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Research Article

Groundwater Artificial Recharge Potentiality in Al-Qilt Catchment Jericho – West Bank – Palestine

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Abstract

The main research objective is to highlight the potentiality of artificial groundwater recharge in Al-Qilt catchment- Jericho – Palestine regarding the water shortage in the groundwater-supplied areas. Artificial recharge can be a possible option in increasing the storability of the underground aquifer, which will add values to the Palestinian strategy to optimize the total accessibility of groundwater resources. The increase of water demands and the scarcity of water resources in the Jordan Rift areas are putting challenges for the water managers and planners to improve the water supplies in order to reach the best ways for the integrated water resources management. In Al-Qilt catchment, the surface water discharge flowing into the wadies in huge amounts had no noticeable significant benefits. A hydrological model was built for the Qilt basin using HEC-HMS software system and it was considered as an essential tool for better understanding of the basin hydrological situation and its hydrogeological characteristics. The surface runoff water speed was measured to be 3.2 m/s (27th of February, 2019) with a cross section width of 9.2 m and 0.75 m hight with water leading to a flow of 18.77 m^3/s and the total flow of approximately 67565 m^3/hr. The estimated model simulations reavealed of 18.5 m^3/s and 66600 m^3/hr for the speed flow and the total flow respectively and matched with the measured ones. The results were used for improving the aquifer-integrated management in Al-Qilt area and determining of the aquifer potentiality for artificial recharge. The built model results gave guiding to the hydrologists and the decision makers for selecting the appropriate techniques and sites for artificial recharge. The model indicated of good simulation tools to be used for other West Bank catchments.

Keywords

Artificial recharge; Al-Qilt catchment; IWRM; groundwater; HEC-HMS

1. Introduction

Water is playing a major role in the evolution of social, agricultural, and manufacturing process for the Palestinian communities. Palestine like many other areas of the Mediterranean regions is facing a raise in the urban works, and suffers from water dropping in the physical hydro ecosystems. It has a minimal evolution of the accessibility of its water resources. Many difficulties in the approval for new water projects result from political views and technical problems, which are due to the absence of appropriate artificial groundwater recharge techniques or earth dams. Recently, the technical obstacles have been minimized by the use of modern methods for rainwater harvesting techniques. These methods are using Geographical Information System (GIS) to make it feasible and easier for the decision makers to choose the best rainwater harvesting artificial recharge method. In Al-Qilt catchment, there were few studies dealing with artificial recharge. The groundwater artificial recharge is a process by which excess water is purposely directed into the ground to rebuild or augment groundwater supplies [1]. It is accomplished by one of three methods: spreading on the surface, injecting water through recharge wells, and by altering natural conditions to increase infiltration [2]. Artificial groundwater recharge systems are engineered systems where surface water is put on or in the ground for infiltration and subsequent movement to aquifers for groundwater resources augment. The weighted overlay method to determine the best locations for artificial recharge in Al-Qilt catchment using parameters of the slope, runoff, infiltration capacity, land use, density of wells and the depth of the ground water table was studied by Thaher [3]. Results showed that 91% of the total area was moderately suitable for artificial groundwater recharge by floodwater with a total area of 159 km^2. If treated wastewater was used as a source for artificial recharge, 66% of the total area was moderately suitable for artificial recharge with a total area of 115 km^2. The yearly average recharge amounts were calculated to be 100 mm/year in the upper part of the catchment and dropped to about 10 mm/year in its lower part. Based on recharge values and its good conditions, it was indicated that most of the actual flood runoff flowing to the Jordan valley can be artificially recharged within Al-Qilt catchment.

The availability of water in Jericho area has been described as an insufficient supply for future development, especially for municipal, agricultural and industrial use sectors. The main objective of the research study is to determine the performance of artificial groundwater recharge methods those were appropriate for Al-Qilt catchment. Their effectiveness criteria were studied depending on slope, land use, geology, runoff, distribution of wells, water quality, rainfall, evapotranspiration, groundwater levels and geomorphology. This will be used in determining the best practical methodology for artificial recharge management. The study is important to the Palestinian communities and the Water Authority (PWA) as a regulator for increasing the potentiality of water supply in Jericho area. The water quality of the Qilt springs studied by Samhan [4] reveled of good spring water quality. Weighted overlay qualitative approach was applied to evaluate the possibility of using groundwater for irrigation in Middle Euphrates region in Iraq. Classifying the groundwater via the weighted overlay approach produced four classes with low, moderate, high, and severe restrictions [5]. Flood is one of the most destructive natural hazards associated with substantial damage in various world regions. A study of Iran's Kalan basin based on the pictures of fuzzy-analytic hierarchy process and fuzzy-linear assignment model [6] indicated that prioritization and ranking of sub-watersheds from the perspective of flood susceptibility can be powerful tools in terms of flood prevention and mitigation.

Water balance was analysed to identify the quantities of water availability as to recharge the aquifer in Al-Qilt catchment. Groundwater and surface water quality were assessed via water samples from different locations and sources and were compared to water quality standards by the World Health Organization (WHO) [7]. Physical, hydrochemical, and biological spring water quality parameters were analyzed in the period between November 2004 and March 2007 in the drainage area of Wadi Al Qilt [8].

The Slugger-Dol model was used to find suitable sites for water reuse in the Jordan Valley, with eight parameters of GIS-prepared layers such as the geology, land use, slope, water quality, explosion, resource distribution, geomorphology and the summer water quality. All parameters are collected and compiled by using the GIS model builder [9]. The increased water demand, excessive exploitation of groundwater, climate change and water availability of certain areas have necessitated the aquifer recharging view as an effective solution for water conservation and recovery [10]. Groundwater recycling projects in Jordan, whether they were designed for re-charging or not, are ending up of being useful recycling by geologic, hydrologic, and hydrogeological methods [10]. An artificial recharge testing site in Jeftlik area of the Upper Jordan Rift Valley was selected. And the pool was in hyperbolic form of 500 cubic meters with input type dimensions of 26 m wide and 2.85 meters deep [11], which indicated of successful recharge results. Geophysical research and watershed hydrological delineation have been linked to the lower reaches of the Alasra dam site in the Norh Azraq area to investigate their groundwater potential for recycling. The total water area was found to be 195 square miles [12].

The runoff flooding that flows towards the Jordan valley can be artificially recharged within Al-Qilt catchment [13]. The artificial recharge amounts will make quantitative changes to the groundwater level system. The hydrological and hydro-geological properties of the studied area were identified for using artificial recharge methods [14]. Artificial recharge for small storage facilities is more recommended than those of the large scale, which is considered as one of the cheapest alternatives to water resources. The experience of vandalism and interlinks to the local community as well as improvements to dam construction are recommended [15]. The study was conducted in the winter of 2007-2008 in Ghor Feifa water flow in Jordan Valley weir for the recycled water to evaluate their quantity and quality. The results showed that there was a meaningful relationship between the quantity values of the diverted river and the quality of the available groundwater. Rated water levels of local aquifers were approximately 0.15 m^3/m/h and the recharge rate ranged from 0.05 to 0.21 m^3/m [16]. Static water level measurements of recorded monitoring wells downstream raised about 5 cm within three months in the locations closed to the diversion weir [17]. The hydrologic simulations using computer models have become important tools for understanding human impacts on river flow and designing environmentally sustainable water management systems [18]. Inductive methods of empirical field-measurements and observations were combined with deductive approaches of extrapolation for Wadi Natuf – Ramallah, which indicated an annual recharge estimation ranging from 235 to 274 mm (24 to 28 Mm^3) in Wadi Natuf Catchment (103 km^2). This was equivalent to recharge coefficients of 39-46% of average annual precipitation (7-year observation period) [19]. Artificial groundwater recharge was investigated in Mujib watershed in Jordan as one of the important options to face water scarcity and to improve groundwater storage in the aquifer using Modflow groundwater model [20]. The best scenario that provided a good recovery for the groundwater table was founded to be by reducing current abstraction rates of 20% and implementing the moderate artificial recharge rates of 26 million (M)m^3/year.

Groundwater is affected by many factors including climate change, industrial and urban activities. The impact of global warming and climate change in the future will affect the groundwater resources through increases in temperature and fluctuations in rainfall. Accordingly, water scarcity and the degradation of the quality of water across different water resources will be escalated. The impact of future global warming and climate change on groundwater natural recharge in an unconfined aquifer in Western Desert of Iraq, which was studied by Hassan et al. [21] who used the simulation tool of Wet-Spass. The calibrated future simulations scenarios projected that precipitation would decrease by 14.1% and the temperature would increase by 0.96°C [21]. However, annual groundwater recharge was predicted to decrease by 13.6% by the end of the present century. The effect of artificial recharge on the quantity of groundwater using reclaimed water was studied in the Dibdibba unconfined aquifer with groundwater modelling system (GMS) in Iraq [22]. The model results indicated that the injection of treated water through twenty wells raised the water table in more than 91 for 5000 m^3/day pumping rates.

1.1 Area of Study

Al-Qilt catchment is located in the eastern side of the West Bank and it has an estimated area of 174 Km^2 (Figure 1). It includes five main spring water resources systems, which are Ein Jumeiz, Ein Fara, Ein Al-Fawwar, Ras Al-Qilt, and Ein Al-Ru'yan. It is surrounding by the catchments of Nueima from the northern side, Soreq and Al Dilb from western side, Mukallak and Marar from the southern side. The Jordan River bounds the catchment from the east [8]. The Qilt drainage system is starting from Ramallah city (western) passing the central mountains of Jerusalem and drains towards to the Jordan River area and ending at the Dead Sea. The average flow in the range of 3.0 Mm^3/year depending on the annual rainfall, and the largest flood occurred in 1991/92 when water level recorded higher than adjacent land [23]. Al-Qilt area geomorphology consists of a cliff rising from about 900 m above sea level in the western part to 400 m below sea level in the eastern part [24]. Al-Qilt catchment contains two main tributaries: Sweanit and Fara. Wadi Sweanit originates from the eastern part of Al-Bireh city and it contains two water springs: Fawwar and Ras Al-Qilt. Wadi Fara contains three water springs: Ein-Jumeiz, Ein Fara and Ru'yan [23].

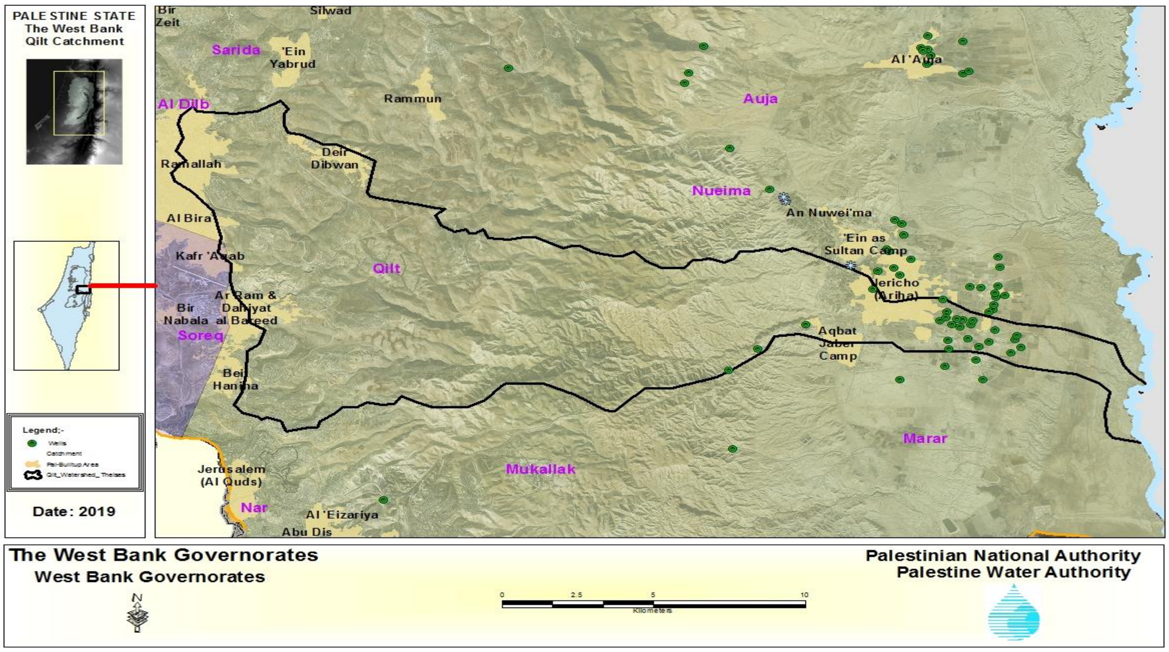

Figure 1 location map of Al – Qilt catchment study area.

The stratigraphic and structural features in Al-Qilt catchment is dominated by E-W striking faults, and a 9 km long normal major fault with throw of 80 m down to the southeast controls the discharge of the Al-Qilt springs. The main aquifer in Al-Qilt basin is the Shallow Turonian Aquifer that feeds the springs with flow quite velocities of average annual discharge of 9 Mcm^3/year (Fawwar, and Ras Al-Qilt springs). The Upper and Lower Cenomanian as well as the Lower Cenomanian-Albian aquifer feed more than 81 production wells of 4 Mcm^3/year pumping [23]. Groundwater depth in Al-Qilt catchment area varies from 10 to 70 m meters below ground surface. Most of the wells in Al-Qilt area have records for water levels. The Palestinian population in the catchment was estimated to be 168,795 inhabitants and 38,344 Isreali settlers living in six settlements [25].

2. Materials and Methodology

Hydrological Engineering Company (HEC) and Hydrological Modelling System (HEC-HMS) in addition to the Watershed Modelling System (WMS) were used to provide a suitable and good estimating for precipitation, runoff simulations and relations in Al-Qilt catchment basin. The design of the catchment hydrological behavior was set to be suitable and applicable for a wide range of geographical regions in order to provide solutions to the biggest possible range of water integrated resources problems. This contained large river basin water supply and flood hydrology, except for large urban - natural catchment runoff. The Hydrographs produced by the watershed modelling system software was used directly by relating the data with other software for appropriate water flow forecasting, urban drainage, water availability, flood damage reduction, future urbanization impact, reservoir spillway design, flood plain regulation, and systems operation. The components of the model were to simulate the hydrologic behaviour within the basin including basin models input data, and metrological models controls specification. The related data such as gridded data, paired data, time series data and the metrological models were essential for building the appropriate model in the basin.

2.1 Data Collection

The used methodology contained several procedures of the related collected data were gained from the field visits, past reports, studies and literature reviews of similar basins. The collected data included hydro-geological maps, distribution of the existing wells and springs as well as discharge flow volumes, the geological cross-sections, topographical maps, climatic data such as (rainfall, temperature and evapotranspiration), water quality characteristics in addition to the infiltration capacity values.

2.2 Using Watershed Modelling System (WMS) Software

The WMS defined the basin commands and each triangle assigned to its drainage basin. The boundaries appear rough or jagged because each triangle was assigned according to the flow from its centroid, when in fact the triangle straddled basin boundaries. The digital elevation model of Al-Qilt catchment was built in the WMS form (Figure 2).

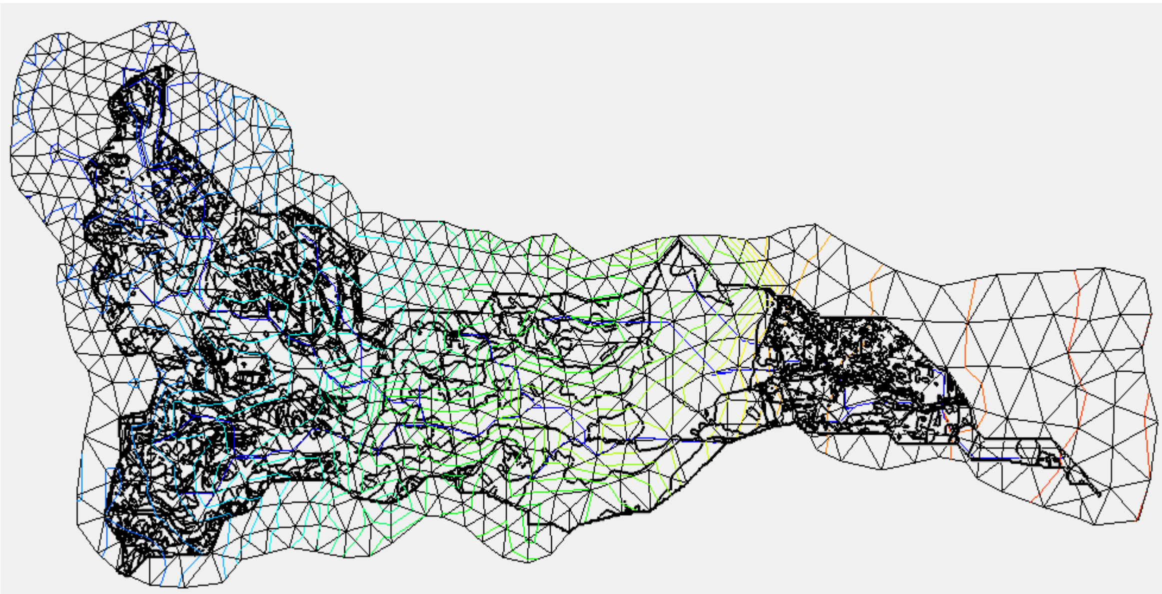

Figure 2 Digital Elevation Model of Al-Qilt watershed as shown in the WMS.

2.3 Model Limitations

Every simulation system has limitations due to the choices made in the design and development of the software. The limitations those arose in this program were due to two aspects of the design: Simplified Model Formulation and Simplified Flow Representation [26, 27]. Simplifying the model formulation allows the program to complete simulations very quickly while producing accurate and precise results. Simplifying the flow representation aids in keeping the compute process efficient and reduces duplication of capability in the HEC software suite [28].

3. Surface Modelling

WMS was used to modify the geometric parameter calculations such as the Curve Number (CN), land use, rainfall depth, and other GIS overlay calculations to be used in the modelling phases.

3.1 Model Components

Model component elements used to simulate the hydrologic response in the watershed environment included metrological models, control data, and the input data. Data set as grid data, the data of the time series, and the paired data are very important for the model builder and metrology models. The first step of building a model was to install Al-Qilt local DEM, setting up a local coordination system and apply metric units for horizontal and vertical measurements. The storm curve number (SCS) was designed for the type of the small drainage area. The intended use was for the estimation of both peak flow rate and runoff volume from precipitation in a certain critical duration. The specified data of the resulted model components was included in the object editor and required data. Notes, alerts and errors were displayed in Logs. In this timeline, the detailed rainfall amount of each area was estimated, noting that the details of Ramallah and Jericho metrological data were takin from the Metrological Department for Palestine [29].

3.2 Curve Number Computations Using Soil Data and Land Use Calculations

WMS divided the total catchment into three sub catchments: Ramallah, Nab'a, and Jericho sub catchments. The sum of the water generated from these sub catchments was the volume of the water generated from the whole of Al-Qilt catchment during a specific storm event, and the Hydrological Modelling module was used to calculate the curve number (CN) by using the soil type and the land use data. The curve number for each sub basin with the correspondence sub-area, according to the shape files for the land use and soil type was obtained from PWA Data Bank (Figure 3) [23].

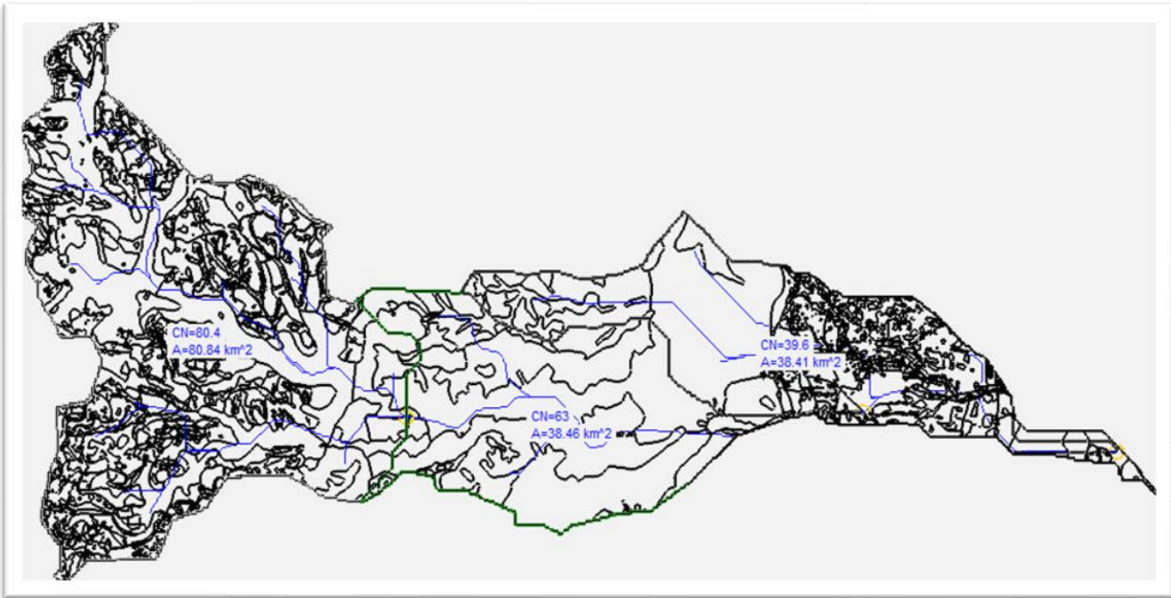

Figure 3 Sub area of the catchment with the corresponding CN as shown in HEC-HMS.

3.3 The Basin Model

The basin model has several types of elements such as sub-basin, reach, junctions, and sink. A sub-basin represents an area or spatial computational unit to convert rainfall to runoff, the reach is representing a linear (river) unit to transport of the water downstream towards the outlet, the junction that represents the combined flows from upstream is representing reaches and sub-basins, and the sink is representing the outlet of the catchment. The peak flow for this storm was obtained by HEC-HMS and calibrated according to site observations. The potential artificial groundwater recharge locations was determined by the geological outcroppings. The basin model and the conjunction point 8C, which was the sink or the outlet of the basin, were illustrated in Figure 4. The sink of the basin could be considered for further investigations in artificial recharge site locations.

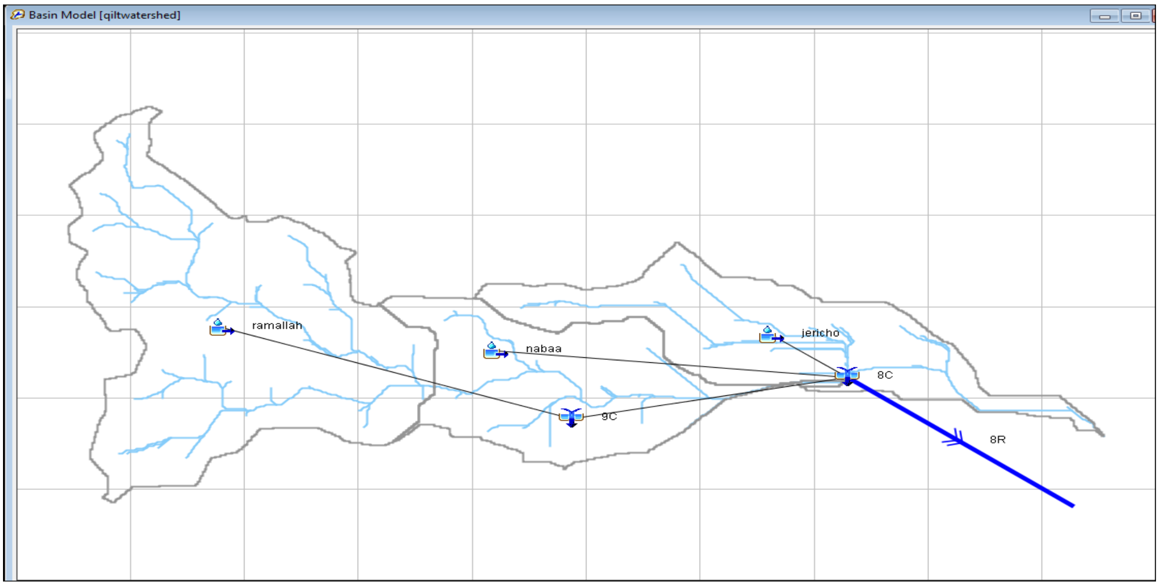

Figure 4 Basin model of Al-Qilt watershed.

4. Results and Discussions

The resulted model can be considered as a standard modelling system that represented many different watersheds in Jericho areas including Al-Qilt and similar catchments in the adjacent basin areas of national and regional levels.

4.1 Time Series Data

The time series of the model was estimated through the rainfall data of each sub-catchment. However, these data for Ramallah and Jericho metrological data obtained from the Metrological Department for Palestine [26]. In order to cover the whole catchment, we created a hypothetical fake metrological station called Naba'a metrological station. The readings of this station were taken by adding 0.4 of RAM00004 (in the western side of the basin) and 0.4 of JER00005 (in the eastern side of the basin) and 0.2 multiplied by the average readings of the two stations. The control specification was taken from the rainy days of 24th of October 2018 to the 3rd of March 2019. The model calculated the rainfall data for each sub-catchment.

4.1.1 The Sub-catchment Obtained Results for the Three Sub-basins

The hyetograph and hydrograph of the three sub-catchments for certain dates were shown in Figure 5, Figure 6, and Figure 7.

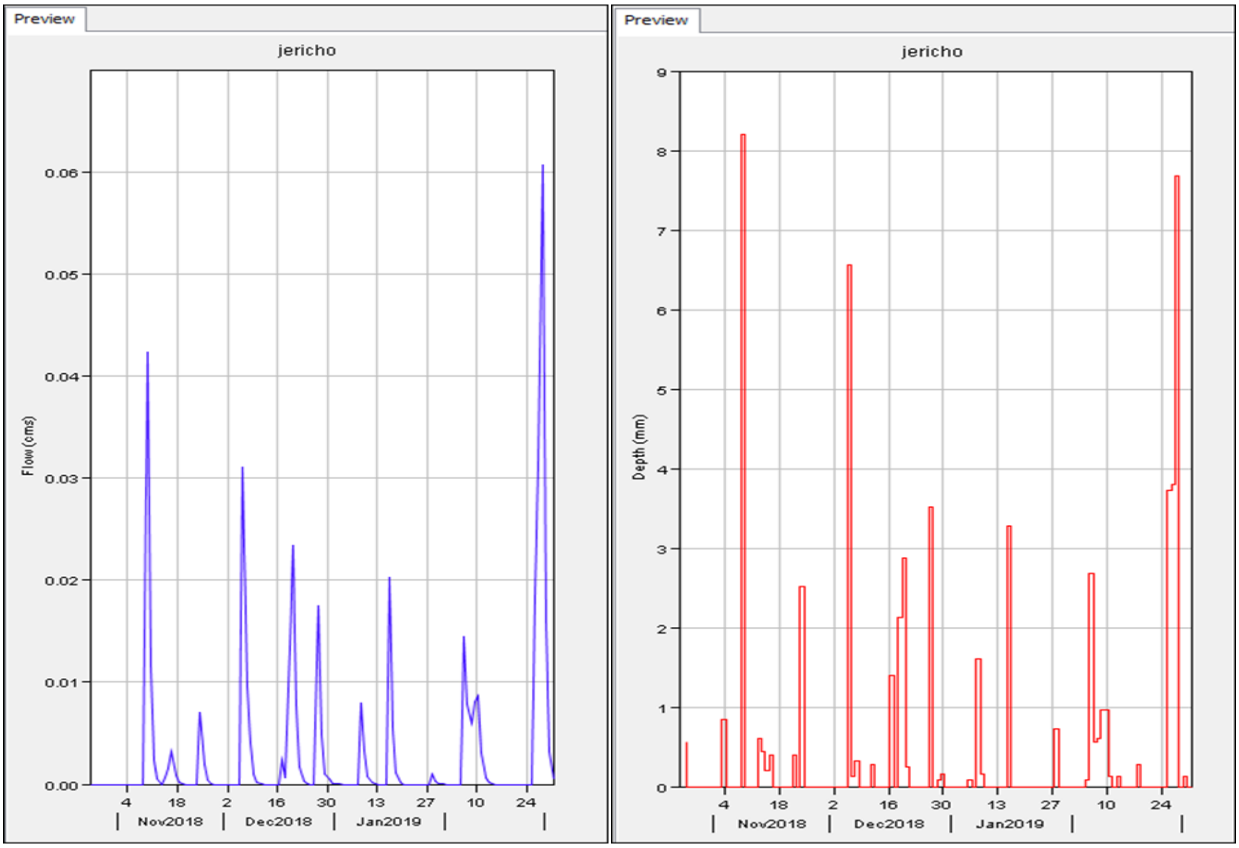

Figure 5 Hydrograph and hyetograph graph for Jericho.

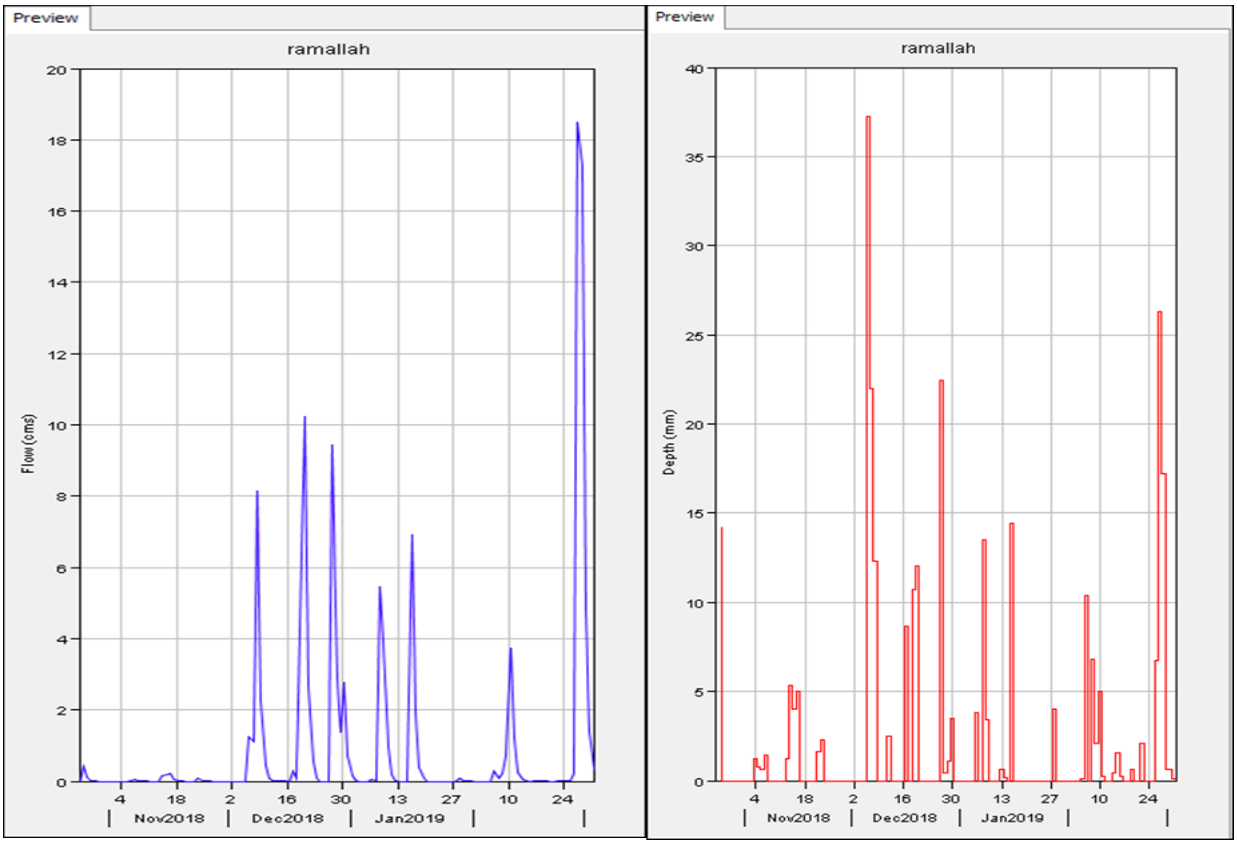

Figure 6 Hydrograph and hyetograph graph for Naba'a.

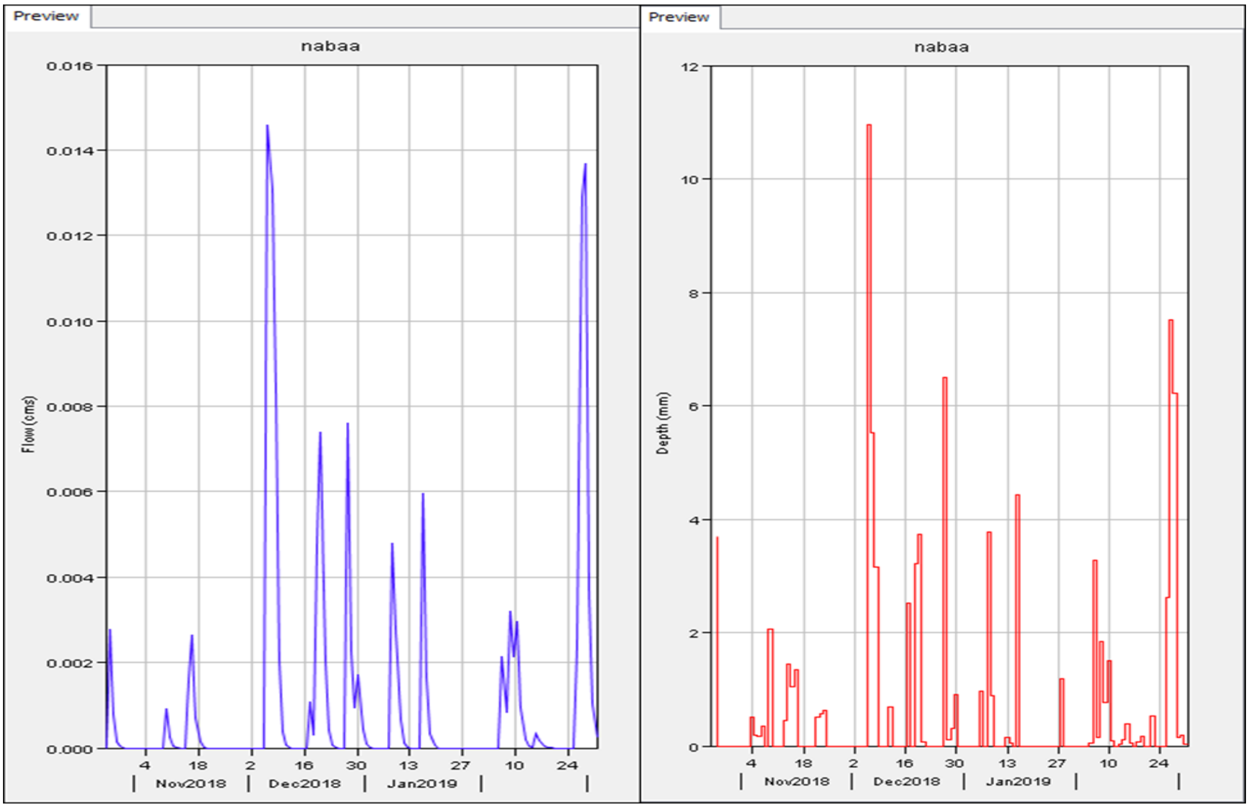

Figure 7 Hydrograph and hyetograph for Al-Qilt.

4.2 Obtained Results

Both measured and estimated results in the field on February 27th 2019 were revealed to surface water speed of 3.2 m/s. The cross section was 9.2 m wide with a water height of 0.75 m taking into account 85% of the flow. The flow was 18.77 m^3/s, and the total flow in the relevant year was approximately 67565 m^3/hr. The results of the model in that section were yielding to the water's flow of 18.5 m^3/s, and by multiplying 18.5*60*60 reaching the volume amount of 66600 m^3/hr. The comparison of the obtained model results including the three sub catchments were shown in Table 1. The basin peak discharge during the specific storm of the three sub catchments were summed to be 35.5 + 12.2 + 10482 = 10530 m^3/hr. This was a comparatively large amount of water that needed to be considered and recorded for potential use in order to let the farmers benefit from it in the downstream of Al-Qilt catchment from quantitative point of view.

Table 1 Summary results for the three sub-basins.

Sub-basin	Precipitation Volume (1000 m^3)	Loss Volume (1000 m^3)	Excess Volume (1000 m^3)	Direct Runoff Volume (1000 m^3)	Discharge Volume (1000 m^3)	Peak Discharge (1000 m^3/s)	Date of Peak Discharge
Jericho	2353	2317	35.6	35.5	35.5	0.1	28/2/2019
Nabaa	3322	3310	12.2	12.2	12.2	0	06/12/2018
Ramallah	23791	13291	10500	10482	10482	18.5	27/2/2019

4.3 Summary for the Sub-basins Results

The results for the three-sub basins after running the model were summarized Figure 8, Figure 9 and Figure 10. Each bar represents the volume of recharge with the corresponding day.

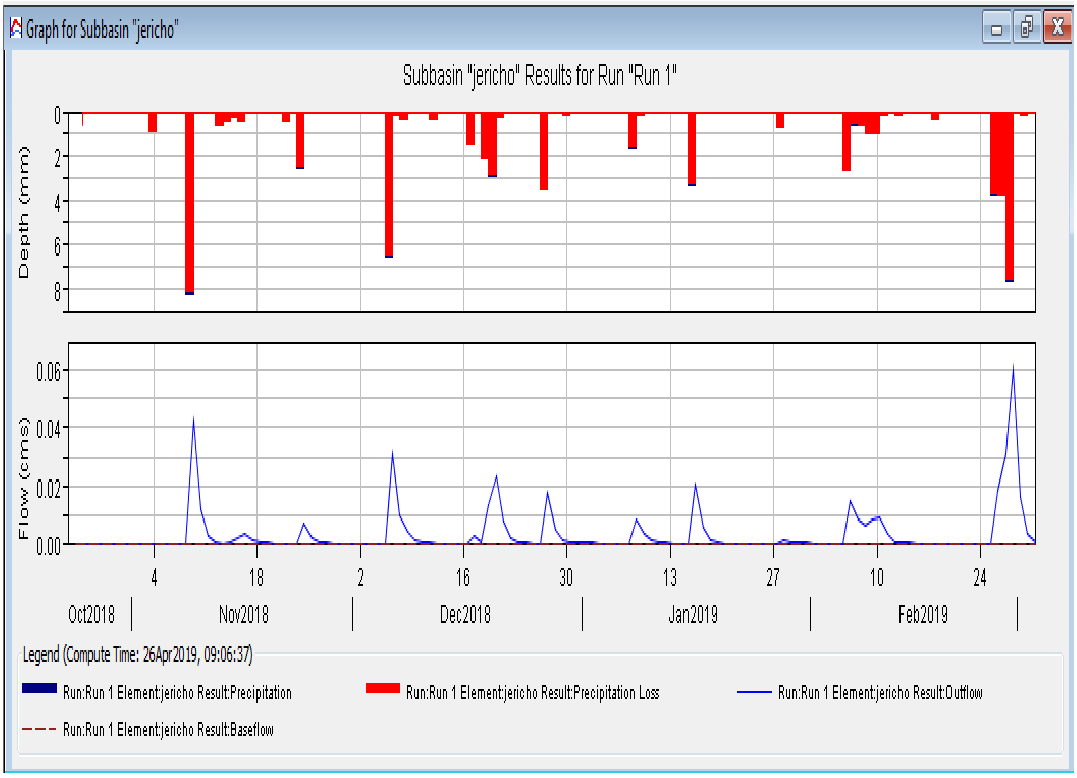

Figure 8 Summary results for Jericho sub-basin.

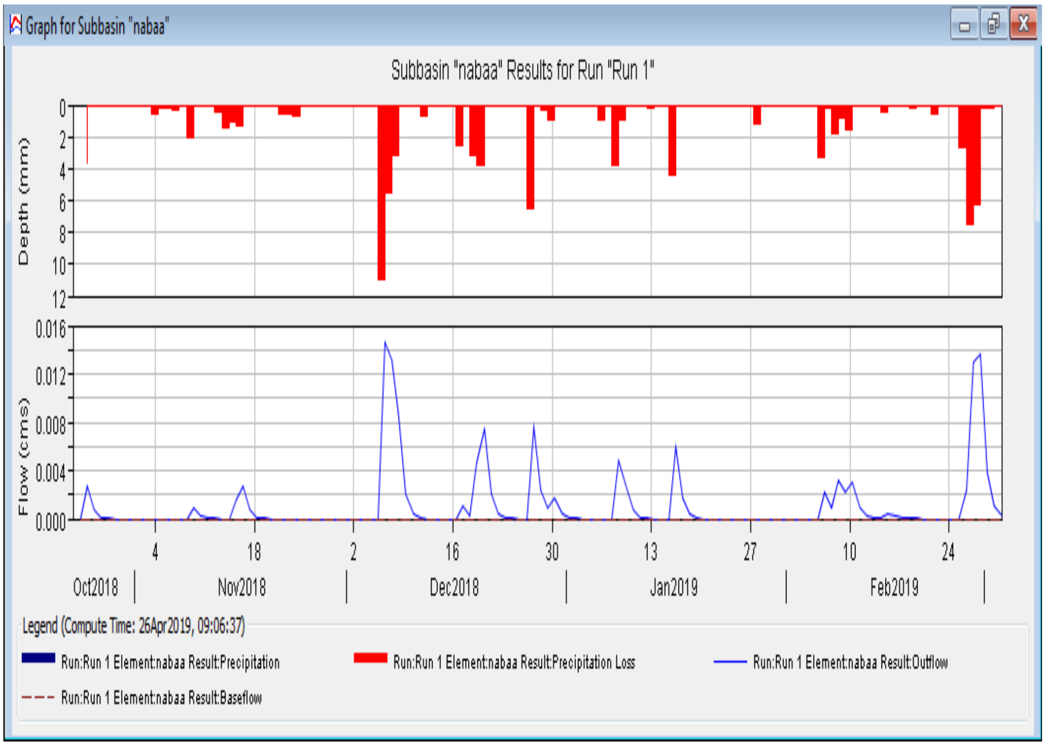

Figure 9 Summary results for Naba'a sub-basin.

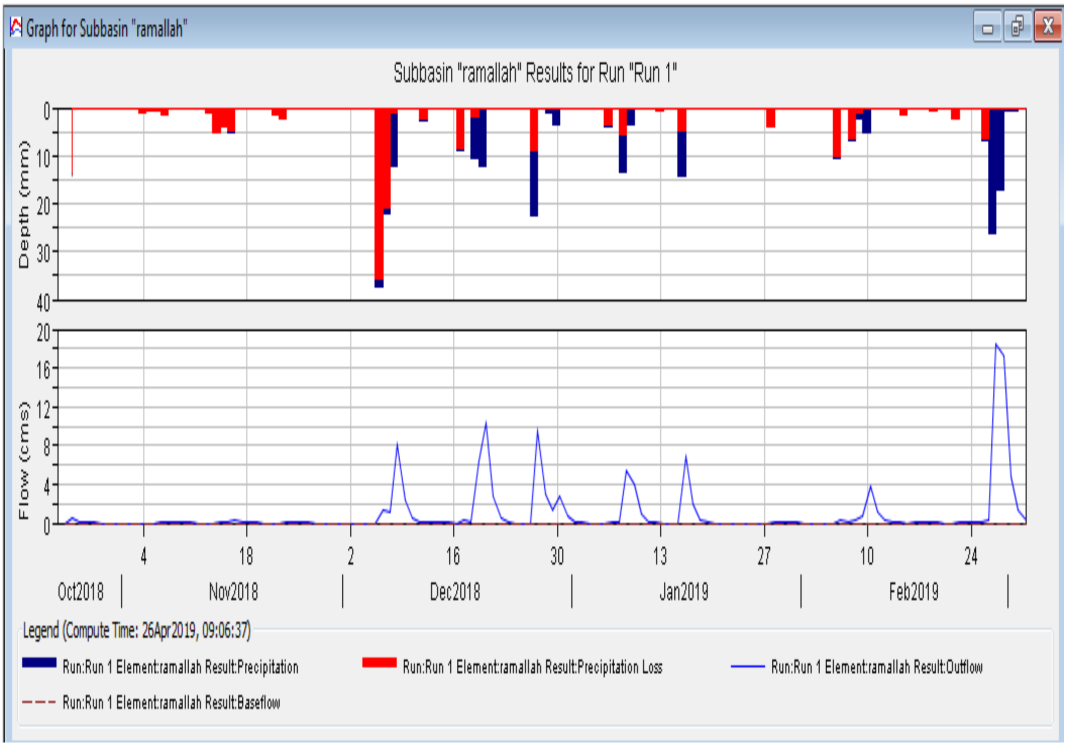

Figure 10 Summary results for Ramallah sub-basin.

5. Conclusion

Al-Qilt Catchment had huge flowing runoff volumes from springs and local streams discharging to the Jordan River and without beneficiary use. The large water runoff amount in Al-Qilt Catchment will put more pressure to benefit from storing it to be used for artificial recharge processes. Based upon the results obtained from the HEC-HMS model, the water flow quantity was estimated by hydrographs and hyetographs of the catchment area. The built HEC-HMS model was verified using storm events by estimating the amount of discharged Al-Qilt catchment water and comparing the model results with the historical results of PWA. The measured and estimated field results on the 27th of February, 2019 storm event revealed to an surface water speed estimation to be 3.2 m/s, in a cross section of 9.2 m wide and water height of 0.75 m. The model results indicated of 18.5 m^3/s water flow speed leading to 66.6 thousand cubic meters per hour. The hydrological behavior of the basin was determined for methodology suitability for the aquifer artificial recharge. The artificial recharge will be fulfilled either through the top surface infiltration routes or by using injection directly into the aquifer through junction wells. Land availability, hydrogeological conditions, and main course flow determined the recharge methodology, which in turn commanded the needed post-recharge method for the water treatment. Surface used percolation methods was more frequently than injection wells because of economic cost and operational considerations. The resulted HEC-HMS model confirmed well during a dense rain day event by water flow calculations from Al-Qilt basin (Including the three sub-basins). Al-Qilt basin required carrying out artificial recharge projects such as building dams and retention structures, storage pools, and deep injection wells in order to protect the beneath aquifer from over-exploitations. HEC-HMS will be used in building an early warning system in Palestine by predicting the flood possibility through assuming a hypothetical storm and discharge volume of each catchment. It is recommended to use the software in Dam's Spillway Design and flood forecasting by bringing more artificial recharge projects in national levels.

Author Contributions

The manuscript is written and revised by MG and AM. The modelling approach is done by AM and the interpretation is done by MG.

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Competing Interests

The authors have declared that no competing interests exist.

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