JJEES

JJEES (2021) 12 (3): 230-240
ISSN 1995-6681

Jordan Journal of Earth and Environmental Sciences

Assessment of Water Resources Management in Azraq Basin, Jordan

Atef Al-Kharabsheh

Department of Water Resources and Environmental Management, Faculty of Agricultural Technology, Al-Balqa Applied University, Jordan

Received 6 September 2020; Accepted 4 January 2021

Abstract

Azraq basin is located in the northeastern part of Jordan with an area of 12710 km^2. The climate is classified as an arid to semi-arid zone with high evaporation rates and low rainfall amounts. This paper was conducted to interpret geological and hydrogeological data of aquifers to study the effects of overpumping on the hadrochemical characteristics of aquifers. Three aquifer systems are forming the basin; the upper one, which is composed of basalts and carbonates (B4) is the most important aquifer, due to its good water quality and low pumping costs. This aquifer is overpumped since the beginning of the eighties from AWSA governmental production wells and increasing the private agricultural activities. The calculated safe yield of the upper aquifer during the period 1967 to 2018 is about 23 MCM while the pumping may reach about 100 MCM including the private wells. This overpumping resulted in the dryness of Azraq Oasis, decreasing the water table by more than 17 meters and increasing the electrical conductivity to more than 7000 µS/cm in Azraq depression. According to the chemical analyses carried out in this study, there are three types of water: earth alkaline water with an increased portion of alkalis and with prevailing sulfate and chloride (mixed type), alkaline water with prevailing bicarbonate (mixed type) and alkaline water with prevailing sulfate and chloride (sodium chloride type). The mixed types of water assure that there is saltwater intrusion bodies began to occur as a result of the artesian pressure from the middle and lower aquifer systems. To solve the water problems associated with crises in Azraq basin, it is highly recommended to stop overpumping from the upper aquifer, decrease agricultural activities and apply artificial recharge projects of the upper aquifer system especially in the recharge areas in the northern and northwestern parts. This will increase recharge to the upper aquifer, since the natural recharge is less than 3 percent of the total precipitation over Azraq Basin, due to thunderstorm effects and clayey type of soil.

Keywords: water, Jordan, Azraq, aquifer, overpumping.

1. Introduction

Jordan falls within the arid to semi-arid climatic region. The climate is characterized by a long dry season extending from May to October and a rainy season, which starts mainly in late October to the middle of May. The peak precipitation occurs in the winter months of December, January, and February. Snowfall occurs occasionally a few times a year over the highlands of elevation above 800 m above sea level. The areal distribution of rainfall is mainly governed by the topographic features of the region. The highest rainfall is recorded in the northern and central highlands of Ajlun and Salt. The long-term average of these two stations is about 620 and 608 mm/year, respectively. Rainfall decreases significantly from west to east and from north to south (Al-Kharabsheh, 2020).

Azraq basin covers an area of about 12710 km^2, about 94 percent is located in Jordan, while the rest lies in Syria (5 percent) and Saudi Arabia (1 percent) (Figure 1). An important oasis is located at the central part of Azraq basin known as Azraq Oasis, which was recharged by large springs (Shishan and Drouz springs). The wetland supports rich and varied aquatic fauna and flora with freshwater habitats (Water Authority, 1989). The highest point is located at Jebel El-Arab area in Syria with an elevation of about 1576 m above the mean sea level (amsl), while the lowest is at the center of Azraq depression (Qa) with an elevation of about 500 m (amsl). The elevation increases to about 900 m in the southern part of the basin.

The average annual rainfall ranges from more than 325 mm in the north at Salkhad to 150 mm in the west at Muwaqqar and less than 50 mm in the south and east at El-Umary (Figure 2), with an average total of around 122 mm. As a desert area, the thunderstorm rainfall types are forming the major rainfall in Azraq Basin (Al-Kharabsheh et al., 1997).

The purpose of this paper is to determine the geological formation including stratigraphy and structure, interpret the hydrological data including meteorological data, rainfall and runoff, interpret the hydrogeological data including aquifer characteristics and dynamics and study the impacts of overpumping on the hydrochemical attributes of aquifers.

* Corresponding author e-mail: atefkh@bau.edu.jo

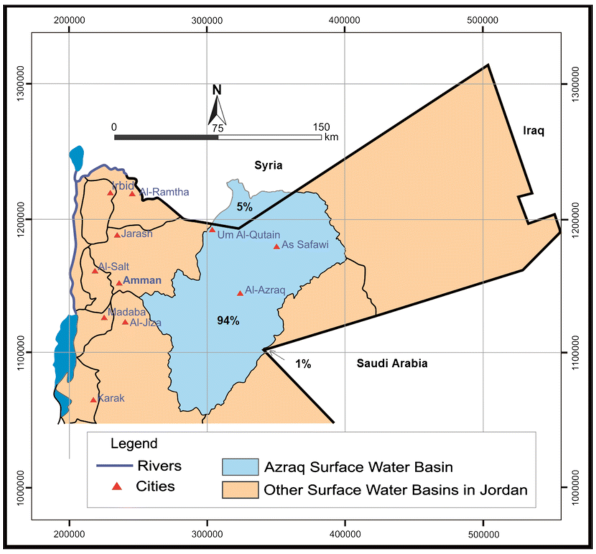

Figure 1. Location Map of Azraq Basin (Ayed, 1996).

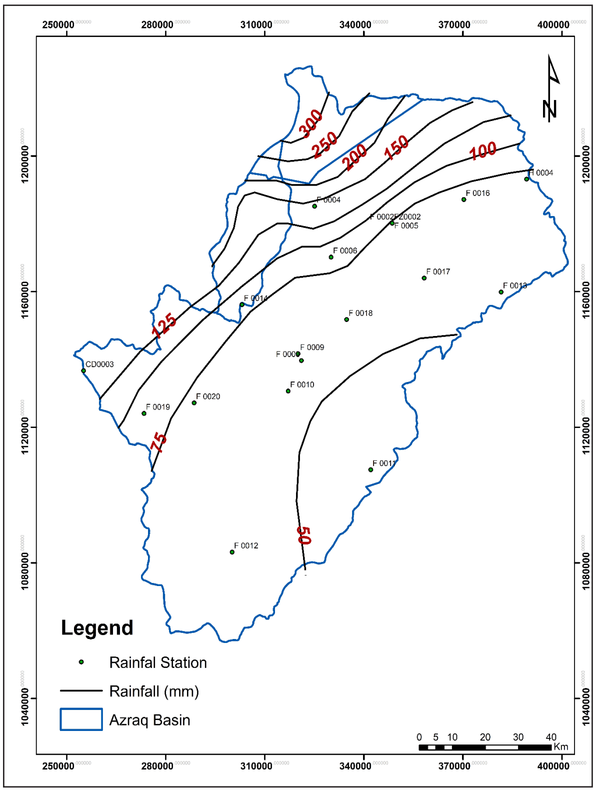

Figure 2. Isohythal Map of Azraq Basin during the Period 1967 to 2018 (WAJ Files Data).

2. Materials and Methods

The climatic parameters representing Azraq Basin were determined and evaluated to obtain the water budget. The long-term monthly and annual means of relative humidity, temperature, wind speed and direction and the class A pan evaporation in Azraq basin are going to be evaluated in this paper. Despite the prevailing thunderstorms, cyclonic rainfall may reach the area, particularly in December, January, February and March.

The methodology used in this study is collecting hydrological and hydrogeological data from different resources, conducting statistical analyses of hydrological data for the different periods, analyzing hydrological data including meteorological data, rainfall and runoff, calculating the runoff volumes affecting the recharge of groundwater, determining modified water budget of Azraq basin, studying the hydrogeological data affecting characteristics of different aquifers, making a relation between overpumping and groundwater salinity and determining methods to evaluate the hydrological characteristics affecting oasis discharge management with time.

3. Water Budget

All the wadis in the Azraq basin are ungauged and no flow measurements are available. The heavy thunderstorm rainfall causes high peak discharges and consequently causes severe inundation in parts of the drainage area. Many ungauged wadis drain into the Qa-Azraq area. Water from these wadis remains several months in Qa-Azraq area as puddles, before evaporating. Water flows to Qa-Azraq area where the good field is located (Al-Kharabsheh, 1991). The ground slopes range between 5-10 percent in the northern part, 3-5 percent in the other directions and exceed 15% in Jebel El-Arab area (Ayed, 1986).

Surface runoff measurements were achieved by using the United States Soil Conservation Service Method (Soil Conservation Service, 1969, 1972 and 1975)) as follows:

$$R = (P-0.2S)^2/(P+0.8S) \quad \text{.......... (1)}$$

Where R is the accumulated depth of runoff, P is the accumulated depth of storm rainfall and S is the maximum retention of the soil related to an assigned Curve Number (CN) given to each type of soil. This relation is known as (United States Department of the Interior, 1960):

$$S = (1000/CN)-10 \quad \text{.......... (2)}$$

Where R is the accumulated depth of runoff, P is the accumulated depth of storm rainfall and S is the maximum retention of the soil related to an assigned Curve Number (CN) given to each type of soil. This relation is known as (United States Department of the Interior, 1960):

Initial abstraction (Ia) can be calculated as Ia=0.2S.

Penman equation is used to calculate the potential evapotranspiration, which is shown below:

$$E = \Delta / (\Delta + \gamma)\, Rc(1 - r) - \Delta / (\Delta + \gamma)\, Rb + \gamma / (\Delta + \gamma)\, Ea \text{ .. (3)}$$

Where R is the accumulated depth of runoff, P is the accumulated depth of storm rainfall and S is the maximum retention of the soil related to an assigned Curve Number (CN) given to each type of soil. This relation is known as (United States Department of the Interior, 1960):

Initial abstraction (Ia) can be calculated as Ia=0.2S.

Penman equation is used to calculate the potential evapotranspiration, which is shown below:

$$I = P-E-R-I_a \quad \text{.......... (4)}$$

Where I is the infiltration (mm), P is the precipitation, E is the actual evapotranspiration (mm), R is the runoff and Ia is the initial abstraction (mm). The evapotranspiration, runoff and initial abstraction are subtracted from the rainfall every year to calculate the water budget.

Fourteen rainfall stations are located in the basin of which, eleven stations are located in the Jordan side of the basin, and three stations are in Syria. Table 1 represents the rainfall stations, their locations, type of gauges, and their approximate record period. Table 2 shows annual statistical analyses of rainfall stations in the Azraq Basin. Table 3 summarizes the monthly and annual averages of the main rainfall stations in the study area. Generally, the heaviest rainfall occurs between December and March. The highest monthly rainfall values were recorded in Salkhad (Syria), and the minimum monthly values were measured in EI-Umary station, while Um El-Quttein rainfall station represents the average monthly values in the basin.

The direct runoff in Azraq Basin is estimated using SCS method. Table 4 shows elements of the water budget of the Azraq Basin. Volumes of rainfall, runoff, evaporation and infiltration range from 254, 0.5, 193 and 3.3 MCM, respectively during the dry seasons, to about 1736, 66, 433 and 72 MCM for the same respective components during the wet seasons. The average of the infiltration is about 32 MCM, while the recharge is about 23 MCM since about 8 MCM of the infiltrated water is lost by evapotranspiration into the atmosphere and 1 MCM is flowing into the adjacent areas.

According to Figure 3 and table 5, the Azraq basin is divided into 11 sub-catchments, the highest estimated natural recharge is occurring through Wadi Hassan, while the lowest is occurring in Wadi Jesha. The catchment subdivisions are accomplished according to many factors like geology, topography and drainage pattern.

Table 1. Rainfall Stations in Azraq Basin during the period 1967 to 2018 (WAJ Files Data).

Station Code No.	Name of Rainfall Station	Coordinates (Palestine Grid)		Altitude (m)	Type of station	Ann. Av. Rainfall in mm (1967-2018)
		East	North			
F 0001	UM E1-Quttein	303.5	192.5	986	Daily	140.7
F 0002	H 5 (Safawi)	348.5	180	715	Daily	66.5
F 0004	Deir E1-Kahf	325	185	1025	Daily	108.1
F 0006	E1 Aritain	330	170	800	Daily	91.7
F 0009	Azraq Evap. St.	320	141.5	533	Daily	59.5
F 0011	E1-Umary	342	107.3	525	Daily	48.9
F 0012	Qasr Tuba	300	83	750	Daily	55.9
F 0013	Wadi Salahib	381.5	159.7	700	Totalizator	64.5
F 0020	Qasr E1–Kharrana	288.5	127	650	Daily	73
CD 0003	E1–Muwaqqar	255	136.5	910	Daily	156.2
H 0004	Tullul E1-Ashqaf	389.2	193	900	Totalizator	67.9
S 0001*	Salkhad	311	210	1447	Daily	325.6
S 0002 *	Imtan	321	203	1260	Daily	247.5
S 0003 *	Khirbet Awwad	310	194	1065	Daily	198.7

* Stations located in Syria

Table 2. Long-term annual rainfall of Azraq Basin during the period 1967 to 2018 (WAJ Files Data).

Rainfall Station	Maximum Annual Rainfall (mm)	Minimum Annual Rainfall (mm)	Mean Annual Rainfall (mm)
Salkhad	533	163.0	325.6
Um EI-Quttein	277	59.4	140.7
Safawi (H5)	189	15.5	66.5
EI-Aritain	170	39.5	91.7
Azraq Evap. Station	149	9.8	59.5
Qasr EI-Kharrana	134	21.0	73
Qasr Touba	108	10.0	55.9
EI-Muwaqqar	323	68.5	156.2
EI-Umary	97	8.5	48.9
Tullul EI-Ashqaf	121	15.0	67.9
Wadi Salahib	110	21.5	64.5
Deir El-Kahf	168	36.1	108.1
Khirbet Awwad	368	76.1	198.7

Table 3. Long-term monthly and annual rainfall averages (mm) for rainfall stations of Azraq Basin during the period 1967 to 2018 (WAJ Files Data).

Rainfall Station	Months								Annual
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
Um EI-Quttein	3.7	14.8	25.4	29.9	29.8	23.2	7.7	6.2	140.7
H5 (Safawi)	3.9	9.4	10.9	12.2	12.7	10.5	5.8	1.1	66.5
EI-Aritain	8.2	10.2	12.2	26.7	10.8	12.5	7.1	4	91.7
Azraq Evap. Station	4.2	6.7	10.4	10.4	9.8	11.8	4.3	1.9	59.5
EI-Umary	3.7	5.9	7.6	9.7	6.1	10.5	4.8	0.6	48.9
Qasr Touba	2.9	8.0	10.9	12.4	6.2	12.2	2.9	0.4	55.9
Wadi Salahib	4.2	9.9	9.8	11.2	11.9	11.2	5.8	0.5	64.5
Qas EI-Kharrana	3.7	9.7	14.8	16.8	8.2	16.9	2.3	0.6	73.0
EI-Muwaqqar	4.0	16.8	29.5	34.0	30.0	31.0	10.7	0.2	156.2
Tullul EI-Ashqaf	4.1	10.5	9.9	11.8	12.7	10.3	7.5	1.1	67.9
Salkhad	10.9	34.0	57.8	68.7	69.0	62.6	19.4	3.2	325.6
Imtan	7.3	21.8	43.5	65.2	45.8	42.5	16.2	5.2	247.5
Khirbet Awwad	5.7	17.8	33.0	52.0	43.0	28.5	17.4	1.3	198.7
Deir El-Kahf	3.4	10.4	19.9	28.9	25.4	12.6	4.9	2.6	108.1
Average	5.0	13.3	21.1	27.9	23	21.2	8.3	2.1	121.8

Table 4. Calculated Water Budget for Azraq Basin during the period 1967 to 2018 (WAJ Files Data).

Water Year	Rainfall (MCM)	Runoff (MCM)	Loss (MCM)			Infilt. (MCM)	Runoff Rate (%)	Infilt. Rate (%)	Loss Rate (%)		
			Ed	Ia	Total				Ed	Ia	Total
1967/1968	1119.8	5.7	251.8	857.5	1109.3	4.8	0.5	0.4	22.5	76.6	99.1
1968/1969	1273.5	48.8	560.5	618.6	1179.1	45.6	3.8	3.6	44.0	52.6	92.6
1969/1970	784.2	12.5	341.1	414.2	755.3	16.4	1.6	2.1	43.5	52.8	96.3
1970/1971	1471.8	69.3	646.3	703.3	1349.6	52.9	4.7	3.6	43.9	47.8	91.7
1971/1972	1657.4	13.2	307.8	1317.5	1625.3	18.9	0.8	1.1	18.6	79.5	98.1
1972/1973	730.8	21.0	204.2	483.2	687.4	22.4	2.9	3.1	27.9	66.1	94.0
1973/1974	2043.8	80.0	421.7	1452.5	1874.2	88.8	4.0	4.3	20.6	71.1	91.7
1974/1975	1244.3	13.3	211.9	964.7	1176.6	54.4	1.1	4.4	18.0	76.5	94.5
1975/1976	1240.5	21.6	354.7	841.0	1195.7	23.2	1.7	1.9	28.6	76.8	96.4
1976/1977	719.4	13.0	419.8	266.7	686.5	19.5	1.8	1.8	37	58.3	95.3
1977/1978	738.5	3.3	117.0	613.8	730.8	4.4	0.4	0.6	15.8	83.2	99.0
1978/1979	542.7	3.1	110.5	421.6	532.1	7.5	0.6	1.4	20.4	77.6	98.0
1979/1980	1736.2	65.8	433.4	1165.3	1598.7	71.7	3.8	4.1	25.0	67.1	92.1
1980/1981	1165.5	54.8	361.2	702.8	1064.0	46.7	4.7	4.0	31.0	60.3	91.3
1981/1982	1137.5	6.9	164.4	953.4	1117.8	12.8	0.6	1.1	14.5	83.8	98.3
1982/1983	995.2	53.1	322.2	549.0	871.2	70.9	5.3	7.1	32.4	55.2	87.6
1983/1984	610.1	15.5	332.7	240.9	573.6	21.0	2.5	3.4	54.6	39.5	94.1
1984/1985	1075.3	18.9	429.0	583.4	1012.4	44.0	1.8	4.1	39.9	54.2	94.1
1985/1986	1042.2	19.1	351.4	649.8	1001.2	21.9	1.8	2.1	33.7	62.4	96.1
1986/1987	1009.2	48.2	364.6	544.7	909.3	51.7	4.8	5.1	36.1	54.0	90.1
1987/1988	1629.4	17.5	438.7	1136.3	1575.0	36.9	1.1	2.3	26.9	69.7	96.6
1988/1989	1422.2	26.3	301.0	1054.6	1355.7	40.2	1.8	2.8	21.2	74.2	95.4
1989/1990	1182.0	10.8	227.3	928.7	1156.0	15.2	0.9	1.3	19.2	78.6	97.8
1990/1991	1238.0	47.2	309.8	822.3	1132.1	58.7	3.8	4.7	25.0	66.5	91.5
1991/1992	1074.0	38.9	312.9	670.4	983.3	51.8	3.6	4.8	29.0	62.5	91.0
1992/1993	795.7	22.1	406.5	349.4	755.9	17.7	2.8	2.2	15.2	43.9	95.0
1993/1994	866.8	2.2	31.9	827.4	859.3	5.3	0.3	0.6	3.7	95.4	99.1
1994/1995	1150.3	13.4	255.9	855.4	1111.3	25.6	1.2	2.2	22.2	74.4	96.6
1995/1996	610	5.2	354.4	238.0	592.4	12.4	0.85	2.03	58.1	39.0	97.1

Continue Table 4

Water Year	Rainfall (MCM)	Runoff (MCM)	Loss (MCM)			Infilt. (MCM)	Runoff Rate (%)	Infilt. Rate (%)	Loss Rate (%)		
			Ed	Ia	Total				Ed	Ia	Total
1995/1996	610	5.2	354.4	238.0	592.4	12.4	0.85	2.03	58.1	39.0	97.1
1996/1997	1037	18.7	352.0	642.5	994.5	23.9	1.80	2.30	33.9	62.0	95.9
1997/1998	1033	13.4	399.5	593.2	992.7	26.9	1.30	2.60	38.7	57.4	96.1
1998/1999	254	0.5	56.5	193.5	250.0	3.3	0.20	1.30	22.2	76.3	98.5
1999/2000	258	1.1	75.9	176.4	252.3	4.1	0.43	1.60	29.4	68.6	98.0
2000/2001	1011.1	18.3	340.2	632.1	972.3	20.5	1.8	2.0	33.6	62.5	96.2
2001/2002	1575.3	59.3	371.5	1079.1	1450.6	65.4	3.77	4.2	23.6	68.5	92.1
2002/2003	1175.0	44.3	288.3	787	1075.3	55.4	3.77	4.7	24.5	67.0	91.5
2003/2004	975.3	47.9	332.8	544.1	876.9	50.5	4.9	5.2	34.1	55.8	89.9
2004/2005	653.2	6.3	382.3	251.5	633.8	13.1	1.0	2	58.5	38.5	97.0
2005/2006	1034.5	37.8	298.4	647.2	945.6	51.1	3.7	4.9	28.8	62.6	91.4
2006/2007	912.3	5.7	338.1	561.7	899.8	6.8	0.6	0.7	37.1	61.6	98.6
2007/2008	1588.3	15.7	422.3	663.2	1085.5	35.1	1.0	2.2	26.6	41.7	96.8
2008/2009	289	2.1	91.3	190.4	281.7	5.2	0.7	1.8	31.6	65.9	97.5
2009/2010	1399.5	25.8	291.0	1043.8	1334.8	38.9	1.8	2.8	20.8	74.6	95.4
2010/2011	789.5	4.9	132.1	674.4	806.5	5.1	0.6	0.6	16.7	85.4	98.7
2011/2012	1088.5	5.5	240.3	838.1	1078.4	4.6	0.5	0.4	22.1	77.0	99.1
2012/2013	1248.3	48.1	552.5	603.9	1156.4	43.8	3.9	3.5	44.2	48.4	92.3
2013/2014	1501.5	71.3	652.8	722.9	1375.7	54.5	4.7	3.6	43.5	48.4	91.6
2014/2015	1644.9	12.8	301.5	1312.5	1614	18.1	0.8	1.1	18.3	79.8	98.1
2015/2016	1198.6	21.1	334.5	820.3	1154.8	22.7	1.8	1.9	27.9	68.4	96.3
2016/2017	995.2	55.3	320.7	558.7	879.4	60.5	5.6	6.1	32.2	56.1	88.4
2017/2018	1321.5	62.3	243.8	945	1188.8	70.4	4.7	5.3	18.4	71.5	90.0
Average	1084.1	26.4	316.9	700.2	1017.1	32.2	2.2	2.8	29.3	64.7	94.9

Total loss =(Evapotranspiration of the storm (Ed)+ Initial Abstraction (Ia)

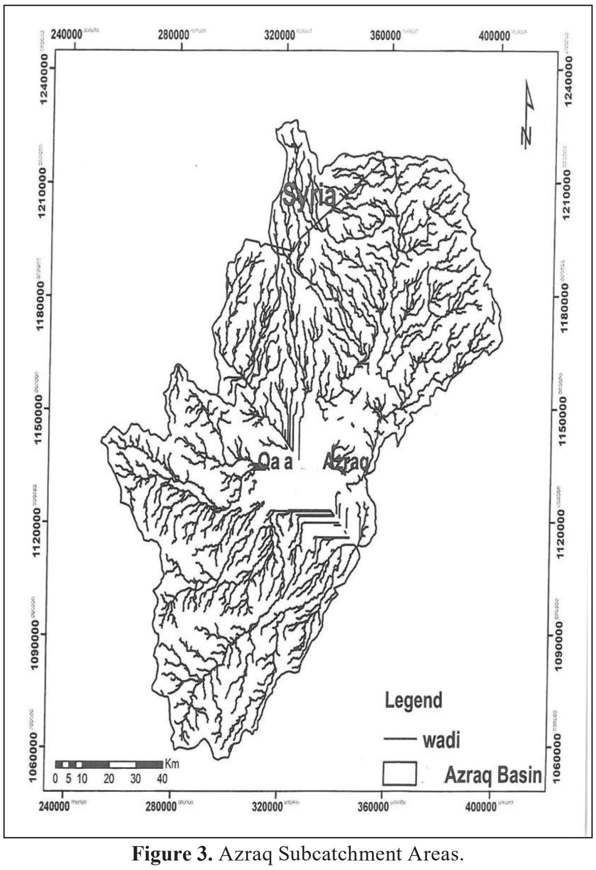

Figure 3. Azraq Subcatchment Areas.

Table 5. Estimated Recharge Quantities of Azraq Subcatchments (mm) during the Period 2000 to 2028 (Al Shamil Engineering Office, 2000).

Year	Wadi Butum	Wadi Ghadaf	Wadi Harth	Wadi Hassan	Wadi Jesha	Qa'a Khanna	Wadi Mudeisisat	Wadi Rajil	Wadi Rattam & Wadi Unqiya	Wadi Uweinid	Wadi Aseikhim
2000	0.92	0	0	0	0	0.6	0.95	0.5	0	0.27	0.00
2001	0.21	0	0	5.79	0	1.25	0.15	2.63	0	0	4.63
2002	7.6	0	4.15	6.81	0	2.34	9.53	3.28	0.74	4.51	5.45
2003	0.21	0	0	9.28	0	3.26	0.01	4.01	0	0.57	7.42
2004	7.14	0.44	3.74	8.81	0.18	4.48	15.02	6.77	0	0.04	7.05
2005	0.56	1.43	0	1.02	0	1.89	0.51	2.26	0	0	0.82
2006	0.49	0	0	4.74	0	2.63	0.65	2.53	0	0.92	3.79
2007	12.7	0.71	10.6	7.61	0.34	2.66	13.94	4.3	2.94	6.67	6.09
2008	1.9	4.21	0	4.08	2.48	1.29	0.89	1.59	1.18	4.63	3.26
2009	3.61	1.76	0	11.88	1.14	3.13	4.53	3.25	0.07	3.38	9.50
2010	2.55	0	0	13.95	0.09	2.62	2.96	3.5	0	0	11.16
2011	1.49	0	0	1.17	0	0.38	1.85	0.7	0	0	0.94
2012	6.34	0	2.12	12.52	0.14	2.02	11.25	4.07	0	0	10.02
2013	14.83	0.81	7.97	10.81	0	4.05	19.9	8.52	1.07	4.03	8.65
2014	0	0	0	1.28	0	0.61	0	0.96	0	0	1.02
2015	1.06	0	0	5.12	0	1.39	1.27	1.72	0	0	4.10
2016	0.06	0	0	14.59	0	4.36	0	6.56	0	0	11.67
2017	0.35	0	0	13.63	0	3	0.27	6.46	0	0.1	10.90
2018	4.47	1	1.8	10.96	0	4.03	5.58	5.7	0	1.35	8.77
2019	2.34	0	0	13.67	0	3.84	2.9	5.08	0.01	3.49	10.94
2020	0	0	0	17.52	0	2.61	0	6.21	0	0.02	14.02
2021	9.61	3.26	2.54	20.89	0.75	6.18	11.52	7.69	0.87	3.39	16.71
2022	2.34	0	0.03	1.69	0	0.54	3.02	0.47	0	0	1.35
2023	0.42	0.44	0	8.49	0	2.11	0.4	3.57	0	0.68	6.79
2024	9.44	3.91	1.59	11.08	2.37	2.89	8.01	7.85	0.12	2.23	8.86
2025	2.72	0	0	6.64	0	2.33	6.24	4.01	0	0.24	5.31
2026	0.26	0	0.72	3.54	0	2.31	0.42	3.02	0	0	2.83
2027	2.7	0.39	0	5.45	4.14	0.66	8.5	1.53	0	0	4.36
2028	0.42	0	0	3.42	0	0.92	0	0.53	0	0	2.74

4. Aquifer Characteristics of Azraq Basin

There are three aquifer systems in the Azraq basin namely: the upper, middle and lower aquifer systems.

The upper aquifer system consists of alluvial deposits (Quaternary), Basalts Miocene-Quaternary), Wadi Shallala (Eocene) and Umm Rijam Chert Limestone (Paleocene) formations. The basalt aquifer is connected with layers of clay, which may give rise to perched groundwater bodies. A gradual thinning of the basalt from east to west and a sharp increase in the hydraulic gradient of the system (Al-Momani, 1991). The transmissivity of the basalt ranges from 3.1x10-3 to 0.76 m2/s (Humphreys, 1982). Wadi Shallala Formation is composed of marl clayey materials. It acts as an aquitard to the groundwater between the Basalt and Rijam aquifers at the northern part of the basin. The Rijam aquifer is considered as a good aquifer and composed of white-coloured chalky limestone and brown chert, underlain by the green marls, and contains occasional gypsum (Al-Kharabsheh, 1995).

The middle aquifer system is composed of Amman Silicified Limestone Formation (Campanian), Wadi Umm Ghudran Formation (Santonian) and Wadi As Sir Limestone Formation (Turonian). This aquifer outcrops at the west and southwest of the basin and underlie most of the area (Ayed, 1996). The Amman Silicified Limestone Formation is composed of chert and limestone. Depth to the aquifer water ranges between 420 and 590 m. The hydraulic conductivity ranges between 3.06×10^{-6} and 4.73×10^{-3} m/s with an average value of 7.16×10^{-4} m/s (Water Authority, 1989).

The lower aquifer system is separated from the middle one by low permeability marls and marly limestone. This aquifer system consists of poorly consolidated multicolored sandstones of the Early Cretaceous age intercalated with thin beds of shales and clays (Lloyd, 1992).

5. Groundwater Recharge and Movement

Groundwater movement depends on the hydraulic conductivity and hydraulic gradient. Groundwater elevations are highest in the northeast of the basin, decreasing from 564 to about 500 m.a.s.l towards Azraq depression. Groundwater flow in the outcropping (B4) Formation is from west and northeast towards Qa-Azraq. The average transmissivity of the upper aquifer system is 11000 m^2/d.

The aquifers are hydraulically interconnected, due to major faults. Groundwater is flowing in different flow directions: water of the upper aquifer system flows from the north at Jebel El-Arab area toward the Qa-Azraq in the south, the water of the middle aquifer system flows from the west and the southwest (Zerqa and Mujib basins) and from the east (Hammad Basin) to reach the Azraq depression, the water of the lower aquifer system flows from east to west to discharge in its lowest point at the Dead Sea Basin (Figure 4). The groundwater flow pattern of the upper aquifer system shows that groundwater flow direction is in the direction Azraq depression (Figure 5), while in the middle aquifer system it flows in the northeastern direction of the depression (Figure 6). Areas of Outcropping Aquifers in Azraq Basin are presented in Figure (7).

The water budget approach was applied to estimate the recharge to the groundwater. The water budget equation is used to perform the water balance on daily basis for each storm event during the period under investigation. The rainfall is the only measured parameter; therefore, daily runoff and initial abstraction were calculated using the SCS-Curve Number method for each storm during a specific year. The potential evapotranspiration was computed by Penman's Equation. Then, the water budget was solved for all storms the occurred during the period of water years (1967/1968-1999/2000). The water budget of the Azraq basin shows that the average yearly infiltration is 32 MCM (Table 4). About 1 MCM flows through the Sirhan structure to adjacent areas and about 8 MCM of the infiltrated water is lost by evapotranspiration. This shows that net recharge to the upper aquifer system is about 23 MCM annually.

6. Results and Conclusions

There were two groups of springs forming the Azraq Oasis in the central part of the Azraq basin near the good field area. The first group, Drouz consists of the Aura and Mustadhema springs; the second group, Shishan includes the Souda and Qaisiyeh springs. They were recharged from the same resource of the upper aquifer system (Jebel El Arab). These two groups of springs run dry, due to the overpumping from the good field area upstream of the springs (Table 6).

Azraq basin suffers environmental problems including loss of biodiversity, drought and pollution, due to human and agricultural activities.

Table 6. Withdrawal from the Upper Aquifer System Compared to the Natural Discharge from Azraq Springs (WAJ Files Data).

Year	Withdrawal from Upper Aquifer System (MCM)	Discharge from Springs (MCM)
1981	1.5	10.49
1982	11	8.35
1983	13.81	6.60
1984	16.36	6.04
1985	19.14	5.27
1986	18.22	3.57
1987	22	4.11
1988	31.64	2.15
1989	28.92	1.96
1990	34.9	0

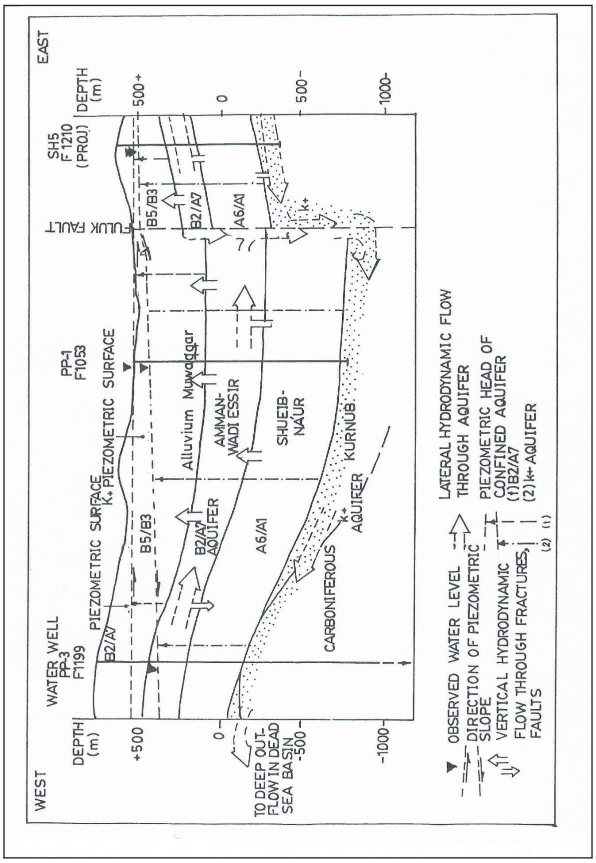

Figure 4. Hydrodynamic Characteristics of Groundwater Flow in Azraq Basin (Salameh and Udluft, 1985).

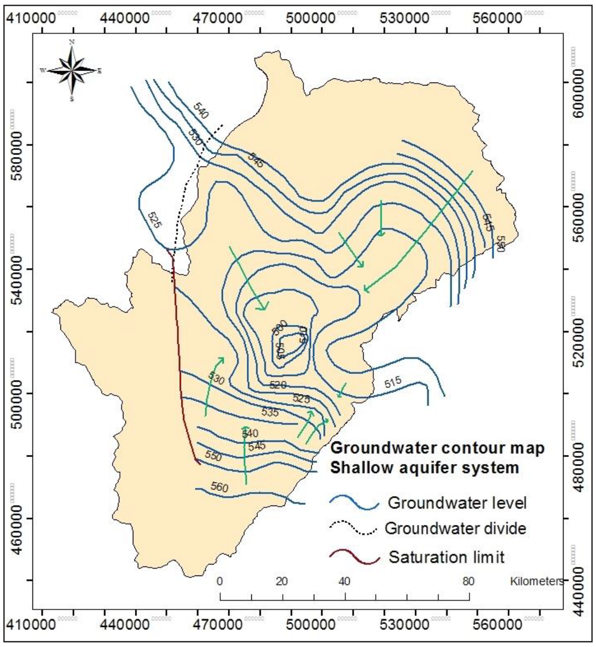

Figure 5. Groundwater flow pattern of the Upper Aquifer System (Hobler et al., 2001).

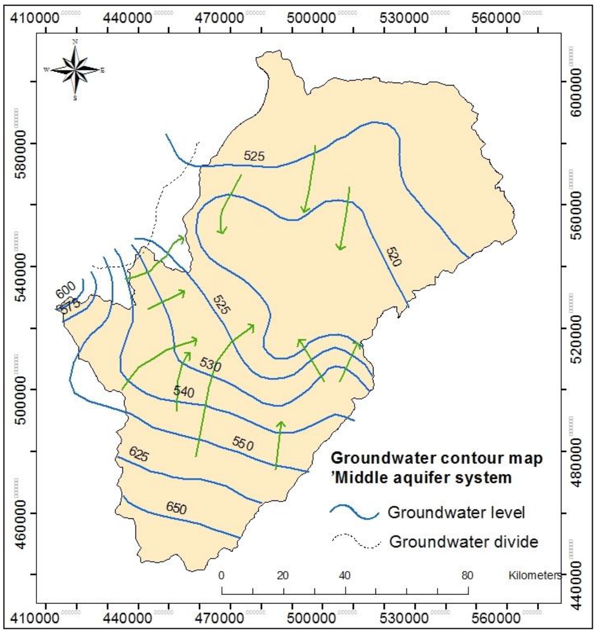

Figure 6. Groundwater flow pattern of the Middle Aquifer System (Hobler et al., 2001)

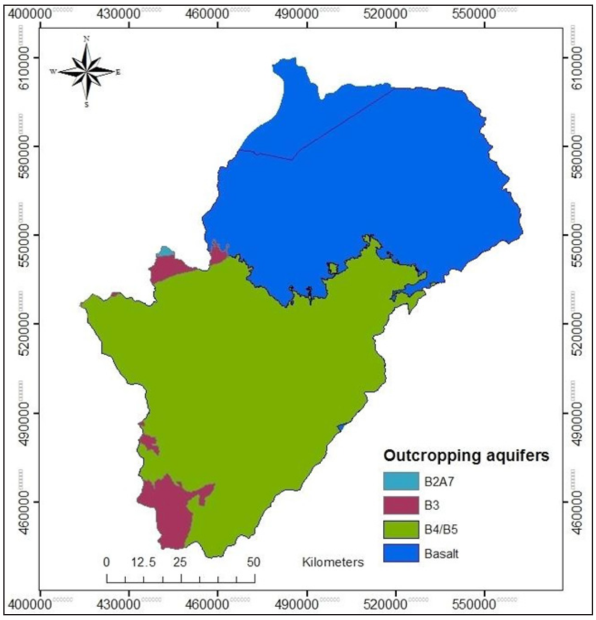

Figure 7. Areas of Outcropping Aquifers in Azraq Basin (Alkhatib, 2017).

The severe pumping is alarming environmental disaster. The groundwater overpumping has also caused environmental, social and economic negative impacts (WAJ Files Data).

Due to the overpumping from the basin for agricultural activities, water tables are dropped significantly at a rate of 80-90 cm/y. Consequently, there is severe ecosystem deterioration. People are losing most of their products and large cropping areas being irreversibly damaged due to lack of water, salinity and soil quality deterioration (Al Wreikat and Al-Kharabsheh, 2020).

Well F 1014 is an example of a declining water table by -0.8/y m at Ain El-Beida. This well penetrates the basalt and the underlying B4 aquifers (Figure 8). The expected saturated thickness of this well is expected to decrease more than 90 percent if the recent pumping continues.

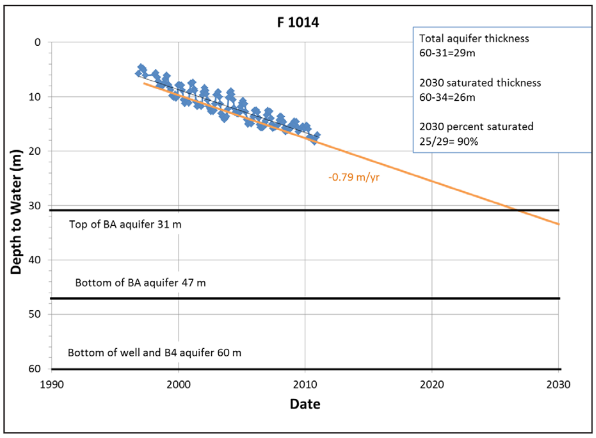

Figure 8. Actual and Estimated Groundwater level Fluctuations at Ain El-Baida Well (F 1014).

Based on the water table fluctuation measurements at the well F 1022, the current trend is -1 m/y. The saturated thickness of B4/B5 aquifer is forecast to decline to 53 percent by the year 2030 (Figure 9).

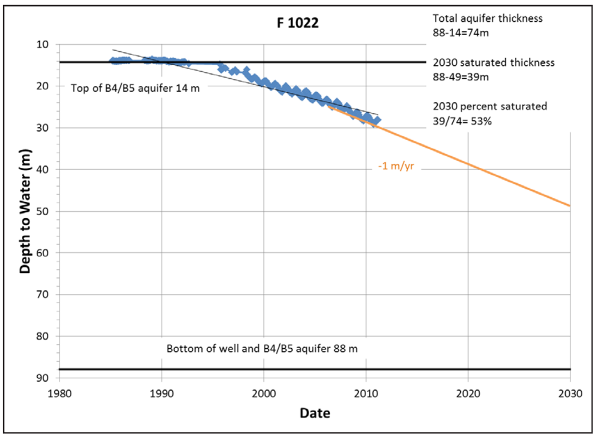

Figure 9. Actual and Estimated Groundwater level Fluctuations at Azraq Oasis Well (F 1022).

Well F 1043 is located in the Azraq oasis area, near several wells with high abstraction rates. The current trend is -0.42 m/y, which is less than the long-term trend of the linear fit to all data. The combined saturated thickness of the Basalt and B4 aquifers is forecast to decline to 85 percent at this location in the year 2030 (Figure 10).

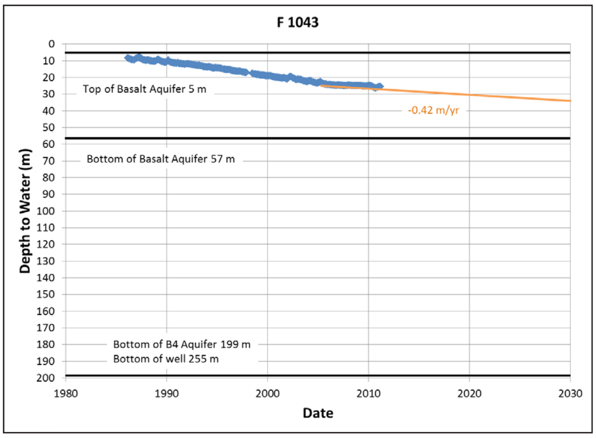

Figure 10. Actual and Estimated Groundwater level Fluctuations at Azraq Oasis Well (F 1043).

Water quality and amount have suffered to incredible significance in Azraq basin over the most recent four decades. The allocated water per capita is expected to decrease from 120 m^3 recently to 91 m^3 by the year 2025, which is far below the international standard (1000 m^3). Water deficiency is a huge challenge affecting the future of different activities in the country, especially after the refugee crises.

The investigations of groundwater of Azraq basin, which is one of the amongst the most vital basins in Jordan. The groundwater withdrawal from Azraq basin reached about 50 MCM/year is utilized to supply Amman, Zarqa and Jordan-northern governorates with a new water supply and about 50 MCM/year from the private agricultural wells. Azraq Oasis is the core of the basin where a large number of transitory flying birds reset in consistently amid their trip from Siberia to Africa. Lack of water affects the hydrochemical and biological system in the basin, due to overpumping from the upper aquifer system. The water level dropped significantly and indications of salinization and exhaustion occurred. The serious drawdown in the Azraq well field caused saltwater intrusion in the central part of the basin (Qa-Azraq). The salinization in the upper aquifer (basalt/B5/B4) likely resulted from the switch of Sabkha water to the AWSA well field and the artesian pressure from the saline middle and lower aquifers, due to the serious drop of the water table of the upper aquifer.

The huge increase in electrical conductivity is occurring at the Azraq depression, due to the saltwater intrusions. The electrical conductivity values increased to about 7000 µS/cm but they could decrease to about 4500 µS/cm in the year 2030 if the pumping from the upper aquifer system decreases to the safe yield average (Figures 11-12). Continuous dropping in the water table also could be stopped by decreasing pumping to a safe yield average (Figure 13).

According to piper plot classification, 1944 for about 33 water samples during the year 2018 (Figure 14), the groundwater of the upper aquifer system shows three types of water according to the major cations (sodium, potassium, magnesium and calcium) and anions (bicarbonate, sulphate, chloride and nitrate) (Figure 15) as follows:

1. Earth alkaline water with an increased portion of alkalis and with prevailing sulfate and chloride (mixed type).
2. Alkaline water with prevailing bicarbonate (mixed type).
3. Alkaline water with prevailing sulfate and chloride (sodium chloride type).

It can be seen clearly that the aquifers are composed of a group of different rock formation, which affects the chemical constituents of the groundwater. The analyses also show a formation of saltwater bodies at the central part of the depression.

Matrics of linear correlation for the combination of parameters of chemical constitutes are shown in table (7). It can be seen a positive relationship affecting the increase of different cations and anions in groundwater.

Groundwater artificial recharge involves collecting surface water in ponds, sand dams, recharge releases, underground dams, recharge wells, drilled wells or other facilities where water infiltrates into the permeable soil to recharge the upper aquifer system, which is composed of fractured carbonates and basalts (Gale, 2005). Trenches and shafts can be used in the unsaturated zone, or water can be directly injected into aquifers through recharge wells. Applying artificial recharge techniques will help in the followings:

1. Increase the safe yield of the basin aquifers
2. Decrease the effects of thunderstorm rainfalls on the basin recharge
3. Decrease the effects of thunderstorm rainfalls on the soil erosion
4. Improve the groundwater quality
5. Alleviate the formation of saltwater intrusions in the upper aquifer system
6. Improve the natural discharge of Azraq springs
7. Increase the tourist activities in the basin
8. Increase the activities of the immigration birds in the eastern deserts
9. Avoid the increasing salinity of the soils as a result of agricultural activities
10. Develop new agricultural activities in the basin.
11. Combat desertification of the ecosystem

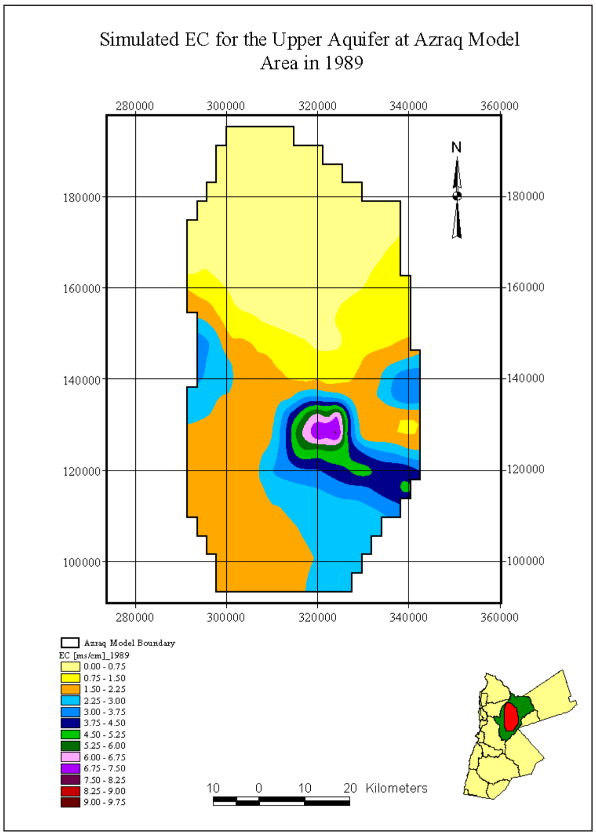

Figure 11. Simulated Groundwater Salinity of the Upper Aquifer System in Azraq Basin in the Year 1989 (WAJ Files Data).

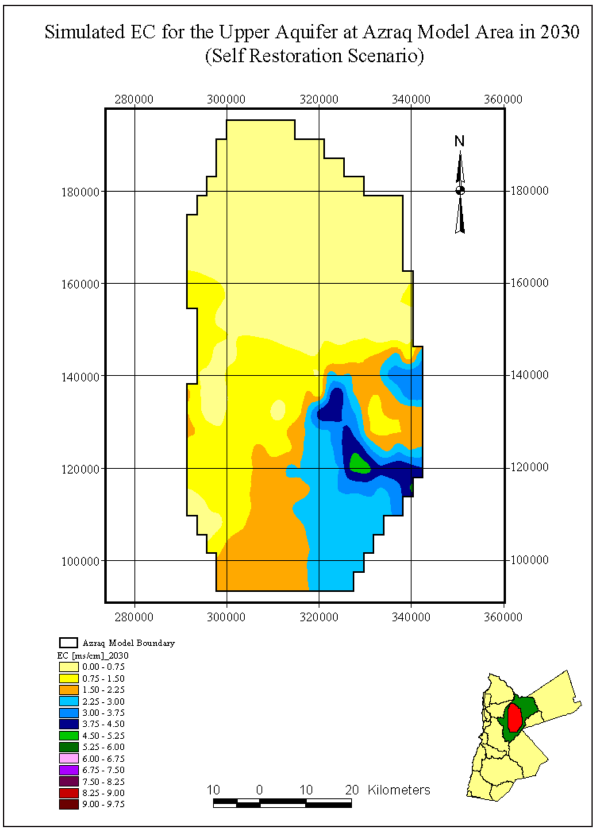

Figure 12. Simulated Groundwater Salinity of the Upper Aquifer System in Azraq Basin in the Year 2030 using Self Restoration Scenario (WAJ Files Data).

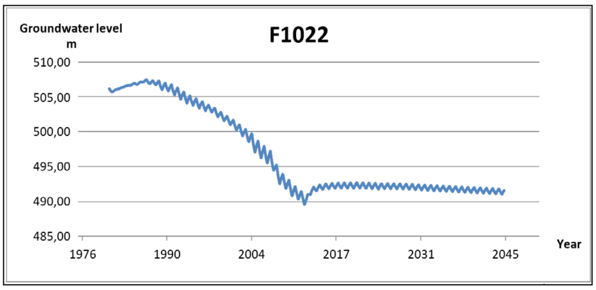

Figure 13. Simultaion of Groundwater Levels under Safe Yield Conditions in the Well F1022 during the Period 1976-2045 (Alkhatib, 2017).

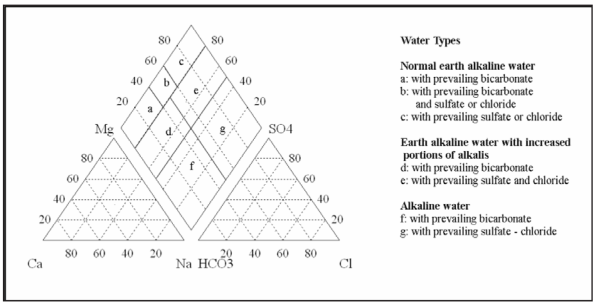

Figure 14. Trilinear Classification of Water Types according to Chemical Constituents (Piper, 1944).

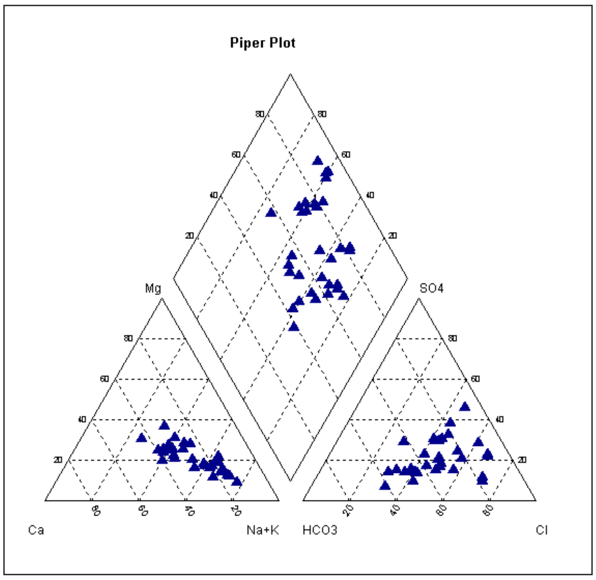

Figure 15. Trilinear presentation of groundwater in the Upper Aquifer System of Azraq Basin.

Table 7. Matrix of Linear Correlation Coefficient of the Chemical Analyses in Azraq Basin (mg/L).

	pH	Na	Mg	Ca	Cl	K	SO4
pH	1	-0.47	-0.565	-0.638	-0.488	-0.407	-0.541
Na		1	0.874	0.89	0.953	0.85	0.867
Mg			1	0.954	0.942	0.724	0.903
Ca				1	0.917	0.731	0.93
Cl					1	0.751	0.825
K						1	0.828
SO4							1

References

Alkhatib, J. (2017). An Integrated Approach of Analyzing Management Solutions for Water Crisis in Azraq Basin, Jordan, Ph. D Thesis, Georg-August University, Germany.

Al-Kharabsheh, A. (2020). Challenges of Sustainable Water Management in Jordan. Jordan Journal of Earth and Environmental Sciences 11 (1): 38-48.

Al-Kharabsheh, A. (1991). Hydrogeological and Hydrochemical Study of the Upper Aquifer System in Azraq Basin. M.Sc. Thesis, Yarmouk University, Jordan.

Al-Kharabsheh, A. (1995). Possibilities of Artificial Groundwater Recharge in the Azraq basin: Potential Surface Water Utilization of Five Representative Catchment Areas (Jordan). Journal of Hydrogeologie und Umwelt 10, 205 pp.

Al-Kharabsheh, A. Al-Weshah, R., Shatanawi, M. (1997). Artificial Groundwater Recharge in the Azraq Basin (Jordan). Dirasat 24(3): 357-370.

Al-Momani, M. (1991). Relationship between AWSA Well Field and Northeast Desert Groundwater (Upper aquifer) and Sources of Salinity in Deep B2/A7 Aquifer, Azraq basin. Unpubl. Report, Water Authority, Jordan.

Al Shamil Engineering Office. (2000). Vulnerability of the Azraq Groundwater System to Climate Change, Amman, Jordan.

Al Wreikat, M. and Al-Kharabsheh, A. (2020). Impact of over pumping on groundwater resources sustainability at Amman Zarqa basin, Jordan: a case study of arid areas affected by Syrian refugees crisis. Environmental Earth Sciences (2020) 79:19 https://doi.org/10.1007/s12665-019-8768-0.

Ayed, A. (1986). Surface Water Resources in Azraq Basin. Unpubl. Report, Water Authority, Amman, Jordan.

Gale, L. (2005). Strategies for Managed Aquifer Recharge (MAR) in semi-arid areas, UNESCO's International Hydrological Programme (IHP).

Hobler, M., Margane, A., Almomani, M., Subah, A. (2001). Groundwater resources of northern Jordan Volume-4 contribution to the hydrogeology of Northern Jordan. BGR-WAJ technical cooperation project.

Humphreys, H. (1982). Azraq Well Field Evaluation (Hydrochemistry & Monitoring), Water Authority 37 pp.

Lloyd, J. W. (1992). Deep Aquifers and the Impact of their Exploitation, Jordan's Water Resources and their Future Potential. Symposium 27th and 28th October 1991 Organized by Friedrich Ebert Stiftung, Higher Council for Science and Technology, Water Research and Study Center: 49-67.

Piper, A.M. (1944). A graphical interpretation of water analysis, Transactions of the American Geophysical Union 25: 914 -928.

Salameh, E. and Udluft, P. (1985). The Hydrodynamic pattern of the central part of Jordan. Geoloisches Jahresbuch 38 (C): 39-53.

Soil Conservation Service (1969). Computer Program for Project Formulation, Technical Release. 20, U.S. Department of Agri¬culture, Washington D., USA.

Soil Conservation Service (1972). National Engineering Hand¬book. Section 4, Hydrology, U.S. Department of Agriculture, Wa¬shington, D.C., USA.

Soil Conservation Service (1975). Urban Hydrology of Small Watersheds, Technical Release No.55, Engineering Division, U.S. Department Agriculture, Washington, D.C., USA.

Ayed, R. (1996). Hydrological and Hydrogeological Study of the Azraq Basin, Jordan, Ph. D. thesis, Baghdad University, Iraq.

United States Department of the Interior, (1960). Design of Small Dams, United States Government Printing Office, 1st edition, 611 p, Washington, USA.

WAJ Files Data, Water Authority of Jordan (Rainfall, Evaporation and Wells Data), Amman, Jordan.

Water Authority (1989). North Jordan Water Resources Project. Investigation Project Staff. Unpubl. Report, Water Authority, Jordan.