JJEES

JJEES (2019) 10 (4): 187-193
ISSN 1995-6681

Jordan Journal of Earth and Environmental Sciences

Potential Artificial Recharge to a Semi-arid Basin: A Case Study in a Shallow Groundwater Aquifer, South of West Bank, Palestine

Abdelhaleem Khader*, Radwan El-Kelani, Sameer Shadeed

An-Najah National University, Faculty of Engineering, Department of Civil Engineering, Palestine

Received 17 December 2017; Accepted 23 February 2019

Abstract

Groundwater is the main source of fresh water for domestic and agricultural uses in Palestine. Increased dependence on groundwater demonstrates the dire need to improve aquifer management in terms of understanding and controlling recharge and discharge issues. An artificial groundwater recharge feasibility study was proposed as one of the viable options to halt the decline of groundwater storage in Wadi Abu Al-Qamrah (WAAQ) area located in Hebron, south of the West Bank. Artificial recharge provides natural storage with minimum surface area requirements. It also minimizes evaporation loss, improves water quality, and utilizes surplus surface water runoff. The geology, soil, land cover, and natural streams were mapped using GIS and spatial analysis techniques. Geologic, hydrologic, and piezometric analyses were performed to support the decision. The geological investigation shows that there are two dominant geological formations in the study area: The Cenomanian formation at the foothills east and west, and the lower Cenomanian formation down in the valley. The hydrological analysis using the SCS-CN method indicates that the annual runoff generation in the catchment is estimated at about 0.33 MCM, among which, 70% comes from the upper urbanized part. The piezometric analysis obtained from monitoring the water level in thirty-three dug wells showed that in a short period of time, three months after the end of the rainy season, water table elevation was being declined at about 8 meters. This can be attributed to excessive abstraction. Based on the results of these analyses, several artificial recharge methods were proposed to check their suitability for the study area. The injection wells method was found to be the most suitable for WAAQ. This will enhance the sustainable groundwater management in the West Bank. To achieve this objective, a design well for the injection process is proposed. The potential locations the injection wells have been suggested based on the hydrological and geological analyses.

Keywords: Artificial recharge, Geographical Information System, Piezometric maps, Hydrological modeling, West Bank, Palestine

1. Introduction

The artificial groundwater recharge aims at modifying the natural movement of surface water by utilizing proper structures, to replenish depleted groundwater aquifers due to excessive pumping. In the West Bank, groundwater is the main source of water for domestic and agriculture uses, and provides more than 90% of all water supplies (PWA, 2013). Recently, the increasing demand on groundwater to satisfy the increasing water needs for domestic and agricultural uses, makes Palestine suffers from the limited water resources. Moreover, the problem of water shortages is exacerbated by the fact that shared water resources in Palestine are controlled by the Israelis, a situation that fuels tensions over water rights and makes water a significant political issue (Haddad and Mizyed, 1996; El-Fadel et al., 2001). In arid and semi-arid regions of the world, the shortage of water is a major limiting factor for economic and social development. In such regions including Palestine, almost any development of the aquifers constitutes over-abstraction conditions. This is due to the fact that groundwater is the only reliable and renewable source of fresh water for human life and development in the absence of perennial surface water (Abdin, 2006; Al-Assa'd and Abdulla, 2009; Shadeed, 2012). Thus, increased dependence on groundwater needs improved aquifer management with respect to understanding recharge and discharge issues (Tompson et al., 1999). Rainfall is the main source of groundwater recharge. In the West Bank, rainfall is characterized by high temporal and spatial variations. This can be attributed to the variable topographic features and climatic conditions. On the other hand, the amount of groundwater available for domestic and agricultural uses has been declining, and its quality has been deteriorating due to excessive pumping and the improper disposal of untreated wastewater (Shadeed et al., 2016). Therefore, comprehensive water management strategies have to be adopted to bridge the increasing water supply-demand gap for both domestic and agricultural uses. Hence, artificial groundwater recharge is one of the potential water management options aiming at bridging the gap between the very limited available water resources and the increased water demand resulting from the expanding human activities. This technique had been used since the eighteenth century and has started to be in use, recently on a large scale as a new non-conventional water resource (Helweg, and Smith, 1978; Asano, 1985; Pyne, 1994). Consequently, artificial recharge in arid and semi-arid regions including Palestine can play an important role in

* Corresponding author e-mail: a.khader@najah.edu

conserving its water resources and avoiding the depletion of the existing aquifers (Al-Assa'd and Abdulla, 2009; Ghanem, 2011; Shadeed et al., 2011; Hamdan, 2012; El Arabi, 2012)

The main objective of this research is to assess the feasibility of adopting artificial groundwater recharge techniques in order to enhance groundwater resources. The methodology of the research will be applied in Wadi Abu Al-Qamrah (WAAQ) located in the southern part of the West Bank as part of the eastern aquifer basin (Figure 1).

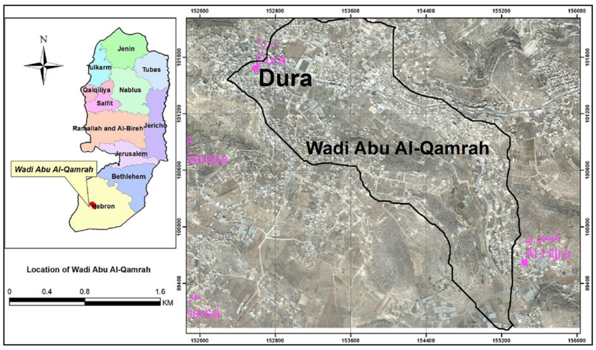

Figure 1. Location map of the study area.

2. Study area

2.1. Geography and Topography

WAAQ is located in the city of Dura (Figure 1), about 7 Km west of the city of Hebron in the southern part of the West Bank. With an area of about 4.3 km^2, the Wadi lies within 35^o 03' 21"and 35^o 01' 42" longitude, and within 31^o 29' 09" and 31^o 30' 34" latitude (between 152-156 E and 99-102 N referenced on the Palestinian grid). This Wadi is a sub-catchment of Besor-Nar catchment, which drains into the Mediterranean Sea (Shadeed and Almasri, 2010). Figure 2 shows that the land surface elevation in WAAQ varies between 897 and 738 m AMSL (above mean sea level).

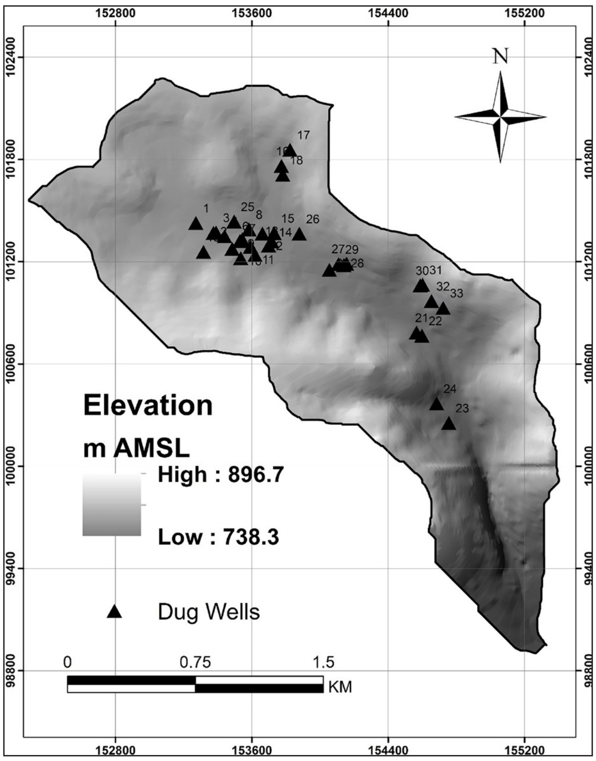

Figure 2. Topographic map of the study area (GeoMOLG 2016).

2.2. Geology and Soil

The geological map of WAAQ (Figure 3) shows that there are two dominant geological formations: The Cenomanian formation at the foothills east and west, and the lower Cenomanian formation down in the valley (Abed and Wishahi, 1999). The Cenomanian (Hebron) Formation is composed of brittle karistified gray dolomite, dolomitic limestone, and gray limestone. At its base, it is formed of hard dolomite and dolomitic limestone with some silicification. The lithology is uniform since dolomite and dolomitic limestone are found throughout the sequence of Hebron Formation. The porosity of this Formation is mainly secondary because the rocks are well jointed and karistified. The Hebron Formation is, without doubt, the most important aquifer within the West Bank. Its Vertical thickness ranges between 70 and 120 m. On the other hand, the Lower Cenomanian (Yatta) Formation, 86 m to128, acts generally as an aquiclude, and separates the Cenomanian aquifer from the Albian aquifer underlying it.

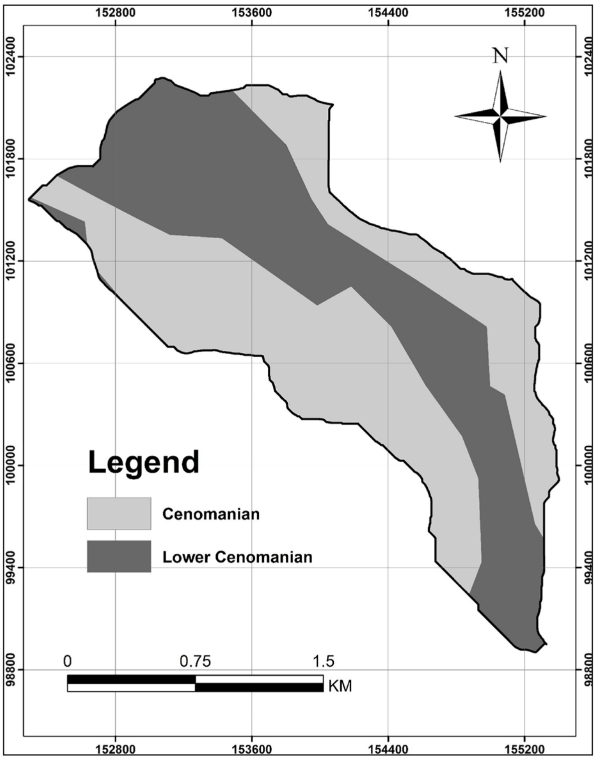

Figure 3. Geological map (GeoMOLG 2016).

The study area has only one soil class which is clay, in particular Terra Rossa Clay, stemming from dolomite and hard limestone. The soil cover has a reddish brown color and its depth varies between 0.5 and 2 meters (Abed and Wishahi, 1999).

2.3. Climate and Hydrology

The area of Hebron Governorate including WAAQ has a Mediterranean climate with hot and dry summers and mild and wet winters. The average daily mean temperature ranges from 22 °C in summer to 7 °C in winter. Average daily maximum temperatures range from 27 °C to 10 °C and minimum temperatures from 17 °C to 4 °C in the summer and winter respectively. The daily relative humidity fluctuates between 48% and 75%. The average wind speed ranges from 4 m/s to 6.4 m/s. The typical potential evaporation ranges from 62 mm in December to 225 mm in August (PMD, 2017).

Based on the available rainfall data at Dura rainfall station for the last 10 years (Table 1), the annual rainfall varies from 284 mm to 587 mm, with an average of 507 mm. Most of the rainfall occurs in the period from October to April, the rest of the year being completely dry.

Table 1. Annual rainfall in Dura, Hebron

Rainy Season	Total Rainfall (mm)
2004/2005	587
2005/2006	357
2006/2007	570
2007/2008	284
2008/2009	342
2009/2010	508
2010/2011	315
2011/2012	568
2012/2013	456
2013/2014	514

2.4. Land Cover

The land cover map of WAAQ (Figure 4) shows that the higher areas at the foothills are mainly occupied by urban built-up zones. The valley and the southern part of the study area are mainly used for different types of agriculture. Politically, WAAQ is divided into three sovereignty zones according to Oslo Accord (Figure 5).

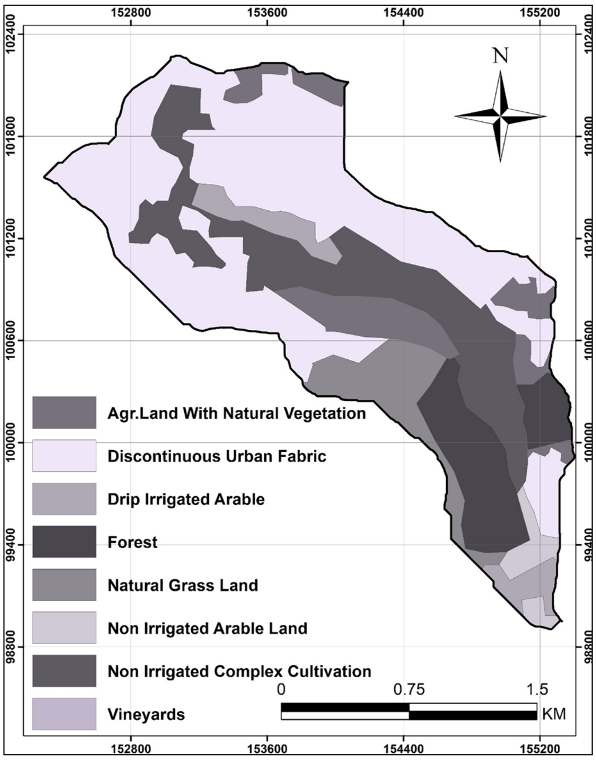

Figure 4. Land cover map of the study area.

3. Results and discussion

3.1. Borehole Logs

Six boreholes were selected to be drilled in the study area; the borehole locations (Figure 5) were chosen to facilitate the drawing of a geological cross section (Figure 6a) and a profile (Figure 6b) in order to understand the geological layers along and across the valley. Based on the aerial photograph, the locations should be easily accessible; meanwhile, sovereignty zones according to Oslo Accord (Figure 5) causes constrains concerning the selection of the sites.

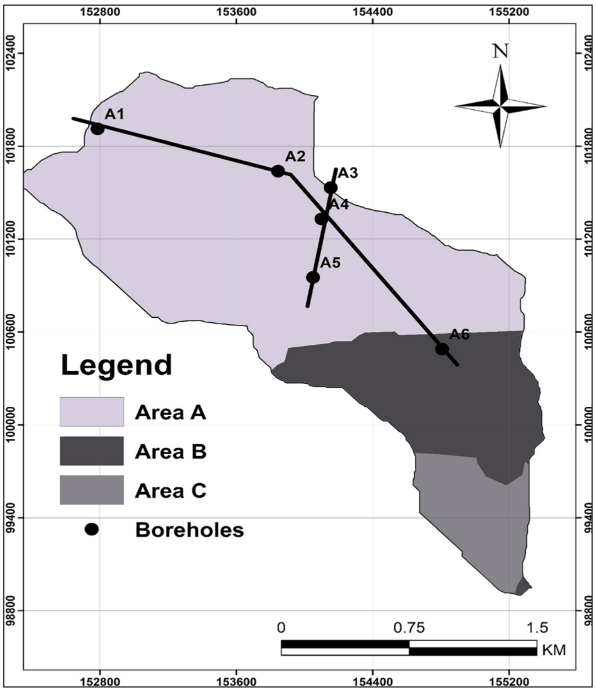

Figure 5. Borehole locations and 2 Sovereignty borders in the study area according to Oslo Accord; zone A: land of Palestinian administrative control and security authority zone B: land of Palestinian administrative control and Israeli security control zone C: land of full Israeli administrative and security control (GeoMOLG 2016).

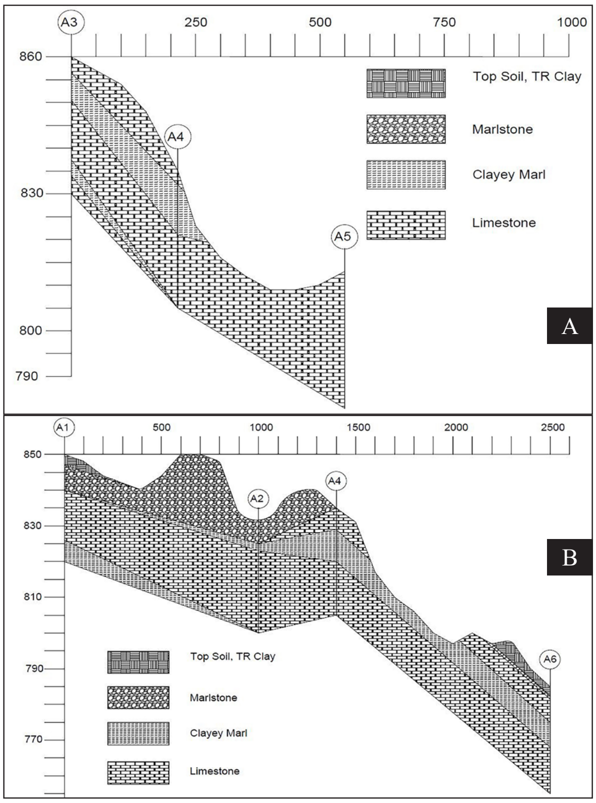

Figure 6. Geological Cross Section (a), and Geological Profile (b).

3.2. Hydrological analysis

3.2.1. Catchment delineation

Before conducting any hydrological study of the catchment, first, the catchment needs to be delineated. The availability of a digital elevation model (DEM), with adequate spatial resolution to cover the whole area of interest, is a basic requirement to achieve the delineation (Bertolo, 2000). The required DEM for this study was obtained from GeoMOLG, 2016. State of the art ArcHydro Tools 2.0, which is an extension of ArcGIS 10.1, was used to delineate the catchment and sub-catchments, and to define the drainage networks (natural streams). Figure 7 shows the distribution of these streams and sub-catchments.

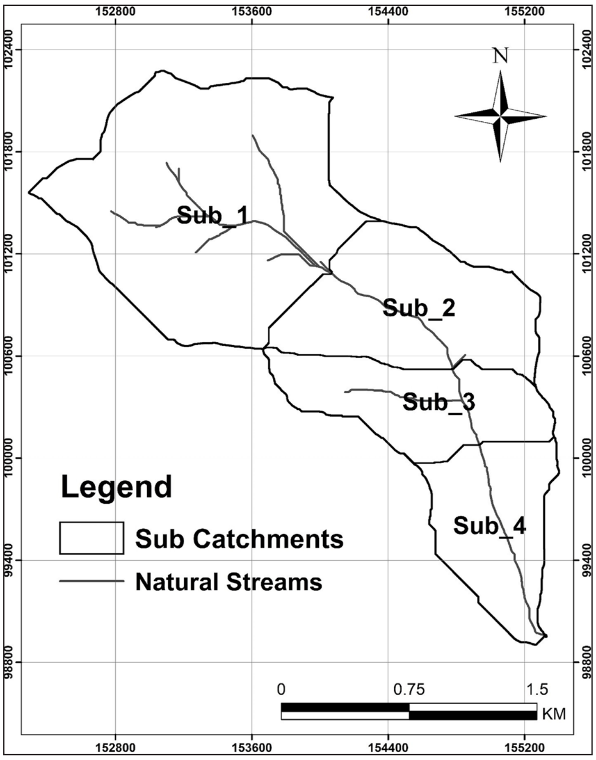

Figure 7. Natural streams and sub-catchments of WAQ.

3.2.2. Hydrological Modelling

The objective of this step is to estimate the surface water runoff from each sub-catchment. To do so, the SCS-CN method was used. The SCS-CN method is one of the most popular methods for computing the volume of surface runoff in catchments for a given rainfall event (Schulze et al., 1992; Shadeed and Almasri, 2010). This approach involves the use of a simple empirical formula and readily available tables and curves. A high curve number means high runoff and low infiltration (urban areas); whereas a low curve number means a low runoff and high infiltration (dry soil). The curve number is a function of land use and hydrologic soil group (HSG). It is a method that can incorporate land use for the computation of runoff from rainfall. The SCS-CN method provides a rapid way to estimate the change in the runoff due to changes in land use.

The standard SCS-CN method is based on the following relationship between rainfall, P (mm), and runoff, Q (mm):

$$Q = \begin{cases} \dfrac{(P - I_a)^2}{P - I_a + S} & P > I_a \\ 0 & P \le I_a \end{cases} \qquad (1)$$

where S (mm) is the potential maximum retention after runoff begins. Through the studies of many small agricultural catchments, I_a was found to be approximated by empirical equations such as

$I_a = 0.2 \times S.$

The variable S, which varies with antecedent soil moisture and other variables, can be estimated as:

$$S = \frac{25\,400}{CN} - 254. \qquad (2)$$

where CN is a dimensionless catchment parameter ranging from 0 to 100. A CN of 100 represents a limiting condition of a perfectly impermeable catchment with a zero retention, in which all rainfall becomes runoff. Conceptually, a CN of zero represents the other extreme, with the catchment abstracting all rainfall and with no runoff regardless of the rainfall amount.

For WAAQ, CN values for the four sub-catchments were obtained by modifying the CN value for Besor-Nar catchment to take into account the percentage of built-up areas in each sub-catchment. Table 2 shows the CN value and the area of each sub-catchment.

Table 2. Sub-catchment characteristics

Sub-catchment	CN Value	Area (Km^2)
Sub-1	78	**2.024**
Sub-2	65	**0.956**
Sub-3	52	**0.674**
Sub-4	65	**0.636**

To apply the SCS-CN method to WAAQ in order to estimate surface water runoff from each sub-catchment, daily rainfall values are needed.

Table 3 shows the results of applying the SCS-CN method to WAAQ sub-catchments for the 2015/2016 rainfall (which is a typical rainy season with 604.4 mm of rainfall). As shown in the results, Sub-1 has the highest runoff/rainfall ratio and the largest volume of runoff. This is due to the large percentage of built-up areas (higher CN value) in this sub-catchment and its large area compared to the other sub-catchments.

Table 3. Runoff values using SCS-CN method

Sub-catchment	Runoff Depth (mm)	Runoff Volume (1000 m^3)	Runoff/Rainfall Ratio%
Sub-1	113.2	229.2	**18.7**
Sub-2	55.1	52.7	**9.1**
Sub-3	20.5	13.8	**3.4**
Sub-4	55.1	35.1	**9.1**
Total		**330.8**	

A high runoff/rainfall ratio in an area indicates a higher runoff and a lower natural recharge in that area, and vice versa. Sub-1 has the highest Runoff/Rainfall ratio in the study area, which indicates that this sub-catchment is more suitable for artificial recharge infrastructure. This is because natural recharge in this sub-catchment is lower, most likely as there is more “room” available for artificial recharge, and because of the availability of more water for recharge from surface runoff.

3.3. Piezometric Analysis

There are forty-six dug wells in WAAQ from which around 170,000 $m^3$of water is being extracted annually; data are available for thirty-three of these wells. Figure 2 shows the locations of these dug wells along the valley. The piezometric water levels in the thirty-three dug wells were monitored seven times between 18/5/2016 and 15/8/2016. The data were interpolated using the inverse distance weighted (IDW) method. The piezometric surface elevation was calculated by subtracting the interpolated depth-to-water surface readings from the surface elevations obtained from the DEM. The piezometric level was the highest on May, 18^{th}, only one month following the rainy season. It started to decline after that. Figure 8 shows that this decline could reach up to 10 meters especially in the southern part of the valley. It is also noted from Figure 8 that the decline in some of the dug wells is significantly higher compared to others. This variability in decline may be attributed to the variability in actual abstraction rates from these dug wells.

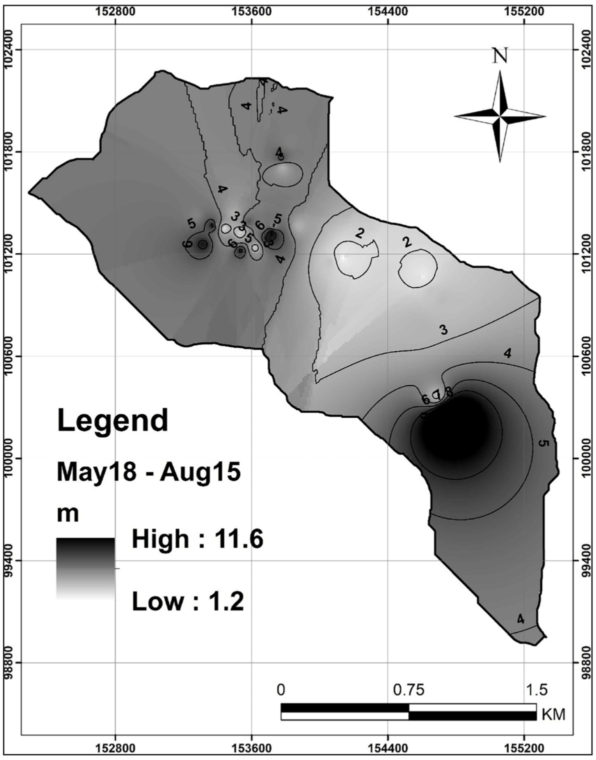

Figure 8. The decline in Piezometric level between May 18th and August 15th 2016.

3.4. Groundwater Recharge Scenarios

Due to variation in rainfall and the limited surface water resources, groundwater has become the main source of freshwater in many parts of the world including Palestine. However, the amount of water that percolates to groundwater varies greatly from region to region and from place to place within the same region depending on the amount and pattern of rainfall (i.e. number and duration of rainy days, rainfall amount and intensity), the characteristics of soils and rocks (i.e. porosity, cracks and loose joints in rocks etc.), the nature of terrain (i.e. hills, plateaus, plains, valleys etc.), as well as other climatic factors including temperature and humidity. As a result, the availability of groundwater varies considerably from place to place.

In order to improve the groundwater situation, it is necessary to artificially recharge the depleted groundwater aquifers. The advantages of artificial recharge are listed below (Ravichandran et al., 2011):

- No need for large storage structures to store water. The structures required are small and cost-effective
- Enhancement of the dependable yield of wells
- Negligible losses compared to losses in surface storages
- Improved water quality due to dilution of harmful chemicals/salts
- No adverse effects such as the inundation of large surface areas and loss of crops
- No displacement of local populations
- Reduction in the cost of energy for lifting water especially where rise in groundwater level is substantial
- Utilization of the surplus surface runoff which, otherwise, drains off

Artificial groundwater recharge is usually applied where groundwater level is declining and where groundwater quality is poor. The source of water for recharge includes rainfall, surface runoff, and properly-treated wastewater. However, there are factors that should be taken into consideration in order to assess the source of water such as quantity, quality, timing, and convenience (Kumar, 1997).

Another factor that should be considered is the infiltration capacity rate of the soil, which governs the rate of recharge. In addition to that, the aquifer characteristics such as storage coefficient, availability of storage space, and permeability, are important factors to assess the suitability of the aquifer for artificial recharge.

Furthermore, the unsaturated thickness of rock formations occurring beyond 3 meters below the ground level should be considered for recharge. Usually, the upper 3 meters of the unsaturated zone are not considered for recharge, since it may cause adverse environmental impacts such as water logging and soil salinity (Kumar, 1997).

There are various methods for artificial recharge ranging from simply modifying the land surface to the technically advanced injection wells (Ravichandran et al., 2011). After investigating these methods, recharge shafts have been found to be the efficient alternative to be considered. But the problem concerning this is that the shaft needs to be drilled exactly in a fracture in the aquifer which is almost impossible to locate in advance. This means that injection wells are the most effective method for confined aquifers and fractured hard rocks, which is the case in this study area.

4. Conclusions and recommendations

As mentioned earlier, injection wells are the most effective method for confined aquifers and fractured hard rocks, which is the case in WAAQ. Thus, the following strategies are proposed:

1- A design well for the injection process, as shown in Figure 9, can be adopted for the artificial recharge mechanism. The estimated cost of one well of this proposed design is detailed in Table 4.

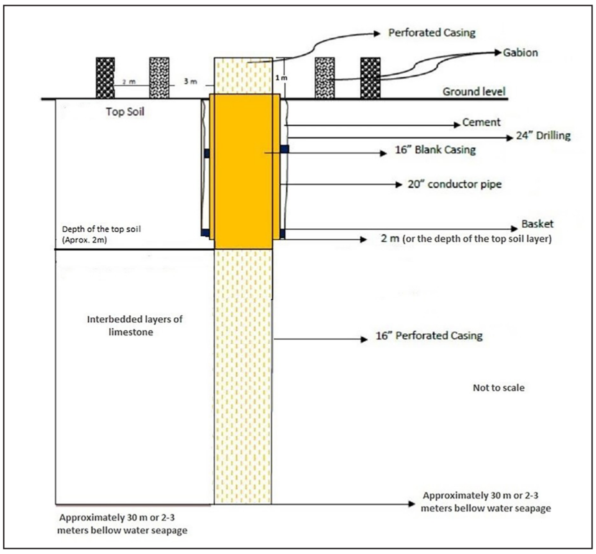

Figure 9. Proposed injection well design.

Table 4. Estimated cost details for the proposed design

Item	Unit	Unit Cost ($US)	Quantity	Cost ($US)
24" drilling	m	300	30	9,000
Gabion 1 (15-20 cm stones)	m	200	20	4,000
Gabion 2 (7-15 cm stones)	m	200	12	2,400
Cement grouting	m^2	100	5	500
16" blank casing	m	150	2	300
20" conductor pipe	m	100	2	200
Pump (injection well)	unit	700	1	700
Screen (perforated casing)	m	200	30	6,000
Total				23,100

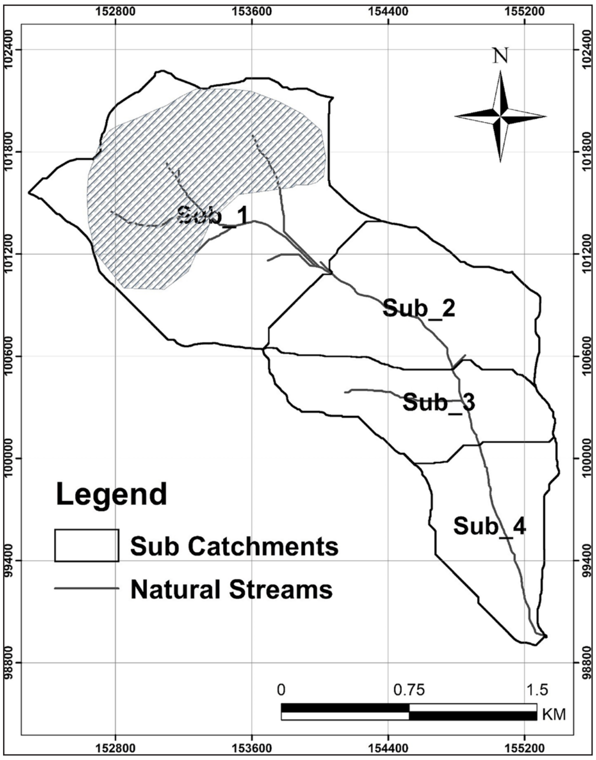

Figure 10. Proposed locations (shaded area) for injection wells.

2- Based on the hydrological and geological analysis, the suggested locations of the proposed injection wells are in the shaded area of Figure 10. The justification of choosing this approximate area is that it is located in sub- 1 (see the hydrological Analysis in Section 3.2), and it is in the upper area where the confining clayey marl layer is thinning (see Figure 6). It should be noted here that the injection wells could be theoretically located anywhere in the study area, but in the suggested area they are closer to the source of water (runoff in Sub-1).

Acknowledgement

The authors would like to acknowledge the Union of Agricultural Work Committee (UAWC), Ramallah, Palestine for providing the relevant information needed for this research. The authors also would like to thank the French decentralized cooperation for sponsoring the field work.

References

Abdin, S. (2006). Qantas a unique groundwater management tool in arid regions, the case of Bam Region in Iran. International symposium on groundwater sustainability.

Al-Assa'd, T., and Abdulla F. (2009). Artificial groundwater recharge to a semi-arid basin: case study of Mujib aquifer, Jordan. Environmental Earth Sciences, 60: 845–859.

Abed, A., and Wishahi, S. (1999). Geology of palestine: the West Bank and Gaza Strip, Palestine. Palestine Hydrology Group (PHG), Ramallah, West Bank, Palestine

Asano, T. (1985). Artificial recharge of groundwater. Butter worth Publishers, Boston, 767 p.

Bertolo, F. (2000). Catchment delineation and characterization, a Review. Space Applications Institute. An Activity of the Euro Landscape Project.

British Geological Survey (2005). A New Map for the West Bank, NERC.

Dura Municipality (2016). Unpuplished report.

El Arabi, N. (2012). Environmental management of groundwater in Egypt via artificial recharge extending the practice to soil aquifer treatment (SAT). International Journal of Environment and Sustainability, 1(3): 66–82.

El-Fadel, M., Quba'a, R., Al-Hougeiri, N., Hashisho, Z. Jamali, D. (2001). The Israeli Palestinian Mountain Aquifer: A Case Studyin Ground Water Conflict Resolution J. Nat. Resour. Life Sci. Educ. 30: 50–61.

GeoMOLG. (2016). The Integrated Spatial Information System of the Palestine Ministry of Local Government. Accessed 2016

Ghanem, M., Marei, A., Hoetzl, H., Wolf, L., Ali, W., Assi, A. (2011). Assessment of artificial recharge test in Jeftlik-Faria area, West Bank. Journal of Water Resource and Protection, 3: 186–191.

Haddad, M., and Mizyed, N. (1996). Water resources in the Middle East: conflict and solutions. p. 3.17. In J.A. Allan (ed.) Water, peace and the Middle East: Negotiating resources in the Jordan basin. Taurus Academic Studies, New York.

Hamdan, S. (2012). Artificial recharge of groundwater with stormwater as a new water resource-case study of the Gaza Strip, Palestine. PhD Thesis, Institute of Applied Geosciences, Berlin Technical University, Berlin.

Helweg, O., and Smith, G. (1978). Appropriate technology for artificial aquifers, Groundwater, 16(3): 144–148.

Kumar, C.P. (1997). Estimation of natural ground water recharge. ISH Journal of Hydraulic Engineering 3(1): 61–74.

PHG, Palestinian Hydrological Group (2013). Groundwater Artificial Recharge, The Marj Sanour Watershed.

Palestinian Meteorological Department (2016). www.pmd.ps, Accessed 2016

Pyne, R. (1994). Groundwater Recharge and Wells: A Guide to Aquifer Storage and Recovery, Lewis Publishers, Florida.

PWA, Palestinian Water Authority (2013). Status report of water resources in the occupied state of Palestine, year of flood water harvesting, Annual Report. Ramallah, Palestine.

Qannam, Z. (2003). A hydrogeological, hydrochemical and environmental study in Wadi Al Arroub drainage basin, south West Bank, Palestine. Freiberg On-line Geosciences. Vol.9

Ravichandran, S., Sathish Kumar, S., Singh, L. (2011). Selective techniques in artificial ground water recharge through dug well and injection well methods .International Journal of ChemTech Research, 3(3): 1050–1053.

Schulze, R.E., Schmidt, E.J., Smithers, J.C. (1992). SCS-SA User Manual PC Based SCS Design Flood Estimates for Small Catchments in Southern Africa. Pietermaritzburg: Department of Agricultural Engineering, University of Natal.

Shadeed, S., and Almasri, M. (2010). Application of GIS-based SCS-CN method in West Bank catchments, Palestine.Water Science and Engineering, 3(1): 1–13.

Shadeed, S. (2012). Spatio-temporal drought analysis in arid and semi-arid regions: A case study from Palestine, The Arabian Journal for Science and Engineering. 38: 2303–2313, doi: 10.1007/s13369-012-0504-y.

Shadeed, S., Sawalhah, M., Abu Jaish, A., Haddad, M., Alawneh, A., Abboushi, A., Doraidi, D., Homeidan, M. (2011). Overview of quantity and quality of water resources in the Faria catchment, Palestine. International Graduate Conference on Science, Humanities and Engineering. An-Najah National University, Nablus, Palestine. 38–51.

Shadeed, S., Sawalhah, M., Haddad, M. (2016). Assessment of groundwater quality in the Faria catchment, Palestine. An - Najah Univ. J. Res. (N. Sc.), 30: 81–100.

Tompson, A., Carle, F., Rosenberg D., Maxwell, M. (1999). Analysis of groundwater migration from artificial recharge in a large urban aquifer: a simulation perspective. Water Resour. Res. 35 (10): 2981-2998.