Harnessing Floods to Enhance Livelihoods and Ecosystem Services in Gash Area, Sudan

***Volume II*:**

Gash River and Gash Delta Water Resources Management

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Summary

Gash River serves different water users in Kassala State, and it is considered as the main source for the domestic, agricultural and environmental uses. One of the biggest challenges in Gash River Basin is to attain the optimum water use and allocation among the different users. The main beneficiaries of the Gash River surface water are: Gash Agricultural Scheme (GAS) which most of Kassala State citizens are dependable on it, environmental flow to Gash Die at the downstream of the river and also the groundwater is mainly recharged from the river and it is the source for the drinking water for all the surrounded area and the Private Agricultural Schemes (PAS) or Sawagi.

In order to allocate the surface and ground water resources in Gash River, the River Basin Simulation Model (RIBASIM) was used. RIBASIM is an effective tool to support the process of water resources planning and the analysis of water uses, sourcing and distribution. It can be used to allocate different water resources at the river basin level by linking the hydrological inputs with the water users and it is based on water balance approach.

First, the schematization and translation of the nature in the model have been done. After that the hydrological data used for the model was entered which includes: the inflow time series for an upstream station which is New Geera, the groundwater recharge that was estimated using two methods as reported by Kabeer, 2016; which provided an average percentage of 32% of the total inflow to be recharged to the groundwater. Other literature stated that the groundwater recharge from the Gash River is 28% of the total inflow. For this study the 32% is considered for the analysis.

The Irrigation data as the areas and the crop water requirements were used for both GAS and PAS, the irrigated areas of GAS were provided by the GAS offices for the previous last years while an average area for PAS was considered. The water consumption rates and the population served from groundwater in that region were also used.

The analysis at first has been carried out for the available records of the previous years (2005 – 2013) to assess the average situation of the water allocation for the different users. The simulation of the Gash system has been analyzed on yearly basis using time step of 10 days and this resulted in average allocation as follows: 54.7% for GAS, 32% for the Groundwater recharge and 13.3% flows to the Gash Die.

Furthermore different scenarios have been tested and analyzed for an average year (650 Mm^3/year). Baseline and three scenarios were carried out for the average flow condition based on applying different priorities for the different users. The scenarios can be described as follows:

1. Baseline was based on the average demands for the different users.
2. Scenario1 has tested the possibility for expansion of the irrigated area in GAS under the current situation and with improving the efficiency considering the average requirements for other users.
3. Scenario2 was related to giving the priority to horticulture for expansion under the current situation and with improving the efficiency.
4. Scenario3 was taken based on the hypothesis of the drop of groundwater table in Gash basin and then a reduction by 25% in horticulture areas was considered for the analysis.

The average flow condition analysis generally showed that for GAS only 8% increase more than the average irrigated areas which is equivalent to about 90,000 feddans to be possible under the current situation, while the improvement in GAS irrigation efficiency up to 65% can contribute in expansion up to 104,000 feddans irrigated area. For the horticulture, the maximum cultivated areas can reach about 61,500 feddans this only with Mesquite control and improving the horticulture irrigation efficiency to 80%. A minimum flow of 8 Mm^3 was allocated for Gash Die but it will require a network rehabilitation.

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GAS	=	Gash Agricultural Schemes
GWR	=	Groundwater Recharge
PAS	=	Private Agricultural Schemes (Swagi)
PWS	=	Public Water Supply
RIBASIM	=	River Basin Simulation Model

1. Introduction

Sustainable development and management of seasonal stream like Gash River requires dependable and properly analyzed data. Long period of observations of seasonal river discharge is very essential as well as other information such as meteorology, topography, structure and soil.
The major limitation of the development of seasonal stream hydrology in arid zones is the lack of high quality observations, especially discharge, rainfall and evaporation records. Remotely sensed data can be used to enhance the limited available observational data to fill this gap. Satellite technology provides some real potential for comprehensive rainfall and evapotranspiration monitoring in space and time; however, most of the satellite rainfall estimation techniques are still experimental and require further research, especially in the calibration stage.
Gash River is the main source of water supply for all purposes to Kassala town and its surrounding towns and villages. It is the only recharge source to Gash ground water basin. Gash River also is the source that created the delta about (300000 feddans) that has the most fertile land for agriculture on which most of the Kassala state socio economic activities depend. People say that without Gash River there will be no Kassala.
Population of Kassala town is more than 0.5 million and it is the most affected town by the flooding of Gash River. It had been attacked by several damaging high floods from the Gash River most of which were very severe. In the last three decades, Kassala was attacked by six devastating floods recorded in the years 1975, 1983, 1988, 1993, 1998 and 2003. The Gash River is considered a source of frequent terror to the inhabitants on both sides of its banks. Figure 1 shows the location map of the Gash River and its topography. It can be seen that almost all the basin area of the Gash River lies outside Sudan in a mountainous land (Figure 1).

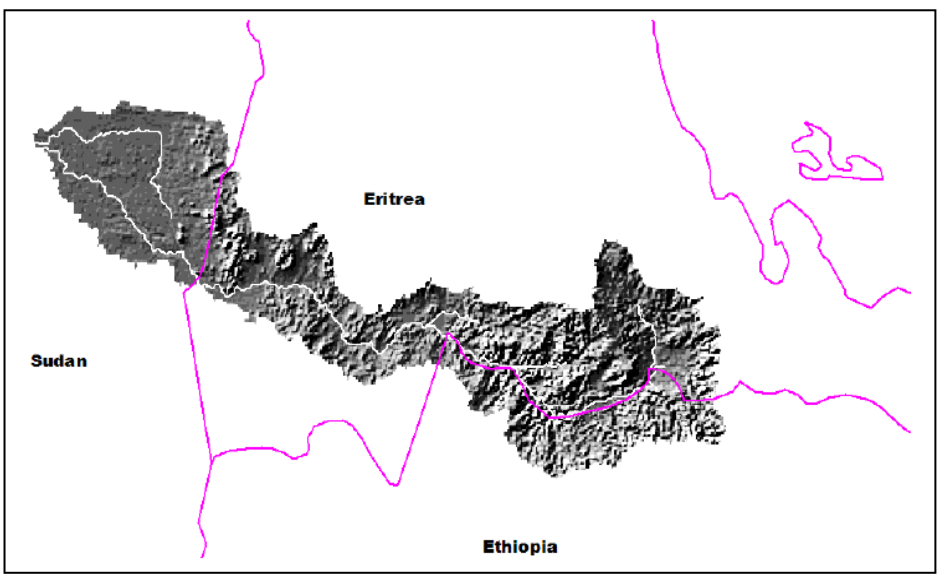

Figure 1: Gash River Basin

1.1 Hydrology of Gash River

In Eritrea 20 km south Asmara, the Gash River which is called Mareb has a catchment ranges from 30 to 90 Km in width and approximately 250 Km in length. The catchment area is estimated to be about 21000 km^2. The first 175 Km is perennial while it becomes ephemeral before it enters Sudan. The bed slope of the river is varying with average of 2m per km. Before entering Sudan, the river passes a narrow rocky course while the flood plain is populated with dense palm trees. From morphological point of view, the Gash River is considered braided river. Thus, it becomes wider and shallower. In such rivers, the flow takes many directions resulting in unstable river that changes its course.

There is no reliable rainfall data available in the catchment. Generally, in the Kassala area the climate is a tropic continental type. It is governed by the dry north wind in the winter and moist south wind in the summer. The temperature ranges from 16 to 42 c^o and relative humidity ranges from 40 to 60%. Geologically the area is Precambrian basement complex. Furthermore, the other formation is the clays of the plain, consisting of a maximum of 18 meters thickness on the east and west sides of the river. The alluvial deposits formed by the Gash River are the third type of formation with a thickness ranging from 17 to 34 meters.

The Gash River is one of three major spate irrigation systems in Sudan, in addition to Khor Baraka and Khor Abu Habil. This River generally flows during wet season over the period from the end of June and continue till October and shortly after extreme precipitation in upstream regions, the flow varies significantly through the season and sudden high waves occurred from time to time. The average annual discharge of Gash is estimated about 680 Mm^3/year. (Y. M. Omer, 2013)

1.2 Objectives

The main aim of this study is to allocate the water resources of the Gash River between the different water users allow (irrigation, public water supply and minimum flow to Gash die…). The objective of this study is to develop an execution scenario using RIBASIM software for water management and sustainable development of the Gash River and Gash River Delta that will focus on the following main items;

1. Insure the safety environmental flow to Gash delta.
2. Provide the best scenario that will support Irrigation of the Gash agriculture Scheme and the Gash River delta.

2. Modeling

In order to assess the impact of different scenarios on surface and ground water resources in Gash system in Sudan, The River Basin Simulation Model (RIBASIM) was used. RIBASIM is software developed by Deltares-Delft. The model is based on a water balance approach. It can be used to allocate different water resources at the river basin level by linking the hydrological inputs with the water users. It is also used to manage the operation of the hydraulic structures and the demand using a time step between one day to one month and allows for the simulation of different types

of structures (reservoirs, hydropower, Groundwater etc...) and large numbers of water demand such as public water supply, industrial water use, irrigation demand and Environmental flow.
The model has been run using 10-daily simulation time step, as it can provide proportionally better results because there is significant variation in Gash flow from a day to another when considering the daily simulation. All inflows and relevant demand were entered on 10-days basis.

3. Used data

Data required for Gash river water resources allocation consists of:

1. The inflow time series at New Geera station to be considered as the total variable flow that will be allocated between different water users.
2. Gash Agricultural Schemes areas, Crop water requirements and Irrigation efficiency.
3. The Ground water recharge which has two main users the Public water supply for Kassala State and the Private agricultural schemes or Sawagi as it is called.

3.1 Inflow data

The New Geera station located on the Sudanese/Eritrean border has records of daily discharge measurementsfrom 2000 to 2013 with 2004 missing. In RIBASIM software, station represents a variable inflow node at the upstream boundary of the Gash River. The graph below shows the time series at New Geera station, (Figure 2).

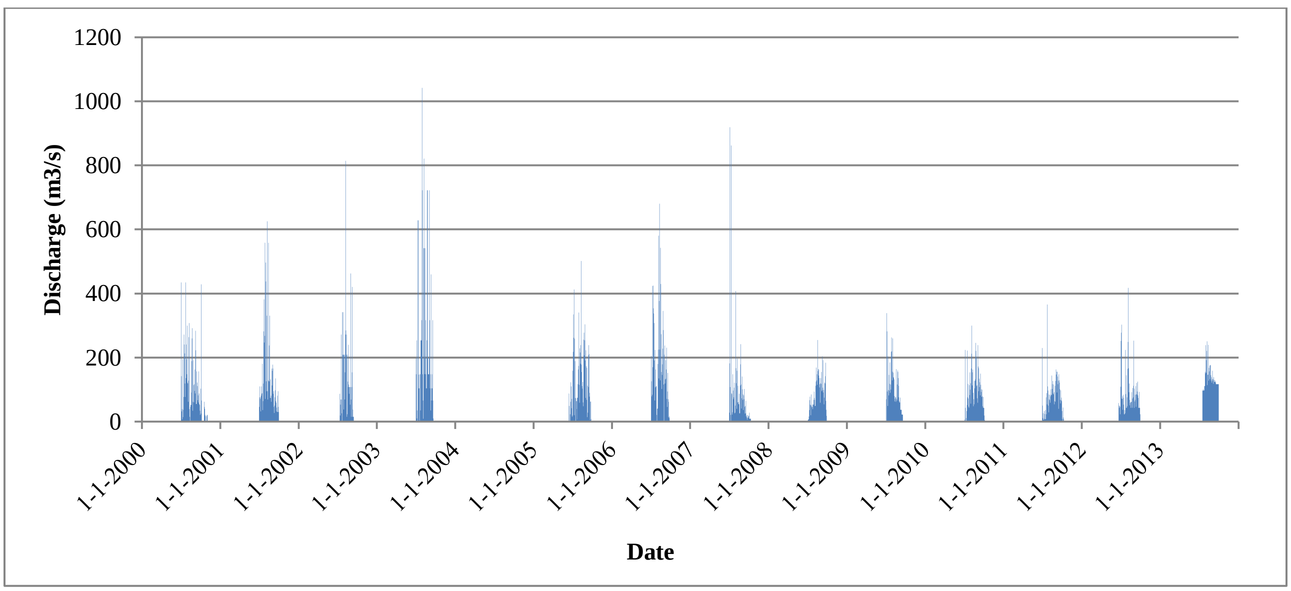

Figure 2: Discharge time series at New Geera station

From the calculated annual yield at New Geera station for all the years as shown in Table 1, one can determine the maximum, average and minimum flows in Gash River.

Table 1: The annual inflow of Gash River at New Geera station

Year	Annual inflow (Mm^3/year)
2000	997.03
2001	1007.39
2002	707.15
2003	1470.19
2004	-
2005	1100.72
2006	1205.74

Year	Annual inflow (Mm^3/year)
2007	711.17
2008	656.43
2009	675.47
2010	780.35
2011	649.25
2012	704.91
2013	867.34

The maximum yield during the period from 2000 to 2013 is 1470.19 Mm^3 (2003), while the minimum record is 649.25 Mm^3 (2011). The average yield for this period is about 915.61 Mm^3. The long term average of the Gash yield is about 650 Mm^3 (1907 – 2005) as reported by (Samir 2011), the minimum annual discharge recorded is 170 Mm^3 (1921) and the maximum annual discharge is 1430 Mm^3 (1983).

3.2 Irrigation data

The irrigated area in Gash Basin is the Gash Agricultural Scheme (GAS) which is irrigated directly from the surface run-off of the Gash River. The Gash Agricultural Scheme is divided into six blocks from Kassala upstream, Makali, Degain, Matateib, Tendalai and Hadalyia blocks. The cultivated areas in each block differ from year to year due to availability of water. The available records of these areas are from 2004 to 2014, Table (2) below gives the yearly cultivated areas in feddans.

Table 2: The cultivated areas in GAS Blocks in feddans

Block	Kassala	Makali	Degain	Tendelai	Metateib	Hadaliya	Total
2004	13500	9000	19000	6000	10500	5000	63000
2005	20174	15200	18000	16000	10000	5000	84374
2006	16623	12503	16850	16159	14000	20000	96135
2007	15743	16042	15700	15006	13780	7821	84092
2008	15000	16000	12500	5208	3350	5000	57058
2009	14430	12478	15191	13642	7509	7500	70750
2010	16983	17652	14050	14355	11350	10462	84852
2011	14062	13484	10624	6953	11877	5000	62000
2012	16100	15900	18222	12956	10840	8000	82018
2013	15340	16101	15563	14021	5316	5000	71341
2014	18892	23525	26763	33136	12488	25201	140005
Average	16077	15262	16588	13949	10092	9453	**81420**

The areas of Gash Agricultural Schemes (GAS) vary within the range of about 57000 (2008) to 140000 feddans (2014). The average cultivated area was found about 81420 feddans.

Regarding the cropping pattern the main crop cultivated in this scheme is Sorghum; the crop water requirement is calculated using "CLIMWAT and CROPWAT" software. The estimation of Sorghum water indent is detailed below:

CLIMWAT Software was used to determine the metrological data at Kassala Station to calculate the reference evapotranspiration (ET_0). The mean parameters are shown in Table (3).

Table 3: The metrological data and ET_0 estimation at Kassala

Monthly ETo Penman-Monteith - D:\KASSALA.pen

Country: Location 41 | Station: KASSALA

Altitude: 500 m. | Latitude: 15.46 °N | Longitude: 36.40 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	16.5	33.7	48	156	8.8	18.8	4.81
February	17.2	35.2	43	156	9.4	21.3	5.48
March	20.1	38.3	40	156	9.3	22.9	6.27
April	23.0	40.8	37	156	9.6	24.3	7.00
May	25.8	41.6	39	156	9.4	23.9	7.18
June	25.7	39.8	42	190	8.8	22.8	7.31
July	23.9	36.1	57	233	7.5	20.8	6.41
August	23.4	34.9	63	233	7.5	20.8	5.90
September	24.0	36.8	55	156	8.9	22.5	5.95
October	24.3	38.7	44	112	9.3	21.6	5.60
November	21.4	37.0	47	156	9.1	19.5	5.46
December	17.9	34.4	52	156	8.8	18.3	4.78
Average	**21.9**	**37.3**	**47**	**168**	**8.9**	**21.5**	**6.01**

The average reference evapotranspiration (ET_0) was estimated as 6.01 mm/day.

The crop factor values for Sorghum and the corresponding crop water requirement (CWR) are as given in Table 4.

Table 4: Sorghum water requirement calculation

Months	ET_0 (mm/day)	Sorghum (K_c)	$ET_{(Sorghum)}$ (m^3/feddan)
Jan.	4.81		
Feb.	5.48		
Mar.	6.27		
Apr.	7.00		
May	7.18		
Jun.	7.31	0.39	359.21

Jul.	6.41	0.95	792.85
Aug.	5.90	1.10	845.00
Sep.	5.95	0.81	607.26
Oct.	5.60	0.81	590.59
Nov.	5.46		
Dec.	4.78		
Total CWR (m^3/feddan/Season)			**3194.91**

The total Crop Water Requirement for Sorghum was estimated at 3200 m^3/feddan/season. Generally the spate irrigation overall efficiency is estimated as 40% (includes a high percentage goes as ground water recharge). In this study the ground water recharge is estimated particularly and the irrigation application efficiency on field is assumed to be 55%, hence the losses are adopted as 15% evapotranspiration losses, 22% deep percolation recharges the groundwater and 8% other losses.

3.3 Groundwater

The Groundwater flow in Gash basin represents a user and a source in the same time. The recharge to the ground water reservoir from the Gash River andon the other handit is considered as the source of the abstractions to two main users which are:

1. The public water supply for Kassala State
2. The private agricultural schemes.

The storage capacity of the Groundwater reservoir is approximately about 502 Mm^3 as reported by Elsheikh (2008). The initial storage will be assumed to be 220 Mm^3 according to the average annual Ground water recharge and the abstractions at the end of each year.

3.3.1 Groundwater recharge

The model requires data entry of the recharge time series and so to estimate the recharge; several studies reported different methods to estimate the recharge in Gash aquifer. Two methods were considered here, Table 5.

a) A method which done by Kabeer, 2016 & Nayl, 2014which is based on calculating the losses between two stations (New Geera and Salam Alaikom). The losses were estimated to represent the ground water recharge and evapotranspiration.
b) Nayl, 2014 also used an equation to determine the annual recharge using the saturated area and the variation in depths between the dry and wet seasons to provide the recharge volume. The Ground Water Directorate in Kassala Town recorded the changes in depths annually. According to Nayl, 2014 there are different calculations for the saturated area, Nayl, 2014 stated the total saturated area is 464 km^2 calculated in three

sub-zones (upstream, middle and downstream Gash River). The equation to calculate the recharge is:

$$QR = A * \Delta h * S_y$$

Where:
QR = Annual Groundwater recharge (Mm^3)
A = Saturated Surface Area (m^2)
Δh = Difference in Water Level (m)
S_y = Specific Yield%

Table 5: Annual groundwater recharge from 2008 to 2012 using the two methods

Year	**Losses Method (Mm^3)**	**Equation method (Mm^3)**
2008	196.05	362.66
2009	123.09	248.40
2010	291.74	178.85
2011	285.58	182.33
2012	119.54	223.56
Average	203.20	239.16
% from average inflow	**29.31**	**34.50**

As the two methods provided almost closeoverall average results; it will be considered here the recharge as the average of the two methods which is 32% of the annual inflow.
The groundwater inflow is also considered as part of the recharge and it can be calculated using the equation below:

$$q = T * i * w$$

Where
q = Groundwater discharge (m^3/s)
T = Transmissivity (m^2/d)
i = Hydraulic gradient
w = Width of aquifer

Nayl, 2014 reported that the average transmissivity is 1400 m^2/d, hydraulic gradient is 0.005 and the aquifer average width is 6 km, and so the ground water discharge is 15.3 Mm^3/year. This is considered insignificant compared with the assumed recharge from the Gash River so it can be neglected.

The Ground water reservoir in the nature has different characteristics from zone to the other forasmuch the difference in the morphology of the aquifers, and so it will be very difficult to be simulated as it is in the model and even the model is more related to the water balance approach than dealing with the ground water reservoir characteristics.
In the model the reservoir is represented by one node to simplify the distribution of the recharged water and abstracted water in the system and so assumed average characteristics are taken, and hence the results of the ground water cannot be representative for the real nature.

3.3.2 Abstractions from Groundwater

The abstractions from the groundwater reservoir mainly serve the public water supply and the irrigation of the private agricultural schemes (in northern and southern Swagi).
Public Water Supply: The demand of the water supply according to (Water Supply Corporation–Kassala) for year (2011 -2013) can be determined according to the population and the demand per capita for the years as in Table (6).

Table 6: Public water supply demand

Year	Population	Demand (l/c/d)	Total (Mm^3/year)
2011	1247280	15.8	7.19
2012	1279710	19.4	9.06
2013	1312982	23	11.02

For the years before 2011; the demand will be considered as 15 l/c/d and the population will be estimated by the same rate (0.026) as for the given years. Comparing the recorded abstraction from groundwater Kabeer, 2016 and assuming the distribution losses; the average domestic water demand is about 20 Mm^3/year.
Horticulture and Private Agricultural Schemes: The water source for the irrigation of “Swagi” is pumping groundwater fromso many number of wells. The (Horticulture Office – Kassala State) stated that there is 55000 and 25000 feddans allocated for the horticultural irrigation in Kassala and within Gash Agricultural Scheme respectively. The number of the abstractions wells in Kassala is about 1819 wells distributed in upstream, middle and downstream areas of Gash basin. Each well serves on average 15 feddans; then the total area according to the horticulture office is about 25000 feddans which is cultivated by onions as the main crop in addition to other vegetables and fruits. While with GAS about 20000 feddans is cultivated which provides on average about 45000 feddans cultivated in the horticultural areas.
Assuming average crop demand for Citrus (1200mm/season) and onions (550mm/season) and 70% efficiency (portion of losses is deep percolation which recharges groundwater and reused) for the horticultural irrigation this results in annual water demand of about 236 Mm^3.

3.4 Gash Die demand

Gash die is located downstream the Gash river and has its own ecosystem that requires amount of water to meet its demand. The lack of measurements in Gash River especially the measurements of the flow to Gas die is a problem.

Roughly estimation has been carried out to estimate a minimum demand of Gash Die which has domestic, livestock and environmental requirements as described by Table 7.

Table 7: Gash Die requirements estimation

User	Unit	Requirements	Total Demand
Domestic	113000	20 l/c/d	1 Mm^3
Livestock	150000	7 l/c/d	0.4 Mm^3
Drought Tolerant multi-purpose tree	5200 feddan	150 mm	6.6 Mm^3
Gash Die Total Demand			**8.0 Mm^3**

4. Schematization and model setup

The inflow node, irrigation schemes, groundwater reservoir, loss flow, public water supply and the terminal node which represent Gash Die are all considered in the schematization which is shown in Figure (3) below. The ground water recharge was represented by two nodes, one is a loss flow node on the river and the second considered as a variable inflow node feed the groundwater reservoir. All inflows and relevant demand were entered on 10-days basis.

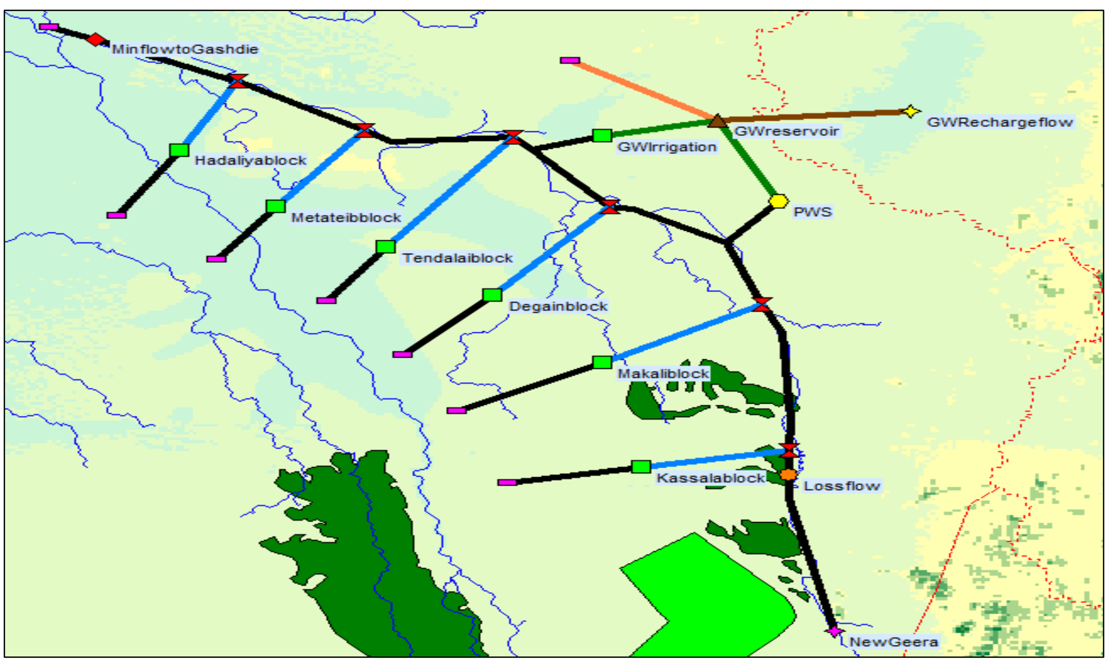

Figure 3: The schematization of the Gash River model

5. Model calibration

RIBASIM depends on the conceptual modeling and simulating the nature as same as possible and so the quality of its results completely depends on the quality of the input data.

A simulation for the model has been done by using the data as described in section (2) and taking the overlapping period (2005 – 2013) where all the data required for the model is available, the model was run in different two ways in attempt to find the proper simulation manner. The results of this testing provided a general idea about the water allocation during the previous years.

i. Considering all years in one model:

Here the model was run considering all the years (2005 – 2013) inflow with average cultivated areas, constant irrigation demand and 32% of the total flow goes to groundwater recharge. Figures 4&5 show the average results of the water allocation.

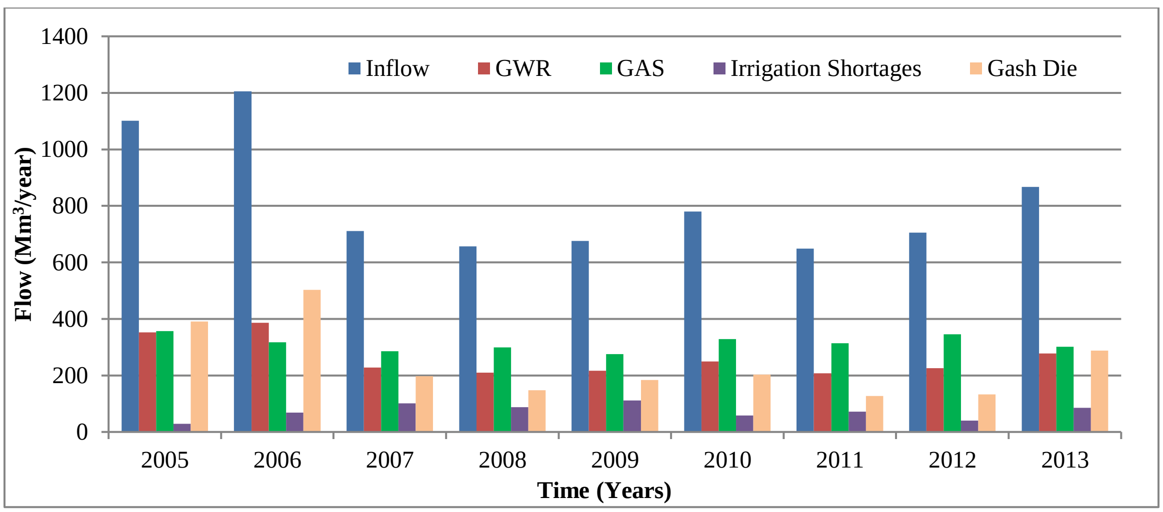

Figure 4: The annual water allocation results by running all the years in one model

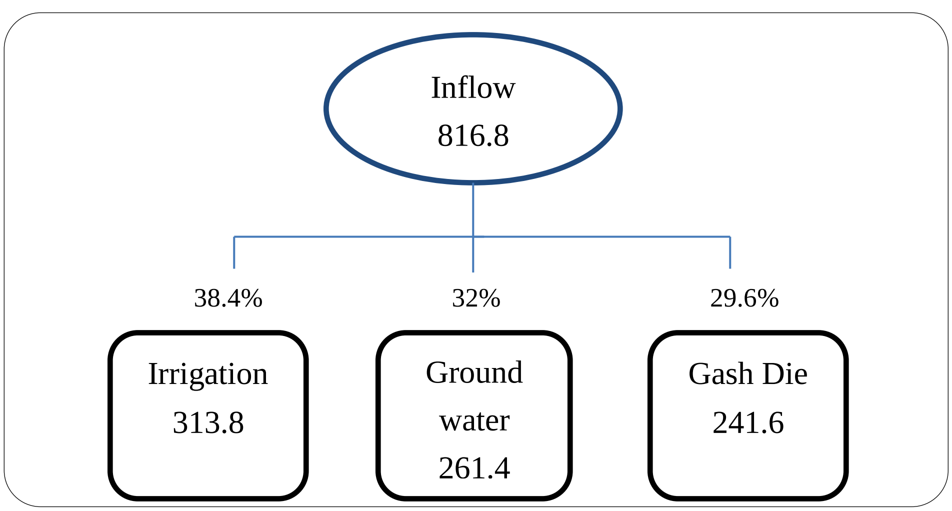

Figure 5: Average results of the water resources allocation (2005 - 2013)

Running all the years together resulted in:-

- Shortages in the irrigation demand as consequent of the variation in the season length and inflow distribution through the season.
- The Ground water storage has been reduced in the last years and it didn't meet the abstractions demand.
- The flow to Gash Die is about 30% of the flow in average and still there are upstream shortages.
- These results were improved by running the model on yearly basis, so more details will be shown in the following section.

ii. Simulation on yearly basis:

Each year was run particularly with entering its data (cultivated areas) and the irrigation demand distributed as percentages from inflow to reduce the shortages in the irrigation areas.For each year the initial ground water storage was adapted from the previous year. The results of this assumption provided water allocation as shown in Figures (6) and (7).

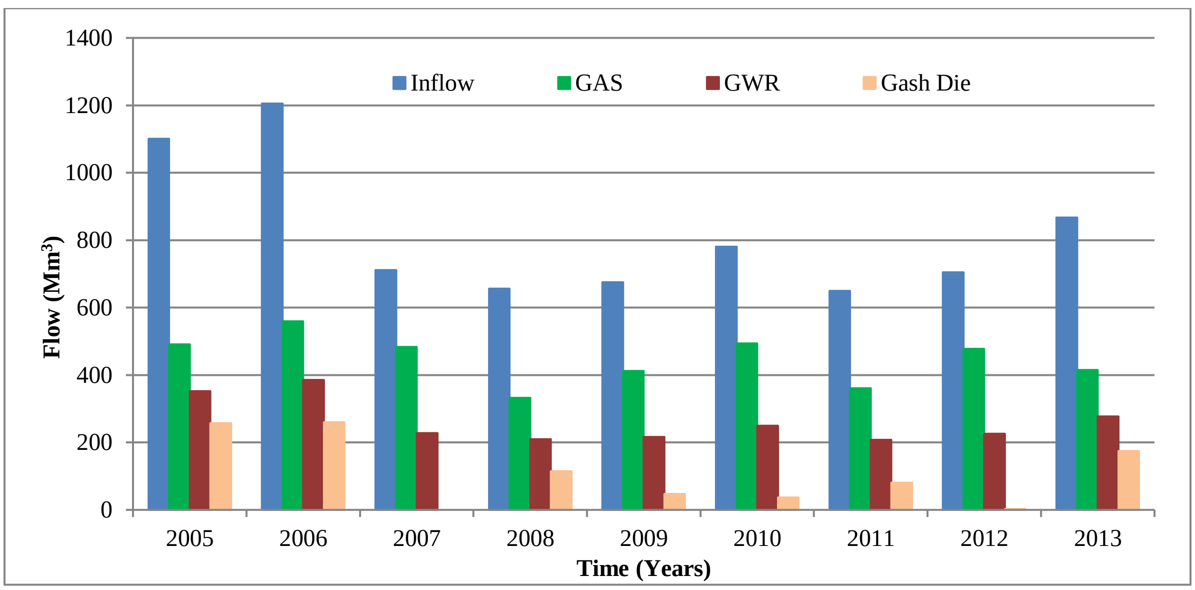

Figure 6: The annual water allocation results for simulation on yearly basis

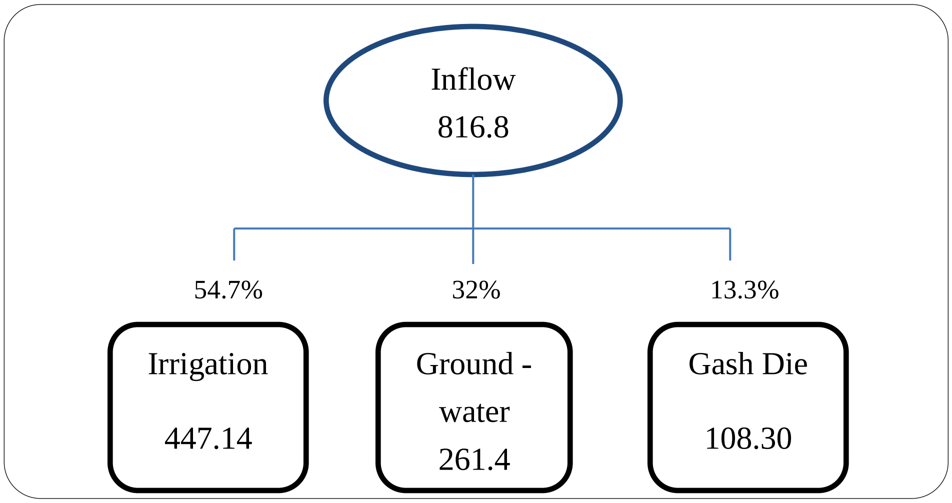

Figure 7: The average water allocation results by considering yearly simulation

6. Scenarios testing

A simple statistical analysis has been carried out for the available Gash River inflows historical records, the available annual data from 1907 – 2013 was ranked to determine the average to be analyzed. Figure 8 shows the available records of the Gash River inflow (Bashar, 2016).

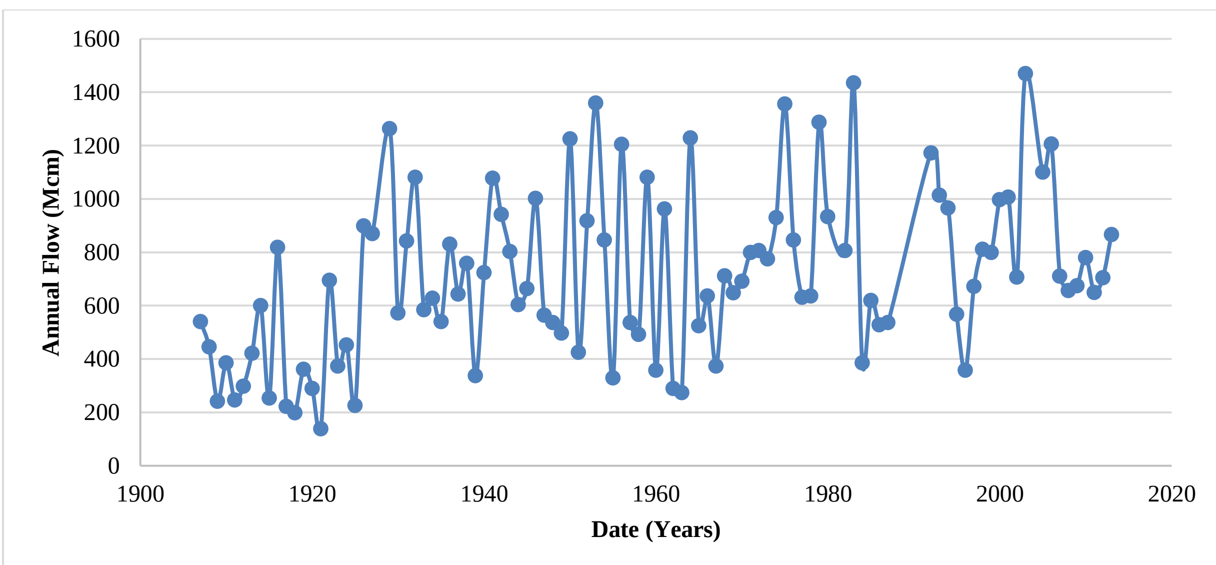

Figure 8: Annual yield of Gash River

6.1 Average year

In this study it was focused on the analysis of an average year; the long term average yield of Gash was considered for the analysis which is about 650 Mm^3, Figure 9. A baseline and other three different scenarios have been considered by applying different interventions in each case as described by Table 8.

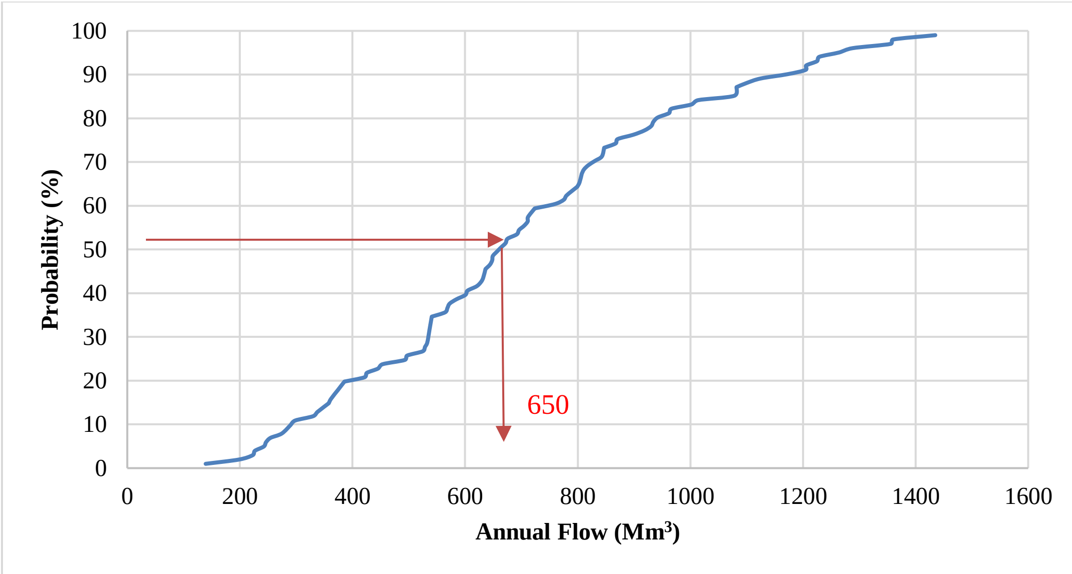

Figure 9: Frequency analysis of the annual Gash River flows

Table 8: Tested scenarios variables

Scenario	GAS	Horticulture (Groundwater)
Baseline	81,420 feddans	45,000 feddans
Sc. 1	Possibilities to expand under current & improved efficiency	45,000 feddans
Sc. 2	81,420 feddans	Possibilities to expand under current & improved efficiency
Sc. 3	81,420 feddans	Impact of reduction by 25% (34,000 feddans)

6.1.1 Baseline

The data that will be used to run the model is the average irrigated areas, average groundwater recharge which was assumed in this case to be about 234 Mm^3 as stated by Kabeer measurements, 2016. The average PWS demands, average private schemes areas and the minimum flow to gash die were also considered. The abstractions from Groundwater were considered to be within the annual recharge from Gash River so the initial groundwater storage will not be affected principally as it is unknown exactly. The demands and the allocated water amounts for this case are shown in Table (9).

Table 9: Baseline analysis results for an average year

Scenarios	**Total Inflow**	**GAS**	**GW - Horticulture**	**GW - Domestic**	**Gash Die**	**Surface water Balance**	**Groundwater Balance**
Average Demands (Mm^3)	650	474	236	20	8	-	-
Baseline – Allocated Water (Mm^3)	650	474	236	20	46	0	+13
Water allocation Percentages (%)	100	73	36	3	7	-	+2

The baseline water balance analysis which was based on the average requirements met all users demands with +13 Mm^3 surplus storage in groundwater which in real is consumed by the Mesquite trees that is widely spread in the Gash River Basin and its consumption was not included in this analysis, Figure 10.

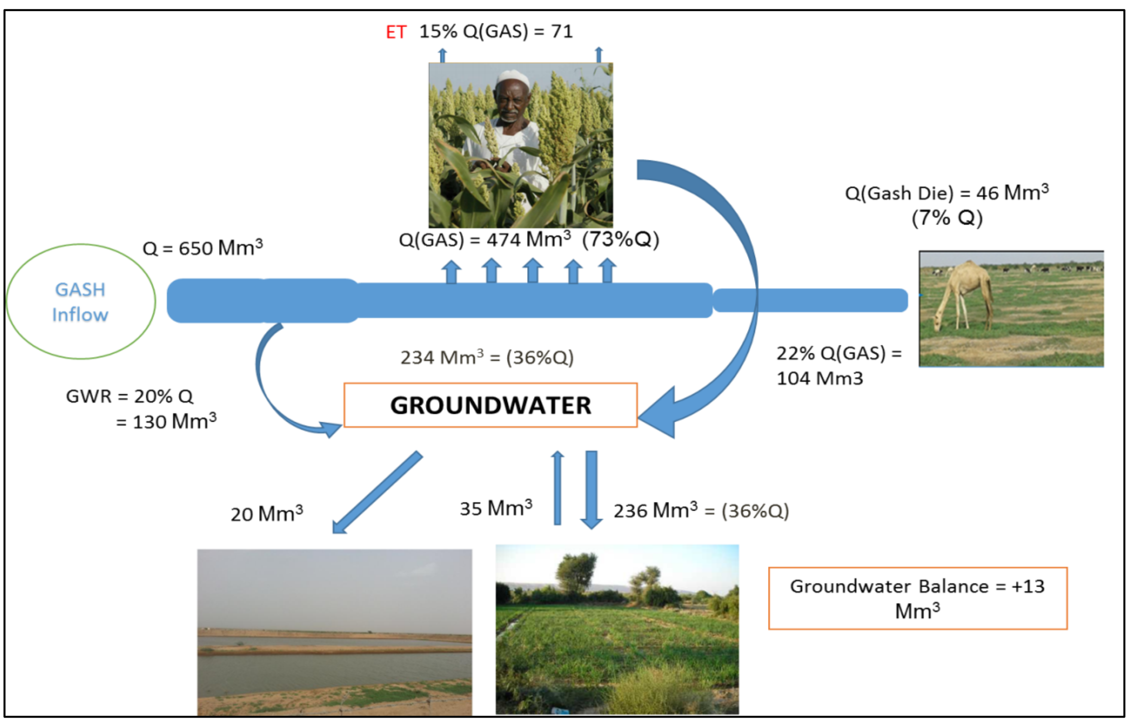

Figure 10: Water allocation for baseline

6.2 Scenarios

Three different scenarios were tested for an average flow condition, the first scenario (Sc.1) is relative to giving the first priority for the Gash Agricultural Scheme (GAS) to determine the possibility to expand GAS areas when considering the average horticultural areas (45000 feddans) and a 8 Mm^3 as a minimum flow to Gash Die. The second scenario (Sc.2) is giving the first priority for horticultural areas and considering the average GAS areas. The impact of reducing the horticultural areas was carried out in the third scenario (Sc.3) where the horticultural areas assumed to be reduced by 25% to 34000 feddans.

6.2.1 Scenario1

This scenario was tested to determine the possibilities to expand the cultivated areas in GAS using the current overall irrigation efficiency of 55% in (Sc.1 – a) and assuming that the efficiency can be increased to 65% (Sc.1 – b) in case of improving some techniques (e.g. on farm management). Table (10) shows the details of (Sc. 1 – a) and (Sc.1 – b).

Table 10: Average year simulation results for scenario1

Scenarios		Sc.1	
		(a)	(b)
Annual Inputs and Demands	Gash Flow (Mm^3)	650	650
	GAS Area	Greater than 81420	Greater than 81420
	GAS Demand (Mm^3)	>> 474	>> 474
	Gash Die (Mm^3)	8	8
	GWR (Mm^3)	234	234
	PAS area	45000	45000
	PAS (Mm^3)	236	236
	PWS (Mm^3)	20	20
Simulation Results – Supply	GAS (Mm^3)	512	512
	GAS Areas (feddans)	87947	103958
	Gash Die (Mm^3)	8	8
	GWR (Mm^3)	234	234
	PAS (Mm^3)	236	236
Surface water Balance (Mm^3)		0	0
Groundwater Balance (Mm^3)		+13	+13

The analysis showed that it can be possible to expand the cultivated areas in GAS to reach about 88000 feddans for an average year condition under the current situation of efficiency and average demands of horticulture and domestic water supply and a minimum flow of 8 Mm^3 to Gash Die.

While with improving the irrigation efficiency in GAS to 65% the cultivated areas can increase to 104000 feddans.

6.2.2 Scenario2

Scenario2 was related to the horticultural cultivated areas expansion, it was assumed to allocate the excess water to the horticulture taking into account the average irrigated GAS areas and the minimum flow to Gash Die. Table (11) details scenario2 analysis in two cases, (Sc.2 – a) and (Sc. 2 – b) for 70% and 80% efficiency respectively.

Table 11: Average year simulation results for scenario2

Scenarios		Sc.2	
		(a)	(b)
Annual Inputs and Demands	Gash Flow (Mm^3)	650	650
	GAS Area	81420	81420
	GAS Demand (Mm^3)	474	474
	Gash Die (Mm^3)	8	8
	GWR (Mm^3)	234	234
	PAS area	>> 45000	>> 45000
	PAS (Mm^3)	>> 236	>> 236
	PWS (Mm^3)	20	20
Simulation Results – Supply	GAS (Mm^3)	474	474
	GAS Areas (feddans)	81420	81420
	Gash Die (Mm^3)	8	8
	GWR (Mm^3)	272	272
	PAS (Mm^3)	252	252
	PAS Areas (feddans)	48050	61500
	PWS (Mm^3)	20	20
Surface water Balance (Mm^3)		0	0
Groundwater Balance (Mm^3)		0	0

Testing of the second scenario has provided that only 3000 feddans expansion is possible under the current efficiency while with improving the efficiency the areas can be expanded to 61500 feddans. As the groundwater balance shows that the recharge and discharge are equal; this means that it should be assumed that the Mesquite trees consumption will be controlled to achieve these expansions.

6.2.3 Scenario3

The drop in Gash River basin groundwater table as reported by Kabeer, 2016 is resulted from the exceeded abstractions from groundwater either for horticulture or by Mesquite trees. The impact of reduction of the horticultural areas was carried out in scenario3 to maintain the groundwater table in the basin. A reduction of 25% of the average areas was assumed and the analysis results are shown in Table (12) below.

Table 12: Average year simulation results for scenario3

Scenarios		Sc.3
Annual Inputs and Demands	Gash Flow (Mm^3)	650
	GAS Area	81420
	GAS Demand (Mm^3)	474
	Gash Die (Mm^3)	8
	GWR (Mm^3)	234
	PAS area	34000
	PAS (Mm^3)	178
	PWS (Mm^3)	20
Simulation Results – Supply	GAS (Mm^3)	474
	GAS Areas (feddans)	81420
	Gash Die (Mm^3)	8
	GWR (Mm^3)	234
	PAS (Mm^3)	178
	PAS Areas (feddans)	34000
	PWS (Mm^3)	20
Surface water Balance (Mm^3)		+38
Groundwater Balance (Mm^3)		+63

It is clear from the analysis that the reduction of the horticultural areas to 34000 feddans will provide an overall surplus flow of about 100 Mm^3 which can be considered for the consumption of Mesquite.

The water allocation percentages for the different users in the different scenarios are summarized in Table (13). The allocated water for GAS reaches up to 79% when assuming expansion, while the horticultural areas water allocation varies between 27% and 39%. While 1% and 3% are the allocated water for the domestic water supply and Gash Die respectively and it is constant in the three scenarios.

Table 13: The water allocation percentages of each scenario for an average hydrological year

Scenarios	Baseline	Sc.1	Sc.2	Sc.3
GAS %	73	79	73	73
GW - Horticulture	36	36	39	27
GW – Domestic Water Supply %	3	3	3	3
Gash Die %	7	1	1	1

7. Conclusions

- The simulation of the actual data over the previous years has shown average results of water allocation as 54.7% for the Gash Agricultural Schemes, 32% for the groundwater recharge and 13.3% for the flow to the Gash Die.
- The baseline scenario which was based on the average requirements provided 73%, 36%, 3% and 7% water allocation for GAS, Groundwater-horticulture, Groundwater-domestic water supply and flow to Gash die respectively with a surplus 13 Mm^3 in groundwater balance that can be considered as the Mesquite trees consumption which was not taken into account in this analysis.
- Scenario1 resulted in a possible maximum 8% expansion in GAS area (to become about 90,000 feddans) under 55% application efficiency and in reducing the flow to Gash Die from 46 Mm^3 (baseline) to 8 Mm^3 which meets the different demand of Gash Die.
- Improving the irrigation efficiency in GAS to 65% (field water management improvement) in scenario1 will allow increasing GAS irrigated area to 104,000 feddans.
- Scenario2 under the current assumption of 70% application efficiency showed that there's no possibility for expansion beyond 48,000 feddans even after reducing the Gash Die flow and controlling the Mesquite trees. But if the efficiency is improved to 80% an area of 61,500 feddans can be irrigated considering the reduction of Gash Die flow to the minimum and controlling the Mesquite trees.
- Scenario3, which has considered 25% reduction of the horticultural area, would be a necessary management option if Mesquite could not be controlled. It provided a +100 Mm^3 that can be considered to be consumed by Mesquite and then the groundwater table can be maintained.

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