IMPACT OF WALA DAM ON GROUNDWATER ENHANCEMENT OF WADI WALA CATCHMENT AREA IN JORDAN

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ABSTRACT

The Wala dam was constructed during the years 1999 to 2003. This study was carried out to evaluate the impact of the Wala dam in enhancing the groundwater of the well-field by artificial recharge and assess its impact on the quality of groundwater resources located in the catchment area. In addition, the water balance was estimated in order to sustainably utilize these groundwater resources. The rate of evaporation ranges between 70.6% in the wet year and 95.9% in the dry water year while average annual recharge of the upper aquifer of Wadi Wala catchment (infiltration rate) ranges between 2.8% and 7.9% respectively for dry and wet water years. The overall evaluation indicated a general positive effect of Wala dam on groundwater augmentation after its construction. A moderate increase in the salinity of the groundwater was also found. Other chemical parameters were within the Jordanian Standards for drinking water.

Key words : Water enhancement projects, Groundwater, Artificial recharge, Water quality, Water balance.

INTRODUCTION

Due to variable topographic features, Jordan annual rainfall distribution varies considerably with location from about 600 mm in the northwest to less than 50 mm in the eastern and southeastern deserts. More than 80% of Jordan receives an annual average rainfall of less than 100 mm (Ta’any and Al-Zu’bi, 2007). Surface water resources are very limited and depend on rainfall for recoupment. The great proportion of the renewable water resources has been utilized to a great extent, reaching a stage between complete utilization and exhaustion (Haddadin, 2005). Uneven distribution and erratic nature of rainfall, mismanagement of renewable water resources, and lack of financial resources to implement water enhancement projects make Jordan one of the countries with the scarcest renewable water resources in the world (Al-Zu’bi et al., 2006). Groundwater resources are, therefore, the major reliable source of water in Jordan. The Wadi Wala reservoir is one of the major sources that supply water to Amman (capital of Jordan) and Madaba Governorate with an annual amount of 10-12 million cubic meters (MCM) of drinking water with approximately 17% share of the total water supply (MWI, 2008). The Wadi Wala catchment is located to the east of the Dead Sea within the Mujib Basin that covers an area of about 6600 km² (i.e., about 7% of Jordan’s total area). It covers an area of approximately 1998 km² largely compromising semi-arid to arid plateau. At present, the surface water resources of Wadi Wala catchment area are used exclusively for agricultural purposes whereas groundwater is used for domestic purposes (Al-Balawi, 2004).
To enhance water resources in the catchment area, the Wala dam was constructed during the years 1999 to 2003 in the Wadi Wala, about 40 km south of Amman. The impoundment started in winter 2002/2003. The Wala dam was mainly constructed to facilitate groundwater recharge of the aquifers, which were being used for drinking water supply to Amman, Madaba and villages near the dam. The maximum storage capacity of the Wala dam is 9.3 MCM. It is currently proposed to increase its storage capacity to 26.3 MCM. Because the groundwater flow path from the dam to the well-field is short, water at the dam needs to be protected against pollution. Water analyses, conducted by Jordan Water Authority (WAJ) and Royal Scientific Society (RSS), show frequent bacteriological contamination of the reservoir (Al-Balawi, 2004). The main sources of contamination are watering of livestock at the reservoir and seepage of domestic wastewater from cesspits in nearby villages to the reservoir.

This study was carried out to evaluate the impact of the Wadi Wala dam in enhancing the groundwater of the well-field by artificial recharge and assess its impact on the quality of groundwater resources located in the catchment area. In addition, the water balance of the catchment area was estimated in order to sustainably utilize these groundwater resources.

MATERIALS AND METHODS
Location of the study area:

The study area lies between 210°-275° E and 90°-135° N according to Palestine Grid System (Figure 1). Wadi Wala Catchment area forms the northern tributary of Mujib Basin. The general shape of the catchment area is triangular, with the longer axis oriented E-W direction. Several Wadis drain in the catchment area; the main Wadis are Wadi Um El-Amad, Wadi Sfuq, Wadi El-Nashiyeh, Wadi El-Zareer, Wadi Shalaq and Wadi Abu Halifiyyeh. The confluence of these Wadis forms Wadi Wala (Figure 1). All of these Wadis drain from north, north-east and east to west, that is, from highland areas to the lowlands of the Jordan Valley. Floods flush in the winter season into Wadi Heidan (Figure 1).

Climate of the study Area:

The Wadi Wala Catchment has a predominantly Mediterranean type climate, characterized by hot dry summers and cool to cold wet winters. As in most semi-arid areas, temperatures exhibit large seasonal and diurnal variations, with absolute daily temperatures ranging from a maximum of around 47 °C in August to –5 °C in January. Rainfall generally begins in October and till May, the remaining months of the year are dry. In general, the mean annual rainfall decreases across the catchment from the north-west to south-east. Annual precipitation decreases eastwards from over 350 mm to less than 150 mm in the extreme east (Figure 2) with an annual average of about 176.3 mm. Towards the end of winter season, thunderstorms are often associated with unstable air at higher altitudes.

Hydrology of Wala Reservoir:

Two types of rainfall gauge were used to measure the rainfall in the study area. These are non-recording gauges and the recording gauges. Two recording rainfall gauges and four non-recordings gauges (standard daily gauges) were installed in the study area. The rainfall in the study area was measured in millimeters and tenths.

The potential evapotranspiration is computed by applying Penman Formula, which appears to be the most suitable and had been widely used with satisfactory results in various parts of the world, particularly in arid and semi arid areas as the case in Wadi Wala catchment area. The potential evapotranspiration (ET) was computed for wet, dry and normal conditions. The essential climatological data which were needed for the computation of the potential evapotranspiration had been collected from WAJ files. In order to obtain the actual evaporation from rainfall, the potential evaporation was calculated during the occurrence of the rainfall storm. Runoff is measured at the Wala gauging
Fig 1: Location map of Wadi Wala Catchment Area.

Fig. 2: Isohyetal Map for Wala Catchment Area (Normal Water Year Condition).
station. The data was obtained from the Ministry of Water and Irrigation.

Water Balance:

The estimation of annual recharge rates was performed using the “Water Budget Approach” (Domenico and Schwartz, 1990). The water budgeting for wet, dry and normal conditions was done. The direct recharge was calculated annually by subtracting the sum of daily runoff and the sum of daily evapotranspiration and initial abstraction from the annual rainfall.

The following water balance equation was applied:

\[ S = P - E - R - I_a \]

Where,

- \( S \) = Change of ground water storage or recharge.
- \( P \) = Precipitation in mm
- \( E \) = Evapotranspiration in mm
- \( R \) = Runoff in mm
- \( I_a \) = Initial abstraction in mm

Hydrogeology of the study area:

Stratigraphy:

The Lower Cretaceous Aquifer Complex:

The Kurnub (Early Cretaceous rocks) sandstone aquifer consists of white massive and varicolored sandstones (Rimawi, 1985; Bender, 1974). The color variation of the rocks is due to the mobilization of iron by groundwater and surface leaching. The rocks are not outcropping in the study area.

The Upper Cretaceous Aquifer Complex:

Generally, Cretaceous rocks in Jordan are mainly subdivided into two main sequences: the Early Cretaceous rocks and the Late Cretaceous rocks, which are further sub-divided into Ajlun and Balqa Groups. This research concerns only with the upper aquifer system of the Late Cretaceous rocks.

Na‘ur Aquifer system (A1-2):

This system includes two rock formations A1 and A2 which are composed of marl and limestone, respectively. The hydraulic characteristics of this system indicate low water potential with low specific capacity ranging from 0.01 – 12 m\(^3\)/h/m, transmissivity ranges from 0.3 – 100 m\(^2\)/d and permeability range from 2\(\times\)10\(^{-8}\) to 3.1\(\times\)10\(^{-5}\) m/s (Rimawi, 1985).

Hummar Aquifer System (A4):

It is composed of highly fractured dark grey. Hard, dense dolomitic limestone and sometimes it is interbedded with marl and marly limestone. The hydraulic characteristics of this system indicate that permeability ranges from 8.1\(\times\)10\(^{-7}\) to 7.5\(\times\)10\(^{-4}\) m/s and transmissivity ranges from 3 – 315 m\(^2\)/d (Ta‘any et al., 2009).

Amman Wadi Es Sir Aquifer System (B2/A7):

This is the most important Aquifer System within the Upper Cretaceous formations and is composed of Wadi Es-Sir and Amman Formations with a thickness of about 100 meter. Wadi Es-Sir Formation is subdivided into three members A7a, A7b, and A7c composed of alternating marl, marly limestone and dolomitic limestone, and alternating marly limestone with limestone, respectively. The Amman Formation is subdivided into two members; B2a and B2b, where B2a is composed of chert, silicified limestone, and chalky marl, whereas B2b is composed of phosphorite, marl, and limestone. The aquifer system in the study area (B2/A7) has the following hydraulic characteristics: the permeability ranges from 1.45\(\times\)10\(^{-6}\) to 4.73\(\times\)10\(^{-3}\) m/s, transmissivity ranges from 19.5 – 5885 m\(^2\)/d (Rimawi, 1985), and specific capacity ranges from 0.6 – 2.31 m\(^3\)/h/m, (Salem, 1999).

Groundwater Movement:

The main groundwater source is (B2/A7) Aquifer. Two recharge systems for (B2/A7) Aquifer are recognized according to JICA, 2001.

The Amman – Madaba Recharge System:

It is the major recharge system including the mountainous northwestern highlands part of the study area. The annual rainfall ranges from 250–500 mm. Most groundwater of this system flows southwards to Jiza town, then southwestward to Wadi Wala / Wadi El Heidan channel stream.

The Libb – Thiban Recharge System:
It is smaller than Amman – Madaba system that finally flows towards Wadi el Heidan through Wadi Wala channel stream (JICA, 2001). The groundwater flow pattern is affected by Swaqa fault which separates Wala basin (upper Mujib) from lower Mujib basin (JICA, 2001).

**Groundwater Resources:**

Springs and groundwater wells are the major outflows from the (B2/A7) aquifer system in the Wala catchment.

**Groundwater Wells:**

The study area has 2 types of wells, private and government. There are more than 150 private wells and more than 30 governmental wells, both are used for irrigation and drinking purposes. Three types of boreholes were drilled in the Upper Aquifer System in the Wadi Wala Catchment; these are, productive, exploratory and observation wells. About 25 wells are used for domestic uses and the remaining wells are used for irrigation. All private wells are used for irrigation and most of them are functional. Generally, the total depth of these wells vary from few meters in the south-west of the

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**Fig. 3 :** Flow-net Map showing Groundwater Movement of B2/A7 Aquifer.
catchment to more than 400 m in the northern part of the catchment penetrating Amman Wadi Es-Sir Formation (B2/A7). The elevation of the water level ranges from 920 m a.m.s.l (above mean sea level) in Na’ur Formation (A1/2) and 320 m a.m.s.l. in Amman Wadi Es-Sir Formation (B2/A7). The yields of the water wells are variable and range between 38 m$^3$/h in CD 1098 and 226 m$^3$/h in Heidan No 4 (CD3135) in the Amman Wadi Es-Sir Formation (B2/A7), between 13 and 62 m$^3$/h in the Hummar Formation (A4) and between 6 and 31 m$^3$/h in the Na’ur (A1/2) and Kurnub (K) Aquifers. The specific capacities have a range between 0.08 and 15599 m$^3$/h/m in the Amman Wadi Es-Sir Formation (B2/A7), between 0.09 and 7.98 m$^3$/h/m in the Hummar Aquifer (A4) and between 0.04 and 12.6 m$^3$/h/m in the Na’ur (A1/2) and Kurnub (K) Aquifers (JICA, 2001).

Groundwater Movement in Amman Wadi Es-Sir Aquifer (B2/A7):

The main mechanism of groundwater movement is by fracture flow. Regional groundwater movement within the Amman Wadi Es-Sir (B2/A7) aquifer mostly follows the regional dip to the west. Groundwater movement generally depends on the hydraulic conductivity and the hydraulic gradient. Groundwater elevations are highest in the extremely north of the catchment area and range from more than 600 m a.m.s.l to less than 300 m a.m.s.l. Figure 3 shows the flow-net map of the Upper Aquifer System (B2/A7) in the catchment area. This figure shows that the flow direction is mainly from east to west and also from north and north-east to west.

Data collection and management:

During the implementation of the present study hydrological data were collected from Water Authority of Jordan (WAJ), NRA and various published reports. Rainfall Isohyetal map was drawn using AutoCAD whereas Flow-net and Isosalinity maps were drawn using Surfer 8.

Water level analysis:

Four monitoring wells were drilled down stream of the dam to see whether an enhancement occurred to the groundwater in the surrounding area or not. These are Wala well No. 11, Wala

| Table 1 : Calculated water balance for Wadi Wala catchment area. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Water Year      | Rainfall        | Runoff          | Evaporation     | Infiltration    | Runoff%         | Evaporation     | Infiltration     |
|                 | MCM             | MCM             | MCM             | MCM             | %              | %               | %               |
| Wet (1991/1992) | 766.6           | 164.8           | 541.2           | 60.6            | 21.5           | 70.6            | 7.9             |
| Normal (1996/1997) | 373.7         | 24.8            | 331.5           | 17.4            | 6.6            | 88.7            | 4.7             |
| Dry (2001/2002)  | 221.4           | 4.3             | 212.3           | 4.8             | 1.3            | 95.9            | 2.8             |

| Table 2 : Percent change in water level. |
|-----------------|-----------------|-----------------|-----------------|
| Well            | Date            | Water level (m) | % change in water level |
| CD 1097         | 26-02-2001      | 329.45          | +3               |
|                 | 18-01-2010      | 339.41          |                  |
| CD 1100         | 18-04-1999      | 333.64          | +14.2            |
|                 | 02-03-2005      | 381.02          |                  |
| CD 3133         | 16-10-2000      | 368.00          | +8.6             |
|                 | 20-01-2010      | 399.70          |                  |
| CD 1213         | 30-07-2003      | 546.35          | -0.46            |
|                 | 20-01-2010      | 543.82          |                  |
well No. 14, Wadi Heidan and Um El-Rasas well. These observation wells were equipped with Stevens automatic recorders and set up for monthly readings. The wells have total depths of 200 m, 244 m, 59 m, and 340 m, respectively. All these boreholes terminated in the Amman Wadi Es-Sir Formation (B2/A7) aquifer. The depth to the water level of selected water wells was measured with an electric probe termed as “Dipper or M-Scope” in order to investigate the static water levels.

Chemical analyses of water samples:

Water samples were collected from the Heidan observation well (CD3133) and the Wala well number14 (CD1100) and analyzed in WAJ central laboratories. For Ca$^{2+}$, Mg$^{2+}$, Na$^{+}$, K$^{+}$ Varian AAS has been used and for HCO$_3^-$ and Cl$^-$, titration method is used while for SO$_4^{2-}$ and NO$_3^-$ UV spectrophotometer is used. The total hardness (TH) in mg/l was calculated as follows:

$$TH = 2.5(Ca) + 4.1(Mg);$$

the concentrations of Ca and Mg are also in mg/l.

Fig. 4: Static Water Level Fluctuation in Wala well No. 11 (CD1097).

Fig. 5: Static Water Level Fluctuation in Wala well No. 14 (CD1100).
### Table 3: Chemical Composition of Heidan Observation Well (CD3133).

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Date</th>
<th>ECIS/cm</th>
<th>pH</th>
<th>Ca²⁺/mg/l</th>
<th>Mg²⁺/mg/l</th>
<th>Na⁺/mg/l</th>
<th>K⁺/mg/l</th>
<th>Cl⁻/mg/l</th>
<th>SO₄²⁻/mg/l</th>
<th>HCO₃⁻/mg/l</th>
<th>NO₃⁻/mg/l</th>
<th>THmg/l</th>
<th>SAR</th>
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<td>7.15</td>
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<td>41.95</td>
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<td>128.51</td>
<td>88.4</td>
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<td>22.74</td>
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<td>(CD3133)</td>
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<td>1094</td>
<td>8.08</td>
<td>99.6</td>
<td>37.7</td>
<td>81.19</td>
<td>5.47</td>
<td>128.16</td>
<td>89.76</td>
<td>348.92</td>
<td>20.86</td>
<td>404</td>
<td>1.76</td>
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<td></td>
<td>8-Apr-09</td>
<td>1080</td>
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<td>97.39</td>
<td>36.12</td>
<td>75.9</td>
<td>5.87</td>
<td>120.7</td>
<td>91.68</td>
<td>326.35</td>
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<td>27-Jun-09</td>
<td>1108</td>
<td>7.28</td>
<td>102.2</td>
<td>37.33</td>
<td>79.58</td>
<td>5.87</td>
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<td>105.12</td>
<td>355.02</td>
<td>21.75</td>
<td>409</td>
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### Table 4: Chemical Composition of Wala well number 14 (CD1100).

<table>
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<th>pH</th>
<th>Ca²⁺/mg/l</th>
<th>Mg²⁺/mg/l</th>
<th>Na⁺/mg/l</th>
<th>K⁺/mg/l</th>
<th>Cl⁻/mg/l</th>
<th>SO₄²⁻/mg/l</th>
<th>HCO₃⁻/mg/l</th>
<th>NO₃⁻/mg/l</th>
<th>THmg/l</th>
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<td>Wala No. 14</td>
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<td>117.43</td>
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<td>5.08</td>
<td>156.20</td>
<td>166.08</td>
<td>366.00</td>
<td>9.11</td>
<td>495</td>
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<td>1-Jun-04</td>
<td>1430</td>
<td>7.86</td>
<td>105.21</td>
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<td>8-Nov-06</td>
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<td>137.39</td>
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<td>393.45</td>
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The accuracy of the analysis has been checked using the ionic balance according to Appelo and Postma (1996). The balance was found to be less than 5%, which indicates that the analysis is satisfactorily accurate.

RESULTS AND DISCUSSION

Hydrological characteristics:

Generally, the mean annual rainfall decreases across the catchment area from the north-west to south-east (Figure 2). The mean annual rainfall varies by more than a factor of three over the study area and the coefficient of variation ranges from 0.39 to 0.55. The minimum variation coefficient was found for the Wala station, whereas the highest variation coefficient was found for Um El-Rasas station. This implies that the distribution of rainfall is much better in the northern part of the catchment (Wala station) than in the southern part of the catchment (Um El-Rasas station). The average annual evapotranspiration (ET) according to Penman equation was found to be 541.2 MCM, 331.5 MCM and 212.3 MCM in the wet, normal and dry conditions, respectively. The rate of evaporation ranges between 70.6% in the wet year and 95.9% in the dry water year while average annual recharge of the upper aquifer of Wadi Wala catchment was found to range between 4.8 and 60.6 MCM in dry and wet water years representing an infiltration rate of 2.8% and 7.9%, respectively. The results of the water balance calculations for the whole catchment area are presented in Table 1.

Water level analysis

Water level both in the reservoir and the surrounding groundwater, discussed in this study, was being monitored since 1998. The groundwater of the Upper Aquifer System (B2/A7) generally occurs under unconfined conditions in the Wadi Wala Catchment area. Therefore, the water table is not stable and fluctuates according to wet and dry seasons and also to withdrawal or abstraction of groundwater. Until now, groundwater in Wadi Wala Catchment area is mostly abstracted from Shallow Aquifer (B2/A7) and minor quantity from the middle Aquifer Hummar Formation (A4). The fluctuation in water levels of the observation wells are shown in figures 4, 5, 6 and 7.

The water levels of these wells were fluctuating before the dam construction. It is obviously seen that the general trend of the water level in the surrounding wells and down stream of the reservoir area is rising up after the dam storage started particularly in wells CD1097 and CD3133 (Figures 4 and 6). This indicates a continuous accretion of groundwater in the reservoir. The water...
level of well CD 1213 clearly declined after the construction of the dam most probably due to the increase in water abstraction. The water level of well CD1100 remains stable in spite of increasing water abstraction from the well. Thus the overall evaluation indicates a general positive effect of Wala dam on groundwater enhancement after its construction (Table 2). The above observations point out that the surface water in the reservoir flows to strike a balance with surrounding groundwater. However, these data imply the importance of utilizing such water resource in a sustainable way.

Hydro-chemical analysis:

The chemical composition of the water samples taken from the same observation wells indicates that there is an enhancement in the groundwater quality. Tables 3 and 4 show the chemical composition of Heidan observation well (CD3133) and Wala well No. 14 (1100), respectively. A moderate increase was observed in the salinity of the Correlation analysis between the electrical conductivity (EC) and soluble cations and anions showed that, for Heidan observation well, the EC was highly positively correlated with Mg ($r = 0.98$) and to a lesser extent with HCO$_3$ ($r = 0.56$) and NO$_3$ ($r = 0.42$), whereas, it was highly negatively correlated with Na ($r = -0.81$) and to a lesser extent with K ($r = -0.57$). Almost similar correlation was found between the EC and soluble cations and anions for the Wala well No. 14. In this well, the EC was highly positively correlated with K ($r = 0.92$) and Mg ($r = 0.74$), while, it was negatively correlated with Na ($r = -0.57$).

CONCLUSIONS

From physiographic, water level and hydro-chemical points of view, it can be concluded that Wala dam is enhancing the surrounding groundwater in the Wadi Wala catchment area, which encourages the construction of more recharging dams in the extremely south west part of the catchment area. This promising area is located at coordinates (220 – 225 E) and (105 – 115 N). Further study is recommended to quantify the volume of water recharge to better understand the impact of this reservoir as groundwater enhancing structure using modeling approaches. Moreover, a detailed geochemical investigation will further consolidate the findings of this research.
REFERENCES