DEVELOPMENT OF A WATER BUDGET MODEL FOR GROUNDWATER SUSTAINABILITY IN THE ARID EASTERN ABU DHABI EMIRATE

M. MOHAMED

Department of Civil and Environmental Engineering, United Arab Emirates University, Al-Ain, PO Box 15551, UAE. Email: m.mohamed@uaeu.ac.ae

EXTENDED ABSTRACT

Accurate estimation of the groundwater recharge is essential for efficient and sustainable groundwater management especially in arid and semi-arid regions. This is because water resources are critical to economic development in most countries located in these areas. However, estimation of groundwater recharge and discharge fluxes in unconfined systems in arid regions are normally difficult because of lack of knowledge on how to distribute water flux and vapor discharge. Various techniques are available to quantify saturated groundwater recharge including hydrological budget method, environmental tracers’ techniques, and analytical and numerical models. The hydrological budget method is widely used for estimating groundwater recharge as it accounts for all inflows (e.g. precipitation, surface flow, irrigation returns, and subsurface inflow), and outflows (e.g. evapotranspiration and subsurface outflow), as well as storage changes in the unsaturated and saturated zones.

Abu Dhabi Emirate is one of the seven Emirates which comprise the United Arab Emirates (UAE) and occupies an area of 67,340 km² or about 80% of the total area of the UAE. The Emirate has an arid climate with less than 100 mm/yr average rainfall, a very high evaporation rate (2-3 m/yr), and no reliable surface water resources. Groundwater is the only conventional source of water in the Emirate of Abu Dhabi. Its share to the total fresh water supply in the Emirate is about 80%. Other unconventional sources of fresh water in the Emirate are desalination plants (17%) and wastewater reuse (3%). The current share of groundwater is estimated based on the estimated water demand in the Emirate and available production of the desalination plants. The sustainable yield of a groundwater aquifer, however, depends mainly on how fast this aquifer is replenished. Yet, the continuously increasing demand puts more pressure on this already scarce source and threatens its quality. In order to attain security in the vital groundwater source, it is essential to accurately estimate replenishment rates of groundwater.

In this paper, a simple hydrological budget model will be developed to estimate the groundwater recharge in eastern arid region of UAE. The control volume selected for this model is the surficial unconfined aquifer in the northeastern part of Abu Dhabi Emirate. A detailed conceptual model representing all potential inflows such as precipitation, recharge from treated sewage effluents ponds, surface flow, irrigation returns, and subsurface inflow; and outflows such as evapotranspiration and subsurface outflow will be developed. This model will use input parameters that are readily available or obtainable.

Keywords: Water Budget, groundwater sustainability, groundwater recharge.

1. Introduction

Accurate estimation of the groundwater recharge is essential for efficient and sustainable groundwater management especially in arid and semi-arid regions. This is because water resources are critical to economic development in most countries located in these areas
(deVries and Simmers, 2002). However, estimation of groundwater recharge and discharge fluxes in unconfined systems in arid regions are normally difficult because of lack of knowledge on how to distribute water flux and vapor discharge (Sekhar et al., 2004; Scanlon et al., 2006; Imes and Wood, 2006). Various techniques are available to quantify saturated groundwater recharge (Healy and Cook, 2002; Scanlon et al., 2002 and 2006; Rushton et al., 2006; Lee et al., 2008) including hydrological budget method, environmental tracers' techniques, and analytical and numerical models. The hydrological budget method is widely used for estimating groundwater recharge as it accounts for all inflows (e.g. precipitation, surface flow, irrigation returns, and subsurface inflow), and outflows (e.g. evapotranspiration and subsurface outflow), as well as storage changes in the unsaturated and saturated zones. The specific yield parameter is used in calculating the drained water volume from saturated storage due to changes in groundwater levels (Scanlon et al., 2002).

Water budget is an important tool that is used to describe water hydrologic cycle by summation of inputs and outputs of water resources through a study area over a fixed period of time. The hydrological system in any study area is governed by mass conservation law (Fig.1). In other words, the rise and drop of water table depends on the difference between total water inputs and total water output from the system. For a specific control volume (study area) within certain time, if a total input is less than the total output, the water table will decline in the aquifer. However, if the total input exceeds the total output, the aquifer will undergo a recharge process. In general, there are several components of a water budget. Inputs include precipitation, runoff, groundwater inflow, surface water inflow, and water diversions. While outputs include evaporation, transpiration, groundwater outflow, surface water outflow, irrigation, industrial uses, residential uses, and water diversions.

Fig. 1: Water Budget Diagram.

Al Ain aquifers are classified as thin surficial units with small to moderate permeability. The composition of those aquifers is mainly rock and gravel as shown in Fig.2 (Rizk and Alsharhan, 2008; Elmahdy and Mohamed, 2012). Al Ain aquifers are of low permeability with thickness ranges from 17 to 127m (Al Shahi, 2002). According to Al Shahi’s study, Al Ain aquifers have transmissibility ranging from 4.9 to 6000 m²/day. The maximum hydraulic conductivity recorded in the study was 266 m/day while the minimum was 0.1 m/day. Storage coefficients for Al Ain aquifers vary from 0.0000086 to 0.046. Table 1 presents the ranges of different properties in Al Ain aquifers.
2. Study Area
The domain for the study is Al Ain area (Fig. 3). The domain includes Um Ghafa, Jabal Hafit, Al Khazan, and Al Jaw plain. The properties for these areas are presented in Table 2. The thickness of the northeastern area of Al Jaww which is mainly formed by permeable rock is 45m while at the near west edge of Jabel Hafet is 130 m. The thickness of Jabel Hafet aquifer ranges between 75 and 100m. However Umm Ghafa’s aquifers have thickness ranges from 17 to 88m, and Al Khazna aquifers are around 63-80 m thick. The permeability values can be classified from small to moderate according to layers' characteristics. (Al Shahi, 2002).
Fig. 3: Domain of the study area. (Adapted from Google Earth).

Table 2: Aquifer properties for selected areas. (Al Shahi, 2002).

<table>
<thead>
<tr>
<th>Region</th>
<th>Soil Type</th>
<th>Thickness Range (m)</th>
<th>Hydraulic Conductivity (m/day)</th>
<th>Specific Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al Jaww</td>
<td>Sand and gravel</td>
<td>45-130</td>
<td>100</td>
<td>0.05</td>
</tr>
<tr>
<td>Jabel Hafet</td>
<td>Limestone, dolomite, gypsum</td>
<td>75-100</td>
<td>62.1</td>
<td>0.05</td>
</tr>
<tr>
<td>Umm Ghafa</td>
<td>Gravel</td>
<td>17-88</td>
<td>1.9</td>
<td>0.23</td>
</tr>
<tr>
<td>Al Khazna</td>
<td>Sand and gravel</td>
<td>63-80</td>
<td>3.4</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Elements of the budget model are illustrated in Figure 4. For the selected study area, the inputs comprise recharge from the Omani Mountains, irrigation, precipitation, treated influent which is re-used in irrigation and some of it is discharged, and leakage from desalination provided by Abu Dhabi and Fujairah. The received desalinated water reaches Al Ain aquifers by many means: wasted water from domestic and industrial uses, infiltration from irrigation, and other uses. Also, leakage in the transmission networks of the desalinated water (from Abu Dhabi to Al Ain) contributes in recharging the aquifers. Currently, 35 MIGD of desalinated water is infiltrating into the water tables in Al Ain, equivalent to 25% of total desalinated water supplied. This excess water causes the tables to increase by an average of 80cm each year, or infiltrates back into the distribution or sewerage network. The following lines explain in details the different components of water budget in the study area and their contribution in groundwater recharge.

3. **Budget Model**

3.1. **Inputs**

- **Recharge from Omani Mountains**
  The topography of the area between Al Ain and Oman is mainly mountains that shape many wadis. Those wadis discharge their runoff in Al Ain after crossing the international borders to UAE. The characteristics of these wadis are steep and active after heavy rainfall, but after crossing the Emirati borders the velocities of the flow are reduced a lot due to the flatter topography of the area (Brook et al., 2006). Groundwater flow entering Al Ain from Oman is calculated to be 1 Mm$^3$/yr using Darcy's Law.
**Inputs of treated Sewage:**
The two main Wastewater treatment plants (WWTP) in the area are Zakher and Al Saad plants. They have a role in recharging Al Ain aquifers as the treated wastewater is used in the irrigation of public parks and landscapes in Al Ain. From 2002 to 2008 the capacity of the Zakher plant was 54,000 m$^3$/day, however with the increase of public water uses the plant's capacity was increased after 2008 to 85,000 m$^3$/day. The actual amount of water received by the plant in average daily bases is 75,000m$^3$/day and all received water is treated and reused in irrigation (ADSSC, 2012). According to ADSSC, AlSaad plant has a capacity of 90,000 m$^3$/day, and the actual amount of the water received is 70,345 m$^3$/day. The whole amount of received water is also treated and reused in irrigation as Zakher plant (ADSSC, 2012). Fig. 5 below represents the inlet and outlet flows of Zakher plant (ADSSC, 2012).

![Fig. 5: Water Budget components for Al Ain (Numbers in Mm$^3$/yr).](image)

From the figure above, it's noticed that the inlet flow to the plant is more than outlet flow and the difference between them presents losses inside the plant. Also, the inlet flow...
experienced a gradual increase each year until 2010, and then it sharply decreased from 2010 up to 2012. We can refer such attitude to the increase of public awareness.

The average inlet flow to AlSaad plant increases annually. In 2011, the inlet flow to the plant was 65,000 m$^3$/day, and 75,000 m$^3$/day in 2012. The total treated effluent is mainly distributed between AlSaad area and AlMaqam, then the received amounts to AlMaqam is used for irrigation in Gharebah and AlMarkhaniya. The table below shows the detailed inflow and outflow from AlSaad plant in 2011 and 2012 (ADSSC, 2012).

- **Treated sewerage effluent discharge**
  Provided reports by AADC show that all the treated sewerage is reused without any disposal. However, other studies show that around 4 MIGD of water is contributing in recharging the aquifer from the disposed treated water. This amount can be justified by considering the excess treated sewage (TSE) which is not reused in irrigation is discharged into pools, lakes, or wadis next to the plants. Mainly, TSE that is used in irrigation along with that extracted from Al Ain aquifers and desalinated water which is also used for irrigation.

- **Leakage in sewerage network**
  Received sewerage water quantities from Zakher plant and the final effluent are presented in Figure 5. The difference between the inlet and the outlet is considered as leakage. It infiltrates back to the aquifer as an input. The average flow of the last 2 years (2011-2012) is calculated to be about 1 Mm$^3$/year.

### 3.2. Outputs

Groundwater in Al Ain is drained at a rate of 13 MIGD. Most of it is used in irrigation. The remaining flow moves towards Abu Dhabi city. Using Darcy’s law this amount is calculated to be 0.3 Mm$^3$/yr.

All the calculated inputs and outputs are summarized in Table 3.

**Table 3:** Inflows and Outflows from Al Ain aquifers.

<table>
<thead>
<tr>
<th>Components of water budget</th>
<th>Quantity (Mm$^3$/yr)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inflow:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow from the Omani Mountains</td>
<td>1</td>
<td>4.9</td>
</tr>
<tr>
<td>Excess Irrigation (by AA GW &amp; TSE)</td>
<td>8.5</td>
<td>41.5</td>
</tr>
<tr>
<td>Treated sewerage effluent discharged</td>
<td>10</td>
<td>48.8</td>
</tr>
<tr>
<td>Leakage in sewerage networks</td>
<td>1</td>
<td>4.9</td>
</tr>
<tr>
<td>Total</td>
<td>20.5</td>
<td>100.0</td>
</tr>
<tr>
<td><strong>Outflow:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow To Abu Dhabi</td>
<td>0.3</td>
<td>1.5</td>
</tr>
<tr>
<td>Discharge from AA aquifers (Pumping)</td>
<td>18</td>
<td>98.5</td>
</tr>
<tr>
<td>Total</td>
<td>18.3</td>
<td>100</td>
</tr>
<tr>
<td><strong>Balance</strong></td>
<td>2.2</td>
<td>-</td>
</tr>
</tbody>
</table>
4. **Summary and Conclusions**

In this paper, a simple hydrological budget model was developed to estimate the groundwater recharge in Al Ain area of UAE. The control volume selected for this model is the surficial unconfined aquifer in the northeastern part of Abu Dhabi Emirate. A detailed conceptual model representing all potential inflows such as precipitation, recharge from treated sewage effluents ponds, surface flow, irrigation returns, and subsurface inflow; and outflows such as evapotranspiration and subsurface outflow was developed. This model used input parameters that are readily available or obtainable from literature. It was found that the input flow is greater than the output flow in the past two years. This might explain the recent groundwater rise that is experienced in different areas in Al Ain. This unaccounted difference could be traced back to several sources such as the use of drinking water in irrigation in some farms or the leakage from the water distribution network. A more detailed study is needed to assess the inflows and outflows from Al Ain over a longer period for a better management of the water resources in this area.

**Acknowledgement**

Major part of this work was conducted as part of graduation project by undergraduate students Omnia Ragab Abou El Hamd, Shamma Obaid Mohammed Obaid Al Zaabi; Shaikha Ateeq Al Dhaheri; and Khadija Rashid Obaid Almatroushi in the department of civil and environmental engineering at UAE University.

**References**