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RESEARCH ARTICLE

OCCURRENCE OF RAINFALL EXTREMES AND RISKS OF FLOODING IN AGROECOLOGICAL ZONE 5 OF BENIN

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Abstract

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The objective of this study is to characterize the risk of flooding in the Agro zone 5 of Benin. The methodological approach can be summarized in several stages: the determination of the various climatic extreme indices (Rx1day, R95p and R99p) obtained by the rain data from the stations of Bohicon, Savè and Parakou, then the analysis of the occurrence of these indices is made by the frequency analysis method, and finally the mapping of areas at risk of flooding is carried out based on the geological funds, the Digital Terrain Model (DTM), the land use units and rainfall data at the various stations covering the study area. The identification of areas at risk of flooding is governed by the combination of thematic maps based on the multi-criteria analysis method. The vulnerability map is obtained thanks to three physical factors which are: the slope, the drainage density and the geological units. The hazard map is obtained by combining land cover and rain fields. The results of this research reveal that in the Agro zone 5 of Benin, daily maximum rainfall of 60.68mm and 126.43mm has a probability of 0.5% and 0.2% of occurring for return periods of 2 and 5 years. The combination of the vulnerability and flood risk map shows that high and very high flood risk areas cover 24% of the total area of the study area.

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Introduction:-

Since the second half of the 20th century, West Africa has experienced the greatest rainfall deficit (Spinoni et al., 2013. Ozer et al., 2014). This has resulted in a recurrence of droughts leading to a decline in available water resources on which the main socio-economic activities are highly dependent (Le Barbé and Lebel, 1997; Nicholson et al., 2000; Hu1me et al., 2001 Le Barbé et al., 2002; Le Lay and Galle, 2005; Sultan et al. 2005; Gachon et al., 2007). The main causes put forward are associated with changes in land cover and deforestation (Charney, 1975; Xue and Shukla, 1993; Zheng and Eltahir, 1998), the variability of surface temperature (TSO) in the North and

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South Atlantic or in the Pacific via in particular potential teleconnections with the El Nino phenomenon (Rowell, 2003; Messager et al., 2004), to the variation of the velocity of atmospheric jet streams (Kanamitsu and Krishnamurti, 1978; Sultan and Janicot, 2003) or the concentration of atmospheric dust (Pinker et al., 1994; Prospero, 1996; N'tchayiMbourou et al., 1997). In Benin, hydro-pluviometric variability is manifested by anomalies and successive or alternating crises of water surplus and deficit. The consequences of such variability can be lasting on the hydrological cycle, especially when they result in long periods of drought or excess water (Afouda et al, 2001). Scientific presumptions support the hypothesis of climate change characterized by global warming accompanied by significant effects on the water cycle. The IPCC estimates that extreme heat and heavy precipitation events will continue to become more frequent, more intense and above all more and more variable from one year to another (Pomerleau, 2009). Even if certain studies have made it possible to analyze in detail the interannual variability and the cycle of the African monsoon (Folland et al., 1986; Le Barbé and Lebel, 1997; Sultan and Janicot, 2000; Le Barbé et al., 2002; Lebel et al., 2003; Sultan and Janicot, 2003; Neil et al., 2005), trends in climatic extremes, have been little studied in Benin. This study aims to analyze the occurrence of extreme rainfall events and the risk of flooding in agroecological zone 5 of Benin.

Material and Methods:-

Study framework

With an area of 31,722 km2 (INSAE, 2013), Benin's agro-ecological zone 5 is the seat of a zone of high crop production whose yields contribute to the increase in national agricultural production. It is bordered to the northeast by the commune of Nikki, to the northwest by the commune of Natitingou, to the east by Nigeria, to the west by Togo, southeast by the commune of Pobè and to the South-West by the municipality of Lokossa (figure 1). The agro-ecological zone 5 of Benin whose physical and socio-economic foundations differ from North to South covers five departments of Benin for 13 communes. The climatic regime is characterized by a climate of the Sudano-Guinean type with two rainy seasons which are difficult to observe in the communes of Bassila, Parakou and Tchaourou. It is an alternation of two rainy seasons and two dry seasons (a small and a large season of each type) in the south and a rainy season and a dry season in the north.

Methods:-

This research is done through the consultation of the databases of the Benin Weather Centers and the IGN. It made it possible to have chronicles of climatological and planimetric data. The climatological data series used in this study were provided by Météo Benin. The meteorological observation network used is made up of 13 stations, including 3 synoptic stations on which rain and temperature data were recorded (at daily time intervals). These three stations were chosen because of the area they cover in the study area. It is noted that the synoptic station of Parakou covers the north of the agro-ecological zone, that of Savè covers the center and that of Bohicon covers the south of the study area. The other 13 stations are rainfall stations where rainfall data are available at daily time intervals. These are the precipitation and temperature chronicles recorded over the period from 1970 to 2016. The choice of this period is justified by the need to consider a maximum of stations on the observation networks and to work on a long series to obtain reliable frequency analyses. The Planimetric data used in this study are multiple and come from several sources: Landsat 8 OLI/TIRS satellite images and Digital Terrain Models (DTM) obtained using the SRTM (Shuttle Radar Topographic Mission) satellite obtained on the site (https://earthexplorer.usgs.gov); data related to the litho-structural domains of Agroecological zone V from the geological map of the study area obtained from IGN Benin and the IGN Benin 2018 topographic funds.

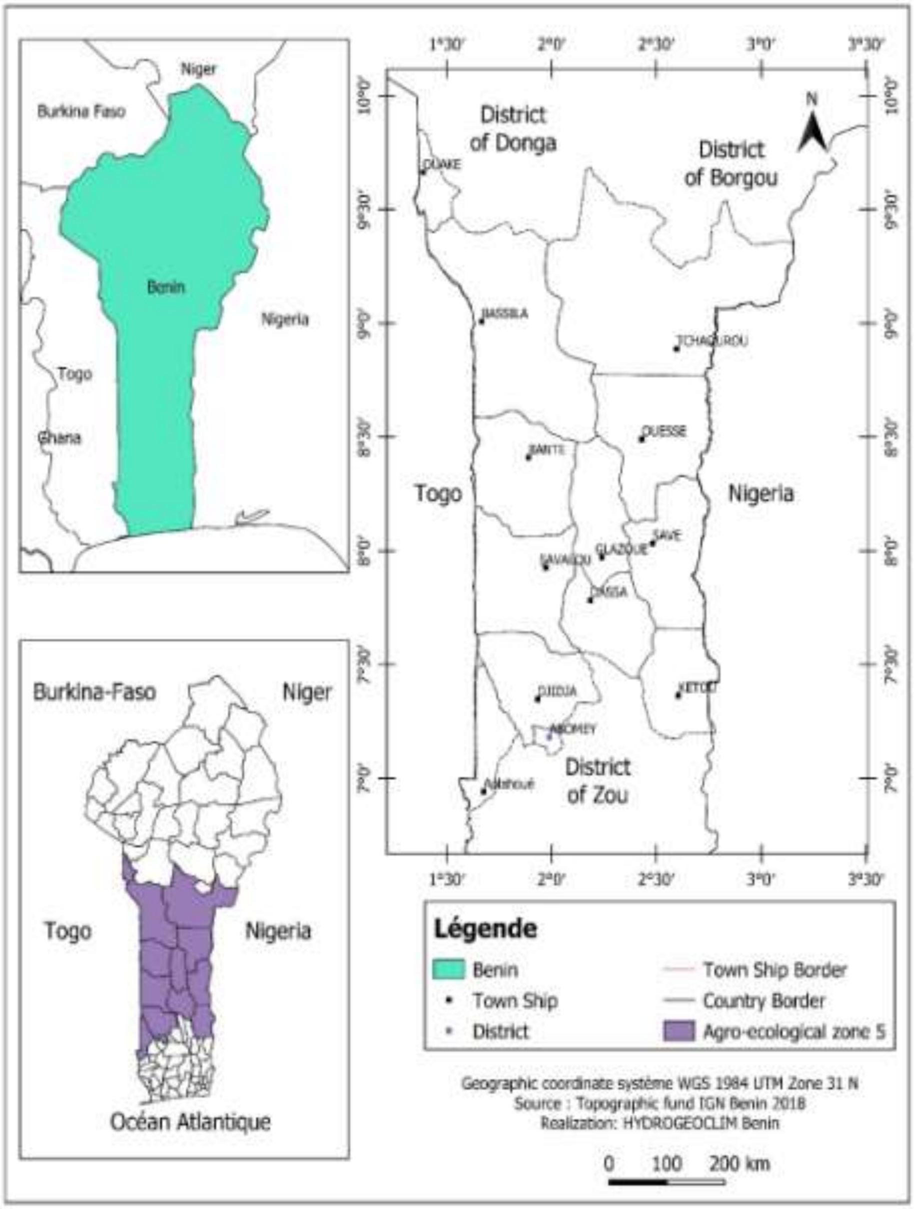

Figure 1:- Geographical location of Agro-ecological zone 5 in Benin.

Analysis of the occurrence of rainfall extremes

From the series of daily rains, a set of three indices characterizing the extreme events were constituted. These are the maximum amount of daily precipitation (RX1day), the proportion of intense precipitation in the total annual rainfall (R95p, total annual PRCP when RR > 95th percentile) which represents the share of intense rainfall and the proportion of precipitation very intense in the total annual rainfall (R99p, total annual PRCP when RR> 99th percentile) which represents the share of very intense rainfall. These indices were obtained with the RClimDex model. A total of 27 core indices have been suggested by the Expert Team on Climate Change Detection Indices ETCCDI. Detailed descriptionsof these indices and RClimDex are available on the ETCCDI website(http://cccma.seos.uvic.ca/ETCCDMI/software.shtml).

The occurrence of extreme events was assessed from the frequency analysis of the constituted indices. This consisted of adjusting the data series to different probability laws: the Gumbel law, the GEV law and the exponential law. Then a frequency model is retained by applying two criteria: the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) commonly used in the choice of the best model from a set. Plausible models

(INRS-ETE, 2005). Finally, the chi2 test was applied to validate the frequency model and the quantiles XT corresponding to the value of each variable at a return period T are determined.

Flood risk mapping method

Floods are the main extreme events known across the sector. Its mapping is linked to the analysis of the state of vulnerability of the sector to the phenomenon and the manifestation of the hazard. Indeed, flood risk mapping takes into account many parameters as underlined by risk equation (1) (Harding et al., 2001 and Henry 2006).

R = f (A, E, V, I, t, s)

With A= hazard, E= issue or element at risk, V= vulnerability, I= resilience, t and s= spatio-temporal dimensions.

The risk is expressed according to the UNDRO (United Nations Disaster Relief Office) by the product of a hazard and a vulnerability (Gilard and Gendreau, 1998; Onna et al., 2005) (2):

Risk = Hazard x Vulnerability

The hazard map results from the combination of the isohyet map and the land cover map. To do this, three levels are retained (low, medium and high). From the distribution of rainfall intensity produced using precipitation data (1970-2017), three classes of rainfall abundance were defined: low (< 600 mm), medium (600 – 800 mm), strong (800 – 1000 mm) and very strong (>1000). The second parameter is the ground cover. By taking into account the role of the different land use units in the production of surface runoff, a classification is made from the land use units and has made it possible to retain three classes: low (dense forest, semi- deciduous, gallery forest and plantation), medium (clear forest, wooded and shrubby savannah, fields and fallow land), high (agglomerations, marshy formations and bodies of water). The intersection of these two factors (rainfall and soil cover) made it possible to determine the spatial extent and the areas potentially exposed to climatic hazards that could cause flooding in the catchment area. To determine the vulnerability and the risk of flooding in the watershed, the method of combination and superposition was chosen. To do this, the variables defined are as follows: drainage density, lithology, structural domain, slope, type of land use, and rainfall intensity. The treatment of the different variables made it possible to draw up thematic maps. These are maps of slopes, drainage density, areas of influence and main watercourses produced on the basis of the SRTM DTM, and the geological map. The combination of these different maps using the Raster calculator tool under Arc-Gis enabled the development of the vulnerability map of the catchment area to flooding. The criteria for determining the areas of vulnerability and risk to flooding are weighted by the Multi-Criteria Analysis (MCA) technique. A reclassification of each thematic map was made in accordance with the information recorded in Table I. To obtain the map of the risk of flooding by overflow, the combination by coding of the vulnerability and hazard maps was made. The risk of flooding is defined as the intersection of the previously defined hazard and vulnerability. A high flood hazard in a low vulnerability area is highly risky. The main steps in determining flood risk are summarized in Figure 2.

Table I:- Criteria and rating for reclassification of thematic maps.

Parameters	Unit	Class	Susceptibility class type and ranking
Slope	%	< 5	Very strong
		5 – 10	Strong
		10 – 15	Average
		>15	Weak
Drain density	Km/km²	< 0.1	Weak
		0.1 – 0.2	Average
		0.2 – 0.3	Strong
		>0.3	Very strong
Geology	Level	Granite	Weak
		Gneiss	Average
		Sandstone	Strong
		Clay, Limestone,	Very strong
Precipitation	mm	< 600	Weak
		600 – 800	Average
		800 – 1000	Strong
		>1000	Very strong

Land use	Level	FCSB, FD, SASa	Weak
		FGFR, FSM	Average
		CJ, CJP	Strong
		AG, PF	Very strong

FCSB: Open Forest and wooded savannah; DF: Dense Forest; SASa: Tree and shrub savannah; FGFR: Gallery Forest and riparian formation; FSM: Forest and swamp savannah; CJ: Cultivation and fallow; CJP: Cultivation and fallow under oil palm; GA: Agglomeration; PE: Body of water

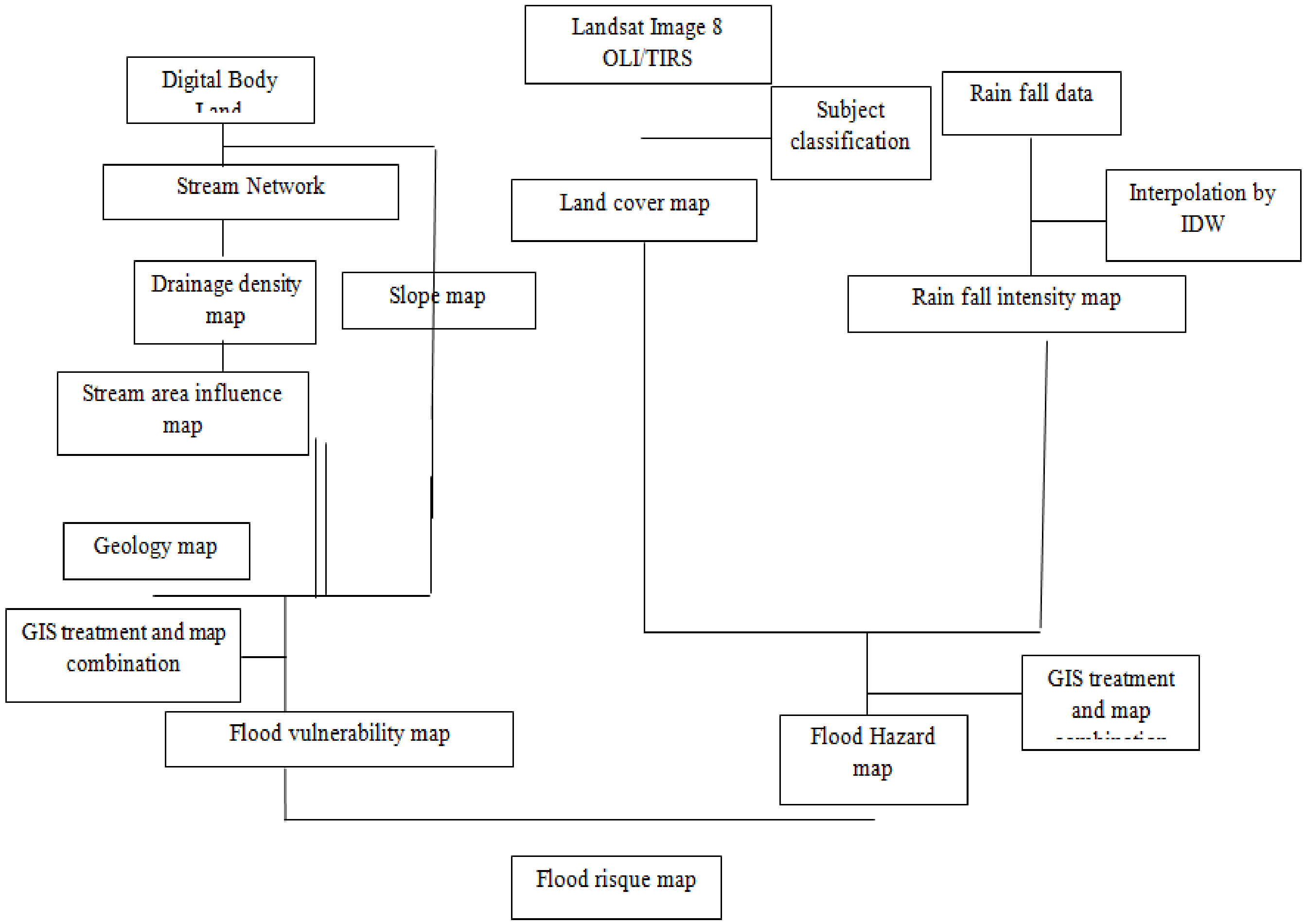

Figure 2:- Flow chart for producing the flood risk map related to river floods.

Results and Discussion:-

Analysis of rainfall index quantiles

Figure 3 shows the statistical adjustment graphs of the constituted extreme rainfall indices. The analysis of this figure 3 confirms the adequacy of the different statistical laws with the series constituted. The equation lines of each graph pass through the experimental points. The GEV, Gumbel and exponential law are adapted for the identification of quantiles of extreme rainfall indices (R1xday, R95p, R99p) in agroecological zone 5 of Benin. The quantiles calculated for each of the indices are given in Tables 2, 3 and 4.

Table 2:- Estimated quantiles in agro-ecological zone V for the R1xday index.

	Quantiles					
	2	5	10	20	50	100
Bohicon	77.84	99.60	114.01	127.83	145.72	159.13
Parakou	87.4	112.37	128.91	144.77	165.30	180.69
Savè	66.45	85.94	98.85	111.23	127.25	139.26

Table 3:- Estimated quantiles in the watershed of agro-ecological zone V for the R95p index.

	Quantiles					
	2	5	10	20	50	100
Bohicon	242.53	357.93	415.09	459.58	505.98	534.52
Parakou	249	387.39	479.02	566.92	680.69	765.95
Savè	302.08	407.78	464.29	510.53	561.02	593.2

Table 4:- Estimated quantiles in agro-ecological zone V for the R99p index.

	Quantiles					
	2	5	10	20	50	100
Bohicon	55.94	120.75	163.66	204.81	258.09	298.01
Parakou	822.95	946.43	1039.83	1133.24	1256.71	1350.11
Savè	793.95	911.05	999.64	1088.22	1205.33	1293.91

From the analysis of Table 2, it appears that the maximum amount of precipitation likely to cause frequent rain floods is between 60.68mm and 126.43mm (return periods between 2 and 5 years). For pluvial floods they are of the order of 87.48 mm to 166.97 mm (return period between 10 -20 years) and finally rare pluvial floods are caused by the amounts of precipitation estimated between 109.95 - 212.51 mm with return periods of 50 - 100 years. The analysis of Table 3 shows that on very wet days, precipitation of the order of 242.53 - 357.93 mm is recorded (return periods between 2 - 5 years). These are capable of frequently causing damage to crops, soils, housing and other activities in the study area. On very wet days the precipitation is very wet the precipitation is in the range of 415.09 - 459.98 mm (return period between 10 - 20 years). This precipitation can go up to 505.98 - 534.52 mm on rare wet days (return periods between 50 - 100 years). The analysis of Table 4 shows that extremely wet days are capable of frequently causing damage to crops, soils, dwellings even to water resources, water reserves and other activities in the study area with precipitation of the order of 55.94 mm and 120.75 mm, this having return periods between 2 and 5 years. Then, we note that there are extremely wet days estimated at 163.66 mm, 204.81 mm are capable of causing average damage in the study area, they have a return period which is between 10 and 20 years. And finally the rare extreme humidities are caused by extremely humid days whose return periods are between 50 and 100 years with estimated values of 258.09 mm to 298.01 mm.

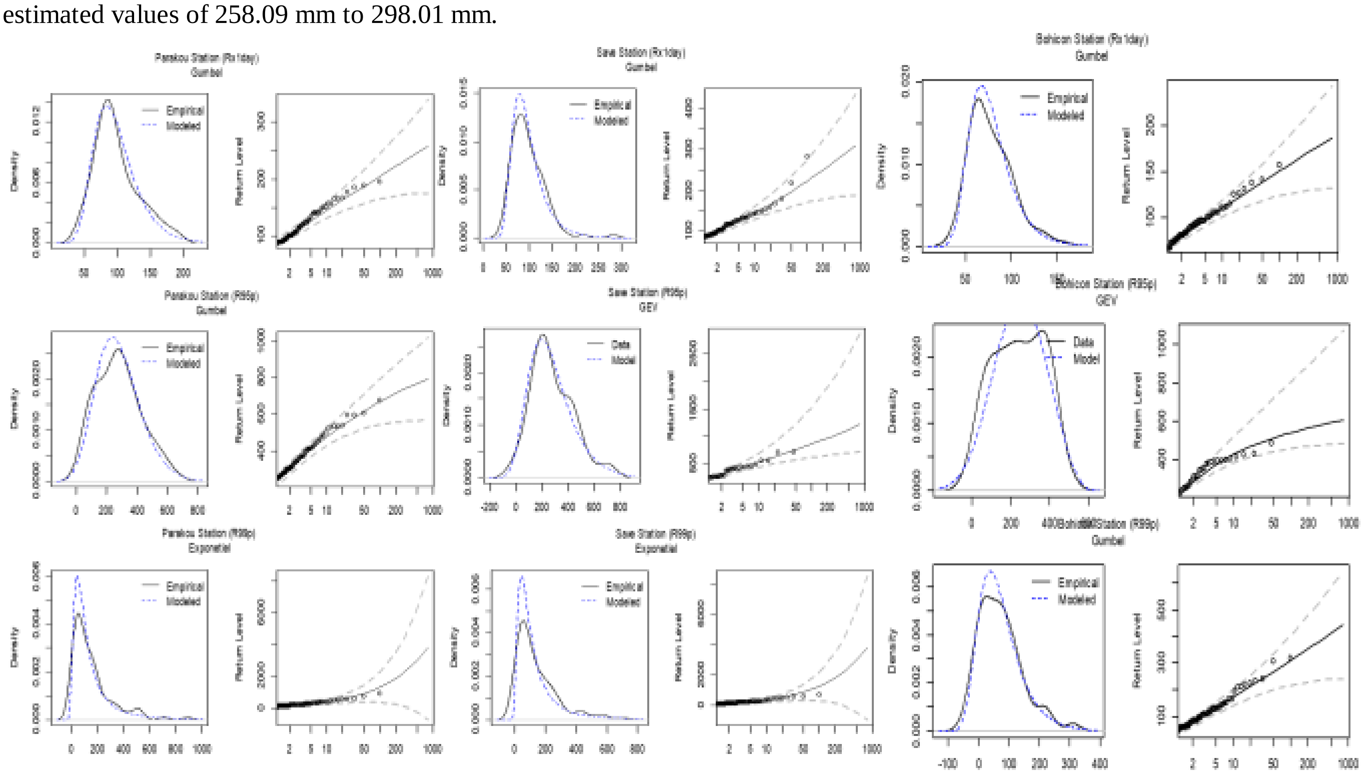

Figure 3:- Adjustments of laws to extreme rainfall indices (R1xday, R95p, R99p) in Parakou, Bohicon and Savè.

Vulnerability to flooding

Several methods allow the determination of vulnerability to flooding. Given the existence of the data, the cartographic method was used. To map the level of vulnerability to flooding in the Agro Ecological Zone V the reclassification of several thematic maps have been established. Figure 4a presents the vulnerability of agroecological zone 5 in Benin to flooding. The analysis of Figure 4a makes it possible to identify four zones whose vulnerability to flooding varies from low to very high. Areas of low vulnerability to flooding cover 12% of the total area of the study area and are scattered especially in the eastern part, precisely in the localities of Tchaourou and Savè. Areas of medium vulnerability to flooding correspond to areas with medium slope where runoff on the slopes does not allow water to stagnate. These areas occupy 22% of the total area. Areas of high vulnerability to flooding occupy 48%, they correspond to plains subject to submersion and are located near watercourses. The agglomeration of Kétou is an area very highly vulnerable to flooding. They occupy 17% of the territory and are located near the major bed and at the lowest points of the major bed of the Ouémé River and its tributaries.

From the analysis of Figure 4b, flood hazards in the study area are classified into four levels; that is to say from weak to very strong passing through medium and strong. It appears that low hazards occupy 10% of the total area of Agro-Ecological Zone 5 and are mainly located in sectors with plant cover (Clear forest and wooded savannah; Dense forest; Tree and shrub savannah) they are more hidden in the southern part of the Study Area. The medium hazard zones are located in the zones of medium vegetation cover (Gallery forest and riparian formation; Forest and swampy savannah) they cover 37% and are found in areas such as Dassa-Zoumey. The high hazard areas are located at the level of the cultivation and plantation areas, they occupy 17% of the total area. Finally, the areas of very high hazard are located in agglomerations and around bodies of water. The flood risks were determined by superimposing the flood vulnerability maps and that of the hazard which is the triggering factor of the flood. Figure 4c shows the sectors at risk of flooding in Agro-Ecological Zone 5. The risk levels are classified into 04 classes which are low, medium, high and very high levels. Medium flood risk areas cover 30%. The regions of high risk of flooding represent 24% of the area of the study area and are located in the regions of Djidja and Abomey. Finally, the areas of very high risk of flooding are found on 24% of the total area of the study area and are located in the regions of Savalou, Kétou and Aplahoué.

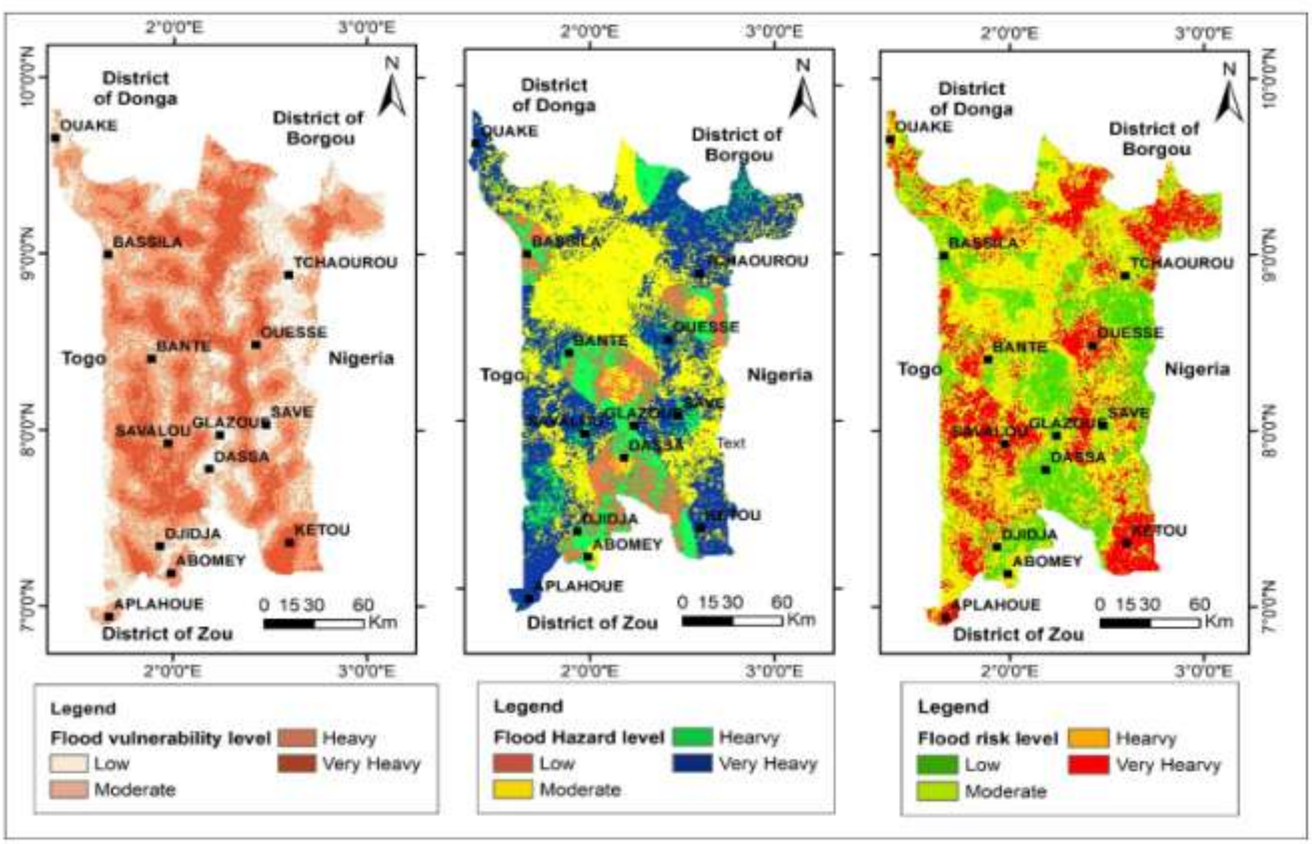

Figure 4:- Flood Vulnerability Map, Flood Hazard Map and Flood Risk Map of Agroecological Zone 5 in Benin.

Discussion:-

The characterization of rainfall extremes makes it possible to know the intensity of rainfall events. For this study, extreme events are characterized by extreme indices (Rx1day, R95p and R99p). These indices represent the maximum amount of rain in one day, very wet days and excessively wet days respectively (Xuebin Zhang et al, 2004). The results of this study show that the different return dates of extreme events are 2, 5, 10, 20, 50 and 100 years. In addition, the results show that the maximum amount of rainfall in Bohicon, Parakou and Savè are estimated at 159 mm, 180 mm and 139 mm for a return period of 100 years. That is to say that these events have a probability of 0.01% chance of occurring. However, the concentration of rainfall quantiles (heavy, very heavy and extremely heavy) could largely contribute to extreme events, including floods which are not without consequences on the dynamics of the basin and on the socio-economic life of the populations living there. (Amoussou, et al., 2015).

The mapping study of areas at risk of flooding in the agro-ecological zone was carried out by combining Landsat OLI 8 type satellite data, MNT, geological and rainfall data.

Zones of medium and high vulnerability represent respectively 12% and 22% of agro-ecological zone 5. This level of vulnerability to flooding is due to the fact that they have a low slope and constitute a plain. The characteristic geological layers of these areas is the continental terminal made up of sand, clay and sandstone. This geological layer is present near watercourses in the plains. The flood hazard is the probability of occurrence or occurrence of the flood phenomenon. It is determined from rainfall intensities and land use units. The low hazard level represents 9% of agro-ecological zone V. This low percentage is explained by the presence of dense plant cover which reduces the speed of water flow and promotes water infiltration. . Medium and high hazard zones represent respectively 37% and 17% of the study environment. These areas are made up of gallery forest, marshy formations and crops and fallow land. Gallery forests and swampy formations are present on the banks of watercourses, which induce their low capacity to resist flooding. It is noted that this high level of hazard in agro-ecological zone V is due to human activities, including massive deforestation to make way for crop and fallow mosaics and construction on the beds of watercourses.

The risk of flooding is the intersection of vulnerability to hazard. The medium and high risk areas represent respectively 30% and 24% of the study area. This part of agro-ecological zone V is located near watercourses corresponding to alluvial plains and major river beds. The results obtained at the end of this study are in phase with those of Koumassi (2014) and Atiyè (2017). These various works carried out respectively in the Sota basin at the Coubérie outlet, the Benin basin of the Mono river at the Athiémé outlet and the Zou basin at the Atchérigbé outlet have revealed that the most vulnerable areas to flooding are located near the minor bed and at the lowest points of the major bed of watercourses. Similarly, areas at high risk of flooding are located in the plains along watercourses and bodies of water. The determination of the slope is of great importance in determining the vulnerable zones. Areas with low slopes (<5%) are the most exposed to the risk of flooding. AbdelazizRhazi al., (2017), Gbaguidi Brice (2011) and Armand Kangah et al., (2015) showed in their work that a relatively flat relief is not favorable to natural drainage, which could accentuate flooding.

Conclusion:-

The characterization of extreme events is essential for decision-making. This study was a contribution to the mapping of the risk of flooding in Agro-ecological zone 5. It consisted first of all in the analysis of the occurrence of extreme rainfall events, the combination of thematic maps (vulnerability and flood hazard).

To achieve the objective of this study, various rainfall and topographic data were used. And the development of an appropriate methodological approach based on frequency analysis and the combination of different physical factors by Multicriteria Analysis (MCA) method.

After applying the frequency analysis method to the various extreme indices, we find that excessively wet days are estimated at 298 mm, 1350 mm and 1293 mm for a return period of 100 years respectively at Bohicon, ParakouSavè. Estimation of quantiles in turn show that extreme events are likely to recur with an intensity proportional to the return period. The rarest events will therefore be the most violent. In addition, the flood risk map makes it possible to assess the proportions occupied by each level of risk over the area of the study area. Thus 30% of the total area is covered by the medium risk of flooding and 24% of the total area is covered by the high and very high risk of flooding.

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