PREDICTION OF FLASH FLOOD SUSCEPTIBILITY USING FUZZY ANALYTICAL HIERARCHY PROCESS (FAHP) ALGORITHMS AND GIS: A STUDY CASE OF GUELMIM REGION IN SOUTHWESTERN OF MOROCCO

S. Talha[1,*], M. Maanan [3], H. Atika[4], H. Rhinane [2]

[1]University Hassan II, Faculty of Sciences Ain Chock, Department of Earth Sciences, Casablanca, Morocco - h.rhinane@gmail.com / talhasoukaina1@gmail.com .

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ABSTRACT:

In recent decades, many of the countries around the world as well as the south-western Morocco (Guelmim region, Assaka watershed), was subject to flood-storm causing huge human and material damages. The current study focuses on the Prediction of flash flood susceptibility using Fuzzy Analytical Hierarchy Process (FAHP) algorithms and Geographic Information System (GIS) technical. Flash floods areas were identified based on seven flash flood conditioning factors (Soil Moisture Index (SMI), Drainage Density, Rainfall, LULC, Altitude, Slope and Soil). Using AHP the weight derived for the factors were SMI 37% Rainfall 24.30%, Drainage Density 15.57%, LULC 9.98% Altitude 6.39% Slope of the river basin 4.06% and Soil type 2.70%. Then, applying a fuzzy inference system to create flash flood vulnerability maps. The resulting maps were classified into three categories: low, moderate and high flash flood susceptibility; indicated that the areas at the outlet of the watershed and which are close of the main affluent wadis (Seyyad and Oum Al-Achar) were very susceptible to flooding. This study will be helping these zones to be prioritized for the conservation and managing of flash floods.

1. INTRODUCTION

Flash floods are considered to be the most widespread natural disaster in the world in these recent decades. Their consequences are not only environmental but also humanical and economical, as they can cause damage to urban zones and cultivated fields and even death (Hallegatte, Hourcade, and Dumas 2007; Jongman et al. 2012; Jonkman et al. 2008).

Morocco is a North-African country, has faced many flood events in several regions due to the impact of climate change (Hoegh-Guldberg and Bruno 2010), therefore The Guelmim region that is located at the south-western of Morocco was the most affected area and declared as a “disaster area” by the Moroccan government. This region was not destroyed for the first time but it has been flooded various times during the past 50 years, specifically in 1968, 1985, 1989, 2002, 2010 and 2014 (TARGA-AIDE and Zurich Insurance 2014). In addition, the increase of flash floods and their destructive results around the world need a continuous improvement on identifying and mapping of flash flood risk. In recent years, flash flood risk susceptibility researches have been realized by many countries (Abdelkareem 2017; Carpenter et al. 1999; Chen, Hill, and Urbano 2009; Curebal et al. 2016; Dawod, Mirza, and Al-Ghamdi 2011; Elkhrachy 2015). However, various methods have been used to identify and evaluate flash flood vulnerable areas in Morocco (Boutaleb et al. 2018; Echogdali et al. 2018; Hakdaoui et al. 2019; El Khalki et al. 2018; Tramblay et al. 2012; Werren et al. 2016). And only a few methods have been used to evaluate flash flood susceptibility in Guelmim region. One of the first studies have used the Remote Sensing and GIS-Science for the Detection of Flooding-Prone Areas (Theilen-Willige et al. 2015). A second study was used the Topographic Attributes, Hydrologic Indices, and GIS for the Detection of Areas Associated with Flash Floods and Erosion Caused by Rainfall Storm (Bannari et al. 2016). In addition, another study did the Synergy between SMOS-MIRAS and Landsat-OLI/TIRS Data for Soil Moisture Mapping before, during, and after Flash-Flood Storm (Bannari, Rhinane, and Bahi n.d.). but all of these methods and studies are insufficient to give the most suitable result, for that reason, in this study case the fuzzy analytical hierarchy process (FAHP) algorithms was used for the first time to predict the flash flood susceptibility areas in Guelmim region. FAHP algorithms are more broadly used and it has been applied to a group of scientific domains (Environmental, Economical and Social). The above-mentioned studies contribute significantly and safely to comprising and removing the complication of the complex Problems by Combining the hierarchical algorithm with the fuzzification algorithm (Saaty 1989; Zadeh 1978). A lot of researchers have applied these algorithms to estimate the flash flood risk and detected that the FAHP help to get the most reliable results (Hategekimana et al. 2018; Motevalli and Vafakhah 2016; Papaioannou, Vasiliades, and Loukas 2015; Tazik et al. 2014; Yang, Ding, and Hou 2013).

2. MATERIALS AND METHODS

2.1 Study Area

The Assaka watershed is located in Guelmim-Oued Noun region (28˚59'17"N, 10˚03'327"W). A region that exists in south-western Morocco (Figure 1). The Assaka River drains a large watershed on the southwest border of the Anti-Atlas and its Saharan boundaries in the Guelmim region (Schulz, Busche, and Benbouziane 2008). It has considered to be the confluence of the wadis, Seyyad and Oum Al-Achar (Ryu et al. 1997), which crosses the last folded chains of the Anti- Atlas before continuing it is flowing process into the Atlantic Ocean with an estimated area of 6500 km2 (Bannari et al. n.d.). In this watersheds, there is a very dangerous area that is declared as "disaster area" by Morocco government because of the serious damage it can make. It's Guelmim city, which exists at the foot of the western Anti-Atlas Mountains with high peaks that are reaching more than 2100 meter, it has an arid to the semi-arid desert climate, it's temperature range varies from
12˚C in winter to 49˚C in summer and it's annually rainfall average is between 70 and 120 millimetres and their population is approximately 134030 hab (HCP 2014). finally, the useful agricultural area of Guelmim Region including 15000 ha irrigated (O.R.M.V 2019).

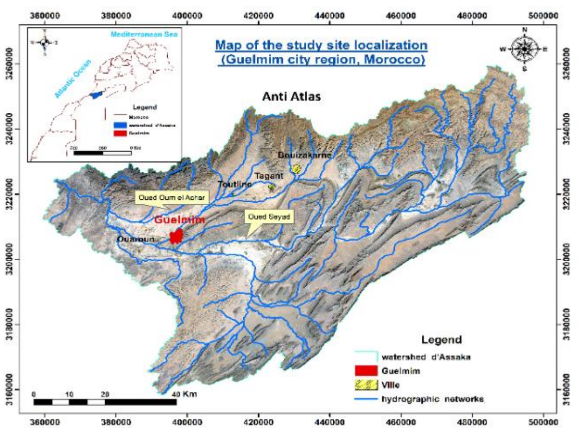

Figure 1. The Geographical Location of the Study Area

2.2 Data Used

The most important dates used in this study are Landsat-8 OLI Sensor and Global Digital Elevation Model (GDEM).

2.2.1 Landsat-8 OLI Sensor Data: Altitude is a natural topography representation (altimetry) of a terrestrial area. It's a very essential factor which can influence any flash flood that may exist (Wang, Yang, and Yao 2012). In general, flash flood frequency increases according to the decreasing pattern of the elevation, which means that the lower areas are more susceptible to flooding condition (Bisht et al. 2018). This Global Digital Elevation Model (GDEM) with moderate spatial resolutions of 30 m, was Downloaded from USGS data explorer. However, in this study area, the elevation was between 17 and 1497 m (Figure 2).

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2.3 Data Preprocessing

Based on the information presented from prior researches (Bannari et al. n.d.; Darabi et al. 2019; Yang et al. 2018) , it has enough knowledge that helps to identified and recognized the seven important flash flood susceptibility factors, that it has been used in this study case which, are soil moisture index (SMI), rainfall, drainage density, Lulc, altitude, slope, and soil.

2.3.1 Rainfall: Heavy flash floods are generally caused by high intense rainfall which means in this study, the preparation of the rainfall maps is very important to identify the flash flood susceptibility areas (Domeneghetti, Schumann, and Tarpanelli 2019), but this preparation needs a several steps one of them was to Download CRU monthly climate dataset and to convert "NETCDF" file to useable format. Another step was to separate months from bands and to generate monthly maps. After this step, we cut those maps in an organized way to form the rainfall map. Finally, the result is getting the final monthly average rainfall map with 30 m resolution. However, in this study, the resulting map indicated that the November rainfall was very high on average compared to the period during December, it has fallen between 24.73 and 83.83mm. But during December the average rainfall was between 14.78 and 25.75 mm (Figure 2).

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2.3.2 Drainage Density: When rainfall happens in a watershed condition, the drainage density has an impact on water circulation (Mohamed and El-Raey 2019). For that reason, the drainage density factor has an important effect on the prediction of flash flood existence possibility. Furthermore, Low drainage systems have several consequences that result in making watershed overflowing and an incessant flooding event in a certain zone. However, because of the important influence that drainage density can make. It was very useful to derive it by using the line density tool from ArcGIS software. In this study area case, the output drainage density map (Figure 2) was between 0 and 3.90km/km2 with 30 m resolution.

2.3.3 Land Use Land Cover (LULC): Lulc. At different scales is a very useful product for a resource manager, it can be drawn from a wide variety of satellite images to meet the needs of users and provide the information needed to decision makers. Land use has an important job in runoff velocity which was the main source of encouragement to use it in this study (Mashaly and Ghoneim 2018). The study zone case land use map that was created from the Landsat 8 OLI satellite image with spatial resolution 30 m × 30 m, and it has an indication about five important classes: Build-up, water, vegetation, agriculture and soil (Figure 2).

2.3.4 Slope: Flash Flood is directly related to slope degree and is an essential morphology characteristic (Bannari et al. 2016; Falah et al. 2019). The slope helps direct the surface runoff velocity and thus influence a flash flood susceptibility (Fenton 2019). The slope degree map was created from the GDEM raster in the ArcGIS environment. In the study area, the slope (Figure 2) was between 0 and 63.59° with 30 m resolution.

2.3.5 Soil Moisture Index (SMI): Soil Moisture (SM) is an important physiographic characteristic for various hydrological applications which helps to have beforehand warned that a flash flood may exist (Bannari et al. n.d.). Areas with low soil moisture index have low water heights which mean that it has poor moisture absorption ability and it is more susceptible to flash flooding, that's why areas with high soil moisture index have high moisture absorption ability and are less vulnerable to flash flooding (Silvestro et al. 2019). In this study case, SMI maps were obtained from Landsat-8 OLI with spatial resolution 30 m × 30 m. Based on the SMI maps the result has indicated that before the flash flood happened in November 14th, 2014 The SMI (Figure2) has an important value only in high mountains which located in Guelmim region but after the flash flood happened in December 09th, 2014 SMI has any important values in mountains and other areas.

2.3.6 Soil: Soil is a porous and three-phase medium (water, air, minerals) in which micro and macro-organisms from the plant and animal world do living. The lack of water absorption by soils is one of the main causes of the genesis offloading (O'Mara et al. 2019). For that reason, the identification of the soil types in any study area is very important, but the preparation of the soil map needs to use FAO data. In this study case, the resulting map (Figure.2) indicated six categories of soil. The Calcaric Fluvisols (Jc); Chromic Luvisols (Lc); Lithosols (I); Yermosols (Y) and Haplic Yermosols (Yh). This map was Re – Projected from WGS84 to UTM.

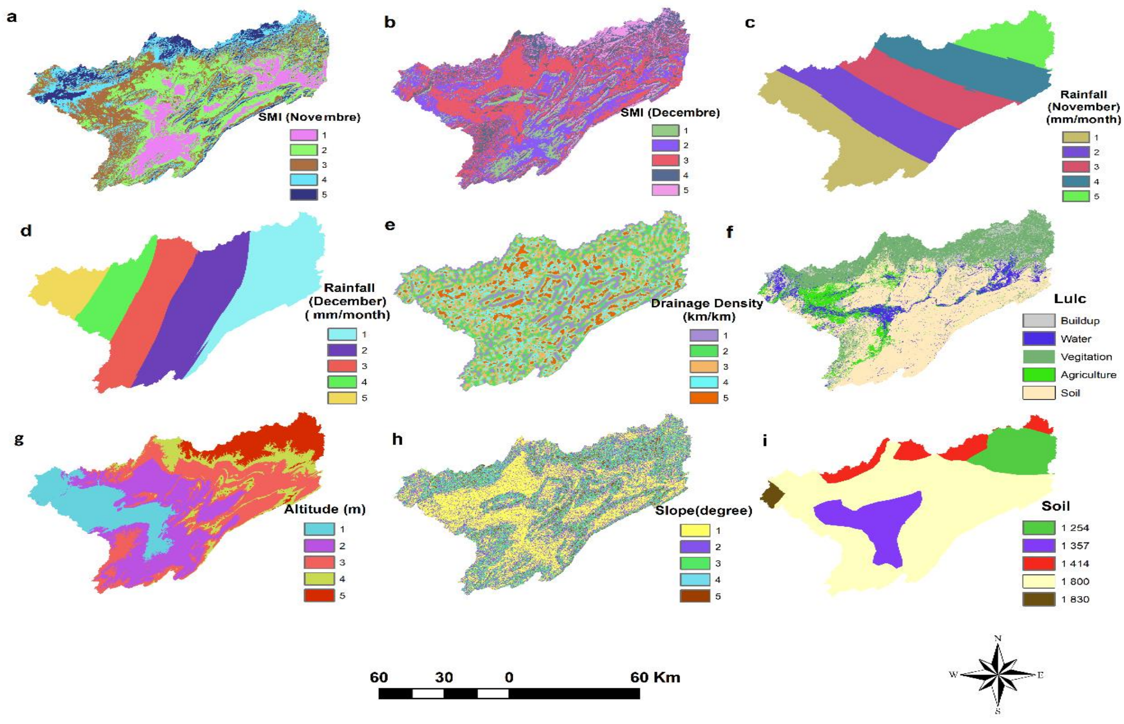

Figure 2. Flash flood conditioning factors used to create the flash flood susceptibility maps: a) SMI before flood (November 2014), b) SMI after flood (December 2014), c) Rainfall before flood (November 2014), d) Rainfall after flood (December 2014), e) Drainage density, f) Lulc , g) Altitude , h) Slope degree, i) Soil type.

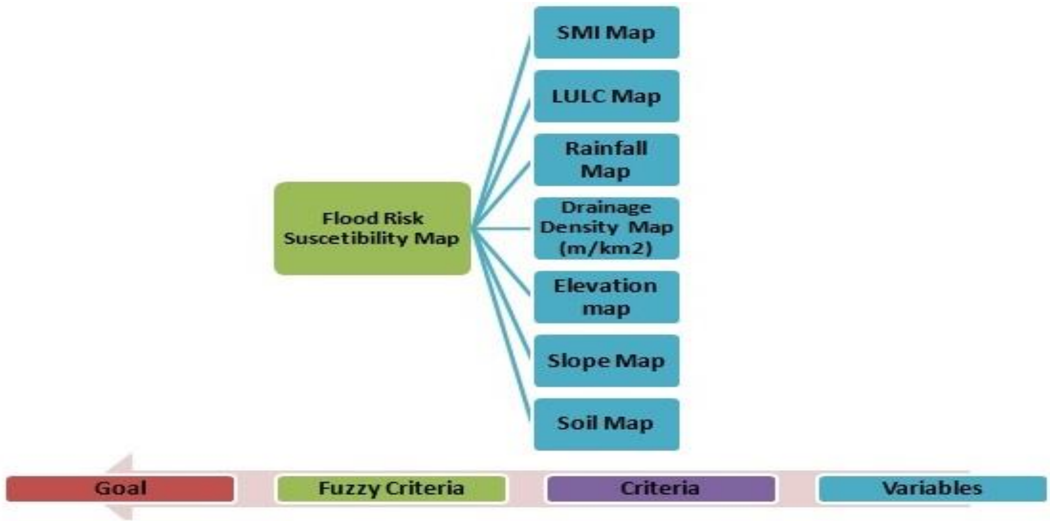

Figure 3. FAHP Analysis Workflow for Flash Flood Susceptibility Analysis.

2.4 Methodology

The process of identifying the flash flood susceptibility areas need to Divided into different steps (Figure 3) the first step involves preparing the flood conditioning factors (Figure 2) (Darabi et al. 2019) by using GIS technicality and geographic data; but the second step has to deal with calculating the percentage of certain Criteria Weights by using the Analytical Hierarchy Process algorithms (Echogdali et al. 2018; Saaty 1989). Furthermore, the third step includes a transformation process of the flood conditioning factors from 0 to 1 scale by using the Fuzzy Membership (linear functions) algorithm (Ait Kacem et al. 2019; Zadeh 1978). In addition, the fourth step includes the multiplication of Fuzzy Criteria with the AHP Criteria. Finally, a flash flood susceptibility map has been produced (Figure 4).

2.4.1 Analytical Hierarchy Process (AHP): The analytic hierarchy process (AHP) is a structured technique which was developed by Thomas L. Saaty. It is the most widely used for organizing, solving and analysing the complex problems. Additionally, AHP technique help to calculate weights of criteria and the relative importance of these criteria (Ait Kacem et al. 2019; Rahmati, Zeinivand, and Besharat 2016; Saaty 1989). Moreover, to check the weights of criteria value are correct or not, the Consistency ratio (CR) should be calculated, that must be less than 0 and 1 to confirm that the matrix is a reasonable consistency. This Consistency ratio (CR), is calculated using this equation (equation 3).

Where:

the maximum eigenvalue (λmax) is getting by this equation (equation 1) ; the Consistency Index (CI) getting by this equation (equation 2); And the Random Index (RI) getting according to the Random Index Table which based on the number of criteria (Echogdali et al. 2018; Elkhrachy 2015; Papaioannou et al. 2015; Rahmati et al. 2016; Saaty 1989)

(1) $\gamma_{max} = Average\ (ws/wc)$

Where, λmax is the maximum eigenvalue.

(2) $CI = (\gamma_{max} - n)/(n-1)$

Where, n is the number of criteria.

(3) $\mathrm{CR} = \mathrm{CI}/\mathrm{RI}$

2.4.2 Fuzzy Logic: Fuzzy logic is a multi-valued logic where the truth values of variables instead of being true or false are really between 0 and 1(Ait Kacem et al. 2019). In this sense, it extends the Boolean logic classic with partial truth values 1 (Papaioannou et al. 2015). It consists of taking into account various numerical factors to arrive at a decision that one wishes to accept, and formalized by Lotfi Zadeh in 1965 (Zadeh 1978). In this case using the fuzzification algorithm in the ArcGIS environment help to transforms each flash flood raster factors into a 0 to 1 scale.

2.4.3 Fuzzy analytical hierarchy process (FAHP): (Darabi et al. 2019; Gigović et al. 2017; Papaioannou et al. 2015; Yang et al. 2013; Zadeh 1978) After calculating factor weights for each criteria (Table 3) , and the fuzzification of each flash flood factor, it must be multiplied by the fuzzy logic output with AHP weight output using this equation (equation 4) then it should be combined by fuzzy overlay tool , to get finally the flash flood susceptibility map of Guelmim region (Figure 4).

(1) $\mathrm{Model}_{\mathrm{FAHP}} = \sum_{\mathrm{ni}}^{\mathrm{n}} \mathrm{W_i} \times \mathrm{F_i}$

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Where:

Wi = Weight of each flash flood factor.

Fi = Fuzzy map of each flash flood.

In this study case the FAHP calculation is:

$\text{Model}_{\text{FAHP}} =$ [0,3700 * (Fuzzy SMI) + 0,2430 * (Fuzzy Rainfall) + 0,1557 * (Fuzzy Drainage density) + 0,0998 *(Fuzzy LULC) + 0,0639 * (Fuzzy DEM) + 0,0406 * (Fuzzy Slope) + 0,0270 * (Fuzzy Soil)].

3. RESULTS AND DISCUSSION

Flash flood susceptibility maps (Figure 3) were created using the effective factors (thematic maps, Figure 2) in flood susceptibility and the FAHP (Fuzzification and Criteria Weights (%)) algorithms.

3.1 Variable Classification of Thematic Map

The categorization of each flash flood factors (variable) is depending on the degree of impact a factor has on susceptibility. for example, drainage density and Rainfall have an important effect on flash flood susceptibility, therefore lower drainage density and lower rainfall regions are designated classes 1 and 2, whereas higher drainage density and higher rainfall regions are categorized 4 and 5 meaning that they are highly vulnerable to flash flood (Domeneghetti et al. 2019; Mohamed and El-Raey 2019) (Figure 2). likewise, Soil moisture index is the most important factor. Regions with less soil moisture index have minus moisture saturation ability and thus are more susceptible to flash flood. Though, regions with high soil moisture index have greater moisture saturation ability and low susceptible to flash flood (Bannari et al. n.d.; Silvestro et al. 2019). So, in the categorization phase, less soil moisture regions were marked classes 4 and 5, and great soil moisture regions were categorized as 1 and 2 (Figure 2). On the other hand regions with greater slope and altitude are marked classes 1 and 2, and regions with less slope and altitude are categorized as 4 and 5 (Figure 2), because when the rainfall occurs and with high intensity during a short period of time, the water goes under briskly in very inclined way and in the flat regions. In addition, regions with less steep and flat areas, the water goes sluggishly, this can consequently cause flash flooding (Bannari et al. 2016; Falah et al. 2019; Fenton 2019).

3.2 Fuzzification & Criteria Weights (%)

The AHP results indicated that 37% of susceptibility the flash flood is induced by Soil moisture index, 24.30% by Rainfall and 15,75 by Drainage density, therefore, is just 9,98 %, 6,39, 4,06 and 2,70 which is induced respectively by LULC, DEM, Slope, and Soil. This result is faithful with the prior researches (Echogdali et al. 2018; Lyu et al. 2018; Rahmati et al. 2016).

3.3 Flash Flood Susceptibility Maps

The resulting map showed that residential areas at the outlet (red region in the North West, Figure4) of the watershed and which are close (around the rivers, Figure4) of the main effluents Sayed and Oum Laachar wadis were very susceptible to flooding and were classified in the high flash flood susceptibility class. this result is consistent with the studies (Echogdali et al. 2018; Elkhrachy 2015; Papaioannou et al. 2015).

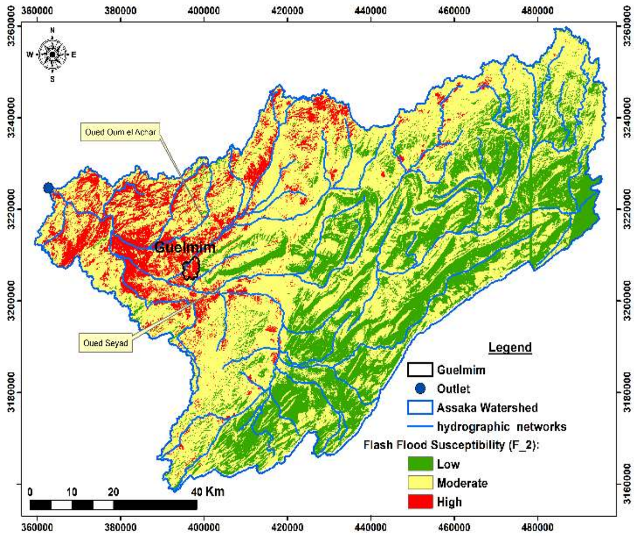

Figure 4. The flash flood susceptibility map

These flash flood susceptibility maps could use to reduce the future harm made by flash floods, to help the disaster management processes in the future, to improve greater methods for the preservation, to extend the research, to develop flash flood predictions and precaution systems. There are two flash flood susceptibility maps have been created in this study. The first map (Figure4) was created by Rainfall of November (before and during flash flood of 2014) and SMI of November 7th, 2014 (before flash flood), but the second map (Figure 4) was used Rainfall of December (after flash flood of 2014) and SMI of December 9th, 2014 (after flash flood). Remarking that the second map predicted more the flash flood susceptibility areas than the first one. Thus concluded that SMI has a very important effect in this study, which conforms to this preliminary study (Bannari et al. n.d.; Papaioannou et al. 2015; Silvestro et al. 2019).

In the resulting Flash flood susceptibility maps, the high susceptibility class covering 42,57%, moderate susceptibility class covering 35,92% and the low susceptibility class covering 21,51% area of the watershed area (Figure 5).

According to HCP statistical data (2014) reveals that about 42,34% population residing in 7 common susceptible to low,

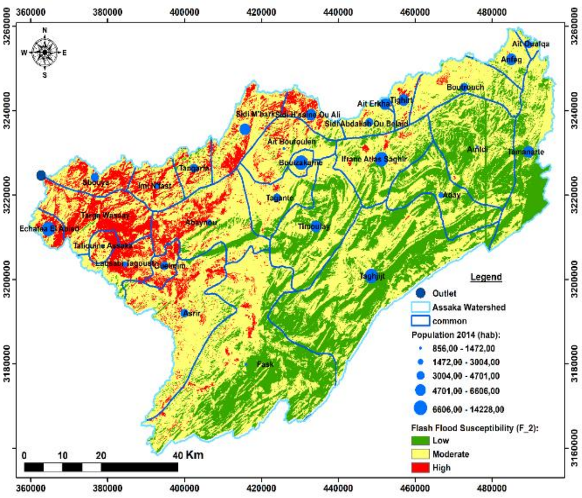

Figure 5. The residential population in a flash flood Susceptibility areas

32,49 % population belongs to 9 common susceptible to moderate and about 25,17 % population part of 9 commons are Generally the FAHP approach has been used in several studies such as getting the Low-Cost Solution for Assessment of Urban Flash Flood Impacts in Ras Ghareb City, Egypt (Mohammed Sadek.2019), another study was used to get the flood hazard index in Mombasa County, Kenya (Yves Hategekimana.2018). However, the quality of the results of those preliminary studies has made the FAHP method a suitable approach for flash flood prediction in the Guelmin region.

4. CONCLUSION

This study combined two algorithms Fuzzy and AHP, to create a flash flood susceptibility maps by using the flash flood conditioning factors which has indicated that soil moister index, Rainfall, drainage density, altitude, slope degree, and soil type from watershed were the most influential factors in flash flood susceptibility mapping. The study totally shows the important role of GIS in the decision making-process. The produced maps in the current study indicated that a residential area at the outlet of the Assaka watershed are vulnerable to flooding and must be a preference for management to stop alleviates flash flooding. This research could be used to other zones to help managing, manipulating, and lowering of the flash flood harm in regions vulnerable to flooding.

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