EVALUATION OF GROUNDWATER RECHARGE AT MAFRAQ WASTEWATER TREATMENT PLANT CATCHMENT AREA USING SCS – CURVE NUMBER METHOD- A CASE STUDY EASTERN BADIA / JORDAN

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ABSTRACT :

This study deals with the calculation of the groundwater recharge at Mafraq wastewater Treatment plant catchment area. The groundwater recharge is the annual total quantity of water, which infiltrates from the ground surface to the aquifer. It is expressed as the annual recharge rate (mm/year), evaluated on the basis of field measurements and derived from the water balance equation, or estimated with the help of aerial photographs or satellite imagery. The amount and quality of recharge significantly affects the physical and chemical processes in the soil-rock-groundwater system. The greater the recharge, the greater the contamination potential to the groundwater. It may lead to leaching and transporting contaminants from the ground surface to the water table. In the present research paper, the water balance equation was applied to calculate the groundwater recharge in the study area. This equation was used to perform the water balance on daily basis for each storm event occurred in wet, normal and dry water year condition. Rainfall is usually concentrated between December and March; in this period, rainfall duration is long and evaporation is low, so that it can be concluded that the recharge occurs mostly during this period. The rainfall was the only measured parameter in the study area; therefore, a daily rainfall and initial abstraction were calculated from three rainfall stations using the SCS-curve number method for each storm during a specific year. The potential evaporation was computed using Turc equation, and then the water balance was solved for all storms that occurred in three different water years (wet, normal and dry). The average annual rainfall in the catchment area varied from about 100 mm southeast to more than 250mm north and northwest of the catchment area. The average annual rainfall volume was about 33.58 MCM, runoff volume was around 2.49 MCM (7.41 % of rainfall) and the calculated evaporation volume was about 30.46 MCM, (90.7% of rainfall). The calculated average annual recharge to the upper aquifer ranged between 0.058 MCM (0.30 % of the annual rainfall) and 2.84 MCM (6.85 % of the annual rainfall).

Key words: *Rainfall, recharge, aquifer, contamination, Turc, evaporation, Mafraq.*

INTRODUCTION

Water is one of Jordan's scarcest resources; about 80 percent of the country is steppe and desert where water is only minimally available. Most of the municipal water supply systems and industry in Jordan presently depend on groundwater and springs. Most of these sources are currently being extracted to or beyond the capacity of the reliable aquifer yields, (MWI, 2012). The present use of water resources in the research area is dependent on

the groundwater resources (mainly pumped wells).

Rainfall is the primary source of water in the study area. The mean annual rainfall in the catchment area ranges from about 100 mm at Um El Jimal to more than 250 mm at Jaber rainfall station and is a function of the land-surface altitude, (JMD, 2010).

The main objectives of this work are to calculate the volume of rainfall and runoff over the catchment area for dry, normal and wet years' conditions; as well as calculate the direct recharge to the groundwater from the rainfall using the water budget approach.

THE STUDY AREA

LOCATION

The study area lies within one of the most important groundwater basin in Jordan (Yarmouk basin) which is considered a shared basin between Jordan and Syria. About 75% of the basin area belongs to Syrian territory while the remaining part belongs to Jordan. The research area is located to the southeast of the basin (60 km northeast of Amman) and covers an area of about 236.1 km2. It lies between 250-280 E longitudes and 196-210 latitudes (according to Palestine Grids). Figure 1 shows the location map of the study area . It is located in the district of Mafraq , it can be reached from Amman via Zarqa and Mafraq main road.

The geological formations outcrop within the study area consist mainly of limestone, marls, chalks and alluvium of Cretaceous to Recent ages. The central part of the catchment area has been buried below thick flows of basaltic lava. The vegetation cover is typical of arid to semi-arid climate zone and the soil is originated from the top weathered rocks and alluvium deposits.

TOPOGRAPHY AND DRAINAGE

The general shape of the catchment area is trapezoid, with a longer axis oriented southwest to northwest direction. The general slope of the area is from south to north, and the average slope of the stream channels varies between 3 and 5 %. Elevation ranges from700 m above the sea level (a.s.l.) at Um El Jimal (south east) to more than 850m above the sea level at Jaber area north, (MWI, 2011). The average elevation of the catchment area is about 750m above the mean sea level, Figure 2.

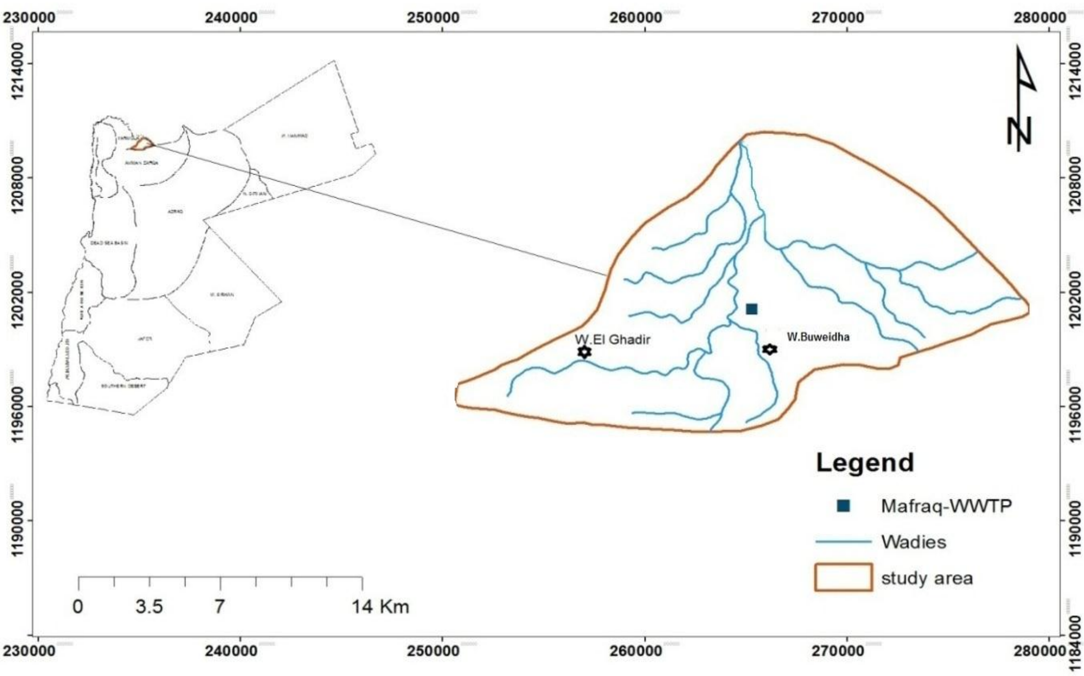

Figure 1 : The location map of the study area

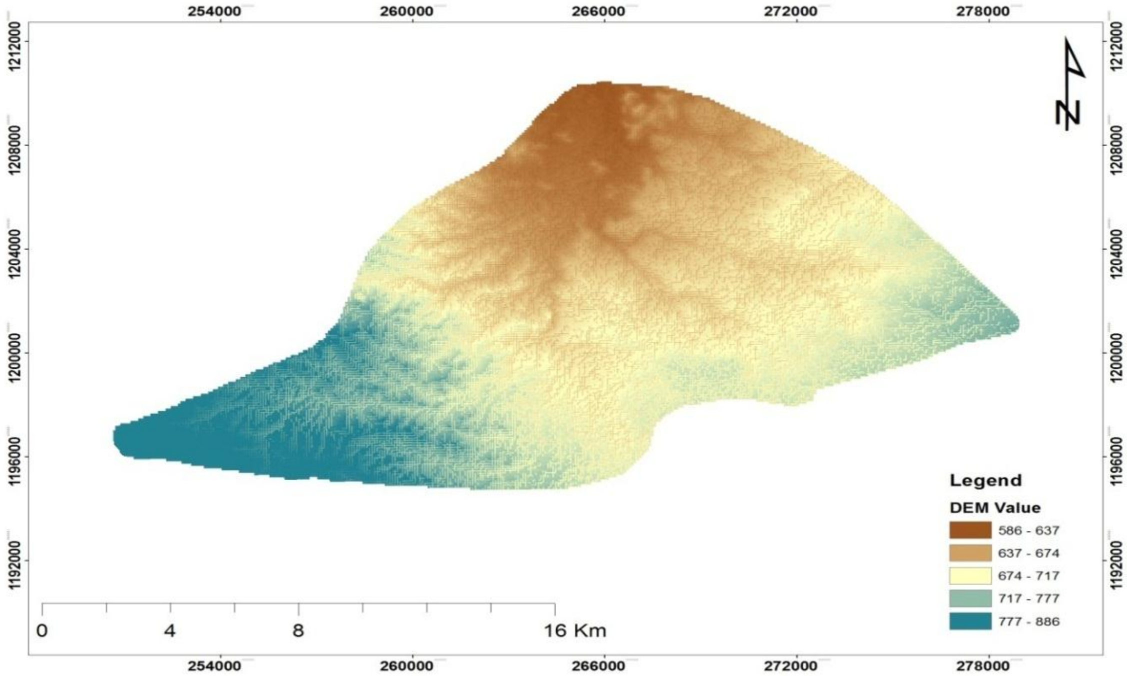

Figure 2 : The topographic map of the study area

Generally, the main trends of the drainage pattern in the catchment are parallel to the major structures which means that the drainage system is highly controlled by the structural features There are two main wadis drain into the catchment area. These are Wadi Buweidha and Wadi El-Ghadir.

MATERIALS AND METHODS

GEOLOGY AND HYDROGEOLOGY

The geology of Jordan has been studied and reported by number of investigation (Quenelle 1951; Burdon 1959; Bender 1974).Jordan forms the northwestern part of the Arabian Plate, which is boarded by the Mediterranean Sea, Red sea and the Arab Gulf. The geological formations outcrop within the study area consist mainly of limestone, marls, chalks and alluvium of Cretaceous to Recent age. However, the central part of the catchment area has been buried below thick flows of basaltic lava, (Figure 3).

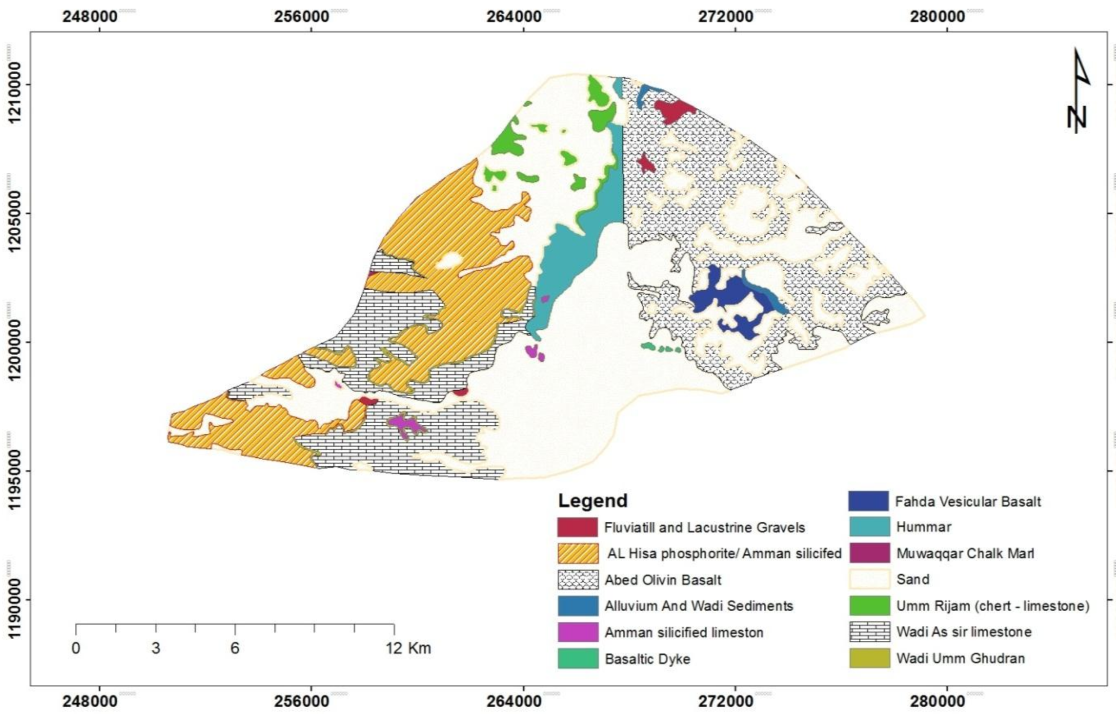

Figure 3: **The geological map of the study area**

The hydrogeology of the study area is controlled by the geological set-up, which also controls the piezometry, occurrence and movement of the ground water and the distribution of productive area in the aquifers (Al-Mahamid, 2005). The aquifer systems of the study area are related to Ajlun and Balqa Group (Upper Cretaceous). It has been agreed that the aquifer systems in the Yarmouk basin are sub-divided into three main aquifer systems. The upper aquifer which consists of Umm Rijam Chert limestone (B4), Shallala (B5) and Basalt (Bs) formations, the middle aquifer that is referred to Amman- Wadi El- Sir limestone formation (B2/A7) and the lower aquifer system which consists of Hummar (A4), Naur (A1/2),Kurnub Sandstone (Ks) and Zarqa Group formations, (Al Zabit, 1993).

DETERMINATION OF THE AREAL RAINFALL

There are three rainfall stations in the study area; all stations measure the daily rainfall, and one of them has rainfall recorders, giving hourly rainfall events. The distribution of rainfall over the study area is represented in two

methods; these are Thiessen polygon technique and Isohyethal method.

Thiessen polygon was applied to estimate the areal rainfall for each considered storm. In this method it is assumed that the point rainfall at the station represents the areal rainfall in its polygon, or its area of rainfall influence. Figure 4 shows the Thiessen polygons for the catchment area. The annual rainfall distribution and water year conditions are listed in Table 1.

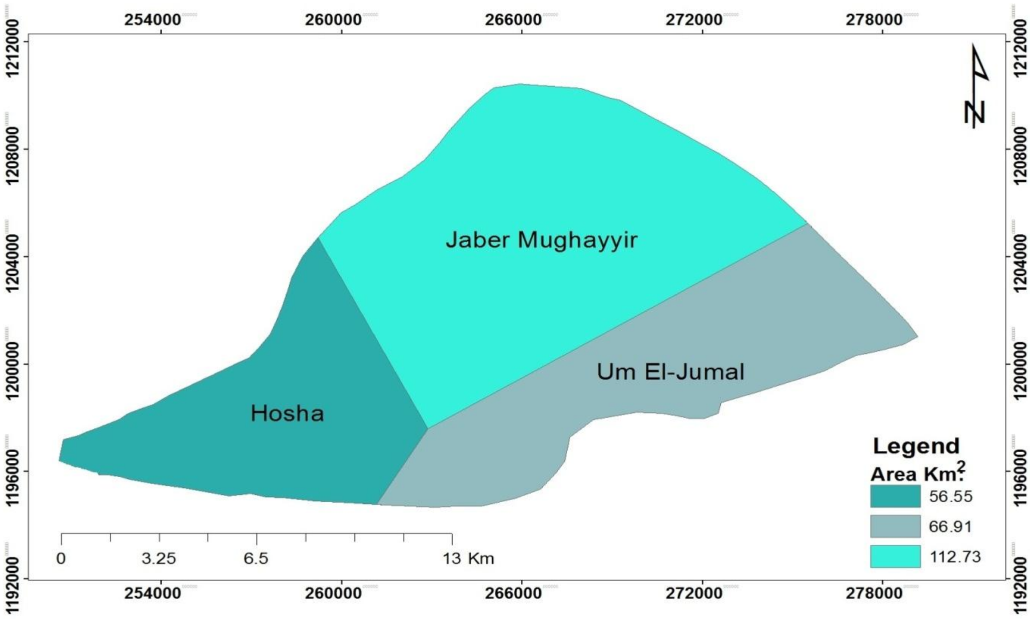

Figure 4: The map of Thiessen polygons of the study area

RUNOFF

There are no gauging stations located in the catchment area of Mafraq wastewater treatment plants. Therefore, to estimate the runoff, which may occur in the winter season, the US soil conservation services method (SCS), was applied, (Wanielista, 1990).

Table 1: Annual rainfall distribution and water year conditions (by Thiessen method) for the period of 1985/986 to 2014/2015

Water year	Jaber	Um Jimal	Hosha	Annual rainfall (mm)	Water year type
	47.70%	28.30%	23.90%		
1985/1986	45.68	13.29	3.18	62.15	Dry
1986/1987	75.75	41.99	10.05	127.78	Dry
1987/1988	0	62.24	14.9	77.14	Dry
1988/1989	44.63	28.75	6.88	80.27	Dry
1989/1990	93.88	33.4	8	135.28	Normal
1990/1991	56.04	32.49	7.78	96.31	dry
1991/1992	128.87	54.22	12.98	196.08	wet

1992/1993	42.53	25.19	6.03	73.74	**Dry**
1993/1994	39.28	15.13	3.62	58.03	**Dry**
1994/1995	49.64	39.95	9.56	99.15	**Dry**
1995/1996	23.15	19.97	4.78	47.9	**Dry**
1996/1997	43.43	25.87	6.19	75.49	**Dry**
1997/1998	53.7	30.65	7.34	91.69	**Dry**
1998/1999	14.41	4.82	1.15	20.38	**Dry**
1999/2000	44.63	13.15	3.15	60.92	**Dry**
2000/2001	45.34	36.66	8.78	90.78	**Dry**
2001/2002	67.63	45.47	10.89	123.99	**Normal**
2002/2003	185.24	52.81	12.64	250.69	**Wet**
2003/2004	97.23	26.32	6.3	129.85	**Normal**
2004/2005	100.09	32.52	7.79	140.4	**Normal**
2005/2006	82.1	24.17	5.79	112.05	**Dry**
2006/2007	83.72	21.67	5.19	110.58	**Dry**
2007/2008	74.41	33.03	7.91	115.35	**Dry**
2008/2009	105.82	22.75	5.45	134.01	**Normal**
2009/2010	110.59	31.13	7.45	149.18	**Wet**
2010/2011	94.98	22.95	5.49	123.42	**Dry**
2011/2012	106.44	28.84	6.9	142.18	**Wet**
2012/2013	93.36	25.55	6.12	125.03	**Normal**
2013/2014	47.63	27.74	6.64	82.01	**Dry**
2014/2015	126.87	39.35	9.42	175.64	**Wet**
Average	**72.6**	**30.4**	**7.3**	**110.2**	**27.4**

This method takes in consideration the antecedent moisture conditions (AMC), the initial abstraction of rainfall, and the land use. The first step for the use of the SCS model was to estimate the volume of the direct runoff, (Q), in inches.

Q = (P - Ia) 2 / (P- Ia + S) ……….……. (1)

WHERE:

Q: is the accumulated depth of runoff in inches.

P: is the accumulated depth of storm rainfall in inches.

Ia: is the depth of the initial abstraction in inches.

S: is the potential abstraction in inches.

Ia and S are related to soil cover conditions. Also the relation between initial abstraction (Ia) and potential abstraction (S) was derived from the studies of different watersheds in the United States of America as follows:

Ia = 0.2 S …………….……….. (2)

THEREFORE, THE ACCUMULATED RUNOFF IN EQUATION (1) IS FORMULATED AS:

Q = (P – 0.2 S) 2 / (P + 0.8 S) ………..…. (3)

The relation between the curve number (CN) and S was established by (Chow, et al., 1990) as,

S = (1000 / CN) - 10 ……………..…..... (4)

These universal equations are the basis of the runoff model used in this study where the flows were derived

EVAPOTRANSPIRATION

The purpose of calculating the evapotranspiration in Mafraq wastewater treatment plant catchment area is to estimate the direct recharge into the groundwater of the upper aquifer system (B4/A5). The potential evapotranspiration was calculated using Turc equations. This equation is written as follows:

$$E = P/(\sqrt{0.9 + (P^2 / f(t)^2)}$$ **….. (Turc, 1951)**

WHERE:

E: the annual actual evaporation (mm)

P: the average annual precipitation (mm)

T: the temperature function, which is equal to,

f(t) = 300 + 25 t + 0.05 t3 …… Where t is the temperature in OC.

The essential climatological data, which were needed for the computation of the potential evapotranspiration had been, collected from the Ministry of Water and Irrigation (MWI) files. In order to obtain the actual evaporation from rainfall, the potential evaporation was calculated during the occurrence of the rainfall storm.

RESULTS AND DISCUSSION

The hydrogeology of the study area is controlled by the geological set-up, which also controls the piezometry, occurrence and movement of the groundwater and the distribution of productive area in the aquifers. The soil conservation service curve number (SCS-CN) approach is widely used as a simple method for predicting direct runoff volume for a given rainfall event and consequently evaluating the groundwater recharge.

The curve number (CN) technique was applied in this paper because there is no runoff gauging station is available in the catchment area and no actual data regarding the runoff are available in the research area. The CN formulas 3 and 4 was applied to estimate the runoff from each effective storm for wet, normal and dry conditions using storm analysis. It is worth to see here that if the storm is less than the initial abstraction, no runoff will be occurred. The rate and quantity of water that infiltrates into the ground is a function of the soil type, soil permeability, ground cover, drainage conditions and duration of rainfall. It is well known that when water reaches the surface of a soil, a part of it seeps into the soil; this movement of water through the soil surface is known as infiltration which plays a significant role in the runoff process. Hence, the infiltration is the primary step in the natural ground recharge.

The daily rainfall data from the available three rainfall stations had been analyzed in terms of storm and frequency distribution for the wet, normal and dry water years. Based on the topographic, geological and the land use maps, the curve number (CN) was chosen for the wet, normal and dry year to be 75, 68 and 65, respectively. The potential abstraction (S) also was calculated using equation (4) for wet, normal and dry year to be 3.33, 4.70 and 6.67 inch, respectively, which was equal to 84.70, 119.53 and 136.76 mm respectively. The initial abstraction (Ia) was also calculated for wet, normal and dry year using equation (2) to be 16.94, 23.9 and 27.35 mm, respectively.

The calculation were performed for each storm occurred in wet , normal and dry

year using the equations were previously mentioned in chapter two . The calculated runoff volumes for wet, normal and dry year are shown in Table 2. As a result the maximum yearly runoff during the studied period was calculated to be 2.48 MCM (5-10/1/2012), and the minimum runoff as 0.025 MCM (12-14/12/2014). Table 2, summarizes the annual runoff for Mafraq Wastewater Treatment Plant catchment area for wet, normal and dry conditions.

Table 2: Calculations of direct runoff using storm analysis

Year	Storm date	Station			Average storm	Runoff (mm)	Runoff (MCM)	Runoff Coefficient %
		Um Jimal	Jaber	Hosha				
		28.30%	47.73%	23.90%				
Wet year (2014/2015)	21-27/11/2014	28.1	48.5	45.5	42.0	5.76	1.18	0.028
	12-14/12/2014	10.7	23.0	25.5	20.0	0.11	0.025	6.02
	7-11/1/2015	32.5	60.0	41.0	47.7	8.24	1.94	0.046
	18-20/2/2015	23.0	22.0	18.0	21.3	0.22	0.051	0.001
Total						**14.33**	**3.38**	**8.16**
Normal year (2012/2013)	5-10/1/2012	39.8	38.0	118.0	57.5	**10.5**	**2.48**	**7.41**
Dry year (2013/2014	7-13/12/2013 10/3/2014	32.5	45.0	41.2	40.5	**1.154**	**0.272**	**1.40**

According to these calculations, the heaviest floods occur between November and February and no significant floods occur in October and May. After that, the evaporation for wet, normal and dry condition was calculated using Turc formula and the results of these calculations are shown in Table 3. The calculated long-term evaporation rates ranged between 85 % in the wet year, and 94 % in the dry year.

The "Water Budget Approach" was used to calculate the annual recharge in the study area. The only measured parameter in this approach is the rainfall; the evaporation and runoff were calculated using Turc and SCS curve number methods, respectively. Then, the infiltration rate was solved for wet, dry and normal conditions. Under the assumption that the evapotranspiration is calculated adequately, as well as, the runoff and the initial abstractions are properly determined, then the following water balance equation can be established as follows:

$$\Delta S = P - (R + E) \pm Ia$$

WHERE:

ΔS: the change in groundwater storage or recharge (mm).

P: the precipitation (mm).

E: evapotranspiration (mm).

R: runoff (mm)

Ia: initial abstraction (mm).

The calculated amount of recharge for the whole studied area was about 0.63 MCM in the dry water year and 2.84 MCM in the wet water year. The recharge rate ranged between 0.3 % of the total annual rainfall in the dry

water year and 6.85 % in the wet water year. The results of recharge calculations for Mafraq wastewater treatment plant area are shown in Table 3.

Table 3: Recharge calculations for Mafraq Wastewater Treatment Plant area

Year	Rainfall (MCM)	Runoff (MCM)	Evap. (MCM)	Infiltration (MCM)	Runoff coefficient (%).	Infiltration rate (%)	Evaporation Rate (%)
Wet	41.49	3.38	35.27	2.84	8.15	6.85	85.0
Normal	33.58	2.49	30.46	0.63	7.42	1.88	90.7
Dry	19.4	0.272	19.07	0.058	1.40	0.30	98.30

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الملخص العربي

تقييم تغذية المياه الجوفية في حوض محطة المفرق لمعالجة المياه العادمة باستخدام طريقة مكتب حفظ التربة الأمريكي - رقم المنحنى - دراسة حالة البادية الشرقية / الأردن

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تتناول هذه الدراسة شحن المياه الجوفية في حوض محطة المفرق لمعالجة المياه العادمة. إن شحن المياه الجوفية هي الكمية الإجمالية السنوية من المياه التي تترشح من سطح الأرض إلى خزانات المياه الجوفية. كما يتم التعبير عن ذلك المعدل السنوي للتغذية (ملم / سنة) تقييمها على أساس القياسات الميدانية، والمشتقة من معادلة التوازن المائي، أو المقدرة باستخدام الصور الجوية أو صور الأقمار الصناعية. إن كمية ونوعية الشحن الجوفي يؤثران بشكل كبير على العمليات الفيزيائية والكيميائية في نظام التربة– الصخر– المياه الجوفية. كلما زادت التغذية كلما زاد احتمال تلوث المياه الجوفية. فقد يؤدي إلى ارتشاح ونقل الملوثات من سطح الأرض إلى المياه الجوفية. في هذه الورقة البحثية الحالية تم تطبيق معادلة التوازن المائي لحساب الشحن الجوفي للمياه الجوفية في منطقة الدراسة. وتم استخدام هذه المعادلة لحساب التوازن المائي يوميا لكل عاصفة حدثت خلال سنة مائية رطبة وعادية وجافة. وعادة تتركز الأمطار في الفترة ما بين ديسمبر ومارس (آذار). حيث تكون في هذه الفترة مدة هطول الأمطار طويلة والتبخر قليل، وعليه فإن الشحن الجوفي يحدث في الغالب أثناء هذه الفترة. ان كمية الأمطار هي العنصر الوحيد المقاس في منطقة الدراسة. وبناءً عليه فقد تم حساب الفاقد الأولي في محطات المطر الثلاثة الموجودة في منطقة الدراسة باستخدام طريقة مكتب حفظ التربة الأمريكي – رقم المنحنى خلال سنوات مائية معينة. كما تم حساب كمية التبخر باستخدام طريقة تيرك وحل معادلة التوازن المائية لثلاثة سنوات مائية (رطبة وعادية وجافة). يتراوح المعدل السنوي للأمطار في حوض محطة المفرق لمعالجة المياه العادمة بين 100 ملم في الجزء الجنوب الشرقي وأكثر من 250 ملم في الجزءالشمالي والشمال الغربي من الحوض. كما يبلغ معدل حجم هطول الأمطار السنوي حوالي 33.58 مليون متر مكعب، وحجم جريان المياه في كامل الحوض حوالي 2.49 مليون متر مكعب (7.41% من حجم مياه الأمطار) وأن حجم التبخر المحسوب حوالي مليون متر مكعب 30.46، أي حوالي (90.7% من حجم مياه الأمطار). يتراوح معدل الشجن الجوفي السنوي المحسوب للخزان المائي الجوفي بين حوالي 0.058 مليون متر مكعب أي بنسبة 0.30 % في السنة المائية الجافة و2.84 مليون متر بنسبة 6.85 % في السنة المائية الرطبة.

الكلمات الرئيسية : هطول الأمطار، الشحن الجوفي، المياه الجوفية، التلوث، تيرك، التبخر، المفرق.