Paper title

Groundwater Recharge Estimation
Gash Basin- Eastern Sudan

Prepared By

Khalid Elsir Ahmed Nayl

Msc. Hydrogeology

Checked by

Dr.Hago Ali Hago

Alneelain University

September 2014

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:

$$QR = A.\Delta h.Sy\% \quad [1]$$

Where:

QR= Annual Groundwater recharge

A= Surface area

Δh= Difference in water level

Sy= Specific Yield%

Table (1) shows the saturated area and specific yield of gash basin (study area).

Sub area	Surface area (km2)	Specific Yield%
Upstream	136	20
Middle stream	200	15
Downstream	128	20
Total	464	

In this study the total saturated area is about 464 $K\,m^2$, considered upstream are (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 $K\,m^2$, Dr.Bereir calculated the total saturated area is about 755 $K\,m^2$ and Dr.Abdalla Eltom calculated the total saturated area (Upstream and Middle area) is about 242.8 $K\,m^2$. 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 2010Gadelmula 2008 and Bireir 2002).

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

Well No.	Type of well	Area	DCLONG	DCLAT	June 2013	Oct 2013
819	H.D	Upstream	36.420556	15.380833	08.20	06.65
851	H.D	Upstream	36.428611	15.373333	13.30	10.00
882	T.W	Middle	36.389444	15.455556	16.82	09.75
G2	T.W	Middle	36.390278	15.448056	21.40	15.05
48	T.W	Downstream	36.377117	15.462050	22.00	18.05
446	H.D	Downstream	36.420278	15.363611	12.25	08.30

▪ 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:

$Q1 = 136(K\,m^2) \times 3(m) \times 20\% = 81.6\ M\,m^3$ (*Upstream area*)

$Q2 = 200\ (K\,m^2) \times 6(m) \times 15\% = 180\ M\,m^3$(*Middle area*)

$Q3 = 128\ (K\,m^2) \times 4(m) \times 20\% = 102.4\ M\,m^3$ (*Downstream area*)

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

Where:

Q1= Annual Groundwater recharge in the (*Upstream area*) (calçulated 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 M m³**

The total annual groundwater recharge =

Calculated annual recharge + the groundwater inflow [3]

$= 364 + 15.3 = \mathbf{379.3}\ M\,m^3/year$

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 hypothering, it was assumed that there is substantial underflow, transmitted through a system of buried channels between El Gira and Kassala Area (Saeed, 1969).

The Gash river flows during the months of July, August and September The discharge are very variable and the water carries a heavy load of silt. In 2003the flood of Gash started on 1/7/2003 and ended on the 20/9/2003, and this represent 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 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

Plant type	Percentage %	Area (Feddan)	Area (Km)
Onion	50 %	17500	73500
Vegetables	30 %	10500	44100
Fruit	20%	7000	29400
Total	100%	35000	147000

▪**Source:** Kassala farmers union (Season 2013)

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

Plant type	Area (Km)	E_o	Crop coefficient	Evapotranspiration (mm/day)	Evapotranspiration In Mm³/year
Vegetation and Horticulture	147000	6	0.80	4.8	257.5

▪**Source:** E_o = Daily average evaporation according to Kassala metrological station (2010).
▪**Source:** Crop coefficient according to Food and Agricultural Organization standard (F.A.O) (1979).

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

$$Actual\ evapotranspiration = E_o \times Crop\ coefficient \times Cultivation\ period\ coefficient \quad [4]$$

$$= 6 \times 0.8 \times 147000 \times 365 = \mathbf{257.5\ M\ m^3/year}$$

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:

Station Name	Location	Station Situation
ELGera	upstream	Working
Killo1.5	Middle	Working
Salam Alikum	downstream	Working

•source: Gash River Training Unit – Kassala

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

Year	ELGera Station(upstream)	Salam Alikum Station (downstream)	Losses between two gauge stations (M m^3)
2008	665	589	76
2009	901	684	217
2010	948	597	351
2012	998	521	477
2013	614	195	419

•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:

$$998 - 521 = \mathbf{477\ M}\ m^3$$

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:

$$q = Tiw \qquad [5]$$

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:

Inflow = 1400(m2/d) × 0.005 × 6000 × 365 = 15330000 = **15.3** M m^3/year.

2.4. Calculation of the groundwater recharge

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

Annual Recharge values = 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 M m^3 annually.
The total annual groundwater recharge =
Calculated annual recharge + the groundwater inflow [7]

= 219.5 + 15.3 = **234.8** M m^3/year

Table (7): shows the Total annual Recharge:

Statement	**M m^3/year**
Annual groundwater recharge	219.5
The groundwater inflow	15.3
The total annual groundwater recharge	**234.8**

Conclusions

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

Statement	M m^3/year
Annual recharge by Equation method	**379.3**
Annual recharge by gauge stations method	**234.8**

References

Aller L., T. Bennett, J.H. Lehr, R.J. Petty, and G. Hackett. 1987. DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings, EPA 600/2-87-035.Ada, Oklahoma: U.S. Environmental Protection Agency.

Bireir, F.A., (2002): The geochemical evolution of the groundwater in Gash Alluvial basin, using isotope hydrochemistry, in Gash an alluvial Basin, Semi-Arid Area. NE Sudan

Elobeid, S. A., (2007): Potentialities of Groundwater Resources of the River Gash Basin, Kassala state, East Sudan. M.Sc.Thesis, Elneelain University, Sudan.105 pp.

Elshekh, A.E.M., Nayl ,K.A., Zeinelabdein,E & Elobeid, S. A. (2010): Groundwater budget for the upper and middle parts of the River Gash Basin, eastern Sudan, Journal Saudi Society for Geosciences, DOI 10.1007/s12517-010-0184-4.

Fetter, C.W.,(1980): Applied Hydrogeology. Charless E. Merrill Publishing Company, Colubus, Toronto, London, Sydne, 592pp.

Hago,A.H.,(2014): Hydrochemical Characteristics of Groundwater Midstream Area-Gash River Basin, Eastern Sudan.Phd. Thesis, Technischen Universität Berlin.Germany.144 pp.

Healy, R. W. (2010). Estimating groundwater recharge, Cambridge University Press, Cambridge.

Saeed, E.M., (1969): Hydrogeology of Kassala district, Kassala province, Democratic Republic of Sudan. Geol. Miner. Resour. Dep., Khartoum, Bull.17, 95 pp.

WAP (1982): Water Resources Assessment Program in the Sudan: Kassala Gash basin. Final Technical Report. N. W. C., Kassala.

Yousef , E. M., (2013): Groundwater and Gash River Interactions, Kassala State, Sudan. M.Sc.Thesis, University of Gezira, Sudan.70 pp.