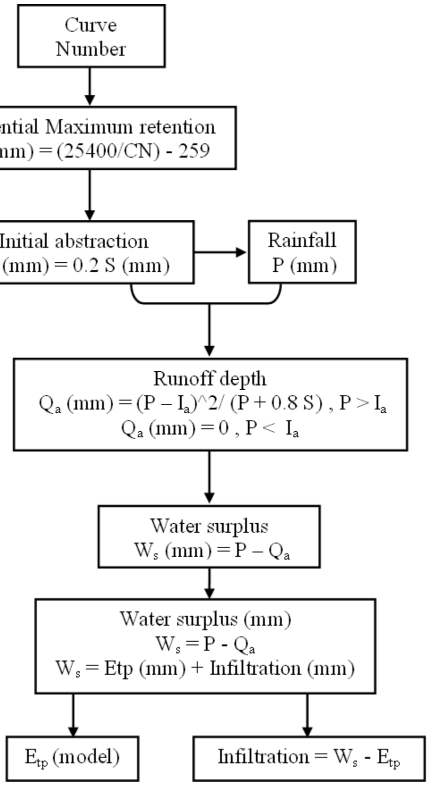


Figure 3: Methodology steps for calculating the water balance components by NRCS-CN model

Table 1: The coordinates of the studied rain stations in Wadi Bishah and Wadi Itwad basins

Station	Station No.	Latitude (north)	Longitude (east)	Height (m)	Station code
Abha	13	18º 13'	42º30'	2249	005 A.
An Namas	15	19º06'	42º09'	2400	007 A
Bishah	64	20º00'	42º36'	1165	004 B
Ad Darb	503	17º42'	42º14'	65	102 SA
Tamniyah	31	18º02'	42º45'	1413	121 A
Tanumah	30	18º53'	42º10'	2367	120A
Khaybar Al Janub	73	18º48'	42º53'	1531	110 B
Rijal Alma	516	18º13'	42º17'	1052	116 SA
Sarat Abidah	12	18º10'	43º06'	2303	004 A
Mahayil	514	18º32'	42º02'	450	113 SA

Table 2: Maximum daily rainfall of the studied stations

Year	Rijal Alma	Sarat Abidah	Abha	An Namas	Tanumah	Tamniyah	Bishah	Muhayil	Khyber Al Janub	Ad Darb
1980	105.0	23.8	52.4	98.3	62.0	54.0	13.3	45.2	42.7	27.0
1981	73.0	91.2	53.8	26.8	38.8	68.0	10.0	28.3	18.2	5.6
1982	50.8	119.0	139.4	194.6	99.3	66.0	23.8	94.2	76.3	2.0
1983	31.0%	12.5	149.6	52.6	28.0	52.4	6.4	54.6	49.5	22.0
1984.	47.5	18.8	38.8	85.2	20.7	12.0	30.0	38.2	25.7	32.0
1985	52.0	19.2	57.2	120.4	100.5	60.0	26.2	60.5	25.5	24.0
1986.	41.5	12.2.	51.2	28.4	33.5	40.0	6.4	25.2	16.0	8.0
1987	4 3.0	8.8	38.6	43.6	51.0	55.0	18.2	43.5	17.0	29.5
1988	48.0	5.6	42.0	46.4	46.2	19.0	15.6	30.2	24.0	68.0
1989	21.6	8.2	32.6	79.4	51.0	80.0	30.6	48.8	24.0	17.0
1990	54.0	33.8	81.4	107.6	114.0	86.2	35.8	60.5	54.0	46.0
1991	14.6	6.6	22.0	25.6	90.0	33.2	9.0	22.2	24.2	9.0
1992	38.6	11.2	58.2	58.2	50.0	37.2	21.6	55.2	9.0	37.0
1993	30.6	10.0	27.8	45.2	50.0	29.5	18.8	45.8	8.0	49.0
1994	50.0	41.2	58.2	31.0	30.6	45.5	84.2	16.8	16.9	22.0
1995	14.6	28.0	22.0	65.6	75.0	30.5	21.2	39.0	41.0	45.0
1996	25.7	16.0	38.8	62.1	71.0	38.5	40.4	40.0	15.0	10.0
1997	41.1	25.7	62.0	81.2	85.0	30.2	22.8	39.0	24.0	25.0
1998	19.0	69.2	248.6	192.4	110.0	186.8	9.8	46.0	70.4	41.0
1999	50.0	21.3	51.4	53.0	130.0	47.2	22.0	2 1.0	19.4	52.0
2000	35.0	28.2	68.0	72.5	83.0	35.0	19.5	39.2	11.0	30.0
2001	19.0	12.3	29.6	121.5	139.0	15.5	31.0	65.6	2 1.0	3.0
2002	60.0	15.8	4.6	100.5	115.0	28.5	14.4.	54.3	9.0	11.5
2003	16.0	38.9	24.2	18.3	34.0	8.2	10.0	9.9	5.5	2 1.0
2004	52.0	30.0	48.1	60.9	42.0	48.5	32.0	32.9	6.0	38.0
2005	45.0	22.0	19.5	55.3	4 4.0	30.6	10.2	29.9	32.0	22.0
2006	39.0	37.5	40.9	54.0	52.0	24.5	34.5	8.0	2.0	9.9
2007	39.0	10.0	24.1	52.0	25.0	40.0	15.2	48.0	13,0	16.2
2008	51.0	10.4	25.0	48.0	20.0	18.5	12.7	19.5	1.5	7.5
2009	40.0	16.6	40.0	55.0	12.0	22.5	12.2.	23.5	17.5	9.1
2010	51.0	19.0	40.0	53.5	13.2	52.5	22.0	33.0	41.0	21.2
2011	51.0	32.0	53.0	50.0	51.0	30.0	9.8	45.0	28.0	12.1
2012	48.0	88.0	23.0	54.0	92.0	28.5	13.5	22.0	50.0	11.5
2013	55.0	25.0	49.0	55.0	35.0	18.6	23.0	52.0	51.0	7.5
2014	52.0	14.0	30.0	40.0	102.0	18.0	11.0	35.0	6.0	7.3
2015	51.0	46.0	47.0	15.0	38.0	35.0	19.0	48.0	38.0	14.1
2016	57.0	32.0	68.0	60.0	84.0	47.9	35.0	34.0	22.0	19.3
2017	51.0	68.5	165.0	55.0	40.0	116.2	2 1.0	71.4	20.1	46.9

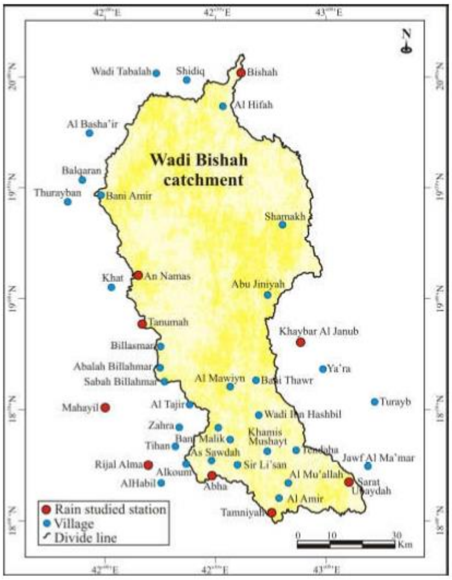


Figure 4: Spatial distribution of the studied rain stations in Wadi Bishah catchment.

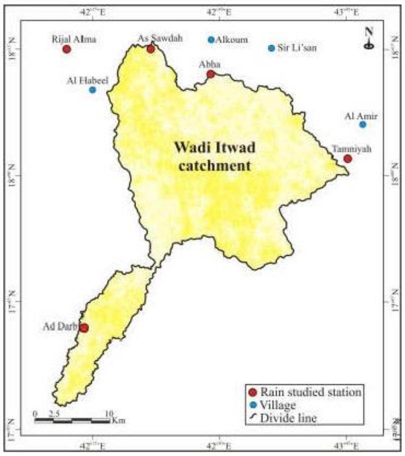


Figure 5: Spatial distribution of the studied rain stations in Wadi Itwad catchment.

3.2. Statistical characteristics of rain data

The table 2 represents the maximum daily rainfall in the studied stations.

To analyze the statistical properties of rain data, the mean, standard deviation and coefficient of variance were calculated and examined by their standard error by applying the following equations:

A. Standard Mean Error:

$$SE_{X'} = \frac{SD}{n^{0.5}}$$

Where (x) = mean, (SD) = standard deviation of rain data for the studied period, and (n) = number of measurements.

B. Standard error of the standard deviation:

$$SE_{SD} = \frac{SD}{2n^{0.5}}$$

C. Confidence interval

The mean and standard deviation were calculated at the confidence interval 0.98, 0.95 and 0.90 by applying the following equations: (Table 3).

Table 3: The mean confidence interval and the standard deviation

Confidence interval	Mean	Standard deviation
0.98	$X' \mp 2.33 \frac{SD}{n^{0.5}}$	$SD \mp 2.33 \frac{SD}{2n^{0.5}}$
0.95	$X' \mp 1.96 \frac{SD}{n^{0.5}}$	$SD \mp 1.96 \frac{SD}{2n^{0.5}}$
0.90	$X' \mp 1.65 \frac{SD}{n^{0.5}}$	$SD \mp 1.65 \frac{SD}{2n^{0.5}}$

3.3. Calculation of the water balance components

Water budget components were calculated by applying a model NRCS-CN by a series of sequential and serial equations as follows:

a. Calculation of the curve number

To calculate the curve number , the types of land cover areas for the drainage area of Wadi Bishah and Wadi Itwad basins were determined (Figure 6 & 7). The values of the soil curve for each land cover have been extracted using the standard table proposed by (USDA-NRCS TR55, 1986). Table 4 represents the spatial distribution areas for the types of land cover in each water basin.

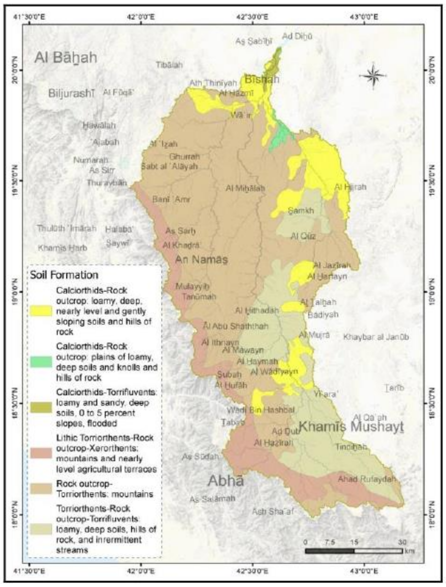


Figure 6: Types of land cover in Wadi Itwad catchment

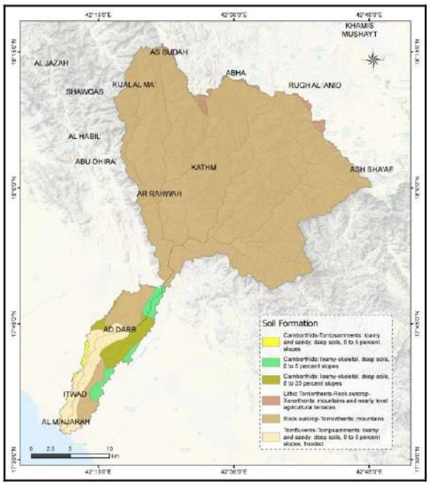


Figure 7: Types of land cover in Wadi Itwad catchment.

Table 4: The relative spatial distribution of land cover types in Wadi Itwad and Bishah basins

Basin	Station	Land cover type	Curve number (CN)	Area (km^2)
Wadi Bishah	Bishah	Mn	91	1652.4
	Tanumah	Ts	51	1900.3
	An Namas	Ts	51	3340.2
	Abha	Mn	91	2372.4
	Sarat Abidah	Ts	51	1074.1
	Mahayil	Mn	91	283.3
	Khaybar Al Janub	Pr	63	1180.8
Wadi Itwad	Tamniyah	Mn	91	329.8
	Abha	Mn	91	956.1
	Ad Darb	Af	55	567.0

b. Calculation of components of NRCS-CN Model

The application of NRCS-CN model depends upon the calculation of the following items:

- **The maximum energy to hold the water in soil, which equals:**

$$S(mm) = \frac{25400}{CN} - 254$$

Where (CN) = Soil curve number.

The initial factor extraction coefficient, which equals:

$I_a = 0.2\ S\ (mm)$

Surface runoff depth, which is equal to:

$$Q_a(mm) = \frac{(P - I_a)^2}{P + (0.8S)}$$

Where P is the amount of rain (mm) and Q_a (mm) =direct surface runoff depth.

The amount of water loss is equal to:

Water Loss (mm) = P - Q_a

Water loss represents the sum of the two evaporation quantities E_{tp} (mm) and infiltration (mm).

Water Loss (mm) = E_{tp} (mm) + Infiltration (mm)

The value of evaporation can be obtained from direct measurements in rainy or climatic stations, or estimated by mathematical models if these measurements cannot be obtained. The daily measured mean evaporation at Bishah and Abha stations has been used by the Ministry of Agriculture for a period.

From the above, we find that the amount of nomination is equal to

Infiltration (mm) + Water Loss (mm) - E_{tp} (mm)

To determine the weighted soil curve number for each water basin, a spatial distribution map of the land cover has been completed using the Land Resources Map of the Ministry of Agriculture on a scale of 500000: 1. Then the coverage area of each rain station in the water basin was calculated using the Thiessen Polygons method.

4. Results and Discussion

4.1 Statistical characteristics of rain data

Table (5) shows that the maximum daily average rainfall for the period 1980-2017 (38 years) in Wadi Bishah basin ranges between 21.4 mm / day at Bishah station and 66.3 mm / day in An Namas station and with a standard deviation of between 13.8 mm / day and 39.7 mm / day in the two stations respectively. Consequently, the variance coefficient ranges between 44% at Mahayil station and 87% at Sarat Abidah station, where the maximum daily rain changes were more fluctuating at Mahayil station and more regular at Sarat Abidah station during the period of study.

Accordingly, it has been found that there is a clear discrepancy between the distribution of the maximum daily rainfall in time in one station and spatially among all stations, with the highest quantities ranged between 76.3 mm / day at Khaybar Al Janub station and 194.6 mm / day at An Namas station during the year 1982.Whereas the lowest quantities ranged between 1.5 mm / day during 2008 at Khaybar Al Janub station and 15.0 mm / day during 2015 at An Namas station, i.e. a difference of 10 times between the two stations.

Table 5: Statistical characteristics of rain data for the period 1980-2017 at the stations studied

Statistical variables		Rijal Alma	Sarat Abidah	Abha	An Namas	Tanumah	Tamniyah	Bishah	Mahayil	Khaybar Al Janub	Ad Darb
X’		43.9	29.7	57.2	66.3	62.2%	44.6	21.4	40.1	25.7	23.1
SD		17.1	25.8	46.0	39.7	34.3	32.3	13.8	17.6	18.2	16.0
CV		0.39	0.87	0.80	0.60	0.55	0.72	0.65	0.44	0.71	0.69
Max.		105.0	119.0	248.6	194.6	139.0	186.8	84.2	94.2	76.3	68.0
Min.		14.6	5.6	19.5	15.0	12.0	8.2	6.4	8.0	1.5	2.0
SE_{Aver}		2.8	4.2	7.5	6.4	5.6	5.2	2.2	9.2	3.0	2.6
SE_{SD}		2.0	3.0	5.3	4.5	3.9	3.7	1.6	2.0	2.1	1.8
X’ Confid. Interval	0.98	6.5	9.7	17.4.	15.0	13,0	12.2.	5.2	6.6	6.9	6.0
	0.95	5.4	8.2	14.6	12.6	10.9	10.3	4.4	5.6	5.8	5.1
	0.90	4.6	6.9	12.3	10.6	9.2	8.7	3.7	4.7	4.9	4.3
SD Confid. Interval	0.98	3.2	4.9	8.7	7.5	6.5	6.1	2.6	3.3	3.4	3.0
	0.95	2.7	4.1	7.3	6.3	5.4	5.1	2.2	2.8	9.2	2.5
	0.90	2.3	3.4	6.2	5.3	4.6	4.3	1.8	2.4	2.4	2.1

The maximum daily rain distribution in the Wadi Bishah basin is characterized by a standard error of between 2.2 and 6.4 mm / day and a standard error of standard deviation of between 1.6 and 4.5 mm / day at the Bishah and An Namas stations, respectively. Therefore, the standard error of the mean represents a percentage of the average ranging between 9.7% at An Namas station and 10.3% at Bishah station, while the standard error of the standard deviation also represents a percentage of the standard deviation ranging from 11.3% at An Namas station to 11.6% at Bishah station.

Owing to what has been mentioned above, it has been found that the lowest average daily maximum rainfall ranges between 16.1 and 26.6 mm / day at the confidence interval 98% and between 17.0 and 25.8 mm / day at the confidence interval 95% and between 17.7 and 25.1 mm / day at the confidence interval 90% at Bishah station. Whereas, the largest mean maximum daily rainfall ranges between 51.3 and 81.3 mm / day at the confidence interval 98% and between 53.7 and 78.9 mm / day at the 95% confidence interval and between 55.6 and 76.9 mm / day at the confidence interval 90% at An Namas station.

It is also evident that the lowest values for the standard deviation range between 11.2 mm / day and 16.4 mm / day at the 98% confidence interval and between 11.6 and 16.0 mm / day at the 95% confidence interval and between 12.0 and 15.7 mm / day at the confidence range 90% at Bishah station. Whereas, the largest values for the standard deviation range from 32.2 to 47.2 mm / day at the confidence domain 98%, between 33.4 and 46.0 mm / day at 95%

confidence interval and between 34.4 and 45.0 mm / day at the confidence range 90% at An Namas station.

Moreover, the average maximum daily rainfall for the period 1980-2017 (38 years) in Wadi Itwad basin ranges between 23.1 mm / day at Ad Darb station and 57.2 mm / day in Abha station, with a standard deviation of 16.0 mm / day and 46.0 mm / day at the two stations, respectively. Consequently, the coefficient of variance ranges between 69% in the Ad Darb station and 80% at Abha station, meaning that the daily maximum rain changes were more fluctuating in the Ad Darb station and more regular at Abha station during the period of the study.

Too, there is a clear discrepancy between the distribution of the maximum daily rainfall in time in one station and spatially among all stations, with the highest quantities ranged between 68.0 mm / day during the year 1988 in Ad Darb station and 246.8 mm / day during the year 1998 in Abha station. Whereas, the lowest quantities ranged between 2.0 mm / day during 1982 in Ad Darb station and 19.5 mm / day during 2005 at Abha station, i.e. a difference of approximately 10 times between the two stations.

The maximum daily rain distribution in Wadi Itwad basin is characterized by a standard error of 2.6 in the Ad Darb station and 7.5 mm / day at Abha station, and a standard error of standard deviation of 1.8 in the Ad Darb station and 5.3 mm / day at Abha station. Therefore, the standard error of the mean represents a percentage of the average of 11.3% and 13.1% at Ad-Darb and Abha stations, respectively. While the standard error of the standard deviation is a percentage of the standard deviation which also reached 11.3% and 11.5% at Ad-Darb and Abha. stations, respectively.

By comparison, that the average maximum daily rainfall ranges between 17.1 and 29.2 mm / day at the confidence interval 98% and between 18.1 and 28.2 mm / day at the confidence interval 95% and between 18.9 and 27.4 mm/day at the confidence interval 90% in Ad Darb station. Whereas, this average ranges between 39.9 and 74.6

mm / day in the confidence interval 98% and between 42.6 and 71.8 mm/ day in the confidence domain 95% and between 44.9 and 69.5 mm /day in the confidence domain 90% at Abha station.

Finally, it is evident that the standard deviation in the trail station ranges between 13.0 mm / day and 19.0 mm / day at the 98% confidence interval, between 13.4 and 18.5 mm / day at the 95% confidence interval, and between 13.8 and 18.1 mm / day at the confidence interval 90%, in When it ranges between 37.3 and 54.6 mm / day in the confidence field 98%, between 38.7 and 53.3 mm / day in the confidence domain 95% and between 39.8 and 52.1 mm / day in the confidence domain 90% in Abha station.

4.2. Calculation of the water balance components

Calculation of components of water balance depends on the soil curve number of NRCS-CN model which is related to the types of land cover that constitute the drainage area of the water basin and the coverage area for each type of these covers relative to the total area of the water basin. The soil curve for wadi Bishah and wadi Itwad basins was calculated as summarized in Tables (6) and (7).

Table (6) represents the soil curve number for the coverage areas of each rainfall precipitation station in Wadi Bishah basin. It is clear that the weighted soil curve number for this basin is 66.8. Accordingly, the maximum water retention capacity of the soil in this basin is 126.2 mm and the initial factor extraction coefficient is 25.2 mm. That is, each amount of daily rain that is less than or equal to this factor is unable to produce a water surplus and the depth of surface runoff is related to the maximum daily rainfall amounts that exceed this factor in wadi Bishah basin.

Table 6: Calculation of soil curve for Wadi Bishah basin.

Station	Area		Curve Number	Land Cover	Weighted curve Number
	S (km^2)	%	CN	Lc	CN_w
Bishah	1652.4	14.0	91	Mn	12.7
Tanumah	1900.3	16.1	51	Ts	8.2
An Namas	3340.2	28.3	51	Ts	14.4.
Abha	2372.4	20.1	91	Mn	18.3
Sarat Abidah	1074.1	9.1	51	Ts	4.6
Muhayil	283.3	2.1	91	Mn	2.2
Khaybar Al Janub	1180.8	10.0	63	Pr	6.3
Total basin					**66.8**

The table (7) represents the soil curve number for the coverage areas of each rain station in Wadi Itwad basin. From the table below, it is clear that the weighted soil curve number for this basin is 80.0.Therefore; the maximum water retention capacity of the soil in this basin is 63.5 mm and that the initial factor extraction coefficient is 12.7 mm. This parameter represents the threshold for the production of water surplus in Wadi Itwad basin, which has the potential to produce direct surface runoff. Consequently, Itwad basin has more capacity to divert rain water more quickly than Wadi Bishah basin, and it is more dangerous than it in terms of torrential runoff.

Table 7: Calculation of weighted curve number for Wadi Itwad basin

station	area		Curve number	Land cover type	Weighted Curve Number
	S (km^2)	%	CN	Lc	CN_w
Tamniyah	329.8	17.8	91	Mn	16.2
Abha	956.1	51.6	91	Mn	47.0
Ad Darb	567.0	30.6	55	Ap	16.8
Total basin					**80.0**

The weighted curve number was used in calculating the water budget components at each rain station, as well as for the total drainage area of the Wadi Bishah and Wadi Itwad basins, as summarized in Tables (8) and (9).

4.3 Calculation of the water balance components

Table (8) summarizes the values of the water budget components in Wadi Bisha Basin while Table (9) sums up the values of the water budget components in Wadi Itwad Basin and (Figures 8 and 9).

Table 8: Daily averages of water budget components for wadi Bishah basin

component	Bishah	Tanumah	An Namas	Abha	Sarat Abidah	Muhayil	Khaybar Al Janub
CN	91	51	51	91	51	91	63
S (km^2)	1652.4	1900.3	3340.2	2372.4	1074.1	283.3	1180.3
%	14.0	16.1.	28.3%	20.1	9.1	2.4	10.0
CN_w	12.7	8.2	14.4.	18.3	4.6	2.2	6.3
S (mm)	25.1	244.0	244.0	25.1	244.0	25.1	149.2
I_a (mm)	5.0	48.8	48.8	5.0	48.8	5.0	29.8
P (mm)	21.4	62.2%	66.3	57.2	29.7	40.1	25.7
Q_a (mm)	6.5	0.7	1.2	35.2	0.0	20.4	0.0
W_s (mm)	14.9	61.5	65.1	22.0	0.0	19.7	0.0
E_{tp} (mm)	5.8	5.8	5.8	5.8	5.8	5.8	5.8
Infiltration(mm)	9.1	55.7	59.3	16.2	0.0	13,9	0.0

CN : Soil curve number, S (km^2) Coverage area: CN_w : Weighted soil curve, S : The maximum energy to hold the soil in water, I_a Primary extraction coefficient, P : The amount of rain, Q_a : Direct flow depth, W_s : Water surplus, E_{tp} The amount of evaporation: Infilt. Amount of filtration.
quantities of surface runoff, evaporation, or filtration in Wadi Bishah basin.

Table (8) expresses that the average initial factor extraction for Sarat Abidah and Khaybar Al Janub exceeds the average of daily maximum rain. Consequently, this average does not have the ability to generate a water surplus that can turn into quantities of surface runoff, evaporation, or filtration in Wadi Bishah basin.

Therefore, the maximum daily rainfall amounts that have the ability to generate a water surplus in the two mentioned stations are the quantities that exceed the average rainfall and the initial factor extraction at the same time.

While it is found that the average daily maximum rain exceeds the average of the initial factor extraction by the rest of the other stations by the equivalent of 13.4 mm / day in Tanumah station, 16.4 mm /

day in Bishah station, 17.5 mm / day in Al- Namas station, 35.1 mm / day in Mahayal station and 52.2 mm / Day for Abha station, equivalent to a percentage of respectively 21.5%, 76.6%, 26.4%, 87.5% and 91.3% of the daily average daily maximum rainfall at the mentioned stations.

The difference between the average maximum daily rainfall and the average initial factor extraction resulted in a runoff of depth of 0.7 mm / day in Tanumah station, 1.2 mm / day in An Namas station, 6.5 mm / day in Bishah station, 20.4 mm / day in Mahayal station and 35.2 mm / day in Abha station, which equals respectively 1.1%, 1.8%, 30.4%, 50.9%, and 61.5% of the average daily maximum rain.

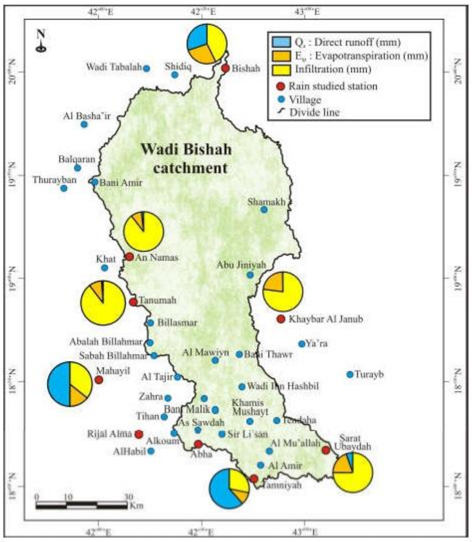


Figure 8: Spatial distribution of water balance components in Wadi Bishah catchment.

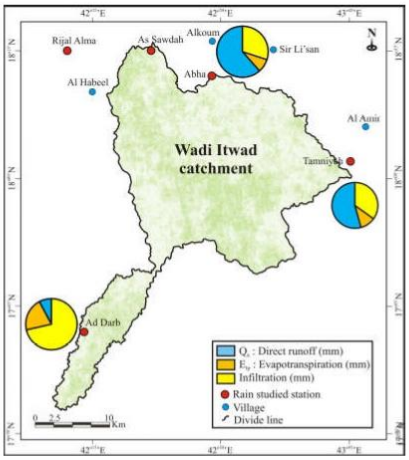


Figure 9: Spatial distribution of water balance components in Wadi Itwad catchment.

The difference between the maximum daily rainfall amounts and the depth of surface runoff resulted in a water surplus of 14.9 mm / day in Bisha station, 19.7 mm / day in Mahayel station, 22.0 mm / day in Abha station, 61.5 mm / day in Tanumah station and 65.1 mm / day in An Namas station , equivalent to respectively 69.6%, 49.1%, 38.5%, 98.9% and 98.2% of the average maximum daily rainfall.

On the other hand, the difference between the amount of water surplus and the amount of evaporation resulted in quantities of filtered water amounting to 9.1 mm / day in Bishah station, 13.9 mm / day in Mahayel station, 16.2 mm / day in Abha station, 55.7 mm / day in the sleep station and 59.3 mm / day At An Namas station, which is equivalent to ratios, respectively, 61.1%, 70.6%, 73.6%, 90.6% and 91.1% of the average water surplus.

The data gathered in Table (9) shows that the average initial factor extraction for Ad-Darb station exceeds the average daily maximum rains. Consequently, this average does not have the ability to generate a water surplus that can transform into surface runoff, evaporation or filtration in Wadi Itwad basin. Therefore, this station is similar in characteristics to the stations of Sarat Abidah and Khyber Al Janub in Wadi Bishah Basin.

While it is found that the average daily maximum rain exceeds the average of the initial factor extraction for the two stations Abha and Tumina, respectively, equivalent to 52.2 and 39.6 mm / day, which is equivalent to a percentage of also respectively 91.6% and 88.7% of the daily average daily maximum rains in the two mentioned stations.

Table 9: Daily averages of the water budget components of wadi Itwad basin

components	Tamniyah	Abha	Ad Darb
CN	91	91	55
S (km^2)	329.8	956.2	567.0
%	0:17.8	51.6	30.6
CNw	16.2	47.0	16.8
S (mm)	25.1	25.1	207.8
I_a (mm)	5.0	5.0	41.6
P (mm)	44.6	57.2	23.1
Q_a (mm)	24.2	35.2	0.0
W_s (mm)	20.4	22.0	0.0
E_{tp} (mm)	4.8	4.8	4.8
Infilt. (mm)	15.6	17.2	0.0

CN : curve number, S (km^2) area: CNw : Weighted soil curve, S : The maximum energy to hold the soil in water, I_a Primary extraction coefficient, P : The amount of rain, Q_a : Direct flow depth, W_s : Water surplus, E_{tp} The amount of evaporation: Infilt. Amount of filtration.

The difference between the average maximum daily rains and the average of the initial factor extraction resulted in surface runoff with a depth of 24.2 mm / day in a wish station and 35.2 mm / day in Abha station, which equates to proportions of 54.3% 61.6% of the average maximum daily rainfall.

The difference between the maximum daily rainfall amounts and the depth of runoff resulted in a water surplus of 20.4 mm / day in Tamniyah station and 22.0 mm / day in the Abha station, equivalent to ratios 45.4% and 38.4% of the average maximum daily rain respectively.

On the other hand, the difference between the amount of water surplus and the amount of evaporation resulted in quantities of filtered water amounting to 15.6 mm / day at Tamniyah station and

17.2 mm / day at Abha station, which is equivalent to ratios of 76.5% and 78.2% of the average water surplus respectively.

Summary

The availability of maximum daily rain data for the period (1980-2017) with a total of (10) rainfall precipitation stations belonging to the Ministry of Agriculture, Water and Environment, including (7) stations in Wadi Bisha basin (11802.8 km2) and (3) rainfall precipitation stations the Wadi Itwad basin (1853 km2) helped to estimate and analyze the water balance components in the two basins mentioned by integrated recruitment of a model NRCS-CN and a map of land resources issued by the Ministry of Agriculture in 1994.

This study has come to define a set of statistical characteristics of rain data that revealed time variations within each rain station and spatial variations to distribute the maximum daily rainfall amounts at the level of the drainage basins of Wadi Bishah and Wadi Itwad as it was shown through the distribution of the average maximum daily rain. The mean ranged between 21.4 and 66.3 mm / day with a standard deviation, ranging from 13.8 to 39.7 mm / day in Wadi Bishah basin on the one hand, and between 23.1 and 57.2 mm / day with a standard deviation ranging between 16.0 and 46.0 mm / day in Wadi Itwad basin, on the other hand. The distribution of the maximum and minimum amounts of rain was characterized by spatial and temporal variations, with maximum quantities ranging between 76.3 and 194.6 mm / day in wadi Bishah basin and between 68.0 and 246.8 mm / day in wadi Itwad basin, where the minimum values ranged between 1.5 and 15.0 mm / day in wadi basin Bishah, between 2.0 and 19.5 mm / day in wadi Itwad basin. Despite these variations, there is a kind of similarity in the standard error values for the mean and for the standard deviation of the maximum daily rain in the two mentioned basins, so that the subjective error of the average ranged between 2.2 and 6.4 mm / day in the Wadi Bishah basin and between 2.6 and 7.5 mm / day in Wadi Itwad basin. The standard error for the standard deviation ranged

between 1.6 and 4.5 mm / day in wadi Bishah basin and between 1.8 and 5.3 mm / day in wadi Itwad basin.

As for the water balance level in the wadi Bishah basin, its variations were linked to the values of the weighted soil curve number, which reached 66.8, with a maximum capacity of water retention of the soil with a value of 63.5 mm / day in a basin and an initial factor extraction of 25.2 mm / day.

These variations led to the different spatial distribution of the components of the water budget. The Sarat Abidah and Khaybar Al Janub stations in Wadi Bishah Basin were characterized by an average of the initial factor extraction greater than the average maximum daily rainfall. Whereas, the mean daily maximum rain exceeded the average of the initial factor extraction in the rest of the other stations, with values ranging between 21.4 mm / day in Bishah station and 66.3 mm / day in An Namas station. This situation resulted in an excess of water with an average fluctuation between 14.9 mm / day in Bishah station and 65.1 mm / day in An Namas station, accompanied by a surface runoff with an average depth of fluctuation between 0.7 mm / day at Tanumah station and 35.2 mm / day at Abha station. The water surplus also resulted in quantities of filtered water that can feed the groundwater with an average of between 9.1 mm / day at Bishah station and 59.3 mm / day at An Namas station.

The water balance components of Wadi Itwad Basin were also affected by the weighted soil curve number, which reached 80.0 with a maximum capacity of water retention of the value of 126.2 mm / day, and with an initial recovery factor of 12.7 mm / day.

This situation led to a difference in the spatial distribution of the components of the water budget, with Ad-Darb station having an average of the initial factor extraction greater than the average daily maximum rain. Whereas, the maximum daily rainfall averages exceeded the average of the primary recovery coefficient at Abha and Tamniyah stations, with values of 44.6 mm / day at Tamniyah station and 57.2 mm / day at the Abha station. This discrepancy resulted in an average water surplus of 20.4 mm / day at Tamniyah station and 22.0 mm / day in Abha station, accompanied by a surface runoff with an average depth of 24.2 mm / day at Tamniyah station and 35.2 mm / day at Abha station. The water surplus also resulted in quantities of filtered water that can feed the groundwater with an average of between 15.6 mm / day in the Tamniyah station and 17.2 mm / day in the Abha station.

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