Water Harvesting of the area North of Khartoum Bahri

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Abstract- The purpose of this study is to solve the problem of rain water of the area north of the Khartoum Bahri and protect the Villages from the floods, and conduct a comprehensive hydrological study of the water basins passing through that area. The methods used in this study were to collect data from different sources such as Digital Elevation Maps, Urban development maps, Rainfall data. In addition to hydrological, hydro geological studies and survey works. These data were analyzed using hydraulics equations and probability distribution functions$f(x)$. From the results the basins catchment drainage has been identified and planned based on hydrology, geological and topography of the area and it was found that the basins that produce the torrents, mostly located north east of the catchment, the area of these catchment is 11.5 km ^{2}. The maximum out flow for catchment is about 138 m^3/s in the central of catchment area, and is considered the best selected area for the construction of water harvesting technique. Normal distribution has been found to be the best fitted distribution for the representation of the annual rainfall in study area. Conclusion and recommendation drawn from this study is to Construct embankment or dike to prevent the water passing in the north-east direction of the study area.

Keywords: Water, Harvesting, Hydrology, Hydrogeology, Basin

المستخلص - الغرض من هذه الدراسة هو حل مشكلة مياه الأمطار في المنطقة الواقعة شمال الخرطوم بحري وحماية القرى من السيول وذلك باجراء دراسة هيدرولوجية شاملة للأحواض المائية التي تمر عبر تلك المنطقة. الطرق المستخدمة في هذه الدراسة هي جمع البيانات من مصادر مختلفة مثل خرائط الارتفاع الرقمية ، خرائط التنمية الحضرية ، بيانات هطول الأمطار. بالإضافة إلى الدراسات الهيدرولوجية والجيولوجية المائية وأعمال المسح. تم تحليل هذه البيانات باستخدام المعادلات الهيدروليكية ودوال التوزيع الاحتمالي. من النتائج تم تحديد وتخطيط تصريف أحواض الأحواض بناءً على الهيدرولوجيا الجيولوجية والتضاريس للمنطقة ووجد أن الأحواض التي تنتج السيول تقع في الغالب شمال شرق مستجمعات المياه ، وتبلغ مساحة هذه الأحواض 11.5 كم 2 و بلغ الحد الأقصى للتدفق الخارج للتجمع 138 م 3 / ثانية في وسط منطقة مستجمعات المياه ، وتعتبر أفضل منطقة مختارة لبناء تقنية حصاد المياه. ووجد أن التوزيع الطبيعي هو أفضل توزيع ملائم لتمثيل الأمطار السنوية في منطقة الدراسة. الاستنتاج والتوصيات المستمدة من هذه الدراسة هي بناء جسر أو سد لمنع مرور المياه في الاتجاه الشمالي الشرقي لمنطقة الدراسة.

INTRODUCTION

This study is the main part of hydrological studies related to the Khartoum State for rainwater harvesting and flood protection projects. It aims to conduct a detailed hydrological analysis of water basins, rain pools and valleys around the study area and to determine their discharge characteristics and their impact on the center and sides.

Statistical and hydrological calculations were conduct to predict the amounts of floods at the ends of valleys. It also aims to propose fossils to harvest the waters of those valleys surrounding the study area and to make the most of the geographical nature of the area in the proposed solutions to identify natural estuaries, and when lacking, other solutions are used, which may increase their economic cost. Need increases for quality drinking water Due to increasing in population, the two components of ground and surface water are used than available. Rain water Harvesting. Water harvesting is an ancient activity in countries and consider as water resources used for drinking water and agricultural purposes [1]

Water harvesting systems are an important method satisfy water demand. Population growth in the world is one of the challenges to be solved and how to provide sufficient quality water for their needs [2].

LITERATURE REVIEW

Rainwater harvesting depends on collecting, transporting and utilizing rainwater for the purposes of watering, increasing productivity and managing it for the optimal benefit of it [3.4]. Harvesting water leakage, operating cost and labor intensive for irrigation are the main challenges as represented by manually pumping water from the pits to irrigate the field [5]. Favorable conditions for the economic situation in the region consider as a main challenger [6].

In Sudan use of water harvesting start in 1947, in North Kordofan Region as an example El Seimah scheme in Khor, Abu Habil and also in north Darfur region 1949 as an example Golo dam [7]. Old water management method for future water shortage in arid and semi-arid areas in many countries concentrated on water harvesting for agriculture in dry land. Haffir an Teru is the traditional names used for water harvesting technique in Sudan [8]. [9] Study in Seleit project in Sudan aiming to determining the water Harvesting as sustainable social development and to develop plan and management strategies, Deltas are flood area zone, so the minimizing of the volume of water reaching them from flash flood could save infrastructural and agricultural area from the severe damage.

The opportunity was provided by the fertility and expansion of these valleys to increase the urban expansion and the demand for agriculture, with scarcity of rain as a threat to agriculture. Water harvesting techniques can be used to develop the area. Water harvesting systems are important for establishing irrigation projects. Accordingly, the obstacles that will help in drawing up and developing future strategies for planning and managing water scarcity for the sustainable development of food on the family and country axes must be identified. [10,11]. Conducting some studies on rainwater harvesting to benefit from it in bridging the water shortage in dry conditions. The study aimed to assess the possibility of rainwater harvesting in the arid to semi-arid Faria area, in the West Bank, Palestine. Water scarcity is increasing due to the increase in population and it is imperative Optimum management of surface water to fill the shortage.

The suitability of the rain water harvesting depend on the two factors, climate and land and also the shortage of water is very dominant factor specially in semi-arid region[12] Water harvesting systems have been introduced and selected to solve the problem of drought and lack of rain in Zimbabwe, where the contour line method is used for harvesting water [13].

As a result of the quantitative and qualitative threats of water, in addition to under-consumption, pollution and climate changes, all of them play a role in stressing some countries, which leads to a decrease in water resources in the coming years [14]. As a result, attention must be paid to the necessity of using alternative water sources such as rainwater. Rainwater harvesting is considered an important and supportive source for other water sources due to its many benefits and moderate costs [15]. Information on rainwater use for household water supply is available; However, there are seldom studies to collect rainwater to fill shrinkage of water uses for irrigation and agriculture purposes.

The study problem is in villages north of the Khartoum Bahri area, water demand is greater than available resources, because it is far away from the safe water supply (urban water systems), it needs stable water sources for human and animal consumption. This study focuses on this problem to reach a safe and stable water source. The objectives of the study as below

i. To access the safe and stable water source for the villages north of Khartoum Bahri by using rainwater harvesting technology from the seasonal valleys.
ii. To Conducting a comprehensive hydrological study of the water basins passing through the study area.
iii. To Finding suitable engineering solutions for the study area and design them

Methodology

The Methodology study consists of the following ***Data Collection and Information Resources:*** The data collect from different sources as below in Table 1.

Table 1: Data Collection and Information Resources

The data	The resource
Digital Elevation Maps	Department of Surveying
Urban development maps	Department of Surveying
Rainfall data	Meteorological Station

Geographical and geological description of the study area

The surface of the Sudan is generally characterized by monotony in its topography, and by the end of the water discharge in general in the River Nile, Khartoum North, takes this position, as its surface is characterized by an incline and an elevation, and the land tends to rise from the north-west side [16]. Some of the valleys and creeks where the rain waters gather during the fall season are running and then are carried out in the site. Figure 1 shows study site.

Figure 1: Aerial photograph for location study site (Google earth)

land towards the Nile. In most months of the year, Khartoum North has a dry climate, except for July and August, with severe tropical rain falling just over 155 mm (6.1 inches) per year on average, and from December to February, the temperature is relatively low. Figure 1 showing the location of the study area.

Hydrological studies

Floods run on the surface of the earth mostly by the heavy rains and the nature of the pelvic basin, where it collects from the retentions and the upper levels, forming small streams so that the streams become deeper in size and faster in the flow down to the minimum levels. The latter are natural estuaries in the seas, or lakes in depressions. Torrents have two types, depending on continuity of flow. The first is continuous torrents where rivers are the most obvious examples (such as the River Nile with its blue and white branches, whose branches and tributaries are grouped from the Tana Lake in Ethiopia and from Victoria Lake to its outlet in the Mediterranean Sea in the Delta of Egypt). The second type is the intermittent floods which are found in almost all regions of the Sudan. Examples of intermittent floods include Abu Halab valley in Kordofan states, and the Gash river valley, whose water flows due to heavy rainfall in highlands at certain periods of the year.

The intensity, the rush and the amount of flood water vary, depending on several factors, overall are the following

- Terrain, area and slope of drainage basins.
- Type of life activities carried out over the drainage basin.
- The geological nature of the area.

The floods have enormous destructive power in some cases if the ways of dealing with them are not taken into account during the urban infrastructure planning (where they are tamed, discharged, stored or used), as the methodology of any hydrological study of the discharge of flood waters, consisting of several parts are detailed and interdependent and depend on each other, starting from the collection of preliminary data for the area to be studied, such as existing infrastructure and facilities through topographic, climatic and geological studies, and finally to identify the characteristics of rainstorms and rainfall curves and calculate water concentration time and estimate the amounts of flood and then design appropriate installations to carry.

There are several ways of estimating and calculating the rainwater that falls on a basin, depending on the design period and the time of concentration. The design period varies according to the hydraulic establishment. For example, dams and the drainage channels are 100 years, and the urban rainwater drainage networks are usually 5 years. The estimation of the quantities of flood water can be calculated in several ways, depending on factors such as discharge basin characteristics, geological and topographic nature, rainfall and others [17]. Of those methods, there are two common methods used in most hydrological studies for their simplicity and non-need for standardization by laboratory and computer simulation methods the Rational Method and the SCS method used in this study.

Starting with the collection of field data from the various sources of information, based on the intensive surveying of the study area, a model was constructed based on the various inputs received. A number of computer models were used to test the outputs and their compatibility with reality, as compared to modern aerial images. The following is details of each stage.

Data Survey

Data survey is the method used to represent the Earth's surface and its natural phenomena and civil installations and output them in the form of maps. The purpose of the topographic survey is the establishment and mapping of relatively large areas with the statement of the features of natural and industrial and indicate the height and decline of the surface of the Earth using lines equal to heights, known as the lines of leveling and contour lines, and is used in preliminary studies of the planning of engineering projects related to the surface of the earth such as irrigation projects, roads, airports and others.

Survey Work

An area adjustment point has been used for use in all survey works of industrial and natural landmarks such as streets, valleys, Benefit from the results of the cadastral

- Make a geometric map of the earth's surface showing general curves in the area.
- Identification of water basins and their passage and water discharge directions.
- Visualization of solutions for drainage networks and waterways.
- Assist in designing the earth dam for rainwater harvesting.
- Identify existing services and conflict with proposed solutions.

Analysis of Rainfall Data

For the purposes of this study, the large daily rainfall series are of great importance for the calculation of the hydrological calculations of the floods, and because there are no stations to monitor rainfall in the study area, the data for some stations located in large cities around the study area has been used and analyzed.

Rain monitoring station

Water harvesting in arid and semi-arid zones present difficulties which are due less to the limited amount of rainfall than to the inherent degree of variability associated with it. For a water harvesting planner, the most difficult task is therefore to select the appropriate "design" rainfall according to which the ratio of catchment to cultivated area will be determined. So Analyses were conducted for both annual and rainy-season rainfall for total rainfall. Figure 2 shows the annual rainfall series for Khartoum state during the period (1965 -2000) Notes that the average rainfall is 125.49 mm. Figure 3. Illustrate Data of Khartoum climatic station.

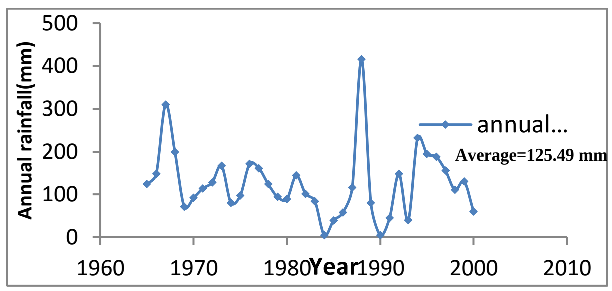

Figure 2: The annual rainfall of the city of Khartoum during the period (1965-2000)

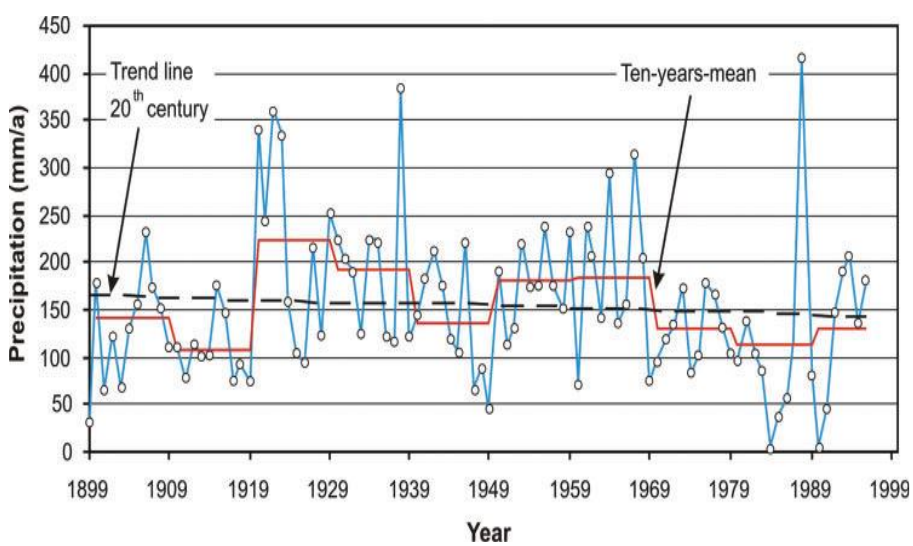

Figure 3: Data of Khartoum climatic station [4]

Calculation Maximum Discharge and Run off

The delay time was calculated using SCS [18]

$$Tlag = L^{0.8}\,\frac{(s+1)0.7}{1900\sqrt{Y}} \quad (1)$$

Where T lag = delay time (hour) L = Basin length (feet), S = maximum retention of the basin and calculated from factor of the curve, Y = basin slope (percentage %). Peak time (T_p) was calculated using [18]

$$T_p = \frac{1.133T_c}{1.7} \quad (2)$$

$$T_{lag} = 0.6\ T \quad (3)$$

where T_p is peak time (hour), T_c is concentration time (minutes). Calculation of maximum discharge (m^3/s) for the basin and for all repetitive periods. By using Equation (4) [18].

$$q_p = \frac{0.208\ A\ Q}{T_p} \quad (4)$$

where q_p is the maximum discharge (m^3/s), A is the area in km^2, Q is surface flow quantity (ml), T_p is peak time (time of maximum discharge) (hour). Because the water unit curve expresses the hydrologic response of the diagram assuming that the rain depth on the diagram is one inch, it is necessary to calculate the depth of the rain (or torrent) in the scheme to deduce the total amount of the torrents at the actual rain value. To calculate Direct Runoff, equation 5 [18] can be used.

$$Q = (P - 0.2\ S)\ 2\ /\ (P + 0.8\ S) \quad (5)$$

where Q is direct torrent (cm), P is rainfall for different frequency intervals, S = maximum soil moisture pressure (cm) Ia is Amount of water before the flow of the stream such as filtration, the residual rainfall on the plant can be estimated from equation number (6)

$$I_a = 0.2 \quad (6)$$

where S can be calculated from [18]

$$S = (1000/\ CN) \quad (7)$$

CN is the curved number (SCS1973).

4.4.5 Analysis of rainfall data

The data were analysis using the following equations, described probability distribution functions $f(x)$ [19] as

For the normal distribution

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}}\,exp\left[\frac{-1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right] \quad (8)$$

Where μ = mean, σ= Standard Deviation.

For log normal

$$f(x) = \frac{\exp\left[\frac{-1}{2}\left(\frac{\ln(x)-\mu}{\sigma}\right)^2\right]}{\sqrt{2\pi x^2\sigma^2}} \quad ....(9)$$

where σ = scale parameter σ>0 μ = shape parameter μ>0

For Gama Distribution

$$f(x) = \frac{1}{\beta^a\Gamma(a)}\,x^{a-1}e^{\frac{x}{\beta}} \quad (10)$$

where β = shape parameter β>0, τ = Gamma function;

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1} exp\left[-\left(\frac{x}{\beta}\right)^{\alpha}\right] \quad (11)$$

where α = shape parameter α>0

For Exponential Distribution

$$f(x) = \frac{1}{\lambda}e^{\frac{1}{\lambda}x} \quad (12)$$

Results and Discussions

Figures from (4 to 6) illustrate the results of rainfall data analysis by using a Hyfran program. Hyfran is software helping the user to choose the most adequate distribution to fit a set of Independent and Identically Distributed data. The data were analysis using the equations 8 to 12 described probability distribution functions $f(x)$. distributions were tested, namely Normal, Log normal and exponential distribution.

Figure 4 represent the analysis of rainfall data by using (Normal distribution). the normal distribution cannot be skewed. It is a symmetric distribution with mean, median and mode being equal. Normal analysis presents an overview of basic concepts of data analysis and some suggestions for additional research.

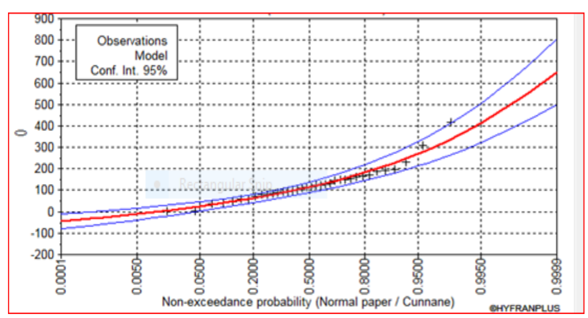

Figure 4. Frequency analysis of rainfall data for Khartoum city by using (Normal distribution)

Figure 5 represent the analysis of rainfall data by using (Log Normal form). In water hydrology, the Lognormal form is used to analyze data as monthly, annual and values of measured daily rainfall and river flow rate volumes. Figure 6 represent the analysis of rainfall data by using (Exponential distribution). In water resources hydrology Exponential type is used to analyze such data as monthly and annually values of daily measurements and discharge volumes for a river cross section. Table 2 presents the values rain depth for the different frequency periods of the study area.

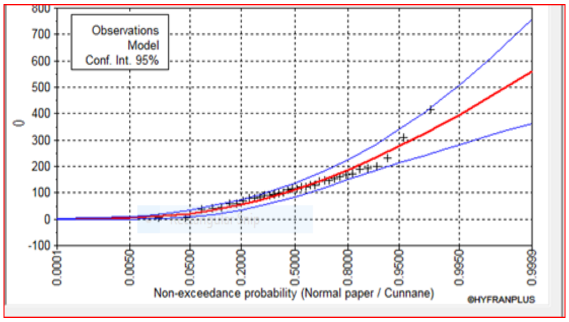

Figure 5: Frequency analysis of rainfall data for Khartoum city by using (Log -Normal distribution).

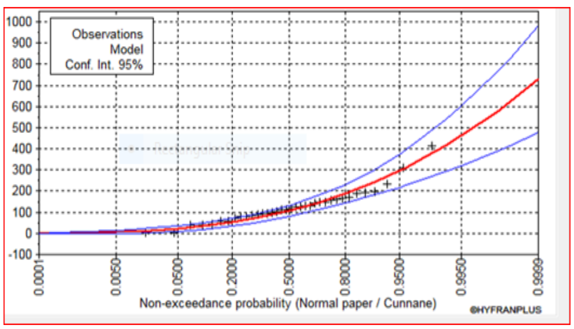

Figure 6: Frequency analysis of rainfall data for Khartoum city by using (Exponential distribution)

In this research, a design value of 75 % of the rainfall depth of 100 years was used. According to the data shown in Figures 3 and 4, the amount of precipitation decreased during this century. This exacerbates the situation and creates a problem in the study area in terms of climatic conditions due to climate changes and makes the situation even worse for the rural areas.

TABLE 2: VALUES RAIN DEPTH FOR THE DIFFERENT FREQUENCY PERIODS OF THE STUDY AREA

Return Period (years)	Normal R.F(mm)	Log - Normal R.F(mm)	Exponential R.F(mm)
5-year	180	185	187
10-year	225	240	235
25-year	280	310	289
50-year	325	366	327
100-year	375	418	362
Design Storm	281.25	13.5	271.5

Valley Network and characteristic of the basin

Using topographic maps, satellites and elevation maps (DEM) and using different modeling programs, the valley network that affects the study area and drainage basins were deriving around the study site, as shown in Figure 7. Basin characteristics of study site were also extracted as shown in Table 3, with lag time varying from 0.17 to 0.25.

Figure 7: The basins affecting the study area

The Perception

The deductive methods were used to calculate the water retention curve for each basin. The Dimensionless Hydrograph (SCS) method was used to calculate the Peak Discharge value for different frequency periods as well as time to peak, which are important values in any study of the design of water installations.

TABLE 3: CHARACTERISTICS OF THE BASIN AFFECTING THE STUDY AREA

Basins	Area(km2)	Length(km)	Slope(%)	CN	Tc (hr)	Lag time(hr)
BS-01	1.240	1.409	4.56	62	0.28	0.17
BS-02	1.838	2.522	4.86	61	0.43	0.26
BS-03	0.492	1.376	3.25	63	0.32	0.19
BS-04	0.635	1.686	3.79	61	0.35	0.21
BS-05	1.494	2.646	4.1	60	0.48	0.29
BS-06	0.375	1.169	4.47	60	0.25	0.15
BS-07	0.937	1.927	4.08	61	0.38	0.23
BS-08	0.410	1.968	3.38	59	0.41	0.25

The method depends on the relationship of a number of variables in the characteristics of the water basin to determine the torrent size of the stream and the time of access to the valley exit area (equations 1 to 7).

Calculation of the CN (curve Number)

From data analysis, satellite imagery, and land use, the curve Number was estimated as shown in Table 3 which range between 59 to 62. This factor depends on the nature of the land cover and the basin surfaces, and takes different values according to type and classification of land uses. Table 4 give examples of runoff values for species of Earth surface nature, the three are land covers, Sandy with a grass and Urban residential areas, runoff coefficient C range from 0.62 to 0.89.

TABLE 4: VALUES OF FLOW FACTOR FOR RESIDENTIAL, MOUNTAINOUS, LAND, AND SANDY AREAS

Runoff coefficient (C)	Type of land cover for basin surfaces
0.990.62 -	Space lands
0.45 – 0. 79	Sandy with a grass
0.78 – 0.89	Urban residential areas

In order to deduce the flow curves of different frequency periods, a hydrological modeling system, HEC-HMS, Figure 8 was used. (HEC-HMS) is a computer package designed to simulate the precipitation- runoff for watershed systems, where all factors are defined as input to programme and using the SCS method. The rainfall distribution considered per day (24 hours), the standard type (SCS Storm Type II). Then the production of the flow curves of the different frequent storms, and the accumulation of the rain value of the influencing basin Table 5 Figure 8.

TABLE 5: CHARACTERISTICS OF THE BASIN AFFECTING THE STUDY AREA. USING HEC-HMS MODEL PEAK DISCHARGE $M^{3/s}$

No	Basin no	Design period	100 year	50 year
1	Basin -01	58.6	100 yr	50 yr
2	Basin -02	70.5	103.1	50.3
3	Basin -03	20.8	124.3	101.1
4	Basin -04	26.0	42.5	37.0
5	Basin -05	52.7	45.8	42.2
6	Basin -06	16.0	90.5	75.7
7	Basin -07	38.4	29	24.4
8	Basin -08	13.4	69.8	53

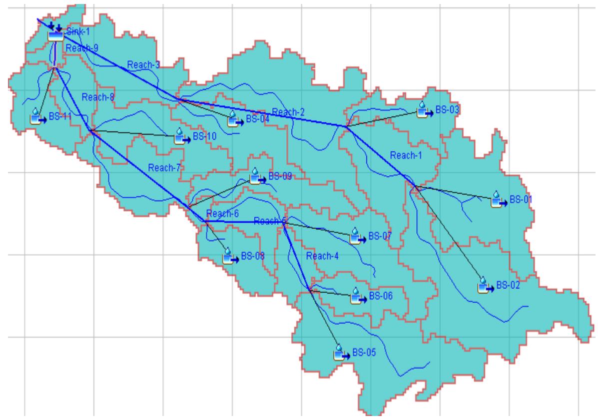

Figure 8: Using the HEC-HMS model in hydraulics analysis of the site of the earthy dam

Results of hydrological analysis

- The basins catchment drainage has been identified and planned based on hydrology geological and topography of the area.
- It was found that the basins that produce the torrents, mostly located north east of the catchment, the area of these catchment is 11.5 km^2.
- The flow of water through this catchment is considered low flow, with the peak of the flood in the event of the design storm (100 years x 0.75), 2.32 hours after the onset of rainfall on the areas and highlands of the southeast of the study area.
- The maximum out flow for catchment at the design period is about138 m^3/s in the central of catchment area, which is considered the best selected area for the construction of water harvesting.
- Rainwater harvesting technique that may be repeated each period maximum period reaches x 0.75).

CONCLUSIONS

Normal distribution has been found to be the best fitted distribution for the representation of the annual rainfall in Sudan. However, log normal distribution is ranked second while exponential distribution is ranked last. Normal distribution adequately described annual rainfall for Khartoum station (that represent study area). According to the hydrological studies in the study area many solutions were suggested that based on location, drainage, Slope of study area and the important of water harvesting for irrigation and water supply.

The recommendations of this study can be summarized as follows: Construction of embankment or dike to prevent the water passing in the north-east direction of the study area, with a lower gate to intake the quantities of water coming from the secondary creek when entering the site. Secondly, it is necessary to do topographic and survey studies and to make accurate contour maps to determine the best width and height in order to storage water. Finally, make good proposal as a plan for water harvesting in the study area by construction of dams.

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