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EVALUATING PEAK RUNOFF HYDROGRAPHS FOR OYUN RIVER CATCHMENT IN KWARA STATE USING GIS AND REMOTE SENSING TECHNIQUES

Olanrewaju, R.M., Adedayo, I.T., and Iroye, K.A.

Department of Geography and Environmental Management, University of Ilorin, Nigeria
rodamoji@gmail.com

ABSTRACT

The power of Geographic Information System and Remote Sensing techniques was used in this work, to determine the required hydrological characteristics of Oyun basin in Kwara State. Both primary and secondary data were used; the primary data are the field coordinates of prominent features in the study area while the secondary data were the administrative maps, satellite imagery, SRTM (Shuttle Radar Topographical Mission) raster data and rainfall data for the study area. The GIS techniques of data analysis used comprised of overlay operation, digital terrain modeling (DTM), spatial query operations and map calculation operations. The rainfall data was fitted using Gumbel distribution to obtain basin discharges for four selected return periods. Snyder's method was used to obtain the unit hydrograph ordinates these ordinates were used in conjunction with the discharges to generate rainfall excesses for the respective return periods while the rainfall excesses were convoluted to obtain the predicted peak runoff (storm) hydrographs for each of the selected return periods. The outcome of this research showed that Oyun river watershed had the following hydrological characteristics; Catchment area is 827 square kilometers, main river length is about 83.57 km, length from Centroid to outlet is 43.24km, average basin slope is 0.01464 %, the peak discharges of the basin for 5years, 25years, 50years and 100years are 129m³/s/cm, 184.4 m³/s/cm, 207.3 m³/s/cm and 230 m³/s/cm, while the corresponding predicted storm hydrographs were 457.12 M³/S ,793.32 M³/S ,941.70 M³/S and 1088.70 M³/S respectively.

Keywords: Catchment, GIS, Remote Sensing, Hydrograph, Peak Runoff

INTRODUCTION

There exists a complex relationship between rainfall and runoff. The complexity of this relationship is as a result of the multidimensional influence of factors such as storm pattern, antecedent soil moisture content, basin characteristics and stochastic changes on runoff. Due to the complexity induced by these

aforementioned factors, many techniques and methods have been developed to estimate runoff from rainfall data. Such methods include empirical, infiltration, rational hydrograph methods. In this work however, the hydrograph method using remotely sensed data in a GIS environment is being employed to establish a relationship between rainfall and runoff. This is by examining those basin

characteristics which influence runoff generation within Oyun River Catchment, producing extreme hydro-meteorological event of flood.

Flood is any high stream flow which inundate natural or artificial banks of river channels. According to United Nations (2011), flooding in recent years have incurred the greatest damage of all natural disasters worldwide and has affected the greatest number of people. Flooding has resulted in much loss of properties and lives, as well as untold hardship and suffering for those who survived it. World Meteorological Organization (2013) report observed that, the decade 2001-2010 was the second wettest since 1901. Globally, according to the report, year 2010 was the wettest year since the start of instrumental records. Most parts of the globe had above normal precipitation in that decade. The WMO (2013) further revealed that within the decade, Eastern Europe was particularly affected between year 2001 and 2005; India in 2005; Africa in 2008; Asia (notably Pakistan, where 2000 people died and 20 million were affected) in 2010, and Australia, also in 2010.

According to Iroye (2010), flood incident is fast becoming a city life experience in most urban centres in Nigeria. The country experienced one of the most devastating floods in her history in year 2012. The flooding which according to Nigerian Meteorological Agency (2013) affected about twenty-seven states resulted in the loss of hundreds of lives, displaced millions of people from their homes and caused extensive damages to

infrastructures. Though flood incident is purely a climatological issue, studies such as Pitlick (1994), Ifabiyi (2004), Iroye (2008), Ajibade *et al* (2010) and Iroye and Sodipo (2013) have observed that basin characteristics, to a great extent exercises a profound influence on its generation.

According to Tilakasiri, *et al.* (2012), flooding is one of the major challenges to sustainable development of the environment. Study such as this which seeks to use GIS and Remote Sensing Techniques to establish a relationship between rainfall and runoff is thus germane for the purpose of environmental management. This is particularly important for a country like Nigeria where most rivers are ungauged. Development of a synthetic hydrograph as being currently done in this study will not only aid in curtailing problems induced by extreme hydro-meteorological events in the study basin, but will also help in developing flood management strategies for similar sized basins.

GIS and Remote Sensing Techniques have proved valuable in analyses of this nature. The techniques which have the ability to integrate data from different sources has gone beyond data management and thematic mapping to conducting sophisticated analysis and simulation for both scientific research and policy analysis. According to Sui and Maggio (1999), GIS has provided hydrologists and hydraulic engineers with the ideal computing platform for data inventory, parameter estimation, mapping and visualizing results for hydrological/

hydraulic modeling; thus greatly facilitating the design, calibration and implementation of various hydrological/hydraulic models.

Study Area

Oyun river catchment is the study area in this investigation (Fig. 1). This catchment is located within Kwara State in the north central geo-political zone of Nigeria. The area is bounded between longitudes $4^{\circ}34'$ and $4^{\circ}55'$ east of Greenwich meridian and between latitudes $8^{\circ}4'$ and $9^{\circ}10'$ north of the equator. The river flows through Offa, Oyun, Ifelodun, Ilorin South and Ilorin East Local Government Areas of Kwara State before joining River Asa in Moro Local Government Area of the state. Oyun Basin has an average slope of 0.0146° and a catchment area of 827km^2 located within the Guinea savannah region of Nigeria.

The six local government areas through which River Oyun passes have humid tropical climate that is characterized by wet and dry seasons. The rainy season in the area spans between the months of April and October when the Tropical Maritime Airmass is prevalent. It is characterized by two peak periods in June and September, with September being the month with the highest probability for floods. Annual rainfall amount in the region ranges between 1,250 and 1,350mm (LNRBD, 2012). Dry season in the catchment is experienced between November and March during the period when temperature is usually high (between 31° and 35°C) except during harmattan which span between December and February when the Tropical Continental Airmass is prevalent (Olanrewaju, 2010).

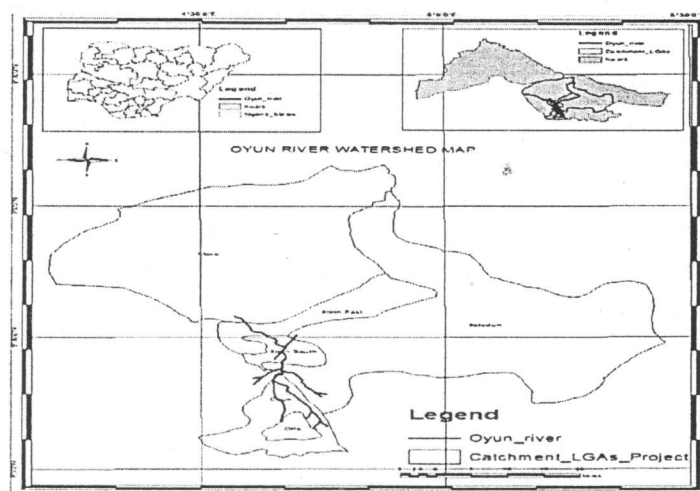


Fig. 1: Map of Oyun River Basin

Source: Ministry of Land and Housing, Kwara State, (2012).

Geologically, Oyun River Catchment is underlain by the Precambrian Basement Complex Rocks comprising mostly of gneiss, granite, schist, undifferentiated meta-sediment rocks and overburden that are composed mainly of clay, sand and silt soils. Average elevation in the catchment is about 300m though mountains as high as 450m can be found in the area. Tributaries of Rivers Oyun include Rivers Agun and Eleyeoka. Anthropogenic activities, having serious implications for deforestation and runoff generation has become endemic within the basin.

Research Methods

Both primary data (GPS coordinates of prominent features) and secondary data (Satellite imagery (March, 2013) obtained from Google Earth, Shuttle Radial

Topographical Mission (SRTM) data version 4 obtained from International Centre for Tropical Agriculture (CIAT), and thirty five year rainfall record for the catchment obtained from Lower Niger River Basin and Rural Development Authority, Ilorin, Kwara State, Nigeria) were used in this investigation.

Both hardware and software computer components which include an A3 Scanner, 100GB free hard disk computer system, Global Mapper 11 software, Suffer 8, Mapwindow GIS software, ArcGIS9.3 GIS software and HP Inkjet printer were used in scanning, downloading, conversion, processing analyzing and visualization of data. Geo-data base design was carried out based on the view of reality, conceptual framework, logical design and physical model as shown on figure 2 below

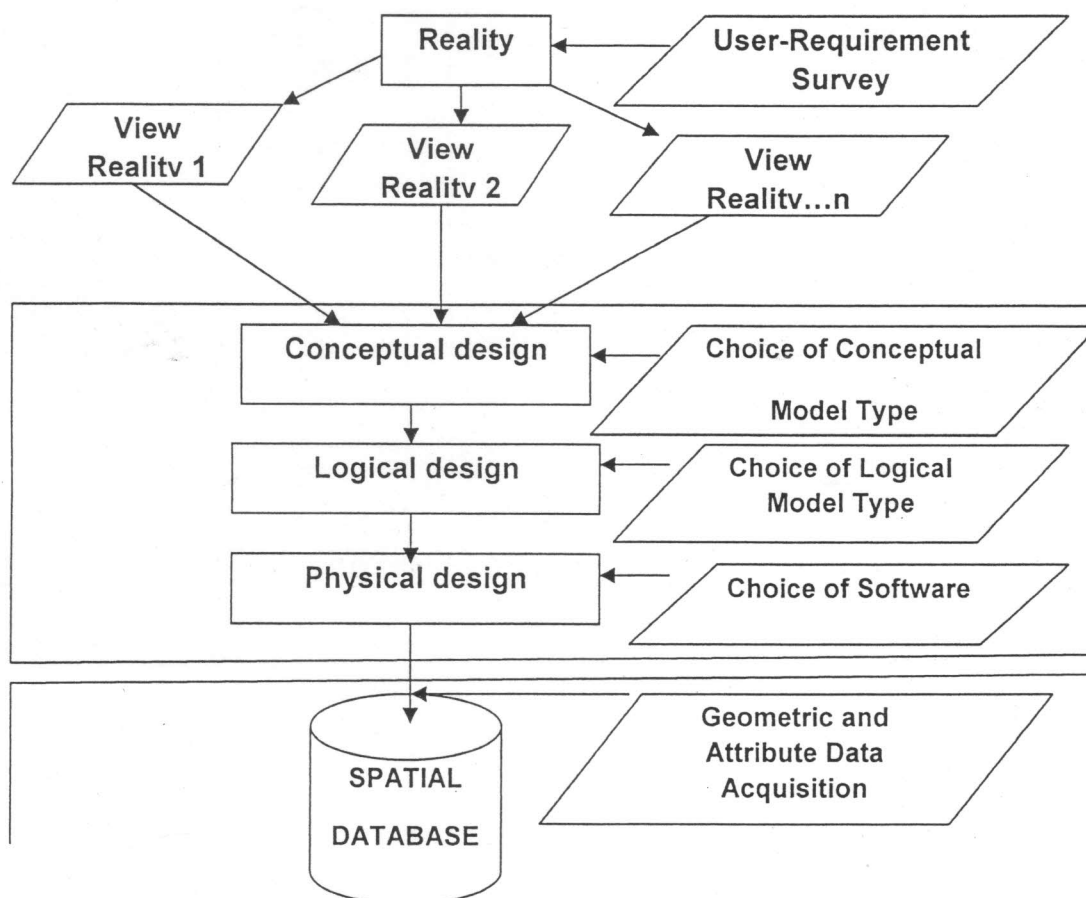


Fig. 2: Design and Construction Phase in GIS

Source: Kufoniyi (2002)

GPS coordinates of river and road crossings as well as other prominent features like Unilorin dam, were collected using differential GPS, these coordinates were then plotted on the overlay of geo-referenced raster image and the processed SRTM elevation data of the entire catchment of Oyun basin. This was done to ensure that features on the image tallies correctly with actual features on ground, this process is called ground truthing. The

river network and the relevant features were then vectorized into shape file. The SRTM elevation data was then processed into Digital Elevation Model (DEM) from which the watershed was delineated using Map window software and was combined with overlay result mentioned above, and analyzed using spatial query and map calculation operations to extract the watershed characteristics (Table 1) required for hydrological calculations

using Snyder (in Ramirez, 2000) method to generate the hydrological parameters (Table 2) for the development of unit hydrograph and the storm hydrographs prediction in accordance with Ramirez (2000) and Arora (2004) which requires fitting the rainfall data by Gumbel distribution to obtain basin discharges for selected return periods. Snyder's method

was then used to obtain the unit hydrograph ordinates, these ordinates were used in conjunction with the discharges to generate rainfall excesses for the respective return periods while the rainfall excesses were convoluted to obtain the predicted peak runoff (storm) hydrographs for each of the selected return periods.

Table 1: Catchment Characteristics used in Generating Unit Hydrograph

Catchment Characteristic	A (km ²)	L _C (km)	L (km)	S (%)
Value	827	43.24	83.57	0.01464

Source: Authors' computation (2014)

Where,

A is the contributing area of the basin

L_C is the main river length from basin Centroid to the river outlet

L is the total length of the main river

S is the average slope of the contributing area of the basin.

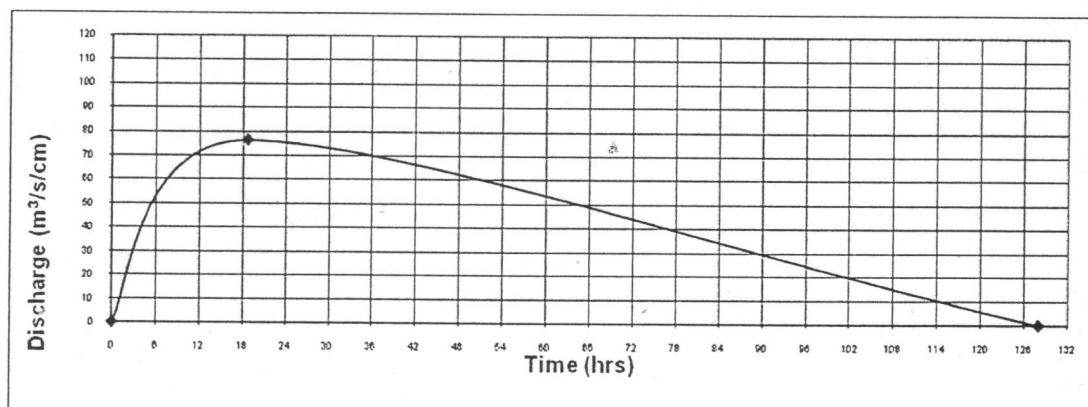


Fig. 3: Depicting a typical unit hydrograph

Source: Salami *et al.* (2009)

Table 2: Hydrological parameters used in Generating Unit Hydrograph

A (km ²)	L (km)	L _c (km)	C _t	C _p	t _L (hr)
827.00	83.57	43.24	1.60	0.62	18.69
t _r (hr)	Q _p (m ³ /s)	q _p (m ³ /s/km ²)	T _b (hr)	W ₅₀ (hr)	W ₇₅ (hr)
3.40	76.29	0.09	128.06	77.40	44.60

Source: Authors' computation (2014)

Data Analysis

Oyun basin has an elongated Z-shape with a catchment area of 827 square kilometers, main river length of 83.57 km and average basin slope of 0.01464°. Figure 4 below shows the result of Watershed delineation on DEM surface while Figure 5 shows the result of River drainage network on DEM

GIS Analysis

Catchment area and DEM creation

The SRTM data was processed in the Map window environment to delineate the watershed of Oyun river (Fig. 4), while ArcGIS was used to generate the Digital Elevation Model (Fig.5) upon which the river network was draped.

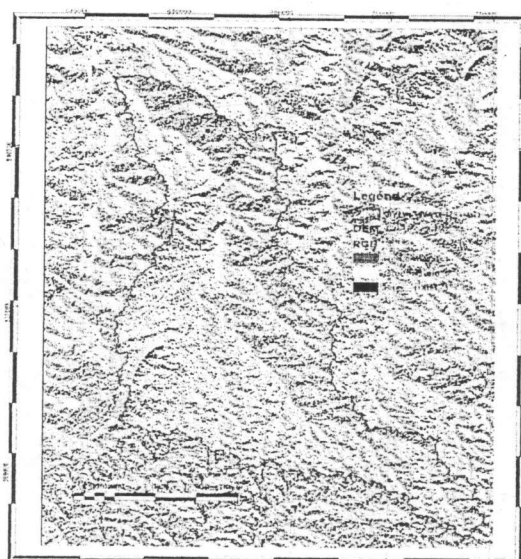


Fig. 4: Watershed delineation on DEM Surface.

Source: Authors, 2014

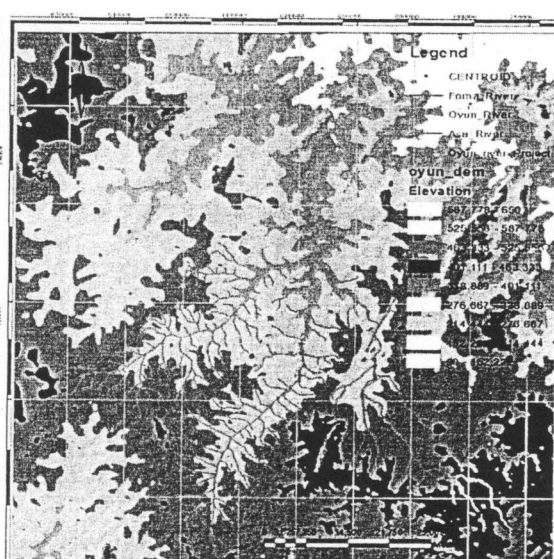


Fig. 5: River drainage network on DEM.

Source: Authors, 2014

Catchment Characteristics (Attribute data) extraction from the database

The Identify Command: This is a GIS analysis tool for attribute data extraction from the database

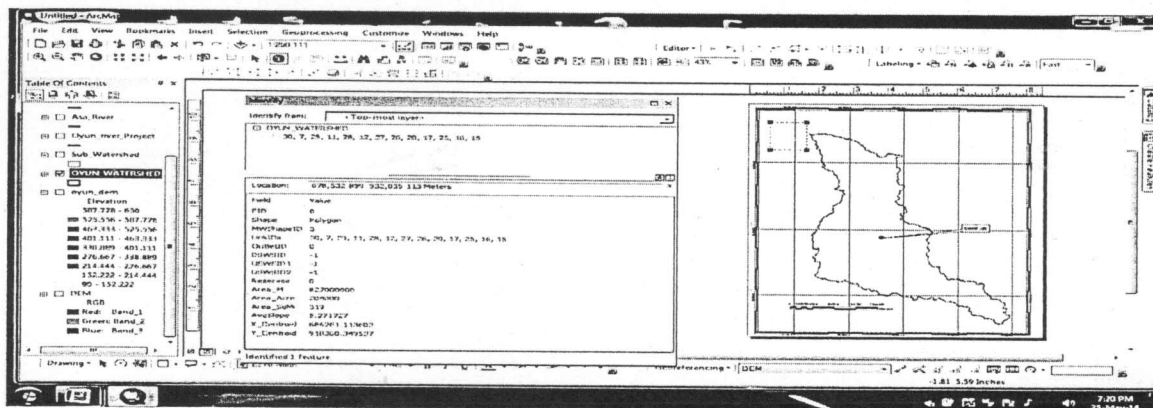


Fig. 6: Identification of the Centroid of the basin

Source: Authors, 2014

The Distance Command (Measurement)

The measure command was employed here to retrieve distance measurements within

the basin i.e. the lengths of tributaries, roads and other linear and non-linear measurements of interest.

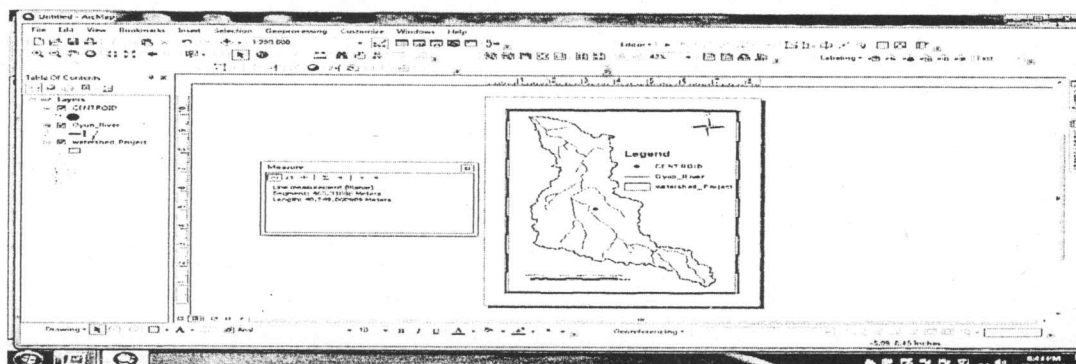


Fig. 7: Measurement command, river source to the Centroid.

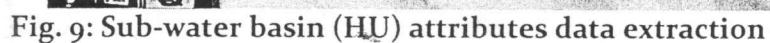
Source: Authors, 2014



Source: Authors, 2014

Attribute data extraction is another very useful analysis that is capable of being carried out using attribute table command in ARCGIS software environment. Under

this analysis the software displays all the attribute data that are inherent in the input data as well as those supplied by the GIS personnel. Figure 4.7 below shows the result of sub-water basin (HU) attributes data extraction from Oyun basin database.



Source: Authors, 2014

Hydrological Analysis (Snyder's Method)

in determining the peak runoff hydrograph for Oyun basin is presented in Tables 3-5 below.

The result of the hydro-metrological analysis

Table 3: Table of time (t) and discharge (q)

T	0.0	6.0	12.0	18.0	24.0	30.0	36.0	42.0	48.0	54.0	60.0	66.0	72.0	78.0	84.0	90.0	96.0	102.0	108.0	114.0	120.0	126.0	132.0
Q	0.0	62.0	71.8	74.0	73.0	71.0	68.0	64.4	60.3	56.0	52.5	47.2	43.0	38.0	33.4	28.2	24.0	19.2	14.8	10.0	5.3	1.6	0.0

Where T= Time in hour

And Q = Discharge in m³/s

Source: Author's computation (2014)

The daily maximum rainfall data for thirty years was fitted to Gumbel distribution and the statistical parameters for the

rainfall excess estimates was evolved and utilized to generate rainfall excesses for the various return periods used.

Table 4: Result of Oyun basin hydrological characteristics used for the determination effective rainfall for the selected return periods

Hydrological parameter	C _t	t _t (hr)	C _p	t _r (hr)	Q _p (m ³ /s)	q _p (m ³ /km ²)	T _b (hr)	W ₅₀ (hr)	W ₁₀₀ (hr)
Value	1.60	18.69	0.62	3.40	76.29	0.09	128.06	77.40	44.60

Source: Authors' computation (2014)

Table 5: Meteorological characteristics used in conjunction with the hydrological characteristics (table 3.1) to determine excess rainfall values for the selected return periods for the basin.

Return period R _t (Years)	R ₅	R ₂₅	R ₅₀	R ₁₀₀
Discharge Q _p M ³ /S/cm	129	184.4	207.3	230.1

Source: Authors' computation (2014)

The established unit hydrographs are then used to develop the storm hydrographs due to actual rainfall event over the

watershed, the storm hydrograph was derived from a multi-period of rainfall excess called hydrograph convolution. It

involves multiplying the unit hydrograph ordinates (U_n) by incremental rainfall excess (P_n), adding and lagging in a sequence to produce a resulting storm hydrograph. The SCS type II curve was used to divide the different rainfall data into successive equal short time events and the SCS Curve Number method was

used to estimate the cumulative rainfall for storm depth of 5yr, 25yr, 50yr and 100yr return periods respectively. The predicted storm hydrograph peak flows were then obtained as 457.12 M^3/S , 793.32 M^3/S , 941.70 M^3/S and 1088.70 M^3/S for the respective return periods and plotted as shown in Figure 10 below:

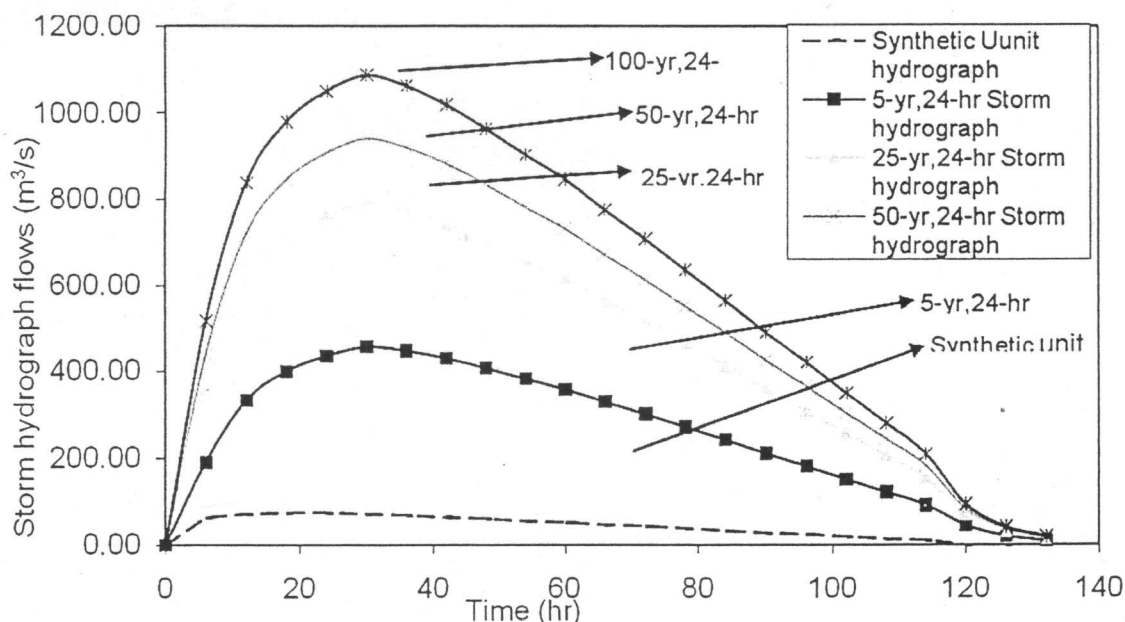


Fig. 10: Unit hydrograph with generated storm hydrographs of different return periods for Oyun Basin (Snyder method)

Source: Authors, 2014

CONCLUSION AND RECOMMENDATIONS

This study revealed that Oyun River catchment area is about 827.0 km with an elongated length of 66.77km and width of 22.17 km. The length of the main stream is 83.57 km, while the length of the river channel from the outlet to a point nearest

to the centroid of the basin was estimated to be 43.24 km. The basin has an average slope of 0.01464° . The estimated discharge for the selected return periods of 5years, 25years, 50years and 100years were; 129 $m^3/s/cm$, 184.4 $m^3/s/cm$, 207.3 $m^3/s/cm$ and 230 $m^3/s/cm$ respectively while the corresponding predicted storm hydrographs were 457.12 M^3/S , 793.32

M³/S, 941.70 M³/S and 1088.70 M³/S respectively. The implication of these values is that the predicted storm hydrographs for each of the return periods are the maximum probable storms that can be expected within the catchment area for each of the return periods based on the meteorological and catchment characteristics of the basin.

Based on the observations from this study, the following recommendations are thus put forward towards effective management of drainage basins.

- i. the replication of this study in similar ungauged rivers. This will assist in prediction of flood occurrence in such basins,
- ii. information generated from such studies nationwide should be harnessed into a geo-database for reference purpose, and
- iii. authorities concerned in education sector should take time to formulate a well-structured curriculum on hydrological education. Such efforts will assist every stakeholder in hydrology to collaborate effectively for better result.

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