Groundwater Recharge Estimation
Gash Basin- Eastern Sudan

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**Definition:**

Net recharge is described as the total quantity of water which is applied to the ground surface and infiltrates to reach the aquifer (Aller et al. 1987). Recharge is that part of the hydraulic cycle which infiltrates the soil surface (Bireir 2002). Recharge is defined, herein, as the downward flow of water reaching the water table, adding to groundwater storage (Healy 2010).

Precipitation is the primary source of groundwater. In the Gash basin the Recharge is seasonally variable according to the precipitation falls in Eritrea and Kassala area. There is less precipitation during the summer when evapotranspiration rates are much higher.

The sources of recharge of the alluvial aquifer are:
- Infiltration from surface water runoff in the Gash basin.
- Infiltration from direct rainfall.
- Inflow of groundwater from the alluvial aquifer and through the fractures from the catchment areas.

Two common methods for calculating the recharge, one is the losses between two gauge stations and the others by equation, and can be described in the following:

1. **Calculation method using equation:**

The Groundwater recharge value can be calculated as:

\[ QR = A \Delta h \cdot Sy \% \]  

[1]

Where:

- \( QR \) = Annual Groundwater recharge
- \( A \) = Surface area
- \( \Delta h \) = Difference in water level
- \( Sy \% \) = Specific Yield%
Table (1) shows the saturated area and specific yield of gash basin (study area).

<table>
<thead>
<tr>
<th>Sub area</th>
<th>Surface area (km²)</th>
<th>Specific Yield %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>136</td>
<td>20</td>
</tr>
<tr>
<td>Middle stream</td>
<td>200</td>
<td>15</td>
</tr>
<tr>
<td>Downstream</td>
<td>128</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>464</td>
<td></td>
</tr>
</tbody>
</table>

In this study the total saturated area is about 464 K m², considered upstream area (width 6km – length 17km) for the west bank and (width 2km – length 17km) for the east bank. And the Middle area (Kassala area)(width 6km – length 20km) for the west bank and (width 4 km – length 20km) for the east bank. And downstream area (width 6km – length 16km) for the west bank and (width 2km – length 16km). While Dr. Hago considered the middle area is about 85 K m², Dr. Bereir calculated the total saturated area is about 755 K m² and Dr. Abdalla Eltom calculated the total saturated area (Upstream and Middle area) is about 242.8 K m². The specific yield ranges in the study area from 20% in the upper stream zone to 15% in the middle stream zone - Kassala area (Hago 2014; Elsheikh 2010; Gadelmula 2008 and Bireir 2002).

Table: (2) Shows selected groundwater measurements from the monitoring 2013:

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Type of well</th>
<th>Area</th>
<th>DCLONG</th>
<th>DCLAT</th>
<th>June 2013</th>
<th>Oct 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>819</td>
<td>H.D</td>
<td>Upstream</td>
<td>36.420556</td>
<td>15.380833</td>
<td>08.20</td>
<td>06.65</td>
</tr>
<tr>
<td>851</td>
<td>H.D</td>
<td>Upstream</td>
<td>36.428611</td>
<td>15.373333</td>
<td>13.30</td>
<td>10.00</td>
</tr>
<tr>
<td>882</td>
<td>T.W</td>
<td>Middle</td>
<td>36.389444</td>
<td>15.455556</td>
<td>16.82</td>
<td>09.75</td>
</tr>
<tr>
<td>48</td>
<td>T.W</td>
<td>Downstream</td>
<td>36.377117</td>
<td>15.462050</td>
<td>22.00</td>
<td>18.05</td>
</tr>
<tr>
<td>446</td>
<td>H.D</td>
<td>Downstream</td>
<td>36.420278</td>
<td>15.363611</td>
<td>12.25</td>
<td>08.30</td>
</tr>
</tbody>
</table>

* Source: Groundwater Research Directorate – Kassala office

Of course the ground water level fluctuations in the gash basin affected by seasonal groundwater recharge, in WAPS report the fluctuations has been ranging between (5-7) m and Dr. Abdalla Eltom calculated the fluctuations as (9-10) m, Dr. Hago calculated The average difference between the maximum and minimum levels.
amounts to approximately 9 m near the gash and 5m away from the gash within the aquifer. But from the recent data (table 2) of the monitoring observations network the fluctuations can be calculated as: For upstream area the difference in water level in about (3) m and for the middle area is about (6) m and for the downstream area is about (4) m.

According to above tables the Groundwater recharge value can be calculated as:

\[
Q1 = 136(K \text{ m}^2) \times 3(\text{m}) \times 20\% = 81.6 \text{ M m}^3 \quad (\text{Upstream area})
\]

\[
Q2 = 200 (K \text{ m}^2) \times 6(\text{m}) \times 15\% = 180 \text{ M m}^3 \quad (\text{Middle area})
\]

\[
Q3 = 128 (K \text{ m}^2) \times 4(\text{m}) \times 20\% = 102.4 \text{ M m}^3 \quad (\text{Downstream area})
\]

Total annual direct recharge \((Q) = Q1 + Q2 + Q3 \quad [2]\)

Where:

\(Q1\) = Annual Groundwater recharge in the (Upstream area) (calculated above).

\(Q2\) = Annual Groundwater recharge in the (Middle area) (calculated above).

\(Q3\) = Annual Groundwater recharge in the (Downstream area) (calculated above).

\(Q = 81.6 + 180 + 102.4 = 364 \text{ M m}^3 \)

The total annual groundwater recharge = \(\text{Calculated annual recharge + the groundwater inflow} \quad [3]\)

\(= 364 + 15.3 = 379.3 \text{ M m}^3/\text{year}\)

2. **Discharge and gauge stations method:**

Through the past years, Gash River water levels and discharges were measured at 3 stations located on the river banks in the upstream area of Gash River as well as the downstream part of the river.

Data from the Ministry of Irrigation in Kassala suggest that approximately 50% of the discharge of the Gash – river is lost between El Gira and Kassala Bridge (25 Km). These losses are ascribed to infiltration and evaporation. Further hypothesizing, it was assumed that there is substantial underflow, transmitted through a system of buried channels between El Gira and Kassala Area (Saced, 1969).
The Gash river flows during the months of July, August and September. The discharge is very variable and the water carries a heavy load of silt. In 2003, the flood of Gash started on 1/7/2003 and ended on the 20/9/2003, and this represents the highest level recorded in the history sheet of the Gash (Elobeid, 2007).

The period when the Gash carries water is usually from late June to early October. The most important source of recharge is the infiltration at ELGira (upstream area) and Killo1.5 (Middle) and Salam Alikum (Downstream). The duration of the river discharge is depending on the period of rainfall in the source area (Eritrean Mountains).

To estimate the groundwater recharge, several things must be calculated:

2.1. Evapotranspiration

Actual evapotranspiration is a complex phenomenon due to the interaction of climate, vegetation, soil and man (WAPS 1982). Evapotranspiration of water in the area includes evapotranspiration by irrigated horticulture zone and by natural vegetation. (Yousef, 2013) calculated the total volume of water used by crop and natural vegetation is about 346.23Mm³, considered the area covered by crop equivalent and natural vegetation is about 152040000 m², while (Elshekh, 2010) calculate the evapotranspiration as 355.8 Mm³.

Table (3): Cultivated area in the Gash basin includes the natural vegetation

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Percentage %</th>
<th>Area (Feddan)</th>
<th>Area (Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onion</td>
<td>50%</td>
<td>17500</td>
<td>73500</td>
</tr>
<tr>
<td>Vegetables</td>
<td>30%</td>
<td>10500</td>
<td>44100</td>
</tr>
<tr>
<td>Fruit</td>
<td>20%</td>
<td>7000</td>
<td>29400</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>35000</td>
<td>147000</td>
</tr>
</tbody>
</table>

*Source: Kassala farmers union (Season 2013)*

Table (4): Shows the evaporation and Evapotranspiration in the Gash basin:

<table>
<thead>
<tr>
<th>Plant type ——</th>
<th>Area (Km)</th>
<th>E₀</th>
<th>Crop coefficient</th>
<th>Evapotranspiration (mm/day)</th>
<th>Evapotranspiration (Mm³/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation and Horticulture</td>
<td>147000</td>
<td>6</td>
<td>0.80</td>
<td>4.8</td>
<td>257.5</td>
</tr>
</tbody>
</table>

According to above tables (3, 4), the Evapotranspiration can be calculated according to following equation:

\[
\text{Actual evapotranspiration} = E_o \times \text{Crop coefficient} \times \text{Cultivation period} \quad [4]
\]

\[
= 6 \times 0.8 \times 147000 \times 365 = 257.5 \text{ M m}^3/\text{year}
\]

2.2. Losses between two gauge stations

Yousef (2013) was discussed the procedure, which was used to estimate the flow discharge of Gash River at each gauging station (Geira upstream and Salamalykom downstream) as a conventional method applied from early time by Kassala Research Office (K.R.O) (Ministry of Irrigation and Water Resources), this method was faced by many obstruction due to many reason, such as:

A. Disability of measuring current velocity by well known instrument such as (current meter).

B. Wide and rapid variation in flow quantities and hence water level.

C. Disability of measuring depth and width of water (changeable cross sectional area) accordingly the area of cross-section during the flood.

Therefore the method applied to estimate the discharge can be described as follows:

1. Measuring surface velocity by using float object over the water surface.

2. Finding the mean velocity by assuming relationship with surface velocity.

3. The cross section area of the river course was calculated before and after flood.

4. The mean cross section area obtained as it is difficult to obtain it during flood.

5. Wetted area according to each gauge reading obtained.

6. Multiplying the area obtained above by the mean velocity gives the discharge of each gauge reading.

7. Summing of all discharge of each gauge gives the total annual discharge.
Table (5): shows the gauge stations in Gash River:

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Location</th>
<th>Station Situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELGera</td>
<td>upstream</td>
<td>Working</td>
</tr>
<tr>
<td>Killo1.5</td>
<td>Middle</td>
<td>Working</td>
</tr>
<tr>
<td>Salam Alikum</td>
<td>downstream</td>
<td>Working</td>
</tr>
</tbody>
</table>

*source: Gash River Training Unit – Kassala

Table (6): shows the Average annual discharge of gauge stations:

<table>
<thead>
<tr>
<th>Year</th>
<th>ELGera Station(upstream)</th>
<th>Salam Alikum Station (downstream)</th>
<th>Losses between two gauge stations (M m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>665</td>
<td>589</td>
<td>76</td>
</tr>
<tr>
<td>2009</td>
<td>901</td>
<td>684</td>
<td>217</td>
</tr>
<tr>
<td>2010</td>
<td>948</td>
<td>597</td>
<td>351</td>
</tr>
<tr>
<td>2012</td>
<td>998</td>
<td>521</td>
<td>477</td>
</tr>
<tr>
<td>2013</td>
<td>614</td>
<td>195</td>
<td>419</td>
</tr>
</tbody>
</table>

*source: Gash River Training Unit – Kassala

Annual recharge of 2012 represented the ideal one because annual recharge of 2013 faced some problems in the cross sections (Gash River Training Unit – Kassala).

The losses between to gauge stations for year 2012 can be calculated as:

\[ 998 - 521 = 477 \text{ M m}^3 \]

2.3. **Underground flow**

The groundwater flow can be divided into two:

- The groundwater inflow
- The groundwater out flow

In our case we interested in the groundwater inflow because it is a part of total recharge and very important to calculate the water balance.
The groundwater inflow from Eritrean boulder is calculated according to the following formula:

\[ q = Tiw \]  \[5\]

Where:
- \( q \) = Groundwater discharge (m3/d)
- \( T \) = transmissivity (m2/d).
- \( i \) = hydraulic gradient (calculated above).
- \( w \) = width of the aquifer.

The average transmissivity is 1400 (m2/d), hydraulic gradient (i) is 0.005 and the average width of aquifers is 6 km estimated to be:

\[ \text{Inflow} = 1400(\text{m2/d}) \times 0.005 \times 6000 \times 365 = 15330000 = 15.3 \text{ M m}^3/\text{year}. \]

2.4. Calculation of the groundwater recharge

According to above calculations the groundwater recharge can be estimated using the following equation:

\[ \text{Annual Recharge values} = \text{Total Loss between gauges (A - B) - ET} \]  \[6\]

(A) = Annual discharge of ELGera station (calculated above).
(B) = Annual discharge Salam Alikum station (calculated above).
ET = Evapotranspiration (Estimated above).

The recharge can be calculated as

\[ = 477 - 257.5 = 219.5 \text{ M m}^3 \text{ annually}. \]

The total annual groundwater recharge =

Calculated annual recharge + the groundwater inflow

\[ = 219.5 + 15.3 = 234.8 \text{ M m}^3/\text{year} \]

<table>
<thead>
<tr>
<th>Statement</th>
<th>M m³/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual groundwater recharge</td>
<td>219.5</td>
</tr>
<tr>
<td>The groundwater inflow</td>
<td>15.3</td>
</tr>
<tr>
<td>The total annual groundwater recharge</td>
<td>234.8</td>
</tr>
</tbody>
</table>
Conclusions

The total annual recharge by Equation and gauge stations methods can be concluded in the table below:

<table>
<thead>
<tr>
<th>Statement</th>
<th>M m³/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual recharge by Equation method</td>
<td>379.3</td>
</tr>
<tr>
<td>Annual recharge by gauge stations method</td>
<td>234.8</td>
</tr>
</tbody>
</table>
References


