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Estimation of runoff and recharge rates by using channel routing mechanism.

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ملخص البحث

إن سبل المعيشة للبدو فى منطقة رأس أبوالجروف الواقعة بالساحل الشمالى الغربى بجمهورية مصر العربية تعتمد بشكل كبير جدا على مياه الأمطار وعلى المياه الجوفية، لذا فإن هذا البحث يهدف إلى تقدير كمية مياه الأمطار وكذلك كمية المياه المتسربة للمياه للجوفية.قد تم تقدير تلك الكميات على الوضع للحالى للمنطقة كما تم فرض سيناريو مستقبلى بإقامة أعمال تنمية مثل إقامة سد أو بحيرة صناعية فى أعالى وادى منطقة الدراسة.حيث تم عمل تخطيط هيدرولوجى للمنطقة باستخدام برنامج نظم المعلومات الجغرافية(GIS) لخريطة مناسيب رقمية ذات دقة 30 مترا ثم تطبيق طريقة (Muskingum) فى قناة التوصيل باستخدام برنامج (HEC-HMS) والتى تعتمد على عاملين فى تطبيقها وهما زمن الرحلة ومعامل كمية التدفق للقناة الافتراضية لتوصيل الجريان السطحى. بإختيار نقطة (PW4) كموقع لأعمال التنمية المستقبلية أعلى الوادى أسفر عن حجز 57% من كمية مياه الأمطار الجارية والتى أدت بدورها لمنع التسرب للمياه الجوفية فى آخر قناة توصيل فى منطقة التخطيط الهيدرولوجى للمنطقة مما يعنى زيادة نسبة ملوحة المياه الجوفية التى فقدت مصدر التجديد لها الوحيد وهو تسرب مياه الأمطار بالإضافة إلى عملية سحب المياه الجوفية المستمر لأغراض المعيشة مثل الشرب والزراعة. كل هذا يدفعنا للبحث عن مصدر جديد للمياه مثل الشحن المتعمد لمياه الأمطار الجارية أو تحلية مياه البحر للوصول إلى تنمية مستدامة داخل منطقة الدراسة.

ABSTRACT

In Ras Abu Elgrof area in the north west of Egypt, the Bedouin livelihoods rely heavily on rainfall and groundwater as a principal resource of water. This paper aimed to estimate recharge rates values in existing and future development scenarios, assuming obstruction such as (dam or levee) constructed at the upstream of the watershed area that delineated by Geographic Information System (GIS) using SRTM 30 m Digital Elevation Model was acquired from the Global Land Facility Cover website (GLCF). A hydrological model was developed to estimate values of runoff and recharge by using Muskingum method, that depends on K (travel time) and X (weighting coefficient). At development scenario at location PW4 at upstream, 57% of runoff will be reserved leads to no recharge occurred due continually runoff flux from the upstream junction to the next channel routing in the last channel of watershed area. Therefore, in case of implantation future development, a new recourse such as recharging mechanism or seawater desalination should be implemented to decrease salt concentration in the study area for future sustainable development.

1. Introduction

In Ras Abu Elgrof area in the north west of Egypt, the Bedouin livelihoods rely heavily on rainfall and groundwater as a principal resource of water. This study aimed to Forecast the recharge variability due to future developments such as manmade (e.g. dam or levee) constructions. Recharge process is very important, although inconspicuous aspects of global hydrological cycle. The most common recharge areas are hills, alluvial fans and ephemeral streams bottoms in dry regions (Rose n.d.). The study area was delineated by using Geographic Information System (GIS) technology. The SRTM 30 m Digital Elevation Model was acquired from the Global Land Facility Cover website (GLCF) was used for delineation (R. E. Daffi and I. I. Ohuchaogu 2015). By development a hydrological model using HEC-HMS and GIS (M.R. Knebl , Z.-L. Yang, K. Hutchison ,and D.R. Maidment 2006), the Muskingum method, that depends on coefficients K (travel time) and X (weighting coefficient) (V. Fasahat , A. Honarbakhsh, H. Samadi and S.J. Sadatinejad n.d.) could be used to estimate runoff and recharge quantities.

2. Meteorological Data Analysis

The analysis of the rainfall data is the most important element in the hydrological study. It is used as input to determine the flood discharges and volumes of water come during the flood. Rainfall is the primary hydrological input, but rainfall in arid and semiarid areas is commonly characterized by extremely high spatial, typically irregular and temporal variability (ELSAYAD 2012). Since any hydraulic and ground water structures should operate under the future needs, it is important to predict the maximum rainfall height by means of valuable historical data.

Historical maximum daily-monthly rainfall data from year 1976 to 2014 for Ras Abo Elgrof have been obtained from the Egyptian Meteorological Authority (EMA) as shown in Table- (1) and figure (1). Despite the available data was maximum-monthly-yearly only, it could be advantage as the worst case, because it assumes that the rain occurs once a day, thus the extreme reading throughout the month could got and therefore the annual maximum rain could be calculated by accumulation maximum monthly rain.

Table (1) Historical maximum daily-monthly-yearly rainfall data from 1976 to2014 for Ras Abo Elgrof area by (EMA).

Ras Abu Elgrof Area.													**Max-Monthly**	**Max-Yearly**
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**		
1976	10.8	3.6	1.7	1.9	12.7	0.1	0.3	0.1	2.8	0.4	11.6	3.1	12.7	49.1
1977	3.4	5.6	11.3	1.4	0.3	0	0.1	0	0	6	1.6	57	57	86.7
1978	11	0.9	10.4	0.4	0	0	0	0	0.1	0.6	14.7	8.4	14.7	46.5
1979	0.8	2	2.9	0.5	0.1	15.6	0	0	0	1.2	15.6	13	15.6	51.7
1980	6.8	13	7.2	2.8	1.2	0	0	0	0.1	0.3	0.1	9.8	13	41.3
1981	3.6	1.4	5.8	2.7	0	0	0	0	0	0	5.1	3	5.8	21.6
1982	2.8	23.7	2.2	0.3	0	0	0	0	0	0	16.7	3.6	23.7	49.3
1983	20.1	8.8	5.5	0.2	0.1	0.5	0	0	0	1.8	2	21.4	21.4	60.4
1984	2	8.5	0.5	8	0	0	0	0	0	2.6	8.5	10.2	10.2	40.3
1985	3.4	8.9	0.4	0.5	0	0	0	0	0	2.3	1.6	31.9	31.9	49
1986	1.3	2.8	0.2	0.1	0.4	0.2	0	0	0	0	7.6	8.7	8.7	21.3
1987	7.4	2.5	4.1	0	0	0	0	0	0	7.7	2.5	14.8	14.8	39
1988	12.2	14	3.8	1.4	0	0	0	0	0	12.5	5.8	10.2	14	59.9
1989	27.5	2.7	6.2	0	0	0	0	0	0	25.6	3.3	16	27.5	81.3
1990	9.3	36.3	5.4	0.4	0	0.7	0	0.1	0.1	0.2	1.5	3.6	36.3	57.6
1991	8.6	2.3	18.2	1.8	0.3	0	0	0	0	0.1	27.8	14.6	27.8	73.7
1992	20	13	0.4	3.2	0.5	0	0	0	0	0	2.4	35.9	35.9	75.4
1993	6.4	8.2	1.2	0	0.4	0	0	0	0	3.2	15.6	4.4	15.6	39.4

Table (1) Historical maximum daily-monthly-yearly rainfall data from 1976 to2014 for Ras Abo Elgrof area by (EMA).

1994	9.6	5.2	9.2	0.2	0.1	0	0	0	0	7.6	43.3	14.7	43.3	89.9
1995	1.2	22	8.6	8.3	0	0	0	0	0	0	1.9	1.8	22	43.8
1996	25	0.1	3.7	2.2	0.1	0	0	0	3.6	8.7	28.7	5.8	28.7	77.9
1997	12	11.6	6.1	0.3	0.4	0	0	0	5.2	9.9	4.2	26.6	26.6	76.3
1998	4.4	10.6	14.6	0.1	3.2	0	0	0	0	0.6	9.6	2.5	14.6	45.6
1999	5.1	5.4	0.1	0	0	0	0	3.5	0	0.6	1	16.1	16.1	31.8
2000	26.9	11.8	8.8	0.2	3.8	0	0	0	3.2	38.4	8.2	10.3	38.4	111.6
2001	2.7	2.4	0.1	0.1	0.1	0	0	0	0	3.4	1	28.2	28.2	38
2002	16.6	3.2	0.7	1.9	0	0	0	0	0.4	14	3.4	10.4	16.6	50.6
2003	3.6	6	22.6	0	0	0	0	0	0	0	15.4	18.7	22.6	66.3
2004	6.6	12.4	3.4	0.9	3.3	0	0	0	0	0	15.8	6.6	15.8	49
2005	19.4	3.1	4	0.2	0	0	0	0	0	0.9	11.9	24.6	24.6	64.1
2006	3.6	5.8	1.6	0.3	0.1	0	0	0	0	10	13.7	14.2	14.2	49.3
2007	6.6	8.2	5.2	1.8	0.6	0	0	0	1.2	0	8.8	13.4	13.4	45.8
2008	37.3	13.1	3.6	0.1	0.1	0.1	0	0	0	8.6	4.1	5.4	37.3	72.4
2009	0.1	17.2	3.1	1.7	0	0.1	0	0	0	9.8	2.3	2.8	17.2	37.1
2010	6.1	5.2	0.5	0	0	0	0	0	0.1	2.9	0	5.3	6.1	20.1
2011	4	12.4	2.2	5.6	0.1	0	0	0	0.2	0	24	1.9	24	50.4
2012	15	6.1	2.4	1.5	0.3	0	0	0	0	12	20.3	5.5	20.3	63.1
2013	22.7	0.2	0	0.2	1.6	0	0	0	0	0	3	10.6	22.7	38.3
2014	3.7	8.7	5	0.3	2.7	0	0	0	0	0	-	-	8.7	20.4

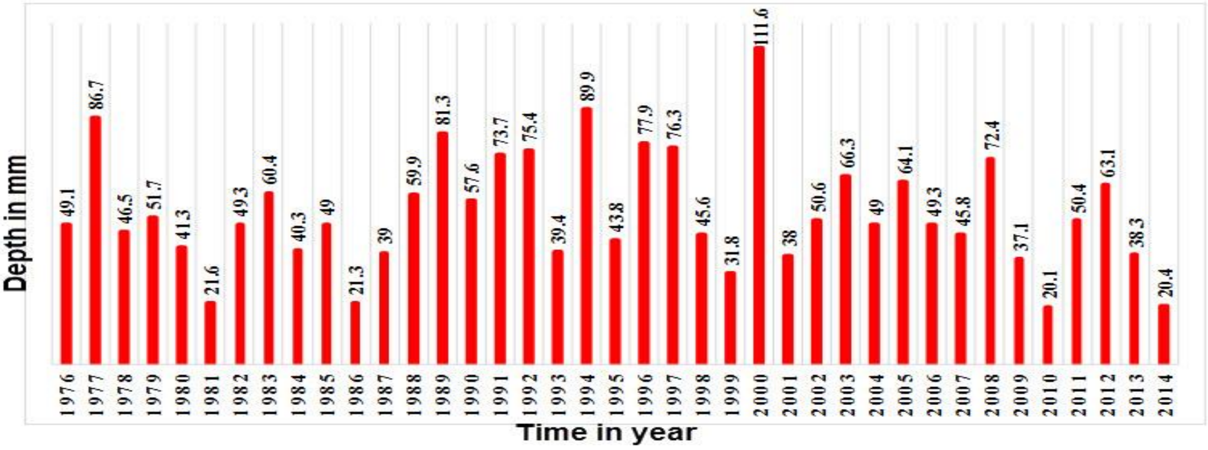

Figure (1) Maximum Daily-monthly-Yearly rainfall (mm) .

3. Estimation of rainfall days in the study area

It is very important to know precipitation days, for making accuracy in calculating runoff and recharge quantities. The next annual average precipitation just helped to know number of precipitation. Figure (2) and table (2) illustrate the average rainfall days that can be reach 48 days per year (Mersa Matrouh Monthly Climate Average, Egypt 2000-2012) taken from year 2000 to 2012) that could be used for estimation number of rainy days for period from year 1976 to 2014. The accumulation of precipitation is 163.2mm/(year=48days). Therefore, the average precipitation of year could be estimated as follow:

Average precipitation= 163.2/48=3.4mm⁄(day/(year=48 days)).

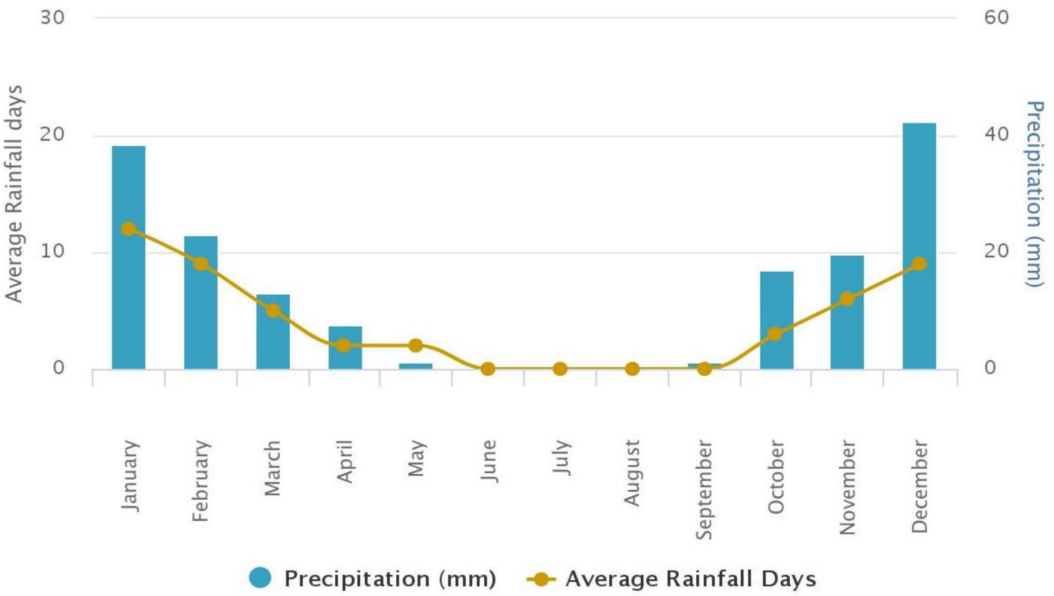

Figure (2) Average rainfall (mm) graph for Marsa Matrouh. Data for charts taken from year 2000 to 2012. Source world weather online.2016)

Month	**Precipitation (mm)**	**Average rainfall (days)**
January	38	12
February	23	9
March	13	5
April	7.5	2
May	1.2	2
June	0	0
July	0.1	0
August	0	0
September	1.1	0
October	17.1	3
November	19.8	6
December	42.4	9
Assumption of precipitation days		48

Table 2 Average rainfall (mm graph for Marsa Matrouh. The data for charts above are taken from year 2000 to 2012.Source world weather online .2016)**.**

4. Delineation of the watersheds for the study area

For delineating watersheds, the heights of surface must be available. These heights can be obtained from digital elevation model (DEM). A digital elevation model (DEM) is a digital model or 3D representation of a terrain's surface commonly for a planet (including Earth), moon, or asteroid created from terrain elevation data (R. E. Daffi and I. I. Ohuchaogu 2015). The SRTM 30 m DEM's was acquired from the Global Land Facility Cover website (GLCF). The watershed area resulted from GIS delineation processes was about 8km2.Sinks (and peaks) are often errors due to the resolution of the data or rounding of elevations to the nearest integer value. Sinks should be filled to ensure proper delineation of basins and streams. If the sinks are not filled, a derived drainage network may be discontinuous. The Fill tool uses the equivalents of several tools, such as Focal Flow, Flow Direction, Sink, Watershed, and Zonal Fill, to locate and fill sinks. The tool iterates until all sinks within the specified z limit are filled. As sinks are filled, others can be created at the boundaries of the filled areas, which are removed in the next iteration. After sinks filled, stream drainage delineated using the 30 m DEM available for ASTER-GDEM (ELSAYAD 2012).

Figure (3) represents the delineated watersheds boundaries in Matrouh with its areas. It represents the drainage paths and subbasins. Arc hydro tools divide the delineated watershed into subbasins with small areas to cover the variable types of the Bedouin’s existing water extraction. After the watersheds delineated according to a certain point which consider the outlet point, the geomorphology characteristics can get. These characteristics of subbasins like area, basin slope and the longest path of streams could be estimated to calculate lag time. By HEC-GEOHMS module in ArcGis it could be prepare the delineated watersheds to export it to HEC-HMS.v4 software to calculate the peak discharge and recharge volume at any point of watershed area. considering soil curve number 86 and Impervious area is 10%.

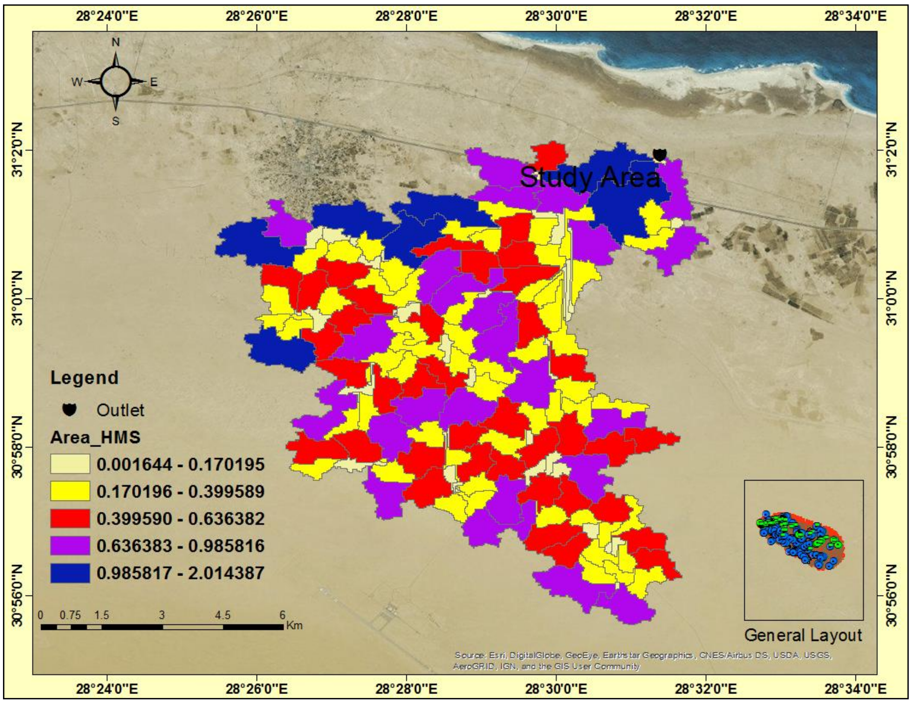

Figure (3) illustrates the delineated watershed area.

5. Estimation of Rainfall Recharge

5.1. Reasons of chosen study area

Figure (4) clarified the location of interested area, that was chosen based on the following conditions: -

1. The study area is planted and some Bedouin live in it. In case of development at the watershed upstream, a direct impact on groundwater levels and salinity expected to occur.
2. Information of the number of water extractions and possibility of estimating the amount of water consumed in drinking and agriculture that helped in assessment future development sustainable.
3. The continuous connection between the aquifers, that known by conducting slug test for estimating hydraulic conductivity and characterization information of the lithology by contraction company (UG 2015) that could be used for simulating groundwater model in the future.

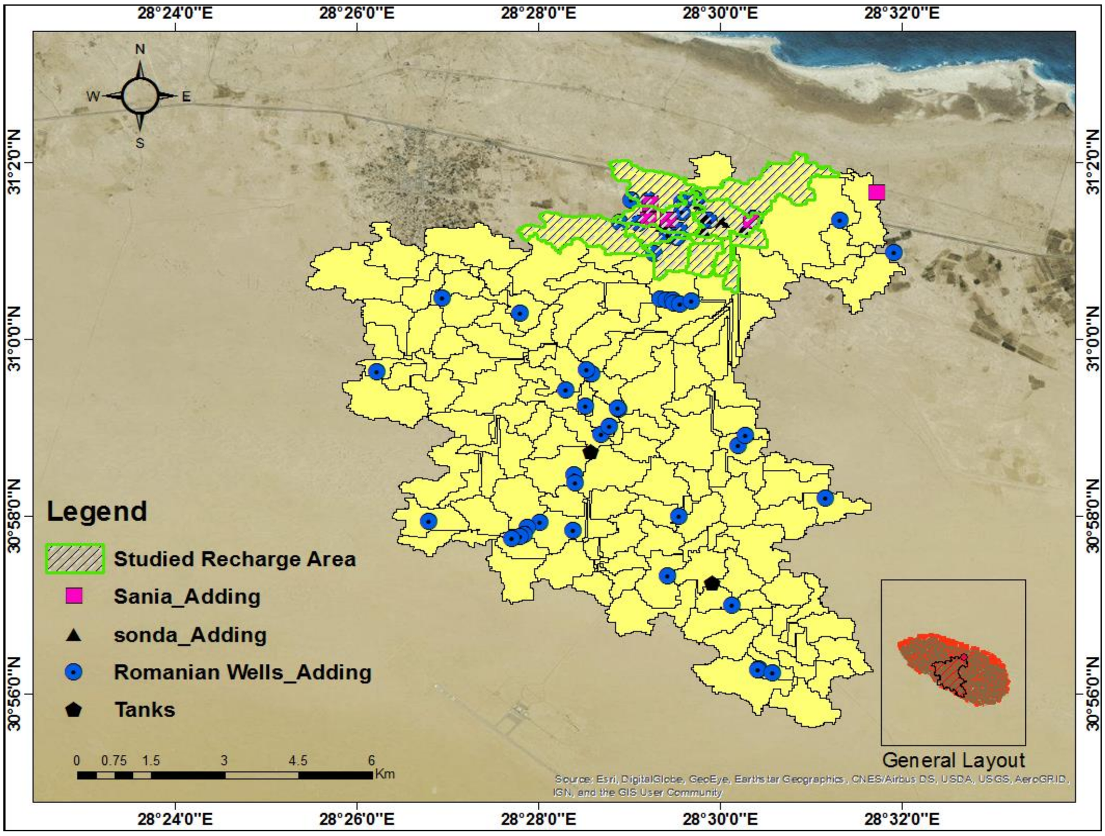

Figure (4) illustrates the interested recharge area relative to the watershed area.

5.2. Channel Routing mechanism.

Precipitation infiltrates directly into subsoil by two ways, the first is infiltration before occurring runoff and the second is during storm in river streams by channel routing mechanism. For estimating recharge occurring before runoff (i.e. by covered area), The seasonal variations in the CN has a significant effect on recharge.” Changes to soil properties are occurring over a range of time scales, such that the soils of the future may not have the same infiltration properties as existing soils. The potential implications involved in assuming unchanging soil properties” (Holman 2006).

Figure (5) ilustrate mechansim of Muskingum routing method that commonly used in a-hydrological model in this type of studies, which its accuracy depends on the way the coefficients of travel time (K) and weighting coefficient (X). where:
Travel time K: travel time of peak through the reach, and
Weighting coefficient X: weight on flow versus outflow (0≤X≤0.5).
X= 5 → Reservoir, storage depends on outflow, no wedge.
X= 0.0-0.3→ Natural stream. (Chow et al., 1988).

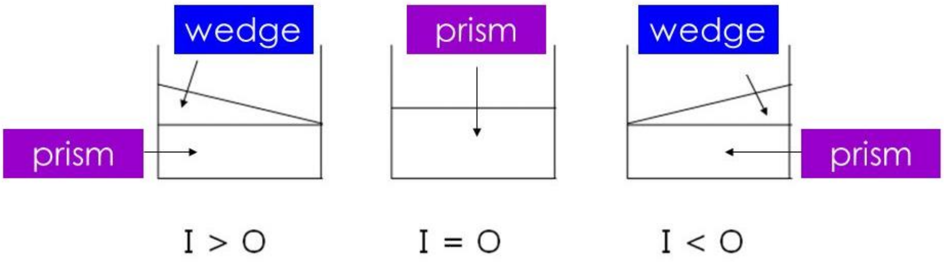

Figure (5)Muskingum method (flow in channel).

I= Inflow and O= outflow.
Storage in wedge: KX(I-O).
Storage in prism: (KO).
So, storage = KX(I-O)+KO.

Figures (6) and (7) depict the hydrographs of the existing scenario and development scenario in case of construcion or levee dam is conyructed.

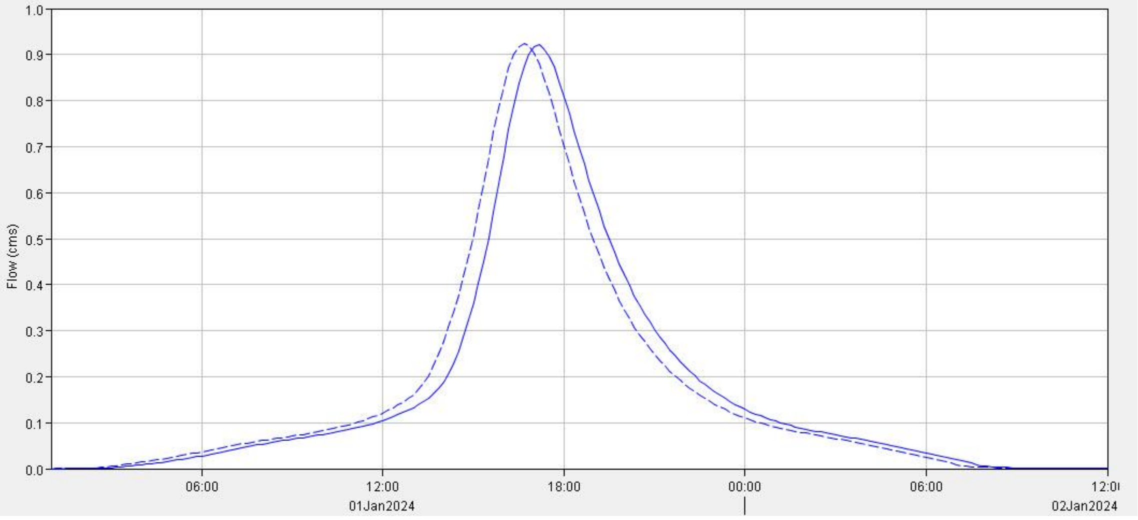

Figure (6) depicts the hydrograph for the last channel routing in the watershed area for existingscenario. (rainfall depth= 3.4 mm).

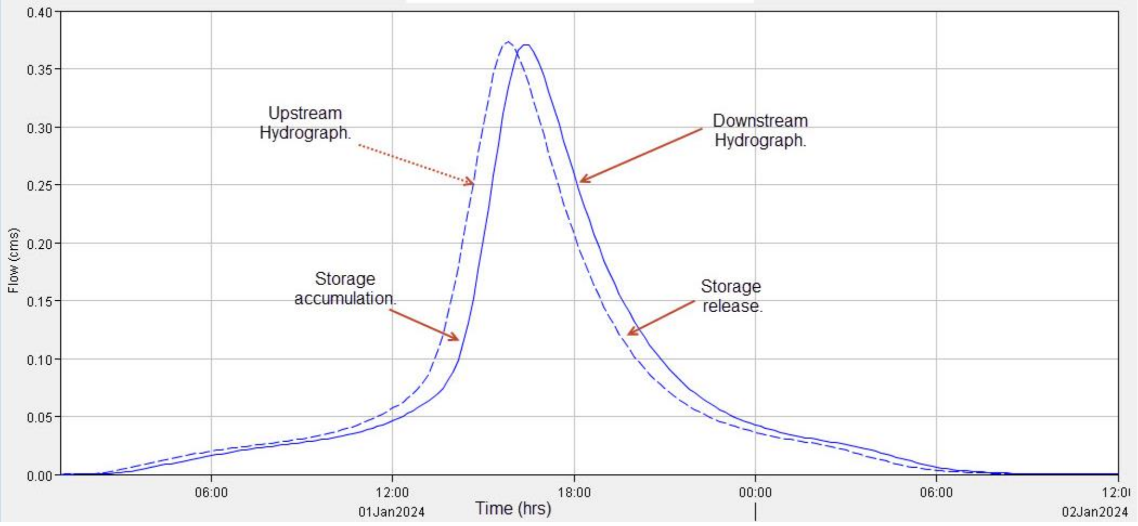

Figure (7) depicts the hydrograph for the last channel routing in the watershed area for development scenario at location point PW4. (rainfall depth= 3.4 mm).

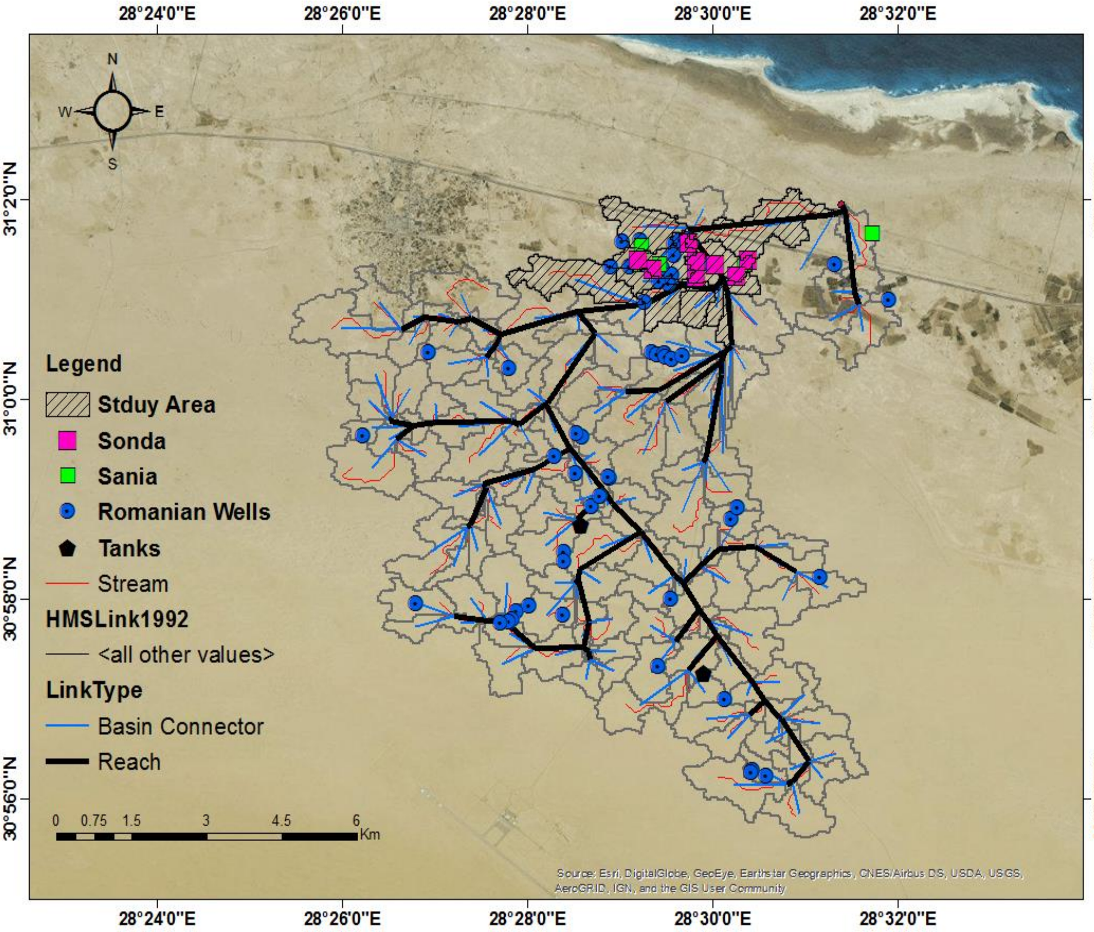

Figure 1 Clarifies (channel routing _ Reach) pathways due to delineated study area.

It is noticed that the water volume at the outlet is more than the inlet without supplying from any subbasins, this is a clear indication that the stream is considered a separate unit far of the basin area and the amount of rain falling is part of being with the stream and the other seep into subsoil according to the soil type and cross section of stream river.

At development scenario At junk (PW4, that represent construction or levee) constructed at upstream, a 57% of runoff quantities will be reserved and no recharge from cumulative runoff occurred in the last channel routing of delaminated area. Figure (9) clarifies location of development (PW4) and the last channel routing R70.

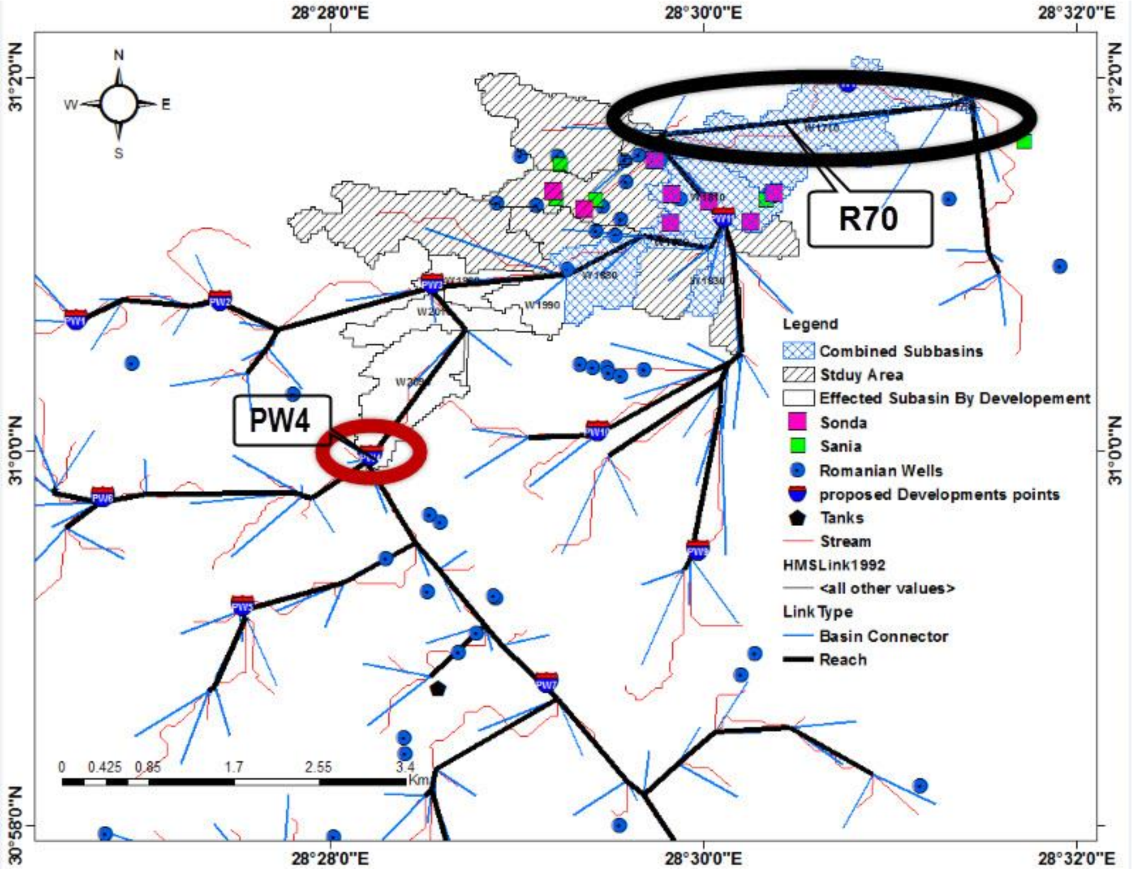

Figure (9) clarifies location of development (PW4) and studied channel routing R70.

In the study area, it is noted that the runoff and therfor recharge quantities affected by a large margin with development works compaired with small values of precipitation in simi arid area as shown in table (3).

Recharge volume could be estimated according to the next equation with the neglect of the rest of the hydrological cycle factors such as evaporation evapotranspiration, and etc...

Recharge Volume = (Precipitation*Interested Area) - (CN* Precipitation*Area).

Recharge by Channel Routing (Losses due to infiltration) = (Outlet Inflow – Inlet Inflow).

An equation was developed to estimate recharge rates in (mm/year) as follow: -

$$Recharge\ Rate = \frac{\text{Recharge Volume in m3 (by HEC} - \text{HMS)by routing method } * \text{ No. of Rainfall days.}}{\text{(Subbasin area in (m2) } * \text{ (2/3) } * \text{ 365days.)}}$$

Table (3) illustrates recharge rates according to exist and future development scenarios.

Basin ID	Area (km2)	Rainfall Depth (mm)	Precipitation Volume (1000m3)	Loss volume (1000m3)	From Routing (1000m3)	Total Recharge Volume (1000m3)	Recharge Rate (m3/year).	Recharge Rate (m3/year). Development case
W1710	1.3435	3.4	4.6	4.1	0.3	4.4	0.000646033	0.000102345
W1740	0.73751	3.4	2.5	2.3	0	2.3	0.001176859	0.001176859
W1750	2.0144	3.4	6.8	6.2	0	6.2	0.00043087	0.00043087
W1760	0.43001	3.4	1.5	1.3	0	1.3	0.00201843	0.00201843
W1770	0.83124	3.4	2.8	2.5	0	2.5	0.001044157	0.001044157
W1800	0.67914	3.4	2.3	2.1	0	2.1	0.001278006	0.001278006
W1810	0.67996	3.4	2.3	2.1	0	2.1	0.001276465	0.001276465
W1830	0.16608	3.4	0.6	0.5	0	0.5	0.005226067	0.005226067
W1840	0.33217	3.4	1.1	1	0	1	0.002612955	0.002612955
W1860	0.27955	3.4	1	0.9	0	0.9	0.003104794	0.003104794
W1870	0.0805755	3.4	0.3	0.2	0	0.2	0.010771825	0.010771825
W1880	0.45961	3.4	1.6	1.4	0.1	1.5	0.001888438	0.000299167
W1890	0.3297	3.4	1.1	1	0	1	0.00263253	0.00263253
W1900	0.34368	3.4	1.2	1.1	0	1.1	0.002525446	0.002525446
W1910	0.0633093	3.4	0.2	0.2	0	0.2	0.0137096	0.0137096
W1930	0.84358	3.4	2.9	2.6	0	2.6	0.001028883	0.001028883
W1940	0.34368	3.4	1.2	1.1	0	1.1	0.002525446	0.002525446
W1950	0.70956	3.4	2.4	2.2	0	2.2	0.001223216	0.001223216

6. Summary and Conclusions:

In case of implementation of future development in the upstream of the watershed area that locate in semi-arid zone, it must consider that the decreasing in runoff quantities will directly effect a large proportion of recharge rates in downstream. At junk (PW4, that represent construction or levee) constructed at upstream, a 57% of runoff quantities will be reserved and no recharge from cumulative runoff occurred in the last channel routing of delaminated area. Decreasing in recharge in recharge rates in addition to continually withdrawal of groundwater by Bedouin eventually lead to increasing salinity, that directly effect on human, animals and plants. Therefore, for future sustainable development, a new recourse such as recharging mechanism or seawater desalination should be implemented for decreasing salt concentration in the study area.

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