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Predicting Flooding Events in Response to Rainfall in Anansa Channel II Drain in Calabar, Cross River State, Nigeria

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ABSTRACT

Detailed study on predicting flooding events in response to rainfall in Anansa channel II drain in Calabar, Cross Rivere State, Nigeria was carried out. The rainfall data for a period of 21 years from 1995-2015 were collected from the meteorological department of Margaret Ekpo International Airport, Calabar. The rainfall data were analyzed for flood prediction in response to rainfall in Anansa channel II drain in Calabar, Cross Rivere State, Nigeria. The peak rainfall was 861.3mm and the mean annual rainfall was 532.6mm. This implies that, the probability of rare flooding event to occur yearly or greater than the given magnitude is 1%. The probability of extreme rainfall with a return period of 100years was calculated. The design peak runoff expected from the probability of extreme rainfall with a return period of 100years was 43.5mm/hr. The design peak runoff discharge was 21m^3/s and velocity flow of 0.2m/s. The study therefore recommend that, government should maintain dam crest and reservoirs, sensitize the public on indiscriminate dumping of refuse in drainage channels and the danger of erecting building structures on drains and provision of adequate drainage system in Calabar.

Keywords: Flood, Event, occurrence, recurrence and Probability

INTRODUCTION

Floods are principally extreme events in hydrology, basically known as inundation of banks in a period of high tides during which water over flows its natural or artificial banks into normally dry land. Floods are universally experienced ecological disasters which normally occur when heavy rains coincided with astronomical high tides and the tidal water overflows into normally dry land. In southern New York and Michigan, floods occur as a result of intense rainfall, melting of accumulated snow and intense summer thunderstorm (Hardey, 1985). Cities in developing countries are particularly vulnerable to climate change impacts, especially changes in rainfall because of the exposure to extreme whether events.

In Nigeria, floods occur as a result of persistent torrential rainfall. The duration of this event may range from a few hours to some days. The severity of the effect varies according to rainfall intensity and drainage system put in place. Floods are primarily due to excess surface runoff and drainage basin soil that is pervious, when infiltration capacity is exceeded (Lensley & Frazeni, 1979). Excessive rainfall leads to flooding especially in areas with poor natural drainage systems, areas where water inundates the capacity of the soil to contain water. Areas where poor land use practices prevent drainages from channeling excess water away. According to Henry (2006), flood hazard is measured by possibility of occurrence of their damaging consequences. This is regarded as flood risk or impact on society, loss of lives and material damage to society.

Flooding is life threatening to man and property. It has great consequences on engineering scheme, agriculture and economic implication. According to Albert (2001), disastrous record of breaking floods occur on some streams, rivers and sea world wide especially in the United State of America, United

Kingdom, India, Cote dIvore, Ghana and Nigeria. The general believe is that floods are increasing in magnitude and frequency annually. The regional impact of climate change resulting in excessive rainfall has brought about sea level rise among the Nigeria coastline. This may threaten life and property and putting it at the risk of flooding on yearly basis. Therefore, there is need to assess the gravity of this ecological disaster of flood events in response to rainfall in Anansa channel II drainage in Calabar, Nigeria.

Studies have been carried out on flooding prediction by (Gumbels,1945; Lensley & Frazini, 1979; Quinn & Garg, 1997). Though, little have been done on predicting flood events in response to rainfall in Nigeria. The aim of the study is predicting flood events in response to rainfall in Anansa channel II drainage in Calabar, Nigeria.

Study Location

The study was carried out at Wapi Junction by Murtala Mohammed Highway, within the metropolitan city of Calabar. The underground channel II drain takes its source and run through Unicem road down to the Calabar River. Calabar is a coastal region in south eastern Nigeria, located within the tropical rain forest belt. Calabar lies between Longitude $7^0$50' and $8^0$29' East, and Latitude $4^0$27' and $5^0$32' North. The city is bounded to the North and South by Odukpani Local Government Area and to the East by Akamkpa Local Government Area (fig. 1). The total area covered is about 604km2. Calabar climate consist of wet and dry season with a relative humidity of 80-100 percent. Calabar features a tropical monsoon climate with a lengthy wet season spanning eight months and short dry season of four months of the year (Oyegun et al., 2016; Abali & Abua, 2016; Abua & Digha, 2015; Abua et al., 2013). Calabar records a relatively constant average temperature ranging between 21-34^0C. The average annual rainfall is between 2400-3800mm. Calabar is an interfluvial city that is drained by two major rivers. These rivers are the Cross River and Great Kwa River (Akpan *et al.*, 2011). The hydrological pattern influences the conventional rainfall commonly experienced in Calabar. Calabar is situated on low lying gentle and undulating terrain that forms the coastal plains of South Eastern Nigeria. The elevation ranges between 120-140meters above sea level (Abua, 2017).

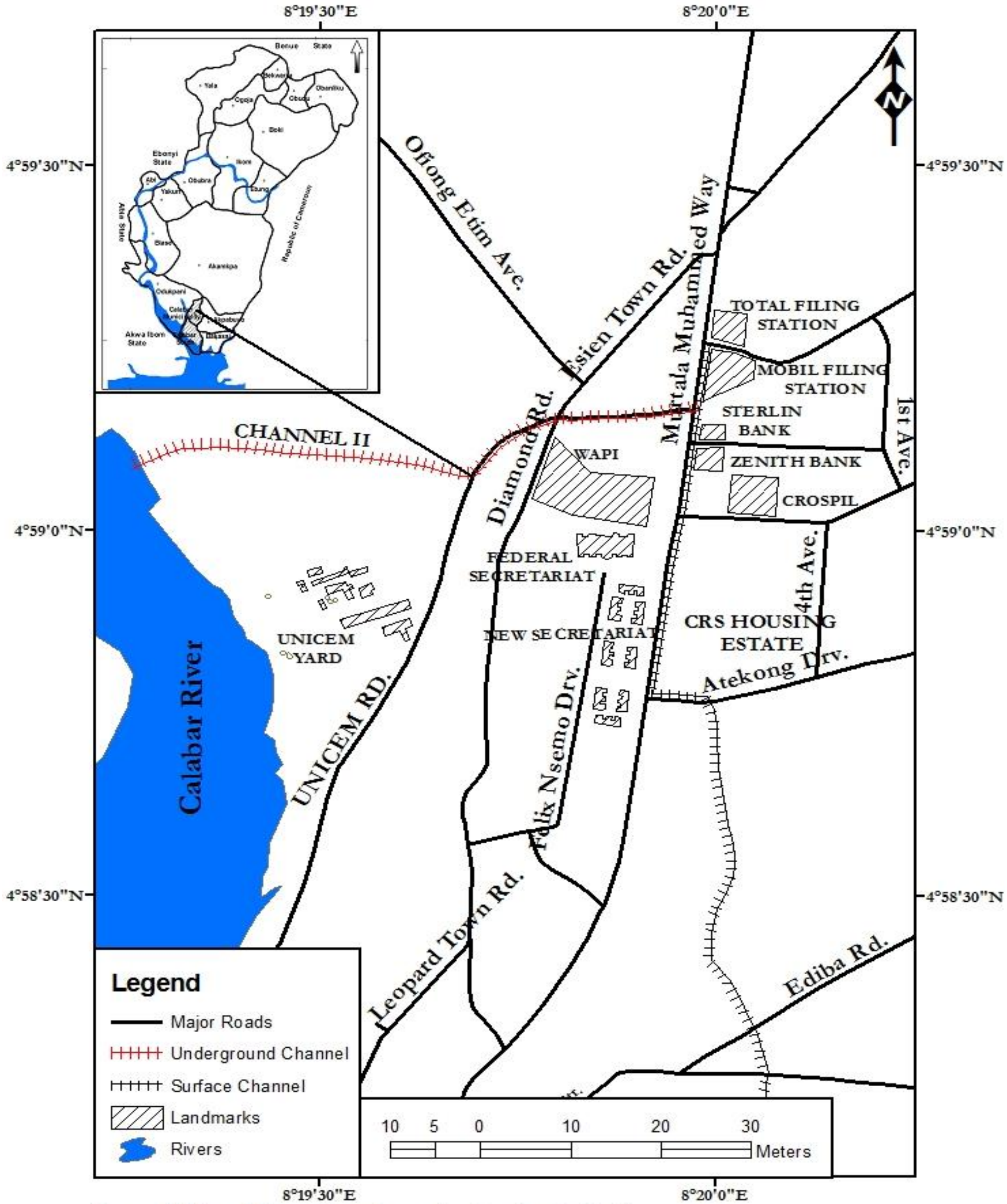

Figure 1: Map of Cross River State showing the Study Site

Source: GIS/Cartography Unit, Dept. of Geography & Environmental Science, University of Calabar, Calabar.

MATERIALS AND METHOD

Techniques of Data Analysis

The daily rainfall data were collected from the period of 21 years duration from 1995 to 2015. The peak daily values on monthly bases that are likely to cause flooding were extracted and analyzed. The maximum rainfall intensities were extracted to predict the recurrence interval of the peak rainfall and the probability of such flooding events occurring in T-years. Using Lensley & Frazini, (1979) and Gumbels,(1945).

$$\mathrm{P} = \frac{1}{tp}$$

$$\mathrm{TP} = \frac{n+1}{M}$$

Where P=probability of occurrence
tp=recurrence interval (return period)
n=number of years occurrence
m=ranking

The Gumbels formula was used to determine the probability that the event of a certain floods magnitude would or would not occur for series of years. The probability of extreme event of floods was also estimated using Fisher and Tippet method.

$$\mathrm{P} = 1 - e^{-e-b}$$

Where P= probability that an event will occur or greater than a given number
b=Reduce variety
e=Base of Naperian logarithms (2.7183)

The hydrological frequency for extreme rainfall (PP_{100}) was used and described as

$$PP_{100} = \overline{x} + \alpha K$$

Where PP_{100} = Rainfall with return period of 100 years
$\overline{x}$= mean of rainfall values
α = standard deviation
K = frequency factor
X = volume of runoff in mm
$\overline{x} = \Sigma \times / n$

$$\alpha = \left| \frac{\Sigma(x-\overline{x})}{n-1} \right| 1/2$$

The rational formula was used to determine the runoff volume and discharge coefficient which is given as follows.

Q=0.0028 CIA

Where Q= Design peak runoff (discharge) in m^3/s
V=1/n R2/3 S1/2
Q = AV

Where Q= Discharge in (m^3/s)
V=Velocity of flow in (m^3/s)
A= Cross sectional area in m^2
R=Hydraulic radius
S= Channel slope
n=Manning number

The rectangular channel design
A=by
P=b+2y
R=A/P=by/b+2y
Where P= Witted perimeter in (m)
b=Channel width in (m)
y=Channel depth in (m)

Table 1: Rainfall Amount, Intensity and Frequencies from 1995-2015 In Calabar

Year	Ppt Amt (mm) x	Intensity Descending order (x)	Ranking (m)	Frequency recurrence interval $F=\frac{n+1}{M}$	$(x-\bar{x})$	$(x-\bar{x})^2$	Cumulative Frequency (exceeds probability %)
1995	691.9	861.3	1	22	328.7	108,043.70	22
1996	474.3	720.6	2	11	188	35,344.00	33
1997	528.4	714.4	3	7.3	181.8	33,051.20	40
1998	485.9	691.9	4	5.5	159.3	25,376.50	45.8
1999	457.6	678.7	5	4.4	146.1	21,345.20	50.2
2000	424.4	648.6	6	3.7	116	13,456.00	53.9
2001	486.8	552	7	3.1	19.4	376.40	57
2002	420.2	528.4	8	2.8	-4.2	17.60	59.8
2003	407.7	511.7	9	2.4	-20.9	436.80	62.2
2004	390.8	499.9	10	2.2	-32.7	1,069.90	64.4
2005	720.6	486.8	11	2	-45.8	2,097.60	66.4
2006	428.5	485.9	12	1.8	-46.8	2,180.90	68.2
2007	511.7	474.3	13	1.7	-58.3	3,398.90	69.9
2008	552	457.6	14	1.6	-75	5,625.00	71.5
2009	366.1	435.2	15	1.5	-97.4	9,486.80	73
2010	435.2	428.5	16	1.4	104.1	10,836.80	74.4
2011	648.6	424.4	17	1.3	108.2	11,707.20	75.7
2012	861.3	420.2	18	1.2	112.4	12,633.80	76.9
2013	499.9	407.7	19	1.2	124.9	15,600.00	78.1
2014	714.4	390.8	20	1.1	141.8	20,107.40	79.2
2015	678.7	366.1	21	1	166.5	27,722.50	80.2
		Σx=11185mm	n=21	$\bar{x}$=532.6mm	Σ=1516.1	Σ=359,914.20	

Table 1 is the representation of the result of rainfall intensity, amount and frequency from 1995 to 2015. The highest peak rainfalls were in 1995, 2005, 2011, 2012, 2014 and 2015 with an annual mean rainfall of 691.9, 720.6, 648.6, 861.3, 714.4, and 678.7mm respectively. The frequency recurrence interval of the highest peak rainfall was 22 and exceeds probability of 22%. The total intensity descending order was 11185mm and a mean value of 532.6mm.

The Probability of Extreme Events

The probability of extreme event occurs very rare and always very severe. This is given in the form:

$$P = 1 - e^{-e-b}$$

Where P= probability that an event will occur or greater than a given number

b=Reduce variate =

e=Base of Naperian logarithms (2.7183)

b = 1/0.7797 $[(x - \overline{x})$+ 0.45 Sd

$\alpha = \left| \frac{\Sigma(x-\overline{x})}{n-1} \right| 1/2$

Rare event= 861.3

Number of years = 21years

Mean value $\overline{x}$=532.6

$(x - \overline{x})$ =1516.1

Summation of $\Sigma(x - \overline{x})^2$ = 359,914.2

$\left| \frac{\Sigma(359{,}914.2)}{21-1} \right| 1/2$

[17995.7]1/2

α= 134.1

b = 1/0.7797 $[(x - \overline{x})]$+ 0.45 Sd

b= 1/0.7797×1516.1+0.45×134.1

b=15.1

P= $P = 1 - e^{-e-b}$

$$P = 1 - 2.72^{-2.72-15.1}$$

P=0.01 ×100= 1%

This implies that, the probability of rare flooding event to occur yearly or greater than the given magnitude is 1%.

The probability that an event will occur is J= $1-(1-p)^n$ for series of years (Quinn & Garg, 1997). The probability of having at least one 10 year event in the next 5 years is given by,

J= $1-(1-p)^n$

J= $1-(1-10)^5$ = J= $1-(1-0.1)^5$ = 0.41×100=41%

100%-41%=59%

This implies that, there is 41% probability of recurrence and 59% of nonoccurrence event of severe flood disaster in every five years from a 10 years flood event.

J= $1-(1-p)^n$

J= $1-(1-50)^{50}$ = J= $1-(1-0.02)^{50}$ = 0.64%

This implies that, there is 64% probability of recurrence and 36% of nonoccurrence event of severe flood disaster in every fifty years from a 50 years flood event.

$J= 1-(1-p)^{n}$
$J= 1-(1-100)^{50} = J= 1-(1-0.01)^{50} = 0.39\times100=39\%$
This implies that, there is 39% probability of recurrence and 61% of nonoccurrence event of severe flood disaster in every fifty years from a 100 years flood event.

Hydrological Frequency For Extreme Rainfall

The hydrological frequency for extreme rainfall is given as thus:

$$PP_{100} = \overline{x} + \alpha$$

Where PP_{100} = Rainfall with return period of 100 years

$\overline{x}$= mean of rainfall values = 532.6mm

α = standard deviation = 134.15
K = frequency factor = 3.811
PP_{100}= 532.6+134.13×3.811
PP_{100}= 1,043.8mm

Design of Drainage Channel

This is given in the form as:
Q=0.0028CIA
Where Q=Design peak runoff (discharge) in (m^3/s)
C=Runoff Coefficient
I= Rainfall intensity in (mm/hr)
A= Catchment area (water shed area in hectares

Design Concept of the Channel

The parameters of the design channel were estimated using the manning equation.
$Q=1/n\ AR^{2/3}S^{1/2}$
$V=1/n\ R^{2/3}\ S^{1/2}$
Q=AV
Where
Q= Discharge in (m^3/s)
V= Velocity of flow in (m/s)
A=Cross sectional area in (m^2)
R=Hydraulic radius
S=Channel slope
N=manning number

Rectangular Channel Design

The rectangular channel design is in the form thus:
A=by
P=b+2y
R=A/P=by/b+2y
Where P= witted parameter in (m)
b=channel width (m)
y=channel depth in (m)

Channel Design Parameters and Calculation
Excavation:
Channel width=2300mm
Channel depth=1800mm
Length of channel=750000mm
Area of excavation = width × depth
=2300mm×1800mm
$=3795000mm^2$

Volume of excavation= L×W×D
=2300×1650×750000
$=2846250000mm^3$
=2846250000/1000
$=2,846.25m^3$

Concrete Drain
Channel width=2000mm
Channel=1500mm
Length of channel=750000mm
Area of concrete=width × depth
=3795000-(2000×1500)
=3795000-3000000mm
$=795000mm=795000mm^2$
Volume of Concrete = 795000×750000=596250000mm/1000
$=596.25m^3$

Design Peak Runoff Expected from the PP_{100}

Q=0.0028CIA
Where Q=Design peak runoff (discharge) in (m^3/s)
C=Runoff Coefficient
I= Rainfall intensity in (mm/hr)
A= Catchment area (water shed area) in hectares
I=pp_{100}/T = 1043.8mm/24hr = 43.5mm/hr

Table 2: Standard runoff coefficient

TYPE OF SOIL	FACTOR OF COEFFICIENT
Rocky soil	1.0
Clay soil	0.9
Loamy soil	0.7
Sandy soil	0.5

Source: (Lendley & Frazini 1979).

Standard runoff coefficient C= 0.5

Cross sectional area A= $750×1.65=1237.5m^2$

I = 43.5mm/hr

Discharge Q= 0.0028CIA

$$\frac{0.0028\times0.5\times43.5\times1237.5\times1000}{60\times60}$$

Discharge Q= $21m^3/s$

Velocity of flow $V=Q/A = \frac{210m}{1237.5}$

$= 0.2m/s$

RESULTS

The rainfall data covering a period of 100 years and the peak rainfall value that is likely to cause rare flooding was analyzed. The peak rainfall was 861.3 and the mean annual rainfall was 532.6.This implies that, the probability of rare flooding event to occur yearly or greater than the given magnitude is 1%. The probability principle that an event will occur is $J= 1-(1-p)^n$ for series of years implies that, there is 41% probability of recurrence and 59% of nonoccurrence event of severe flood disaster in every five years from a 10 years flood event.

There is 64% probability of recurrence and 36% of nonoccurrence event of severe flood disaster in every fifty years from a 50years flood event. This suggests that, there is 39% probability of recurrence and 61% of nonoccurrence event of severe flood disaster in every fifty years from a 100 years flood event.

The probability of extreme rainfall with a return period of 100years was calculated. The mean rainfall was 532.6mm, standard deviation of 134.15, frequency factor 3.811. This implies that the volume of extreme rainfall with a return period of 100 years is equal to 1,043.8mm (43.5mm/hr). The channel design was $3795000m^2$. The volume of excavation was $2846.25m^3$. The concrete drain was $795000mm^2$ and volume of the concrete was $596.25m^3$. The design peak runoff expected from the probability of extreme rainfall with a return period of 100years was 43.5mm/hr. The design peak runoff discharge was $21m^3/s$ and velocity flow of 0.2m/s. The study therefore recommend that, government should maintain dam crest and reservoirs, sensitize the public on indiscriminate dumping of refuse in drainage channels and the danger erecting building structures on drains and provision of adequate drainage system in Calabar.

CONCLUSION

The rainfall data for a period of 21 years from 1995-2015 were collected from the meteorological department of Margaret Ekpo International Airport, Calabar. The rainfall data were analyzed for flood prediction in response to rainfall in Anansa channel II drain in calabar, Cross Rivere State, Nigeria. The peak rainfall was 861.3 and the mean annual rainfall was 532.6. This implies that, the probability of rare flooding event to occur yearly or greater than the given magnitude is 1%. The probability of extreme rainfall with a return period of 100years was calculated. The design peak runoff expected from the probability of extreme rainfall with a return period of 100years was 43.5mm/hr.

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