Appraisal of Existing River Protections in Kassala Town

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ABSTRACT- Kassala Town is frequently inundated by the Gash River. The flood of 2003 caused great damages and extensive losses of lives, resulting in an estimated loss of 575 million U.S.Dollars.The main objective of this study is the appraisal of the existing protection and training structure, and quantifying the sediment transported by the Gash River. It is found that the Gash River transports 15 million tons (40 million cubic meters) of sediment annually passing downstream Kassala Town. The appraisal revealed that although the adopted spur and dike system was and still is the ideal approach to train the Gash River and protect Kassala Town, yet the undesired man activities coupled with absence of maintenance were the main causes of inundations. In 1984, the bed of the Gash River near Kassala Town was 10 centimeter below the general ground level of Kassala Town. After 1984 the practiced undesired activities raised the bed of the Gash River two meters higher than Kassala Town general land level. It is recommended to enforce a law prohibiting these undesired activities as well as rehabilitation of the existing spur dike system

***Keywords**:Spur, Dykes, Scour, Sediment.*

المستخلص:يتكرر غرق مدينة كسلا لكثير من فيضانات القاش. فيضان عام 2003 تسبب فى وفيات متعددة وخسائر تجاوزت خمسمائة خمسة وسبعون مليون دولار امريكى.الهدف الرئيس من الدراسة هو تقويم منشآت الحمايه والترويض القائمة اضافة لمعرفة كميات الطمي المرحلة بواسطة النهر.نهر القاش يحمل خمسة عشر مليون طن (اربعين مليون متر مكعب) من الطمي سنويا تعبر خلف جسر مدينة كسلا.التقويم اوضح انه بالرغم من ان نظام العراضات والجسور كان ولا زال الطريقة المثلى لترويض نهرالقاش وحماية مدينة كسلا لكن الممارسات غير المرشدة مقرونه بغياب الصيانه كانت هى السبب الاساس المباشر لغرق مدينة كسلا.فى عام 1984 كان منسوب مجرى نهر القاش عند مدينة كسلا أقل من منسوب المدينة العام بعشرة سنتيمترات. بعد عام 1984 تسببت الممارسات غير المرشدة فى رفع منسوب مجرى نهر القاش مترين فوق منسوب مدينة كسلا. ختمت الدراسه بالتوصية لسن قانون يمنع الممارسات غير المرشدة فورا بالاضافة لتأهيل نظام الجسور والعراضات القائمة.

INTRODUCTION

Kassala State is in the eastern part of the Sudan, with population about 1.7 million.Figure 1 shows the general layout of Kassala State. Kassala Town has an average rainfall of 300 mm. Its high temperature resulted in water deficits, low vegetation cover, and low populationdensity. The Gash River Delta area is 240,000 feddans, with horticultural area of 10,000 feddans. Geologically the Basement rocks are found in the vicinity of Kassala Town. Alluvial deposits occur along the major drainage system of the Gash River with maximum thicknesses of 30-40meters. The Gash River is an ephemeral river which flows for 80 to 100 days per year. It deposits a huge sediment load in its course and the Delta. The existing river bed in Kassala Town is now two meters higher than the ground level in the Town.

In 1975, 1988, 1996 and 1998, Kassala Town was subjected to flooding. The worstflooding was experienced in July 2003 when the level of the Gash River upstream rose above its normal level. The existing series of spurs and dikes that has protected Kassala Town and its neighborhoods against floods for more than 90 years failed to be in tact.

There are four gauging stations to measure river stage and velocity. These are Gira 24 km upstream Kassala town, Kilo 1.5 Kassala, Futa and located 7 km and 10 km downstream Kassala bridges respectively. Communication between these gauging stations and the town is not available.

Figure 1: General layout of Kassala state Previous Researches in the Study Area[3]

Statement of the Problem

How to train the Gash River and protect Kassala Town against its flood, to fulfill the objectives, while it has the following characteristics:

- The Gash River is Ephemeral River, unpredictable braided river.
- The Gash River deposits about 13 million tones of sediment load in its course and the Delta due to steep gradient, and absence of vegetation cover.
- Sediment deposits led to gradual build up of the river channel, the existing river bed in Kassala Town is now two meters higher than the ground level in the Town.
- The level of the river bed under Kassala old Bridge is one meter below the bridge soffit.
- The change in the river course often isolate intake structures of irrigation canals from the river channel and thus irrigation of the areas under command of these canals in the delta becomes impossible.

It became apparent that the Gash River poses the biggest potential danger to lives, properties and livelihoods in the area. The flood of the Gash River in 2003 breached its banks. This resulted in the Gash River changing its course to the centre of Kassala Town, causing extensive losses of lives, properties and injuring several persons. At least 600 buildings were swept away and the old bridge was completely submerged. The flood damaged 70% of the town, affecting 100,000 persons, and 17,000 householders in Kassala Town were left homeless.

Swan [18] gave historical engineering works summary about the whole length of the Gash River including the study area. He indicated that the first recorded construction work was a dam implemented upstream Kassala Town in 1840,to divert the Gash River to Khor Somit to irrigate Kalhote area. The channel leading to Kalhote was silted in1871.Figure 2 shows the location of Khor Somit and Kalhote area.

In 1905 a weir was constructed across the Gash River, designed to pass a discharge of 300 $m^3/\sec$,three kilometres upstream the old bridge location. In 1921 it was washed out and removed in 1929. In 1930 the first Spur was constructed at the removed weir location. In 1931 flood the spur was damaged and Kassala Town was severely attacked. The construction of spurs continued from 1930 to 1936. Upstream those spurs the Gash River widened from only 150 meters in 1904 to more than one kilometre, when it became necessary to use brushwood revetments. In 1943 a dry pitching reach was built in the east.

In 1949 the old bridge was constructed. Its piers have the dimensions1.83 x 7.93 meters with six equal spans of 20 meters. As recorded by Swan[18] Kassalsa was attacked in 1950 and 1952 high floods.

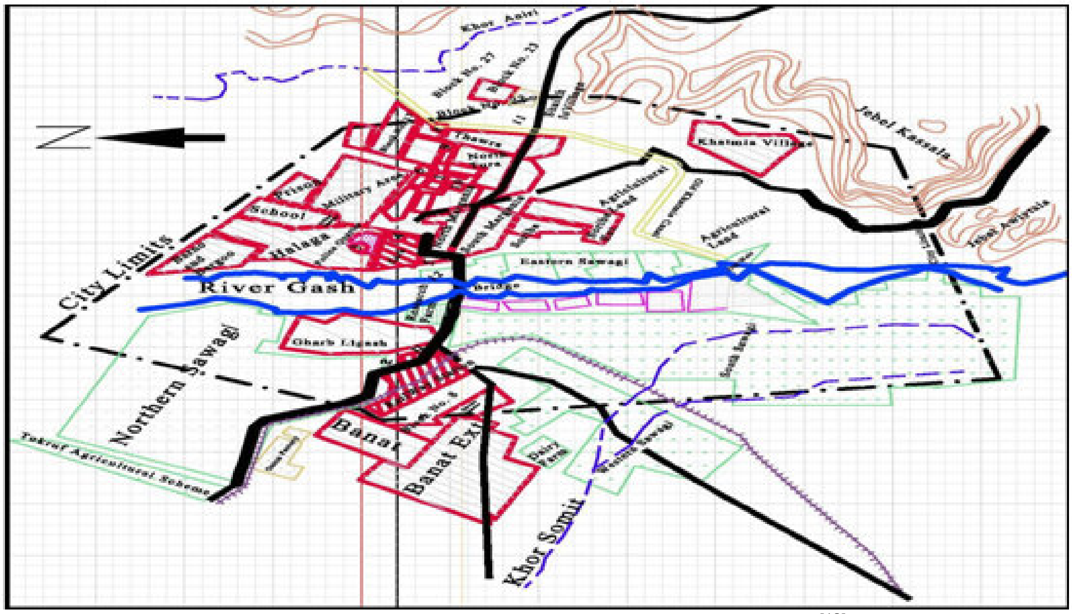


Figure2: The location of khor Somit and Kalhote area[18]

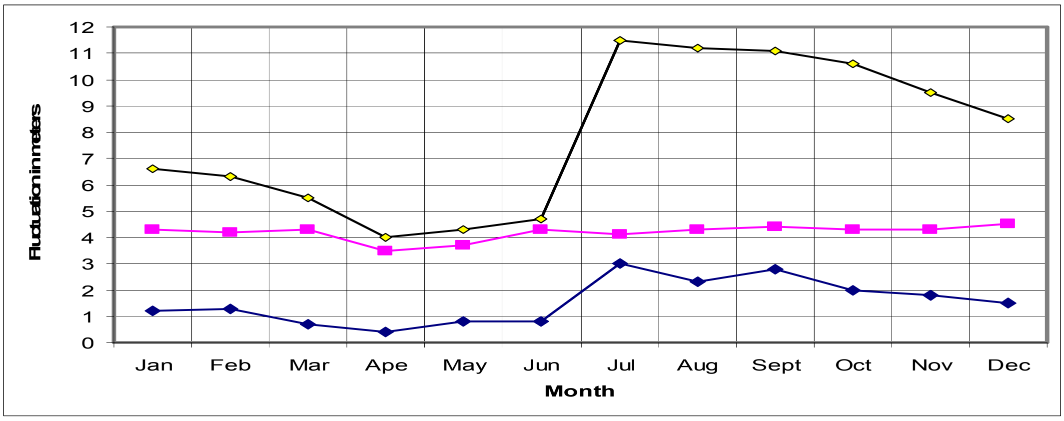


Figure3:Water surface fluctuation in wells[18]

After 1954 no records about the Gash River banks was recorded. The Awaytala bank was breached and the whole town was completely inundated in the east. The western bank downstream the bridge was breached and the west part of the town was also inundated.Khor Somit crossing the railway line in the west was also flooded which breached the railway line connecting Kassala town with Khartoum.

In 1975 flood the maximum level at the bridge, K.0 Kassala gauging station was 505.50 R.L.the bed level was 503.95 R.L. The measured bed slope ranged from 120 to 165 cm/kilo upstream the bridge and 105 cm/kilo downstream the bridge. Awaytalla bank and the western downstream bank were covered with Nicolon.matrix tissues.

In 1976 Abbas [1,3] noticed that the reaches upstream and downstream the stable straight three kilometre reach spurs system were wide divided with islands and characterized as typical braided reaches.

Although these spurs were attacked by the Gash River repeatedly yet they were not damaged.Abbas[1,3] also noticed that silt deposition was accumulated in the U shaped spaces between the successive spurs and created the famous Sagias areas through land reclamation. The reclaimed land is very fertile with abundant ground water[3,4,5].

Abbas [2,3] noticed that the ground water level within the spurs system area was raised with increased ground water yield. He recorded water level readings shown in Figure 3 at El Sabeel, nine kilometres upstream kassala Town and at Tukrof, four kilometres downstream.Abbas [2] indicated that cross sections taken in successive years downstream the bridge has shown that the bed of Gash River was raised 10 cms per year during the period from 1936 to 1975. He conducted levelling investigations in extension of the spur and dykes system in the Gash River upstream and down stream the bridge.

In 1984 Abbas recommendations were implemented. This resulted in reducing the bed level of the Gash River 10 cms below the general land level of Kassala Town downstream the bridge.

In 1988, 1996 and 1998 Kassala Town was subjected to flooding [4,5]. These floods were controlled with minor mitigation measures. The Gash River continued to transport the thirteen million tones of sediments from the upper reaches of Eritrea. It was reported that the Gash River bed in the vicinity of Kassala Town became two meters higher than ground level inthe Town. In July 2003 the worst flooding inundated Kassala Town[7,11].

The frequency of high flood occurrence which was 1 in 10 years before 1984 became 1 in 4 years after 1984[11].The successive researchers and construction engineers engaged in the Gash River training and Kassala protection recommended continuation of spurs and dikes upstream and downstream the existing system as Abbas Suggested [7,11].

Objectives of the Paper

The objectives of this research work focused on:

I. Appraisal examination of the existing protection and training structure.

- The length of the Gash River in the vicinity of Kassala Town under appraisal study is nine kilometers upstream and ten kilometers downstream Kassala bridges.
- The appraisal study includes consideration of the bridges and their effect on the river morphology and hydrology.

II. Checking and quantifying the sediment transported into the Gash River to the channel and the delta, causing the two meters rise in bed level.

MATERIALS AND METHODS

Rivers are in equilibrium when no trend of variation occurs over several cycles. There are three channel patterns; straight, meandered and braided.A straight channel has flat slopes and a narrow section. A meander has an unchanged bed and bank materials, discharge, and sediment load. A braided channel is fairly straight in plan but substantially wider and carries heavy sediment loads, with steeper slope.Statical relations [8] are:

$$\lambda = 65.2Q^{0.5} ---(1)$$

$$\lambda = 61.1Q^{0.467} ---(2)$$

where$Q$=Dominant discharge or the discharge which generates the meander length (cumecs). λ = Meander length or the distance measured along the axis of the valley between two corresponding points on successive meanders (meters).The meander belt width is related to meander length, channel width and discharge, by the equations [8].

$$\beta = 1.83\lambda^{(1.06)}[rivers - in - flood - plains] ---(3)$$

$$\beta = 1.29\lambda^{(1.07)}[Incised - rivers] ---(4)$$

β = Meander belt width of a belt between parallel lines which contain the meandering channel [meters].Figure 4 is a plot of actual straight-line water surface slope against discharge for straight and meandered channels.

i_{sc} = Critical straight-line water surface slope above which alluvial channels meander. A critical slope separating the two channel patterns for sediments of medium particle size ranging from about 0.04-mm and 5.0-mm is shown.

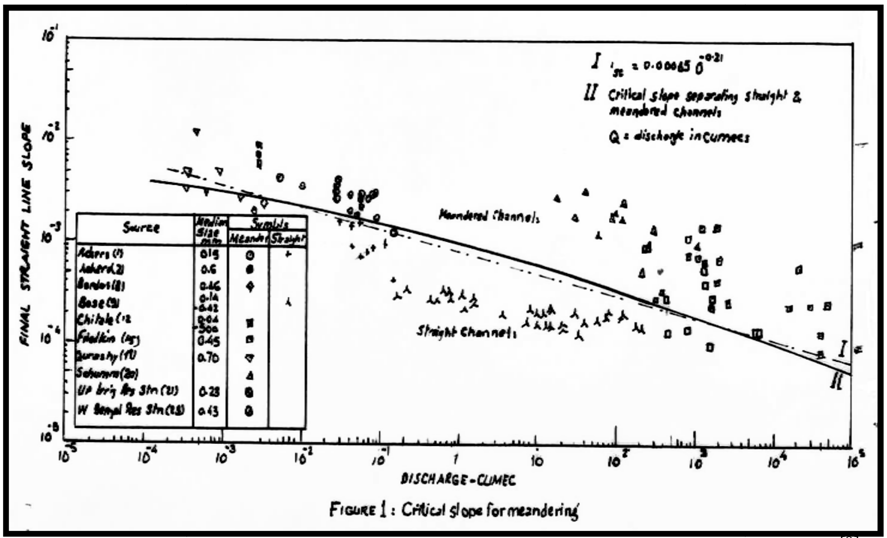


Figure4: Plot of actual straight-line water surface slope against discharge [8]

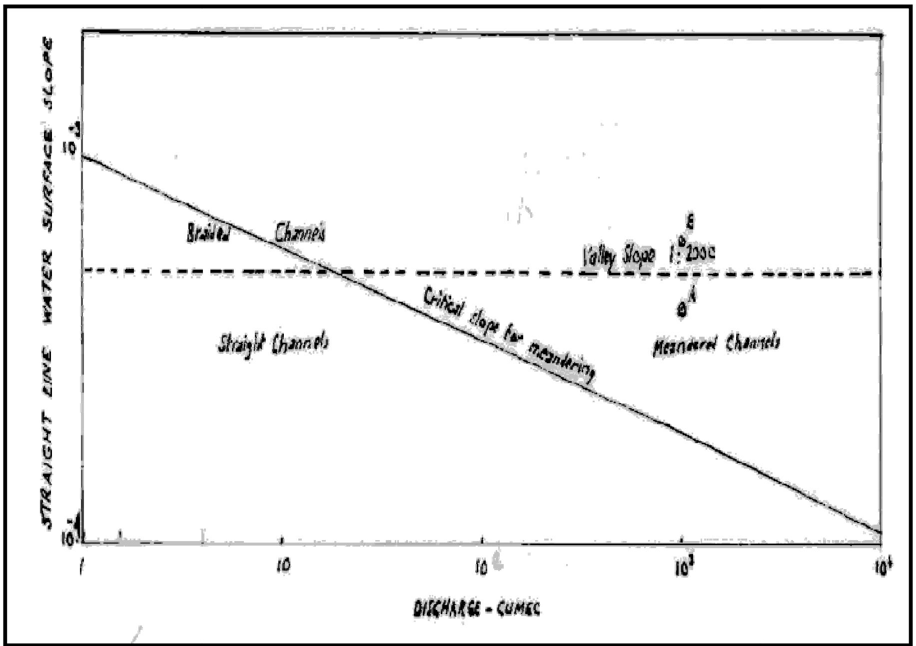


Figure 5: Application of critical slope [8]

Channels requiring relatively flat straight-line water surface slopes to convey the water sediment complex or with small bed sediment transport rates, tend to remain straight, while the steeper channels or those with higher bed sediment loads tend to meander [8].Braids and meanders represent the extremes of the ranges of channel patterns. Simons and Senturk [16] applying Lane's method of 1957 formulated a relationship, among slope, discharge and pattern in meandered and braided streams as:

$$SQ^{\frac{1}{2}} = K \; ---(5)$$

where: S = Slope of the channel, Q = Dominant discharge, K = Constant. They plotted a graph and indicated that when:

$$SQ^{\frac{1}{2}} \leq 0.0017 ---(6)$$

The stream is meandering, and when:

$$SQ^{\frac{1}{2}} \geq 0.01 --- (7)$$

The stream is braided and those between the two limits are transitional.Leopold and Wolman[13,14] expressed the relation between discharge and (λ) meandered length as:

$$\lambda = 36Q^{\frac{1}{2}} --- (8)$$

Meandering streams sinuosity ≥1.5 and straight sinuosity ≤1.5. Braids are separated from meandered by a line:

$$S = 0.06Q^{-0.44} --- (9)$$

InFigure5a valley slope of 1:2000, dominant discharge 1000 comics, actual straight line water surface slope is 4×10^{-4} a meandered channel occurs at point A. Increased sediment supply results in a greater slope of 6×10^{-4} at (point B) with a braided form [16]. Precautions must be taken with meandering and braided channels when designing control works to prevent the outflanking of those works by their lateral channel movements. Construction of spurs will cause an embayment on the opposite bank downstream.

Measurement of discharges using floats is done when it is impossible to use a current-meter (excessive high velocities or very low velocities). The float velocity is measured over the reach between measuring the distance *L* and the travel time *t* between both sections [7,11].

$$V_{float} = \frac{L}{t} --- (10)$$

The beds that may from in a river may be plane bed, ripples, dunes, anti dunes chutes and pools. The sequence of occurrence of bed roughness as affected by the flow is proportional to the increase of stream power (T_oU) for bed materials having D_{50} less than 1.6 mm [16], where T_o = shear stress on the bed, U = velocity of flow, D_{50} = mean fall diameter of bed.

The use of spurs or groins for river training has became popular. Relations developed for selection and design of different groins types, in particular for scour whole equilibrium scour depth. This is due to the fact that groins failure occurs at the nose where the local scour hole developed at the front of the groin degrades the foundations. Abbas[1,2,3] ,and Akode[4,5] made critical review for these relations and their applications to river Gash in Sudan and proposed the relations for D_{50}=0.3 – 0.52 mm, b/B = 0.19 – 0.31, Fr= 0.18 – 0.30.

$$\frac{d_s}{y} = 2.639\left(\frac{E_L}{b}\right)^{-.092}\left(\frac{E_w}{B}\right)^{0.248}\left(\frac{\tau_o}{\gamma_{sub}d_{50}}\right)^{0.106} --- (11)$$

$$\frac{E_L}{b} = 0.089\left(\frac{b}{B}\right)^{-1.995} Fr^{-.899} --- (12)$$

$$\frac{E_w}{B} = 0.736\left(\frac{b}{B}\right)^{0.604} Fr^{0.135} --- (13)$$

where Y=Depth of approaching flow, d_s = Depth of scour below bed level.d_{50}= Median particle diameter, B = Width of channel, b = Length of groyne, E_L = Eddy length generated by a groyne, E_W = Eddy width generated by a groyne, Fr = Flow Froude number. And τ_o = shear stress in uncontracted section

Gill [9]1972, used a small range of sand sizes and opening ratios proposed the following relation to calculate the local erosion depth.

$$\frac{y_2}{y_1} = 8.375\left(\frac{D_s}{d_1}\right)^{1/4}\left(\frac{B_1}{B_2}\right)^{5/7} --- (14)$$

where:y_1=depth of flow in uncontracted section, y_2 = depth of flow in contracted section, B_1 = width of uncontracted section, B_2 = width of contracted section, and D_s = bed material median diameter

Examination of Existing Protections

The existing hydraulic structures upstream and downstream Kassala Town in both the West and East banks of the Gash River are examined. This examination is to fulfill the objective which is to asses their effects on Kassala Town and its neighboring areas. The Gash River approaches Kassala Town and passes through the main parts of the reach system under study. The reach covered by the main parts of the system is shown in Figure 6. It consists of nine categories of protection and training structures.

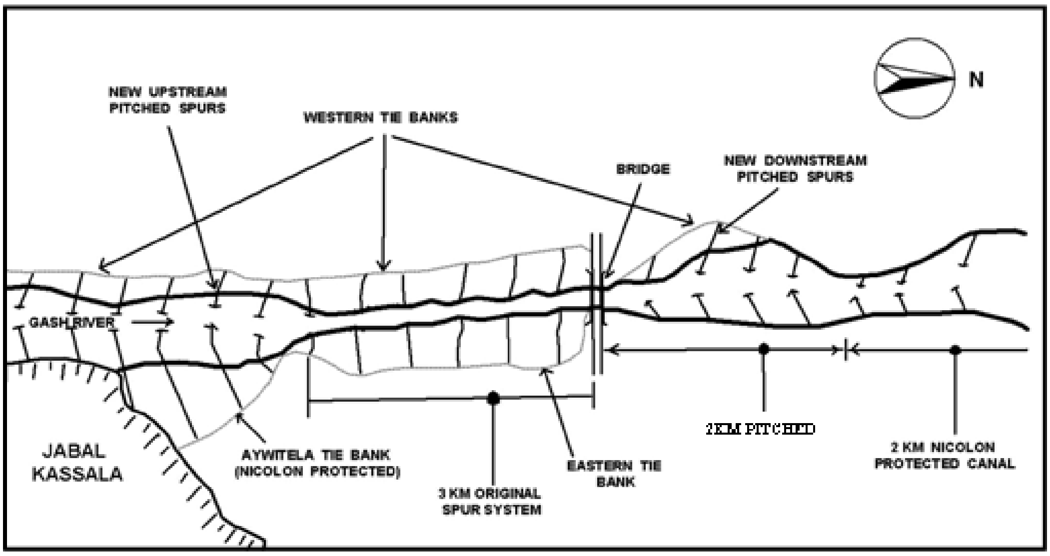


Figure 6: Existing protection works near kassalatown

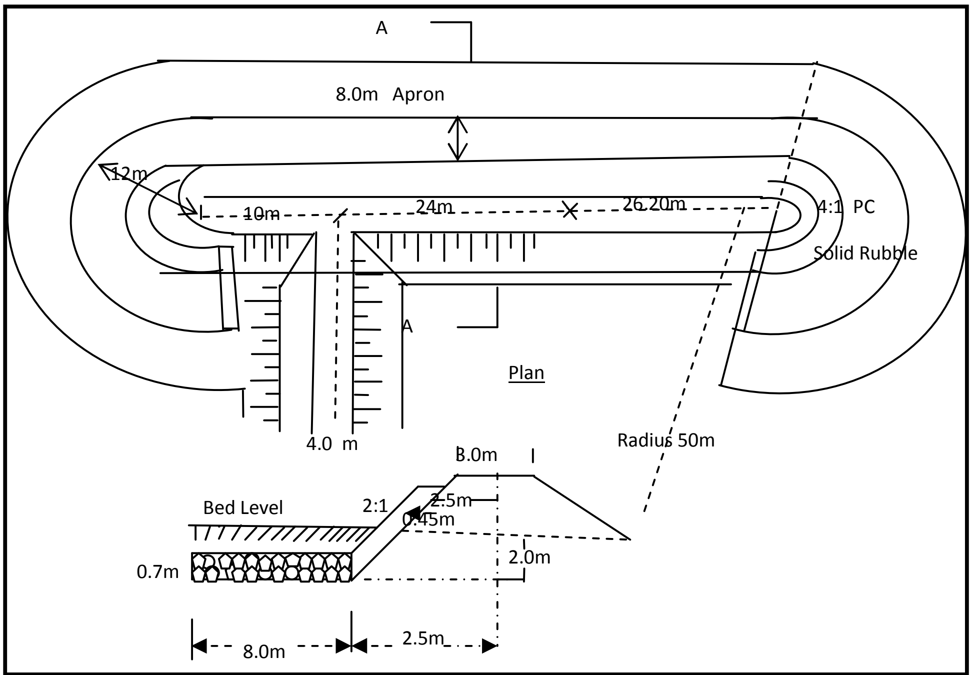


Figure 7: Plan and section of a spur[18]

These are three Kilometers Original Spur System. Two Kilometers Pitched Bank. Two Kilometers Nicolon Covered Bank. New Upstream Pitched Spurs. The Bridges. Eastern Tie Bank. Western Tie Bank. Aywitella Tie Bank. New Downstream Pitched Spurs. There are also the two reaches which are: The reach between the ends of the new downstream pitched spurs to Futa head. The reach between Futa and Salam Alikum head.

- system as shown in Figure 6 are the seven pairs of spurs implemented during the period from 1931 to 1936, which were with cross section shown in Figure 7, spaced 500 meters apart with a similar length of their shanks, bounding a U shaped area between their shanks on both sides of the Gash River in the vicinity of Kassala Town. The distance between their heads across the Gash River forming its constricted bed width was designed as 120 meters which coincided with the same width of the old bridge. They were reported as being slightly affected by 2003 catastrophic flood. This reveals the fact that these upstream spur heads have survived for about (2003-1931=72) seventy-two years with little or no maintenance over this long period and are still surviving.

- The three kilometers original spur and dyke
- The Two Kilometers Pitched Bank being outside and at the end of the old spurs and dykes system was an earth bank and directly adjacent to Kassala Town. It has a foundation toe of dry stone section. This pitching was constructed several decades before the implementation of the new downstream spur system. This type of protection does not resist concentrated localized scour. In case of silt accumulation which was observed to occur in their vicinity, it is essential to heighten the pitching on the side slope, which can be cited as a draw back disadvantage against this type of construction.
- The two kilometers Nicolon covered bank is immediately downstream the two kilometers pitched bank .The Nicolon is a type of matrix made of strong cunvus and naylon.The construction requires stone gravel sand and cement.
- The total number of spurs upstream the old bridge were eleven in 2005. The new upstream pitched spurs were four pairs. The lengths of the shanks of these spurs were variable, and the horizontal distance between their heads are also different as shown in Figure 8. After 2005 the spurs and dyke system was further extended.
- In 1984 the building of the new downstream pitched spurs was started. Two pairs of spurs were constructed. Observations downstream the old bridge indicated that the bed of the Gash River which was 10 centimeter higher than Kassala Town general land level became 10 centimeters below Kassala Town general land level. The Municipal Council of Kassala Town celebrated that occasion in the presence of Kassala State Governor who praised and encouraged the then irrigation divisional engineer and his staff. Relaying on this result, after 1984 more pairs of spurs were constructed.
- Pitched Spurs Futa Reach is an extension to the downstream pitched spurs reach of Figure 6. It lies further downstream to the north of Kassala Town.Futa off take with its Gauging Station was maintained to remain in tact as shown in Figure 10.
- Futa Salam Alikum Reach comprises Salam Alikum off take is similar to that of Futa with its Gauging Station. It received similar maintenance.
- Hydromorphological Data and Cross Sections refer to velocity measurements in the Gash River gauging stations. Cross sections are taken by an ordinary survey level. The data is plotted using excel software [11]. The overall theme of the cross section was reviewed to prevent the existence of any odd data. For the flow stage records, the data checked for writing and digitizing errors; and is plotted using excel software (Gauge vs. Time). The data was collected during seasons 2005, 2006, 2008 and 2009 from Kassala Bridge station by current meter and float method.
- Sediment Transport And Soil Analysis Field survey data collection and analysis of soil samples from the Gash River bed were
- conducted [7,11]. The purpose is to check and quantify the sediment transported into the Gash River channel and the delta, on one hand and clearly specify soil to be used in banks building on the other.The samples were taken from seven locations in the Gash River bed.

Four samples were taken upstream the bridges. These were at the heads of the pitched upstream spurs number nine and number five, together with the two gauging Station at 1.5 kilometer and the gauging station at the bridges.The other three sample were taken from Futa gauging Station, Futa Spur and Salam Alikum gauging Station.

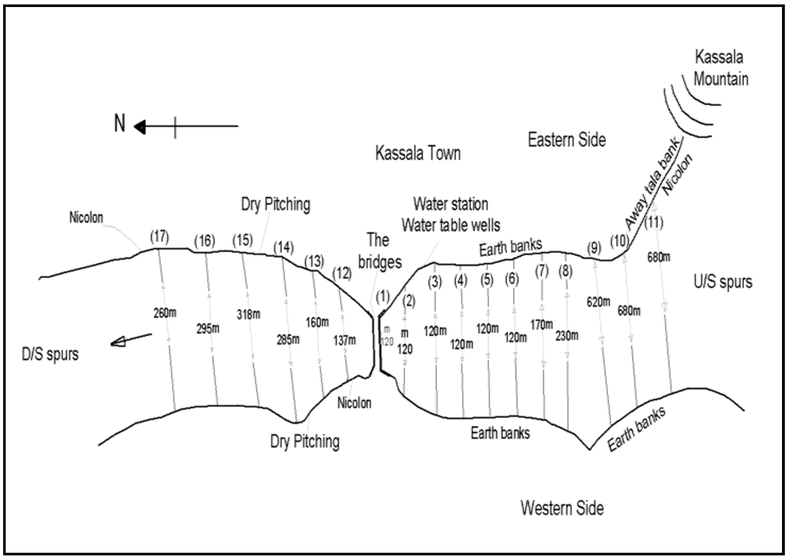


Figure 8: The variable lengths of the shanks and distance between spurs

Figure9:Photo of old bridge during 2003 flood

Figure 10: Futa off take and gauge

RESULTS

Soil Data Collection and Analysis

The collected soil samples data at the seven different locations were analyzed. The laboratory soil analysis was conducted in the Laboratory Department of TheSudan University of Science and Technology (SUST). A typical data grain size distribution curve is shown in Figure 11 for location No (7).Further necessary conducted soil analysis to the seven soil samples was the computations of the Atterbeg limits namely (L.L.,P.L.and P.I) and classifications were tabulated.

Soil compositions are worked out based on Massachusetts Institute of Technology(MIT)criteria and classifications according to the triangular chart developed by the Bureau of Public Roads(USA):Table1 gives the composition and classification of the different soil samples. Soil analysis are usually conducted to determine their physical properties, most important of which is their strength. The soils strength properties are related to their shear strength. The shear strength properties of all the cross sections were computed using Neill equation. Table 2; present the shear strength properties of all the locations.

$$\tau_c = 2.4964\gamma\left(S_g - 1\right) d_{50}^{\frac{2}{3}} \nu^{\frac{1}{3}} ---(15)$$

where: τ_c = Critical shear stress (lb/sq. ft)(N/sq m), d_{50} = Median particles diameter (mm) or diameter for which 50% of the soil particles are finer[10]. γ = Unit weight of water (=62.4 lb/cubic.ft). S_g = Specific gravity of soil which is defined as the ratio of the density of the soil particles to the density of water and is approximately equal to 2.65 for most of the channel Bed Materials, y = The water depth in the approaching channel (ft).

Hydrological Data Collection and Analysis

Discharge [18] measurements, which go back to 1907 in the River Gash, were mainly conducted by the float method with recent and occasional use of current meter measurements. Figure 12 is the Gash River Hydrograph for several years. The average annual rainfall is about 300 mm with maximum monthly rainfall usually occurring in August. The area being urban, the runoff coefficient varies from 0.70 to 0.95. Due to the absence of rainfall intensities and duration data, these coefficients can be used to estimate the runoff that may be drained into the Gash Rivers. Using the available hydrological data for a return period of 100 years the flood frequency analysis was conducted. The analysis indicated the average hydrological parameters as shown in Table 3. These parameters can be used for design of the flood protection works.

Recent Hydrological Data 2010-2012

The importance of the recent data is its noticeable difference from the old data. It consists of cross sections longitudinal section and detailed levels in the vicinity of the bridges. Some data during the period from 1984 to 2011 are recorded. They consist of maximum levels which were expected to form a bottle neck obstruction at Kassala old bridge. The levels with the star sign (*) were observed to form a bottle neck. Table 4 shows the recorded maximum data.

The spurs area in the vicinity of Kassala Town is always under strict observations. The level of the Gash River at their locations before and after the flood in a number of years was recorded, namely 2004, 2005, and 2006.Table 5 shows the observed bed level before and after the flood of each year.

Sediment Data Collection and Analysis

Using some of the popular formulae such as Mayer Peter and Muller, the calculated bed load passing Kassala gauging station was found to be 56 kg/sec. Samples of bed load material were taken during the dry season upstream as well as downstream of the old bridge. The laboratory analysis of the samples revealed that total bed load ranges from 0.5-1.5 million tons per year are passing Kassala gauging station as shown in Table 6.

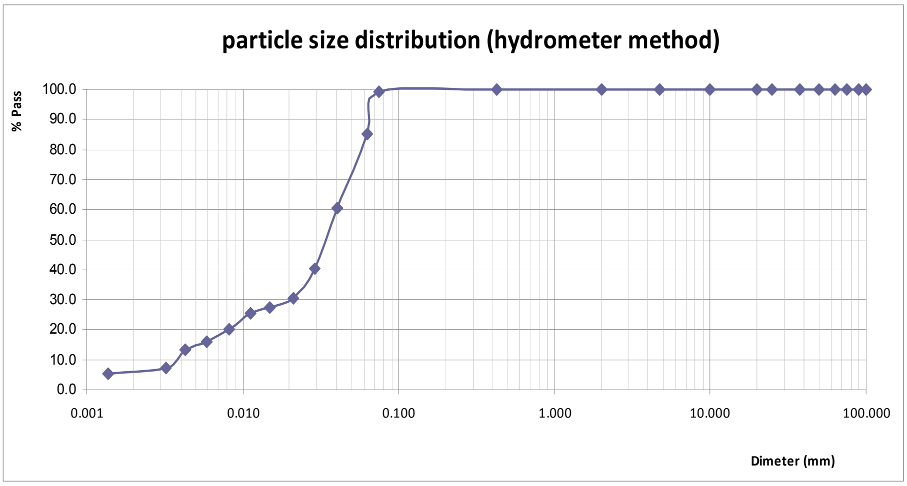
Measurement of suspended load, being easier than bed load, was conducted at Kassala bridge near Kassala gauging station, indicated that the transported sediment in suspension passing Kassala gauging station ranges from 4-11 millions tons per year. Thus the total sediment load passing Kassala gauging station ranges from 5-13 millions tons per year. On the other hand measurement of scour during flooding at Kassala gauging station indicated that the maximum scour depth attained 2.0 meters below the general bed level.

DISCUSSION AND CONCLUSIONS

Durable river training works depend on understanding the behavior of the river. It depends on careful designing and layout of structures.Econmy and economic worth of the project, together with use of local materials should be preferred to imported materials. The behavior of the Gash River in the vicinity of Kassala town as well as the reaches upstream and downstream were studied.

Kassala town was frequently subjected to the flood attacks. Some of the numerous famous and catastrophic attacks were in the years1921, 1926, 1927, 1929, 1931, 1932, 1939, 1941, 1944, 1950, and 1952. During the period from 1953 to 1972 no observations were recorded. After that gap the succeeding floods were in the years 1973, and 1974. In 1975, occurred the most catastrophic flood, then, 1983, 1988, 1992, 1998 were less severe, while that of 30th July 2003 was the most severe and most catastrophic flood ever recorded.

Before the pathetic inundation of the town on the 30th of July, the town was subjected to rain storms on the 27th and 29th of July, with intensities of **48.6**[1]and **102** mm respectively.



CLAY	SILT			SAND			GRAVEL			Cobbles
	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	

Figure11: Grain size distribution curve futa spur (b) sample No.(7)

Table 1: Soil samples composition and classification

Sample No.	**Date**	**Location**	Sample composition			Classification
			% sand	**% silt**	**% clay**	
1	2012/5/18	Spur 9 U/S	40	60	0	Sandy silt
2	2012/5/18	Spur 5 U/S	42	58	0	Sandy silt
3	2012/5/18	Spur K1.5 U/S	90	10	0	Silt sand
4	2012/5/18	Kassala Bridage(Zero)	80	20	0	Silt sand
5	2012/5/19	Spur 7 D/S	90	10	0	Silt sand
6	2012/5/19	Spur Fota (a) D/S	93	7	0	Silt sand
7	2012/5/19	Spur Fota (b)D/S	15	80	5	Clay Sandy Silt

Table2:Calculated critical shear stress of the gash river channel cross sections

Cross Section Location	**ft)** d_{cr}	$d_{cr}^{\frac{1}{3}}$	$\tau_c = 2.4964\,\rho(s_g - 1)d_{50}^{\frac{2}{3}}d^{\frac{1}{3}}$
Spur K.9 Locations(1)	8.40	2.03	68.29
Spur K.5 Locations(2)	9.94	2.15	76.00
Kassala K.1.5 Locations(3)	8.46	2.04	143.30
Kassala Bridge Locations(4)	6.25	1.84	114.37
Futa Spur Locations(5)	6.25	1.84	125.42
Futa Spur (a) Locations(6)	7.22	1.93	130.25
Futa Spur (b) Locations(7)	7.22	1.93	50.51

Table 3: Average hydrological parameters

Parameter	**Kassala Gauging**	**Parameter**	**Kassala Gauging**
Max Water Level (m)	507.70	Max Daily rainfall mm)	104.5
Min Water Level (m)	505.13	Runoff Coefficient	5%
Max retaining height(m)	3.70	Wind speed (m/s)	8
Annual Rainfall (mm)	232.9		

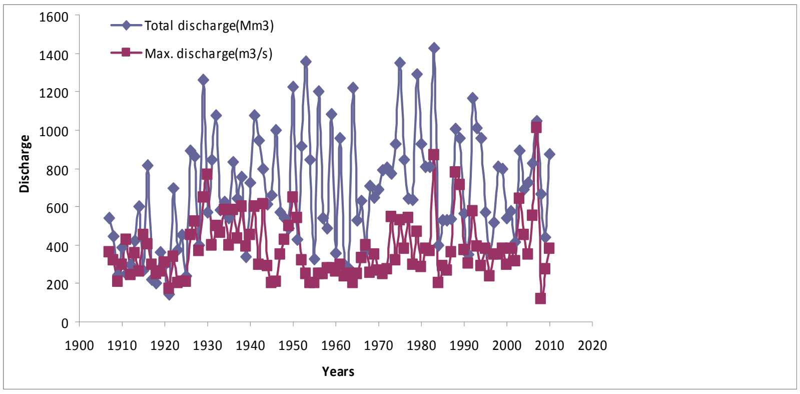


Figure12: Gash River Several Years Hydrograph at Kassala Gauging Station

Table 4: Observed maximum readings Kassala gauging station

Year	Max. Recorded Water level(m)	Year	Max. Recorded Water Level(m)
1984	505.900	2000	506.450
1985	506.000	2001	506.750
1986	506.000	2002	506.300
1987	506.000	2003	507.000
1989	505.600	2004	506.700
1990	505.900	2005	506.200
1991	505.950	2006	506.700
1992	506.100	2007	507.300
1996	505.950	2008	505.13
1997	506.400	2010	505.39
1998	506.400	2011	505.23
1999	506.100		

Table 5: Recordedbed levels in the vicinity of the spurs system

Spur	Ch.	2004		After 2005			After 2006
		Before flood	After flood	Max	Min	Average	
12	0	511.960	511.835	512.620	511.780	512.080	511.972
11	500	511.880	511.275	512.270	511.240	511.850	511.234
10	1000	511.000	510.490	511.610	510.970	511.210	510.496
9	1500	510.120	509.940	510.900	509.890	510.590	509.758
8	2000	509.910	509.300	510.180	509.420	509.870	509.020
7	2500	509.720	508.710	509.090	508.540	508.850	508.282
6	3000	508.320	507.955	508.460	507.940	508.220	507.544
5	3500	507.450	507.160	507.720	507.250	507.520	507.205
4	4000	506.860	506.850	507.300	506.660	507.070	506.546
3	4500	506.730	506.170	506.770	506.020	506.460	506.161
2	5000	505.990	505.740	506.370	505.550	506.030	505.295
1	5500	505.780	505.710	505.890	504.940	505.530	505.037
BRIDGE	6000	504.913	504.391	505.54	503.911	505.210	504.348
1	6500	504.400	503.834	504.826	503.751	504.436	503.978
2	7000	503.780	503.587	504.442	503.574	503.954	503.301
3	7500	503.860	502.999	503.707	502.838	503.385	502.659
4	8000	502.777	502.473	502.956	502.376	502.681	502.087
5	8500	501.845	501.698	503.139	501.846	502.309	501.681
6	9000	501.825	501.093	502.295	500.981	501.726	500.755
7	9500	501.099	500.637	501.905	500.679	501.208	500.023

Table 6: Laboratory data analysis of bed load

Date	Gauge R.L.(m)	Q M m^3/day	Concentration PPM	Q_s Ton/day
6/8/1999	507.50	19.95	17913	357364
8/8/1999	507.30	14.89	10500	156345
11/8/1999	507.10	10.51	10588	111279
18/8/1999	507.30	14.89	19829	295253
20/8/1999	507.90	32.16	24788	797182
22/8/1999	507.50	19.95	8333	166243
24/8/1999	507.10	10.51	29389	308878
27/8/1999	506.80	5.25	12686	66601
30/8/1999	507.00	8.58	9500	81510
2/9/1999	507.10	10.51	11891	124974
15/8/2000	506.91	8.90	19250	171325
17/8/2000	506.81	7.03	18711	131538
19/8/2000	506.72	5.49	18304	100488
21/8/2000	507.06	12.05	18889	277612
24/8/2000	506.88	8.32	5860	48755
26/8/2000	506.73	5.66	7910	44770
21/9/2000	506.52	2.60	4903	12747
24/9/2000	506.65	4.40	4385	24472
30/9/2000	506.46	1.76	6492	6805
2/10/2000	506.61	3.81	4127	24734

These rainstorms, although not up normal, yet were reported that they caused damage to about **670** houses. It was also reported that the highest instantaneous gauge level and discharge that ever observed at Kassala was that of the 30th of July 2003.The reported out come of that flood were the immediate occurrence of seven breaches on both sides of the river; four in the east and three on the west.

The town market, central hospital, and many other governmental utilities were also inundated. The tragedy included **6** deaths and **60** wounded. It was reported that the losses in residences was about twenty thousand houses; in the marketing area over eight hundred units; governmental health, public and educational utilities more than **160** units. The total loss of the public and private sectors was reported to approach **150billion** Sudanese Dinnars **(575** million U.S.Dollars) .Some of the pathetic sceneries are shown in Figure 13. River training for the protection of the town, which goes back to 1905,was worked out along intermittent and short lived approaches. The absence of long-term plans is greatly responsible for the present complex problems.

The two braided zones of the River Gash upstream and downstream the bridges and spurs receive their share of sediment transported from the upper reaches. It was noticed, downstream the bridge, that, the River Gash widened and accumulated sediment.

Figure 13:Disastrous Flood of 2003

Cross sections taken in successive years 1971 to 1974 has shown that the bed of the River Gash was raised by 40 centimeters [1,2,3] in that downstream zone. Comparing the bed level of 1936 with that of 1974, at the same location, the increased height was found to be 380 centimeters.

This reveals the fact that there was an average rise in bed level of 10 centimeters per year, in the zone downstream the bridge. Also leveling in 1976 revealed that the bed of the River Gash in that zone was higher than the town ground level by 10 centimeters.

These draw the attention of the designers [2] that the method adopted in protection and training in that zone, which was dry pitching to the outer main banks, was not successful. Consequently before the flood of 1984 funds were available and two pairs of spurs were constructed downstream the bridges. The immediate outcome was that, the area of the zone downstream the bridges was scoured between the spur heads to the extent that it became 10 centimeters less than the town general ground level.

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. Khor Abu Alaga on the other hand discharges its flow on the eastern side of the River Gash about one kilometer downstream Quenti as was shown in Figure2.

Khor Somit, also called Kalhote, was in the past known as a natural channel fed from the River Gash, 18 kilometers upstream Kassala town on the left side of the River Gash.In the year of the catastrophic flood of 1975,it was noted that the off take of the Khor became wider, more discharge was noticed to enter the Khor than that used to be in the past. The contour of the Khor being lower than that of the Gash River, the railway line joining Kassala with Khartoum was wash out by the Khor torrential flow. The anticipated risk was the tendency that the Gash River might change its course to Khor Kalhote.It was decided to close that off take immediately. Before the flood of 1976 the off-take was closed by closing dykes and since that time no more discharge was passed through that reach of the Khor.

Many studies have been conducted on Khor Somit, most of it were about the feasibility of irrigating an area ranging from 7 to 12 thousand feddans from the Gash River[1,7]. The existing artificial off take of the Khor is located about 9 kilometers upstream Kassala bridges on the west bank adjacent to Quenty.Quenty is the old channel connected to the old Khor Somit closed natural channel. It is the only channel with an off-take from the River Gash upstream Kassala town.

It could be used as escape drain to drain water from the River Gash before it arrives to Kassala town. However its maximum capacity should be studied to know if it would satisfy the requirements. Furthermore, from the artificial off-take up to the feeder road crossing, joining the high way, the channel passes through a number of villages. Most of the villagers have their houses built very close to the channel banks on both sides. Further downstream the channel passes through the new extension of Kassala town. Hence it is important to carry out leveling investigations in order to decide the suitable required by pass location, which is believed to be one of the necessary measures of Kassala protection.

This problem should be solved through research including a physical model. The horticultural activity, in the neighborhood of Kassala Town with excellent qualitative and quantitative production, by which Kassala is famous, is due to success of reclaiming the U shaped lands suitable for horticultural activity between successive spurs in the old and the new spurs system. These lands which consisted of first class agricultural soil, suitable for fruit and vegetable gardens, were distributed among farmers, according to a lease extending to a number of years. Increasing population engaged in horticultural activities, now known as Southern Sagias and Northern Sagias inhabited these lands.

These lands extend from the south upstream the bridges to the north downstream the bridges on both sides of the River Gash banks. As these reclaimed lands are inside the flood plain of the River Gash, the farmers were not allowed to build their permanent living houses in the plain. It was witnessed by some inhabitants living in the neighborhood of Kassala Town that no permanent houses were built in the spurs and dykes system before 1954.

Figure 14:Typical example of undesired activities

In 1975 it was observed that many undesired activities were conducted in the flood plain. Lined irrigation channels, residential houses, were built on the top the middle and the side slope of the protection banks. Irrigation wells and pit latrines as well as brick quarries were dug adjacent to the banks. Similar undesired activities were observed in the banks adjacent to Kassala town. Figure 14 depict some undesired activities. Another important type of the undesired activities, which is believed to be useful by the majority of the inhabitants led by the V I P's including the State Governor and the other involved stakeholders excluding the civil engineers in charge is earthwork activity conducted under the bridge and in the vicinity of the ridges both upstream and downstream. In this activity time and money are spend stravagendly.Usually at the end of the flood when the flow becomes very slow huge amount of sediment is deposited under the bridges as well as both upstream and downstream the bridges.

Heavy machines such as Dozers Scrapers are used to remove the accumulated sediment before the flood. It was, however observed by the naked eye that at the beginning of the flood the removed silt rebuild instantaneously as if it was not removed. When the current becomes strong with high stage and high velocity all the silt is removed instantaneously.

The removal of soil from the bed of the river under the bridges as well as from up stream and downstream the bridges is considered as an undesired activity similar to building houses on top of banks and digging pit latrine adgecant to bank toe, and even whether because it waste money and time. It worth mentioning here that during the construction of the high way road joining Kassala and Port Sudan a borrow pit was made downstream the bridges. A huge amount of earth was removed from the bed. The depth dug was more than 6 meters and the plan area dug was 120 X500. That time was before 1984 before the construction of the downstream pitched spurs. In July just at the beginning of the flood the location of the borrow pit became higher than the general bed level and even an island was clearly seen in that location.

From the above discussions, it is of utmost importance that the undesired activities must be stopped immediately. Prior to this a committee of different disciplines should be nominated to study the different cases of all inhabitants living or having any type of activity within 20 meters from the outer and inner toes of the spurs and dykes system. Those who are entitled to be compensated should be paid their dues immediately. This step should be followed by immediate implementation and enforcement of a law. The punishment should be very harsh and severe so that all people will refrain from breaking the law. To ensure the immediate application of the law there must be daily follow up from the beginning of implementation.

Before the inundation of the town, which was caused by the sudden breaches in the seven locations during the catastrophic flood of 2003, it was reported that all the U shaped areas between the spurs upstream the bridges were all inundated by the up normally high flood. The number of these U shaped areas upstream the bridges in the year 2003 were **10** units on each side of the River Gash (i.e.**10** pairs of spurs). The shanks of almost all these upstream spurs were attacked by the residents making cuts or trenches through them to drain the water away from their inundated houses.

The area of each U between two consecutive spurs is **250000** square meters. The total area of all the twenty units on both sides upstream Kassala bridges, totals **to 5000000** (five million square meters). All this area being upstream the bridges and all full of water to a depth not less than one meter; i.e. making a total of at least five million cubic meters, has to be instantaneously discharged with the on coming water from the upstream which was also reported to be up normally excessive.

According to theory, practical design, logic, and practical experience with the Gash River the designed channel of the Gash River will not pass all the discharge coming from upstream plus that stored between the spurs instantaneously. The usual and logical practice in the past was that the water that enters into the U shaped areas was retained i.e. stay in detention, until the level of water in the main channel drops down; whence it returns back to the main channel with out causing any problem.

It was argued by many observers of the 30th of July 2003 flood, that the old bridge constituted an obstruction to the River Gash flow. However it is logical that the five million cubic meters of water instantaneously drained by the flood plain inhabitants to the bridges location were mainly responsible of the heading up of water upstream the bridges.

Furthermore the spurs downstream the bridges being not properly constricted to increase the stream force to generate bed scour under the bridges and further downstream was also responsible about temporary deposition of silt and causing resistance to flow. This argument is inferred, by the fact that during 1984 flood when the downstream spurs were in tact having the proposed designed constricted width of 120 meters the water has not touched the top invert level of the old bridge soffit, Further downstream scour was generated and the bed level in that location was less than the town general ground level by 10 centimeters.

The functions of spurs or Groynes system as that in the River Gash is to attain maximum scour at its noses removing all accumulated silt in the cross section between their heads and the longitudinal section along the spacing distance between their heads. They also create retarded flow inside the U shape between their shanks, where silt can be accumulated there reclaiming the land.

Another important function of the Groynes is that they convey water discharge and all remaining sediment from an upstream reach to the downstream one. If the Groynes heads were subjected to toe failure, or the transverse distance or and the longitudinal distance between their heads were increased or decreased the Groynes or the group of the Groynes will not function. The maximum scour depth in the Groynes system zone must be known in order to design the proper foundation depth and avoid undermining.

To determine the scour depth before the flood of the year 1976 broken red bricks were buried in the maximum scour zone near the heads of Groynes, and after the flood the maximum scour depth was found to be about 2 meters below the general bed level of the Gash River.

Investigation or research activity was carried out to reveal the reason for that great rise in the bed of the Gash River in the vicinity of Kassala Town. The Gash River being well known with its great transport and accumulation of sediment, all researchers and engineers simply relied on this fact being the main cause of the bed rise. However, there is strong believed that this was not the right reason. This is because that area of the spurs and dyke old system has had a constant bed level of R.L.since 1936 to 1984, as was reported. During that past period some enforced rules were exercised by the successive resident engineers prohibiting undesired activities in the flood plain of the Gash River. These were:

The spur system shanks were strengthened and raised to the mother spur height. No cuts were allowed through these shanks. No cuts were allowed between successive spurs heads leading shooting flow to the agricultural land in the U shaped area between the spurs heads system. Twenty meters on both sides of the shanks of the spurs and dyke system toes was left clear for the free movement of the machines used to maintain the banks and shanks. Dug wells or pit latrines within the above mentioned distance were buried before the floods. Fixed permanent or temporary built houses within that area were also removed before the floods. Any agricultural activity within that area such as water channels or any type of vegetable or fruits was also removed.

It was because of these enforced rules that the shanks of the spurs and dyke system remained in tact .The enforcement of these rules was exercised by the resident engineers with the farmers and the resident population. The local authority has not implemented any law prohibiting these undesired activities.

CONCLUSIONS

The implementation of the River Gash Law is an urgent prerequisite to guarantee survival of existing protection and training structures.Rehabilitation of the old and new existing structures is important to guarantee the safety of Kassala Town.

It is important to decide the suitable required by pass location from Khor Somit, believed to be one of the necessary measures of Kassala protection.

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