Journal of Science, 2017, Vol. 58, No.4B, pp: 2128-2138
DOI: 10.24996/ ijs.2017.58.4B.17

Iraqi Journal of Science

ISSN: 0067-2904

Using Annual Rainfall to Estimate the Surface Runoff and Groundwater Recharge in Lialan Basin (Southeast Kirkuk - North of Iraq)

Qusai Y. Al-Kubaisi[1], Arjan Ali Rasheed[2*]

[1]Department of Geology, College of Science, Baghdad University, Baghdad, Iraq
[2]General Commission for Groundwater, Ministry of Water Resources , Baghdad, Iraq

Abstract

The present study intends to estimate the surface runoff and groundwater recharge in Lialan basin using the soil conservation service method (curve number) and chloride mass balance method (CMB) respectively. Lialan basin is located at the southeast part of Kirkuk governorate, between longitudes (44° 21' 00" E - 44° 42' 00" E) and latitudes (35° 7' 30" N - 35° 28' 30" N) , which covering an area of about 436 km2 and contains many geological formations. In this study, based on the annual rainfall data extending from (1970 - 2016) obtained from the Kirkuk meteorological station, the surface runoff was calculated using the curve number method (CN), and found to be equal to 90.4 mm/year, which represent 26.07 % of the total rainfall. While the groundwater recharge was calculated depending on the annual rainfall and chloride concentrations in rainfall and groundwater using the chloride mass balance method (CMB) and found it equals 23.07 mm/year, representing 7.42 % of the total rainfall. Thus the annual recharge amount for the whole basin is equal to 10.0585×10^6 m^3 / year. Generally, the results indicate a direct relationship between the systems of runoff and groundwater recharge in Lialan basin with total rainfall .

Keywords: surface runoff, groundwater recharge, rainfall, Lialan basin.

إستخدام الامطار السنوية لتقدير الجريان السطحي وتغذية المياه الجوفية في حوض ليلان(جنوب شرق كركوك – شمال العراق)

قصي ياسين الكبيسي[1] ، أرجان علي رشيد[2*]

[1]قسم علم الارض، كلية العلوم، جامعة بغداد، بغداد، العراق.

[2]الهيأة العامة للمياه الجوفية، وزارة الموارد المائية، بغداد، العراق.

الخلاصة

تهدف الدراسة الحالية إلى تقدير الجريان السطحي وتغذية المياه الجوفية في حوض ليلان باستخدام طريقة ال(curve number) وطريقة موازنة الكلور على التوالي. يقع حوض ليلان في الجزء الجنوبي الشرقي من محافظة كركوك، بين خطي طول (E "00 '42 °44 - E "00 '21 °44) ودائرتي عرض (N "30 '28 °35 - N "30 '7 °35) وتغطي مساحة تقدر ب 436 كم^2 تقريبا وتتكشف فيها العديد من التكاوين الجيولوجية. في هذه الدراسة ، استنادا إلى بيانات الأمطار السنوية للفترة من (1970 – 2016) التي تم الحصول عليها من محطة الأرصاد الجوية في كركوك، تم حساب الجريان السطحي باستخدام طريقة ال (curve number) وهي تساوي 90.4 ملم / سنة، اي ما يمثل 26.07٪ من مجموع الأمطار

*Email: arjantuz@yahoo.com

الكلي. بينما مقدار التغذية للمياه الجوفية فقد تم احتسابه اعتمادا على معدل الامطار السنوية ونسب الكلور في الامطار والمياه الجوفية باستخدام طريقة موازنة الكلور وهي تساوي 23.07 ملم / سنة ، اي ما يمثل 7.42 % من مجموع الأمطار الكلي . كمية التغذية السنوية لكل الحوض وجدت انها تساوي (10.0585×10^6 m^3 / year). عموما نتائج الدراسة تشير إلى وجود علاقة مباشرة بين أنظمة الجريان السطحي وتغذية المياه الجوفية في حوض ليلان مع مجموع الأمطار الكلي.

Introduction

In the present study the soil conservation service method (SCS) and chloride mass balance method (CMB) have been used to estimate the surface runoff and groundwater recharge in Lailan basin. The Soil Conservation Service - Curve Number method (SCS- CN) was developed to compute direct runoff from areas without stream flow records, but where detailed data on soil and vegetative covers are available [1]. The SCS- CN method is a simple, predictable and stable conceptual method for estimation of direct runoff depth based on storm rainfall depth [2]. Due to its simplicity, it quickly became one of the most popular methods among the engineers and the practitioners, especially for small catchment hydrology [3]. On the other hand, the main weak points of the SCS-CN method is it did not consider the impact of rainfall intensity and its temporal and spatial distribution, as well as it does not address clearly the effect of adjacent moisture condition [4,5,6] .

There are many methods have been developed to estimate groundwater recharge from precipitation, like direct measurement, water-balance methods, and tracer techniques [7]. Most of these methods are costly and time consuming, and a long monitoring time is needed to obtain dependable results from direct methods. So, natural tracer methods based on environmental elements are widely and successfully used [8]. The chloride mass balance (CMB) method is a simple, inexpensive method to estimate groundwater recharge. The essential concept of this method is that the atmospheric input of chloride precipitation remains in and enriches soil, water during evapotranspiration [9].

There are a number of previous studies that included the study area such as, Sogiria [10], studied the hydrology of Kirkuk and northern part of Al Adhaim Basin. Araim [11], studied the hydrogeological basins of Iraq. Al-Nakash et al. [12], they designed an operational program for wells in Kirkuk. The State Company of Geological Survey and Mining studied the hydrogeology and hydrochemistry of groundwater of Kirkuk quadrangle sheet (NI-38-2) [13]. Saud [14], studied the Hydrogeology and hydrochemistry of groundwater of Kirkuk governorate. The General Commission for Groundwater / Branch of Kirkuk, studied the hydrochemistry of groundwater of Lailan sub-basin [15]. The main objective of this study is to estimate the surface runoff and groundwater recharge in Lailan basin using (SCS- CN) and (CMB) methods.

Study Area

The study area is situated at the southeast part of Kirkuk governorate, north of Iraq, between longitudes (44° 21' 00'' E - 44° 42' 00'' E) and latitudes (35° 7' 30'' N - 35° 28' 30'' N), with an area about 436 km^2 Figure-1. Geologically, The most important geological formations that are exposed in the study area are Bai Hassan and Mukdadiyah Formations as well as Quaternary deposits Figure-2 [16]. The basin is located between two structures; Kirkuk structure from the northeast side and Jambur Anticline from the southwest side, where the basin is confined between two thrust faults. Bai-Hassan formation and the older Quaternary deposits forms the major aquifer unit in the basin. Bai- Hassan Formation is characterized by thick layers of conglomerates interbedded with sandstone, siltstone, and claystone. While the older Quaternary deposits are characterized by layers of gravel, sand, silt and clay [12, 17].

Materials and Methods

In order to estimate the surface runoff and groundwater recharge in Lialan basin, the annual rainfall data for the period 1970 - 2016 for Kirkuk station were retrieved from the archives of the Iraqi meteorological Organization and Seismology [18]. Twenty-two groundwater samples were collected in April 2017 from wells distributed in the study area, their locations and depths are shown in Table-1 and Figure-1. Five rainfall samples were collected for the rainy period of the water year (2016 – 2017) extending from December to April . All samples were analyzed for chloride content in the laboratory of the General Commission for Groundwater / Kirkuk Branch . The results of analyses are shown in Table -1 for groundwater samples and Table -4 for rainfall samples. All these data were used to estimate the surface runoff and groundwater recharge in Lailan basin using the soil conservation service (SCS-CN) and chloride mass balance (CMB) methods. Soil conservation service (SCS-CN) method is widely used to estimate direct runoff amount for a given precipitation. Generally, this method was presented by the National Resources Conservation Service (NRSC), United States Department of Agriculture (USDA) in 1969 [2].

The SCS-CN method is based on the water balance equation (1), where (P) is rainfall in millimeters, (Q) is runoff in millimeters, (Ia) is initial abstraction and (F) is a retention [19].

$$P = Ia + F + Q \quad (1)$$

The empirical relation between rainfall and runoff as follows [19] as shown graphically in Figure-3:

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \qquad For\ P > 0.2S \quad (2)$$

Where:

Q Runoff in (mm)
P Total precipitation (mm) (annual total used)
S Potential water retention, including the initial abstraction(Ia) which is assumed to be (0.2S), and could be estimated from the following equation (3), where CN is curve number :

$$S = \frac{25400}{CN} - 254 \quad (3)$$

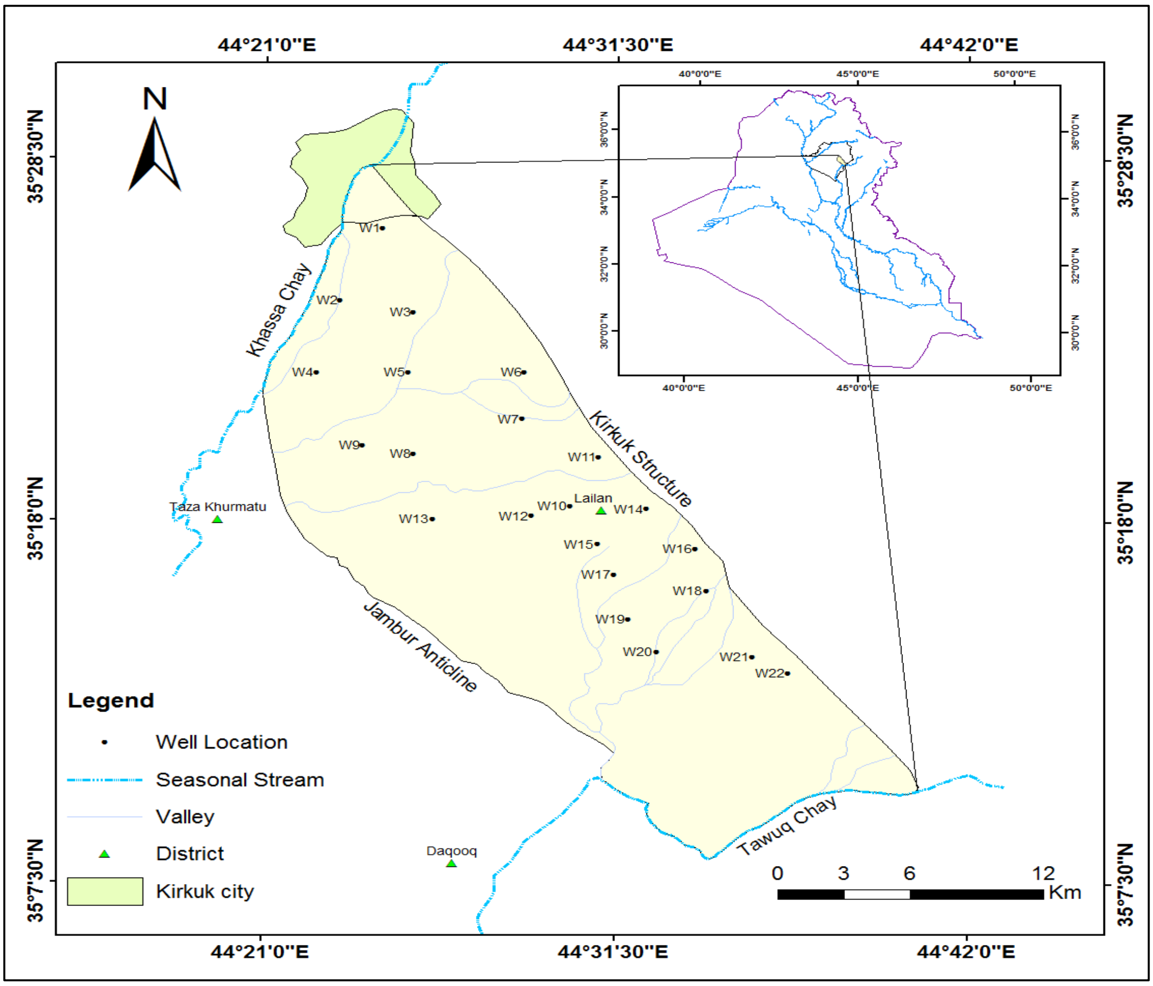

Figure 1- Location of the study area showing the sampling points

The chloride mass balance (CMB) method was developed by [20]. The chloride ion is used in chemical recharge studies due to its conservative nature. The ion neither leaches from nor is absorbed by the sediment particles, and it does not participate in any chemical reaction. The ion is assumed to move through the unsaturated zone with the same velocity of water particles [21]. Assuming chloride is a conservative ion and the precipitation and aerosols is the only source of chloride, conservation of mass leads to a relation between precipitation and recharge [21]:

$$R = \frac{P \times Cl_p}{Cl_{gw}} \qquad (4)$$

Where :

R annual recharge amount (mm)

P average of annual precipitation (mm)

Cl_p *average of chloride concentration in precipitation (mg/l)*

Cl_{gw} *average of chloride concentration in the groundwater (mg/l)*

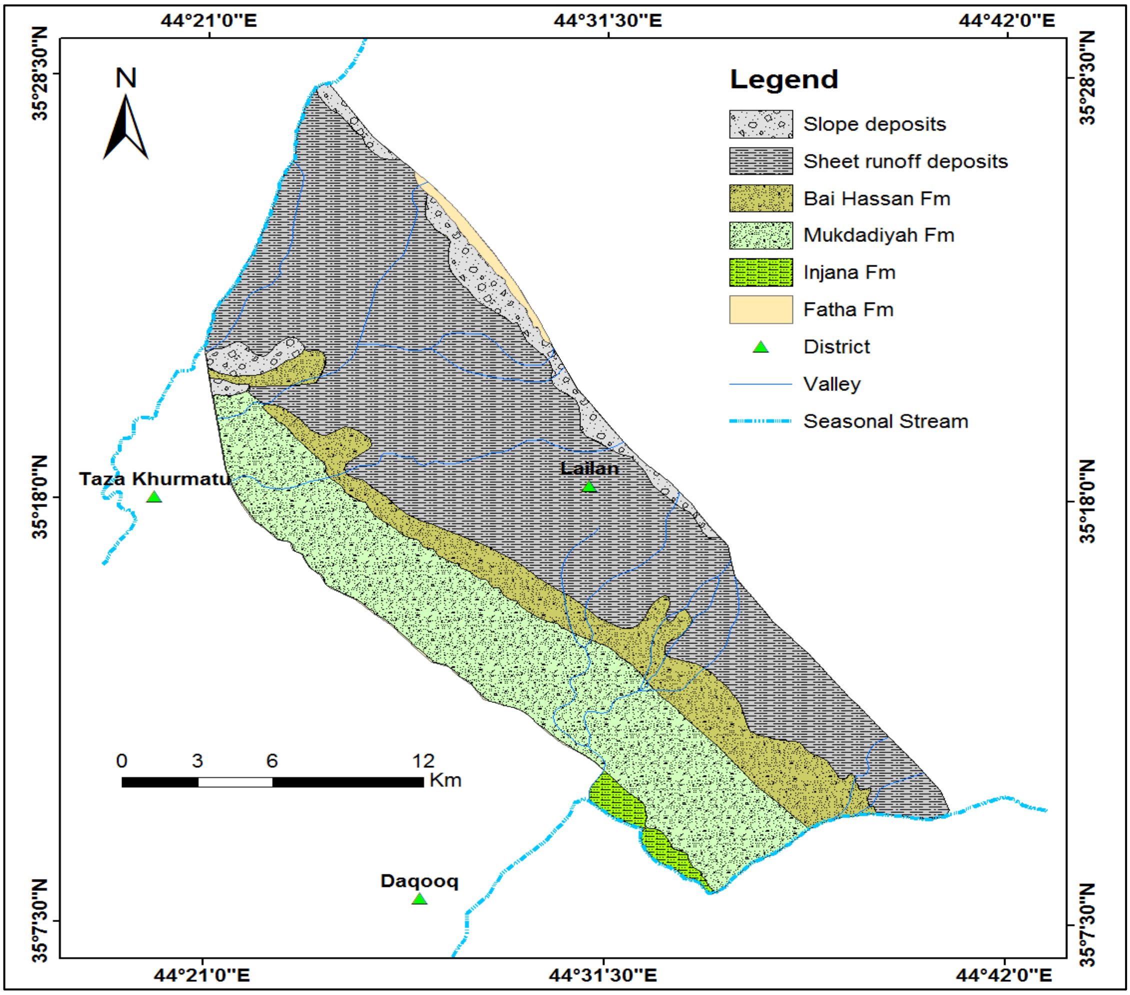

Figure 2 - Geologic map of the study area, after [16].

Results and Discussion

1. Soil Conservation Service Method (SCS-CN)

The soil conservation service (SCS-CN) method was applied to estimate the surface runoff of Lailan basin using the empirical relation between rainfall and runoff . The curve number (CN) could be estimated as a function of land use, soil type and antecedent watershed moisture. Based on the land morphological features and the lithology of expected rock units, the study area could be divided into various zones Figure- 4. Accordingly, different curve numbers were assigned to the zones using reference tables provided by the United States soil conservation service [22] . The study area has more than one CN value, a total CN value was calculated using the following equation as shown in Table -2 [19] :

$$CN_{total} = \frac{A_1CN_1 + A_2CN_2 + \ldots\ldots + A_nCN_n}{A_1 + A_2 + \ldots\ldots + A_n} \quad (5)$$

Where :

$A_1, A_2, \ldots, A_n$ *is the areas of various zones*

$CN_1, CN_2 \ldots CN_n$ *is the curve members*

Based on the annual rainfall average, which equal to 346.7 mm, the amount of runoff was calculated by compensating CN_{total} value and the annual rainfall average in the equation (2). The result showed that the total runoff from the annual rainfall is equal to 90.4 mm/year, which represent 26.07 % of the total rainfall. Accordingly, the amount of runoff was calculated for the last 47 years, that extending from (1970 – 2016) as shown in Table-3. Indicating the direct relationship between rainfall and runoff in Lailan basin Figure-5 .

Table 1- Wells properties and chloride content in groundwater of study area.

Well	Coordinates		Well depth	Chloride
	longitudes	latitudes	m	mg/l
W1	44°24'30.00"	35°26'30.00"	90	188.8
W2	44°23'13.77"	35°24'24.36"	108	195.3
W3	44°25'25.55"	35°24'3.82"	156	383.3
W4	44°22'32.40"	35°22'18.43"	150	200.2
W5	44°25'16.34"	35°22'19.25"	150	85.2
W6	44°28'44.72"	35°22'20.04"	130	65.29
W7	44°28'40.57"	35°20'58.58"	102	106.5
W8	44°25'27.22"	35°19'57.42"	127	57.61
W9	44°23'55.73"	35°20'11.58"	100	63.89
W10	44°30'8.42"	35°18'28.07"	100	95.97
W11	44°30'58.52"	35°19'52.57"	110	68.96
W12	44°28'59.35"	35°18'10.09"	157	74.49
W13	44°26'1.80"	35°18'4.42"	140	526.3
W14	44°32'24.79"	35°18'22.83"	160	95.79
W15	44°30'56.69"	35°17'21.33"	200	220
W16	44°33'52.43"	35°17'13.49"	110	63.38
W17	44°31'26.81"	35°16'28.73"	150	59.65
W18	44°34'11.74"	35°16'0.46"	120	67.36
W19	44°31'52.79"	35°15'11.29"	96	39.46
W20	44°32'43.01"	35°14'13.92"	96	53.21
W21	44°35'35.04"	35°14'6.45"	110	255.6
W22	44°36'38.95"	35°13'38.23"	120	153.1
SUM.				3119.36
Mean				141.78

2. Chloride Mass Balance Method (CMB)

In order to avoid a change in chloride concentration with precipitation intensity during the rainy period, the weighted average of chloride in rainfall (Cl_{wav}) was calculated based on the following equation as shown in (Table 4) [23]:

$$Cl_{wav} = \frac{\sum Cl_i h_i}{hi} \quad \textbf{(6)}$$

Where:

Cl_i *chloride concentration in monthly precipitation (mg/l)*

h_i *monthly precipitation amount (mm)*

Through a mathematical and statistical treatments the equation (4) was modified by adding the arithmetic mean, the correlation coefficient between the rainfall and its chloride content and the standard deviation as follows [24] :

$$\overline{q} = \frac{\bar{R}Cl_{wav} + \hat{\rho}_{RClr}\,\hat{\sigma}_R\,\hat{\sigma}_{Clr}}{Cl_{gw}} \quad \textbf{(7)}$$

Where:

$\overline{q}$ *annual recharge amount (mm)*

$\overline{R}$ *average of annual precipitation (mm)*

$\hat{\rho}_{RClr}$ *orrelation coefficient between the rainfall and its chloride content*

$\hat{\sigma}_R$ *and* $\hat{\sigma}_{Clr}$ *standard deviation of rainfall and its chloride content.*

When the correlation coefficient between the rainfall and its chloride content is equal to zero, implying independence of chloride concentration of rainfall amount. Whereas if one of the standard deviations is equal to zero, indicates to homogeneity, i.e. temporal and/or spatial constancy. However, the equation (7) is expected to yield comparatively higher results than equation (4) [24]. The chloride mass balance (CMB) method was applied to estimate the recharge for Lailan basin aquifers using the best possible values of the measured components, i.e., annual rainfall and chloride concentration in rainfall and groundwater. Monthly rainfall and chloride concentrations of rainfall was statistically evaluated as shown in (Table- 4) , where the standard deviation for rainfall and chloride are 43.35 and 2.14 respectively , while the correlation coefficient is 0.9 , indicating a strong relationship between them. The chloride content in groundwater samples is equal to 141.78 mg/l Table- 1. By compensating of all the relevant values in the equations (4) and (7), the annual recharge amount was calculated which is equal 22.78 mm/year and 23.37 mm/year respectively. The mean of two equations is 23.07 mm/year, representing 7.42 % of the total rainfall. Therefor the annual recharge average for the whole basin could be computed by multiplying the value of 23.07 mm/year by the total area of study and equals 10.0585×10^6 m^3 / year. Accordingly, the amount of annual recharge was calculated for the last 47 years, that extending from (1970 – 2016) as shown in Table-5. Indicating the direct relationship between rainfall and groundwater recharge in Lailan basin Figure-6.

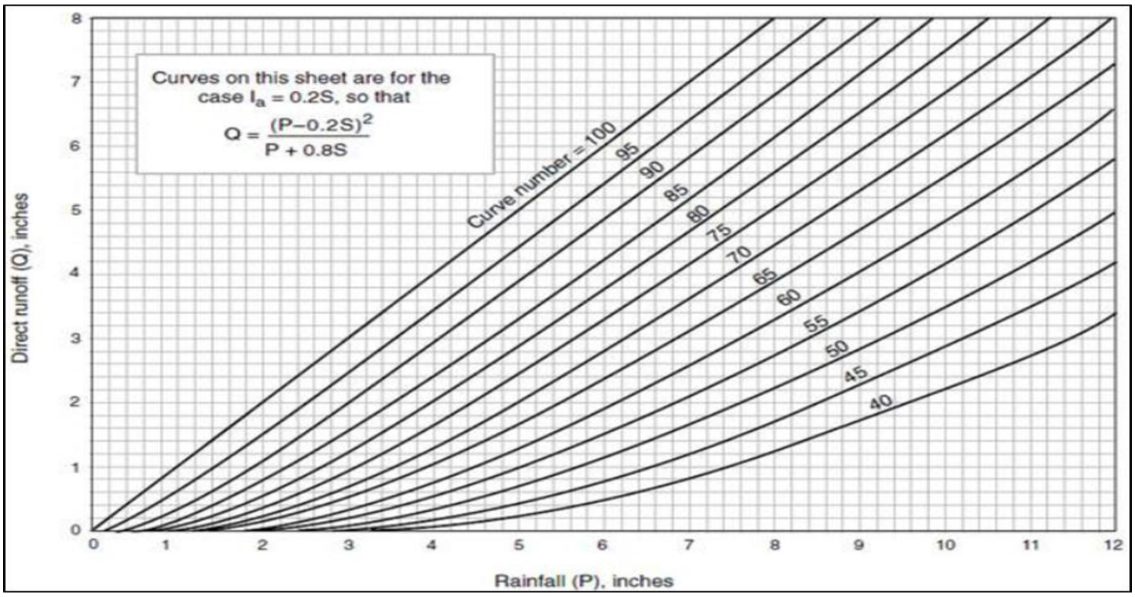

Figure 3 - Graphical relation between Rainfall and Runoff (SCS-CN method), [22].

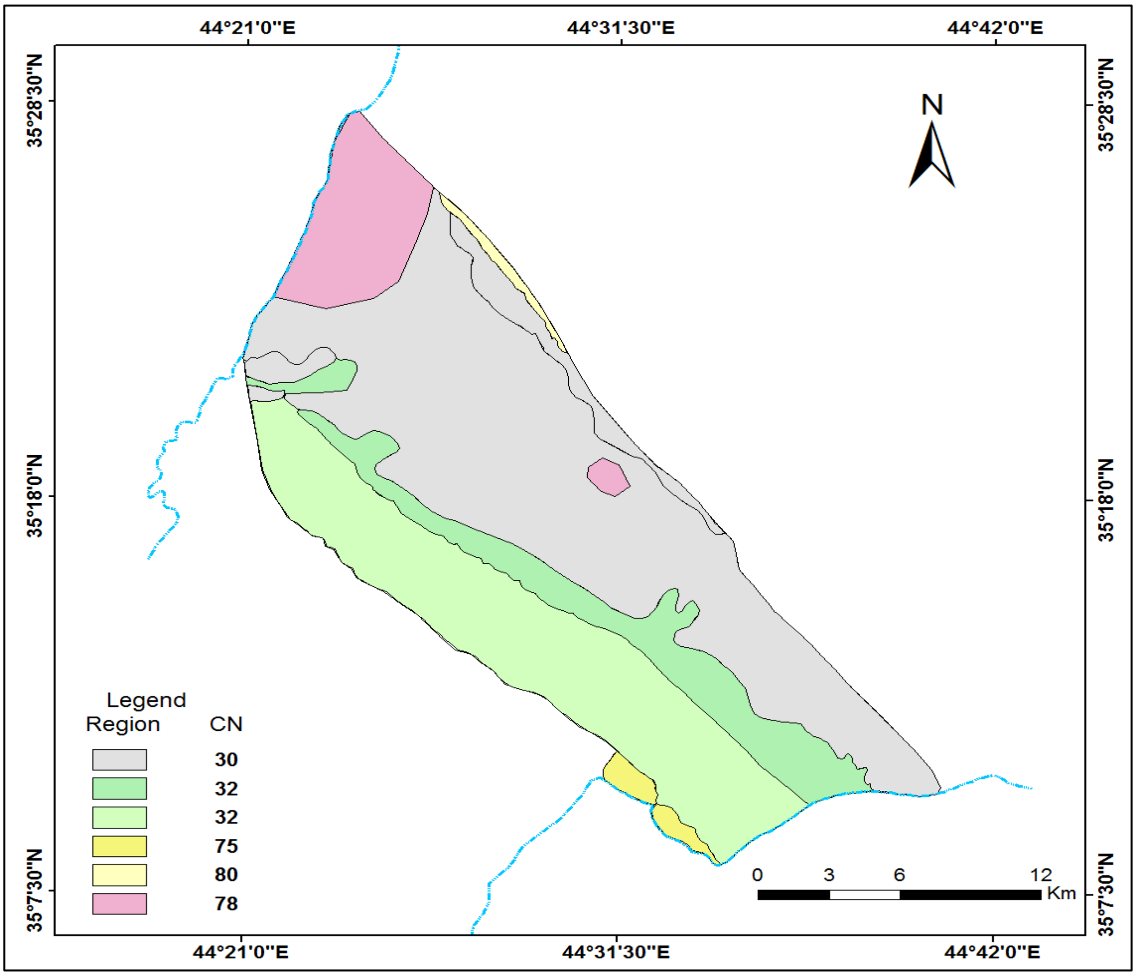

Figure 4 - Hydrological (CN) Zones in the study area

Table 2- Weighted curve number for hydrologic group and land use of study area, according to [22].

Area specification	Area Km^2	CN	CN x area
Recent Deposits	220	30	6600
Bai Hassan Fn. (Conglomerate + sand+ clay)	54	32	1728
Mukdadiya Fn. (sandstone + gravel + mudstone)	119	32	3808
Injana Fn.	5	75	375
Fatha Fn.	3	80	240
Urban area	35	78	2730
Total	436		15481
CN			35.50

Table 3- The annual runoff from the annual rainfall average for the last 47 years for Kirkuk meteorological station.

Year	P	Q	Year	P	Q	Year	P	Q
1970	214.4	25.55	1986	313.2	71.52	2002	461.6	164.17
1971	361.1	98.95	1987	306	67.64	2003	304	66.58
1972	465.4	166.80	1988	458.1	161.75	2004	312.1	70.92
1973	260.9	45.12	1989	346.8	90.47	2005	249.4	39.90
1974	695.9	342.08	1990	244.4	37.71	2006	458.4	161.96
1975	420.8	136.61	1991	490.95	184.77	2007	173.1	12.04
1976	351	92.94	1992	669.4	320.68	2008	134.9	3.60
1977	346	90.00	1993	594.7	261.87	2009	225.81	29.96
1978	243	37.10	1994	365.3	101.48	2010	267.2	48.07
1979	292	60.32	1995	285.5	57.02	2011	221.8	28.38
1980	360.6	98.65	1996	398.5	122.14	2012	295.1	61.92
1981	489.4	183.67	1997	495.3	187.88	2013	394.3	119.46
1982	532	214.54	1998	287.7	58.13	2014	319	74.68
1983	201.7	20.97	1999	229.8	31.57	2015	315.5	72.77
1984	281.6	55.07	2000	246.3	38.54	2016	292.7	60.68
1985	343.6	88.60	2001	277	52.80			
Mean							346.7	

Table 4- Precipitation and its chloride content within five rainy months of water year (2016 – 2017).

Months	P(mm)	Cl^- (mg/l^{-1})	Cl_{wav} (mg/l^{-1})
December	107	10.5	3.61
January	19.9	8	0.51
February	25	6.5	0.52
March	109	12	4.21
April	50	9.6	1.54
Sum	310.9	46.6	10.39
Arith Mean	62.18	9.32	2.078
Harm Mean	38.82	8.9	0.99
St. Dev.	43.35	2.14	1.73
Correl.Coeff	0.9		

Table 5- The annual recharge amount from the annual rainfall average for last 47 years.

Year	P	R	$\bar{q}$	Year	P	R	$\bar{q}$	Year	P	R	$\bar{q}$
1970	214.4	15.71	16.30	1986	313.2	22.95	23.54	2002	461.6	33.83	34.42
1971	361.1	26.46	27.05	1987	306	22.42	23.01	2003	304	22.28	22.87
1972	465.4	34.11	34.69	1988	458.1	33.57	34.16	2004	312.1	22.87	23.46
1973	260.9	19.12	19.71	1989	346.8	25.41	26.00	2005	249.4	18.28	18.87
1974	695.9	51.00	51.59	1990	244.4	17.91	18.50	2006	458.4	33.59	34.18
1975	420.8	30.84	31.43	1991	490.95	35.98	36.57	2007	173.1	12.69	13.27
1976	351	25.72	26.31	1992	669.4	49.06	49.64	2008	134.9	9.89	10.47
1977	346	25.36	25.94	1993	594.7	43.58	44.17	2009	225.81	16.55	17.14
1978	243	17.81	18.40	1994	365.3	26.77	27.36	2010	267.2	19.58	20.17
1979	292	21.40	21.99	1995	285.5	20.92	21.51	2011	221.8	16.25	16.84
1980	360.6	26.43	27.01	1996	398.5	29.20	29.79	2012	295.1	21.63	22.21
1981	489.4	35.86	36.45	1997	495.3	36.30	36.89	2013	394.3	28.90	29.48
1982	532	38.99	39.58	1998	287.7	21.08	21.67	2014	319	23.38	23.97
1983	201.7	14.78	15.37	1999	229.8	16.84	17.43	2015	315.5	23.12	23.71
1984	281.6	20.64	21.23	2000	246.3	18.05	18.64	2016	292.7	21.45	22.04
1985	343.6	25.18	25.77	2001	277	20.30	20.89				
Mean									346.7	25.40	25.99

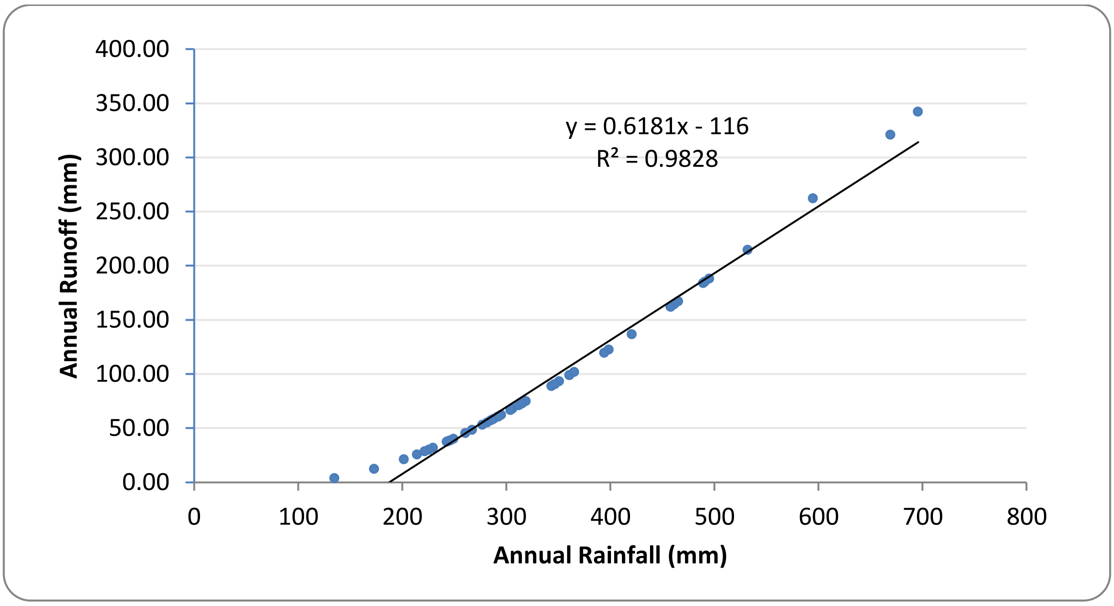

Figure 5 - Relationship between rainfall and runoff along last 47 years

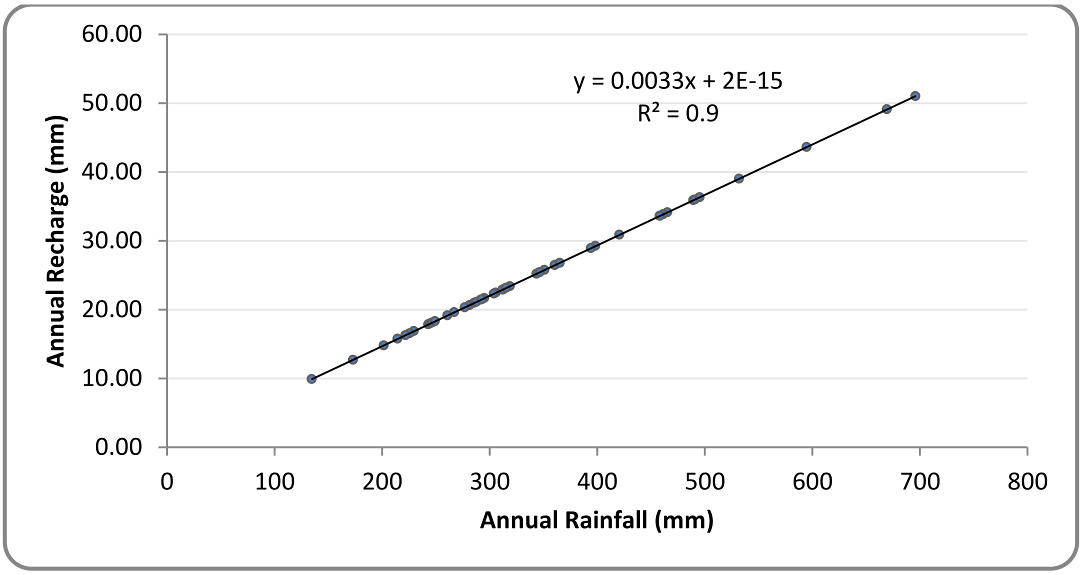

Figure 6 - Relationship between rainfall and recharge along last 47 years

Conclusion

The surface runoff and groundwater recharge in Lialan basin has been estimated depending on the annual rainfall data . The surface runoff was calculated using the soil conservation service method (SCS), and found to be equal to 90.4 mm/year, which represent 26.07 % of the total rainfall . While groundwater recharge was calculated using the chloride mass balance method (CMB), and found to be equal to 23.07 mm/year, representing 7.42 % of the total rainfall. Thus the annual recharge amount for the whole basin was calculated and equal to 10.0585×10^6 m^3 / year. Generally the results of the study showed a direct relationship between the systems of runoff and groundwater recharge in Lialan basin with total rainfall.

Reference

1. Hawkins, R. H. **2004**. *National Engineering Handbook*. United States Department of Agriculture Natural Resources Conservation Service, 791 P.
2. Ahmad, I., Verma,V. and Kumar Verma, M. **2015**. Application of Curve Number Method for Estimation of Runoff Potential in GIS Environment. 2nd International Conference on Geological and Civil Engineering, IPCBEE vol. 80. 4 © IACSIT Press, Singapore.
3. Mishra, S. K. and Singh, V. P. A. **2006**. Relook at NEH-4 curve number data and antecedent moisture condition criteria. Hydrol. Proc., **20**: 2755–2768.
4. Hawkins, R. H. **1993**. Asymptotic determination of runoff curve numbers from data. *J. Irrig. Drain. Eng. ASCE*, **119**(2): 334–345.
5. Ponce, V. M. and Hawkins, R. H. **1996.** Runoff curve number: Has it reached maturity. *J. Hydrol. Eng. ASCE*, **1**(1): 11–18.
6. Michel, C., Andr´eassian, V. and Perrin, C. **2005**. Soil Conservation Service Curve Number method: How to mend a wrong soil moisture accounting procedure? *Water Resour. Res*., **41**, W02011.
7. Lerner, D.N., Issar, A.S. and Simmers, I. **1990**. Groundwater Recharge, a Guide to Understanding and Estimating Natural Recharge. *International Association of Hydrogeologists:* Hannover,Germany, **8**: 345.
8. Naranjo G., Fuentes T. C., Cabrera M.C. and Custodio E. **2015**. Estimating Natural Recharge by Means of Chloride Mass Balance in a Volcanic Aquifer: Northeastern Gran Canaria (Canary Islands, Spain). *Water Jour*., **7**: 2555-2574.
9. Saghravani,S.R.,Yusoff I.,Wan Md Tahir W. Z. and Othman Z. **2014**. Comparison of water table fluctuation and chloride mass balance methods for recharge estimation in a tropical rainforest climate: a case study from Kelantan River catchment, Malaysia. *Environ Earth Sci Jour*., **73**: 4419.
10. Sogiria. **1981**. *Hydrologic Study of Kirkuk Basin*. Baghdad, Al – Furat Center.

11. Araim, H.I. **1984**. Regional Hydrogeology of Iraq. Vol. 6. GEOSURV, int. rep.no. 1450.
12. Al-Naqash, A. B., Ismaeel, S. K., Hassan, A. H, and Rahey, K. M. **2003**. Evaluation study of wells operation of national campaign project for watered wells drilling in Kirkuk governorate. Technical Final Report, Ministry of Irrigation, p.185.
13. Saud, Q. J. and Mohammed, R. A. **2007**. Hydrogeological and hydrochemical study of Kirkuk quadrangle sheet (NI-38-2), Scale 1:250 000 , GEOSURV, Baghdad , Iraq. internal report, No. 2986.
14. Saud, Q. J. **2009**. Hydrogeological and hydrochemical study of Kirkuk governorate; Northern Iraq, Geol. Min. *Irq. Jour*., **5**(1): 1-15.
15. Al-Hamdani, J.A., Wely, H.A., Khorsheed, S.A., Nief,A.J. **2012**. Hydrochemical study of groundwater Lailan sub-basin, Kirkuk, Ministry of water resources, General Commission for Groundwater, internal report, 144p.
16. Sissakian, V.K. **1993**. The Geology of Kirkuk Quadrangle, sheet NI-38-2, scale 1: 250 000. GEOSURV, Baghdad, Iraq.
17. Jassim, S. Z. and Goff, J. C. **2006.** *Geology of Iraq*. 1st Edition, Doline, Prague and Moravian Museum, Brno, Czech Republic, 341 P.
18. IMOS, **2017**. Iraqi meteorological Organization and Seismology, Climatic elements data of recorded in Kirkuk station for period from (1970- 2016).
19. Soulis, K. X. ,Valiantzas,J. D., Dercas, N. and LondraHydrol, P. A. **2009**. Investigation of the direct runoff generation mechanism for the analysis of the SCS-CN method applicability to a partial area experimental watershed. *Earth Syst. Sci. Jour*.,**13**: 605–615.
20. Eriksson E., Khunakasem V. **1969**. Chloride concentrations in groundwater, recharge rate and rate of deposition of chloride in the Israel coastal plain. *Hydrol Jour*., **7**: 178–197.
21. Ting Ch., Kerh T. and Liao Ch. **1998.** Estimation of groundwater recharge using the chloride mass-balance method, Pingtung Plain, Taiwan. *Hydrogeology Jour*., **6**: 282–292.
22. USDA NRCS, **2004**. National engineering handbook. Part 630 hydrology,Chapters 9, 20p, and Chapter 10, 79p.
23. Dassi, L. **2010**. Use of chloride mass balance and tritium data for estimation of groundwater recharge and renewal rate in an unconfined aquifer from North Africa: a case study from Tunisia. *Envi. Ear. Sci. Jour*., **60**: 861- 871.
24. Subyani, A. , Şen, Z. **2006.** Refined chloride mass-balance method and its application in Saudi Arabia. *Hydrol. Proc*., **20**: 4373-4380.