Modeling of the stormwater runoff quantity and quality in Amman-Zarqua Basin, Jordan

Othman Al-Mashaqbeh[1] · Malek Shorman[2]

Abstract

The Storm Water Management Model (SWMM) was applied to simulate stormwater runoff quantity and quality generated from different land uses at Amman-Zarqa Basin (AZB) over two winter seasons (October 25, 2012 to May 31, 2014). The model was calibrated and validated using several storm events over two winter seasons for a measured surface flow data at the inlet of King Talal Dam (KTD). The calibration and validation results showed good agreement between simulated and measured surface runoff flow data at AZB. The results showed that the total precipitation estimated by the model is about 1106 MCM during the study period. About 93.2% of precipitation (1031 MCM) is lost by infiltration and evaporation and 6.8% (75 MCM) is generated as runoff in AZB. The total predicted surface flow by the model was about 207 MCM compared with a measured value of 213 MCM in the basin. It is noticed that the contribution of surface runoff flow is about 36% of the total storage of KTD during the study period. Based on the results of this preliminary modeling study, pollutant loads (BOD5, COD, and TSS) carried by stormwater runoff were much higher than those by treated wastewater over the study period. The SWMM is a very effective model and has successfully modeled both hydraulic and pollutant loads generated from Amman-Zarqa Basin.

Keywords Rainfall-runoff simulations · Stormwater modeling · Pollutant loads · SWMM

Introduction

Nonpoint source (NPS) pollution at urban catchment is considered the largest source of water quality problems. Also, it is still the main source of water pollution in many water bodies such as rivers, dams, lakes, and estuaries (USEPA 2015). Most water quality problems of non-point source pollutants are assessed by water quality modeling. Many water quality models have been extensively used to evaluate non-point source pollution, such as the Storm Water Management Model (SWMM). The USEPA SWMM is a software package capable of simulating the movement of precipitation and pollutants from the catchment area through a collection of networks and treatment facilities to the receiving water.

The Amman-Zarqa Basin (AZB) is one of Jordan's important basins as more than a half of the Jordanian population (Jordan population ~6.5 million in 2013, DOS 2013) live within the urban areas of the basin. The main populated centers are the cities of Amman, Zarqa, Jaresh, Mafraq, and Balqa (DOS 2013). Land uses within the AZB watershed range from high-density urban areas in the west to typical rural areas at the east of the basin (Al-Afayfeh et al. 2006). Most of the surface flow, including floods and effluents, are drained and stored downstream at King Talal Dam (KTD), which is considered the main source for irrigation in the Jordan Valley. Protecting water resources at AZB has been one of the biggest water challenges for almost three decades in Jordan. Many studies are still reporting a continuous deterioration of the water quality bodies in the basin such as KTD (Shatanawi and Fayyad 1996; Al-Kharabsheh 1999; Al-Jassabi and Khalil 2006; Hadadin and Tarawneh 2007; Fandi et al. 2009; Abu Hilal and Abu Alhaija 2010; Alqadi and Kumar 2011; Yahya et al. 2017; Hadadin 2015). Recently, the rapid growth of the population and urbanization activities

✉ Othman Al-Mashaqbeh
    othman.mashaqbeh@rss.jo

    Malek Shorman
    mshorman86@gmail.com

1   Water and Environment Centre, Royal Scientific Society, Amman, Jordan

2   KEO International Consultants, Kuwait, Kuwait

at AZB are expected to increase at both the level of point-source and non-point-source pollution. Most of these studies have mainly explored the degree of point-source pollution and its impact on the water quality of water resources at AZB (Alawi and Haddadin 2004; Al-Afayfeh et al. 2006; Al Kuisi et al. 2012; Al-Rawabdeh et al. 2014). Therefore, local authorities have made significant headway in addressing point-source pollution and taken the proper measures to control it. However, little attention is given to the impact of NPS pollution on the downstream water bodies at the basin. This might be due to the lack of data and studies exploring the amount of pollution generated from non-point sources (i.e., stormwater runoff) at the basin. Therefore, a detailed hydrological modeling is undertaken for AZB to assess both hydraulic and pollutant loads generated at the basin from October 2012 to May 2014. This study aims to estimate the levels of quantity and quality (e.g., BOD5, COD, and TSS) carried by stormwater runoff in the AZB and stored at KTD using the SWMM model.

Methodology

The hydraulic and pollutant loads of storm water runoff generated from AZB were modeled using SWMM from October 25, 2012 to May 30, 2014. Input model data are required to run the SWMM model such as hydrologic and hydraulic parameters, surface flow data at inlet KTD, water quality data of treated wastewater (TWW), and runoff generated from AZB. These data were collected from three different sources: literature review, field measurements, and water authorities' records (unpublished data).

Study area

The AZB is the largest watershed in Jordan and comprises several cities (Amman, Zarqa, Mafraq, Jerash, and Balqa) (Fig. 1). The total area of the basin is about 3860 km^2, about 95% of the area is within Jordan and 5% is in Syria, reaching to the Syrian city of Salkhad in Jebal al-Arab. The average rainfall is about 250 mm/year. The Zarqa River is the main watercourse passing through the study area and discharges into KTD. The Zarqa River consists of two main creeks; the first creek (Sail Al-Zarqa) originates in Amman city centre at Ras Al-Ain, while the second creek (Wadi Duleil) originates from the south of Syria (Fig. 1).

The Wadi Duleil portion of the basin includes significant amounts of natural habitat and rural or non-urban land uses including small ranches, tree farms, horse stables, and rural residential areas. The Sail Al-Zarqa portion is highly urbanized and is covered with different impervious surfaces including parking lots, roads, commercial and residential buildings, universities, driveways, and sidewalks.
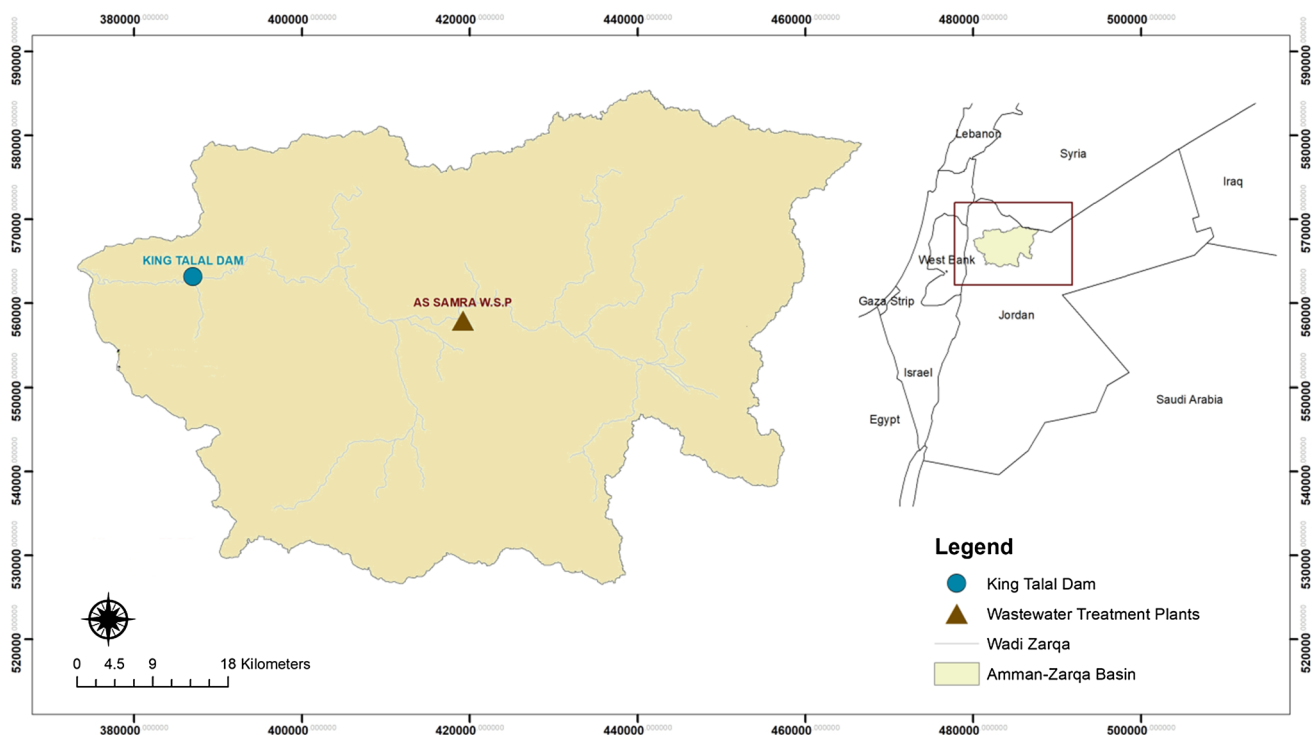

Fig. 1 Location map of Amman Zarqa basin

The SWMM model

The SWMM is a dynamic rainfall-runoff simulation model used for single-event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas (Rossman 2010). It can be used for discrete event simulation (a single event) or continuous-time simulation. SWMM accounts for various hydrologic processes that produce runoff from urban areas. These include: time-varying rainfall evaporation of standing surface water, snow accumulation and melting, rainfall interception from depression storage, infiltration of rainfall into unsaturated soil layers, percolation of infiltrated water into groundwater layers, interflow between groundwater and the drainage system, nonlinear reservoir routing of overland flow, and capture and retention of rainfall/runoff with various types of low-impact development (LID) practices. In addition to modeling the generation and transport of runoff flows, SWMM can also estimate the production of pollutant loads associated with this runoff.

SWMM simulation (module RUNOFF) was used to simulate rainfall-runoff through hydrologic and hydraulic conditions in Amman Zarqa watershed at the inlet of KTD during a continuous time period from October 25, 2012 to May 31, 2014. Soil conservation service (SCS)–curve number (CN) has been used to simulate stormwater runoff in the AZB. Input data for each sub-area are required to run the SWMM model such as precipitation and evaporation data, drainage area, sub-catchment width (shape factor) and slope, imperviousness, surface roughness, depression storage, soil infiltration parameters, and event mean concentrations (EMCs).

These parameters are very important for model simulation that have a major effect on the quantity and quality of water runoff. The values of some of these parameters were taken from the user's manual and previous studies reported in the literature (Haan et al. 1994; USEPA 2007; Rossman 2010). For example, Manning's roughness for impervious area was set at 0.025 and for pervious area was 0.1 (Warwick and Tadepalli 1991).

The initial abstraction depth was used as the fitting parameter for the calibration of the model because it is changeable in arid regions during the year and very difficult to determine (FAO 1991; Anderson 1997). The initial abstraction incorporates all losses before runoff begins, including water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. The value of initial abstraction depends on many factors such as soil type, the land use (specifically, the percent impervious of the land use), the hydrologic condition, and soil infiltration capability. Therefore, the initial abstraction depth was manually adjusted between 1.25 and 2.5 mm at each sub catchment until reaching the best fit for the observed data. Further details about the input data required for model simulation are described in the following sections.

Horton's method was used to calculate the infiltration in the catchment area at the model; Horton's equation is presented as follows (Rossman 2010):

$$f(t) = f_c + (f_0 - f_c)e^{-kt}, \tag{1}$$

where f is the infiltration capacity (in in/h), f_0 is the initial infiltration capacity, f_c is the final infiltration capacity, k is the decay constant, and t is the drying time.

The values of Horton's equation parameters were identified from SWMM user's manual (Rossman 2010) (Table 1).

Elevations and land use

The elevation values play an important role in the simulation of the drainage system, especially for the streams and channels. The elevation data were extracted from the topographical map (scale 1:25,000) provided by the Royal Jordanian Geographic Center (RJGC). Global Mapper was used to generate the sub-catchment and wadis to extract the

Table 1 Values of input parameters used for Horton's method

Sub-catchment	Maximum infiltration rate (mm/h)	Minimum infiltration rate (mm/h)	Infiltration rate decay (1/h)	Drying time (day)
AL-Qunyyah	76	1.16	2	10
Amman1	76	1.16	2	14
Amman2	80	1.16	2	14
Baalama	80	10.92	2	14
Beren	76	10.16	2	10
DerElkhf	80	10.92	2	14
Rmemen	76	1.16	2	10
Sabha	80	10.92	2	10
UmEljmal	80	10.92	2	14
Zarqa1	80	10.92	2	10
Zarqa2	80	10.92	2	14
Zarqa3	80	10.92	2	14

elevations and slope index within the basin. Figure 2 shows that the elevations of the basin ranged from 1570 m above the sea level at Jabal Al Arab (located at the north/east of the basin) to 120 m at KTD (located at the west of the basin). Therefore, all sub-catchment areas are naturally draining toward the KTD at the west.

The AZB area was divided into 12 sub-catchments according to main stream lines (Fig. 3). The hydrological

characteristics and percent land use of each sub-catchment are shown in Table 2.

It is well known that storm water quantity and quality are very sensitive to the type of land use at the catchment. Therefore, each sub-catchment area was divided into five main land-use categories: residential, commercial, industrial, farm, and natural lands. Google Earth images were manually processed to delineate land-use types at

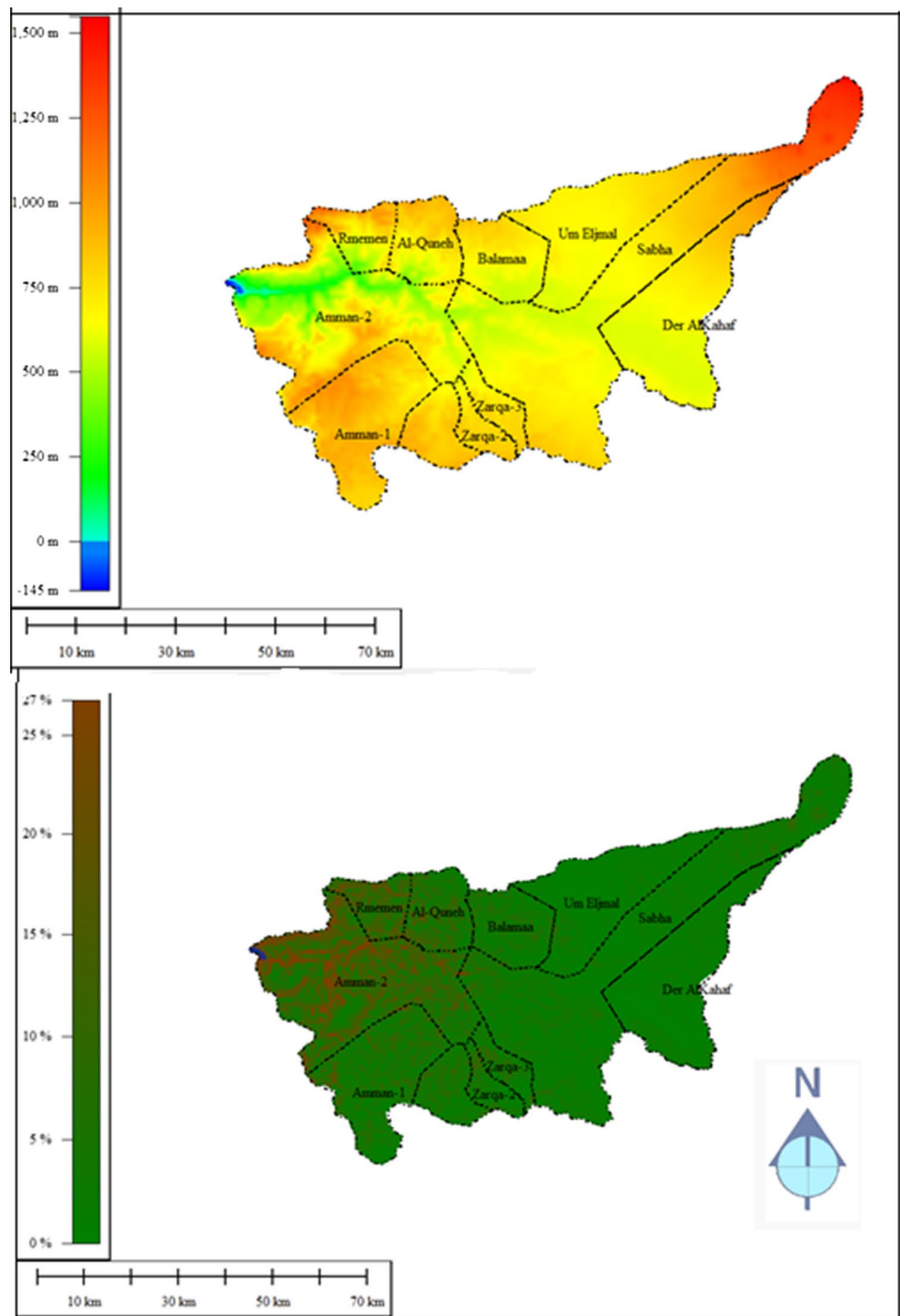**Fig. 2** Elevation and slope index for sub-catchment at Amman Zarqa basin

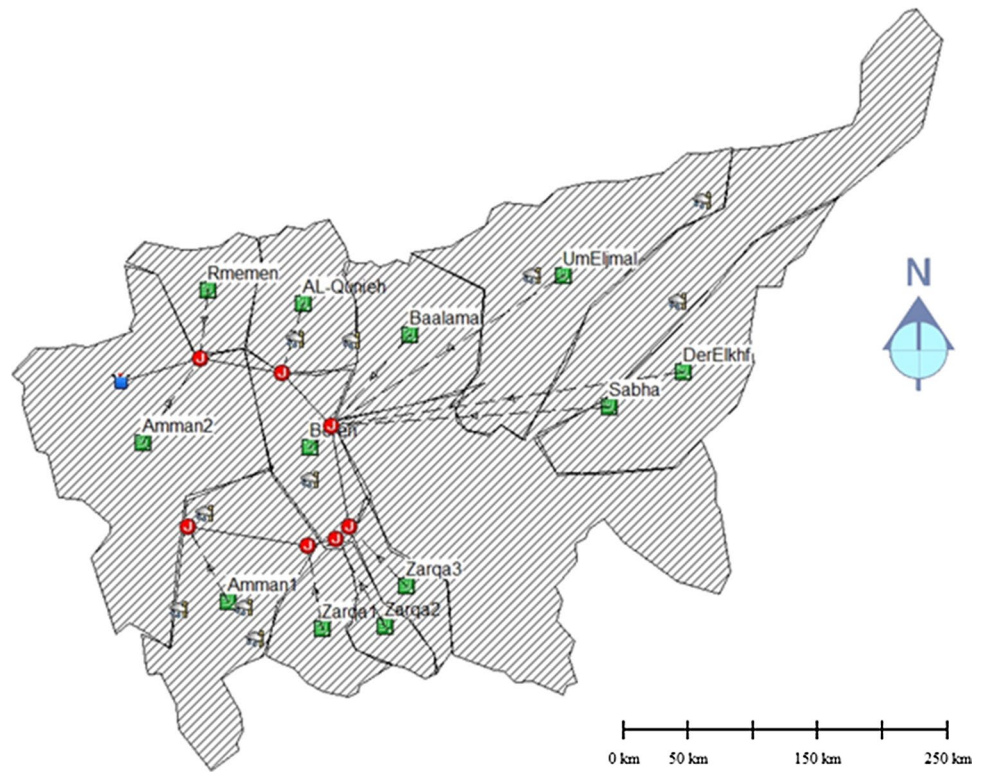**Fig. 3** Proposed sub-catchment areas and the location of rain gauges

Table 2 Hydrological characteristics and categories of land use of proposed sub-catchment areas

	Area (km^2)	Natural land (%)	Farm (%)	Residential (%)	Commercial (%)	Industrial (%)	Average slope	[a]Impervious (%)
AL-Qunieh	181.3	85.0	10.0	5.0	0.0	0.0	1.96	14
Amman1	529.8	31.1	0.4	66.8	0.1	1.7	1.16	30
Amman2	264.9	91.1	4.4	4.4	0.1	0.0	1.161	30
Baalama	272.4	83.0	10.9	5.2	0.2	0.7	1.47	16
Beren	190.2	74.7	6.3	18.4	0.2	0.2	2.4	30
DerElkhf	341.9	85.4	12.7	1.8	0.1	0.0	2.2	16
Rmemen	130.9	56.5	34.1	9.1	0.4	0.0	4.23	19
Sabha	1263.1	88.8	6.2	4.4	0.3	0.3	1.21	16
UmEljmal	390.7	78.4	13.6	7.5	0.5	0.1	0.517	16
Zarqa1	136.3	97.5	0.0	2.2	0.4	0.0	1.14	18
Zarqa2	74.7	97.0	0.0	2.7	0.3	0.0	1.01	16
Zarqa3	83.9	95.3	0.0	4.8	0.0	0.0	1.087	16
Total	3860	77.9	7.6	13.9	0.2	0.4		20

[a]Cawley and Cunnane (2003)

the AZB. Table 2 shows the percentage of different land uses at the studied sub-catchments. The analysis of land-use data revealed that the catchment area is covered with 11.56% residential, 0.24% commercial, 0.32% industrial, 8.33% farm, and natural lands 79.45%. In addition, 20% of AZB area is covered by impervious surfaces.

Rainfall data

Daily rainfall data were collected using 12 gauge stations distributed in the sub-catchments, as shown in Fig. 3. These data were used for the calibration and validation of SWMM simulation for AZB through the study period. Unavailable

rainfall data at each gauge station were supplied with readings from the nearest station at the basin. The location of rain gauges (GPS latitude/longitude coordinates values) and the cumulative rainfall measured at each gauge station for two winter seasons are shown in Table 3.

Evaporation data

The average monthly evaporation rates were obtained from Water Authority Jordan (WAJ) for the study area (Table 4). These values ranged from 2.64 mm/day in January to 11.49 mm/day in July (WAJ 2002).

Surface flow data

The total surface flow generated from AZB is monitored at streamflow station located at the upper inlet part of KTD. Surface flow daily data were obtained from Dams Directorate/Jordan Valley Authority for the study period (JVA 2014). The data of the first period (October 2012–May 2013) were used for model calibration, while the data of the second period (June 2013–May 2014) were used for model validation.

Water quality data

King Talal Dam is currently receiving surface flow including stormwater runoff from AZB and TWW discharged by the

four wastewater treatment plants (As Samra, Al-Baqa, Abu Nusair, and Jarash) (Fig. 4). Therefore, the quality of stormwater runoff and TWW in the AZB are needed to assess the water pollution in the KTD. The quality of runoff data were obtained from a recent study that has reported the runoff quality at seven sites at AZB during the winter season 2012/2013 (Al-Mashaqbeh et al. 2014, 2015). These sites represent different land uses such as residential, commercial, industrial, and agricultural areas (Fig. 4). The averages of the concentration of BOD5, COD, and TSS of these sites were used to estimate the pollution loads carried by stormwater runoff in the basin and entering the KTD (Table 5). In addition, the quality of TWW data were obtained from the Water Authority of Jordan. The average concentration of BOD5, COD, and TSS of As-Samra TWW was used to estimate the pollution loads carried by TWW in the basin (WAJ 2012).

Model performance evaluation

The SWMM model performance was evaluated through graphical comparison and the Nash–Sutcliffe efficiency (NSE) as a statistical criteria for goodness-of-fit (Nash and Sutcliffe 1970). The NSE coefficient is commonly used to evaluate the accuracy of hydrological discharge models. It is defined as follows:

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{n}(X_{\text{obs},i} - X_{\text{model}})^2}{\sum_{i=1}^{n}(X_{\text{obs},i} - \overline{X_{\text{obs}}})^2}, \tag{2}$$

where X_{obs} is observed values and X_{model} is modeled values at time/place i.

Nash–Sutcliffe efficiencies can range from $-\infty$ to 1. An NES value of 1 corresponds to a perfect match between model and observations. An NES value of 0 indicates that the model predictions are as accurate as the mean of the observed data. NSE value between 0 and 1 is considered acceptable.

Results and discussion

Calibration results

The calibration process of the rainfall-runoff model was started using initial values of the initial abstraction between 1.25 and 2.5 mm as recommended by ASCE, 1992 in the SWMM manual. The modeled runoff data from each rain event were compared with the measured data at the inlet of KTD during the

Table 3 GPS latitude/longitude coordinate values of rain gauge locations and the total measured rainfall during two winter seasons

Rain gauge name	E	N	Total rainfall (mm) 2012/2013	Total rainfall (mm) 2013/2014
Abu-Nusair	35°53.101	32°03.799	351.8	278.6
Um-Alsumaq	35°50.576	31°58.133	506.9	372.2
Al-Abdali	35°55.797	31°57.454	393.1	276.1
Downtown	35°56.298	31°57.097	273.2	192.5
Al-Qunyyah	35°59.816	32°14.357	289	169.4
Beren	32°3′23.58	36°0′42.50	288	72
Baalama	32°14′11.54	36°5′2.87	148.9	98.8
Um Eljmal	32°16′25.17	36°18′54.69	96.8	82
Der ELkahf	32°14′59.58	36°26′22.70	113.7	64.5
Sabha	32°21′29.69	36°27′58.20	181.8	75
Dhuleil	32°07′53.36	36°16′19.37	137.3	104.6
Zarqa	32°04′51.49	36°06′21.07	149.1	103

Table 4 Average monthly evaporation data of the study area

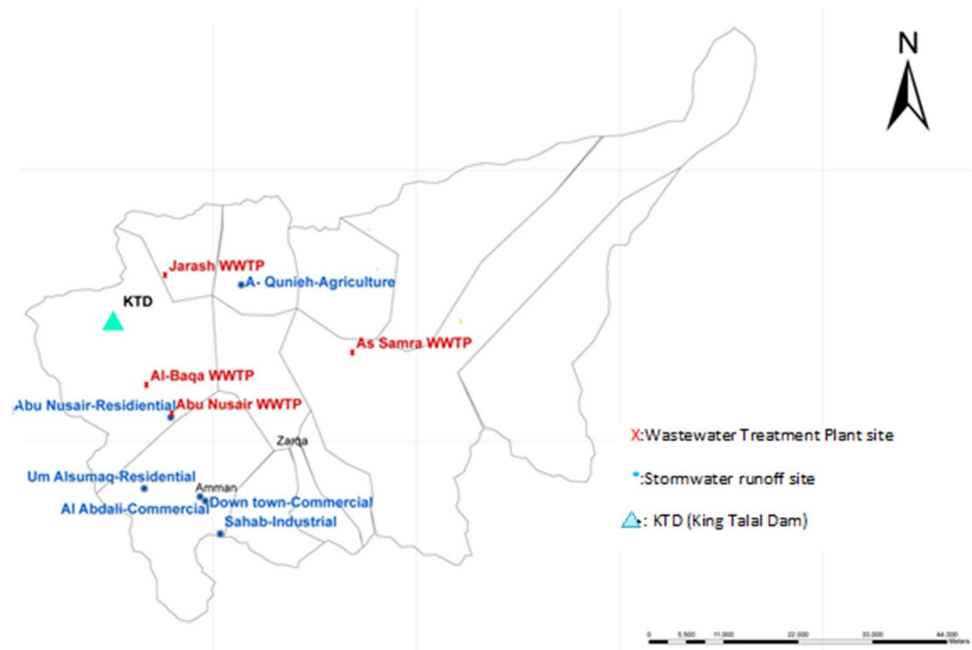| Month	January	February	March	April	May	June	July	August	September	October	November	December
Evaporation rate (mm/day)	2.64	3.33	4.38	7.29	9.58	10.69	11.49	10.13	8.5	6.66	4.67	3.11

Table 5 Average concentrations BOD5, COD, and TSS of stormwater runoff and treated wastewater in the AZB

Typical parameters	Stormwater runoff	TWW of As-Samra
COD (mg/l)	1114	61.5
BOD (mg/l)	318	3.6
TSS (mg/l)	2624	10.3

first winter season (October 25, 2012 to May 31, 2013). The values of initial abstraction of each sub-catchment are manually adjusted in the model until to reach the best fit between observed and modeled daily streamflow runoff data (Fig. 5).

For calibration process, the best fit was obtained at an initial abstraction of 1 mm for impervious areas and 4 mm for pervious areas. These values for the initial abstraction were later used for model validation. Figure 5 shows a graphical comparison between observed and simulated flow data at the Inlet of KTD. Figure 5 also shows that there is a slight difference in the timing and magnitude of peak flows and the shape of recession curves. Moreover, the results show that there is a good agreement between the simulated and observed stormwater runoff flow at the inlet of KTD against most of the rain events except for small events at the beginning, which were not predicted by the model. It is well known that calibration of big rain events produces better results than small events. Moreover, the poor performance for modeling for the first event might be due to the difference in dynamics of a small rain event compared to big events. This phenomenon is consistent with those reported in the literature that it is generally more difficult to calibrate small

Fig. 5 Calibrated results for measured and simulated daily surface flow at the inlet of King Talal Dam (KTD) from October 25, 2012 to May 31, 2013
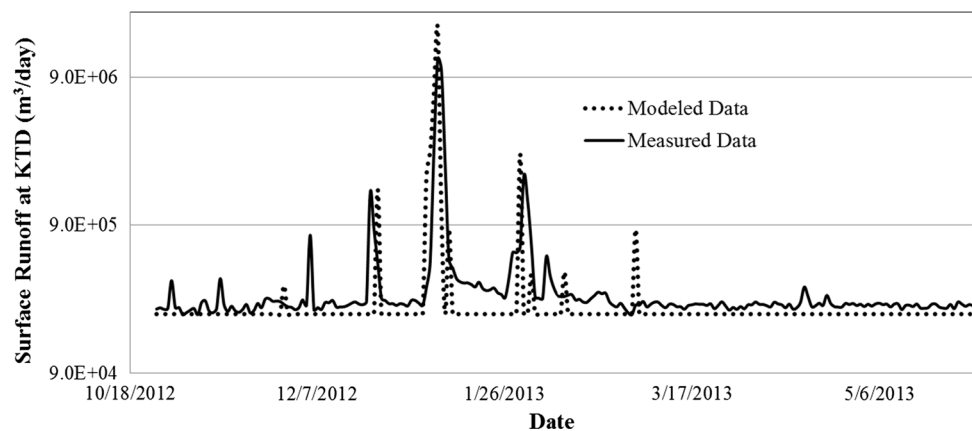
events (Krebs et al. 2014; Warwick and Tadepalli 1991). In addition to the graphical comparison, NSE was used to measure the efficiency of SWMM for calibration runoff results at the inlet of KTD. The NSE was calculated about 0.513 for the calibration of first winter season. This value is between 0 and 1 and slightly higher than 0.50, which is considered acceptable based on some studies reported in the literature (Moriasi et al. 2007).

Hydraulic loading rates

After satisfactory calibration results, the estimated parameters were transferred to validation simulation in the basin. The quantity of storm water runoff generated from AZB was successfully simulated using SWMM model (Table 6 and Fig. 6). Table 6 shows the total precipitation, modeled losses, and runoff for each sub-catchment in AZB. The results showed that the maximum peak flow occurred in Amman1 catchment (203.6 m^3/s). This is mainly due to the high rainfall and high percentage of impervious area in Amman catchment (about 30% is impervious area). Also, the minimum peak flow occurred in the eastern sub-catchments (Sabha and Zarqa2). This is mainly due to the low rainfall and low percentage of impervious area (high infiltration capacity).

Figure 6 shows precipitation data and simulated results of runoff and losses that occurred at all sub-catchments in AZB. Figure 6 also shows that the peak of rainfall occurred in January 2013 (snowfall event). Moreover, the results show that the first rainfall event occurred in October 2012 while the first runoff occurred in November of 2012.

Figure 6 also shows that the runoff has started in the basin after a period of time from occurring of some rainfall events. For example, in the first winter season, the runoff started on January 5 (snowfall event). This might be due to the high

losses (high infiltration and evaporation) that occurred at the beginning of the winter season. The losses are mainly due to infiltration. It is well known that the soil will be very dry at the beginning of the winter season. Therefore, many rainfall events are required to reach the soil saturation point in order to start runoff. Also, Fig. 6 shows that the runoff did not occur at the last rainfall event. This is mainly due to the long dry period (53 days) that occurred between the last two storm events during the winter season. These simulation outcomes suggest that the SWMM model responds very well in the simulation of hydrological processes in AZB using meteorological observation data. However, the NSE coefficient resulting from the validation of the second winter season was − 0.0498. This value is significantly lower than 0.50, and is therefore unacceptable. These findings are consistent with some modeling studies that reported negative NSE using SWMM. For example, Tan et al. (2008) found that calibrating SWMM for event-based and continuous stormflow periods has produced reliable hydrographs and direct runoff volumes. However, prediction of runoff for low-flow events had negative NSE coefficients. It is important to note that the average annual rainfall at the AZB for the calibration period (winter season 2012/2013), 183.6 mm, is higher than for the validation period (winter season 2013/2014), which is 102.8 mm.

In general, the low performance of the model for certain rainfall events of validation could be related to the poor quality of collected rainfall data in some areas at the basin. For example, 5% of AZB is located in Syria and the rainfall data are not available for this region. Moreover, the limited number of distributed rain gauges (12 gauges) in the basin are not adequate to cover the AZB, which has high variability of precipitation patterns across the basin. Evidence of high variability of precipitation patterns for our case study is clearly seen in Table 3, which shows that the

Table 6 Model output data of storm water runoff quantity for two winter seasons (October 25, 2012 to May 31, 2014)

Catchment area	Area (10^3 m^2)	Total precipitation (mm)	Total losses (mm)	Total runoff (mm)	Peak runoff (m^3/s)	Time of concentration (days:hh:mm:ss)
AL-Qunieh	181,340	428.18	408.1	20.1	19.6	5 01:53:52
Amman1	529,820	495.27	422.8	72.5	203.6	7 15:47:03
Amman2	264,910	585.03	496.7	88.4	83.1	4 10:08:08
Baalama	272,400	222.50	220.5	2.0	4.5	7 14:22:24
Beren	190,150	222.50	216.8	5.6	7.2	5 16:19:32
DerElkhf	341,900	167.50	163.2	4.3	13.3	9 22:57:39
Rmemen	130,942	428.18	393.4	34.6	26.7	3 17:34:46
Sabha	1,263,145	223.50	223.4	0.1	4.7	26 07:35:18
UmEljmal	390,680	160.10	158.7	0.7	5.1	7 02:02:39
Zarqa1	136,298	167.50	163.5	4.0	6.7	21 01:07:16
Zarqa2	74,653	167.50	162.8	4.7	4.1	15 05:00:37
Zarqa3	83,924	167.50	162.2	5.3	5.0	10 22:04:11

Fig. 6 Precipitation and simulated data of runoff and losses in AZB during two winter seasons (October 25, 2012 to May 31, 2014)
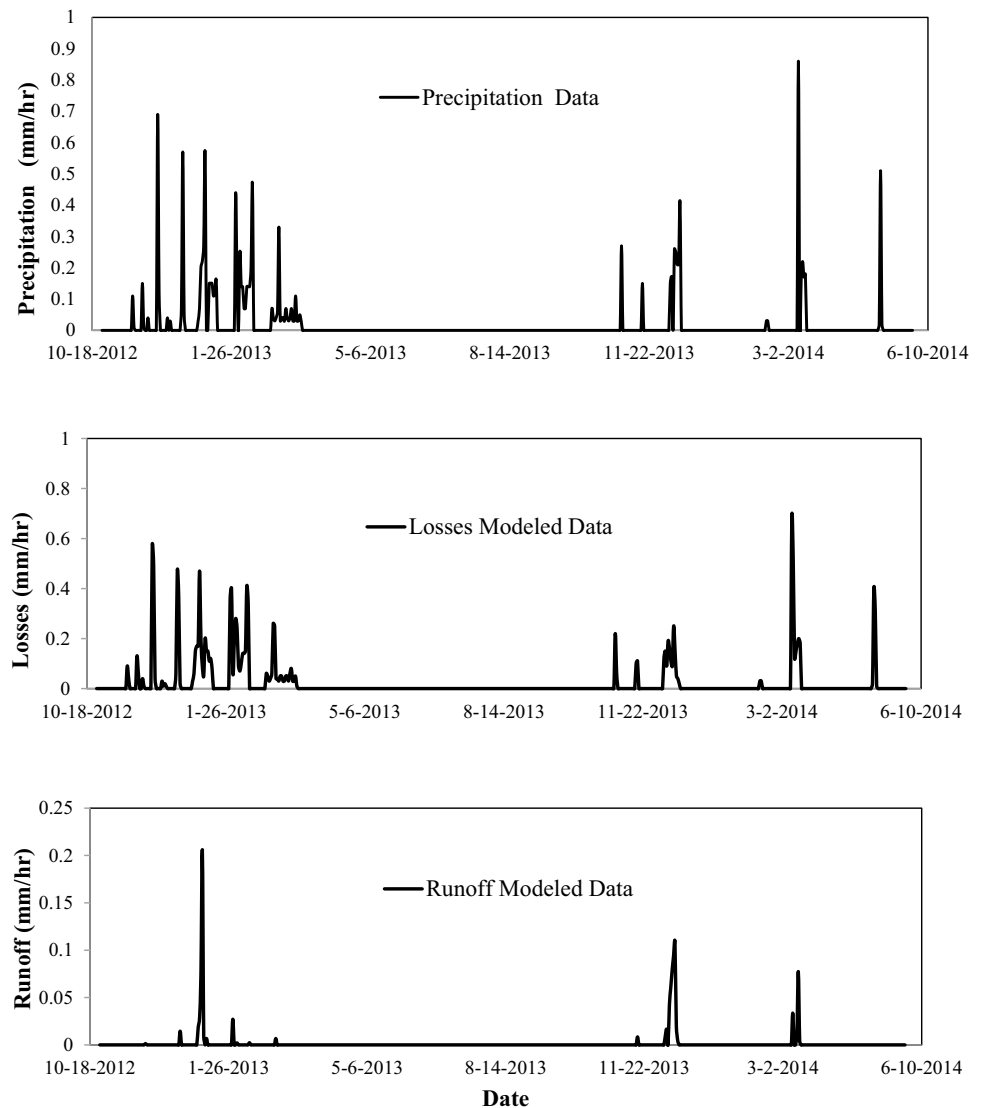

total measured rainfall during two winter seasons at western stations (such as Um-Alsumaq station) is very high compared to the eastern stations (such as Um Eljmal station). KTD is one of the biggest dams in Jordan and is considered the main water source for irrigation in the Jordan Valley (Hadadin 2015). It drained and stored most of the surface flow including stormwater runoff and TWW generated in Amman Zarqa watershed (Salamah 1980). Figure 7 shows a comparison between measured and modeled data of total surface flow entering KTD from AZB during two winter seasons from October 2012 to May 2014 (584 days). This predicted amount of surface flow includes the stormwater runoff and TWW generated from AZB. The results clearly show that the model can fit the measured data well over the study period. The total surface flow entering KTD was estimated by model to be about 207 MCM, while the measured value was 213 MCM. It is very clear that the calibration and validation results represent a good fit between the observed

and simulated daily surface flow discharged to KTD with about 2.3% difference. Generally, the SWMM simulated values reflect the actual changes in the surface runoff at the KTD. Therefore, it is expected that the SWMM can be used for the subsequent scenario analysis.

In general, stormwater runoff and rainfall losses are produced after a certain interaction for rainfall with the land. The runoff is usually collected in waterways and water bodies while rainfall losses are disappeared through different process such as evaporation from surfaces or the atmosphere, evapotranspiration by plants, and infiltration into the soil or groundwater. Table 7 shows the components of the water balance; total rainfall, runoff, and losses generated at AZB according to SWMM model during two winter seasons (October 2012–May 2014).

The average annual rainfall at the AZB was estimated by SWMM about 183.6 mm and 102.8 mm for the two winter seasons 2012/2013 and 2013/2014, respectively. The

Fig. 7 Comparison between measured and modeled data of total surface flow at the inlet of KTD from October 25, 2012 to May 31, 2014
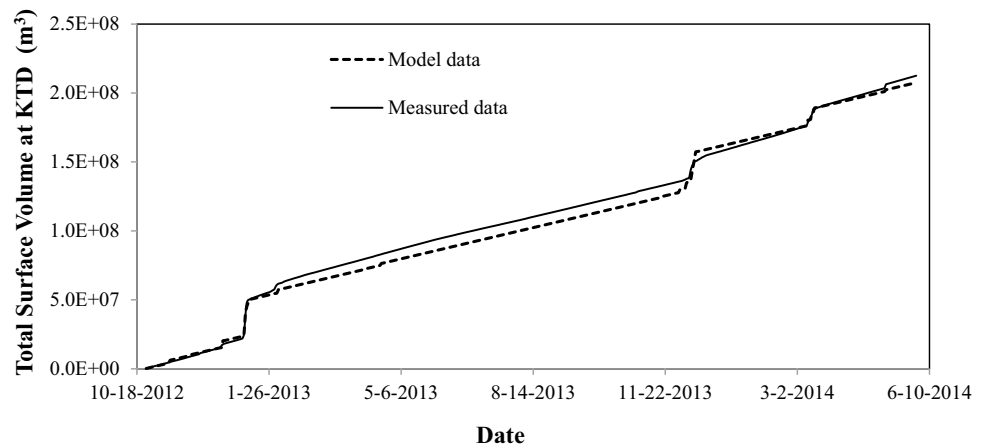
average annual rainfall for the two winter seasons was about 143.2 mm, which is slightly lower than the long-term average rainfall of 156.7 mm from 1967 to 2002 reported in the literature for the basin (Hammouri and El-Naqa 2007). The total volume of precipitation falling over the entire watershed is estimated by the model to be about 1106 MCM. The majority of rainfall leaves by evaporation and infiltration in the AZB, which accounts for about 1031 MCM (93.2%). The total volume of stormwater runoff estimated by the model was around 75 MCM during two winter seasons (2012–2013 and 2013–2014). The average value of stormwater runoff per winter season will be 35 MCM. This value is higher than the long-term average of annual flood flow (26.6 MCM) during the period 1970–2002 (Al Mahamid 2005). This increase in runoff is mainly due to the high expansion of urban activities that occurred at AZB during the last two decades. It is well known that urbanization activities generated high amounts of stormwater runoff and increased pollutant loading within catchment area (Arnold and Gibbons 1996). The percentage of runoff is 6.8%, which is slightly higher than those reported in similar studies conducted in semiarid regions. For example, the average runoff coefficient was found to be 3–5% for analyzed rainfall-runoff events in AZB in the period from 1950 to 2008 (Al Mahamid 2005). As mentioned above, KTD is receiving surface flow via Zarqa River, which is mainly stormwater runoff from AZB and TWW discharged

by the four wastewater treatment plants (As Samra, Al-Baqa, Abu Nusair, and Jarash). The total surface flow and stormwater runoff were estimated by modeling to be about 207 and 75 MCM, respectively. The difference between these values (132 MCM) represents the total TWW discharged by the four WWTPs and entering the KTD during the study period (584 days). This suggests that the storage water of KTD consisted of 36% stormwater runoff and 64% TWW during the study period (October 25, 2012 to May 31, 2014).

Pollutant loading rates

SWMM has the ability to analyze the buildup, wash off, transport, and treatment of any number of water-quality constituents. The most common method for estimating non-point pollutant loads is using constant EMC for pollutants, EMCs for pollutants are typically determined based on flow-weighted water-quality sampling and laboratory analysis. Two sources of pollutant within the catchment area, first source is surface runoff and second source is WWTP's. The pollutant load from surface water was simulated by SWMM by using the EMC method while those for TWW were calculated by multiplying the average daily flow of TWW discharged by WWTPs.

The SWMM model was calibrated and validated using the hydraulic data for the study period (October 25, 2012 to May 31, 2014). After that, the quality runoff simulation was performed to estimate the pollutant loads of BOD5, COD, and TSS (kg) generated from AZB over the study period (584 days). The water quality of the KTD is directly linked to the quality of two types of surface water; storm water runoff generated from AZB and TWW. In order to understand the level of pollution loads generated by runoff (non-point sources pollution) at the basin and entering the KTD, a comparison was made between runoff pollution loads with the pollution loads of TWW (point source pollution) discharged by the four plants during the study period. The pollution

Table 7 Components of the water balance predicted by SWMM for AZB during two winter seasons (October 25, 2012 to May 31, 2014)

Parameters	Total volume for two winter seasons		%
	(MCM)	(mm)	
Total rainfall	1106	286.3	100
Total runoff	75	19.4	6.8
Total losses[a]	1031	266.9	93.2

[a]Losses is the summation of infiltration and evaporation

Table 8 Hydraulic and pollutant loads for stormwater runoff and TWW generated from Amman-Zarqa basin from October 25, 2012 to May 31, 2014

	Hydraulic load	BOD5		COD		TSS	
	(MCM)	(mg/l)	(kg/year)	(mg/l)	(kg/year)	(mg/l)	(kg/year)
Runoff	75	318	1.14E+07	1114	4.00E+07	2624	9.42E+07
TWW[a]	157.4	3.6	5.67E+05	61.5	9.65E+06	10.3	1.62E+06

[a]The measured volume of treated wastewater (269,603 m^3/day ~ 157.4) discharged by four wastewater treatment plants (As Samra, Al-Baqa, Abu Nusair, and Jarash) according to WAJ reports 2013

loads of stormwater runoff were estimated by SWMM while those for TWW were calculated by multiplying the average daily flow of TWW discharged by As Samra, Al-Baqa, Abu Nusair, and Jarash WWTPs (269,603 m^3/day ~ 157.4 MCM) by the average of concentration of BOD5, COD, and TSS of TWW discharged by As-Samra wastewater treatment plant (WAJ 2012) (Table 8).

Table 8 shows a comparison between the estimated BOD5, COD, and TSS loads of stormwater runoff and TWW generated from AZB. SWMM simulation results showed that the estimated BOD5, COD, and TSS loads were much higher than those calculated for TWW. The results showed that the pollutant loads generated by runoff were much higher than those discharged from Asmara WWTP by 20 times for BOD5, four times for COD, and 58 times for TSS. These findings suggest that the level of runoff pollution is a major source of water pollution in AZB. Therefore, land-use management must be considered in AZB to reduce high vulnerability of fresh water resources in the basin due to different human activities.

Conclusions

In this study, the SWMM was used to evaluate the levels of quantity and quality of stormwater runoff generated from AZB and stored at KTD during two winter seasons (October 25, 2012 to May 31, 2014). The results clearly show that the SWMM has successfully modeled the real data for runoff entering the KTD. The modeling results show that about 93.2% of precipitation is lost by infiltration and evaporation and 6.8% is generated as runoff in AZB. The total surface flow entering KTD was estimated by modeling about 207 MCM during the study period (584 days). This estimated value consisted of 75 MCM stormwater runoff and 132 MCM of TWW as base flow. It is concluded that the stormwater runoff flow contributed about 36% to the total capacity of KTD during the study period. Based on the results of this preliminary modeling work, pollutant loads carried by non-point pollution sources (storm water runoff) are much higher than the current point-source pollution (As-Samra WWTP) in AZB. Therefore, the proper management of land use must be considered to protect and sustain the fresh water resources at the basin.

Compliance with ethical standards

References

Abu Hilal AH, Abu Alhaija MM (2010) Nutrients in water and sediments of King Talal Dam-Jordan. Jordan J Biol Sci 3(3):87–100

Al Kuisi M, Al-Qinna M, Margane A, Aljazzar T (2012) Spatial assessment of salinity and nitrate pollution in Amman-Zarqa Basin: a case study. Environ Earth Sci 59(1):117–129. https://doi.org/10.1007/s12665-009-0010-z

Al Mahamid J (2005) Integration of water resources of the upper aquifer in Amman-Zarqa basin based on mathematical modeling and GIS, Jordan. Freib Online Geol 12:223

Al-Afayfeh N, Al-bakri J, Naber S, Shammout M, Shatanawi M (2006) Optimization for sustainable water resource management. Environmental Software and Services GMBH Austria

Alawi A, Haddadin M (2004) Dead populations of fish in the rivers Jordan and Zarqa. Biol Conserv 6(3):215–216

Al-Jassabi S, Khalil AM (2006) Initial report on identification and toxicity of microcystis in King Talal Reservoir, Jordan. Lakes Reserv Res Manag 11(2):125–129

Al-Kharabsheh A (1999) Ground-water quality deterioration in arid areas: a case study of the Zerqa River basin as influenced by Khirbet Es-Samra wastewater (Jordan). J Arid Environ 34:227–239

Al-Mashaqbeh O, Jiries A, El-HajAli Z (2014) Stormwater runoff quality generated from an urban and a rural area in Amman-Zarqa basin. Published in water pollution XII. ISSN 1743-3541, Print ISBN 978-1-84564-776-6

Al-Mashaqbeh O, Jiries A, El-HajAli Z (2015) Characterization of stormwater runoff generated from urban areas in Amman City/Jordan. In: Proceeding of 7th conference on scientific research in Jordan, Amman 14th November 2015

Alqadi K, Kumar L (2011) Water issues in the Kingdom of Jordan. A brief review with reasons of declining quality. J Food Agric Environ 9(3–4):1019–1023

Al-Rawabdeh A, Al-Ansari N, Al-Taani A, Al-Khateeb F, Knutsson S (2014) Modeling the risk of groundwater contamination using modified DRASTIC and GIS in Amman-Zerqa Basin. Cent Eur J Eng 4(3):264–280

Anderson NJ (1997) Modelling the sustainable yield of groundwater resource in riverbed aquifers in arid and semi-arid areas. MPhil to PhD Transfer Report. Department of Civil Engineering, University of London. London, England

Arnold C, Gibbons J (1996) Impervious surface coverage: the emergence of a key environmental indicator. J Am Plan Assoc 62(2):243–258

Cawley AM, Cunnane C (2003) Comment on estimation of greenfield runoff rate. In: Proceedings of the Irish National Hydrology Seminar, Tullamore, Ireland, November, 29–43

Department of Statistics (DOS) (2013) Jordan statistical yearbook. Department of Statistics, Amman, Jordan

Fandi K, Qudsieh I, Mubibi S, Massadeh M (2009) Water pollution assessment of King Talal Dam. Adv Environ Biol 3(1):92–100

FAO (1991) Water harvesting: a manual for the design and construction of water harvesting schemes for plant production. AGL/MISC/17/91. FAO. Rome, Italy

Haan CT, Barfield BJ, Hayes JC (1994) Design hydrology and sedimentology for small catchments. Academic Press, San Diego

Hadadin NA (2015) Dams in Jordan current and future perspective. Can J Pure Appl Sci 9(1):3279–3290 **(ISSN: 1920-3853; Print ISSN: 1715-9997)**

Hadadin NA, Tarawneh ZS (2007) Environmental issues in Jordan, solutions and recommendations. Am J Environ Sci 3(1):30–36

Hammouri N, El-Naqa A (2007) Drought assessment using GIS and remote sensing in Amman-Zarqa Basin, Jordan. Jordan J Civ Eng 1(2):142–152

JVA, Jordan Valley Authority (2014) Annual reports, Dams Directorate

Krebs G, Kokkonen T, Valtanen M, Setälä H, Koivusalo H (2014) Spatial resolution considerations for urban hydrological modelling. J Hydrol 512:482–497

Moriasi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, Veith TL (2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans ASABE 50(3):885–900

Nash JE, Sutcliffe JV (1970) River flow forecasting through conceptual models part I—a discussion of principles. J Hydrol 10:282–290

Rossman LA (2010) Storm water management model user's manual. U.S. Environmental Protection Agency, Cincinnati

Salamah E (1980) Hydrogeology and hydrochemistry in catchments area of King Talal Reservoir (Jordan). Z dt Geol Ges Hann 131:319–338

Shatanawi M, Fayyad M (1996) Effect of Khirbet As-Samra treated effluent on the quality of irrigation water in the Central Jordan Valley. Water Res 30:2915–2920

Tan SBK, Chua LHC, Shuy EB, Lo EY, Lim LW (2008) Performances of rainfall-runoff models calibrated over single and continuous storm flow events. J Hydrol Eng 13(7):597–607. https://doi.org/10.1061/(ASCE)1084-0699(2008)13:7(597))

US Environmental Protection Agency (USEPA) (2007) Stormwater management model user's manual. Version 5.0

US EPA (2015) Stormwater homepage. http://www.epa.gov/npdes/npdes-stormwater-program. Accessed 26 Jan 2016

Warwick JJ, Tadepalli P (1991) Efficacy of SWMM application. J Water Resour Plan Manag ASCE 117(3):352–366

Water Authority Jordan, WAJ (2002) Jordan climatological handbook. Annual reports, Water Authority Jordan

Water Authority Jordan, WAJ (2012) Wastewater sector annual report for the year 2011—Department of Wastewater Systems and Water Reuse and Environment Unit. Water Authority Jordan

Yahya T, Zaatera M, Khatera D (2017) Semi-volatile organic pollutants in Jordanian surface water. Arab J Chem 10:3318–3323