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GIS-based runoff estimation for hydraulic design of ring road crossing with Khor Shambat, Central Sudan

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Abstract

Rainfall-runoff modeling has become an essential element in water resources management including planning, hydraulic design and flood protection. This paper aims to estimate peak runoff in order to design hydraulic structures at Khor Shambat crossing with the Ring Road (Omdurman Sector). Geographical Information system (GIS) and Remote Sensing were employed to model catchment and drainage characteristics. Frequency analysis of 100-year rainfall data was performed and Intensity-Duration-Frequency (IDF) curves were construction based on Gumbel distribution. Peak runoff was computed using Rational model and contributing area method. The Manning formula was used to design hydraulic structures. The peak runoff for the catchment of Khor Shambat was found to be 43.2 and 45 m^3/s for the return periods 10 and 25 year, respectively, obtained applying rainfall intensities from IDF curves and routing through different nodes according to contributing area method. The peak runoff values were used to compute appropriate hydraulic design (culvert cross section) at the crossing point following reasonable assumptions and solving and substituting different parameters in a set of equations. Three culverts were proposed at kilo 9, at kilo 8 and at kilo 9.3, with 33.5, 3.4 and 10.2 m^2 trapezoidal cross sectional area, respectively, designed for the 25-year return period.

Keywords: Runoff; GIS; Frequency Analysis; Rational Model; Hydraulic Design

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1. Introduction

Hydrology is the science concerned with the occurrence, distribution, movement and properties of all the waters of the Earth. For highway design, the primary focus of hydrology is the water that moves on the earth's surface and in particular the part that ultimately crosses transportation arterials (i.e., highway stream crossings). Other concerns include providing interior drainage for roadways, median areas, and interchanges (McCuen et al., 2002).

Water is continuously renewed while circulating between oceans, land and atmosphere. All processes like evaporation, condensation, precipitation, interception, transpiration, infiltration, storage, runoff, groundwater flow, which keep water in motion constitute the hydrologic cycle. Surface runoff in particular is an important aspect in hydrological, geographical and engineering research and applications (Vojtek and Vojtekovà, 2016). In highway design, the primary concern is with the surface runoff portion of the hydrologic cycle in addition to precipitation, infiltration, and storage. In fact, designing new hydraulic structures and responding to flood are some of the major applications of Rainfall-runoff modeling (Blandford and Meadows, 1990; Ibrahim et al., 2015).

The Ring Road is a national engineering project planned for Khartoum City, the Capital of Sudan which circulates the city crossing the main River Nile, the Blue Nile and the White Nile as well as several seasonal wadies and Khors flowing towards the Nile flood plain from the east and west. One of the large seasonal wadies crossing the Ring road is Khor Shambat which passes through Omdurman Town and flows eastward towards the main Nile. The objective of this research paper is to estimate peak runoff and to design hydraulic structures at the crossing point of Khor Shambat and the proposed Ring Road (Omdurman Sector). Specific hydrologic aspects of highway design such as rainfall frequency analysis, catchment and drainage characteristics, peak discharge estimation and hydraulic design will be addressed.

2. Materials and methods

Several types of data were used in order to fulfill the objective of the research. Remote sensing data such as the ETM+ Landsat image of Khartoum area (8 bands, resolution 15~30m) (Raw/path 173/49, 2000) and the STRM Digital Elevation Model (DEM) (90m) were used to investigate the surface land cover, topography and to model Khor catchment, flow direction and drainage characteristics. The Geological map of Khartoum (1:250,000, 1993) and the Soil classes' map of Libya Chad, Egypt and Sudan, FAO (1:18,000,000, 2002) were also utilized. Hundred-year Meteorological data of Khartoum were used for frequency analysis of rainfall. The following methods were followed in this study:

- The geographical Information system (GIS) and Remote Sensing (RS) are employed to model catchment and drainage characteristics such as flow direction, network, density and order applying a set of neighborhood and connectivity functions on the remotely sensed digital elevation data. The output was then used to identify and describe the Ring Road stream crossing with Khor Shambat. GIS is also used to describe the topography and prepare the different thematic maps. Remote sensing imagery is used for land surface investigation and identification of topographic characteristics. Recently, GIS-based catchment analysis and Runoff estimations have been widely used in different regions (Osman, 2012; Khalda et al., 2015; Ningaraju et al. 2016, Tyseer et al., 2017).

- Frequency analysis of rainfall data and Intensity-Duration-Frequency curves construction based on the assumption that the rainfall intensities within a particular duration follow an Extreme value type I distribution or Gumbel distribution function (Gumbel, 1958), and then the intensities R_T for various return periods (T) were obtained according to Wilson (1990) as follows;

$$P = 1/T \quad \text{Eq.1}$$

$$R_T = \text{mean} + SD * K_T \quad \text{Eq.2}$$

Where K_T given by the expression

$$K_T = -\frac{\sqrt{6}}{\pi}\left[0.5772 + \ln\left(\ln\left(\frac{T}{T-1}\right)\right)\right] \quad \text{Eq.3}$$

Where:

R = Rainfall amount in (mm)

R_T = Rainfall intensities for T return periods (mm/h)

T= Return period

P= Probability

K_T = Extreme value type I distribution frequency factor (Gumbel frequency factor)

SD = Standard Deviation

The Gumbel distribution is widely used for modeling the extreme rainfalls (Nguyen et al., 1998).

- Estimation of peak runoff using the Rational model (Kuichling, 1889), the contributing area method and velocity method:

$$Q = K_u CIA \quad \text{Eq.4}$$

$$Tc = \frac{L}{60V} \quad \text{Eq.5}$$

Where:

Q = Peak rate of runoff (m^3/s)

C = Dimensionless runoff coefficient function of the of the watershed cover

I = Average rainfall intensity (mm/h)

A = Drainage area (km^2)

K_u = Unit convertor factor (0. 278 for metric unit)

Tc = Time of concentration (min)

L = Longest flow path (m)

V= Average velocity (m/s)

- Design of hydraulic structure using the following hydraulic design formulas:

Manning equation (Chin, 2006):

$$Q = \frac{1}{n}\frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}}S^{\frac{1}{2}} \qquad \text{Eq.6}$$

The continuity equation:

$$Q = A\,V \qquad \text{Eq.7}$$

Where:

n = Manning roughness coefficient

A = Flow cross sectional area (m^2)

P = Wetted parameter (m)

S = Longitudinal slope (m/m)

V = Flow velocity (m/s)

Q = Discharge (m^3/s)

The Chezy Formula: $V= C\sqrt{RS_0}$ Eq.8

Where C is a coefficient which depend on the nature of the surface and the flow and known as Chezy coefficient, So is bed slope of the channel. C can be calculated from the Ganguillet -Kutter formula (Pillai and Ramakrishnan, 2006):

$$C = (23+1/n+(0.0015)/S)/(1+(23+0.00155/S)n/\sqrt{R}) \qquad \text{Eq.9}$$

- Field survey in order to inspect the surface cover and the section of stream crossing.

3. The study area

The study area which includes the proposed route of the ring road and the surroundings is located in western Omdurman to the west of the White Nile and Nile rivers. The first part of the ring road (18 km) starts at the Omdurman end of Al Halfaya Bridge continues northwestward for 4km before turning southward towards western Omdurman residential area. It then, crosses Khor Shambat before passing nearby J. Almarkhyat (Figure 1).

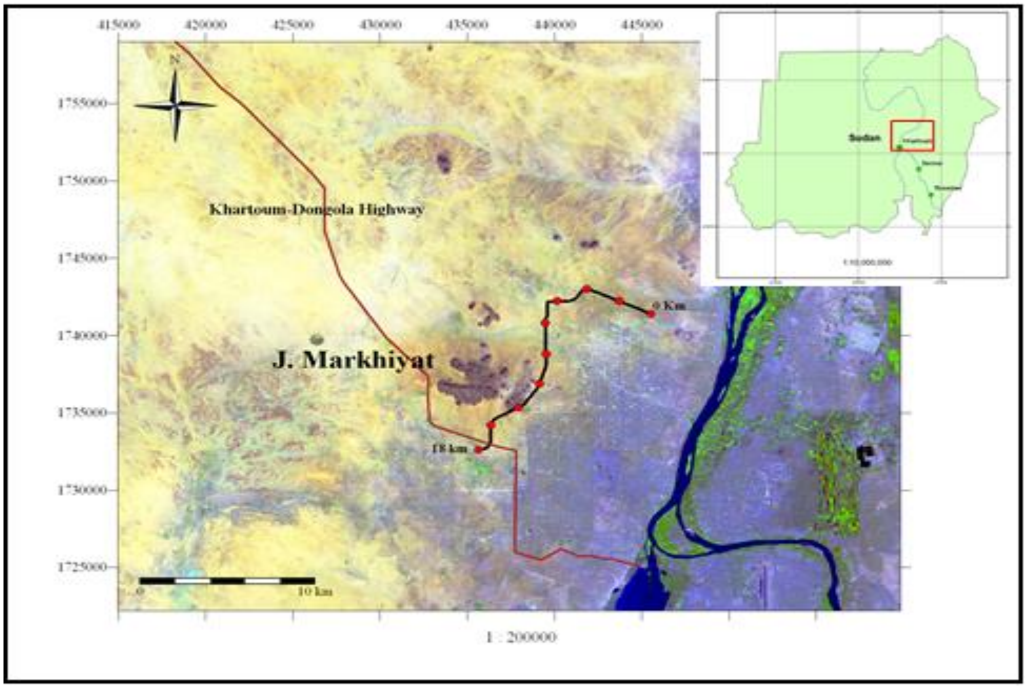

Figure 1. Location map of the study area based on Land Sat colour composite image 7,4,1, in RGB. UTM Projection zone 36

The area west of the River Nile and White Nile (Omdurman) is part of the flat flood plain of central Sudan. The elevation ranges from 375 m.a.s.l along the River plain to over 480 m.a.s.l in the northwest. The terrain, therefore, slopes gently from northwest to southeast. The average land surface slope is gentle (1.3 %). The most prominent topographic features in the area are the few scattered hills mainly of sedimentary rocks exposed by erosion such as Jebel El Markhiyat (490 m.a.s.l). The River Nile and White Nile represent the main drainage pattern in the study area together with some seasonal wadies and khors draining the area from the west to the east towards the River Nile such as Wadi El Miegil, Wadi Saidena and Khor Karari, Khor Shambat and Khor Abu Anga (Wadi El Fetera) (Figure 2). They form a dendritic pattern of 655 m/km^2 density.

The study area is part of the arid semi-arid zone of central Sudan characterized by hot (39-43^{o}C) dry summer (March~June), moderately cold (10-32^{o}C) dry winter (November~February). The rainy season in Khartoum lasts generally from June to October with 80% of annual rains fall during the months of August and September. The annual rainfall in Khartoum region varies spatially from north to south and ranges between 150 mm in north to 200 mm in the south. The dark clay soil and sandy clay soil covers most of the study region. FAO has classified the soil west of the River Nile and White Nile at Khartoum as xerosols. The desert and semi-desert grasslands and shrublands dominate in the region. Locally this section of the Ring Road (Omdurman sector) is characterized by well-developed soil layer made of sandy clay gravely soil reddish in colour may be due to weathering of the ferruginated (rich in iron oxides) sandstone underlying the region and outcropping in some localities such as in J. Merkhiyat. Generally, the whole Khartoum region is covered by the so called Nubian Sandstone Formation which was deposited unconformably over the basement rocks and is overlain by recent Gezira formation and surface deposits and is cut by the Tertiary volcanics mainly, basalts. Hydrogeologically, the study area lies within the Nile-Sahara Nubian basin which trends NW-SE. This basin hosts the Nubian sandstone aquifer which represents the most important groundwater aquifer in the whole region covering 70% of its area. Generally the Nubian aquifer is characterized by good groundwater, both in terms of quantity and quality and suits domestic, irrigation and industrial uses. Partially, the superficial deposits form shallow unconfined perched aquifers consisting of silt, clay with sand and mud (Nile alluvium). The water bearing layers are one to five meters thick and it depends mainly on the surface recharge from the Nile River and seasonal wadies. The static water table level depends on the topography, geology and change of hydraulic head. In Omdurman area, the static water table level decreases from the east to the west indicating the general groundwater flow direction and defining the recharge from the River Nile in the east.

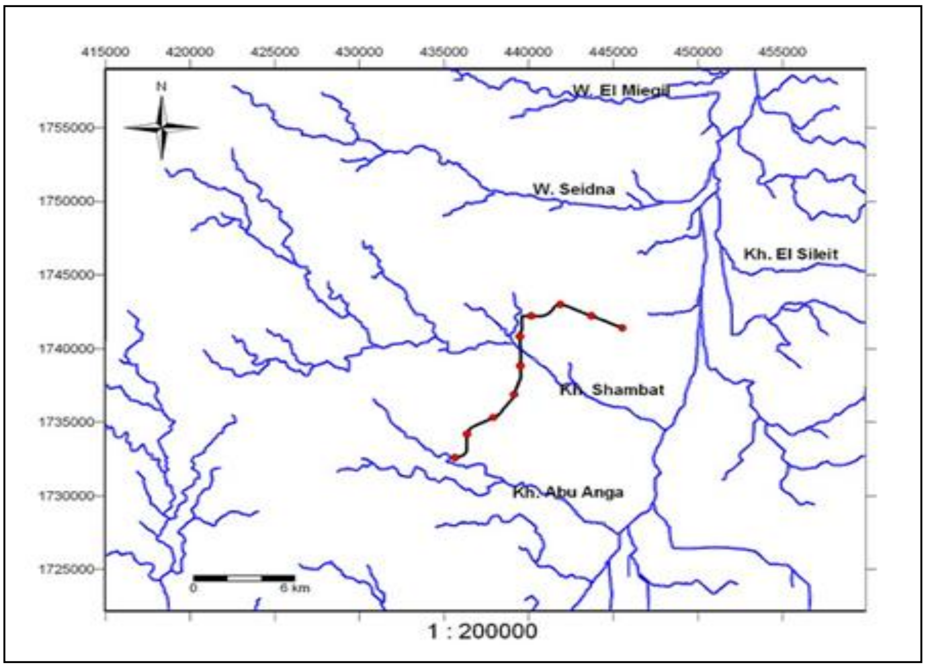

Figure 2. Drainage pattern map of the study area showing the crossing of the Ring Road and Khor Shambat

4. Results and discussion

4.1. Catchment characteristics

Catchment characteristics were obtained by hydrological modeling of remotely sensed digital elevation data (DEM) of the study area using GIS. The study area represents part of the River Nile basin extending from central and eastern Africa to the Mediterranean Sea in North Africa. Locally, the study area (Figure 1) was found to consist of 64 sub-catchments obtained after catchment merge taking into consideration the network order, flow accumulation, flow direction and sink-filled digital elevation model (Figure 3). Only four sub-catchments (A~D) are traversed by the Ring Road in this section. The characteristics of the four sub-catchments computed using the HYDRO-GIS Model of ILWIS 3.7 are given in Table 1. Catchment B represents the catchment area of the stream crossing of Khor Shambat with the Ring Road for which specific hydraulic computations will be performed to allow accurate estimation of peak discharge and design of culvert in order to fulfill the objectives of this research. Obviously, more than two thirds of catchment B is supposed to contribute to the runoff at the crossing of Khor Shambat with the ring road (at kilo 9, coordinate: 439521.319, 1739794.532). The area of this section equals 309km^2. Thus, estimation of peak discharge runoff applying simply the "rational formula" is not appropriate. It is based on the assumption that the catchment area is generally smaller than 1km^2 and the surface properties are constant (implying single runoff coefficient C).

The contributing area method was applied in order to provide reasonable variation in the runoff received at the crossing point from the different parts of the huge catchment. It is based on the idea that different soil, ground cover and distance from outlet point in large mixed catchments will most probably present different hydrograph shapes. All contributing hydrograph estimates are then added (linearly) with respect to time to produce a final hydrograph shape. A modified merge was performed using an outlet map of stream nodes across the catchment. (Figure 4). This has resulted in the splitting of catchment B into 11 sub-catchments each of which will be considered separately for the calculation of peak discharge at the Ring Road crossing. Table 2 presents the total contributing area (A), the equivalent impervious area (C x A) for each node and the longest flow path to node 12 (stream crossing). The coefficient "C" was taken to equal 0.3. For describing contributing sub-catchments, for routing and for keeping inventory of calculations, a nodal stick diagram was constructed (Figure 5).

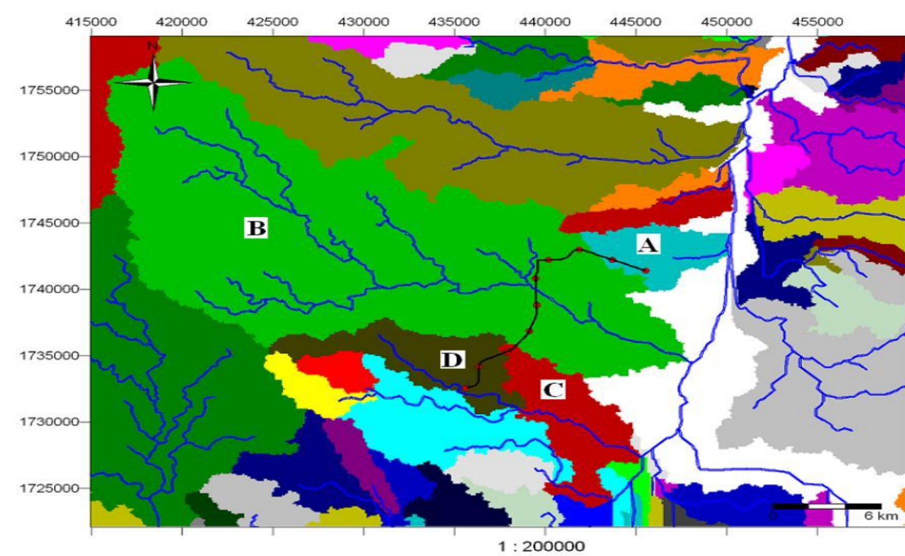

Figure 3. Four catchments (A~D) traversed by the Ring Road section

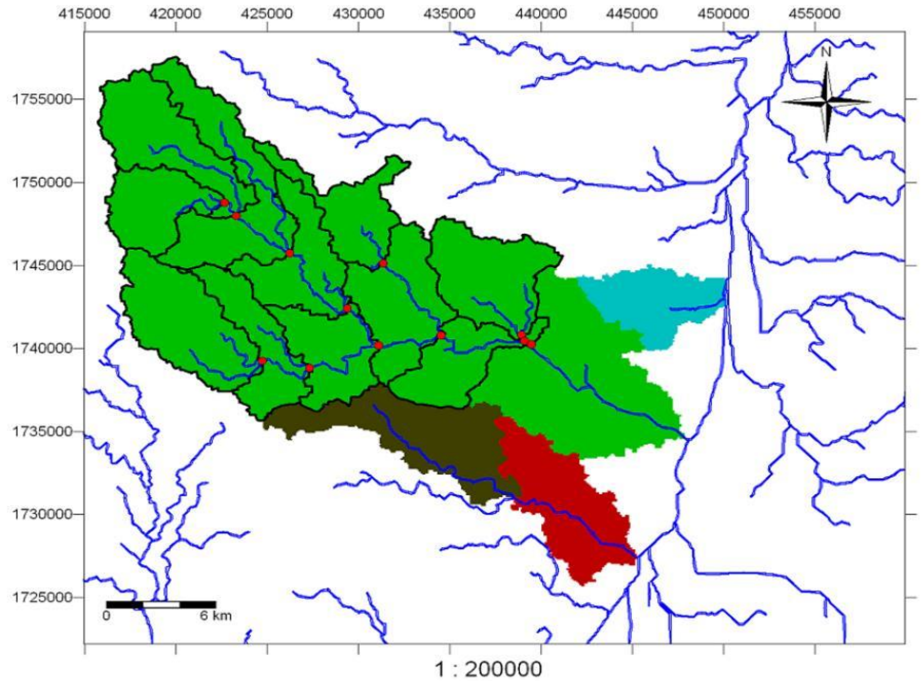

Figure 4. Catchment merge of catchment B using stream nodes (red circles) as outlets

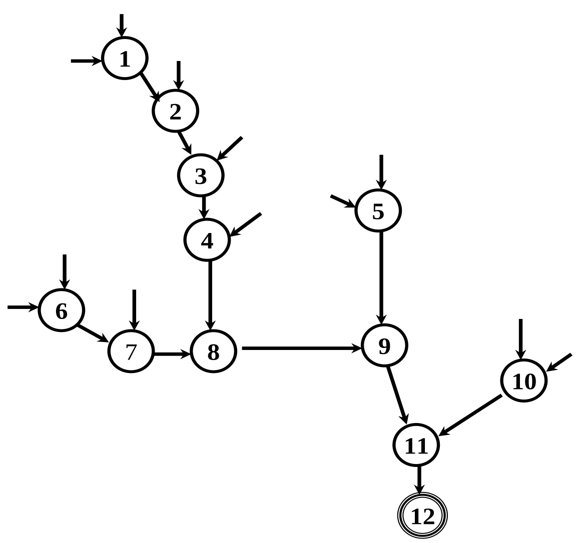

Figure 5. Schematic (stick) diagram of Khor Shambat sub-catchments

Table 1. Characteristics of catchments traversed by the Ring Road section. (Source: calculation results of hydrological modeling using GIS)

Parameter	Sub-catchment			
	A	**B**	**C**	**D**
Perimeter	26127.47	129535.96	38205.64	45615.62
Catchment Area (km^2)	24631036.58	380.17	36512090.19	41514955.94
Total Upstream Area (km^2)	24631036.58	380.17	123006682.3	41514955.94
Total Drainage Length	4804.7	112487.3	9300.8	11911.8
Drainage Density(m/km2)	195.07	295.89	254.73	286.93
Longest Flow Path Length	11966.92	51055.69	9300.8	18851.37
Longest Drainage Length	4804.7	45639.2	9300.8	11911.8
Center Drainage	(446288.47, 1741821.84)	(41147.11, 1740119.55)	(445392.53, 1727486.82)	(432222.24, 1734654.33)
Outlet Coordinate	(450230.60, 1744151.28)	(448080.35, 1734475.14)	(445392.53, 1727486.82)	(438583.40, 1730980.98)
Outlet Elevation	379	379	382	394
LFP Upstream Coordinate	(441987.97, 1744240.87)	(416005.75, 1755529.70)	(438583.40, 1730980.98)	(424965.13, 1735819.05)
LFP Upstream Elevation	421	484	394	438
LDP Downstream Coordinate	(447094.82, 1742359.40)	(418603.97, 1752125.13)	(438583.40, 1730980.98)	(430878.33, 1736535.80)
LDP Downstream Elevation	390	467	394	422

Table 2. Contributing area to stream (Khor Shambat) nodes. (Source: calculation results of hydrological modeling using GIS)

Node number	Contributing area (km^2)	Equivalent impervious area (km^2)	Longest flow path to node 12
1	21.7	6.5	59176.3
2	21.9	6.6	51806.7
3	36.5	11.0	41804.5
4	31.5	9.5	27031.0
5	32.1	9.6	24116.8
6	22.4	6.7	24194.7
7	40.0	12.0	20548.4
8	25.6	7.7	16253.2
9	23.2	7.0	9943.4
10	32.3	9.7	10771.5
11	20.7	6.2	6556.8
12	1.2	0.4	559
Total	309.1	92.8	

4.2. Stream crossing

Information about Ring Road crossings were obtained from Landsat imagery and digital elevation data (DEM) and were confirmed by field survey and measurement. Khor Shambat, the main stream of catchment B, represents the main stream crossing in this section of the Ring Road (Figure 3). The map in Figure 6 and cross section in Figure 7, indicate a wide depression extending for about 2km while the actual stream crossing is located at kilo 9 (coordinate: 439521.319, 1739794.532). The deepest point of the stream is 399 m.a.s.l lower than the immediate surroundings by about 3 meters. On the Landsat image and during field inspection one small branch drains towards Khor Shambat running approximately parallel to the Ring Road in a NNE-SSW direction and makes a crossing at kilo 8. At observation point 5 another branch was seen however it may represent part of the khor channel that gets braided in this section (Figure 6). Both branches can also be seen as depressions in the topographic cross section made from the digital elevation model (Figure 7). From the flow direction map (Figure 8), khor Shambat catchment surface mainly, drains to the N-NE-E or S-SW-W towards the main stream which flows from NW to SE. Apparently, the flowing velocity is low, mainly in the lower reaches being degenerated by urbanization, channelization (e.g. khor culvert at Al Wadi street, Eastern Omdurman), silting and low topographic gradient. The hydraulic gradient of the catchment B along the total flow path length equals 0.002 m/m.

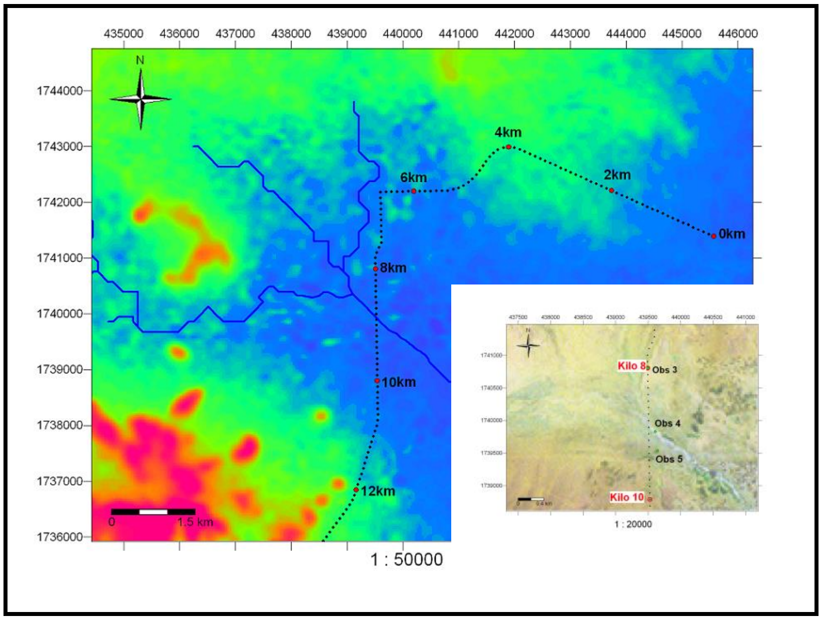

Figure 6. A map showing the stream crossing of khor Shambat at kilo 9. The large plate is the DEM from the STRM data and the small plate is the true colour composite of Landsat image of the study area

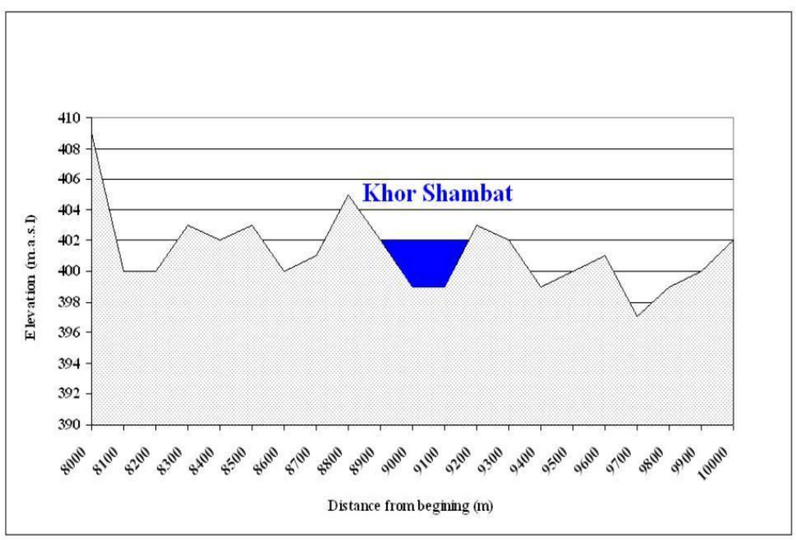

Figure 7. The cross section of the stream crossing of khor Shambat (from DEM (90m)

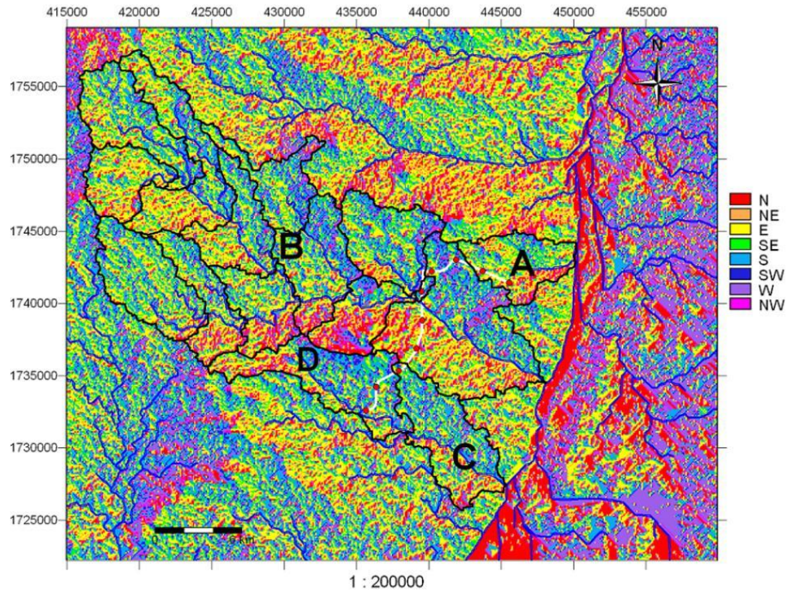

Figure 8. The flow direction map of the study area

4.3. Rainfall characteristics (frequency, intensity, duration)

Runoff estimation based on rainfall storm values provides an important parameter for surface water resources availability and management (Abdel-Magid and Shigidi, 2013). The study area is located within the arid-semi arid zone which is characterized by scarce rainfall and distinct seasonality. The scarcity and extreme variability of rainfall is reflected on the statistical summary of the 10-day time series data (Table 3).

Table 3. Statistical summary of 10-day time series rainfall data (Rainfall depth in mm) at Khartoum Station. (Source: Sudan Meteorological Authority)

Statistical Term	Value	Remarks
Mean (Average)	60.32	1924, 1925, 1963
Standard Deviation	35.69	
Variation Coefficient	0.59	
Maximum Record	224.1	10 days record (Aug. 1988)
Minimum Record	2.0	10 days record (Jul. 1990)

By its definition, frequency is a probabilistic concept and is the probability that a rainfall event of a given magnitude may be equaled or exceeded in a specified period of time, usually 1 year. Exceedence frequency is an important design parameter in that it identifies the level of risk during a specified time interval acceptable for the design of a highway structure. Return period is a term commonly used in hydrology. It is the average time interval between the occurrence of storms or floods of a given magnitude (Eq.1). Intensity-duration-frequency curves are necessary in hydrologic analysis of stormwater, to conduct this analysis summary of data on the intensity for various durations have been obtained for Khartoum station for which average values have been estimated (Figure 9).

Assuming that the intensities within a particular duration follow an Extreme value type I distribution, the intensities R_T for various return periods (T) were obtained according to Eq.2 and Eq.3 and the Intensity – Duration Frequency IDF curves were obtained for various events as shown in Figure 10. IDF curves give an upper boundary of rainfall intensity in 100-yr return period of 103.7 mm/h that probably occurs during 10-min, and a lower boundary of 8.7 mm/h in 2-hours. In fact a study by Al Hassoun (2011) found no much difference in results of rainfall analysis of IDF curves between Gumbel and Log Pearson III methods in Riyadh area, Saudi Arabia which is characterized by a semi-arid climate and flat topography.

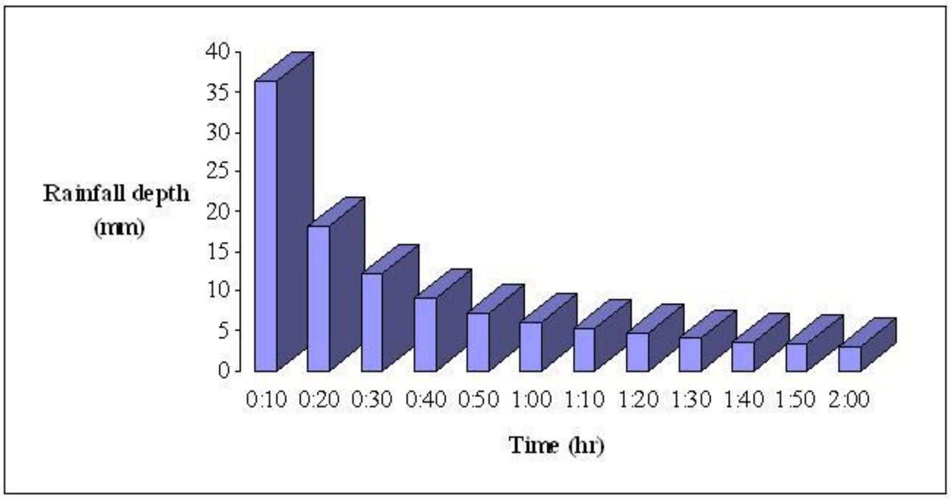

Figure 9. Average rainfall intensities and duration at Khartoum station

4.4. Peak runoff

Exclusive of the effects a given design may have upstream or downstream in a watershed, hydrologic analysis at a highway stream crossing requires the determination of either peak flow or the flood hydrograph. Peak discharge (sometimes called the instantaneous maximum discharge) is critical because most highway stream crossings are traditionally designed to pass a given quantity of water with an acceptable level of risk. This capacity is usually specified in terms of the peak rate of flow during passage of a flood, called peak discharge or peak flow. Associated with this flow is a flood severity that is defined based on a predictable frequency of occurrence (i.e., a 10-year flood, a 50-year flood, etc.). Typical design frequencies for hydraulic structures associated with different roadway classifications, are identified in drainage guidance developed by the American Association of State Highway and Transportation Officials (AASHTO) (AASHTO, 1999). According to the Design Storm Selection Guidelines the 10-year and 25-year return periods (10% and 4%, probability of exceedence) are considered appropriate for the hydraulic design calculation in this study. For example, the IDF curves have given an upper boundary of rainfall intensity in 10-yr return period equal to 65.4 mm/h that probably occurs during 10-min, and a lower boundary equal to 5.5 mm/h in 2-hours.

The contributing area method and the rational method (Eq.4) were used to determine peak runoff for catchment B at the main stream crossing of Khor Shambat. The runoff rate Q (m^3/s) for two return periods of rainfall intensities (10yr and 25yr) were computed for different time of concentration corresponding to each node. Time of concentration was calculated using the velocity method (Eq.5). The American Society of Civil Engineers (ASCE) (1960) presented Runoff Coefficients for the Rational Formula that matches different types of watershed covers. Obviously, in the case of arid regions partitioning of rainfall input- including runoff- is determined by surface characteristics (Osman, 2012). The study area is generally flat (mean slope <2% taken as 0.0025m/m allowing average velocity of 0.26 m/s) mostly bare land consisting of Cretaceous clastic continental sediments covered with a younger weathered material forming stable soil layer. Based on field observation and the character of soil, the "C" value was taken to be 0.3. The intensity corresponding to each time of concentration was obtained solving the regression equation of the 10-year and 25-year intensity curves (IDF curves, Figure 10).

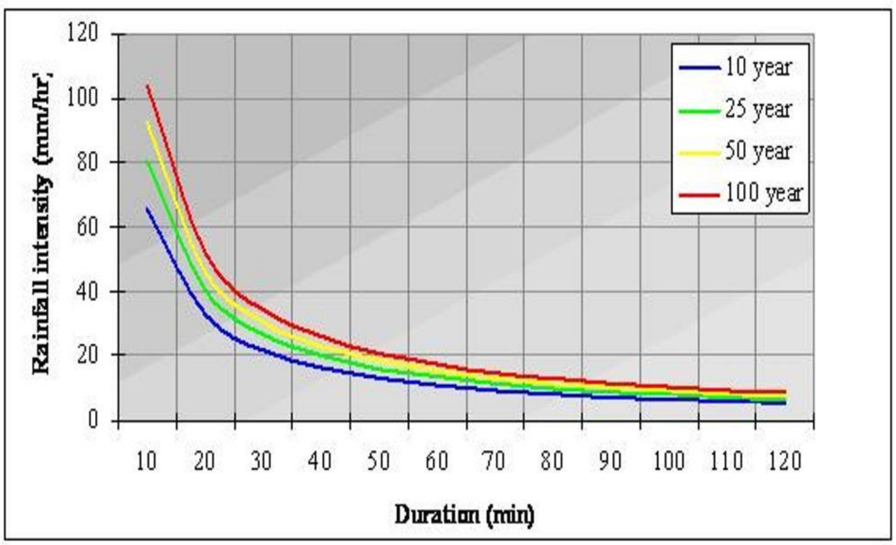

Figure 10. Intensity-Duration-Frequency curve

Time of concentration is the time required for a parcel of runoff to travel from the most hydraulically distant part of a drainage area to the outlet and is given by Eq. 5. For catchment B, the time of concentration was computed for the 11 sub-catchments using the longest flow path from any node to node 12 (the crossing) following the nodal stick model. It was then used to find the corresponding intensities from the IDF curves. Long time of concentration was observed reflecting the extensive watershed area, the flat topography of the study area as well as the surface cover of the watershed formed of natural well developed soil.

The catchment B of Khor Shambat, the stream crossing the Ring Road at the kilo 9, displayed peak runoff equal to 43.2 and 45 m^3/s for the return periods 10 and 25 years, respectively, as obtained from routing through different nodes according to contributing area method. The later discharge values are considered for the hydraulic design analysis (Table 4). Based on the Curve Number CN method, Aldoma and Mohamed (2014) estimated rainfall runoff process for Khartoum State (Sudan) using remote sensing and geographic information systems (GIS). They estimated a runoff ranging between 42 and 93 m^3/s for the area west of the Nile.

Table 4. Peak runoff computed for catchment B

Drainage Area (Km^2)	**Effective area (km^2)**	**Average rainfall intensity (mm/hr)**		**Peak runoff discharge (m^3/s)**	
		10-year	**25-year**	**10-year**	**25-year**
309.1	92.8 (contributing area method)	1.6	1.7	**43.2**	**45**

4.5. Design of hydraulic structures

Table 5. Hydraulic design parameters for Khor Shambat-Ring Road crossing

Return Period	**Design discharge (m^3/s)**	**Area A (m^2)**	**b (m)**	**y(m)**	**Hydraulic radius R (m)**	**Design velocity**
Main culvert at kilo 9 (439521.319, 1739794.53)						
10-year	43.2	32.3	21.5	1.5	1.3	1.3
25-year	45	33.5	22.3	1.5	1.3	1.4
Minor culvert at Kilo 8 (439504.3, 1740794.4)						
10-year	2.6	3	2.5	1.2	0.6	0.9
25-year	3.2	3.4	2.6	1.3	0.7	0.9
Minor culvert at kilo 9.3 (439653.0, 1739538.0)						
10-year	10.3	8.4	5.6	1.5	1	1.2
25-year	13.5	10.2	6	1.7	1.1	1.3

In previous sections the contributing area method and the Rational method were used to compute the peak runoff for catchment B (Table 4) at the stream crossing (kilo 9) with the Ring Road. For the minor crossing at kilo 8, the contributing area to node 10 (Figure 5) was considered for the calculation of peak runoff which was found to be 2.6 and 3.2 m^3/s for the 10-year and 25-year return periods, respectively. For the minor crossing at kilo 9.3 it has been assumed that as it branches from the main stream of Khor Shambat it may carry 20% of its discharge value at a given moment. Accordingly, the runoff discharge of 10.3 and 13.5 m^3/s for the 10-year and 25-year return periods, respectively was taken to calculate the design parameters.

Then appropriate flow cross sections were computed (Table 5) employing the Manning equation (Eq. 6), the continuity equation (Eq. 7), the Chezy formula (Eq. 8) and Ganguiller and Kutter formula (Eq. 9) using different scenarios. The parameters of the trapezoidal cross section were computed according to the geometry described in Pillai and Ramakrishnan (2006). The Manning roughness coefficient (n) was taken to equal 0.04 (Chow, 1959). Three culverts were proposed at kilo 9, at kilo 8 and at kilo 9.3, the first one represents the main culvert with 33.5 m^2 trapezoidal cross sectional area designed for the 25-year return period.

5. Conclusion

Khor Shambat is one large seasonal wady that crosses the proposed national Ring Road surrounding Khartoum, the Sudan Capital in the first part of Omdurman sector. It flows from west to east for over 100 kilometers total drainage length with a total watershed area over 300 square kilometers. The paper demonstrated an integration of mathematical modeling and geographical information system for modeling rainfall, estimating peak runoff and designing hydraulic structures at the crossing point. Geographical information system proved to have grate value in the process of catchment modeling and drainage analysis while remotely sensed data enabled the identification of channel behaviour at the crossing point and the accurate estimation of natural channel size. All of that allowed putting suitable assumptions concerning peak runoff estimation and design of hydraulic structures. The study area is generally flat (mean slope <2%) bare land consisting of old Nile River terraces covered with thin wind blown sand. The flat character of the surface implies a lower runoff coefficient, consuming longer time of concentration (duration) allowing more infiltration losses through the study area covered by natural soil. IDF curves gave an upper boundary of rainfall intensity in 100-yr return period of 103.7 mm/h that probably occurs during 10-min, and a lower boundary of 8.7 mm/h in 2-hours. According to the Design Storm Selection Guidelines the 10-year and 25-year return periods (10% and 4%, probability of exceedence) were considered appropriate for the hydraulic design calculation in the current assignment. Accordingly, the peak runoff for the catchment of Khor Shambat was found to be 43.2 and 45 m^3/s for the return periods 10 and 25 years, respectively, as obtained from routing through different nodes according to contributing area method. The obtained peak runoff values were used to compute the appropriate hydraulic design (culvert cross section) at the crossing point by solving and substituting different parameters in a set of equations. Finally, three culverts were proposed at kilo 9, at kilo 8 and at kilo 9.3, the first of which represents the main culvert with a total cross sectional area equal to 33.5 m^2. For better future results the 25-year return period is recommended for the hydraulic design taking into account the recent climate variability at regional and local scales.

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