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Flood Modeling Water Appraisal and Land Reclamation: A Case Study of Gash River

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ABSTRACT **-** With the objective to solve Kassala Town flooding on one hand and appraise and utilize the surface and ground water potential on the other, a Correlation Model applied at El Gira, station with Kassala indicated that Kassala is continuously subjected to high floods risks. Gumbel Distribution Model and digitized map of the Gash River catchment area gave the same degree of risk. A four to five years flood return period was found to be about 600 m3/sec at Kassala Station with a discharge at El Gira about 750 m3/sec. Only 5 % of the surface water passing Kassala Town is consumed for irrigating an area of 20 000 feddans per year. It was found that the agricultural area can be reclaimed through a by pass upstream Kassala Town, making Kassala safe on one hand and using the excess water in cultivation on the other. Using HEC-HMS Model at the confluence of Khor Abu Alaga with the Gash River a hydrograph was obtained which indicated that the base flow has a maximum of 400 m3/sec. with a maximum observed surface flow of 900m3/sec. Hence the HEC-HMS Model besides indicating ground water base verified the results of the surface flow upstream Kassala gauging station obtained by both Empirical and Gumbel Distribution Models. The observed surface flow being 900 m3/sec is logical and consistent with the corresponding result obtained at Kassala which was found to be a maximum of only 750 m3/sec. Using G.I.S. available facilities contour maps were plotted, and ground water potential being both quantitatively and qualitatively excellent were found to be 3897.6 Mm3. The study recommended cooperation between Sudan, and Gash River Basin countries, as well as establishing an early warning system to reduce the risk hazards.

Keywords: *Correlation ,Gumbel, HEC-HMS ,G.I.S.*

المستخلص – بهدف حل مشكلة الفيضان بكسلا من جهة وتقويم كميات المياه الجوفية والسطحية من جهة أخرى،فقد طبق أنموذج ارتباط تجريبي لمحطة قياس الجيرة في أعالي النهر مع محطة كسلا والذي أوضح أن مدينة كسلا تتعرض باستمرار لأخطار الفيضانات. إن تطبيق نموذج قامبل المعروف بالإضافة للخريطة الرقمية لحوض نهر القاش الساكب أتت بنفس نتيجة المخاطر. تكرار الفيضان كل اربع الى خمس سنوات يبلغ حوالى 600 m^3/sec عند كسلا يقابله تصرف حوالى 750 m^3/sec عند محطة الجيرا. لا تتجاوز المياه التى تستهلك فى الرى 5 % سنويا وذلك لرى حوالي 20 000 فدان فقط. أوضحت الدراسة ضرورة استرجاع الأراضي الزراعية باستعمال مصرف أو قناة تنفيس أمام مدينة كسلا مما يجعل كسلا آمنة من جانب ويزيد الرقعة المزروعة من جانب آخر. بإستعمال نموذج HEC-HMS عند مقرن خور أبو علقة مع نهر القاش تم الحصول على المخطط المائى. وقد اتضح من دراسة المخطط المائى أن السريان الجوفي له سرعة 400 m^3/sec اضافه للسريان السطحي الذي بلغ 900m^3/sec. بالتالي فبالاضافة إلى أن أنموذج HEC-HMS دلل عن مصدر المياه الجوفية فإنه كذلك أكد نتائج السريان السطحي الأعظمي عند كسلا والذي تم الحصول عليه بكل من النموذج التجريبي وأنموذج قامبل. السريان السطحي المرصود الاعظمي والذي بلغ900 m^3/sec يعتبر منطقي ويوائم نتيجة السريان الأعظمي المقابل له عند كسلا والذي بلغ 750 m^3/sec. باستعمال التسهيلات المتاحة عن تطبيق المعلومات الجغرافية تم رسم خرائط كنتورية بينت أن المياه الجوفية المتوفرة هي3897.6 Mm^3 والتى وجدت ممتازة كماً ونوعاً مما يمكن استغلالها فى كل استعمالات المياه المختلفة. هذا وقد أوصت الدراسة بضرورة التعاون الإداري بين كل من بلدان حوض نهر القاش. كما أوصت الدراسة بإنشاء آليه انذار مبكر.

INTRODUCTION

Kassala State is situated between longitudes 35 and 37°E; latitudes 14.15 and 17.15, °N in the eastern part of the Sudan. Figure 1 shows Sudan political boundaries with Kassala State shown in green. Kassala Town the capital of Kassala State is about 300 kilometers from Khartoum and 30 km from the Sudanese Eritrean border. Kassala State has an area of approximately 42,282 square kilometers, with population of 1,812,995 and annual population growth rate of 2.51% [8]. Gash the name of the river, is a local word that means to clear and clean. Its headwater rises south of Asmara in Eritrea, with its catchment area partly in Eritrea and partly in Ethiopia. It flows from early July to late September. Its flow is torrential and highly variable with an average silt content of about 5.5 kg/m^3. The length of the river catchments is about 200 kilometers and the slope of the river valley is about 1.5 m/km [3]. The average annual rainfall in the catchments area is about 600 mm.

The rainy season usually starts in June, with peaks in August, and ends in September with series of flood flows. The maximum average flood was estimated as 1, 000 m^3/sec at Kassala bridges. The average annual yield was indicated to be 1,000 million m^3. At the existing gauging stations, flow discharge records were obtained using the float method. The recorded observed float discharge measurements were obtained at Kassala bridges gauging station and other four measuring sites [3]. Previous researchers and investigators indicated that the minimum and maximum flood discharges in the Gash River were 140 Mm^3 in (1921) and 1430 Mm^3 in (1983) respectively at Kassala Town. They also indicated that the average flood for a hundred year is 1050 m^3/sec [2].

In 2005 when flow measurement and sediment sampling equipments were obtained, records of flow were checked using current meter measurements. Some current meter flow measurements were accurate and it was revealed that the float method has had probably overestimated the actual flow with an error ranging from 5 to 10%.There are five gauging stations in the Gash River. El Gira, the most upstream station is located 24 kilometers upstream Kassala Town. The other four stations are Kilo 1.5 upstream the bridges, Kassala bridges, Futa and Salam Alikum stations. Futa and Salam Alikum stations are 7.4 and 10.0 kilometers downstream Kassala Town. Figure 2 is a sketch showing the location of the gauging stations [6].

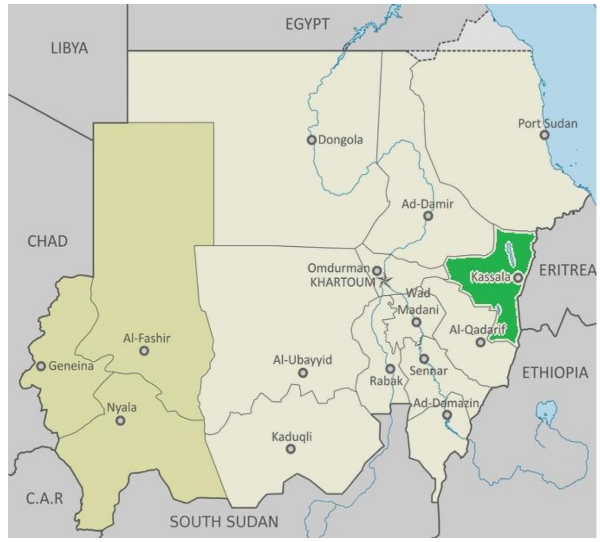

Figure 1: Sudan Political Boundaries

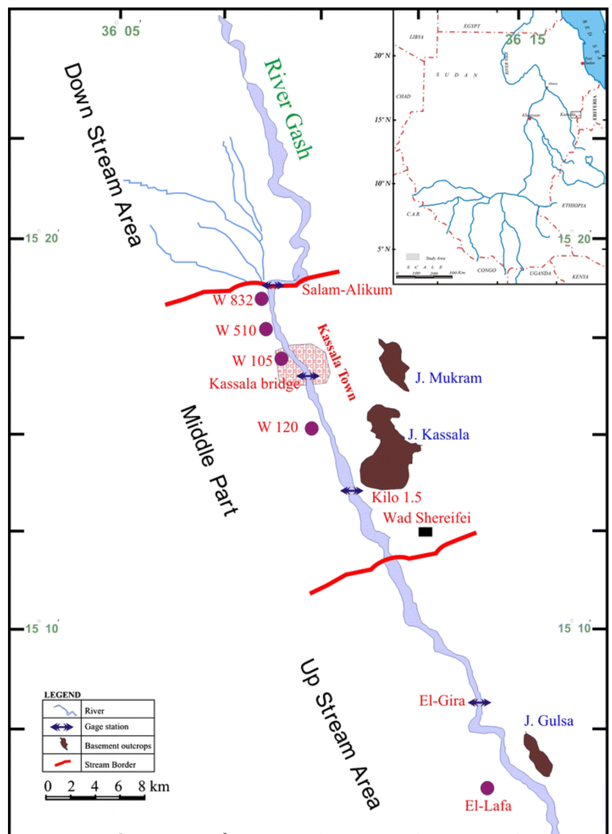

Figure 2: Locations of the Gauging Stations [6]

The Gash River is the only source of water for irrigated agriculture and domestic use, through recharge of the alluvial river bed deposits and accompanying aquifer. It has a demarcated area, estimated about 400,000 feddans with commendable area of 250,000 feddans. Flood risk has a return period of four to five years. Flood disasters became a major threat to Kassala Town and neighboring areas, which consequently threatened the population livelihood sustainability. There is no existing flood early warning system while the existing protection infrastructures are not properly maintained [5].

The tools used to solve the problems of Kassala Town and its neighboring area where three Models, namely Empirical correlation Gumbel, distribution and HEC-HMS Models. An early warning system was suggested leading to fulfill the main objective as well as appraisal of surface and ground water potentials of Gash River and reclaimd the diminishing delta agricultural areas which constitute the main part of the specific objectives. It was also indicated that the ground water as well as the surface water are basically fed from the Gash River. The observed surface flow was found to be 900 m^3/sec at Khor Abu Alga confluence with the Gash River compared with that at Kassala which was found to be a maximum of 750 m^3/sec.

MATERIAL AND METHODS

It is not possible to describe hydrologic processes with exact physical laws. Using system concept with efforts in construction with a model relating input and output is more practical and acceptable. However, knowledge of physical system develops good model with verifying accuracy. The objective of a hydrologic system is to study its operation and predict its output.

A hydrologic system model is an approximation of the actual system, with measurable input and output hydrologic variables. The structure of the hydrologic system model is a set of equations linking the inputs and outputs, involving the concept of system transformation. Expressing input as $I(t)$,and output as $Q(t)$, the system transformation is as presented in equation (1).

$$Q(t) = \Omega I(t) \quad (1)$$

$Q(t)$ = Belongs to time range (T). I(t) The transformation equation of the system. Ω = Transfer function between input and output, and it could be an Algebraic operator.

$$Q(t) = CI(t) \quad (2)$$

C is Constant. The transfer function is the operator

$$\Omega = \frac{Q(t)}{I(t)} = C \quad (3)$$

If the transformation is described by a differential equation, then the transformation serves as a differential operator. For example a linear reservoir has its storage (S) related to its outflow as shown in equation (4).

$$S = kQ \quad (4)$$

k is Constant with dimension (T) is time.

About 18 kilometers upstream Kassala town there was the natural off-take of Khor Somit from the Gash, which was closed since 1976. Nine kilometers downstream old Khor Somit off-take is Khor Quenti, joining Khor Somit again with the River Gash. These two channels are on the west side of the river, Khor Abu Alaga on the other hand discharges its flow on the eastern side of the River Gash about one kilometer downstream Khor Quenti[0] .

The ground water is affected by its location relative to its distance from the Gash River banks. The level of the water in the wells is directly affected by its location from the flood plain of the Gash River. Contour maps will be the best to depict the ground water levels at different locations in the vicinity of Kassala Town and Aroma Town.

However although there is available data about wells in that area, it was not possible to obtain the most recent data to give the real level. Figure 3 and Figure 4 show the Study Area Map.

Flood frequency analyses are used to predict design floods for sites along the Gash River. The technique involves using observed annual peak flow discharge data to calculate statistical information such as mean values, standard deviations, skewness, and recurrence intervals. The statistical analysis for the Gash River historical data are as shown in Table I.

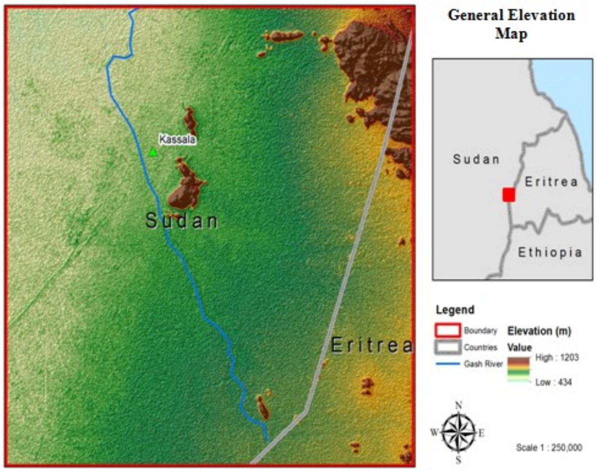

Figure 3: Study Area Map

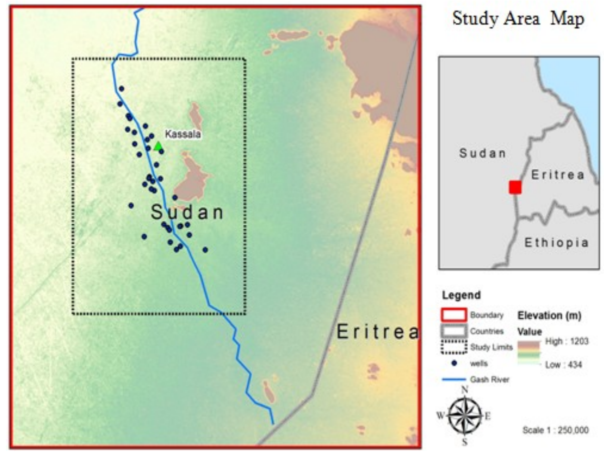

Figure 4: Study Area Map

Table I: Statistical Data for Gash River during the period 1907 to 2010

Total Discharge $M.m^3$		Maximum Discharge $m^3/\sec$	
Mean	680.670	Mean	380.042
Standard Error	29.008	Standard Error	15.597
Median	642.500	Median	350.000
Mode	540.000	Mode	250.000
Standard Deviation	295.822	Standard Deviation	159.056
Sample Variance	87510.797	Sample Variance	25298.877
Kurtosis	-0.404	Kurtosis	2.265
Skewness	0.436	Skewness	1.351
Range	1290.000	Range	895.139
Minimum	140.000	Minimum	118.750
Maximum	1430.000	Maximum	1013.889
Sum	70789.704	Sum	39524.316
Count	104.000	Count	104.000
Largest(1)	1430.000	Largest(1)	1013.889
Smallest(1)	140.000	Smallest(1)	118.750
Confidence Level(95.0%)	57.530	Confidence Level(95.0%)	30.932

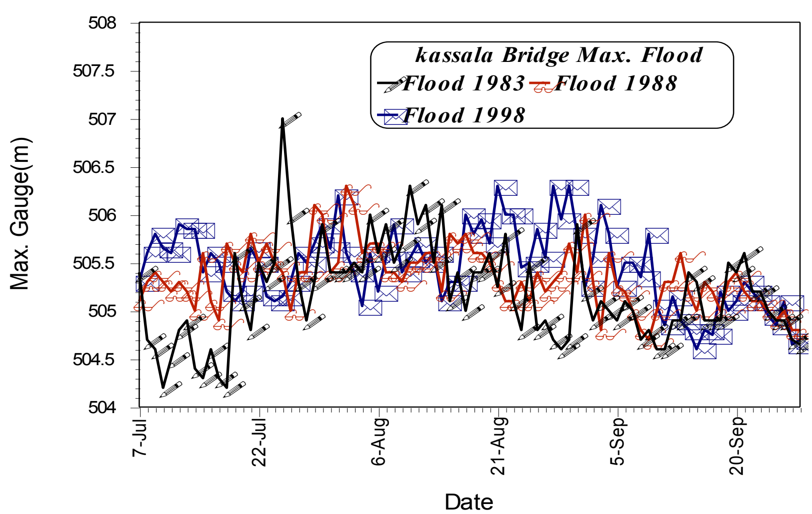

Figure 5a: Gauge Hydrographs Fluctuations

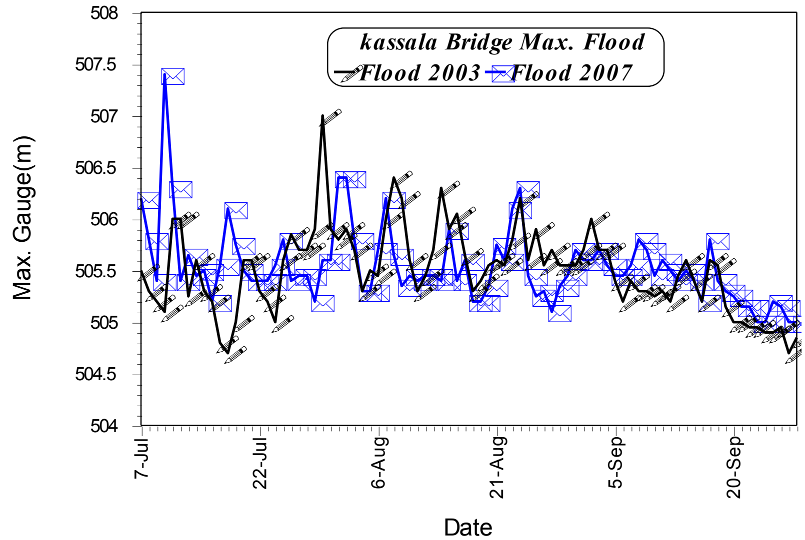

Figure 5b: Gauge Hydrographs Fluctuations

Flooding is directly affected by rainfall storms in the catchment area. In the downstream reaches of rivers like that of the Gash River in the vicinity of Kassala Town statistical analysis or flood routing can be applied to indicate the runoff and discharges parameters. The parameters should best include short duration of peak flow, maximum, minimum, and averages gauge hydrographs. Figure (5a) and (5b) clearly depicts the hydrographs of the fluctuation of the gauges reading during the different floods in years 1983, 1988, 1998, 2003 & 2007. Two figures were used so as to clearly show the details of the different years.

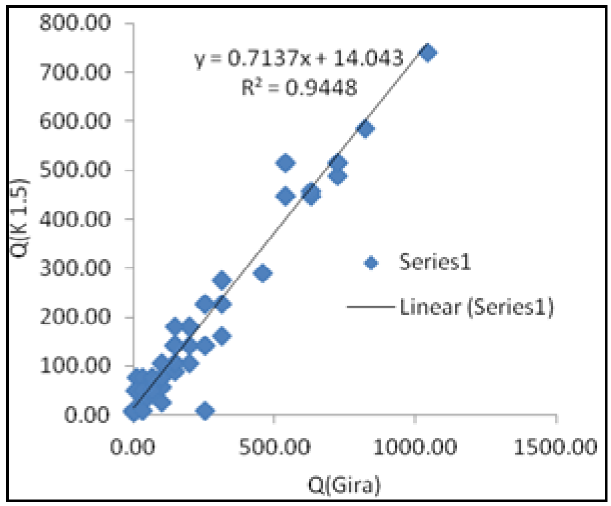

Figure 6: Empirical Model Discharge Correlation of El Gira and K1.5 Kassala

RESULTS AND DISUSSION

Development of the Selected Empirical Model:

The selected empirical model is used to find the correlations among the discharge values in three of the four other gauging stations versus discharges of El Gira Gauging station in the Gash River. Kassala Bridge gauging station was not correlated because it is very near to K 1.5 Kassala gauging station. The three gauging stations are K1.5 Kassala, Futa and Salam Alikum, as shown in Figure (2). El Gira being the most upstream at the border of the Sudan is taken as the base station for correlations application. Hence El Gira discharges are taken as inflow input and the other stations as outflow output. The results of these three correlations are shown in figures Figure 6 to Figure 8 for the three gauging stations.

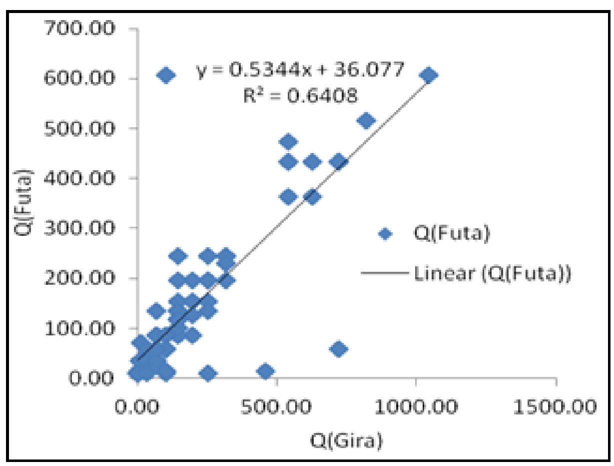

Figure 7: Empirical Model Discharge Correlation of El Gira And Futa

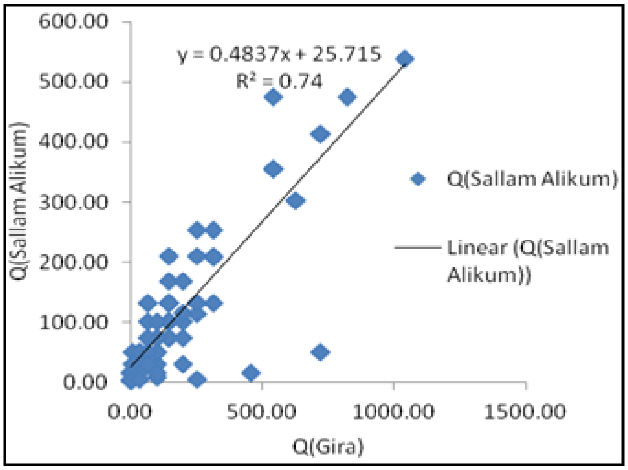

Figure 8: Empirical Model Discharge Correlation of El Gira And Sallam Alikum

The application of the selected empirical model revealed that; the best fit of the three correlations was obtained with a linear trend at Kassala station of K1.5 upstream the bridges Figure 6. The empirical formula has the form presented in equation 5.

$$Q_K = aQ_G + b \tag{5}$$

Where Q_K = Discharge at K1.5 (m^3/sec). Q_G = Discharge at El Gira Gauging Station (m^3/sec). a = Slope of the line. b = Intercept. Interpretation of Figure 6, and equation (5) indicates that when El Gira has a discharge of 1000 m^3/sec Kassala has a discharge more than 700 m^3/sec.The values of a and b of equation (5) can be determined. A good fit of the three correlations was also obtained with a linear trend at Futa station downstream the bridges as shown in Figure 7. The empirical formula has the form depicted in equation (6).

$$Q_F = aX + b \tag{6}$$

Where: Q_F = Discharge at Futa Gauging Station (m^3/sec). X = Discharge at El Gira Gauging Station (m^3/sec). a = Slope of the line. b = Intercept. Interpretation of Figure 7, and equation (6) indicates that when El Gira has a discharge of 1000 m^3/sec Futa has a discharge more than 550 m^3/sec.The values of a and b of equation (6) can be determined.

It is also interesting to find that best fit was also obtained with a linear trend at Sallam Alikum station Figure 8. The empirical formula has the form shown in equation 7.

$$Q_S = aQ_G + b \tag{7}$$

where Q_S = Discharge at Sallam Alikum Gauging Station (m^3/sec). Q_G = Discharge at El Gira Gauging Station (m^3/sec). a = Slope of the line. b = Intercept. Interpretation of Figure 8 and equation (7) indicates that when El Gira has a discharge of 1000 m^3/sec Salam Alikum has a discharge more than 500 m^3/sec. The values of a and b of equation can be determined.

Comparison of the three above results of the correlations clearly depict that the losses upstream are much lesser than those downstream. This means that Kassala Town is exposed to flooding risks at K.1.5 more than downstream areas at Futa and Sallam Alikum.

Furthermore to test the reliability of equation (5) linear discharges correlation relation at K1.5 upstream Kassala gauging station was correlated with the real time measured discharge at K1.5 upstream Kassala gauging station of Figure 6. Figure 9 shows the correlation between the measured and correlated linear values of discharge for the gauging station. The result fits admirably giving relative error of only 3.6 % as given in equation (8), which is very reliable. This reveals the fact that the maximum instantaneous discharge passing Kassala Town is higher than 700 m^3/sec.

$$R^2 = 0.97 \tag{8}$$

Subsitituting these values of the coefficients and El Gira discharge of 1000m^3/sec in the above equations (5); (6) and (7) give the results in Table III below.

Flood Freguancy Estimate:

Gumbel Distribution Model was used to find the relationship between rainfall on the catchment area and maximum discharge for the Gash River at Kassala Gauging Station. Table (4) shows the result obtained from Gumbel distribution Model for return period range and probability of maximum discharge. From Table IV Figure 10 is plotted to indicate the return period of the maximum flood. Table (4) read with Figure 10 reveals that the maximum instantaneous discharge is more than 700 m^3/sec with a return period of twenty years. Table II shows the empirical model coefficient values from the three figures of the three stations.

HEC-HMS Model:

Considering the hydrographs obtained from the HEC-HMS Model as in Figure (11) below it can be clearly seen that the rainfall loss has a maximum depth of 80 mm, and a minimum depth of 10 mm while the rainfall maximum depth is 145 mm with a minimum less than 60 mm. Further interpretation of the hydrograph shows that the base flow has a maximum of 400 m^3/sec at zero time (6PM).The observed flow has a maximum of 900m^3/sec at 3 PM. The outflow reading has a maximum of 2900 m^3/sec and then it merges to be equal to the observed flow which has a maximum of 900m^3/sec. These results indicate that the flood of 2007 was significantly high. It also indicates that the ground water as well as the surface water are basically fed from the Gash River. Hence the HEC-HMS Model beside indicating ground water base verified the results of the surface flow upstream K.1.5 Kassala gauging station obtained by both the Empirical and Gumbel Distribution Models.

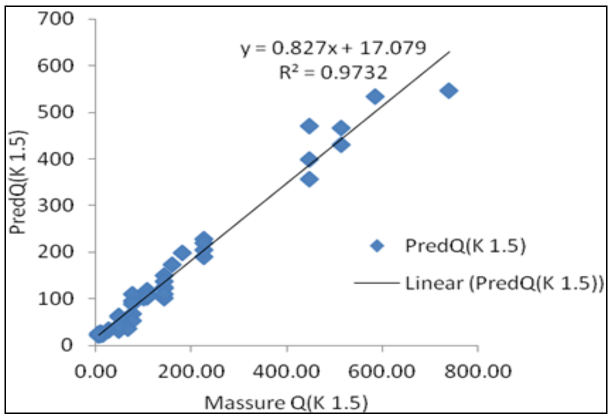

Figure 9: Empirical Model Discharge Correlation Predicted and Measured of K1.5 Kassala

Table II: The Empirical Model Coefficient For The Four Stations

Gauging Stations	Coefficient	a	b	R^2
Kassala at K1.5	Linear	0.7137	14.043	0.945
Futa	Linear	40.996	0.0034	0.6408
Sallam Alikoum	Linear	0.4837	25.715	0.740

Table III: Discharges Correlation Results

Gauging Stations	Discharge (m^3/sec)
El Gira	1000.00
Kassala at K1.5	727.74
Futa	570.5
Sallam Alikoum	509.42

Table IV: Maximum Discharge Gumbel Distribution

i	Return period T(yr)	Probability P (percent)	Gumbel variety y	Flood Discharge (m^3/s)
1	1.05	95.2	-1.113	160
2	1.11	90.1	-0.838	196
3	1.25	80	-0.476	244
4	2	50	0.367	355
5	5	20	1.5	504
6	10	10	2.25	603
7	25	4	3.199	728
8	50	2	3.902	820
9	100	1	4.6	912
10	200	0.5	5.296	1004

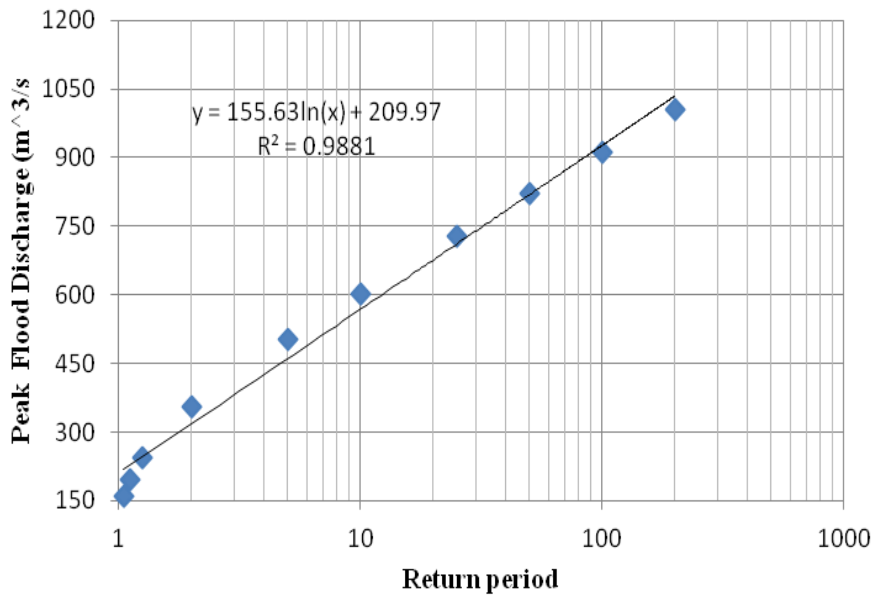

Figure (10): Return Period Of Maximum Flood

The observed surface flow being 900 m^3/sec is logical and consistent with the result obtained at K.1.5 Kassala which was found to be a maximum of 750 m^3/sec, which is less than that the flood of Abu Alaga at the application point. **Contour Map:**

The contour map of ground water levels in Gash basin are illustrated in several figures Figure (12), is a typical presentation for all the figures. These figures revealed that the large basin aquifer has abundant water potential. This can be used in domestic water supply for Kassala State. These contours were interpreted and indicated that the area covered by the contour maps is 420 km^2 with an average depth of 9.28 m. This obviously reveals the fact that the ground water potential upstream and downstream Kassala area is 3897.6 M m^3. This can be utilized in domestic, industry and agricultural water supply. Samples taken from wells in scattered areas upstream and downstream Kassala area indicated that the water quality is excellent.

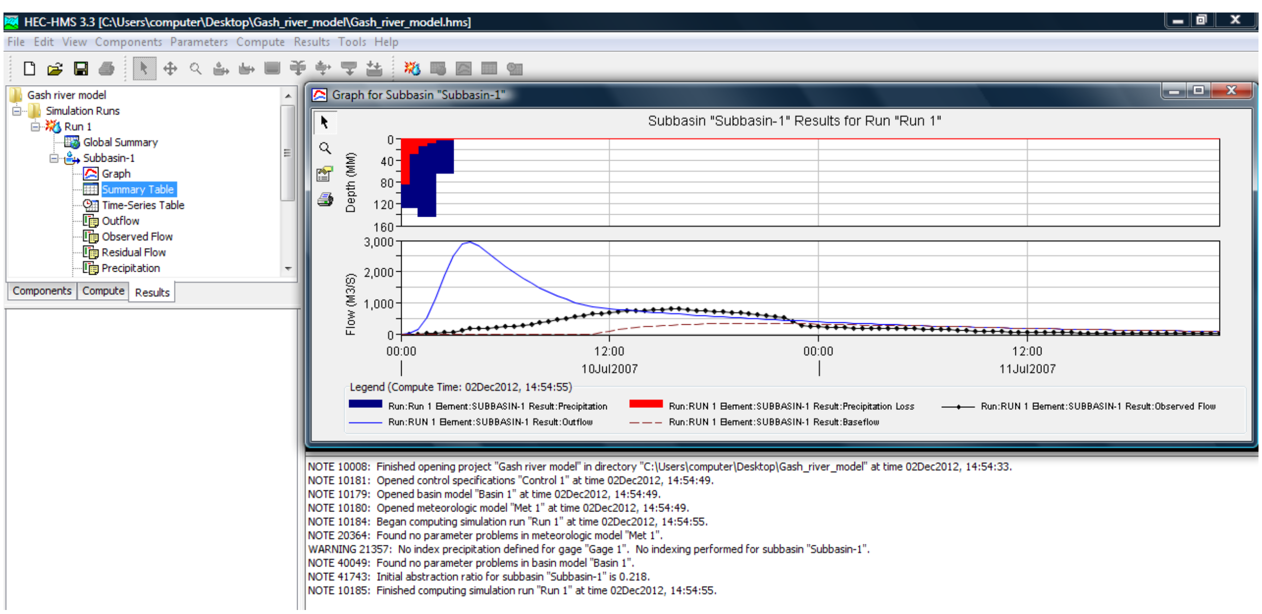

Figure 11: Hydrograph Sub Basin and Kassala Bridge Station 2007

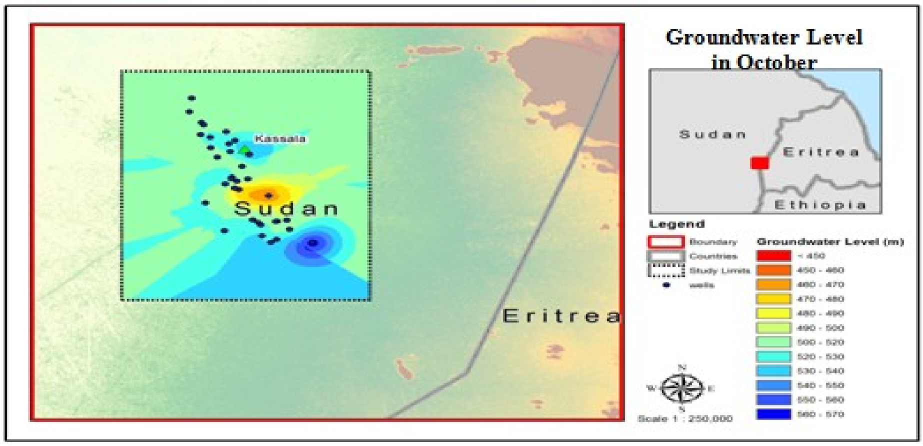

Figure 12: Ground water contour map – Oct 2003

CONCLUSIONS

From the work undertaken herein the following conclusions emerged:

- The frequency of expected maximum flood of 600 m3/sec. occurrence has a recurrent period of four to five years.
- The Gash River flows for 80 to 100 days per year transporting 40 million meter cube of sediment resembling the Yellow suspended River in China.
- The Ground water was found to be quantitatively and qualitatively excellent.
- No early warming system in the Kassala Town
- Only 5% of the Gash River flood water is used in agriculture.

RECOMMENDATIONS:

- Cooperation among Sudan, Eritrea and Ethiopia in the Gash River Basin management.
- Establishment of an early warming system in Kassala Town.
- Encourage use of the available abundant ground and surface water potential in the different uses of water.
- Implementation of a bypass upstream Kassala Town to reduce risk of floods against Kassala Town.

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