LAGOS’ VULNERABILITY TO FLOOD’S CHANGES MAPPING
ADOPTING ANALYTICAL HIERARCHY PROCESS USING
GEOGRAPHICAL INFORMATION SYSTEM

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ABSTRACT
Flood disaster is considered a major natural hazard plaguing Lagosains due to its devastating effect on affected communities. Analytical Hierarchy Process (AHP) was adopted using Geographical Information System (GIS) to determine areas vulnerable to flood in Lagos for 1984 and 2013. This research considers the contribution of rainfall, elevation, land use, slope and soil to flood. AHP method was applied to these factors by means of ranking and pairwise comparison. This products a relative weight of 34.45% for slope, 19.58% for rainfall, 18.79% for land use, 18.61% for elevation, and 8.57% for soil. The consistency value was found to be reasonable with a consistency index of 0.0738 with a consistency ratio of 7%, these aids in flood vulnerability mapping. This reveals that the impact of flood is high for residential and socio-economic activities in Lagos, thus, this will assist decision makers on the menace posed by the disaster and mitigation measures to adopt.

INTRODUCTION
Natural disasters happen every year, and their incidence and frequency seem to have significantly increased in recent decades, mostly because of environmental degradation, such as deforestation, intensified land use and the increasing population (Faizatul et al., 2017). Floods are among the most frequent and costly natural disasters in terms of human and economic loss (Pradhan, 2009). Flooding has caused considerable damage to highways, settlement, agriculture and livelihood (Pradhan, 2009). Flood disaster is defined in terms of risk to humans and human society and is seen as a product of the severity and probability of occurrence of flood hazard and the vulnerability of the population/system (Brooks, 2003). Since risk can be perceived as a function of hazard, exposure and vulnerability (Crichton, 1999), assessment of vulnerability to flooding will generally assist in understanding the major drivers of flood risk and means of reducing them (Nkwunonwo et al., 2015). Flooding, which is a natural occurring phenomenon, has also led to the destruction of properties in the flood prone parts of the world, leading to major economic damages in such places. Although, flood hazard is natural, human modification and alteration of nature’s right of way can accentuate the problem, while the disastrous consequences are dependent on the degree of human activities and occupancy in vulnerable areas (Eludoyin & Weli, 2010). In Lagos, the causes of flooding have been attributed to many factors. Over time some causes of flooding in most urban areas have been due to increase in population, blockage of channels as a result of bad waste disposal as well as human activities at flood plains.

However, in addition to having knowledge of these causes, a precise location of areas that are vulnerable to flooding as well as their assessments is of great importance in preparing for and
managing flood disasters (Olayinka & Irivbogbe, 2017). Quick urban growth in Lagos is a critical factor to flooding in the area. With more than 1.2 million houses that currently exist in the conurbation (Sambah and Miura, 2014), it is easier to imagine a situation in which overcrowding would appear to have occasioned a serious lack of space for the myriad of human activities. As a result, much of the population has been pushed towards unsuitable locations (possibly prone to pluvial flooding) (Poursaber & Ariki, 2016), and more and more built-up structures have tended to be unplanned and have rarely adhered to local building regulations and town planning guidelines. Encroachments, illegal structures and slum envolutions are everyday issues in the area. Arguably, the condition of these buildings is not sufficiently taken into consideration in many flood hazard assessment discussions. Additionally, a good number of the houses either have long exceeded their life spans, or have been built with inferior materials or are built along natural drains and channels, thus, making them and their occupiers susceptible to flooding (Saaty, 1987; Kayasthaa et al., 2013). Flooding in Lagos, Nigeria is generally attributed to poor urban planning and climate change especially in increased rainfall frequency and intensity (Kayasthaa et al., 2013; Shahabi & Hashim, 2015). Other possible triggers are: the influence of canals, lagoons and beaches, and the topography of the area. It is commonly known that Lagos state drains two-thirds of South-west Nigeria into the Atlantic Ocean, and having just one-off estuary, the possibility of frequent discharges into the lowlands during heavy storms is undisputable. Historically, flooding in this part of Nigeria dates back to the early 1960’s and with the exception of 1973, the drought year, flooding in Lagos area has since occurred annually (Shahabi & Hashim, 2015; Ahmed, 2015; Rozos et al., 2011). Whilst coastal and fluvial floods (due to rivers overtopping their natural and artificial defenses and affecting nearby human settlements) often occurred in the historic years of flooding in the Lagos area, pluvial floods (due to severe storms which overwhelm drainage infrastructure and soil infiltration capacity) have been more widespread in recent times (Adeloye & Rustum, 2011). This in-turn has made Lagos vulnerable flooding.

Problems related to flooding have greatly increased, and there is a need for an effective modeling to understand the problem and mitigate its disastrous effects. In the recent years, remote sensing and Geographic information systems have been embedded in the evaluation of the geo-environmental hazards (Pradhan, 2009). One of the approaches in determining areas vulnerable to flood disaster is by spatial multi-criteria analysis through Analytical Hierarchy Process (AHP), introduced by Saaty; this method selects the required criteria by ranking the parameters and combines qualitative and quantitative factors (Saaty, 1977; Saaty, 1987; Kayasthaa et al., 2013). The AHP method applies to the decision-making process. Some studies employed AHP for hazard assessment such as floods (Ouma & Tateishi, 2014; Siddayao et al, 2014; Kazakis et al., 2015; Bathrellos et al., 2017; Bathrellos et al., 2016), tsunamis (Sambah & Miura, 2014a; Sambah & Miura, 2014b; Poursaber & Ariki, 2016), landslides (Bathrellos et al., 2016; Kayasthaa et al., 2013; Ekrami et al., 2016; Shahabi & Hashim, 2015), droughts (Ekrami et al., 2016) and seismic hazards (Bathrellos et al., 2016).

In this study, Analytical Hierarchy Process (AHP) was adopted into GIS in order to produce a flood vulnerability map for Lagos. This map was however produced and re-classified into four
different levels of vulnerability namely high, moderate, and low and very low according to expert’s knowledge-based classification. This kind of approach was also used to analyze flood vulnerable areas in Okazaki city, Aichi Prefecture, Japan (Andi et al., 2017). This research used five spatial criteria each to present and store layers using ArcGIS 10 software and generate criterion values. The maps were combined using GIS and pairwise comparison method in AHP to ascertain and map areas vulnerable to flooding in Lagos. Also, the vulnerability of Lagos to the risk of flooding was ascertained for Lagos using the land use land cover (LULC) and local Government Areas (LGAs) to show how well she fairs under the menace.

METHOD

This research adopts Analytical Hierarchy Process (AHP) integrated into Geographical Information System (GIS) to map flood vulnerability for 1984 and 2013. The information needed for flood vulnerability mapping was obtained from two major sources, namely: primary and secondary data. Primary data acquired for this study includes: (1.) DEM (Digital Elevation Model) data from SRTM (Shuttle Radar Topography Mission) 90m resolution; (2.) Map of the Local Government Areas (LGAs) and towns in Lagos (GIS vector file format) acquired from Guinea Current Large Marine Ecosystem (GCLME) and Unilag Regional Centre for Environmental Management, University of Lagos, Nigeria; (3.) An analogue soil map acquired from Wageningen, the Netherlands with a scale of 1:650,000 for 1997; and (4.) Landsat Thematic Mapper (TM) 5 and Operational Land Imager (OLI) 8 imagery for 1984 and 2013 with a Path/Row of 191/055,056 and a resolution of 30m was acquired from USGS Earth Explorer. In addition, (5.) field surveys were carried out by going to a few flood prone areas in parts of Lagos (ground trotting) and identifying factors that contribute to flooding in Lagos. Secondary data was acquired from Oshodi met station of NIMET (Nigerian Meteorological Stations Agency) which includes rainfall for 1984 and 2013. The study area of Lagos was selected based on its proximity to the coastline, high rainfall and its annual experience of flood.

In other to model flood vulnerability, Analytical Hierarchy Process (AHP) a spatial model from Multi-Criteria Decision Analysis (MCDA) was adopted for Lagos. The acquired analogue base map (soil map) was converted to GIS shape file format by: (1.) scanning and converting the analogue base maps to digital/raster images. (2.) The scanned analogue map was geo-referenced and projected using UTM 31N. (3.) The scanned analogue map was digitized and database created. This was implemented using ArcGIS 10 software. The LGA and town map acquired in GIS format was used as input in studying the effect of flood on Lagos. Landsat 8 OLI and 5 TM imagery was used to create a Land use Land cover (LULC) by selecting band 4, 5 and 7, performing image mosaicing, enhancement and creation of a composite for training sites and then, making of signature. In this research, supervised classification was adopted with maximum likelihood classification procedure and implemented using Idrisi Selva software to classify remotely sensed imagery into nine (9) classes of Land Use Land Cover (LULC) which includes: (1.) Residential area, (2.) Bare ground/open space; (3.) Agricultural land; (4.) Other built-up area; (5.) Commercial/industrial service’ (6.) public/educational institution; (7.) Forest area; (8.) Wetland
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and (9.) Water body. The LULC created was used as input: (a.) in the creation of Land Use/Land Cover (LULC) factor in AHP modeling and (b.) to study the effect of flooding on infrastructures and residents of Lagos. LULC factor was created based on the criteria listed in table 1. The digitized soil map derived was converted into GIS raster image base on its geological formation and criteria listed in table 1 to produce soil factor.

Then, a criteria selection process was carried out and selected based on their relevance to the study. These criteria are considered to be indicators or factors that influence flood. Five factors or indicators were considered in this study and they are given as follows: (1.) Elevation, (2.) Slope, (3.) Soil, (4.) LULC, and (5.) Rainfall. All factors were converted to raster images as stated above and reclassified using the criteria listed in table 1. Weights were determined for the indicators using a pairwise comparison method as provided by the Analytical Hierarchical Processing (AHP). A detailed process of this was given as follows below in table 1. ArcGIS 10 software was used with Analytical Hierarchy Process (AHP) extension, a decision-making technique utilized for solving complex problems, with many parameters of interrelated objectives or concerned criteria (Ahmed, 2015).

<table>
<thead>
<tr>
<th>Factors</th>
<th>Criteria</th>
<th>Weights</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall</td>
<td>125-127</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>127-129</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>129-130</td>
<td>0.1958</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>130-132</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>&gt;132 (greater than)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Slope (%)</td>
<td>0 - 2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 - 10</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 - 15</td>
<td>0.3445</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>15 - 45</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>45 - 100</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Elevation (meters)</td>
<td>1 - 7</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 - 16</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16 - 25</td>
<td>0.1861</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>25 - 34</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>34 &gt; (greater than)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Soil (Classified base on geological formation) from Wageningen, The Netherlands</td>
<td>Coastal plain sands</td>
<td>0.0857</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Deltaic basins &amp; tidal flats basin</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Recent alluvium</td>
<td>0.1879</td>
<td>5</td>
</tr>
<tr>
<td>Land Use Land Cover (LULC)</td>
<td>Water body</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wetland</td>
<td>0.1879</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Agricultural</td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>
**Table 2. Flood Vulnerability Criteria for AHP Modeling**

<table>
<thead>
<tr>
<th>Intensity of Importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Two elements contribute equally to the objective</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
<td>Experience and judgment slightly favor one parameter over another</td>
</tr>
<tr>
<td>5</td>
<td>Strong importance</td>
<td>Experience and judgment strongly favor one parameter over another</td>
</tr>
<tr>
<td>7</td>
<td>Very strong importance</td>
<td>One parameter is favored very strongly and is considered superior to another; its dominance is demonstrated in practice</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
<td>The evidence favoring one parameter as superior to another is of the highest possible order of affirmation</td>
</tr>
</tbody>
</table>

***Note: 2, 4, 6, 8 can be used to express intermediate values, 1.1, 1.2, etc. for parameters that are very close in importance***

Source: (Saaty, 1987; 2008)

The level of each parameter is not equal; some parameters are dominant over others. Different weights can generate the difference in the level of susceptibility (Ahmed, 2015). It is based on ranking from experts, literatures and previous study. The AHP pairwise have to be consistent with all pairwise comparisons. The AHP parameter for flood was adopted from Andi et al. (2017), and was slightly modified by the researcher. Five high-influence parameters (rainfall, elevation, slope, soil and land use) were selected. Flood parameters selected were modified based on relevant, existing literatures and additional evaluation from experts. Thus, we utilized rainfall, elevation; slope, soil and land cover as the parameters. Parameter ranking is related to their relative importance as listed in table 2. The relative importance has a range from 1 to 9; 1 means an equal contribution of the pairwise parameter and 9 means a very important parameter (Saaty, 1987; 2008). The proposed method used a $5 \times 5$ matrix. The comparisons of parameters were generated from the expert judgment, literature review and the previous study. The weighting calculation based on equation 1 is as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix}$$

$$a_{kk} = 1, a_{kk} = \frac{1}{a_{kk}}, a \neq 0$$

(1)
Where, $A$ is the weight of the parameter, $a_{kl}$ ($kl = 11, 12 \ldots 54, 55$). The right eigen value ($v$) corresponding to the maximum eigen value ($\lambda_{\text{max}}$) calculated to normalize and find the relative weight ($A_v$) of the matrix based on equation 2:

$$A_v = \lambda_{\text{max}} v$$  \hspace{1cm} (2)

The output of AHP has to be consistent for all the pairwise comparisons measured by Consistency Index ($CI$) and Consistency Ratio ($CR$) (Saaty, 1977). The Consistency Index ($CI$) was calculated based on equation 3:

$$CI = \frac{\lambda_{\text{max}} - n}{n - 1}$$  \hspace{1cm} (3)

Where, $\lambda_{\text{max}}$ is the maximum eigen value and $n$ is the number of parameters. The final calculation is consistency ratio; it is a ratio of the $CI$ and random index; $RI$ value for five parameters [10] (Saaty, 2008).

The maximum threshold of $CI$ is $\leq 0.1$ and $CR \leq 10\%$ [17]; the rational value is when the $CI$ and $CR$ have fulfilled the maximum threshold value. The consistency ratio ($CR$) was calculated based on equation 4:

$$CR = \frac{CI}{RI}$$  \hspace{1cm} (4)

Finally, AHP output generated represents Flood Vulnerability Index. While the Flood Vulnerability was obtained from Flood Vulnerability Index reclassified into five classes’, namely very low, low, moderate, and high to create a flood affected area. The affected area and percentage value was calculated and graphically presented for each Local Government Area (LGA) and LULC in 1984 and 2013. Town and settlements affected were extracted using spatial query similar to the method adopted by Ibeabuchi and Nwilo (2020) to select flood high priority areas. This method was used because it gives us an objective view of the impact and assessment of the risk of flood-vulnerability on Lagosains who are the most affected in the light of any disaster.

RESULT AND DISCUSSION

Environmental and Land Use Change of Lagos Between 1984 and 2013

Based on the adopted classification scheme, figure 2 shows changes in land use land cover (LULC) for 1984 and 2013 respectively for Lagos. Figure 3 shows Land use Land cover (LULC) distribution for Lagos in 1984 and 2013. Agricultural area was found to be 174.07 Km² in 1984 and decline to 17.08 Km² in 2013. While commercial /industrial area increased from 29.35 Km² in 1984 to 106.32 Km² in 2013. A reduction was observed in forest area from 133.42 Km² to 31.54 Km² from 1984 to 2013. Residential area experienced an increased from 213.99 Km² to 400.68 Km² respectively between 1984 and 2013. Bare ground/open space increased from 13.67 Km² in 2000 to 28.61 Km² in 2013. Public/educational institutional experienced an increase from 97.23...
Km² in 1984 to 73.39 km² in 2013. Other built up area increased from 44.21 Km² in 1984 to 44.85 km² in 2013. Water body increased from 65.57 Km² in 2000 to 85.56 km² in 2013.

Figure 2. Land Use/Land Cover (LULC) of Lagos for 1984 and 2013

In Lagos, it was observed that changes in LULC (figure 2) have increased the demand for land which in-turn has altered the micro climate and ecosystem between 1984 and 2013. The observed changes was found to influence and increase flood vulnerability in Lagos. This was achieved through Land reclamation by filling up of swamps and floodplains, and destruction of wetlands which generally reduces the flood storage capacity of the urban land as the case of Tin can Island, Eko Atlantic city, Eti Osa and Lagos Island areas between 1984 and 2013 (figure 3). Furthermore, between 1984 and 2013, the wetland cover which is an important buffer against coastal floods has significantly been reduced and largely exposed. Rapid and largely unplanned urban growth has resulted in land use changes and subsequent changes in the hydrological fluxes in the urban watershed thereby increasing flood hazard and risk in many parts of Lagos. Along the Lekki Peninsula, development has been undertaken with little or no consideration for sea-level rise and the possible risks of flooding, making this rapidly urbanizing area and its growing population vulnerable to sea-level rise and climate change [29]. This observed human intervention through land use change has exacerbated climate change and land degradation processes which increases rainfall intensity and flooding with outcomes being modulated by land management.

The main use of AHP is the ranking and prioritization of multi-criteria parameter. Priority framework quality affects the effectiveness of available sources which are the essential judgment from the decision maker (Saaty, 2008). Each of the expert participants determines the weight and design factors adopting the following procedures:

1) Determine each factor percentage to distinguish the weight;
2) Assign the least important factor from step 1 and assume the importance scale among the objective is linear; and
3) The importance of factor should be ranked from 1 to 5, where 1 represents the least important factor and 5 represents the most important.

The calculation on the rank of each factor was conducted by using pairwise comparison which can be seen in equation 1. Table 2 in appendix 1 presents the preference matrix; these are factors which were considered in this process, namely rainfall, elevation, slope, soil and LULC. Then, normalization was applied to the converted matrix using equation 2. More details on the AHP results are presented in appendix 1. The priority in table 3 and 4 (appendix 1) is called normalized principal eigenvector; this was used to weight the standardized raster layer. In addition, the calculation of the eigenvector is used as a coefficient for the respective factor maps combined in the weighted overlay. The Consistency Index (CI), which is a measure of departure from consistency. This was calculated using the formula in equation 3 and result presented in appendix 1. The Consistency Index (CI) computed was found to be 0.0738. This implies that the expert judgment is reasonably consistent and lower than the threshold 0.1, as a result of this the determined weights are acceptable. Also, the Consistency Ratio (CR) was computed using equation 4. This step is necessary to determine if our comparisons are consistent. The CR is designed in such a way that if CR < 10%, the ratio indicates a reasonable level of consistency in the pairwise comparison. The CR is less than 10%, the ratio indicates a reasonable consistency in this analysis, and it implies that the determined weights are acceptable at 7%. A summary of targeted factors, their weights and rankings are listed in table 2. The information on table 2 was applied to generate the distribution of areas vulnerable to flooding. The ranking of each reclassified
factor is based on existing literatures. The range of ranking was 1 to 5; the highest influence factor was rank 5 and the lowest influence factor was 1.

The order of normalized relative weight of 34.45% for slope, 19.58% for rainfall, 18.79% for LULC, 18.61% for elevation, and 8.57% for soil was derived (table 5, appendix 1). Looking at the weight of each factor, one can see that slope has the highest weight. It implies that the slope contributes more to flooding than other factors. Slope influences the direction of the runoff or subsurface drainage. Furthermore, the slope has dominant control of the rainfall, stream flow, duration of flow and duration of infiltration process. Once the weight in each factor was determined, the multi-criteria analysis was performed to produce a Flood Vulnerability Index using ArcGIS 10 software Analytical Hierarchy Process (AHP) extension. Flood vulnerability index of Lagos for 1984 and 2013 is presented in Figure 4. From the result shown in figures 4, vulnerability of Lagos to flood was categorized into four classes which include: (1.) very low, (2.) low, (3.) moderate, and (4.) high, according to expert’s knowledge-based classification to produce a flood vulnerability map of Lagos as presented in figure 5. As shown in figures 5, the level of Lagos vulnerability to flood is high, due to its very slow infiltration rates and the low level of the slope. In addition to this, the slope of Lagos shows a low gradient at the bottom and accumulation of water is more within this areas, this implies that towns within these areas are prone to high level of flood given the nature of the slope. Residents and people living within these towns are also at the risk of flooding but not as those living within the vulnerable areas. Towns and locations vulnerable to low and very low flood are basically located at a higher elevation making elevation an important factor. The result reveals that at higher elevation water will really not infiltrate the ground and accumulate and flow downwards to a low elevated areas and accumulate. People living within high elevated areas are not really at risk to flood. Rainfall is another important factor in Lagos, and is higher than its surrounding area. Rainfall is usually heavier and can create serious
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flash floods which are aggravated by the characteristic poor surface drainage conditions of coastal lowlands. The observed flood incident in Lagos reflects the impact and damage incurred on Lagosians whose encroachments, illegal structures and slum envolutions are everywhere induced by LULC change. Land reclamation achieved through filling up of swamps and floodplains, and destruction of wetlands through LULC change had significantly reduced the wetland cover, which is an important buffer against coastal floods, and largely exposes Lagos to changes observed in flooding. The result presented in-terms of its vulnerability and extent covered by flood in figure 6 shows that in 1984 very low flood level covers 371.15 km² with a percentage of 41.67%, low flood level covers 183.24 km² with a percentage of 20.58%, moderate flood level covers 222.11 km² with a percentage of 24.94%, high flood level covers 114.11 km² with a percentage of 23.23%. While in 2013, very low flood level covers 483.74 km² with a percentage of 54.32%, low flood level covers an area of 24.66 km² with a percentage of 2.77%, and moderate flood level covers an area of 184.23 km² with a percentage of 20.69%, high flood level covers 197.98 km² with a percentage of 22.23% (figure 6).

Figure 5. Flood Vulnerability of Lagos for 1984 and 2013

Evaluating Changes in the Vulnerability of Lagos to Adapt to Flood Between 1984 and 2013

Evaluating changes in the risk due to vulnerability to flood on Lagos was studied by using the land use land cover and Local Government Areas (LGAs). This was ascertained using the extent covered by flood which was computed using the map of flood vulnerability in Lagos in figure 5. Figure 7 shows the risk of Lagos to flood vulnerability for the Local Government Area (LGAs) for 1984 and 2013. The impact of flood on Lagos using LGA reveals that in 1984 for Agege, very low vulnerability covers 10.76 km², low vulnerability covers 0.00 km², moderate vulnerability covers 0.44 km², and high vulnerability covers 0.00 km². For Ajeromi/Ifelodun, very low vulnerability covers 0.36 km², low vulnerability covers 0.97 km², moderate vulnerability covers 4.01 km² and high vulnerability covers 6.77 km² in 1984. For Alimosho, very low vulnerability covers 139.36 km², low vulnerability covers 22.74 km², moderate vulnerability
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covers 20.89 km² and high vulnerability covers 1.07 km² in 1984. For Amuwo Odofin, very low vulnerability covers 24.29 km², low vulnerability covers 26.36 km², moderate vulnerability covers 26.65 km² and high vulnerability covers 25.22 km² in 1984. For Apapa, very low vulnerability covers 1.43 km², low vulnerability covers 2.37 km², moderate vulnerability covers 6.38 km² and high vulnerability covers 9.23 km² in 1984. For Eti Osa, very low vulnerability covers 42.68 km², low vulnerability covers 42.83 km², moderate vulnerability covers 51.21 km² and high vulnerability covers 24.67 km² in 1984. For Ifako/Ijaye, very low vulnerability covers 25.08 km², low vulnerability covers 0.79 km², moderate vulnerability covers 0.49 km² and high vulnerability covers 0.03 km² in 1984. For Ikeja, very low vulnerability covers 34.91 km², low vulnerability covers 7.08 km², moderate vulnerability covers 3.47 km² and high vulnerability covers 0.32 km² in 1984. For Kosofe, the impact of flooding reveals that very low vulnerability covers 18.93 km², low vulnerability covers 25.45 km², moderate vulnerability covers 19.56 km² and high vulnerability covers 7.08 km² in 1984. For Lagos Island, very low vulnerability covers 0.61 km², low vulnerability covers 1.03 km², moderate vulnerability covers 2.22 km² and high vulnerability covers 1.78 km² in 1984. For Lagos Mainland, very low vulnerability covers 1.12 km², low vulnerability covers 2.15 km², moderate vulnerability covers 6.14 km² and high vulnerability covers 5.80 km² in 1984. For Mushin, very low vulnerability covers 3.94 km², low vulnerability covers 5.32 km², moderate vulnerability covers 7.35 km² and high vulnerability covers 0.73 km² in 1984. For Ojo, very low vulnerability covers 49.28 km², low vulnerability covers 32.95 km², moderate vulnerability covers 41.48 km² and high vulnerability covers 17.21 km² in 1984. For Oshodi/Isolo, very low vulnerability covers 17.25 km², low vulnerability covers 8.69 km², moderate vulnerability covers 16.02 km² and high vulnerability covers 1.97 km² in 1984. For Shomolu, very low vulnerability covers 0.93 km², low vulnerability covers 1.92 km², moderate vulnerability covers 5.84 km² and high vulnerability covers 2.08 km² in 1984. While for Surulere, very low vulnerability covers 0.12 km², low vulnerability covers 2.59 km², moderate vulnerability covers 9.95 km² and high vulnerability covers 10.14 km² in 1984.

In 2013, the impact of flooding on Lagos using LGA reveals that for Agege, very low vulnerability covers 10.75 km², low vulnerability covers 0.45 km², moderate vulnerability covers 0.00 km² and high vulnerability covers 0.00 km². For Ajeromi/Ifeleodun, very low vulnerability covers 0.93 km², low vulnerability covers 0.00 km², moderate vulnerability covers 4.05 km² and high vulnerability covers 7.13 km² in 2013. For Alimosho, very low vulnerability covers 146.58 km², low vulnerability covers 16.79 km², moderate vulnerability covers 14.28 km² and high vulnerability covers 6.43 km² in 2013. For Amuwo Odofin, very low vulnerability covers 43.88 km², low vulnerability covers 0.00 km², moderate vulnerability covers 25.50 km² and high vulnerability covers 33.14 km² in 2013. For Apapa, very low vulnerability covers 3.98 km², low vulnerability covers 6.15 km² and high vulnerability covers 1.97 km² in 2013. For Eti Osa, very low vulnerability covers 55.61 km², low vulnerability covers 0.00 km², moderate vulnerability covers 38.97 km² and high vulnerability covers 66.82 km² in 2013. For Ifako/Ijaye, very low vulnerability covers 25.70 km², low vulnerability covers 0.32 km², moderate vulnerability covers 0.29 km² and high vulnerability covers 0.07 km² in 2013. For Ikeja, very low vulnerability covers 24.29 km², low vulnerability covers 26.36 km², moderate vulnerability covers 26.65 km² and high vulnerability covers 25.22 km² in 1984.
vulnerability covers 42.65 km$^2$, low vulnerability covers 1.36 km$^2$, moderate vulnerability covers 1.46 km$^2$ and high vulnerability covers 0.32 km$^2$ in 2013. For Kosofe the impact of flooding reveals that very low vulnerability covers 1.49 km$^2$, low vulnerability covers 0.00 km$^2$, moderate vulnerability covers 2.22 km$^2$ and high vulnerability covers 1.92 km$^2$ in 2013. For Lagos Island, very low vulnerability covers 1.49 km$^2$, low vulnerability covers 0.00 km$^2$, moderate vulnerability covers 2.22 km$^2$ and high vulnerability covers 1.92 km$^2$ in 2013. For Lagos Mainland, very low vulnerability covers 3.36 km$^2$, low vulnerability covers 0.00 km$^2$, moderate vulnerability covers 5.93 km$^2$ and high vulnerability covers 6.00 km$^2$ in 2013. For Mushin, very low vulnerability covers 9.23 km$^2$, low vulnerability covers 0.04 km$^2$, moderate vulnerability covers 7.28 km$^2$ and high vulnerability covers 0.79 km$^2$ and very high vulnerability covers 8.07 km$^2$ in 2013. For Ojo, very low vulnerability covers 70.91 km$^2$, low vulnerability covers 0.00 km$^2$, moderate vulnerability covers 37.57 km$^2$ and high vulnerability covers 32.45 km$^2$ in 2013. For Oshodi/Isolo, very low vulnerability covers 20.99 km$^2$, low vulnerability covers 4.30 km$^2$, moderate vulnerability covers 10.75 km$^2$ and high vulnerability covers 7.90 km$^2$ in 2013. For Shomolu, very low vulnerability covers 2.73 km$^2$, low vulnerability covers 0.00 km$^2$, moderate vulnerability covers 5.83 km$^2$ and high vulnerability covers 2.22 km$^2$ in 2013. While for Surulere, very low vulnerability covers 3.34 km$^2$, low vulnerability covers 0.00 km$^2$, moderate vulnerability covers 9.60 km$^2$ and high vulnerability covers 9.85 km$^2$ in 2013.

Figure 6. Vulnerability of Lagos to Flood for 1984 and 2013

Figure 7. Vulnerability of the Local Government Areas (LGAs) in Lagos to Flood for 1984 and 2013
The level of vulnerability was computed in percentage (%) to ascertain the impact of flooding on the Local Government Areas (LGAs) between 1984 and 2013. For Agege, very low vulnerability decreased from 96.11% to 96.02%, low vulnerability increased from 0.03% to 3.99%, moderate vulnerability decreased from 3.89% to 0.02% and high vulnerability maintained a value of 0.00% to 0.00% between 1984 and 2013. For Ajeromi/Ifelodun, very low vulnerability increased from 3.25% to 7.71%, low vulnerability decreased from 8.70% to 0.00%, moderate vulnerability decreased from 36.12% to 33.45% and high flood level vulnerability decreased from 60.94% to 58.85% between 1984 and 2013. For Alimosho, very low vulnerability increased from 75.71% to 79.63%, low vulnerability decreased from 13.36% to 9.12%, moderate vulnerability decreased from 11.35% to 7.76% and high vulnerability increased from 0.58% to 3.49% between 1984 and 2013. For Amuwo Odofin, very low vulnerability increased from 23.70% to 42.80%, low vulnerability decreased from 25.71% to 0.00%, moderate vulnerability decreased from 26.00% to 24.87% and high vulnerability increased from 24.60% to 32.33% between 1984 and 2013. For Apapa, very low vulnerability increased from 7.35% to 20.50%, low vulnerability decreased from 12.23% to 0.00%, moderate vulnerability decreased from 32.86% to 31.68%, and high vulnerability increased from 47.58 to 47.83% between 1984 and 2013. For Eti Osa, very low vulnerability increased from 26.44% to 34.46%, low vulnerability decreased from 26.54 to 0.00%, moderate vulnerability decreased from 31.73% to 24.15% and high vulnerability increased from 15.29% to 41.40% between 1984 and 2013.

For Ifako/Ijaye, very low vulnerability decreased from 100 to 97.39%, low vulnerability decreased from 3.00% to 1.22%, moderate vulnerability decreased from 1.85% to 1.12% and high vulnerability increased from 0.10% to 0.27% between 1984 and 2013. For Ikeja, very low vulnerability increased from 76.25% to 93.14%, low vulnerability decreased from 15.47% to 2.98%, moderate vulnerability decreased from 7.58% to 3.19% and high vulnerability maintained a 0.70% to 0.70% between 1984 and 2013. For Kosofe, the impact of flooding reveals that very low vulnerability decreased from 26.66% to 58.58%, low vulnerability decreased from 35.83% to 1.89%, moderate vulnerability decreased from 27.54% to 20.21% and high vulnerability increased from 9.97% to 19.23% between 1984 and 2013. For Lagos Island, very low vulnerability increased from 10.77% to 26.52%, low vulnerability decreased from 18.21% to 0.00%, moderate vulnerability decreased from 39.40% to 39.36% and high vulnerability increased from 31.59% to 34.10% between 1984 and 2013. For Lagos Mainland, very low vulnerability increased from 7.88% to 21.97%, low vulnerability decreased from 14.07% to 0.00%, moderate vulnerability decreased from 40.10% to 38.77%, and high vulnerability decreased from 37.94% to 39.24% between 1984 and 2013. For Mushin, very low vulnerability increased from 22.74% to 53.22%, low vulnerability decreased from 30.66 to 0.23%, moderate vulnerability decreased from 42.38% to 41.99% and high vulnerability increased from 4.22% to 4.55% between 1984 and 2013. For Ojo, very low vulnerability increased from 34.97% to 50.32%, low vulnerability decreased from 23.38% to 0.00%, moderate vulnerability decreased from 29.44% to 26.66% and high flood vulnerability increased from 12.21% to 23.03% between 1984 and 2013. For Oshodi/Isolo, very low vulnerability increased from 39.26% to 47.78%, low flood level vulnerability decreased from
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19.78% to 9.79%, moderate vulnerability decreased from 36.48% to 24.47% and high vulnerability decreased from 4.49% to 17.98% between 1984 and 2013. For Shomolu, very low vulnerability increased from 8.67% to 25.32%, low vulnerability decreased from 17.82% to 0.00%, moderate vulnerability decreased from 54.26% to 54.10% and high vulnerability increased from 19.28% to 20.61% between 1984 and 2013. While for Surulere, very low vulnerability increased from 0.52% to 14.64%, low vulnerability decreased from 11.35% to 0.00%, moderate vulnerability decreased from 43.64% to 42.12% and high vulnerability decreased from 44.47% to 43.22% between 1984 and 2013. Based on the above, an increase was observed for high vulnerability and a decrease was observed in very low, low and moderate vulnerability for Lagos. This reveals that the vulnerability to flooding was recorded to be high for Lagos with greatest effect and impact felt on Ajeromi/Ifelodun, Apapa, Lagos Mainland, and Surulere for 1984 and 2013 in Ajeromi/Ifelodun, Apapa, Surulere, Eti Osa, Lagos Mainland, Lagos Island and Amuwo Odofin.

Also, evaluating the vulnerability of Lagos to flood was studied using the extent covered by flood based on the flood vulnerability map in figure 5 for the Land Use Land Cover (LULC). Figure 8 shows the risk of Lagos to flood vulnerability for the LULC in 1984 and 2013. The impact of flood on Lagos using LULC reveals that in 1984 for residential area, very low vulnerability covers 178.86 km², low vulnerability covers 53.08km², moderate vulnerability covers 77.77km² and high vulnerability covers 35.34 km². For bare ground/open space, very low vulnerability covers 2.2 km², low vulnerability covers 1.19km², moderate vulnerability covers 3.41 km² and high vulnerability covers 4.16km² in 1984. For agricultural land, very low vulnerability covers 330.47 km², low vulnerability covers 58.35km², moderate vulnerability covers 64.25 km² and high vulnerability covers 14.40km² in 1984. For public/educational institutional, very low vulnerability covers 56.53 km², low vulnerability covers 15.01km², moderate vulnerability covers 29.30 km² and high vulnerability covers 17.46 km² in 1984. For commercial/industrial service, very low vulnerability covers 10.00 km², low vulnerability covers 4.60km², moderate vulnerability covers 10.36 km² and high vulnerability covers 7.01 km² in 1984. For other built up area, very low vulnerability covers 10.00 km², low vulnerability covers 4.60km², moderate vulnerability covers 10.36 km² and high vulnerability covers 7.01 km² in 1984. For forest, very low vulnerability covers 196.68km², low vulnerability covers 83.05 km², moderate vulnerability covers 54.72km² and high flood level vulnerability covers 7.00 km² in 1984. For wetland, very low vulnerability covers 87.80 km², low vulnerability covers 57.74 km², moderate vulnerability covers 19.99 km² and high vulnerability covers 5.20 km² in 1984. While for water body, very low vulnerability covers 7.63 km², low vulnerability covers 3.24 km², moderate vulnerability covers 1.38 km² and high vulnerability covers 1.69 km² in 1984.

While for 2013, the impact of flood reveals that for residential area, very low vulnerability covers 292.04 km², low vulnerability covers 20.53 km², moderate vulnerability covers 137.31 km² and high vulnerability covers 133.80 km². For bare ground/open space, very low vulnerability covers 19.03km², low vulnerability covers 1.84km², moderate vulnerability covers 7.63 km² and high vulnerability covers 12.24km² in 2013. For agricultural land, very low vulnerability covers 273.85 km², low vulnerability covers 7.20 km², moderate vulnerability covers 29.72 km² and high
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vulnerability covers 0.00 km² in 2013. For public/educational institutional, very low vulnerability covers 87.84 km², low vulnerability covers 7.63 km², moderate vulnerability covers 27.63 km² and high vulnerability covers 22.21 km² in 2013. For commercial/industrial service, very low vulnerability covers 49.72 km², low vulnerability covers 3.69 km², moderate vulnerability covers 27.68 km² and high vulnerability covers 35.90 km² in 2013. For other built up area, very low vulnerability covers 6.24 km², low vulnerability covers 0.11 km², and moderate vulnerability covers 12.97 km², and high vulnerability covers 21.37 km² in 2013. For forest, very low vulnerability covers 148.80 km², low vulnerability covers 0.51 km², moderate vulnerability covers 23.36 km² and high vulnerability covers 0.00 km² in 2013. For wetland, very low vulnerability covers 362.06 km²; low, moderate and high vulnerability covers 0.00 km² in 2013. For water body, very low vulnerability covers 12.58 km²; low, moderate and high vulnerability covers 0.00 km² in 2013. The level of flood vulnerability was computed in percentage (%) to ascertain the impact of flood on Lagos between 1984 and 2013. For residential area, very low vulnerability increased from 11.57% to 16.34%, low vulnerability decreased from 3.43% to 1.15%, moderate vulnerability increased from 5.03% to 7.68% and high vulnerability increased from 2.29% to 7.49% between 1984 and 2013. For bare ground/open space, very low vulnerability increased from 0.14% to 1.06%, low vulnerability covers increased from 0.08% to 0.10%, moderate vulnerability increased from 0.22% to 0.53% and high vulnerability increased from 0.27% to 0.69% between 1984 and 2013. For agricultural land, very low vulnerability decreased from 21.37% to 15.32%, low vulnerability covers decreased from 3.77% to 0.40%, moderate vulnerability decreased from 4.15% to 1.66% and high vulnerability decreased from 0.93% to 0.00% between 1984 and 2013. For public/educational institutional, very low vulnerability increased from 3.66% to 4.91%, low vulnerability covers decreased from 0.97% to 0.43%, moderate vulnerability decreased from 1.89% to 1.55%, high vulnerability increased from 1.13% to 1.24% between 1984 and 2013. For commercial/industrial service, very low vulnerability increased from 0.65% to 2.78%, low vulnerability covers decreased from 0.30% to 0.21%, moderate vulnerability increased from 0.67% to 1.55% and high vulnerability increased from 0.45% to 2.01% between 1984 and 2013. For other built up area the impact of flooding reveals that very low vulnerability decreased from 0.97% to 0.35%, low vulnerability decreased from 0.45% to 0.01%, moderate vulnerability decreased from 0.89% to 0.73% and high vulnerability decreased from 0.71% to 1.20% between 1984 and 2013. For forest, very low vulnerability decreased from 12.72% to 8.33%, low vulnerability decreased from 5.37% to 0.03%, moderate vulnerability decreased from 3.54% to 1.31% and high vulnerability decreased from 0.45 to 0.00% between 1984 and 2013. For wetland, very low vulnerability increased from 5.68% to 20.26%, low vulnerability decreased from 3.37% to 0.00%, moderate vulnerability decreased from 1.29% to 0.00% and high vulnerability decreased from 0.34 to 0.00% between 1984 and 2013. While for water body, very low vulnerability increased from 0.49% to 0.70%, low vulnerability decreased from 0.21 to 0.00%, moderate vulnerability decreased from 1.29% to 0.00% and high vulnerability decreased from 0.11% to 0.00% between 1984 and 2013.
An evaluation of the risk of flooding using the LULC reveals that Lagos is highly vulnerable to flooding with impact felt on agricultural land by 30.23%, 22.31% for residential areas, 22.08% for forest and 11.04% for wetland 1984 and while in 2013 residential areas increased to 32.66%, wetland by 20.26%, and agricultural land decreased by 17.39%, while the lowest vulnerable area was located in the water body by 0.90% and bare ground/open space by 0.71% in 1984, Other built up area decreased by 2.28% and 9.66% for forest in 2013 of the total flood-vulnerable area.

Based on this, the impact of flooding reveals that an increase was observed for high and moderate vulnerability and a decrease was observed in very low and low vulnerability for Lagos. Further evaluation of the risk of flooding using the LULC for Lagos reveals that an increase was observed in high flood vulnerable from 12.81 to 22.23%, a decrease of 24.94 to 20.69% for moderate flood vulnerable, 20.58% to 2.77% for low flood vulnerable and 41.67 to 54.32% increase for very low flood vulnerable. Lagos recorded a high vulnerability to flooding for residential areas and public/educational institutional which is the most vulnerable in 1984 and while in 2013 residential areas, public/educational institutional and commercial/industrial service is the most vulnerable, while the lowest vulnerable area are other built up area and bare ground/open space in 1984, agricultural land and forest in 2013. This stress the fact that large portions of the population are housed in residential areas that do their business in and around Lagos, and are located less than six feet above sea level, including the wealthiest areas of Victoria Island and Lekki Peninsula in Eti Osa, Lagos Island, poorest areas of Lagos located in Lagos Mainland which includes Makoko, industrial areas of Lagos which includes Ijora and New Ijora settlement in Apapa and Animashawun in Surulere LGA which are highly vulnerable to the risk of flooding. Also, other less economically vibrant LGAs such Ajegunle in Ajeromi/Ifeidun and Olute in Amuwo Odofin LGA are highly vulnerable to the risk of flooding. Figure 9 and table 7 shows towns vulnerable to (high) flood in Lagos. According to LULC, more than half of the population is located on lowlands which are flood-prone areas in Lagos. Most of the agricultural sector now is located around areas categorized as flood-prone area also accompanied largely by public/educational institutional and commercial/industrial service in Lagos. The high flood-vulnerable condition of Lagos has caused major economic losses in terms of GDP, home lost and livelihood, in particular as infrastructure are damage, agricultural areas are lost and business...
activity suspended. Such flood disaster cannot cause economic loss alone but also cause various diseases such as waterborne disease, vector-borne disease, etc.

![Vulnerable Flood Towns](image)

**Figure 9.** Towns Vulnerable to Flood in Lagos

**Table 6:** Towns vulnerable to flood in Lagos.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Town</th>
<th>Local Government Area</th>
<th>S/N</th>
<th>Town</th>
<th>Local Government Area</th>
</tr>
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<tr>
<td>1</td>
<td>Ajegunle</td>
<td>Ajeromi/Ifelodun</td>
<td>15</td>
<td>Oruba Agboyi</td>
<td>Kosofe</td>
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<td>2</td>
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<td>Ajeromi/Ifelodun</td>
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<td>Agboyi</td>
<td>Kosofe</td>
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<tr>
<td>3</td>
<td>Olute</td>
<td>Amuwo Odofin</td>
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<td>Iddo</td>
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<td>Apapa</td>
<td>19</td>
<td>Ebute-Metta</td>
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<tr>
<td>6</td>
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<td>Apapa</td>
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<td>Makoko</td>
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<td>New Ijora Settlement</td>
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<td>Coker</td>
<td>Surulere</td>
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<tr>
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<td>Ijora Village</td>
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<td>Eti Osa</td>
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<td>Animashawun</td>
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<td>Ijesa-Tedo</td>
<td>Surulere</td>
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<td>Ogudu</td>
<td>Kosofe</td>
<td>28</td>
<td>Akangba</td>
<td>Surulere</td>
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</table>

*Source: Authors Analysis, 2020*
CONCLUSION

The study clearly and analytically maps out vulnerable areas to flood into four classes, namely very low, low, moderate and high vulnerability with the aid of Analytical Hierarchy Process (AHP) using Geographical Information System (GIS) for Lagos between 1984 and 2013. In this study, an increase in high flood vulnerability and a decrease in very low, low and moderate vulnerability were observed between 1984 and 2013, thus, making Lagos very vulnerable to flood. Rainfall data was imported into ArcGIS 10 environment as point shapefile to model the rainfall distribution. Using GIS interpolation model - Kriging technique, rainfall distribution was modeled and reclassified based on the criteria listed in table 1. This was used to model rainfall factor. Slope and elevation factor was obtained from SRTM DEM and reclassified using the criteria listed in table 1. The study critically examines the role of GIS in decision-making and evaluation of different criteria’s in decision process. The flood vulnerability index map produced for Lagos can assist planners, policy makers and emergency service providers as a valuable tool for assessing flood risk zones. Flooding in Lagos is a continuous and constant occurrence as long as there is rainfall which occurs both naturally and artificially. For proper mitigation of flooding in Lagos proper management and planning it can be directed in a desirable and sustainable way to ensure proper and careful solution oriented goals. Therefore it is recommended that proper and adequate with ensured operational regulated/policies should be put in place and enforced to manage and mitigate against flooding through afforestation on areas prone to flood and proper orientation and environment education/awareness should be given its proper place and the populace should be educated on the dangers associated with building and settling on flood plain.

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