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Influence of urbanization on water quality deterioration during drought periods at South Jordan

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The study investigated the effect of urbanization, drought and pollution on the deterioration of water quality in the Tafila Basin in southern Jordan during the year 2000. Six representative springs were chosen, from which 84 water samples were analysed for their chemical and biological characteristics. In addition, 75 samples were analysed for their chemical characteristics during the period 1978–1999. The arid and semi-arid climatic characteristics, high population growth and the lack of sewer systems cause pollution. The infiltration of waste water from septic tanks into springs and ground-water resources is considered the most prominent cause. The primary evaluated parameters are EC, NO_3, faecal coliform, total coliform and total count. Their concentration is accelerating, due to the increase of waste water in comparison to fresh water quantity. The fracture system associated with Upper Cretaceous carbonates allows the waste water to recharge the springs very quickly and without any purification. Connecting the scattered buildings with the Tafila Treatment Plant (TTP), built in 1988, will stop or decrease the pollution and allow the springs to refresh themselves. The TTP is under-loaded, and its effluent water can be used for irrigation.

Keywords: spring; pollution; drought; waste water; recharge; carbonates

Introduction

Pollution and scarcity of water resources are some of the most important challenges facing Jordan, a country in which 91% of the land area receives an annual rainfall of less than 200 mm. The thunderstorms, which are characterized by their irregularity in intensity and duration, are responsible for most rainfall in the country. This type of rainfall associated with degraded land condition is increasing soil erosion and decreasing ground-water recharge (Sa'ad, 1996). Pollution is caused by the arid to semi-arid climate, high population growth and the lack of sewer systems, which results in the infiltration of waste water into springs and ground-water resources.

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In urban areas, the infiltration of waste water from septic tanks into the ground-water accelerates the pollution problems. It increases the stress on the fresh water resources by increasing their salinity, and ground-water levels are depressed through over-pumping (Salameh, 1996).

To explain the effects of pollution on water resources during drought periods, the Tafila Basin in southern Jordan was selected as a case study. The average rainfall is about 150 mm over an area of about 80 km^2 (Fig. 1). The average population growth is around 4% per year, and the number of inhabitants has been increasing sharply during the last two decades (Fig. 2). Many new buildings, using septic tanks, have been constructed adjacent to springs, causing their pollution.

Springs water is the major source for drinking water and agricultural activities. The average discharge of springs range from $0{\cdot}3\,m^3\,h^{-1}$ for Zibleh spring to $8{\cdot}5\,m^3\,h^{-1}$ for Um-Qaryah spring (Table 1).

The surface water systems are composed of ephemeral wadis that drain their water during winter to recharge the springs, but more than 89% of the rainfall precipitated over the basin evaporates into the atmosphere (Table 2). Ground-water resources consist of 21 springs emerging from Upper Cretaceous aquifers (Amman, Wadi Es-Sir, Hummar, Naur and Kurnub sandstone).

The Tafila Treatment Plant (TTP) is located at the lower part of the Tafila Basin and discharges about $0{\cdot}33 \times 10^6\,m^3$ annually. The plant is under-loaded and the discharged treated waste water is of good quality and is used for unrestricted irrigation (WAJ Files).

The basin is characterized by a gentle slope, whereas the elevation increases from 200 m above the mean sea level at the north to about 400 m above the mean sea level at the south. The high population growth and drought conditions during the years 1995–2000 accelerated the springs' water pollution.

The goals of this study are to investigate the water quality of the springs in the Tafila area, determine the deterioration in water quality, identify sources of pollution and characterize the suitability of springs for drinking and agricultural uses. Six representative springs were analysed for their chemical and biological characteristics.

Hydrogeology

The hydrogeology of Tafila Basin is controlled by the geological set-up, which controls the piezometry, occurrence, movement and productive areas of the aquifers. Based on the potentiality of water bearing, the main aquifers are Upper Cretaceous like Amman–Wadi Es-Sir (B_2/A_7) is thinly bedded marly limestone with chert bands and chalk. Naur ($A_{1/2}$) is marly limestone, dolomitic limestone and marlestone. Hummar (A_4) is dolomitic limestone, thin to massive bedded and cavernous, and Lower Cretaceous like Kurnub sandstone (K) is yellow, white massive sandstone with marly clay and sandstone (UNDP, 1992).

The B_2/A_7 aquifer consists of limestone, dolomite, limestone, marl and chert. It crops out at the southern part of the study area. It is a semi-uniform aquifer with widespread hydraulic connections in the entire study area with a thickness of 100–300 m. The direction of ground-water movement is from south-east to north-west. The fissures and joints of the B_2 /A_7 aquifer intrinsic permeability ranges from $0{\cdot}5\,m\,day^{-1}$ to more than $9\,m\,day^{-1}$ and transmissivity between 120 and $2400\,m^2\,day^{-1}$, causing the aquifer to be productive (BGR, 1991).

The Hummar and Naur aquifers (A_4 and $A_{1/2}$) are outcropping at the central part of the basin, and they are composed of limestone, marl and dolomite with thickness ranges from 100 to 220 m (Macdonald, 1965). The hydraulic conductivity of these aquifers ranges from $0{\cdot}07$ to about $65\,m\,day^{-1}$.

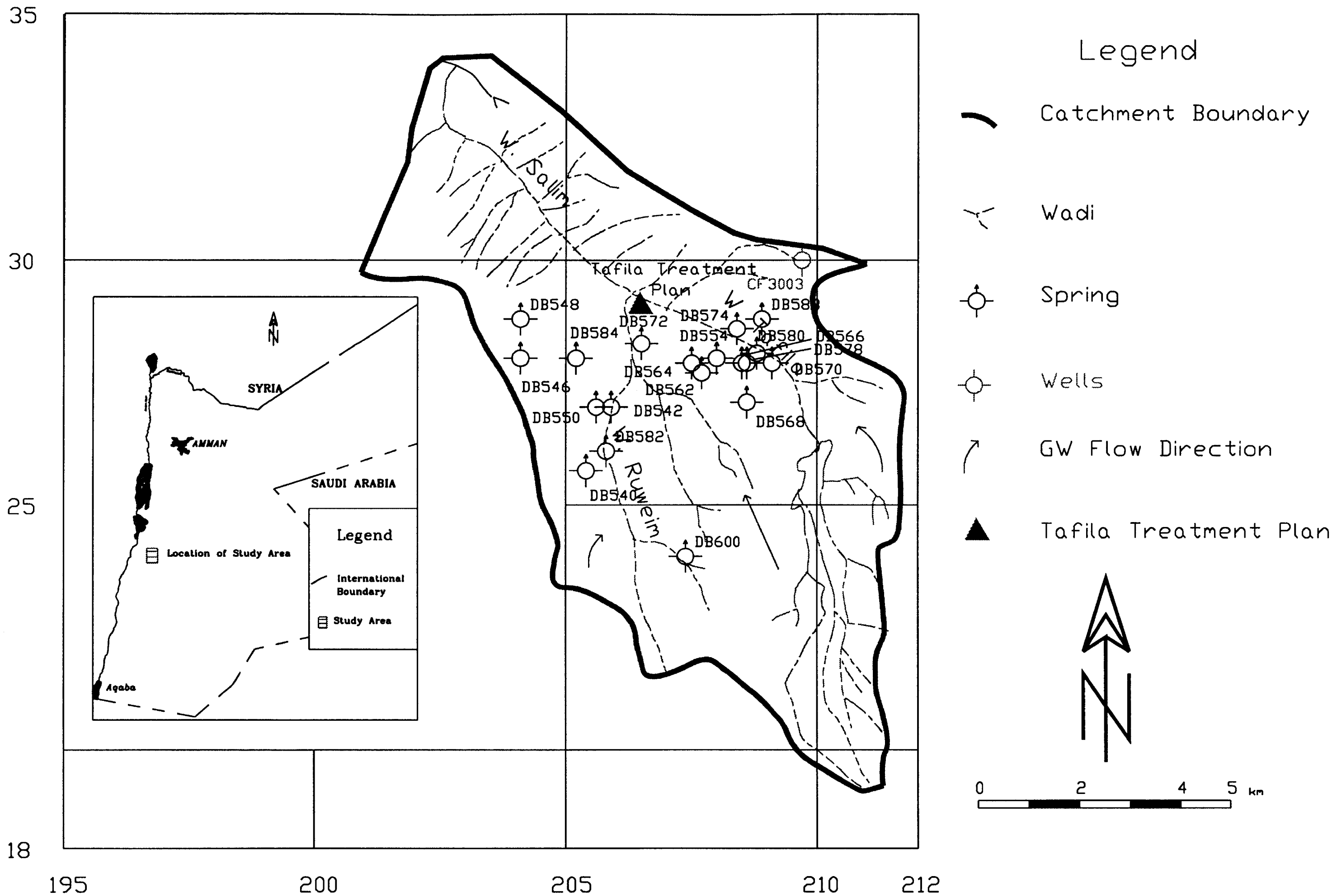

Figure 1. Location map of springs and drainage system of Tafila Basin.

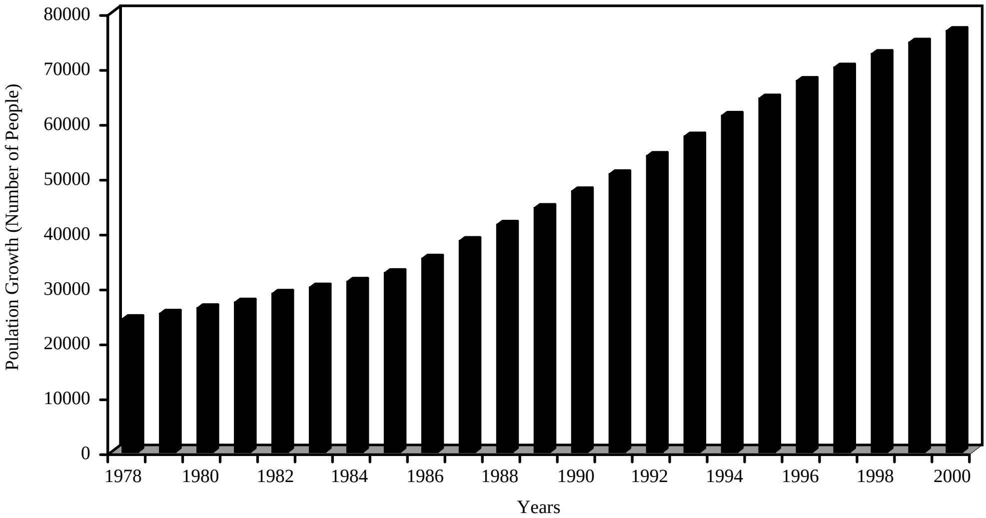

Figure 2. Population growth at Tafila Basin (Statistical Department Files, 2000).

Table 1. *Major springs with their average discharge at Tafila Basin (Water Authority Files, 2000)*

Spring name	Identification number	Coordinates East	Coordinates North	Discharge ($m^3 h^{-1}$)	Aquifer type
Zibleh	DB 584	205·2	28·0	0·3	A_4*
El-Beidah	DB 550	205·6	27·0	2·8	A_4
El-Had	DB 574	208·4	28·6	6·3	A_4
Um Es-Said	DB 588	208·9	28·8	2·9	A_7
Um Keis	DB 572	206·5	28·3	7·2	K†
Shalha	DB 564	207·5	27·9	6·8	A_4
Unsor	DB 562	207·7	27·7	6·8	A_4
Mawardeh Tahta	DB 542	205·9	27·0	3·4	$A_{1/2}$‡
Um Ruweim	DB 582	205·8	26·1	3·3	A_4
Dawara	DB 540	205·4	25·7	1·8	B_2/A_7§
Jarrar	DB 580	208·8	28·1	2·7	A_4
El-Beida	DB 570	209·1	27·9	5·4	A_4
Um Qaryah	DB 566	208·5	27·9	8·5	A_4
Awajan	DB 578	208·6	27·9	2·6	A_4
El Jaheer	DB 568	208·6	27·1	7·2	A_7
Abil	DB 600	207·4	24·0	1·8	A_7
El Hasdeh Fouqa	DB 548	204·1	28·8	2·2	A_4
Mawardeh Fouqa	DB 544	205·9	26·9	1·4	$A_{1/2}$
El Balad	DB 546	204·1	28·0	2·4	A_7
Faraheed	DB 576	208·6	27·9	1·9	A_4
Jfut	DB 554	208·8	28·0	2·4	A_4

*A_4 is dolomitic limestone, thin to massive bedded and cavernous.
†K is yellow, white massive sandstone with marly clay and sandstone.
‡$A_{1/2}$ is marly limestone dolomitic limestone and marlestone.
§B_2/A_7 is thinly bedded marly limestone with chert bands and chalk.

Table 2. *Calculated water balance for the studied area*

Water year	Rainfall ($m^3 \times 10^6$)	Runoff ($m^3 \times 10^6$)	Infiltration ($m^3 \times 10^6$)	Loss ($m^3 \times 10^6$)	Runoff rate (%)	Infiltration rate (%)	Loss rate (%)
1978	19·45	0·42	0·64	18·19	2·2	3·3	94·5
1979	27·62	0·36	0·77	26·49	1·3	2·8	96·2
1980	29·34	1·06	1·42	26·86	3·6	6·4	90·0
1981	25·31	2·99	2·34	19·98	11·8	12·2	76·0
1982	14·01	0·31	0·40	13·30	2·2	3·8	94·0
1983	28·24	3·30	0·64	24·29	11·7	3·0	85·3
1984	7·58	0·09	0·13	7·35	1·2	2·3	96·5
1985	16·14	1·08	0·53	14·53	6·7	4·3	89·0
1986	18·24	2·13	1·22	14·89	11·7	8·8	79·5
1987	16·90	0·30	0·50	16·09	1·8	3·9	94·3
1988	29·62	2·25	0·31	27·06	7·6	1·4	91·0
1989	21·95	2·61	0·60	18·74	11·9	3·6	84·5
1990	12·52	0·90	0·36	11·26	7·2	3·8	89·0
1991	27·70	9·53	0·55	17·62	34·4	2·6	63
1992	25·50	1·25	1·28	22·97	4·9	6·6	88·5
1993	15·90	0·1	0·25	15·55	0·6	2·1	97·3
1994	21·24	0·34	0·71	20·19	1·6	4·4	94·0
1995	24·93	1·25	1·45	22·23	5·0	7·7	87·3
1996	17·15	0·612	0·38	16·16	3·6	2·9	93·5
1997	18·73	0·71	0·97	17·05	3·8	6·8	89·4
1998	18·95	0·76	0·40	17·79	4·0	2·8	93·2
1999	12·30	0·28	0·21	11·82	2·3	2·2	95·5
2000	8·91	0·05	0·10	8·77	0·5	1·5	98·0
Average	19·92	1·421	0·70	17·79	6·2	4·3	89·5

The Kurnub sandstone aquifer (K) crops out at the northern part of the study area with thickness ranges from 400 to 500 m. At the southern part, Kurnub sandstone aquifer is confined with more than 600 m to reach the piezometric surface (Bender, 1974). Figure 3 shows the geological map of Tafila Basin.

Tafila Waste Water Treatment Plant

The TTP was built in 1988 with a design capacity of 1600 m^3 day^{-1}. The present daily effluent is only 900 m^3. Thus, connection of more buildings to TTP is possible and advisable; this would decrease pollution, and the springs would be able to refresh themselves again. The average COD and BOD of the effluent are 198 and 37 mg l^{-1}, respectively (Table 3). The treated waste water is chlorinated before discharging into Wadi Tafila and is used for irrigation without restrictions.

Water analyses

Water samples for the period 1978–1999, and for the year 2000 from six representative springs were analysed, for their physical, chemical and biological constituents according to the methods suggested by Rand *et al.* (1995). The

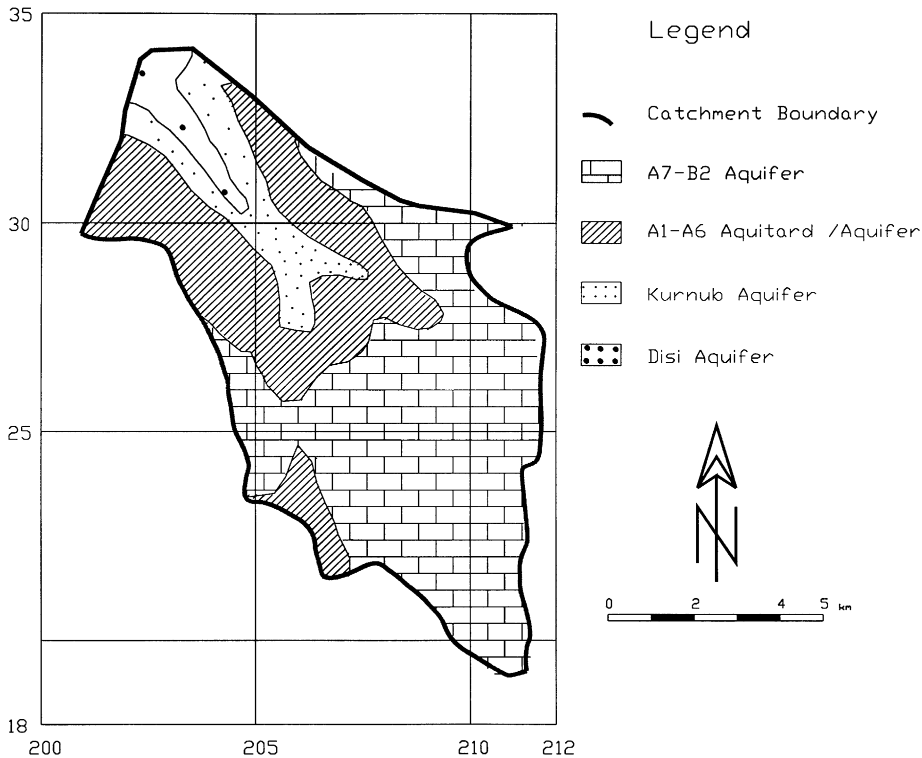

Figure 3. Geological map of Tafila Basin.

Table 3. *Average annual chemical and biological composition of waste water at TTP*

Parameters	Influent	Effluent
No. of samples	6	6
EC ($\mu S\,cm^{-1}$)	1686·67 ± 85·44	1461·17 ± 109·15
Ca ($mg\,l^{-1}$)	69·5 ± 3·08	44·50 ± 3·89
Mg ($mg\,l^{-1}$)	40·13 ± 6·78	28·12 ± 3·94
Na ($mg\,l^{-1}$)	194·44 ± 12·34	174·23 ± 10·63
K ($mg\,l^{-1}$)	64·67 ± 2·73	39 ± 9·63
Cl ($mg\,l^{-1}$)	202·61 ± 1·91	174·08 ± 19·41
SO_4 ($mg\,l^{-1}$)	91·86 ± 2·34	70·60 ± 5·13
HCO_3 ($mg\,l^{-1}$)	466·32 ± 15·52	380·78 ± 7·04
pH	6·67 ± 0·20	7·30 ± 0·49
NO_3 ($mg\,l^{-1}$)	51·02 ± 4·64	47·18 ± 13·56
PO_4	10·31 ± 5·77	14·15 ± 6·92
Total coliform (MPN $100\,ml^{-1}$)	$3{\cdot}2 \times 10^8 \pm 6{\cdot}2 \times 10^8$	$9{\cdot}3 \times 10^6 \pm 6{\cdot}8 \times 10^6$
Faecal coliform (MPN $100\,ml^{-1}$)	$4{\cdot}8 \times 10^7 \pm 6{\cdot}4 \times 10^7$	$1{\cdot}7 \times 10^6 \pm 1{\cdot}3 \times 10^6$
Total count (count ml^{-1})	$1{\cdot}3 \times 10^8 \pm 1{\cdot}8 \times 10^7$	$5{\cdot}5 \times 10^6 \pm 4{\cdot}9 \times 10^6$
COD ($mg\,l^{-1}$)	1592·73 ± 496·13	198·43 ± 240·24
BOD ($mg\,l^{-1}$)	466·67 ± 103·47	37·33 ± 15·27

±: standard deviation.

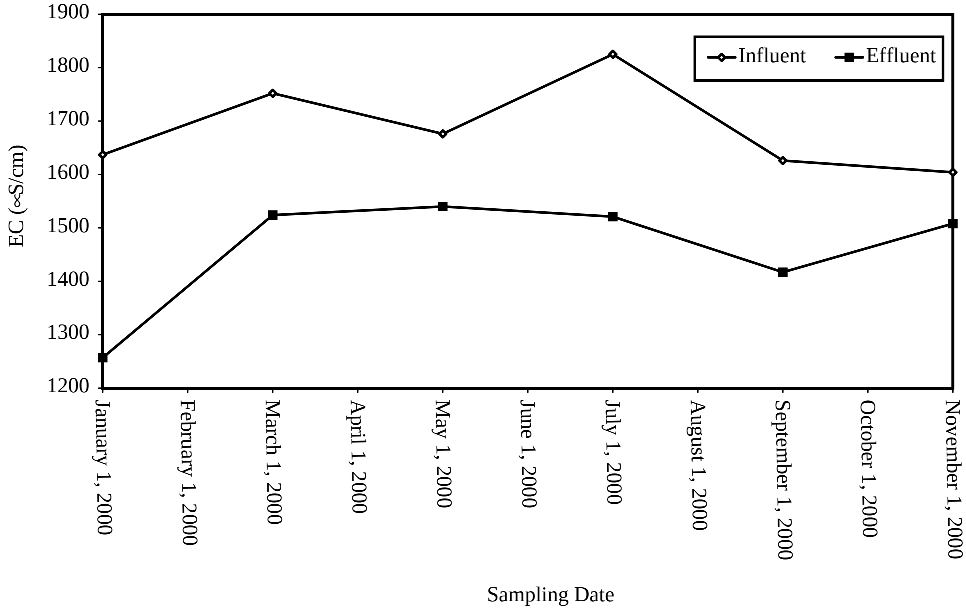

Figure 4. Variation of electrical conductivity of the influent and effluent of TTP.

parameters analysed were EC, Ca, Mg, Na, K, Cl, SO_4, HCO_3, pH, NO_3, PO_4, COD, BOD and total and faecal coliform bacteria. In addition, influent and effluent water of the TTP was analysed on a bimonthly basis during the year 2000.

Results and discussion

Jordan water resources are suffering from a growing gap between supply and demand. Meeting the deficit by over-extraction of ground-water increases the salinity of ground-water and depreciates its levels. Most of the country has an arid to semi-arid climate, which decreases the recharge of fresh water resources and accelerates pollution. More than 65% of the country area is covered with Upper Cretaceous fractured carbonate, which facilitates the pollution of ground-water (Al-Kharabsheh, 1999).

Due to its very limited water resources, among the lowest in the world, and its very high population growth, Jordan is facing a very dangerous future. Per capita water resources are projected to fall from 200 to $90\,m^3\,cap^{-1}\,year^{-1}$ by the year 2025, placing the country in the category of absolute water scarcity.

The pollution of water resources during drought periods was the main purpose of this study. The Tafila Basin was selected as a case study, due to its arid climate and the urbanization near the main springs. The number of inhabitants in Tafila Basin has sharply increased from 24,130 in 1978 to 76,595 in 2000. Recharge of the springs from septic tanks has also increased, while fresh water recharge has decreased, due to drought conditions.

The increasing number of scattered buildings and the high population growth increases the stress on water resources. The springs are directly invaded by pollution sources through the fractures associated with limestone aquifers.

Eighty-four water samples from six representative springs and the TTP were analysed during the year 2000. In addition, 75 historical samples during the period

Table 4. *Average annual chemical and biological composition of spring water at Tafila Basin*

Parameters	El-Hasdeh	Um Es-Said	Jfut	Unsor	El-Beida	Jarrar
No. of samples	12	12	12	12	12	12
EC ($\mu S\ cm^{-1}$)	739·5 ± 7·62	722·83 ± 82·66	846·92 ± 56·92	807·17 ± 51·85	907·33 ± 130·85	685·25 ± 48·66
Ca ($mg\ l^{-1}$)	76·17 ± 4·37	66·11 ± 8·99	68·50 ± 6·49	57·2 ± 2·99	78·46 ± 13·26	56·67 ± 2·27
Mg ($mg\ l^{-1}$)	25·94 ± 3·01	25·06 ± 4·50	28·33 ± 6·67	27·27 ± 2·67	28·31 ± 10·04	22·7 ± 3·10
Na ($mg\ l^{-1}$)	17·8 ± 3·48	37·74 ± 11·05	62·64 ± 9·21	48·32 ± 15·97	57·47 ± 10·50	29·78 ± 5·05
K ($mg\ l^{-1}$)	2·44 ± 1·04	3·43 ± 0·77	1·92 ± 0·75	3·8 ± 1·17	3·79 ± 1·48	2·12 ± 0·32
Cl ($mg\ l^{-1}$)	58·75 ± 3·31	54·07 ± 9·7	93·81 ± 6·86	38·33 ± 5·16	101·82 ± 13·92	44·25 ± 4·18
SO_4 ($mg\ l^{-1}$)	27·43 ± 8·07	28·7 ± 9·53	38·97 ± 8·92	24·82 ± 8·34	35·86 ± 9·53	24·74 ± 5·19
HCO_3 ($mg\ l^{-1}$)	209·71 ± 5·05	267·33 ± 44·77	181·83 ± 22·92	212·93 ± 8·223	215·78 ± 42·15	164·2 ± 3·96
pH	7·91 ± 0·30	7·37 ± 0·37	7·65 ± 0·16	7·89 ± 0·25	7·5 ±	7·79 ± 0·23
NO_3 ($mg\ l^{-1}$)	71·13 ± 8·88	41·90 ± 4·81	116·14 ± 21·6	135·17 ± 14·49	110·2 ± 25·85	123·32 ± 26·93
PO_4 ($mg\ l^{-1}$)	0·02 ± 0·03	0·26 ± 0·14	0·02 ± 0·02	0·06 ± 0·06	0·03 ± 0·05	0·05 ± 0·10
Total coliform (MPN 100 ml^{-1})	145·67 ± 237·6	9483·33 ± 6398·98	1·92 ± 6·64	7608·33 ± 6539·04	4714·17 ± 5850·58	1501 ± 4584
Faecal coliform (MPN 100 ml^{-1})	3·83 ± 11·42	9089·17 ± 6831·33	1·92 ± 6·64	3561·08 ± 5904·46	1799·67 ± 4547·53	409·17 ± 1041·99
Total count (Count ml^{-1})	1050·83 ± 1833·57	3799·17 ± 3710·16	1014·17 ± 1430·47	29505 ± 63362·79	5291·67 ± 3411·53	2163·33 ± 2851·52

±: standard deviation.

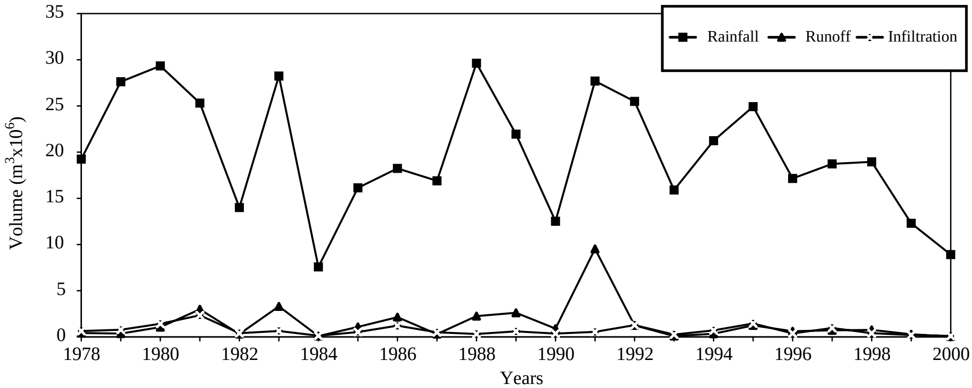

Figure 5. Rainfall, runoff and infiltration relationship.

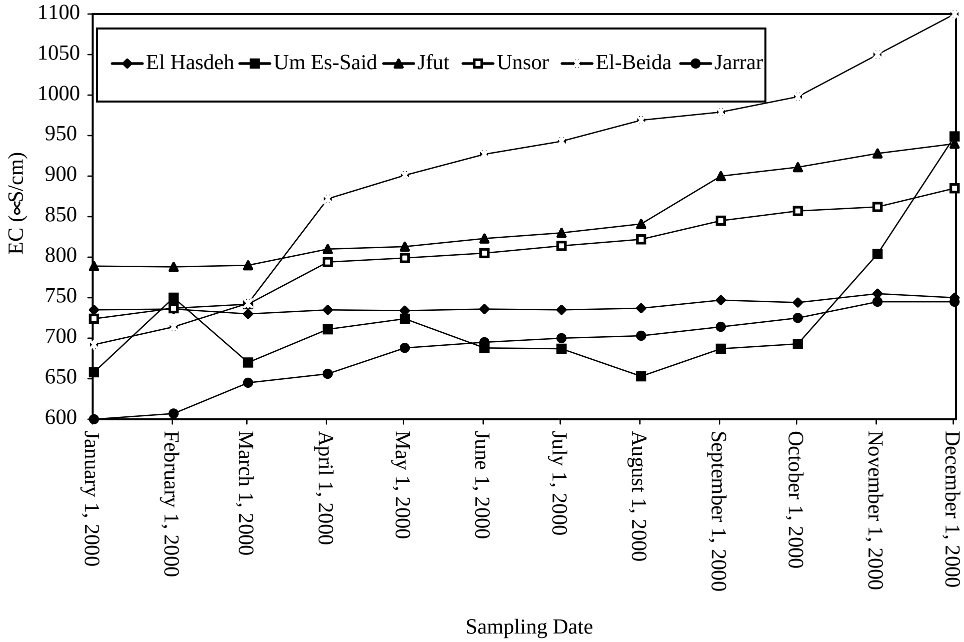

Figure 6. Electrical conductivity fluctuation of the studied springs at Tafila Basin.

1978–1999 were studied. The springs, which form an important source for drinking and irrigation, are suffering due to the invasion of waste water from septic tanks and the decrease of fresh water recharge. Chemical and biological analyses indicate that pollution will accelerate in the near future, and the springs will be polluted chemically and biologically for all uses.

The average EC of influent water decreased from 1686 to 1461 $\mu S\,cm^{-1}$ after treatment, the other chemical and biological contents have also decreased with different ratios (Fig. 4). Table 3 shows that the concentrations of effluents like total coliform, faecal coliform, total count, BOD and COD are too high. This increases the pollution effects on the springs, especially with the limitation of fresh water resources recharging them.

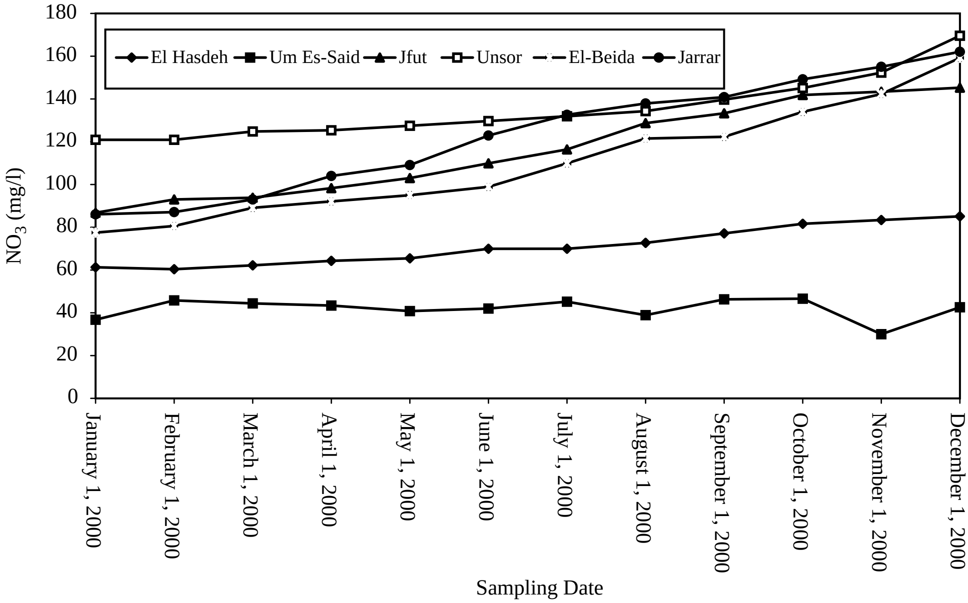

Figure 7. NO_3 fluctuation of the studied springs at Tafila Basin.

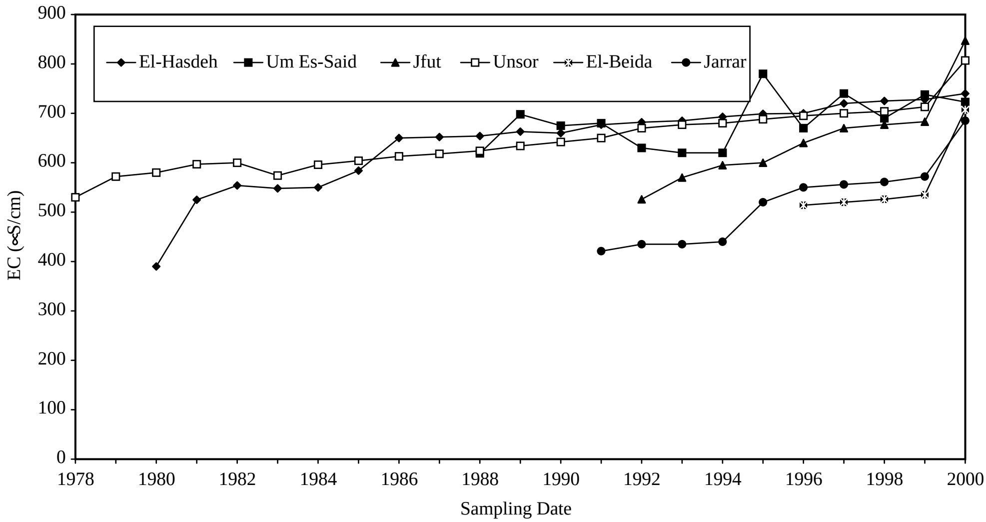

Figure 8. Historical electrical conductivity fluctuation of the major springs at Tafila Basin during 1978–2000.

The EC, NO_3 and biological content of the springs have increased sharply during the year 2000, which indicates that the pollution of springs will accelerate sharply in the near future and the water will not be suitable for any use. The springs that are located near residential areas have been affected more than other springs. These springs are directly recharged with waste water through fractures and fissures characterizing limestone at the southern part of Jordan (Table 4). In addition, for the five seasons 1995 through 2000, rainfall infiltration was much below average (Fig. 5).

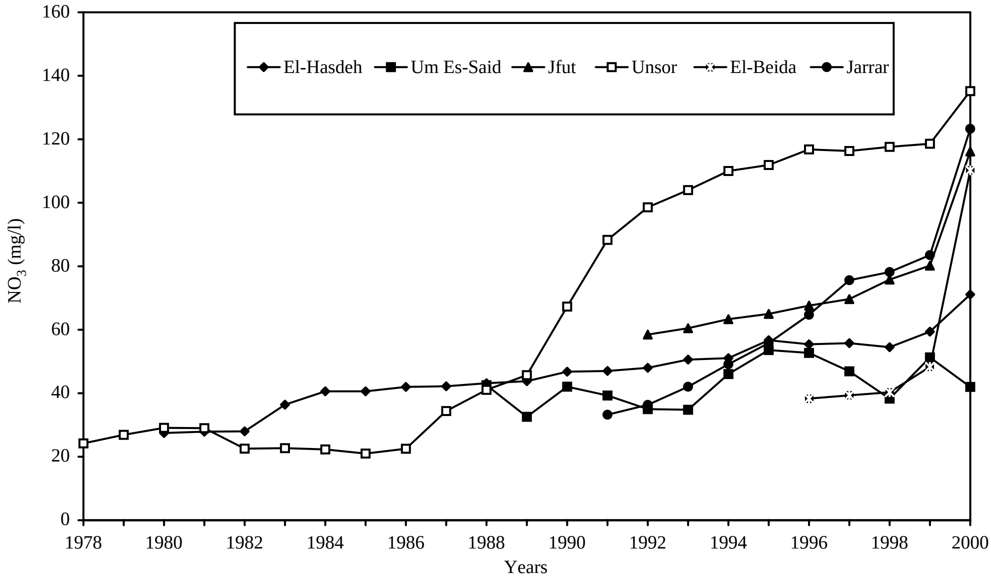

Figure 9. Historical NO_3 fluctuation of the major springs at Tafila Basin during 1978–2000.

Table 3 shows that the most affected parameters from spring pollution are EC, NO_3, total coliform, faecal coliform and total count. Figure 6 shows that EC of the springs Unsor, Jfut and Um Es-Said has increased at a very high ratio.

The NO_3 ratio has doubled for the springs El-Beida, Jarrar, Jfut, Unsor and Um Es-Said (Fig. 7). The accelerating ratio is too high and the springs have been damaged, because they are invaded by water from septic tanks through the fractures and faults associated with limestone aquifers. The influence of urbanization is most obvious at the El-Beida, Jfur and Unsor springs, which lie at the centre of the Tafila Basin.

Biologically, the springs are polluted and the concentration of total coliform, faecal coliform and total count are not decreasing, even during winter, because the fresh water recharge is negligible in relation to the waste water recharge from septic tanks.

The chemical analyses of 75 water samples during the period 1978–1999 confirm the results of this study. The EC and NO_3 have increased at a very high ratio (Figs 8 and 9).

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