Assessment of Rainfall-Induced Flooding using the Soil Conservation Service Curve Number Method and Geographic Information System in Mararaba, Nasarawa State, Nigeria

J. E Nicholas, Nigerian Meteorological Agency, Abuja, Nigeria
J O Folorunsho, PhD, Federal University Lokoja, Nigeria
J D Jeb, National Centre for Remote Sensing, Jos, Nigeria
Assessment of Rainfall-Induced Flooding using the Soil Conservation Service Curve Number Method and Geographic Information System in Mararaba, Nasarawa State, Nigeria

Nicholas J. E. 1, Folorunsho J.O2 (Phd) and Jeb D. N.3(Phd)
1Nigerian Meteorological Agency Abuja, 2 Department of Geography, Federal University Lokoja, Kogi State and 3 National Centre for Remote Sensing, Jos
Email: nicklyjake@yahoo.com

Abstract
This study is aimed at generating a flood hazard map for Mararaba sub-Urban using the Soil Conservation Service Curve number (SCS-CN) method and Geographic information System (GIS). The SCS-CN Model was used to determine the rainfall-runoff relationship of the study area in ILWIS environment. Daily rainfall data, Digital Elevation Model (DEM) and soil maps were also used as input for the runoff modeling while the blind weight of several factor maps was used to create flood hazard map for the study area. The results of the study showed an estimated total runoff of about 831.24mm from Mararaba urban watersheds for the rainy season (April to October, 2012) representing about 52 percent of the total rainfall that was converted into surface runoff. Similarly, monthly runoff contribution ranges between, 3% to 21% while the peak runoff estimates were in the Month of July (174.21mm). Flood hazard analysis showed that high flood hazard (21.6%) occurs mostly within the built-up areas; moderate flooding (58%) in agricultural land area while very high flood hazard (9.2%) is concentrated mostly in the gullies and streams within Mararaba. The study demonstrated the potentials of SCS-CN Model and GIS in flood hazard mapping with greater call on the local and state government, urban planning and environment control department to make concerted efforts towards mitigating flood hazard in Mararaba sub-urban area by constructing drainage channels along the streets and expanding the existing drainage structure to increase their capacity for containing high stream flow especially in areas at high risk.

Keywords: Flooding, SCS-CN, Rainfall Runoff, Land Use Land Cover and GIS.

Introduction
Urban flooding poses a serious challenge to development and the lives of people, particularly the residents of rapidly expanding towns and cities in developing countries (Jha et al, 2012). Urban growth, generally, causes hydraulic hazard, due to the sealing of natural surfaces, thus strongly increasing surface water runoff which often times result to flooding (Bates et al, 2008, Cristina et al. 2017). Furthermore, climatic change exacerbates these aspects because of the increase in the number and frequency of extreme rainfall events (‘pluvial flooding’) which overwhelms the efficiency of drainage systems and soil infiltration capacity (Merz et al. 2007, Houston et al. 2011). Pluvial flooding and it attendant problem in some areas of Mararaba sub-urban area over time has become a serious issue and as such there is need to control it. A detailed understanding of the flood hazard relevant to different localities is crucial for implementing appropriate flood risk reduction measures such as development planning, forecasting and early warning systems (Jha et al, 2012). However, according to Komolafe et al. (2015) there is a crucial gap in flood risk reduction in Nigeria because of the absence of the use of state of the art flood models integrating all hydrological processes for accurate prediction and mapping of flooding and its associated risks. More so, the lack of or scarcity of reliable recorded hydro - meteorological data is another serious problem, which planners and researchers face for the analysis of the hydrology of urban watersheds.

This study employed the use of new tools, like remote sensing and Geographic Information System (GIS) and Soil Conservation Curve Number (SCS-CN) method, to generate supporting land based data for flood control. Remote sensing is a useful tool to rapidly acquire land surface information over large scale area and derive data such as DEM and LULC can be used as input for hydrologic model. On the other hand, GIS provides a platform for simulation of hydrologic model (Gambolati, 2002). The runoff curve number (also called a curve number or simply CN) is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. The curve number was developed by USDA Natural Resources Conservation Service which was formally called the Soil Conservation service. It is widely used and is efficient method for determining the approximate amount of direct runoff from rainfall event in a particular area. The runoff curve number is based on the area’s hydrological soil group, land use, treatment and hydrologic condition (SCS, 1972). SCS-CN is
useful in providing the runoff of a given region with the use of precipitation value. Flood hazard mapping is a vital component for appropriate land use. It creates easily read, rapidly accessible charts and map which facilitates the identification of risk areas and prioritizes their mitigation (Bapalu and Sinha, 2005). The aim of this study is to identify and map out areas prone to flood hazard in Mararaba sub-urban area using the SCS rainfall-runoff method and GIS technique.

Study Area
The study area (figure 1 and 2) is located between Latitude 9°00'30"N - 9°03'00"N and Longitude 7°35'00"E - 7°37'00"E in Karu Local Government Area (LGA) that has a common boundary with the Federal Capital Territory (FCT) Abuja to the West; Kokoma LGA and Keffi L.G.A.s to the east, Kaduna state to the north and it is bounded by Nasarawa L.G.A. to the south (Binbol, 2007).

Figure 1: Study Area
Tropical humid climate characterized by two distinct seasons is experienced in the Karu local government area where the study area is located. The wet (rainy) season last from the ending of March and ends in October while the dry season is experienced between November and February; monthly total can vary widely, and so the annual total annual rainfalls range between 1100mm to about 2000mm with about 90 percent of the rainfalls between May and September (Yari et al., 2001). Temperature is generally high in the area during the day between the month of March and April partly because of its location in the tropical sub-humid climatic belt. There is a marked seasonal variation in temperature in the area with gradual increase in temperature from January to March. A single maximum is achieved in March when maximum temperatures can reach 39°C. Minimum temperatures on the other hand can drop to as low as 17°C in December and January (Binbol, 2007)

Figure 2: Spot 5 Image of the Study Area

Materials and Method
The input data for the modelling include the land use Land Cover map, Digital elevation model generated from shuttle Radar Topographical Mission (SRTM), a digital Map of dominant soil of Nigeria (Sonneveld, 1996), 2012 Rainfall data obtained from Nigerian Meteorological agency, the Soil conservation Service Curve Number model table and 2005 Spot 5 Satellite imagery of the study area with 5meter resolution was obtained from National Centre for Remote Sensing Jos. The methodology adopted is presented in the form of a flow chart (Fig. 3) All the data collected from different sources was analyzed. Analysis of Rainfall induced flooding was achieved through computation of Rainfall runoff and the eventual integration of LULC map, Slope Map, Soil Map to generate the output as a flood hazard map.
Data Preparation and Processing

The Spot 5 satellite image, Soil Map and administrative map of the study area were sub-stetted in ERDAS 9.2 resampled to a common georeferenced coordinate system for GIS integration. The image and maps were then imported in ArcGIS for features extraction and thematic map creation. The vector data for the LULC and soil maps were exported to ILWIS data format and subsequently rasterized for the rainfall-runoff and flood hazard analyses.

Land Use / Land Cover Classification (LULC)

Land use and Land cover (LULC) classes were derived from the SPOT 5 satellite image by manual digitization in ARC Map into eight classes namely: bare land, earth dam, farmland, high density area, low density, medium density area, stream, and wet land. Values were then assigned for different class polygons, which help in the calculation of curve numbers. The LULC map was exported from ArcGIS to ILWIS as a shape file. These classes were then reclassified by assigning weight to each of them to produce the LULC Map of the study area. Finally, Curve number (CN) was assigned to each class of the LULC of the study area.

Creation of Slope

A slope map (in degrees) was generated from the SRTM DEM in ILWIS 3.4 GIS software and was subsequently reclassified into four topographic classes as follows: flat, very gentle, undulating and upland. The reclassified slope map indicates the degree of the susceptibility of the area to collect water pools during any rainfall event.

Generation of Hydrological Soil Map

A Hydrological Soil Group which is required for determining a rainfall-runoff relationship was derived by creating an attribute map for the soil map and using the Slice Operation in ILWIS, the output HSG map with three hydrological soil groups was created as follows: (A) Clay loam, (B) Coarse Loam, (C) Fine loam.

Soil Conservation Service Method

The SCS-method is often applied in sub-urban and rural areas (Dingman, 2002). For this reason, the SCS method has been applied to simulate the rainfall-runoff processes in the Mararaba Sub-urban catchments. The SCS curve number method (SCS, 1972), also known as the Hydrologic Soil Cover Complex Method was developed by the Soil Conservation Service (SCS) of the U.S. Department of Agriculture for use in rural areas. It is a versatile and widely used procedure for runoff estimation. The model computes direct runoff through an empirical equation that requires rainfall (antecedent soil moisture condition, land cover and the curve number (CN), which represents the runoff potential of the land cover soil complex (SCS, 1972). The CN is a dimensionless parameter and its value ranges from 1 (minimum runoff) to 100 (maximum runoff). Since, standard table for CN values (ranges from 1 to 100), considering land use/cover and HSG are given for AMC-II (Vandersypen et al. 1972) method for predicting storm runoff. The main parameters of the model depend on the factors of the underlying surface such as land use and soil, so it is important to apply remote sensing information to the model. The derived SCS runoff equations were used to compute the direct runoff.

\[ Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \]  \hspace{1cm} (1)

Where \( Q \) = accumulated direct Runoff (mm)

\( P \) = accumulated rainfall or potential maximum Runoff (mm)

\( S \) = potential maximum soil retention (mm)

\( CN \) = Curve number

\[ S = \frac{25400}{CN} \]  \hspace{1cm} (2)

Antecedent Moisture Condition (AMC)

According to SCS (1972), AMC refers to the total cumulative rainfall during the 5 days immediately preceding the rainfall event. The AMC is used as index of wetness in a particular area. Antecedent moisture conditions were computed considering the summation of last five raining days using Microsoft office excel spread sheet as shown in appendix (A) (Table1).
Table 1: Antecedent moisture condition (AMC)

<table>
<thead>
<tr>
<th>AMC</th>
<th>Total rain in Previous 5 days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dormant season</td>
</tr>
<tr>
<td>(I) Less than 13mm</td>
<td>Less than 36mm</td>
</tr>
<tr>
<td>(II) 13 to 28mm</td>
<td>36-53mm</td>
</tr>
<tr>
<td>(III) More than 28 mm</td>
<td>More than 53mm</td>
</tr>
</tbody>
</table>

(Source: Adapted from Bhola and Singh, 2010).

Daily changes in the AMC condition and its distribution due to variation in the rainfall estimate were used to modify base CN map for AMC-I and AMC-III using formulas presented in equation 3 and 4, respectively. Three levels are used (Table 1.) The conversion formulas in equations 3 and 4 were used to convert CN from AMC-II (average condition) to the AMC-I (dry condition) and AMC-III (wet condition) (SCS, 1972).

For dry condition (AMC-I):

\[
CN_{(AMC \, I)} = \frac{4.2 \times CN_{(AMC \, II)}}{10 - 0.058 \times CN_{(AMC \, II)}}
\]  

(3)

For wet conditions (AMC-III):

\[
CN_{(AMC \, III)} = \frac{23 \times CN_{(AMC \, II)}}{10 - 0.13 \times CN_{(AMC \, II)}}
\]  

(4)

Generation of Rainfall Runoff Map

Rainfall-runoff analysis was carried out in ILWIS. A cross operation was used to overlay the landuse/landcover map and the HSG map. The initial abstraction (Ia), runoff (Q) in mm was inputed manually and the model was ranked to produce the Rainfall runoff map (Figure 3).

Method Adapted for generating the flood Hazard map

The degree of flood hazard of a certain area is determined by a number of factors like: slope, land use land cover type, soil type and the runoff. Thus, the following factor maps (i.e. Slope, LULC, HSG and runoff) were created. The “Blind Weight” method was used in assigning weights to each factor map. The steps for the derivation of the flood hazard (equation 5) by van Westen (1997) was adopted as follows:

i. Assigning weight values to the classes of the parameter maps.
ii. Renumbering the parameter maps to weight maps. Classes Maps were changed into value maps, with weight value maps.
iii. Combining the weight maps into one single hazard map. The weight maps were combined in this study by simply summing them up using equation (5) in the command line in ILWIS environment.
iv. Classifying the combined weight map into a final hazard map of five classes: Very low, low, medium, high and very high flood hazard zone.
Flood Hazard = WLULC + WSloP + WHSG + WRunoff  (5)

Results and Discussion
Remote sensing technique of visual interpretation and GIS analysis was used to identify eight classes of LULC as shown (Table 2 & Figure 4). Farmland area constitutes the largest percentage coverage 612.31 hectares (31%), followed by Low density (built up area) with 562.80 hectares (29%), high density (highly built up area) covers a land area of 531.12 hectares (27%), while marginal land like bare land, Earth dam and wetland are on the lower side. This showed that significant areas of the study are still undeveloped and unpaved.

<table>
<thead>
<tr>
<th>CLASS</th>
<th>Area (Hectares)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bareland</td>
<td>17.00</td>
<td>0.86</td>
</tr>
<tr>
<td>Earth Dam</td>
<td>1.30</td>
<td>0.07</td>
</tr>
<tr>
<td>Farm Land</td>
<td>612.31</td>
<td>31.05</td>
</tr>
<tr>
<td>High Density</td>
<td>531.12</td>
<td>26.94</td>
</tr>
<tr>
<td>Low Density</td>
<td>562.80</td>
<td>28.54</td>
</tr>
<tr>
<td>Medium Density</td>
<td>167.88</td>
<td>8.51</td>
</tr>
<tr>
<td>Stream</td>
<td>50.01</td>
<td>2.54</td>
</tr>
<tr>
<td>Wetland</td>
<td>29.25</td>
<td>1.48</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1971.77</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Source: Authors’ Analysis, 2016
The results of the slope analysis (figure 5) shows five classes of land with pockets of flat surfaces surrounded by very gentle terrain, followed by gentle slope, while the upland land areas is surrounded by undulating surfaces in the study area.
The Rainfall runoff analysis (Figure 7) using the polynomial equation derived from the scatter diagram (figure 6) of rainfall(mm) / runoff (Q)mm plotted for the month of July revealed that the estimated total runoff of Mararaba urban watersheds calculated for the rainy season (aggregating 1 April to 31 October, 2012) is 831.24mm. The observed peak cumulative runoff estimates (Table 5) was 174.21mm (21%) in the Month of July.

Table 3: Cumulative Estimated Rainfall (April - October, 2012)

<table>
<thead>
<tr>
<th>Month</th>
<th>Rainfall (mm)</th>
<th>Runoff(mm)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>45.2</td>
<td>25.52</td>
<td>3.07</td>
</tr>
<tr>
<td>May</td>
<td>184.9</td>
<td>86.28</td>
<td>10.38</td>
</tr>
<tr>
<td>June</td>
<td>228</td>
<td>124.98</td>
<td>15.04</td>
</tr>
<tr>
<td>July</td>
<td>331.9</td>
<td>174.21</td>
<td>20.96</td>
</tr>
<tr>
<td>August</td>
<td>270.5</td>
<td>135.11</td>
<td>16.25</td>
</tr>
<tr>
<td>September</td>
<td>274.4</td>
<td>139.09</td>
<td>16.73</td>
</tr>
<tr>
<td>October</td>
<td>278.9</td>
<td>146.05</td>
<td>17.57</td>
</tr>
<tr>
<td>Total</td>
<td>1613.8</td>
<td>831.24</td>
<td>100</td>
</tr>
</tbody>
</table>

Figure 6: Rainfall–Runoff relationship Study Area Estimate
(Source: Authors Analysis, 2016).
The results of flood hazard in percentage and spatial distribution over the study area (Table 4 and Figure 8); shows that high flood hazard area covers about 410.3 hectares (22%) and this corresponds with the high density areas. However, very high hazard area covering about 175 hectares (9.2%) are limited to marginal land use area along gullies within the study area. The predominant flood hazard of the entire study area is medium flood hazard which covers about 1098.8 hectares (58%) of the area. This corresponds with the agricultural land use area which may not portend serious danger to residents of the area in the immediate, but wider implication to sheet and gully erosion in farming practices if it is not adequately checked.

Table 4: Flood Hazard of the Study Area

<table>
<thead>
<tr>
<th>Hazard Class</th>
<th>Area (Ha)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low Hazard</td>
<td>110.01</td>
<td>5.78</td>
</tr>
<tr>
<td>Low Hazard</td>
<td>108.27</td>
<td>5.69</td>
</tr>
<tr>
<td>Moderate Hazard</td>
<td>1098.8</td>
<td>57.75</td>
</tr>
<tr>
<td>High Hazard</td>
<td>410.34</td>
<td>21.57</td>
</tr>
<tr>
<td>Very High Hazard</td>
<td>175.23</td>
<td>9.21</td>
</tr>
<tr>
<td>Total</td>
<td>1902.65</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Authors Analysis, 2016
This study has produced a flood hazard map presented of an easily replicable procedure applied to Mararaba sub-urban area using a sequence of tools in GIS environment. The map has proven to serve as a tool for administrator, planners and disaster managers to facilitate the identification of areas at risk of flood hazard and prioritization of mitigation action during the emergency phase of such event. The study has also revealed that due to paved surfaces in the built up areas, high rainfall - runoff was generated and together with other factors such as low relief and lack of proper urban planning. These were evident in some sections in the study area where it was found to be highly vulnerable to flood hazard. Based on the foregoing, concerted efforts should be made by the local and state government, urban planning and environment control department towards containing flood hazards by the construction of new drainage channels along inlands streets in Mararaba suburban areas were drainages have been absent and expand existing ones to increase their capacity for detaining and conveying high stream flow especially in areas at high risk. Further studies could be carried out to validate and calibrate the SCS model over the study area.

References.