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Effect of Rainfall Distribution over the Blue Nile Watershed on Filling the Grand Ethiopian Renaissance Reservoir (GERR)

Osama M. Moussa[1], Aly I. Aly[2], Mohaed H. El-Sabaa[2] and Mohamed R. Hashem[2]

(1) Brig. Gen (R) Prof.(M.T.C.).,(2) Civil Eng, Students (M. T. C.), Egypt

Abstract

The Abyssinian Plateau’s climate varies with latitude, altitude and exposure or slope. The rainy season is extended from June until September (Hurst et al., 1931). The West of Ethiopia receives higher amount of rainfall than the remainder of the country. Highland rainfall normally peaks in August in the administrative regions of Welo and Northern part of Shewa. Rains decreases over most of the highlands during September (Henricksen, 1986).

The maximum rainfall amount was extracted for regular years from the Jemma station and found to be 287 mm. On the other hand, the minimum amount of rainfall was acquired and found to be 164 mm for drought years. The effect of these amounts for overall the Blue Nile Basin on the life span of Grand Ethiopian Renaissance Reservoir (GERR) were studied before by Moussa et al.,2016 and 2017 with time duration of 24 hours.

About 98 percent of the annual sediments are carried by the Nile during the flood season. Most of these sediments are eroded from the Blue Nile high lands (about 82%). Since the Grand Ethiopian Renaissance Dam (GERD) starts to store the flooding water and sediment during this year, then water and sediment that will be stored by this dam will be varied from regular to the drought years especially when rainfall amounts are distributed over different administrative regions of the Blue Nile Basin. The objective of this research is to determine water and sediment discharge of the Nile Basin with respect to the new regulation of rainfall that will fill the GERR.

Volume of water and sediment for the Blue Nile basin were determined by using remote sensing techniques and by the aid of hydrological model, watershed storm hydrograph model (WASHMO), that was established by Andy Ward 1986. Hydrological parameters for 15 sub basin were extracted from digital elevation model (DEM) of Shuttle Topographic Radar Mission. Other parameters that concern rainfall, soil characteristics and land cover were collected from Atlas of the Blue Nile Basin (Yilma and Awulachew, 2009) and input in the model in order to determine sediment yield from the Blue Nile Watershed.

Keyword: Hydrological model, Sediment yield, Life span

1. Introduction

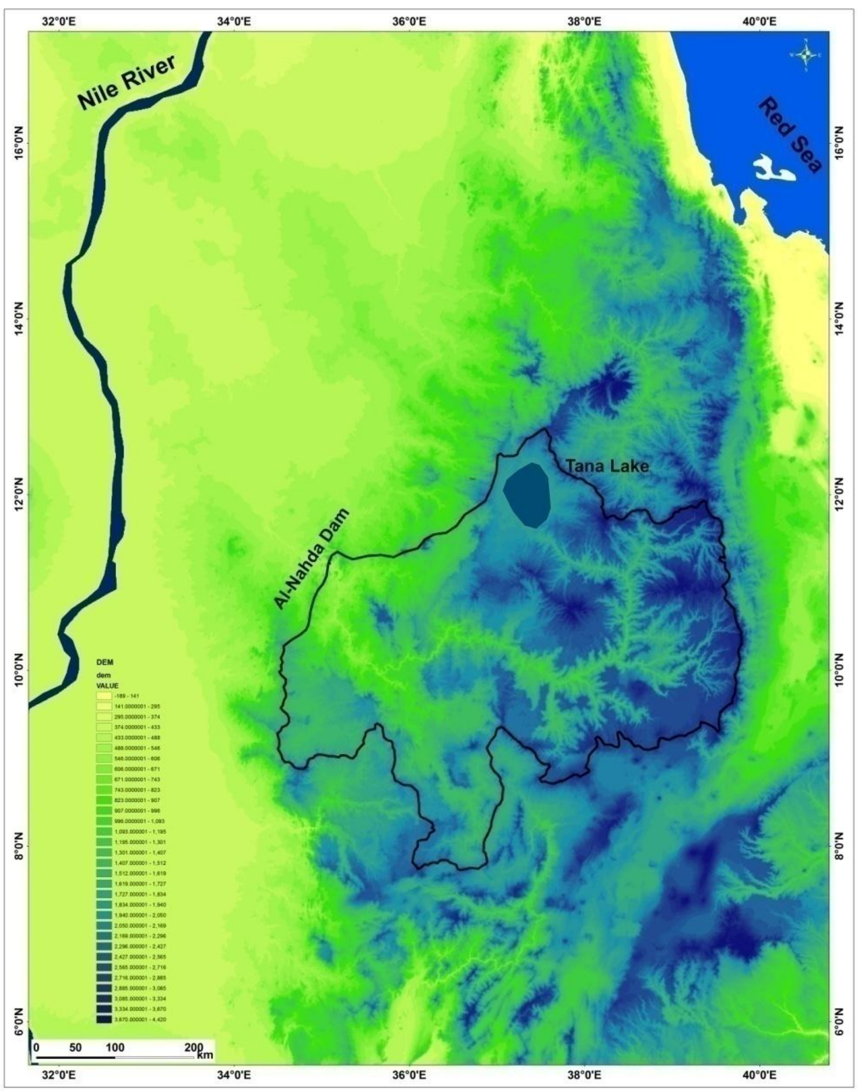
Grand Ethiopian Renaissance Dam (GERD) is a gravity dam on the Blue Nile River in Ethiopia currently constructed. It is in the Benishangul - Gumuz region of Ethiopia, about 40 km East of the border with Sudan. The dam is 170 m height; 1,800 m long gravity-type composed of roller-compacted concrete. The Grand Ethiopian Renaissance Reservoir will have a volume of 63 billion cubic meters (51 million acre feet).

During the last two years M.T.C. students had studied life span of the GERR during the regular and drought storms. Rainfall events were taken as a fixed parameter all over the Blue Nile's provinces. Two rainfall amounts: 287 mm and 164 mm were taken for the regular and drought years.

Most of sediment transport models were based on the Universal Soil Loss Equation (USLE). The new version of the USLE (WASHED model) which is modified by Ward 1986 was used to determine the water inflow and sediment yield from 15 small catchments of the Blue Nile watershed. Based on rainfall data that were extracted from Atlas of the Blue Nile Basin (Yilma and Awulachew, 2009), volume of water and sediment which resulted from WAHMO model will be used to determine the filling capacity of the Grand Ethiopian Renaissance Reservoir during regular and drought years.

2. Study areas

2.1 Blue Nile Watershed -Grand Ethiopian Renaissance Reservoir (GERR)



The Blue Nile watershed is located in the Eastern region of the African continent (extended from 7° 30`N to 13° 00` N and from 34° 00` E to 40° 00` E). This area covers most of the Ethiopian plateau highlands at an elevation of 2000 to 3000 meters above mean sea level, see Figure 1.

Figure 1: Location of the Blue Nile Watershed.

Source: Ashour S.A., et al. (2014)

2.2 Topography

The Blue Nile and its tributaries all rise on the Northern Ethiopian Highland, or plateau, at heights of 2000 to 3000 meters above Mean Sea Level. Most of the Northern Ethiopian plateau is hilly with grassy downs, swamps valleys, and scattered trees. The highest point in this plateau is the peak of Simien Mountains, 4620m above sea level (Hurst,1950). Huffnagle (1961) describes the Northern Ethiopian plateau with respect to its topographic variation. This variation ranges from hilly and mountainous to broad rolling and nearly level plains. The Ethiopian plateau is cut up by the deep ravines or canyons in which the rivers flow. In some places the Blue Nile flows into a channel that is about 1300m below the level of this plateau on either side.

2.3 Rainfall

The Abyssinian Plateau's climate varies with latitude, altitude and exposure or slope. The rainy season is extended from June until September (Hurst et al., 1931). Global weather is change regarding to the effect of the Ozone hole that been exist from increases in carbon dioxide concentration during the last few decades. This phenomenon effect strongly on rainfall distribution all over the World especially the tropical regions. Rainfall over different district during the regular years are varied from 208 mm at Jemma to 340 mm at Dedessa. On the other hand, rainfall during the drought years are varied from 168 mm at Jemma to 280 mm at Anger.

2.4 Soil Types

The composition of the volcanic materials, particularly in the Ethiopian North Central Highlands, which cover most of the study area have a major importance for engineers and hydrologists. This is due to severe erosion which is caused by continuous events of storms during the rainy season. Two main soil types had been distinguished by Huffnagle (1961) : the red to reddish brown clayey loams and black soils. The red soils bare the specific latosols characteristics and they have an excellent permeability. The black soils which are derived from disintegration of dolerites are found in the lower parts (depressions) of the study area. This soil type has tendency to dry out quickly and to crack. In wide deep valleys the black soil may have been intermingled with alluvial material (Huffnagle, 1961).

2.5 Soil Erodibility Factor, K.

Direct measurement of the soil erodibility factor, K, is costly as well as time consuming. To achieve a better determination of soil erodibility factor for different soil types, the use of field-plot rainfall simulators had been recommended by Wishmeier and Smith (1978) in at least 12 different stations to obtain comparative data on numerous soils. The value of K is varied from a specific kind of soil to another according to the different properties of soil itself. Silt fraction content, percent of sand in soil, soil structure, organic matter content and permeability class are the most common properties that have been used to determine such factor either from empirical equations, tables or from soil erodibility nomographs.

Values of soil erodibility factors for different soil types vary during the year. Dickinson et al., (1982) determined the variation of K from season to season due to the change of the shear values for surface soils. The plant coverage strongly affects some of soil properties such as, infiltration and organic matter content. It increase infiltration as plant roots open up the soil and increases the organic content of the soil (Mogran,1980).

2.6 Vegetation

The study area land cover includes agricultural crops, coffee forests, grazing grounds, closed forests, open woodlands, open brush and scrub, as well as lakes and rivers. The important resources for the study area are fertile and climatic conditions which are favorable for cultivating a variety of crops and raising livestock. The cultivated area in Ethiopia are mostly on the highlands, in low valleys and on river plains which have sufficient rainfall or allow a form of irrigation (Huffnagle, 1961).

3. Model Description

The WASHMO (Watershed Storm Hydrograph Multiple Option) model was developed by Ward et al., (1979) at the University of Kentucky, Department of Agricultural Engineering. WASHMO had been used to determine volume of water runoff and sediment yield from watershed.

This model consists of two models. The first model describes the hydrology of the watershed and determines a design storm hydrograph. The second model describes the associated detachment, transport and deposition along with sediment yield from the watershed. Detachment occurs when a soil particle is dislodged from the soil surface and/or from the aggregate to which it was attached. When the soil surface is exposed, bare soil, the impact of falling rain drop is sufficient to detach soil particles from the soil mass. As far as the infiltration, percolation and saturation processes take place, and rainfall intensity exceeds the infiltration capacity, some of the excess water may be intercepted as surface storage in depressions, and the remainder becomes surface runoff. The soil particles can be easily transported by water, surface runoff. When the available energy is insufficient to transport soil particles, they will deposit either at a few millimeters of the detachment site or several kilometers downstream in rivers (Ward et al., 1979).

Sediment yield (in tons) was determined by using the modified version of the Universal Soil Loss Equation (USLE) which developed by Hann and Barfield (1978). This modified equation was written in the form:

$$Y_s = 95 \; (Q \, q_p)^{0.56} \, KL_s \; S_f \; C \; P_r \qquad \ldots\ldots\ldots\ldots\ldots (1)$$

Where Y_s is the sediment yield in tons from a storm, Q is the volume of runoff in acre-ft, q_p is the peak runoff rate in cfs, K is the soil erodibility factor, L_s is the slope - length factor, C is the ground cover factor and P_r is the reclamation practice factor.

4. Data Acquisition for BNW

Data preparation consists of creating main streams and tributaries from digital elevation model (DEM) with the aid of Arc-Map software. The other parameters such as Soil Conservation Factor Curve Number (SCS-CN), soil erodibility factor (K), Conservation Practice factor (CP) were collected from other sources and they will be discussed in the following subtitle.

4.1 Digital Elevation Model

A 30 m resolution of Digital Elevation Model (DEM) provided by Shuttle Radar Topography Mission (STRM) for the study area is used to describe the elevation of the Blue Nile watershed as shown in Figure 2.

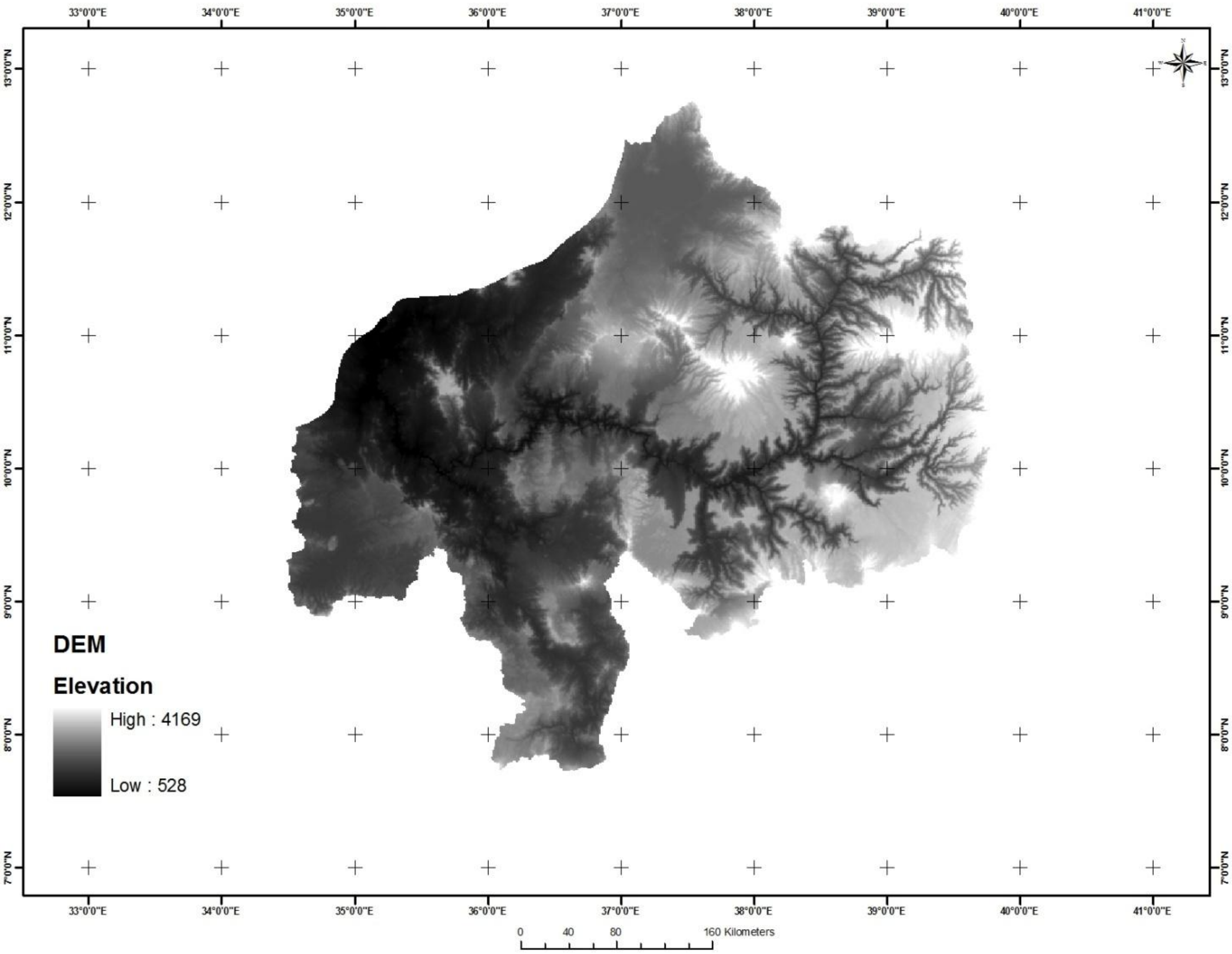


Figure (2) Digital Elevation Model for the study area.

4.2 Sub-watersheds extraction

Main stream and tributaries were extracted from DEM by using Arc-Map software. Fifteen sub-watersheds had been determined from both DEM and the drainage pattern of each catchment as shown in Figure 3.

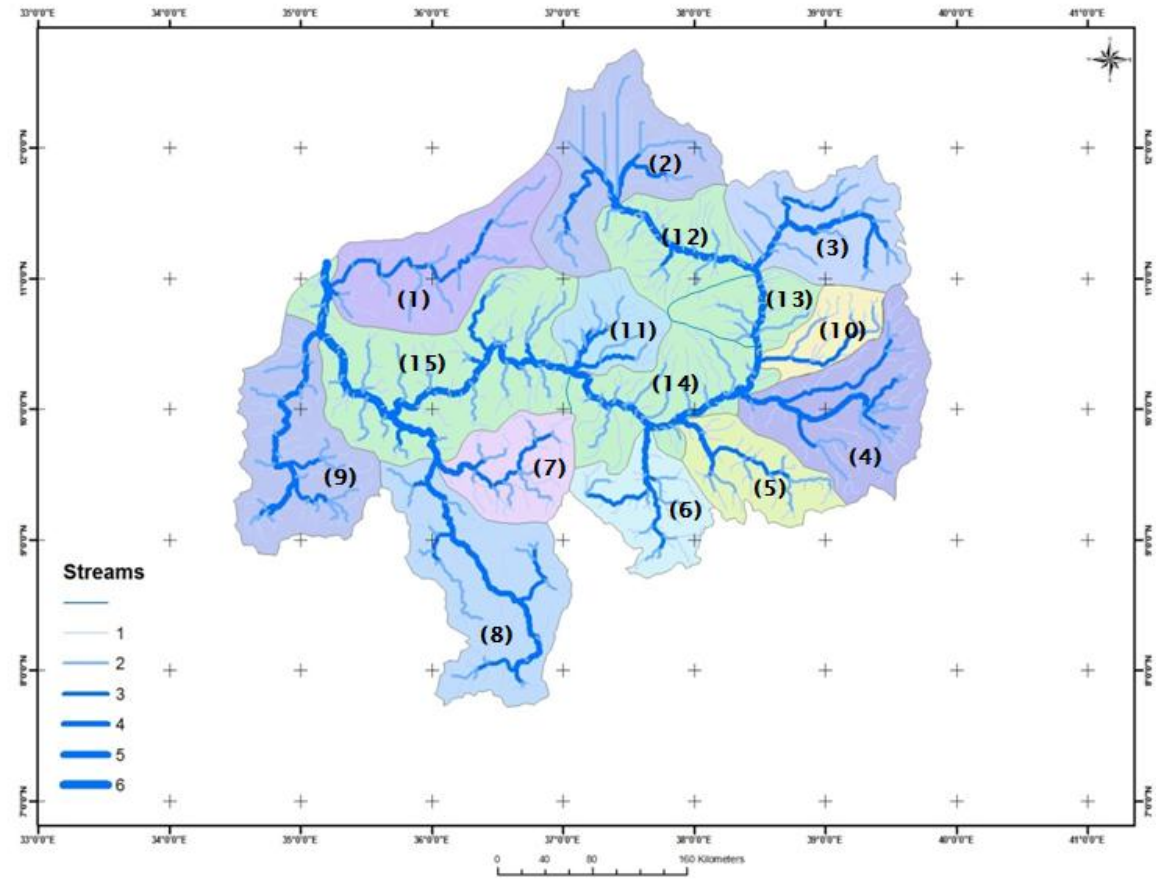


Figure 3: Sub-watersheds of study area.

4.3 Hydrological Parameters

The area of the watershed and its 15 sub-watersheds, the lengths of main streams and their slopes and overland flow lengths and their mean slopes were extracted from the Arc-Map software. These values were tabulated in Table 1.

Table 1: Hydrological parameters that been extracted from Arc-Map Software.

Sub-watershed	Area (ha)	Channel length (m)	Channel slope %	Hydraulic length	Overland flow length (m)	Overland flow slope %
Sub1						
1-D	104513.76	3164.47	3.0	37872.99	6059.68	5.0
2-D	55820.35	35876.13	2.0	20123.80	3219.81	6.0
3-D	151746.40	56067.86	1.0	54897.72	8783.64	5.0
4-D	82055.77	69983.41	2.5	35699.26	5711.94	5.0
5-D	51792.10	81059.04	2.0	18513.89	2962.22	7.0
6-D	71269.44	91619.43	2.0	39442.64	6310.82	10.0
7-D	44709.40	112865.99	1.5	31956.59	5113.05	5.0
1-U	24892.66	16349.75	2.0	13603.69	2176.59	2.5
2-U	35944.59	29210.47	2.0	17507.70	2801.23	2.5
3-U	38334.99	63553.05	2.0	26402.42	4224.39	2.5
Sub2						
1-L	471440.72	24281.20	1.0	115550.85	43909.32	1.3
1-R	254946.88	24281.20	3.0	68179.43	25908.18	2.0
2-R	159950.47	24281.20	2.8	47371.42	18001.14	2.0
Sub-3						
1-D	76906.10	11014.78	3.5	43048.94	13323.63	7.0
2-D	79444.03	16248.32	2.9	45439.54	14086.26	5.7
3-D	84505.20	43349.14	5.9	27287.87	8459.23	13.0
4-D	102123.36	72904.45	3.0	49625.29	15383.84	7.8
1-U	82409.90	6923.29	4.1	29541.74	9157.94	5.5
2-U	103510.38	21704.99	3.2	37591.225	11653.28	6.0
3-U	301648.30	273323.96	2.75	102027.66	31628.57	7.3
4-U	97106.46	63289.34	3.6	33003.03	10230.94	6.8
Sub-4						
1-U	290197.95	21725.28	1.3	141470.30	58002.70	1.7
1-R	453955.36	70591.95	2.6	46968.94	19257.26	5.2
1-D	342285.14	32679.21	5.0	40247.59	16501.51	7.3

Cont. Table 1: Hydrological parameters that been extracted from Arc-Map Software.

Sub-watershed	Area (ha)	Channel length (m)	Channel slope %	Hydraulic length	Overland flow length (m)	Overland flow slope %
Sub-5						
1-D	158238.80	25457.73	4.2	30628.42	5513.12	7.3
2-D	67654.33	43470.85	7.9	19037.11	3426.68	15.0
3-D	65072.10	57082.12	11.8	10142.39	1825.63	15.0
4-D	77230.69	68036.04	3.6	30507.68	5491.38	5.5
1-U	56749.95	13692.41	9.7	15414.83	2774.66	15.0
2-U	45122.56	62559.08	10.3	9739.92	1753.18	17.0
Sub-6						
1-L	245695.10	29453.89	1.3	91120.56	33714.60	1.2
1-R	200631.60	22678.68	5.3	26362.18	9754.00	6.1
2-R	98936.15	55581.02	8.5	9377.69	3469.74	11.5
Sub-7&8						
1-U-L	67624.80	6572.35	1.0	35699.62	5247.84	6.7
2-U-L	107671.45	47418.32	2.3	41857.50	6153.05	4.9
3-U-L	357586.68	75350.83	0.5	125129.78	18394.07	1.6
1-U-R	809402.48	35843.68	1.0	152377.39	22399.47	1.0
2-U-R	305410.95	124144.50	1.3	75665.48	11122.825	5.4
3-U-R	99423.10	164673.99	1.0	29944.21	4401.80	6.8
Sub-9						
1-U-L	72169.53	14199.53	1.4	50792.47	7857.595	1.0
2-U-L	50198.48	41219.2	1.1	35860.51	5547.62	1.0
3-U-L	49180.34	63390.77	1.0	22498.41	3480.504	3.0
1-U-R	28006.1	28338.2	1.8	21693.45	3355.976	6.0
2-U-R	194581.8	83040.89	1.0	91241.3	14115.03	1.4
3-U-R	316182.53	89883.04	0.5	100095.77	15484.8	1.3
Sub-10						

1-L	118811.9	13306.99	3.9	74015.33	27989.64	2.5
1-R	41935.35	51077.74	2.9	37551.01	14200.29	4.2

Cont. Table 1: Hydrological parameters that been extracted from Arc-Map Software.

Sub-watershed	Area (ha)	Channel length (m)	Channel slope %	Hydraulic length	Overland flow length (m)	Overland flow slope %
Sub-11						
1-U-L	28876.66	27181.96	2.6	30386.96	6872.38	2.6
2-U-L	67447.7	16775.73	1.1	53006.08	11987.98	3.3
3-U-L	63080.1	8621.144	1.0	42823.44	9685.05	1.5
1-U-R	234377.6	4564.14	2.3	88303.23	19970.86	3.0
Sub-12						
1-D	62844.01	61625.97	2.40	41133.04	9837.65	4.10
2-D	153797.40	40022.40	2.90	47210.43	11291.2	5.30
3-D	66503.40	21988.99	4.60	47089.7	11262.3	5.30
1-U-L	66695.21	44059.12	2.20	35578.9	8509.3	4.70
2-U-L	102211.89	29494.5	3.10	62786.25	15016.4	4.00
Sub-13						
1-U-L	96132.6	14929.8	3.80	56749.11	10316.99	5.80
2-U-L	59450.22	9270.30	5.60	27770.84	5048.74	11.80
1-R	77968.5	11643.62	2.70	59083.50	10741.38	3.70
Sub-14						
1-D	180357.43	26613.98	1.00	50510.73	18264.68	1.00
1-U	49475.45	29109.04	4.30	28133.10	10172.92	9.80
2-U	128196.46	33855.74	2.80	79529.25	28757.78	2.80
3-U	150949.56	87953.67	2.80	77597.4	28059.21	2.90
Sub-15						
1-D	106579.54	41117.78	1.00	49263.10	11783.72	1.00
2-D	93624.14	100289.26	2.80	49947.27	11947.4	3.30
3-D	89049.91	132846.76	2.30	53207.32	12727.2	2.40
4-D	69351.22	150210.76	2.30	39764.63	9511.7	5.30

1-U	158209.31	37385.34	2.70	59566.44	14248.3	2.10
2-U	102182.4	62761.93	2.30	60009.2	14354.2	2.30
3-U	143483.24	29192.82	1.90	46727.46	111177.21	3.60
4-U	82395.15	111121.48	3.00	32801.79	7846.2	2.50
5-U	234776.03	118221.24	1.60	112733.51	26965.86	1.50
6-U	206032.14	146295.75	1.90	84922.43	20313.45	1.50

Percentage of agriculture, forest, and grass land coverage for the each Sub-Watershed is tabulated in table 2.

Table 2 : Land Cover and SCS (CN) for each Sub-Basin

Sub Basin	Land Cover			Soil Concervation service curve number (CN)
	Agriculture	Forest	Grassland	
Sub(1)	40	50	10	57
Sub(2)	60	1	5	62
Sub(3)	90	0	1	57
Sub(4)	40	6	40	56
Sub(5)	54	6	40	58
Sub(6)	55	5	35	63
Sub(8)	40	45	5	54
Sub(9)	20	55	25	52
Sub(10)	80	0	15	61
Sub(11)	40	10	50	63
Sub(12)	41	0	59	61
Sub(13)	10	5	80	62
Sub(14)	70	0	30	60
Sub(15)	5	90	3	53

4.4 Soil Conservation Service Curve Number

Regarding to the land use and soil characteristics for the study area, Soil Conservation Service – Curve Number (SCS-CN) which represents the runoff potential of an area for each sub-watershed was determined by using Hann and Barfield (1978) approaches, see tables 2 and 3. The hydrologic soil groups that are given in Table 3 are based on the infiltration rate, depth, drainage and texture of different types of soil. The weighted mean value of the CN was used as a combined value for different kinds of vegetation coverage in each small catchment, when more than one type occurred. CN was found to be 42. The vegetation coverage percentage for each catchment was determined from Atlas of Ethiopia. The description of different types of land cover was discussed widely by Huffnagel (1961).

Table 3: Definition of SCS hydrologic soil groups.

Soil Type	Description
A	These soils with high infiltration rate are chiefly deep, well-drained sands or gravel (Low runoff potential).
B	These soils with a moderate infiltration rate when thoroughly wet, are chiefly moderately deep, well-drained soils of moderately fine to moderately coarse texture.
C	These soils with a slow infiltration rate when wet are chiefly moderated deep, well-drained soils of moderately fine to moderately coarse texture.
D	These soils with a very slow infiltration rate, are chiefly clay soils with a high swelling potential, soils with a permanently high water table , soils with a clay pan at or near the surface and shallow soils over nearly impervious materials (high runoff potential).

Table 4: Runoff Curve Number for Selected Agriculture.

(Antecedent Rainfall = 1.4 – 2.1 inches).

Land use description	Hydrological soil group			
	A	B	C	D
Cultivated Land: * Without conservation treatment. ** With conservation treatment.	72 62	81 71	88 78	91 81
Pasture or range land: * Poor condition. ** Good condition.	68 39	79 61	86 74	89 80
Meadow: good condition.	30	58	71	78
Wood or forest land: * Thin stand, poor cover, no mulch ** Good cover	45 25	66 55	77 70	83 77

4.5 Soil Erodibility Factor

The soil erodibility factor, K, was found to be 0.20. This factor was determined by using soil erodibility monograph given by Wischmeier and smith (1978). The soil's structure for different soil types in the Blue Nile Basin varies from fine granular (Cambisols dystric) to medium or coarse granular (Cambisols humic, Cambisols eutric, arenosols cambic and nitosols eutric). The corresponding permeability classes are slow to moderate for the fine granular and very slow for the medium or course granular.

Sieve analysis of soil samples was studied and the particle size distribution of sediment flow was found to be as follows:

Particle size (mm)	0	0.002	0.05	0.1	2.0
% Finer	0	48.1	77	82	100

Conservation Practice factor (CP) was found to be 0.05 (Wischmeier and smith ,1978).

4.6 Rainfall Extraction

Regarding to Lack of rainfall observations for different metrological data sites, rainfall are determined based on the rainy months and the amount of maximum and minimum annual rainfall for each district. Rainfalls distribution over different districts for regular and drought years were extracted from Atlas of the Blue Nile Basin (Yilma and Awulachew, 2009) and tabulated in table 5.

Table 5 : Rainfall distribution for regular and drought years

For different districts

Sub	District	Rainfall-Regular Years (mm)	Rainfall-Drought Years (mm)
1	Beles	300.9	235.2
2	Lake Tana	296.4	220
3	Beshlo	229.5	185.4
4	Jemma	208	168
5	Muger	215.9	183.3
6	Guder	255.1	190
7	Anger	331	280
8	Dedessa	340	260
9	Dabus	295.5	217
10	Welaka	219	160.6
11	South Gojam	287.7	219
12	North Gojam	262.5	200
13	Main Stream	224.25	173
14	Main Stream	252.9	197.4
15	Wenbera	305.5	225

5. Surface Runoff & Sediment Yield Based on Rainfall Distribution

Surface runoff (Q_W) in m^3 and sediment yield (Q_S) in tones are determined by using data acquired in previous title and WASHMO model for regular and drought years. These values are tabulated in table 6.

Table 6 : Q_W and Q_S based on Rainfall distribution for regular (R) and drought (D) years

For different districts

Sub	District		Q_W X10^3 m^3	Q_S (in tones)
1	**Beles**	R D	11063.97 7271.85	40854.65 25691.04
2	**Lake Tana**	R D	110784.40 68612.15	635720.70 370895.00
3	**Beshlo**	R D	380911.30 253817.70	28330524 18000187
4	**Jemma**	R D	41965.13 27343.34	3040899 1875919
5	**Muger**	R D	276342.80 202831.00	23845011.10 16737470.40
6	**Guder**	R D	447713.70 273505.30	21060539 12061441
7	**Anger**	R D	83716.61 56763.75	8556393 5587084
8	**Dedessa**	R D	83716.61 56763.75	8556393 5587084
9	**Dabus**	R D	15259.30 8421.29	360592.60 187857.80
10	**Welaka**	R D	25876.69 14493.28	231315.60 122370.60
11	**South Gojam**	R D	41701.60 26943.13	233485.80 144784.30
12	**North Gojam**	R D	36166.94 68722.69	199842.40 2529223
13	**Main Stream**	R D	64087.09 40529.83	4127096 2466774
14	**Main Stream**	R D	60967.43 39439.91	3816619 2346829
15	**Wenbera**	R D	10205.30 5737.42	334280.10 180063.30

6. Results and Analysis

From previous study Moussa and Shawky (2016) :

The maximum rainfall at Jemma station (287 mm) with duration 24 Hours gives volume of water = 2633365×10^3 m^3 and sediment volume = 57495094.34 m^3.

Since the capacity of GERR was estimated by the Ethiopian Government by the value of 63×10^9 m^3 , then the following assumptions will be taken in consideration:

1- The Grand Ethiopian Renaissance dam will retain sediment into GERR.
2- No water losses from evaporation.
3- Effect of permeability is minimum.
4- No consumption of the stored water behind the reservoir for public use or irrigation purposes.

According to the resulted values of water volumes and sediment weight (weight in tones should be converted to volume) and under the mentioned conditions, the required filling time for the regular years is found to be:

I) In case of filling of water and sediment :

*Since the reservoir capacity is 63×10^9 m^3

*And the total volume of water and sediments for 1 storm = 2.69 $\times 10^9$ m^3/yr.

*The required filling time of the reservoir is $(63 \times 10^9) / (2.69 \times 10^9)$ = 23.42 years

*The required filling of the reservoir for 4 storm /year = 5.86 years

And From the previous study that done by Moussa et al.(2017):

The minimum rainfall at Addis -Ababa station (164 mm) with duration 24 Hours gives volume of water = 801910×10^3 m^3 and sediment volume = 23433000 m^3.

According to the resulted values of water volumes and sediment weight (weight in tones should be converted to volume) and under the mentioned conditions, the required filling time for the drought years is found to be:

II) In case of filling of water and sediment :

*Since the reservoir capacity is 63×10^9 m^3

*And the total volume of water and sediments for 1 storm = 0.945 $\times 10^9$ m^3/yr

*The required filling time of the reservoir is $(63 \times 10^9) / (0.945 \times 10^9)$ = 66.667 years

*The required filling of the reservoir for 4 storm /year = 16.66 years

From table 6 volume of water for the whole watershed ***during regular*** years is found to be 1690478.87×10^3 m^3 and sediment volume=39007383.38 m^3

According to the resulted values of water volumes and sediment weight (weight in tones should be converted to volume) and under the mentioned conditions, the required filling time for the regular years is found to be:

III) In case of filling of water and sediment :

*Since the reservoir capacity is $63x10^9$ m^3
*And the total volume of water and sediments for 1 storm = 1.729 $x10^9$ m^3/yr
*The required filling time of the reservoir is $(63x10^9)$ / $(1.729\ x10^9)$ = 36.44 years
*The required filling of the reservoir for 4 storm /year = 9.11 years

From table 6 volume of water for the whole watershed ***during drought*** years is found to be 1151196.39 $x10^3$ m^3 and sediment volume=25744782.43 m^3

According to the resulted values of water volumes and sediment weight (weight in tones should be converted to volume) and under the mentioned conditions, the required filling time for the drought years is found to be:

IV) In case of filling of water and sediment :
*Since the reservoir capacity is $63x10^9$ m^3
*And the total volume of water and sediments for 1 storm = 1.177 $x10^9$ m^3/yr
*The required filling time of the reservoir is $(63x10^9)$ / $(1.177\ x10^9)$ = 53.53 years
*The required filling of the reservoir for 4 storm /year = 13.38 years

It is concluded that the distributed rainfall all over the watershed is more reliable.

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