International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
Foundation of Computer Science FCS, New York, USA
Volume 12 – No. 15, September 2018 – www.ijais.org

Realization of an Early Flood Warning System in the Abobo Commune (Abidjan, Côte D'ivoire): Contributions of HEC-GEORAS and HEC-RAS

Délla André Alla
(IGT)
Institute of Tropical Geography
F. H. Boigny University
(Abidjan, Côte d'Ivoire)

Kan Désiré Kouassi
(CURAT)
University Center for Researchand Application in Remote Sensing
F. H. Boigny University
(Abidjan, Côte d'Ivoire)

Boyossoro Hélène Kouadio
(CURAT)
Researchand Application in Remote Sensing
F. H. Boigny University
(Abidjan, Côte d'Ivoire)

Bachir Mahaman Saley
(CURAT)
University Center for Researchand Application in Remote Sensing
F. H. Boigny University
(Abidjan, Côte d'Ivoire)

Yao Simon Dedjo
Kobe Institute of Computing Information Technology
Engineer, Graduate School of Information Technology, Kobe, Japan

Kouamé Simon Saraka
(CURAT)
Researchand Application in Remote Sensing
F. H. Boigny University
(Abidjan, Côte d'Ivoire)

ABSTRACT
Among the ten communes of Abidjan, Abobo has the sad reputation of being the most vulnerable to the risk of flooding because of its recurrence and the many victims and material damage it causes each year. The demolition of dwellings in the numerous basins is causing more and more households to settle in the Sagbé and Anonkoi Kouté watershed valleys. This makes these populations more vulnerable to floods. This study was initiated to study its drainage system in order to limit the vulnerability of the stakes. The main goal is to prevent the risk of flooding with high performing tools and high precision. For this purpose, data were first collected on the study area. Then a flood simulation model was created. Finally, the future floods of the study area were simulated using the tools HEC-GeoRAS and HEC-RAS. The results of this study made it possible to know the influence of the floods in the valleys of the Sagbé-Anonkoi Kouté watershed, and to make flood maps for the return periods of 5, 25; 50; and 100 years, to facilitate decision-making.

Keywords
Abidjan, abobo, flood, risk

1. INTRODUCTION
In Africa, floods have become classic hazards (DAVİD, 2004) due to climate change (MAGNAN, 2009, N'GUESSAN BI, 2014, etc.). If this trend continue, modeling **predicts** that by 2050, sub-Saharan Africa will experience a warming of 0.5 to 2 ° C, and the consequences will be dramatic (YAMIN et *al*., 2006). According to previous studies (ALLA, 2013, BANI and YONKEU, 2016, etc.), the frequency of floods in recent years is favored by the uncontrolled occupation of urban spaces and areas not suitable for habitation. This situation, combined with the lack of an adequate sanitation policy, will expose more human settlements to recurring floods, thus increasing the vulnerability of populations (BANI and YONKEU, 2016). This is the case in the commune of Abobo where after the occupation of basins, the current trend is the colonization of the valleys, thus accentuating the urban disorder. That said, the situation in Abobo which is already alarming will be catastrophic if no durable solution is proposed to reduce areas at risk of flooding. The purpose of this article is therefore to forecast the risk of flooding incurred by the population around the valleys of the Anonkoi Kouté / Sagbé watershed, in the municipality of Abobo. A modeling of this network, true to the reality would allow to simulate the conditions of flow which reigns there with a high reliability and the capability to solve durably the problem of flood in the area.

1.1 Objectives
The main objective of this study is to prevent the risk of flooding with high-performance and high-precision tools.

It will be specific to :

1- collect basic data on the elements of the drainage system of the watershed under study;

2-create a flood simulation model, to simulate future floods with reliability;

3- simulate future floods, with a view of producing flood maps for use in raising public awareness and facilitate decision-making.

1.2 Presentation of the Study Area
The commune of Abobo is one of ten (10) communes of the city of Abidjan. Located in its northern part (Figure 1). It was reared as a full-function commune by Law No. 80-1182 of 17

October 1980 on the municipal organization of the Republic of Côte d'Ivoire. It covers an area of 112,72 km2 and is subdivided into twenty-eight (28) districts (PRİ-Cİ, 2016). It is inhabited by a total of 1,030,658 inhabitants according to the 2014 data of the National Institute Statistics (INS). However, the high rainfall pattern of Abidjan, the physical peculiarities of Abobo, as well as its land-use pattern exposes many of its neighborhoods to recurring floods.The commune of Abobo has 19 watersheds, the largest of which has an area of 17.1 km2. The flood warning system set up in this study concerns the BANCO (BC) watercourse draining the Abobo Sagbé-Anonkoi Kouté watershed, consisting of an 8.5 km2 urban area located south-west of Abobo. It includes Anoukoua-kouté, Anonkoua, Abobo-Sagbé Nord, and Sagbé Sud and part of the Banco forest (Figures 2 and 3). This watershed opens in Banco Bay (PRI-CI, 2016).

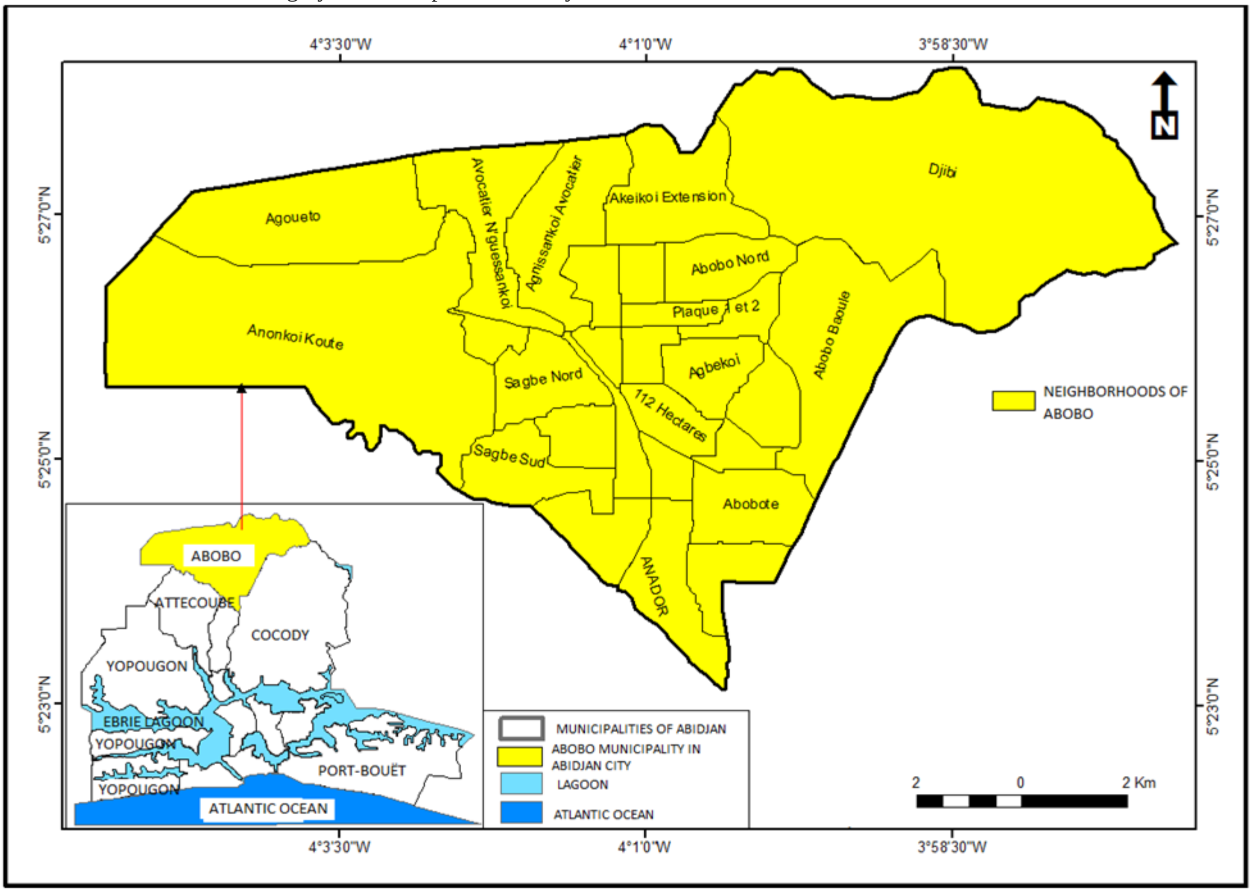

Fig 1. Location of Abobo municipality in Abidjan city

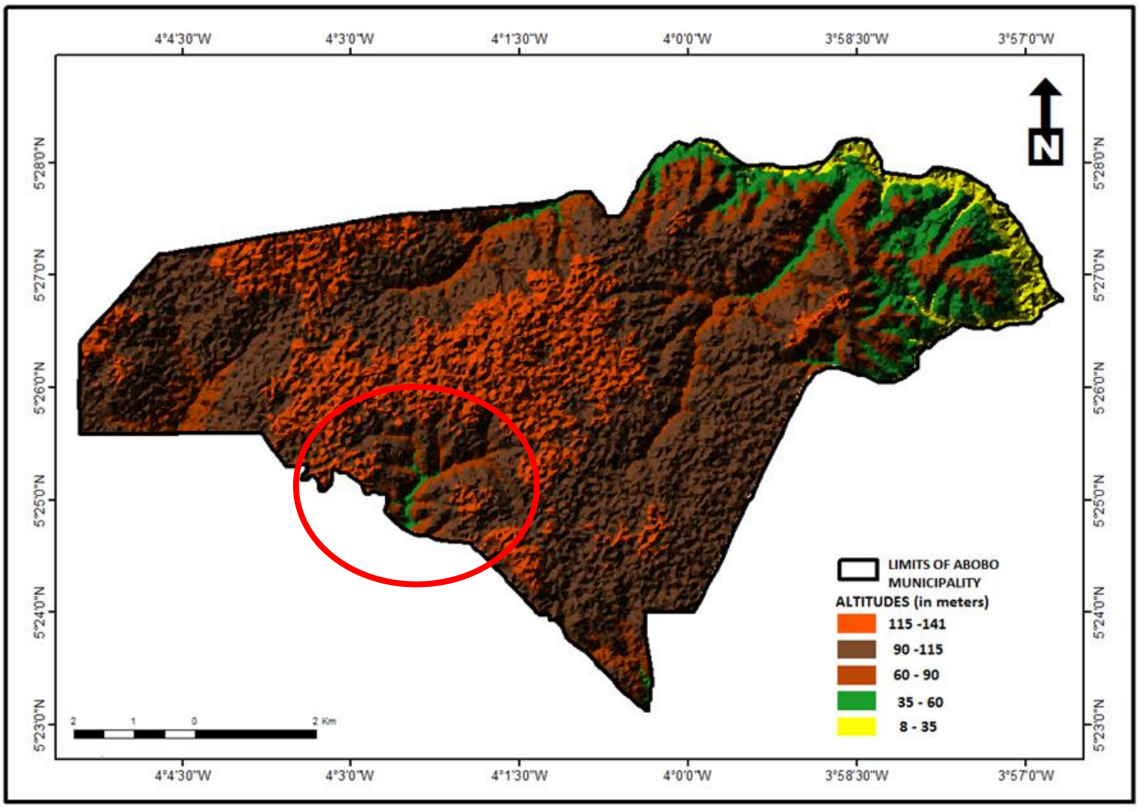

Fig 2: Location of the Sagbé-Anonkoi Kouté watershed (in the red circle), in Abobo municipality Digital Elevation Model

2. MATERIEL AND METHODS

2.1 Materials

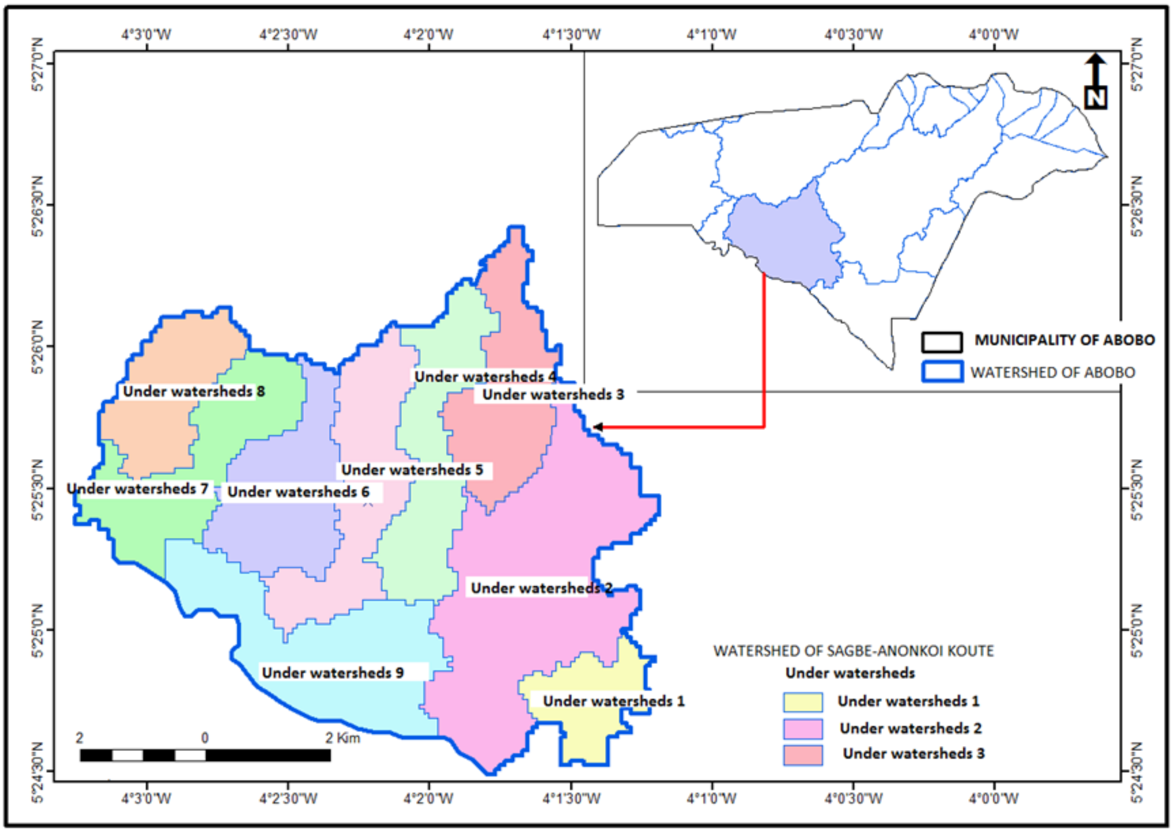

Fig 3: Location of Sagbé-Anonkoi Kouté watershed in Abobo municipality

The computer hardware used in the data processing in this study consists of Geographic Information System (GIS) software and flood risk simulation tools. In total, three tools were used to generate the flood risk simulation. These are two extensions of the ESRI (Environmental Systems Research Institute) software Arc.Gis.10.3.1, which have been downloaded to extend its scope of treatment:

- the tool, ARCHYDRO, which was used to extract the drainage network from the study area and tracing of the flood zones;

- HEC-GeoRAS was used to pre-process a portion of the SRTM image for the execution of the model that served as a flood warning;

- hydraulic simulation software HEC-RAS .5.03, created by US Army engineers, which allowed the geometric model to be executed;

Other tools were also used during this study.

- Thus, at the end of the treatments, the ArcMap tool of the software Arc.Gis.10.3.1 was used for cartographic restitutions;

- GPS has also been used to lift points;

- likewise, a " baseMap " image incorporated in Arc.Gis.10.3.1, for the accuracy of the digitization;

- The IFAS tool was used to correct satellite precipitation data;

- The land use map was used to calculate the roughness of the soil according to the runoff coefficient of the city of Abidjan which is 0.70%, according to SIGHOMNOU (1983).

2.2 Data

This study also benefited from the input of several data. It included:

- data on previous floods collected from various sources (government agency reports, newspapers, international reports);

- Precipitation data and hydrological units. Here, two categories of rainfall data are considered: this is on the one hand rainfall data in situ obtained at the Company Development and Aeronautical Exploitation, Airport and Meteorological (SODEXAM), and secondly satellite data, downloaded free of charge from the website of the Japan Aerospace Operations Agency (JAXA). Rainfall data were used to calculate the discharge.

- two SRTM images of Abidjan and its surroundings (precisely scenes 04 and 05), with a resolution of 30 m were used. The region of interest of the SRTM image has been transformed into TIN, as required by HEC-GeoRAS.

For the realization of the model which made it possible to simulate the floods, the parameters required as input are:

- the amount of rain in mm / hour;

- the amount of rain in m / second (it comes from the conversion of the amount of rain in mm / hour);

- the rainfall runoff coefficient in the city of Abidjan.

- the total area of each set of sub-basins drained by each watercourse.

2.3 Methods

2.3.1. Collection of basic data on the study area

2.3.1.1. Calculation of the period of return of extreme precipitation

Daily rainfall data over a period of 43 years (1971 - 2014) provided by SODEXAM were collected. This exercise is important and helps to know how much precipitation is likely to cause flooding in the study area. It also calculates the probability of the occurrence of extreme events of rain (equation 1) and the return period of extreme precipitation (equation 2 and table I) (DEDJO, 2016).

$$\textbf{Probability of occurrence } (\%) = \frac{r\_0{,}44}{n+0{,}12} x100 \quad (1)$$

(1) (GRINGORTEN, 1983)

Where: **r** represents the rank and **n**, the number of observations.

$$\textbf{Return period } (\textbf{Tx}) = \frac{100}{Px} \quad (2)$$

Table I: correlation Between Return Period and Daily Rainfall (DEDJO, 2016)

Return period Tx (year)	Probability (Px) an	Estimation of the quantity of daily rainfall (mm)
1	100	86,33
2	50	119,34
5	20	162,97
10	10	195,98
25	4	239,61
50	2	272,62
100	1	305,62

The data contained in this table I can be interpreted as follows:

- the probability that a rainfall of 86.33 mm falls in Abidjan in one year is 1% (recurrence 1/100 years) (line 1);

- the probability that a rainfall of 119.34 falls in Abidjan in one year is 2% (recurrence 1/50 years) (line 2);

2.3.1.2. Calculation of input and output flows of sub-basins

Depending on the directions of flow in the watershed and sub-basins were grouped together. Thus four large sets have been created and their area, inflow and outflow rates have been calculated (Figures 4 and 5).

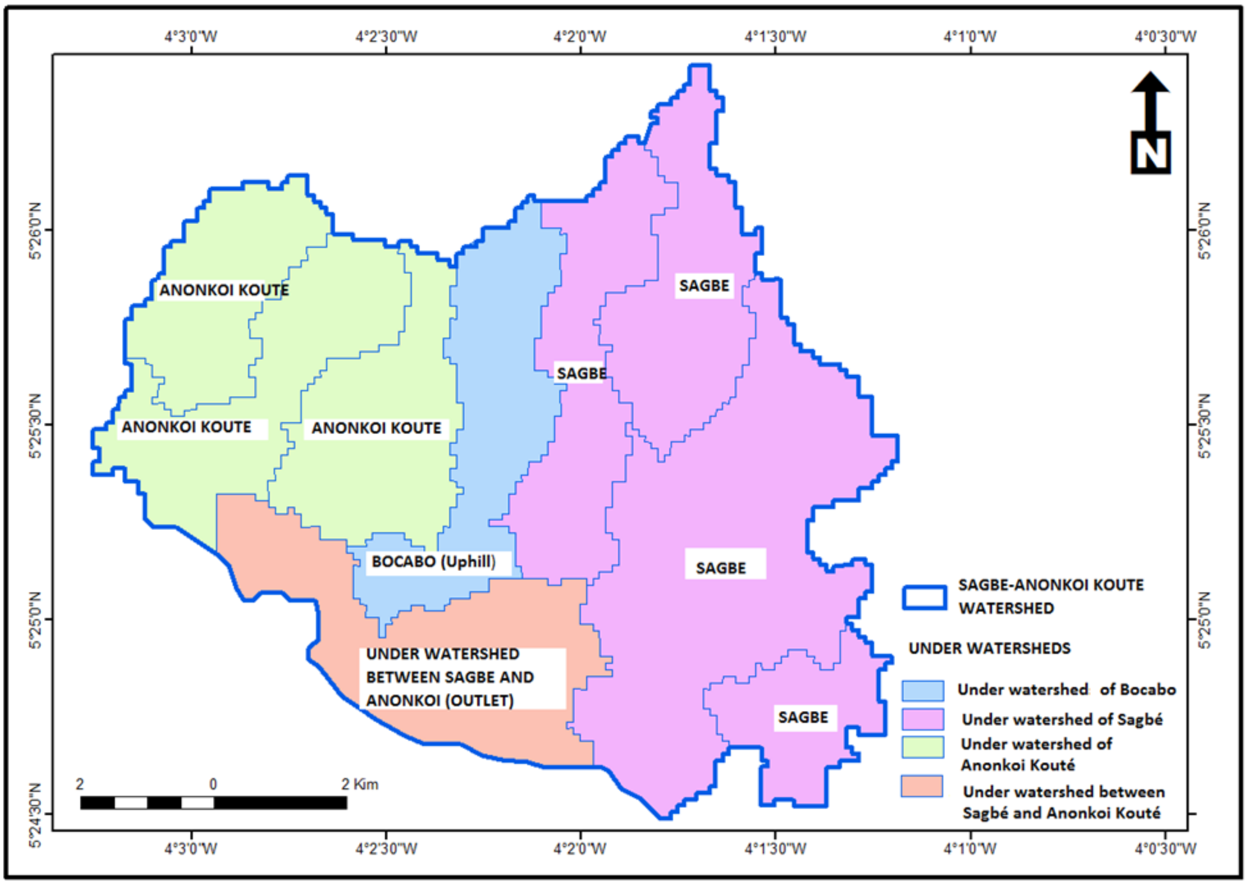

Fig. 4: Sagbé-Anonkoi Kouté subwatershed grouped into four major groups

2.3.2. Creating a Flood Simulation Model

2.3.2.1 Simulation of an earlier flood

A previous study on the commune of Cocody (a commune in the West of Abobo), undertaken by DEDJO (2016) has made it possible to build a model to simulate an earlier flood (Figure 5), in order to simulate future floods in the city in Abidjan. This is the flood following the precipitations of June 29 to July 1, 2014 which caused a large number of casualties and a lot of material damages. The rainfall corresponding to this flood was extracted from the JAXA global precipitation data archive, obtained from satellite mapping. These data were then corrected using the IFAS tool. Finally, they were introduced into the model to estimate the 5, 50 and 100 year runoff and return period for each sub-basin (DEDJO, 2016).

2.3.2.2. Validation of the model

A questionnaire interview was conducted with 92 residents of the commune of Cocody in order to compare the results of the modeling to the realities experienced by the populations, in particular the magnitude and the duration of the flood, as well as the depth of the 'water. This interview confirmed the simulation results that made it possible to identify the flood zones in the municipality of Cocody (DEDJO, 2016).

2.3.3. Simulation of Future Floods in the Study Area

The simulation phase of future floods was done on HEC-GeoRAS, allowing ArcGIS to preprocess the data and create geospatial information that can be used by the HEC-RAS program. This study uses HEC-GeoRAS version 3.

Return Period	5	10	25	50	100
Flow (ft/s)					
Flow (m3/s)					

5-year — Cubic feet per second

HydroID	RiverCode	ReachCode	1mm/h to 1m/s	Rain(mm/h) 5-y	Runoff (coef	Drainage (m2)	Discharge Q(m3/s)	Discharge Q(ft/s
1	Bocabo	Tributaire	2.77778E-07	8.65	0.70	847,809.92	1.43	50
2	Sagbe	Tributaire	2.77778E-07	8.65	0.70	39,088,685.37	65.74	2322
3	Anonkoi	Tributaire	2.77778E-07	8.65	0.70	2,221,210.41	3.74	132
4	Sagbe	Emissaire	2.77778E-07	8.65	0.70	43,269,725.11	72.78	2570

10-year

HydroID	RiverCode	ReachCode	1mm/h to 1m/s	Rain(mm/h) 5-y	Runoff (coef	Drainage (m2)	Discharge Q(m3/s)	Discharge Q(ft/s
1	Bocabo	Tributaire	2.77778E-07	23.17	0.70	847809.92	3.82	135
2	Sagbe	Tributaire	2.77778E-07	23.17	0.70	39088685.37	176.11	6219
3	Anonkoi	Tributaire	2.77778E-07	23.17	0.70	2,221,210.41	10.01	353
4	Sagbe	Emissaire	2.77778E-07	23.17	0.70	43,269,725.11	194.94	6884

25year

Fig 5: Shows the calibration model used to calculate drainage area and runoff rates for sub-basins

2.3.3.1. Pretreatment of data in HEC-GeoRAS

The use of HEC-GeoRAS for pretreatment involves, first of all, creation of attributes (population of layers) in ArcGIS, then exporting them to the HEC-RAS geometry file (DEBIANE, 2010; MERWADE, 2016).

This pretreatment procedure consists of digitizing over the TIN, the layers generated automatically by HEC-GeoRAS (DEBIANE, 2010, BOZZA, 2012, MENDİZABAL, 2016, MERWADE, 2016, DÉDJO, 2016). The digitized layers are listed and presented below (Figure 6).

- the central flow layers (river centerline). However, here the previously imported drainage network vector file was directly used as the central flow layers;

- the minor bed (River banks);

- the major bed (flowpaths);

- cross sections or cross sections (XSCutLines). These are segments perpendicular to the lines);

- Introduction of Manning values.

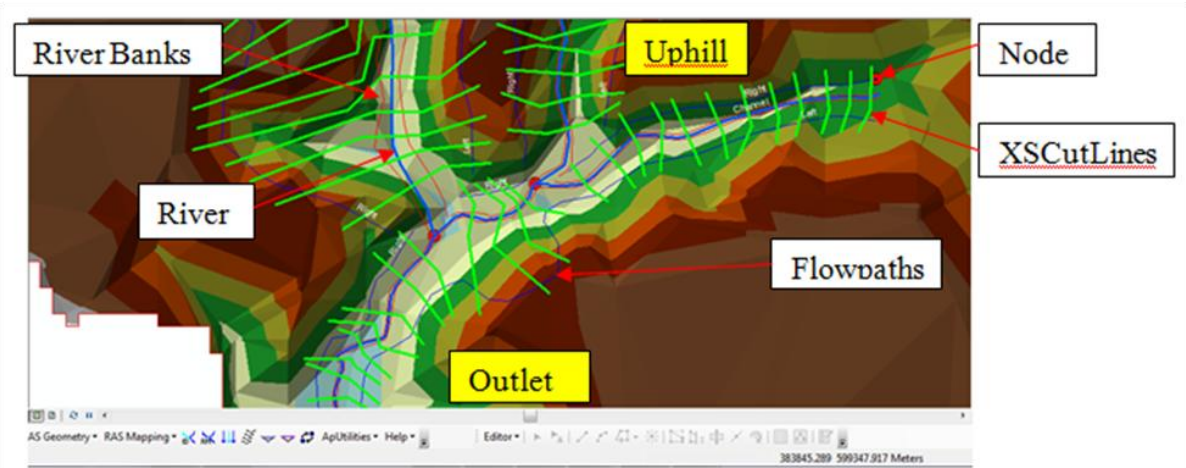

Fig. 6: Scanning on the TIN or preprocessing phase on HEC-GeoRAS

2.3.3.2. Hydraulic Simulation

In HEC-RAS software, in addition to the geometric schematics, the runoff discharge values of different rain event return periods (5, 50, and 100) were also entered into the HEC-RAS program by calculating water level for each cross section for each watershed. Then, the model was run to obtain the floodplain, depth, and velocity for each return period and for each watershed. Finally, the modeling results were exported in ArcGIS for analysis and mapping.

2.3.3.3. Validation of preprocessing and simulation

The validation of preprocessing (HEC-GeoRAS) and simulations (on HEC-RAS) is automatic. Indeed, at the end of each process a message of success testifies to the validation of the operations.

3. RESULTS

3.1. Viewing results on ArcMap

Processed data on HEC-RAS was exported to ArcMap for post-processing. These are in fact cartographic restitutions of flood maps over the return periods of 5 years, 25 years, 50 years and 100 years.

3.1.1. Flood Maps

Figures (7, 8, 9, and 10) show flood control maps for the 5-year, 25-year, 50-year, and 100-year return periods, respectively. In other words:

- the probability that the amount of rain in figure (7) falls in one year is 1/5 x 100, or 20%;

- the probability that the amount of rain in figure (8) falls in one year is 1/25 x 100, or 4%;

-The probability that the amount of rain in Figure 52 falls in one year is 1/50 x 100 = 2%;

-The probability that the amount of rain in Figure 53 falls in one year is 1/100 x 100 = 1%.

The various flood maps below (figures 7, 8, 9 and 10) reveal that the thalwegs are indeed flood-risk areas. The evolution of flood rows according to the return periods is not noticeable on the different cards taken individually. This can be explained by the fact that the floods rows evolve more in height than in width because of the configuration of the valleys which are narrower than wide. However, in some places on the maps, flood rights are perceptible in width. This shows, therefore, that the dwellings located in the bottom of the valleys will be very soon submerged by runoff. Over time, those located in the major beds and certainly beyond, will also be flooded.

3.1.2. Validation of the Cartographic Results

The flood zones identified and mapped as part of this study were validated by the results of the work of the consultants of the Environmental and Social Impact Assessment (ESIA), who worked on the same study area with the HEC software.-ras. This is the Group formed by the companies ROCHE Ltée (Canada), CONCEPT S.A. (Tunisia) and MENSO SARL (Ivory Coast). These consultants did not produce maps as did this study, only the flood zones were represented in the different thalwegs from a Google Earth image. Their study identified eight (8) localized flood zones that can be the site of catastrophic damage (PRI-CI, 2016). These flood zones correspond to the right-of-way of the flood identified by this study (Fig. 11).

4. DISCUSSION

Flood risk prediction is part of a risk management approach. It can predict future floods and set up an early warning system to anticipate risk. It is in this context that several future flood warning maps were then produced to predict the flood risk (on return periods of 5, 25, 50, and 100 years) in a catchment area. voice of colonization. This discussion focuses on these key findings.

This study was able to model the elements of the drainage system of this flood risk zone in the process of colonization and set up an alert system to prevent future floods, for return periods of 5 years, 25 years, 50 years. years and 100 years. It has combined scientific research and engineering, particularly with the use of HEC-GeoRAS and HEC-RAS software.

This study can enable decision-makers to put in place a flood management plan. For example, as seen from the data in Table I, for to know how much rain can cause disasters in Abidjan.

It can also be used to resize the gutters, put in place a sanitizing director scheme, etc. It can go further to calculate the hydrodynamic force of the flowing water from which we can determine whether a dwelling can withstand during a flood or not. It can also be used in insured houses to calculate the risks to which clients are exposed and to calculate the amount of damages to be paid to a client.

5. CONCLUSION

In the end, this study carried out an early warning map of flooding for the municipality of Abobo. This map is an important tool for flood forecasting in the municipality. The results obtained will enable the authorities to develop risk management programmes, to carry out infrastructures, etc., in order to improve the resistence of the populations of Abobo in the face of flood risk. HEC-GeoRAS and HEC-RAS can also be used for other studies in several localities such as high performance tools.

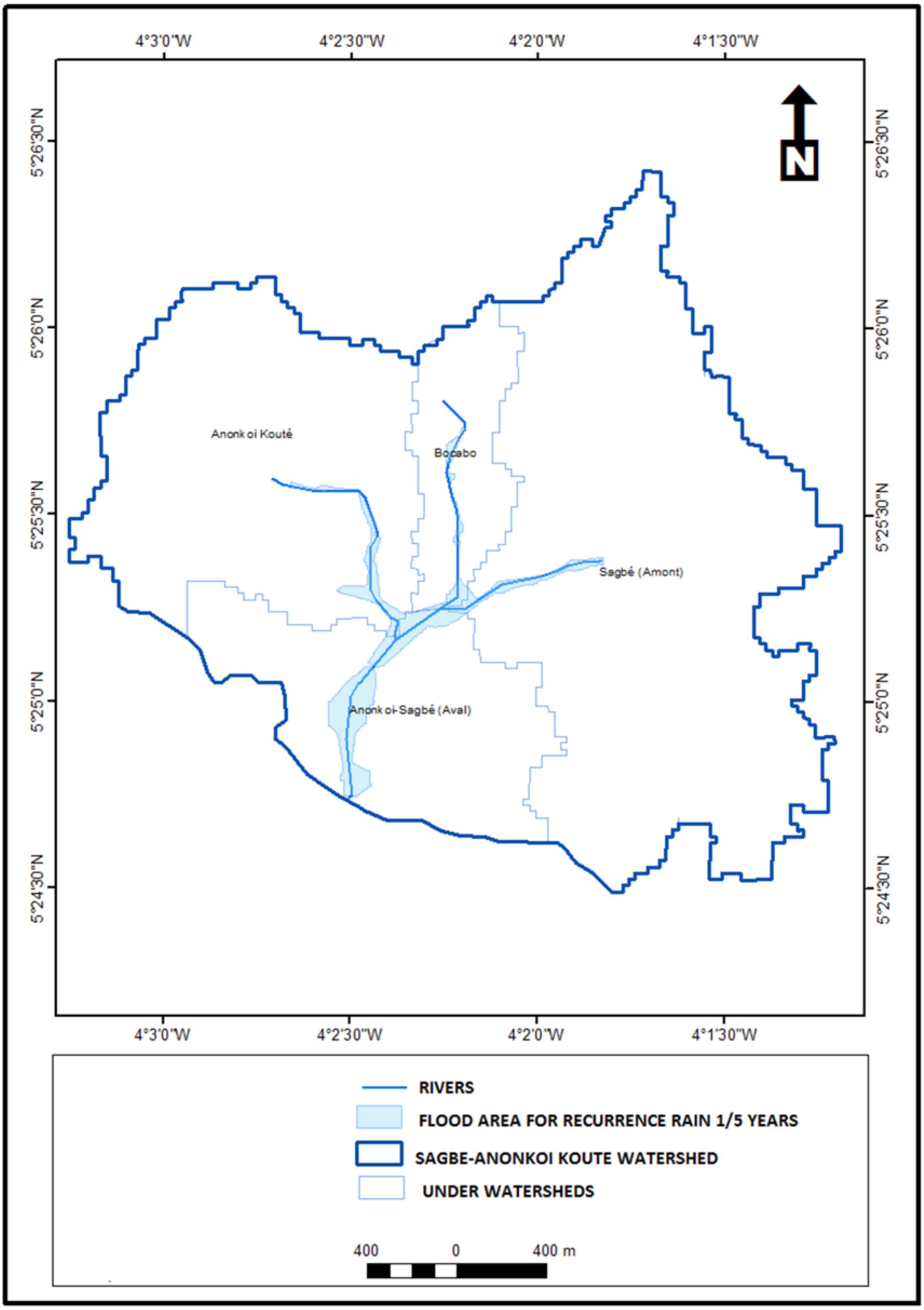

Fig. 7: Flood area for recurrence rain 1/5 years

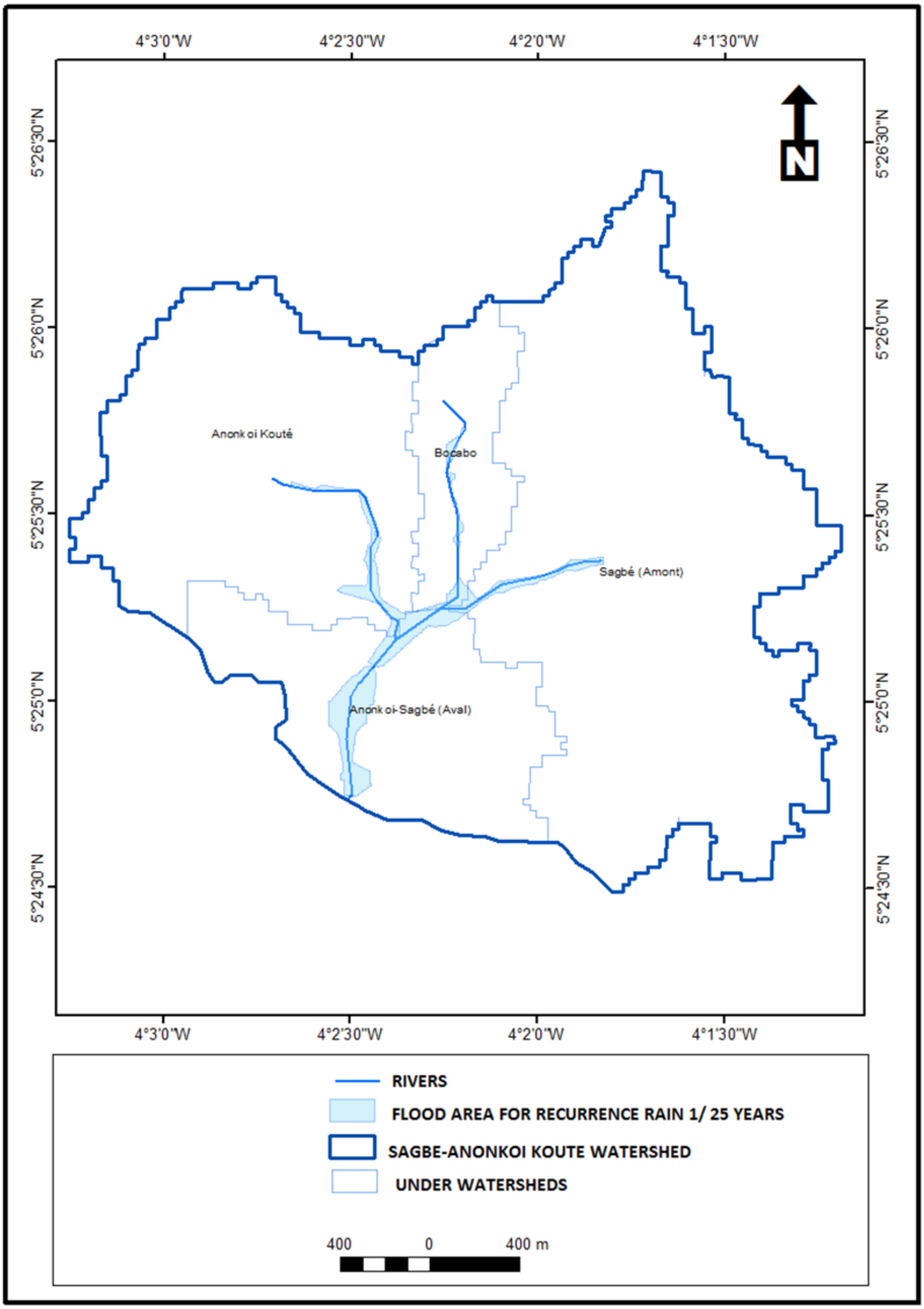

Fig 8: Flood Area for Recurrence Rain 1/25 Years

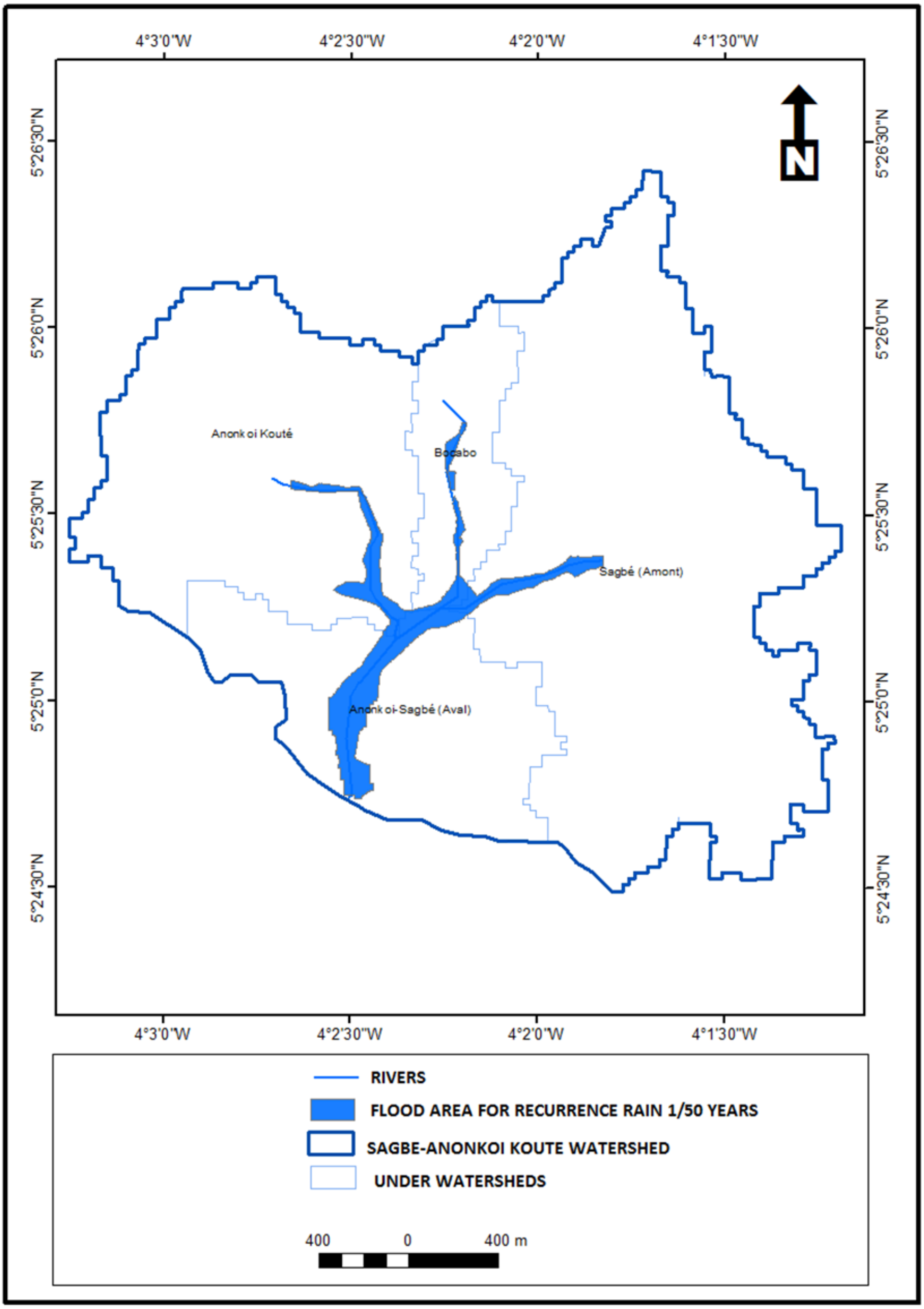

Fig. 9: Flood Area for Recurrence Rain 1/50 years

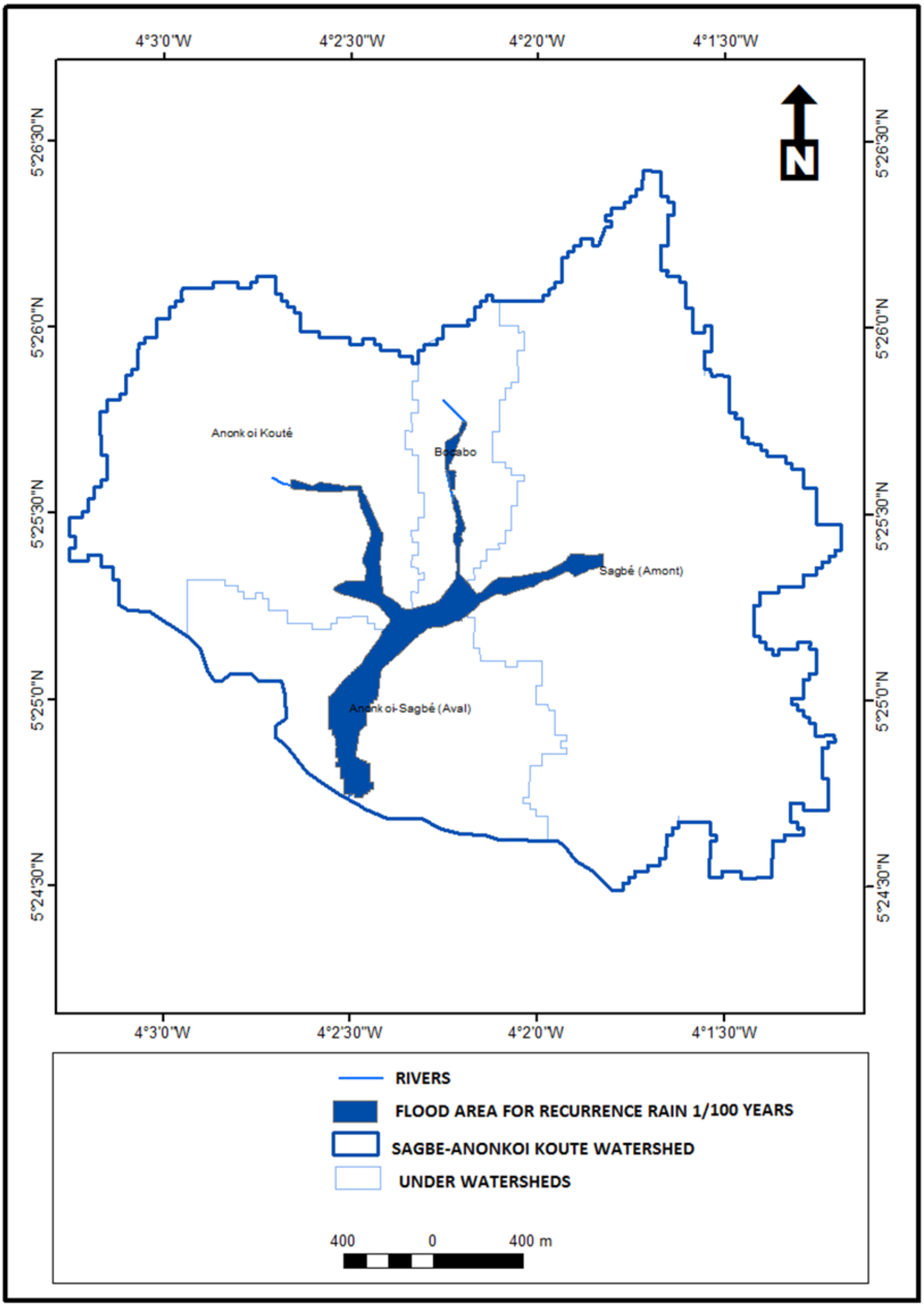

Fig. 10: Flood area for recurrence rain 1/100 years

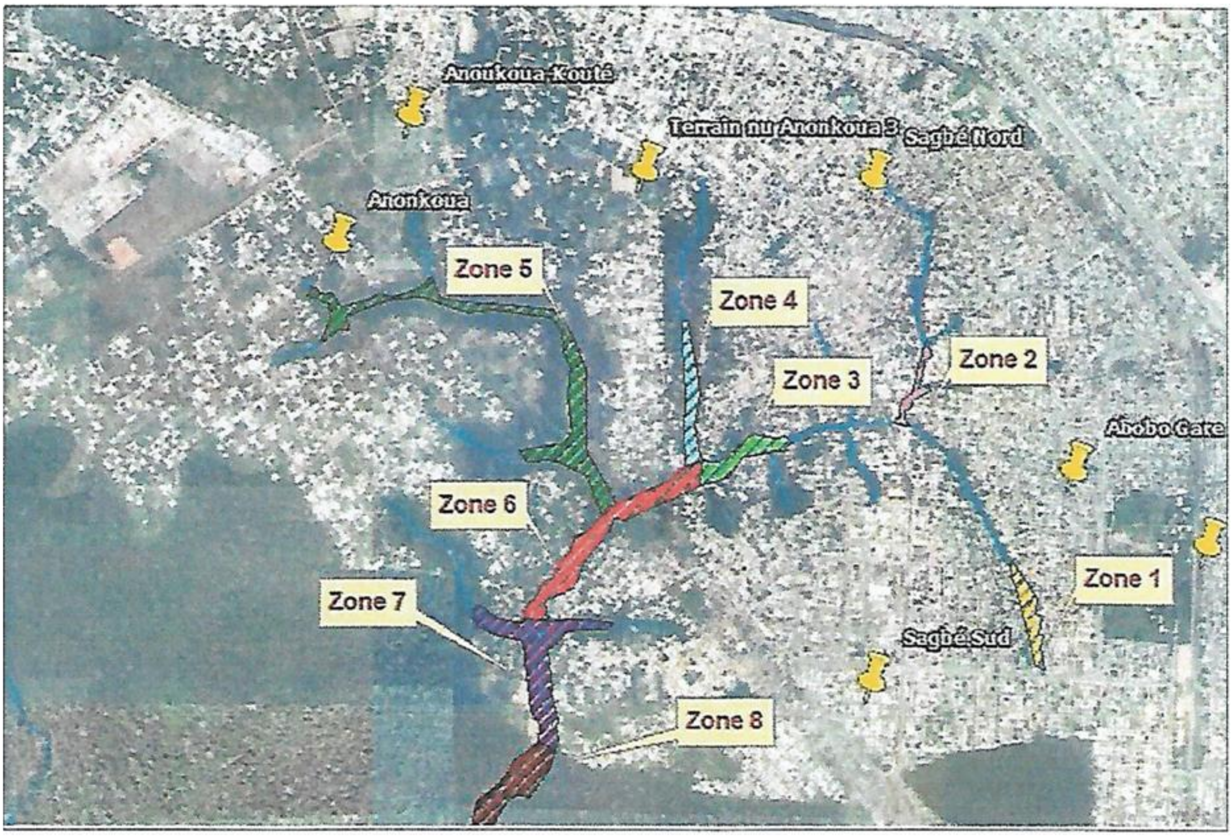

Fig. 11: Flood Zones Located by Consultants in Sagbé-Anonkoi Kouté Watershed (in Abobo municipality) on a Google Eath Image

6. ACKNOWLEDGMENT
We express our thanks to Mary Ann Ifunanya Onuoha (Kwame NKRUMA University of Science and Technology, Kumasi, Ghana) and Mouassom Claudie Lauraine (Douala, Cameroon), for their contribution to the translation of our manuscript into English.

7. REFERENCES
[1] **DAVID, G. 2004**. Espaces Tropicaux et Risques : Du Local au global ; Actes des X^{e} journées de Géographie Tropicale, IRD, collection du CEDETE, 449.

[2] **MAGNAN, A. 2009.** La vulnérabilité des territoires aux changements climatiques : Mise au point conceptuel et facteurs d'influence, hypoesthésies de recherche, de l'institut de développement durable et des relations international (IDDI), Changements climatique n° 01/2009 30 p.

[3] **N'GUESSAN, BI. V. H., SALEY, M. B., WADE, S., DJAGOUA, E. V., KOUAMÉ, K. F., KOUADIO, A. 2014**. Cartographie du risque d'inondation par approche couplée de la télédétection et des Systèmes d'Informations Géographiques (SIG) dans le département de Sinfra (Centre ouest de la Côte d'Ivoire). European Scientific Journal, January 2014 edition vol. n°2, 22 .

[4] **YAMIN, F., ATIQ. R et HU, S. 2006.** Vulnérabilité, Catastrophe et changement climatique. Cahiers édités par le Centre Tricontinental, Louvain-la-Neuve, Alternatives Sud, Vol. XIII (2006)/2, 6 .

[5] **ALLA, D. A. 2013.** Cartographie des zones à risques d'inondation, d'érosion et de mouvement de terrain dans la ville d'Abidjan, PNUD, MESUDD, 37.

[6] **ALLA, D. A. 2013.** Risques naturels dans l'agglomération d'Abidjan (Côte d'Ivoire), Thèse de Doctorat d'Etat ès Sciences Humaines, Université Félix Houphouët-Boigny, UFR des Sciences de l'Homme et de la Société, Institut de Géographie Tropicale, 384.

[7] **BANI, S.S., YONKEU, S. 2016.** Risques d'inondation dans la ville de Ouagadougou : cartographie des zones à risques et mesures de prévention. Journal Ouest-Africain des Sciences de Gestion 1(1) :1-18.

[8] **PRI-CI. 2016**. Aménagement du réseau de drainage des Bassins Versants d'Abidjan Est et Ouest, Étude d'Impact Environnemental et Social 2ème Tranche ; 381.

[9] **SIGHOMNOU, D. 1983**. Étude du ruissellement en milieu urbain tropical humide (Abidjan - Yopougon), rapport d'élève en année de spécialisation, Office de la Recherche Scientifique et Technique Outre – Mer, Centre d' Adiopodoumé (Côte d'Ivoire), 80 .

[10] **DEDJO, Y. S. 2016.** Reducing Flood Risk in Megacity : Using Mobile Application and Value Capture for Flood Risk Prevention and Risk Reduction Finacing. Master of Science in Information Systèms, Kobe Institut of Computing. Graduate School of Information Technology, 68 p.

[11] WMO. 1983. Guide to climatological practice. Geneva, Switzerland: World Meteorological Organization.

[12] **DEBIANE, K. 2010**. Hydraulique, fluviale et torrentielle avec présentation et prise en main des logiciels HEC-RAS, ArcGis et HEC-GeoRAS, Réohydro, *3 BIS SCOP*, 162.

[13] **BOZZA, A. 2012**. Modélisation du risque de ruisselement et d'inondation à Port-au-Prince ; Rapport de stage de master 2 ; Université de Toulouse, SIGMA ; 56.

[14] **MENDIZABAL, S. 2016.** Modélisation et planification de l'évacuation de la zone nord dans la ville de Santa Fe de la Vera Cruz (province de Santa Fe, Argentine) contre le risque d'inondation, rapport de stage, Université de Toulouse Jean Jaurès, SIGMA, 87 p.

[15] **MERWADE, V. 2016**. Tutorial on using HEC-GeoRAS with ArcGIS 10.x and HEC-RAS Modeling, Purdue University, School of Civil Engineering, 38 p.