Technical Report

Towards more effective and productive Gash Agriculture Scheme

Case: Hydrological Data Analysis in Gash River

BY
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January, 2013

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This report is a part of HRC and UNESCO-IHE sponsored project titled **"Spate Irrigation for Rural Economic Growth and Poverty Alleviation in Sudan"** of which this study report is one of the outputs. The report describes the methods used for discharges computation in Gash River and the accuracy of existing flow measurements.

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ABSTRACT

This study is concerned with the flow measurement in Gash River for the purpose of computing the hourly, daily, monthly and annual River discharges for the last six years (2007 to 2012).

The computation is based on available data and information; and is mainly focused on three selected Gauging Stations along the River. These stations are: New Geera, Kassala Bridge and Salamalekum.

Above all, the accuracy of existing method for discharge computation (AVSM) was estimated by using evaluation criteria of Root Mean Squared Residuals (RMSE), Mean Absolute Error (MAE) and Mean Percentage Error (MPE) base on the values of Velocity-Area method (VAM).

The existing method of discharge computation (AVSM) gives good indication about flow hydrographs in Gash River, but to get more accurate discharge the following two points should be taken in consideration:

(1) Measuring river cross-section during flood at regular intervals
(2) Using more numbers of velocity measuring points along river cross-section

However, at present, the only possible station to get accurate discharge measurements from, is Kassala Bridge where the previous points can be conducted.

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Abbreviations

HRC	Hydraulic Research Center
GRTU	Gash River Training Unit
KRO	Kassala Research Office
AVSM	Average Velocity-Stage method
VAM	Velocity-Area method
RMSE	Root mean squared residuals
MAE	Mean absolute error
MPE	Mean Percentage Error
Mm^3	Million Cubic Meter

1. Introduction

1.1 General:

Spate System is a type of Water Management that is unique to semi-arid environments. Flood water from rivers and from mountain catchments is diverted from ephemeral river beds and spread over large areas for agriculture, forestry, ground water recharge and drinking water.

Spate systems are very risk-prone. The uncertainty comes both from the unpredictable nature of the floods as well as from the frequent changes to the river beds from which the water is diverted. It is often the poorest segment of the rural population whose livelihood and food security depends on the spate flows. Substantial local wisdom has developed in organizing systems and managing both the flood water and the heavy sediment loads that go along with it (SPN, 2011).

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 (July, August and September) and shortly after extreme precipitation in upstream regions with trans-boundary catchment along Eretria, Ethiopia and Sudan (Figure 1).

Gash is the main source of water supply for all purposes to Kassala and its surroundings. It is the only recharge source to Gash ground water basin. Gash also is the source that created the delta (300 thousand feddans) that has the most fertile land for agriculture on which most of the Kassala socio economic activities depend. People say that without Gash there will be no Kassala (Bashar, 2005).

In developing a spate system, it is important to understand the entire hydrology of the system - the base flow, sub-surface flow and ground water and the pattern of spate floods that will dictate the potential yield of spate system, the design of diversion structures and canals and the area to be potentially irrigated.

1.2 Purpose and scope of work:

The Study started on July 2012. It is basically concerned with the measurement of Gash River flow which is required for river management purposes, including water resources planning, flood control and also to assist planners, Hydrologists, Agronomists and local organizations in designing and managing irrigation systems for Gash Scheme Project. The main objectives of this study are:

- To compute hourly, daily, monthly and annual discharge of Gash River for flood during seasons of years from 2007 through 2012.
- To evaluate the accuracy of existing flow measurement methods.

To achieve the main objectives of the study mentioned above, the following steps have been done:

(1) Firstly: collecting of available field data of Gash river which were prepared by GRTU.
(2) During the latest flood, more filed measurements were done in Kassala Bridge station such as: current-metering measurements, measurements of bed level during the flood at regular intervals and more velocity measuring points distributed along x-section of the river.
(3) Analysis of available data was conducted to compute the discharges of Gash River during the period from 2007 through 2012.
(4) The river characteristics such as: the rating curves and the daily hydrographs for three selected gauging stations: New Geera, Kassala Bridge and Salamalekum on Gash River are obtained.
(5) The accuracy of the measuring method employed in Gash is checked by comparing its results with other more accurate methods.

2. Description of study Area

2.1 General description of The Gash River:

Upper reaches:

The catchment covers an area of approximately 21,000 square kilometers and it is delineated between latitudes 36.5 – 39.5 East and longitudes 14.0 – 15.5 North, shared with Eretria, Ethiopia and Sudan (Figure 1). Elevation in the catchment varies between 1100 m and 2000 m. In its upper reaches the Gash is known as the river Mareb. It starts from Eretria, about 20Km south of Asmara. From here to Sudan frontier the river basin is long and relatively narrows (Swan, 1956).

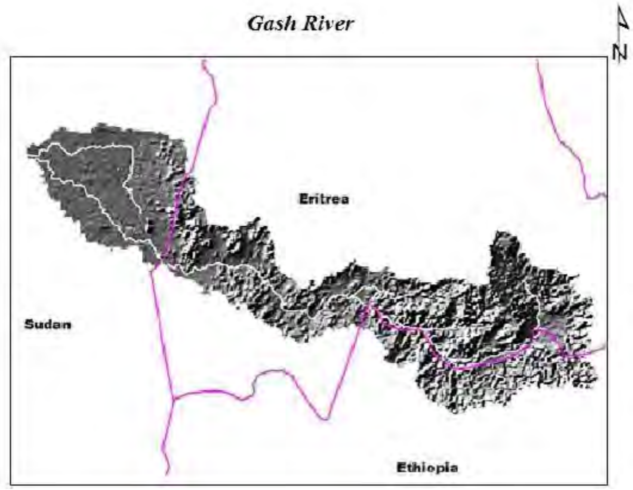

Fig (1): Location of Gash catchment

Lower reaches

After passing the narrow rocky gap at Tessenel, a wide shallow stream with a sandy bed and extensive flood plains flows slightly north-west for some 20 Km; and then runs north for about 5 Km before crossing the Sudanese frontier close to Jebel Gulsa. Thereafter, it runs to North-northwest for about 20 Km to the southern bastion of Jebel Kassala. Here it is joined by a major tributary from the east, Khor Abu Alga. From the frontier to Jebel Kassala the Gash varies in width between 100 m and 800 m, with an average about 300 m. The slope of the bed is relatively constant throughout at 1.3 m/km **(**Swan, 1956).

2.2 Gash River Hydrology:

The River originates from the Eritrean Highlands and the Ethiopian Plateau. It is a seasonal and flashy river with high variation in flow during the wet season of July, August and September.

The minimum annual total discharge of The Gash River is 140 million m3, which was recorded in 1921, while the maximum annual discharge is 1430 million m3 recorded in 1983. The maximum annual flow is almost 10 times the minimum one, indicating the high variability of the flows in Gash River. The annual average flow is 680 million m3 (Bashar, 2005).

Kassala town was the most affected town by the Gash flooding. It had been attacked by several damaging high floods from the Gash River. In the last three decades, the town was attacked by six devastating floods recorded in the years 1975, 1983, 1988, 1993, 1998 and 2003. The most damaging one occurred in year 2003, where almost of half the city washed out (Bashar, 2005).

The aquifer is unconfined; the water level in the aquifer rises during the river gash flow period and declines when the river is dry. Kassala drinking water depends on it. The percolation amount is 250 million cubic meters (Meki, 2008).

2.3 Gash River Monitoring Program

The regular Gash river monitoring program has been implemented in period from 1970 until the year of 2004. During the period, the monitoring of the river was the responsibility of Kassala Research office (KRO). Following the flood disaster of July 2003, the responsibility of the river monitoring has been transferred to Gash River Training Unit (GRTU), which was established in January 2004 (Saied, 2010).

2.4 Gauging stations along Gash River:

The Gash River has six gauging stations along the river (Figure 2) where the water level and velocity (by float method) are regularly measured. These stations are: New Geera gauging station, Old Geera gauging station, Kilo 1.5 gauging station, Kassala Bridge gauging station, Fota gauging station and Salamalekum gauging station. The regular water level measurement started in 1970, except for the new Geera that was established in 2007.

This study is mainly focused on the last six years from 2007 to 2012, with more focus on three gauging stations: New Geera, Kassala Bridge and Salamalekum gauging stations

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Fig (2): Location of Gauging stations along Gash River

1) New Geera Gauging station

This gauging station was built in 2007 near the right bank of Gash River to measure the water level and velocity by float method (see figure 3). New Geera is located at 15.262 N latitude and 36.4783 E longitude. It is the first upstream gauging station on The Gash River inside Sudan, about five Kilometers from Sudanese Eritrean border. The velocity measurement near the left bank has recently been added.

New Geera station is located just after the river bend and the cross-section at this site is relatively stable about 260m width, but there is a little scouring in the outer bend of the river.

Fig (3): Inclined gauge staff placed upon the right bank of New Geera gauging station

2) Old Geera Gauging station

It is located at 15.2682 N, 36.4773 E, about 700m downstream of New Geera. The measurement in old Geera station started from 1970 on the right bank of Gash River, but over time the gauging station suffered from extreme erosion at the left bank of River (Figure 4), also the width of river section in this site is very wide, about 450m, thus the Old Geera readings are considered to be less reliable compared with the New Geera gauging station.

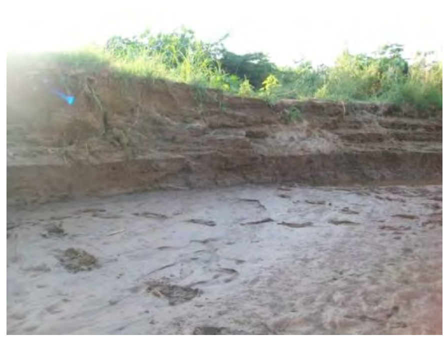

Fig (4): Erosion on the left bank of Old Geera gauging Station

3) Kassala Bridge gauging station

It is located in Kassala town at 15.4477 N latitude and 36.389 E longitude, about 22 Km downstream of the Old Geera. In the past Kassala Bridge gauging station was only used for water level measurements, but since 2005 both velocity methods float and current-meter have been used. The study is mainly focused on this station because it is the only possible location for current-meter and measurement of bed level during floods. The cross-section at this site is relatively narrow compared with the previous upstream stations, about 120m (See Figure 5).

Fig (5): Right bank of Gash River at Kassala Bridge station

4) Salamalekum gauging station

Salamalekum station is located at latitude and longitude of 15.5249 N, 36.358 E, respectively, about 9 Km downstream Kassala bridge. This station is used for measurement of water level and velocity by float method near the left bank of river. The measurement near the right bank has recently been added. The width of river cross-section at this station is just about 95m.

3. Methodology, Data

3.1 Data sources

Flow measurements data and surveying works for study area were obtained from GRTU which is responsible for flood management in Gash River.
In 2012 flood season, additional measurements were made in coordination with staff at GRTU and HRC to get more accurate data.

3.2 Basic Concept of Discharge

In general, River discharge Q in any cross-section and at any moment is given by:
$Q= \bar{V} . A$
Where: $\bar{V}$ is average velocity, A is wetted cross sectional area of river
Thus the discharge can be determined if the area A is known (or measured) and the average velocity is calculated on the basis of velocity measurements carried out in that particular section.
Flows in Gash River are classified as unsteady non-uniform flow; in which the cross-section and discharge both vary with time and distance and this is the most complex flow to analysis.
The main parameters of discharge are velocity and wetted cross-sectional area. For this study, the float method used for computation of discharge in Gash River and current-meter are mainly used to calibrate the float measurements.
The float method measures surface velocity, but mean velocity is obtained by using a reduction coefficient to reduce the surface velocity to the mean velocity. For many years ago, the reduction coefficient has been taken as 0.87 in Gash River; this value is used by KRO (Toam et al., 2005).
The reduction coefficient generally ranges from 0.8 for rough beds to 0.9 for smooth beds (Herschy, 1985). The appropriate coefficient is best determined from current-meter measurements which include surface velocity measurement (Herschy, 1985).

3.3 Field measurements

The following measurements were done during floods of Gash River:

(a) Water level:

Water level in Gash River is measured on hourly basis during the flood periods. The gauge readings are taken directly from inclined gauge staffs placed upon the river bank. In the end of each flood season, the gauge records are collected from all stations by GRTU staff.

(b) Velocity measurements:

Surface float method:

Stream velocities of Gash River were measured in each of the six stations using the Surface float method. In most of stations, the velocity is measured thirteen times during the day hours, on hourly basis from 6:00 am to 6:00 pm. In each measurement a random wooden piece or stick (See Figure 6) is thrown by hand into the river three times and; simultaneously the float time taken to travel a distance of 50m by a stop watch.

In 2012 flood season, beside the above measuring method, velocities were taken five times during the day hours, on 3-hourly basis from six positions distributed along river cross-section of Kassala bridge station.

Fig (6): wooden stick used to float velocity measurement

Current-meter:

Current-meter measurements are essential to calibrate results obtained by determining float coefficient. The only possible location for current-meter measurement is Kassala bridge station.

In the last season, only 12 current-meter measurements were made during the flood season using Akim Hydrometery current-meter with 50 kg weight (See Figure 7). This weight was found not to be sufficient for stages greater than 506 m.

During the last years, many types of current-metering instruments were used in measurements, for instance, Bray- stoke, Seba and Armfield.

Fig (7): current-meter instruments used at Kassala Bridge Gauging Station

(c) River cross-section

During dry season, Gash river cross-sections are taken at each gauge station before and after flood season using differential leveling by GRTU staff. But during flood season, cross-sections on Gash River were only taken in Kassala bridge station.

3.4 Data analysis steps

The discharges of Gash River can be estimated by the following steps:

(1) Collecting field data from gauging stations, which includes water levels records, float measuring and surveying works.

(2) Organizing data into Excel format and arranging the same in sub-folders.

(3) Screening and filling missing data of water levels records:

- Plot time series of data to see outliers, missing values, trends, etc.
- Creating water balance relation between all measuring stations from upstream to downstream: New Geera -> Old Geera -> Kilo 1.5 -> Kassala bridge -> Fota -> Salamalekum

(4) Computing the river discharges according to one of the following methods:

(a) Average Velocity-stage method (AVSM)

The average velocity-stage method is adopted in Gash by GRTU. In this method, the flow is assumed to be as steady hydraulic flow regime. The velocity change during river rising and falling is neglected, so that the flow occurs with a single value relation between stage and discharge. This method is set by following steps:

- Sorting ascending stage/ Velocity data base on the stage readings
- Calculating the average velocity for the same stage reading
- The velocity data is discarded if the value is greater than 50% of the average
- Obtaining velocity equation by plotting stage versus average velocity
- Calculating the wetted cross-sectional area for each gauge reading
- Obtaining discharges by multiplying the average velocity by the average area of river cross-sections before and after flood.

(b) Velocity-area method (VAM)

In velocity area method, the river is divided into segments and the discharge through each segment is computed by multiplying the average velocity in each segment by the segment area. The sum of the products of area velocity for each segment gives the discharge. This method requires following conditions:

- Continuous velocity measurements, not possible during nights.
- Measuring cross-sectional area of river during flood periods and this is only possible at Kassala bridge station.

3.5 Evaluating Quality of computed Discharge

The following four steps were used to evaluate the quality of a discharge measurement in Gash River:

- Comparing the flow hydrograph in one station with the others, to see the compatibility of data
- Computing discharge at Kassala bridge station using velocity-area method (VAM) and comparing its results with existing discharge computation method (AVSM).
- Computing discharge at Kassala Bridge station using cross sections during flood period at weekly regular intervals and comparing with the existing way of measurement/cross section before and after floods.
- Computing velocity at Kassala Bridge using more numbers of floats distributed in different measuring points along river cross-section and comparing with the existing way of measurement.

Three evaluation criteria: Root mean squared residuals (RMSE), Mean absolute error (MAE) and Mean Percentage Error (MPE) were used in the study to estimate the accuracy of discharge measurements. Table 3.1 gives a description of these criteria.

Table 3.1: **Evaluation criteria, description and formula:**

Criterion	Description	Formula
RMSE	Root mean squared residuals	$\sqrt{\frac{1}{N}\sum_{i=1}^{N}(Q - Q)^2}$
MAE	Mean absolute error	$\frac{1}{N}\sum_{i=1}^{N}\lvert Q - Q \rvert$
MPE	Mean Percentage Error	$\frac{1}{N}\sum_{i=1}^{N}\frac{\lvert Q - Q \rvert}{Q}$

Where:
Q = flow computed by VAM (see Annex V), m^3/s
Q’ = flow computed by AVSM, m^3/s

Criterion RMSE evaluates the sum of the squares of the flow residuals. MAE gives an indication of the average absolute departure of AVSM from the VAM discharge. The values of RMSE, MAE and MPE criteria are expected to be at a minimum for better quality of discharge.

4. Data Analysis and Results

4.1 Calibration of float method

Current-metering measurements during current flood:

During the current flood, only 12 current-metering measurements were made at Kassala Bridge Gauging Station, using Akim Hydrometery current-meter (See Annex I).
After plotting values of discharges measured by current-meter versus those measured simultaneously by float method, the calibration coefficient for current flood season is 0.73 (see Figure 8).

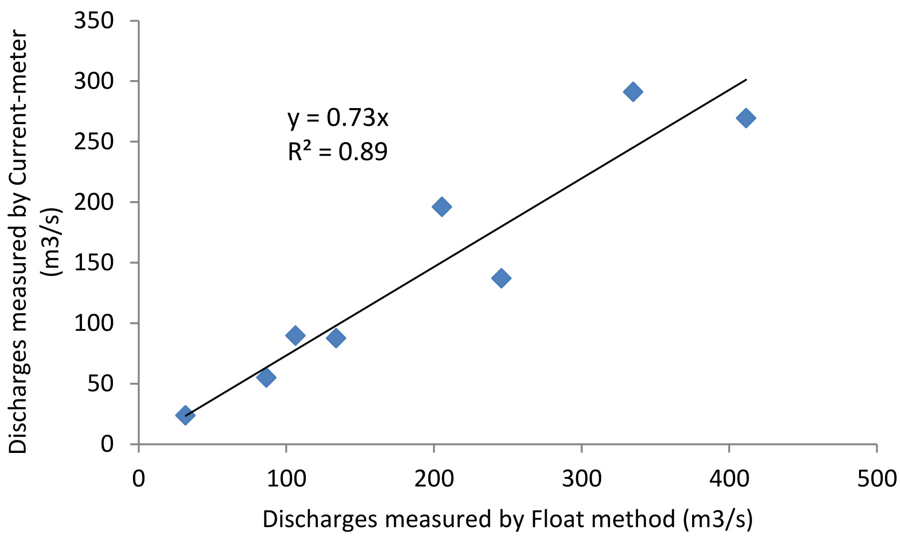

Fig (8) current-metering measurements versus float for calibration

4.2 Results of Discharge computation

4.2.1 Using Average velocity-stage method (AVSM)

The Results of discharges computation for the Gash River during flood season of (2007-2012), using Average Velocity-Stage method (AVSM) and cross-sectional area before and after floods are shown in Annexes (II), (III), (IV) and (VI).

(a) Daily Flow hydrographs of Gash river

The Flow Hydrographs of the Gash River from the year of 2007 through 2012, using Average Velocity-Stage method (AVSM) and cross-sectional area before and after floods are shown in Figure 9. It is clear that Gash River generally moves as a flood wave. Flow hydrographs are characterized by great variation in the size and frequency of floods (an extremely rapid rise in time, followed by a short recession).

In 2007 a catastrophic floods affected Kassala state. The flow hydrograph of Gash River in this year is shown in Figure 9(a) which illustrates that the peak flow which had occurred early in July caused this disaster, and after that the Gash River started to fall. The period of flow from 4^{th} to 12^{th} July is clearly the time when an extreme flood had occurred in downstream regions.

Following years, the daily flow hydrographs of Gash River for flood (2008-2012) shown in Figure 9(b), (c), (d) and (e), indicates that most of flow usually occurs in August, after which the Gash River starts to fall.

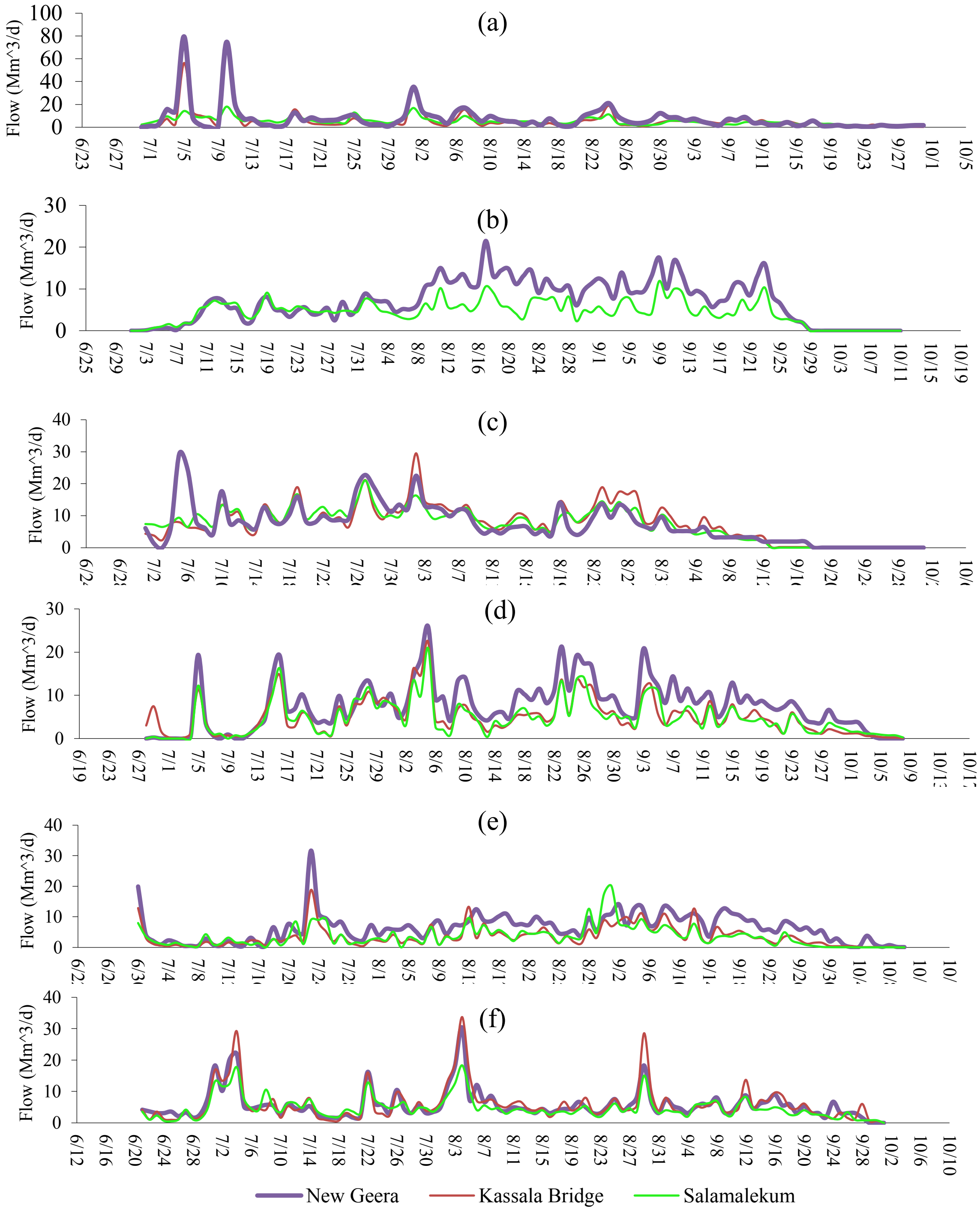

Fig (9): Daily Flow hydrograph of Gash River measured at New Geera, Kassala bridge and Salamalekum station for flood of (a) 2007, (b) 2008, (c) 2009, (d) 2010, (e) 2011 and (f) 2012

(b) Monthly Total flows of Gash River

Figure 10 shows the mean monthly flow of Gash River (2008 - 2012) measured at Kassala Bridge Gauging station. It indicates that most of the flow had occurred in July, August, and September with the peak flow in August. But in 2007, the monthly flow of Gash changed remarkably as the peak flow started early in July as shown in figure 11.

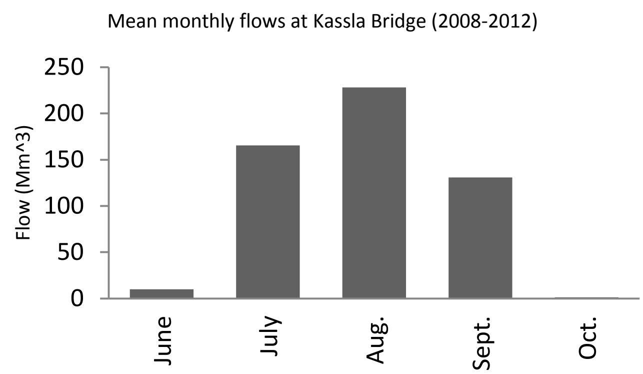

Fig (10) Mean monthly flow of Gash River (2008-2012) measured at Kassala Bridge Station

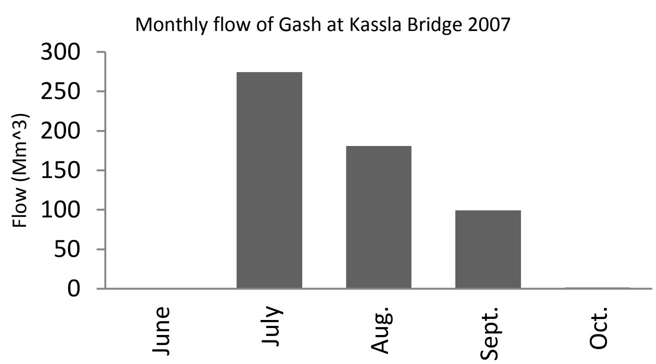

Fig (11) Monthly flow of Gash River 2007 measured at Kassala Bridge Station

(c) Annual Total flows of Gash

The Results of annual discharges computation for Gash River during the period from 2007 through 2012 are shown in table 4.1 and Figure 12. Discharges are divided into those taken at New Geera, Kassala Bridge and those taken at Salamalekum gauging station.

Table 4.1: **Total annual discharge, Maximum flow and duration of floods (2007-2012):**

Year	Duration of continuous flood			Total Annual	Max flow	Remarks
	From	To	Days	Discharge Mm^3	m^3/s	
(1) Discharges measured at New Geera gauging station						
2007	30/6	9/10	102	711	1715	a
2008	1/7	29/9	89	656	635	a
2009	1/7	30/9	90	675	974	a,d
2010	28/6	8/10	103	780	580	a
2011	30/6	11/10	104	649	592	a
2012	21/6	28/9	99	591	610	b
(2) Discharges measured at Kassala Bridge gauging station						
2007	30/6	9/10	102	556	1381	b
2008	1/7	28/9	88	460	304	b
2009	1/7	30/9	90	507	817	b,d
2010	28/6	8/10	103	514	423	b
2011	30/6	11/10	104	362	583	b
2012	21/6	30/9	101	616	674	e,d
(3) Discharges measured at Salamalekum gauging station						
2007	30/6	9/10	102	496	310	c
2008	1/7	28/9	88	460	323	c
2009	1/7	30/9	90	675	387	c
2010	28/6	8/10	103	488	318	c
2011	30/6	11/10	104	364	260	c
2012	21/6	30/9	101	491	367	b

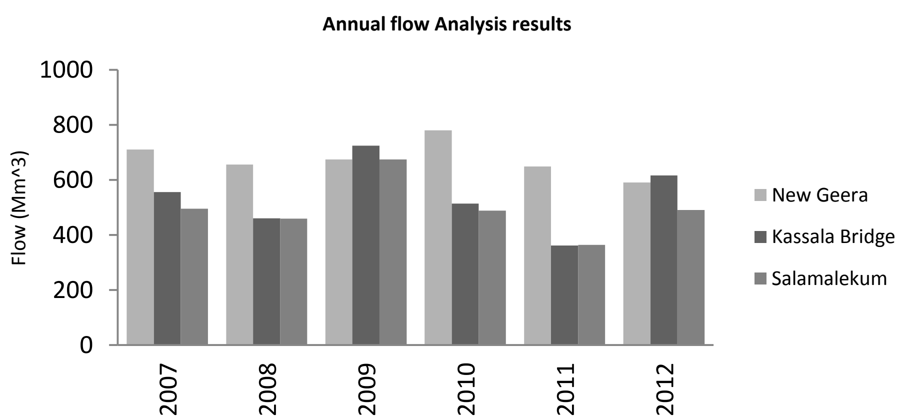

Fig (12): Annual computed discharges measured at New Geera, Kassala Bridge and Salamalekum station

Remarks:

a) Stream velocities were measured only on the right bank of river.
b) Stream velocities were measured at both sides of river
c) Stream velocities were measured only on the left bank of river.
d) Total Discharge measured in Geera station is less than that measured in downstream stations and this could mean that a large amount of flow came from Khor Abu Alga.
e) Stream velocities were measured at 6 points distributed along X-section of the river.

From the results, it is evidence that Kassala Bridge station is good for measuring low and medium stages flow. But it seems not reliable for measuring high-stage flow for the following reasons:

- High turbulence flow around the piers.
- Backwater; the bridge's piers will obstruct the flow and cause an increase in water levels upstream of the bridge, this impact will be more significant during the high-stage flow.

(d) Rating curves (QH relations)

The rating curve is an approximate method employed for estimating discharge in rivers. The relationship between the water-surface stage (i.e. the water level) and the simultaneous estimated flow discharges in Gash River is obtained by fitting 6-years flow data (2007-2012) with a polynomial curve as presented below.

New Geera Station

For New Geera gauging station, rating curve was developed from 6-years flow data (2007-2012) as shown in Figure 13. The graph has $R^2 = 0.93$ and the representative equation of the rating curve is shown below:

$$Q = 352.61759\ H^2 - 376{,}976.03909\ H + 100{,}754{,}273.31201$$

Where: Q = Discharge in m^3/s

H = Water-surface Stage in m

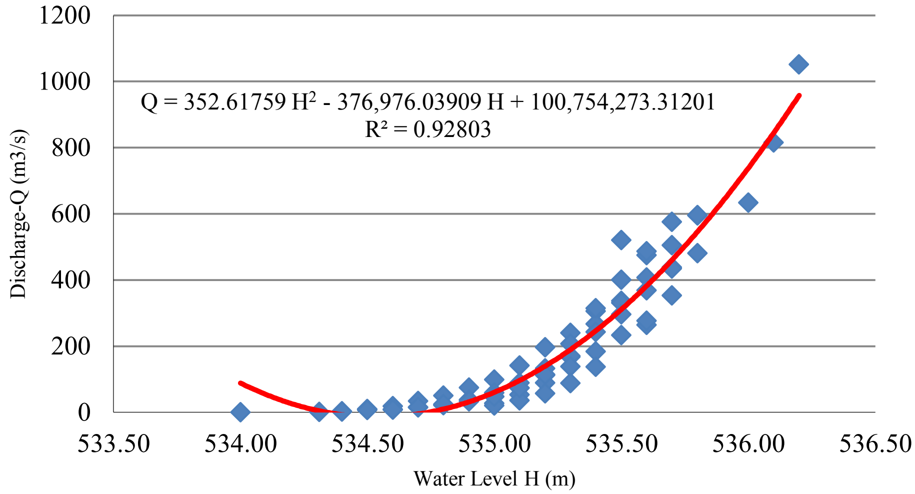

Fig (13): Rating Curve for New Geera station

Kassala Bridge Station

from 6-years flow data (2007-2012) at Kassala Bridge gauging station, a rating curve was developed as shown in Figure 14. The graph has R^2 = 0.93 and the representative equation of the rating curve is shown below:

$$Q = 151.14524\ H^2 - 152{,}534.85468\ H + 38{,}484{,}282.66386$$

Where: Q = Discharge in m^3/s

H = Water-surface Stage in m

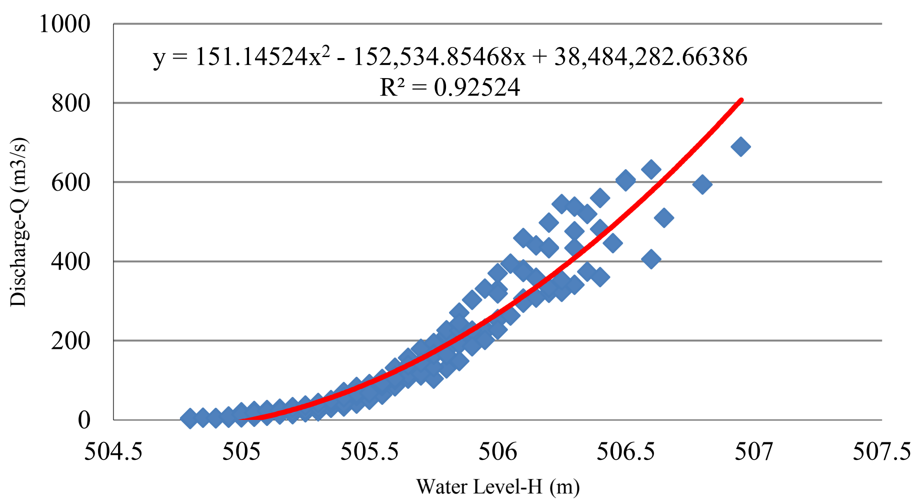

Fig (14): Rating Curve for Kassala Bridge station

Salamalekum Station

For Salamalekum gauging station, rating curve was developed from 6-years flow data (2007-2012) as shown in Figure 15. The graph has $R^2 = 0.82$ and the representative equation of the rating curve is shown below:

$$Q = -3.31249\, H^2 + 3{,}412.76007\, H - 877{,}528.00242$$

Where: Q = Discharge in m^3/s

H = Water-surface Stage in m

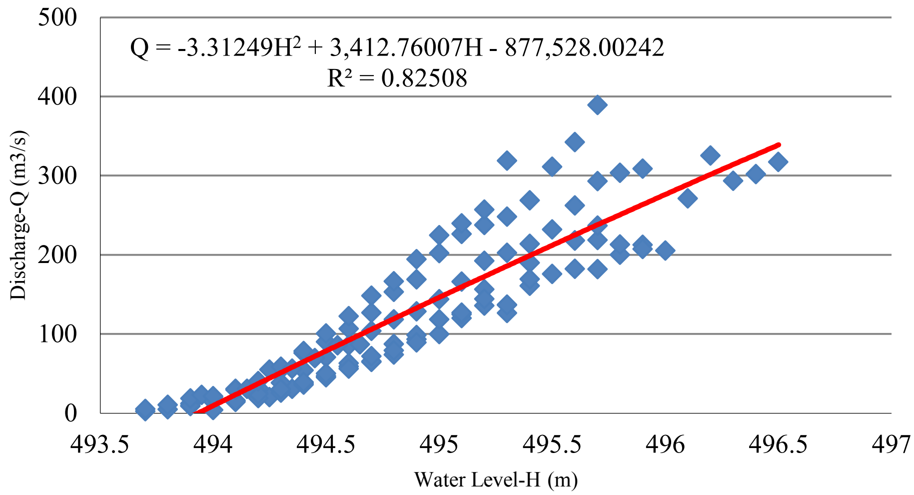

Fig (15): Rating Curve for Salamalekum station

4.2.1 Using Velocity Area method (VAM)

The VAM gives more accurate values of flows. But it is only possible at Kassala bridge station during a day hours (from 6:00 am to 6:00 pm). In the study, the VAM is mainly used to evaluate the accuracy of AVSM. The results of discharge computation by VAM are shown in Annex V.

4.3 Correlation between AVSM and VAM

The results of discharges computation for Gash River during the 2012 flood season, using AVSM and cross-sectional area before and after flood are correlated with the results of VAM. This method is used to represent a linear relation between two methods of discharge computation which found as following (see figure 16):

$Q_1 = 1.54\ Q_2$

Where: Q_1 = Discharge computed by VAM
Q_2 = Discharge computed by AVSM

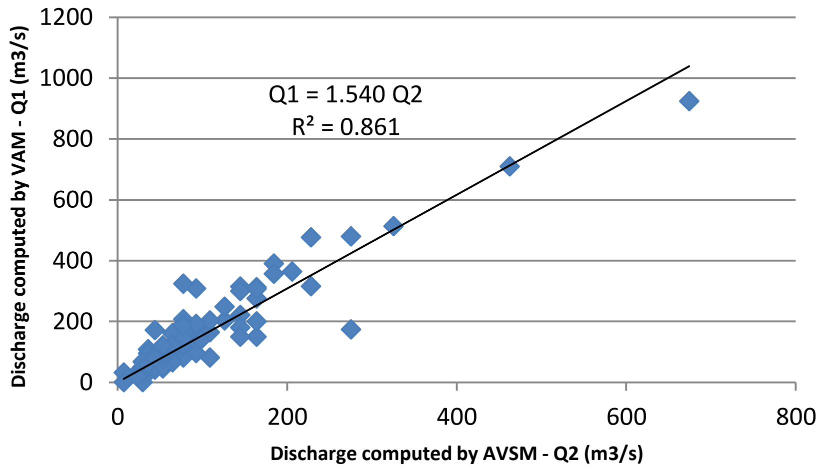

Fig (16): Correlation between VAM and AVSM

4.4 Quality of computed discharge

To get more accurate results of discharge computation in Gash River, two factors should be taken in consideration for the existing method (AVSM):

(a) Changes in bed level during flood

Cross-sections have been taken at Kassala bridge station during flood show relatively large changes in streambed elevation and shape (see Figure 17). This can provide an indication of high scouring occurred during a peak flow when Gash River moves fast and then refilling during flood recession. Therefore, more accurate values for discharge computation can be obtained by using more cross-sections during flood season, instead of existing method of taking average cross-section before and after flood.

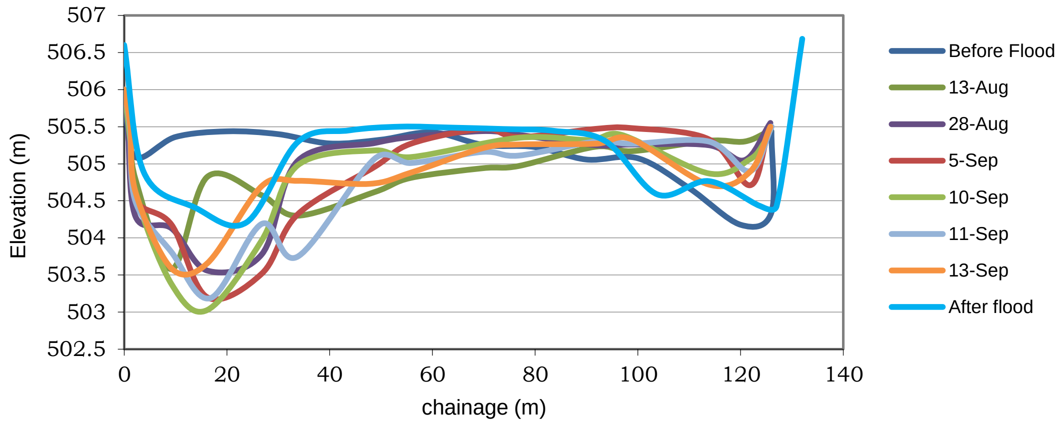

Fig (17): Changes in bed leveling at Kassala Bridge station during flood of 2012

(b) Distribution of velocity measuring points along River cross-section

Stream velocity is highest at the centre of River cross-section and diminishes to zero at the edges. Therefore, accurate measurement of the surface velocity requires placing the float in different locations along the River cross-section.

4.5 Estimating the accuracy of existing method

A methodology of Average Velocity-Stage method (AVSM) to estimate discharges in Gash River is developed by GRTU. In this method the flow is assumed to be as steady hydraulic flow regime and that mean, the velocity change during river rising and falling is neglected. The Mean Percentage Error of the discharge estimates were within (40% - 35%) of the Velocity-Area method (VAM), with the Root mean squared residuals within 75 m^3/s and Mean absolute error within 50 m^3/s. This level of accuracy was achieved using (1 - 2) velocity measuring points and average area of cross-sections before and after flood. But by using 6-velocity measuring points along river cross-section and weekly interval cross-sections during flood, the Mean Percentage Error decreased to 25%, with the Root mean squared residuals within 45 m^3/s and Mean absolute error within 30 m^3/s.

However, using 6-velocity measuring points and weekly interval cross-sections during flood improved the accuracy to within 15% (see Figure 18).

Table 4.2 shows the result of evaluation criteria which was developed from about 150 discharge measurements during 2012 flood season.

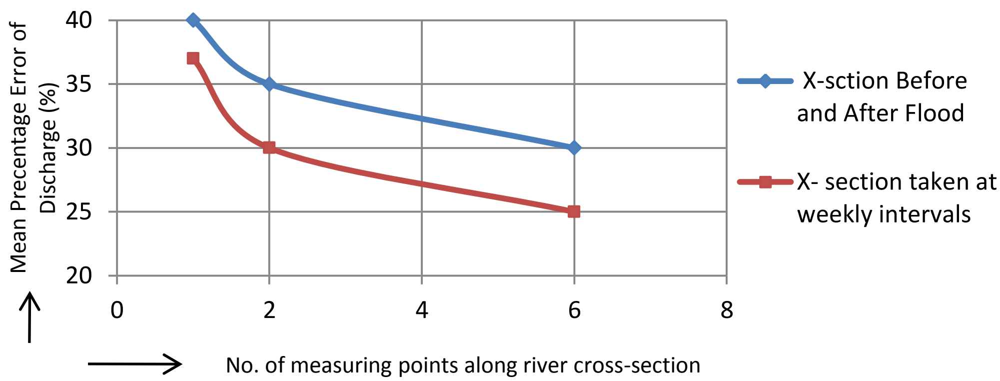

Fig (18): Relation of the number of measuring points and Mean Percentage error of Discharge %

Table 4.2: **Estimating accuracy of AVSM base on values of RMSE, MAE and MPE:**

Method	No. of measuring point distributed along x-section	RMSE (m^3/s)	MAE (m^3/s)	MPE %
(1) AVSM/ Average x-section before and after flood	1	76	53	40
(2) AVSM/ Average x-section before and after flood	2	78	50	35
(3) AVSM/ x-sections taken at regular weekly intervals	2	55	36	30
(4) AVSM/ Average x-section before and after flood	6	67	46	32
(5) AVSM/ x-sections taken at regular weekly intervals	6	45	30	25

5. Conclusions

The analysis of the available information and data reveals the following results:

- Calibration coefficient for float method in Gash River is 0.73. This coefficient is derived from simultaneous current-metering and floats measurement at Kassala Bridge gauging station during flood season 2012.

- The results of discharge computation for Gash River (from 2007 to 2012) show high fluctuation. Maximum annual discharge is 780 million cubic meters, which was recorded in 2010 at New Geera station, while minimum annual discharge is 316 million cubic meters recorded in 2011 at Salamalekum station. However, the maximum instantaneous discharge is 1715 m3/s in 2007 at New Geera station.

- Rating curve for New Geera, Kassala Bridge and Salamalekum gauging stations were developed base on a measurement data for 6-years (2007 to 2012). The following equations are developed:
  - For New Geera:

    $$Q = 352.61759\ H^2 - 376{,}976.03909\ H + 100{,}754{,}273.31201$$

  - For Kassala Bridge:

    $$Q = 151.14524\ H^2 - 152{,}534.85468\ H + 38{,}484{,}282.66386$$

  - For Salamalekum:

    $$Q = -3.31249\ H^2 + 3{,}412.76007\ H - 877{,}528.00242$$

  Where: Q = Discharge in (m^3/s)
  H = Water-surface stage in (m)

- The accuracy level of existing method could be improved to within 15%, in case of using 6-velocity measuring points along river cross-section and weekly interval cross-sections during flood.

6. <u>Recommendations</u>

A few recommendations that are proposed for an enhanced discharge measurements in Gash River:

- New Geera station is just located after the river bend and its cross-section is relatively stable. But there is a little scouring in the outer reach of the river, so it is important to do some bank pitching on the left bank to avoid erosion that may happen in the future.

- It would be better to use a Current-meter with a Cable in a suspended way to eliminate the risks to operators of working from boats.

- The change of river cross-section during flood should be taken in consideration to get accurate results of discharge.

- It would be more accurate to use more number of velocity measuring points placing in deferent location along river cross-section of Kassala Bridge station.

- Further analysis should be undertaken to improve and evaluate quality of Average Velocity-Stage method. Also, it would be better to focus on another gauging station, such as New Geera or Salamalekum gauging station; to avoid the probable impacts of Kassala Bridge's piers.

7. References

SPN, 2011. Brochure of International Spate Irrigation Network available at http://www.spateirrigation.org/wordpress/wpcontent/uploads/2011/08/SpN_brochure_2011.pdf

Toam H. A, Saied M. S. and Eisa A. S. 2005. Annual Report of Gash River- Year 2005, Ministry of Irrigation and Water Resources, Gash River Training Unit, Kassala, Sudan.

Swan C. H. 1956. The Recorded Behavior of River Gash in the Sudan, Ministry of Irrigation and hydroelectric power, Khartoum, Sudan.

Saied M. S. 2010. Comparison of River Gash Flow Parameters as Estimated by Float and Current meter Methods, SUDAN, MSc Thesis, University of Gezira, Wad Medani, Sudan.

Bashar KE,2005. Gash River flash floods challenges to Kassala town: Mitigation and Risk Management. Khartoum, Sudan

Hider Awad Meki, 2008. Spate Profile of Sudan(The Case of Gash), FAO International Expert Consultation Meeting On Spate Irrigation, Cairo, Egypt

Reginald W. Herschy, 1985. Stream flow measurement, ELSEVEIR APPLIED SCIENCE PUBLISHERS, London, UK.