Detection and Ranking of Vulnerable Areas to Urban Flooding Using GIS and ASMC (Spatial Analysis multicriteria): A Case Study in Dakar, Senegal

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Abstract—*Dakar region is confronted in recent years with episodes of repetitive and devastating floods. The structures in charge of the matter, yet does not have enough knowledge of space and tools to preciselylocate vulnerable areas. It is in this particular context that we have through this study process by coupling GIS and ASMC techniques. We aim in this coupling, to develop an efficient tool for support decision making in terms of identification strategies, intervention or adaptation. The defined criteria for this are: the rainfall, the groundwater level, geology, topography, wetlands, population density, living standards and the type of habitat. We have used an analytical hierarchical process (AHP) by foursteps: a) the breakdown of problematic vulnerabilities; b) scanning and harmonization of layers factors (criteria); c) the weight assignment of different layers criteria according to the comparison procedure in pairs; d) and aggregation criteria layers, through the weighted superposition of the SOC software tool. This has helped us to hierarchically locate the vulnerable are as to flooding. The results have showed a very low vulnerability (1.67%), low vulnerability (50.53%), high vulnerability (43.66%) and a very high vulnerability (4.14%). Approximately, 50% of the Dakar region are vulnerable to flooding and particularly the suburban area concerning the departments of Pikine and Guediawaye. These informations are very useful for governments in the effective and sustainable flood management and identification of priority intervention areas.*

Keywords—GIS, ASMC, Vulnerability, urban flooding, Dakar, Senegal

I. INTRODUCTION

The vulnerability of cities to risks and disasters has been a growing academic interest [1]. The relative risk of urban flooding is becoming more topical due to the exponential growth of urban centers, population growth and climate change. Flooding is one of the major environmental crises one has to contend of within the century [2]. In all countries, they become a scourge increasingly feared [3-4]. The vulnerability is perceived as a conjunction of risks, impacts and adaptive capacity [5]. It is a form of insecurity in the well-being of individuals, households and communities including sensitivity to change [6-7]. "She's the extent of harmful consequences of the flooding on the issues" or "the fragility of a socio-economic system as a whole with risk" [8]. It is a lack of resilience to environmental change, economic and social that threaten the well-being. Vulnerability to flooding is inherently linked to the place, that is to say the physical configuration and man in the middle: some areas are more vulnerable than others. The two other urban vulnerabilities are intrinsic. There is first the destructive effects of natural phenomena, which are compounded by the very structure of materials and urban morphology. Urban morphology accentuates the induced effects, since the site early cities was quickly overwhelmed by the consumption of the available space, or exposed to the dangerous sites. The second factor is the pronounced segmentation of urban society, reflecting the underdevelopment and socio-economic conflicts in a limited and coveted space [9]. In West Africa, urban populations are increasingly vulnerable to flooding. The vulnerability of the Dakar region is mainly due to physical, economic, environmental, which reduce people's adaptive power faces the floods that are more exposed. Indeed, the landscape of the region is marked by the alternation of dunes and dune slacks called inter *niayes*[10]. The regions and the most vulnerable societies to flooding and climate change and their damage are those whose economic situation is unfavorable and whose location is at risk [11-12-13]. In the periphery of the Dakar region, the repetition of these phenomena pushes people to adopt multiple responses to the risk and its consequences [14]. Since 2005 Dakar is increasingly confronted with repeated flooding, especially in the peri-urban area, corresponding to the departments of Pikine and Guediawaye. In 2009 it was about 360 000 people who were directly affected by floods in Pikine and 22 000 people Guediawaye; respectively 44% and 7.2% of the population in both cities [15]. The number of concession affected by the floods is estimated at 20 000 in these two departments [16]. Apart from habitat degradation, floods cause considerable economic losses for the population and lead to degradation of social ties within these urban areas. Also part of life (housing, equipment and infrastructure) is highly degraded [14-17].Dakar capital of Senegalis characterized by an out of control urbanization process [18-19-20-21-22-10]. The reasons of this are the rapid growth of population and settlements over time while a limited effort is made to better manage urban areas particularly in the outskirts of Dakar [20]. Despite efforts by actors in the field of research palliation floods, populations of the periphery of the Dakar region still live in fear of storms that each year seem to be growing in the 'particular ecosystem Niayes where habitats are. It is indeed unfortunately not possible to respond to flooding problems only through the implementation of retention basins or granting of pumps and foods; today we have an obligation to think about legal solutions, structural, organizational and preventive [23]. This national policy did not solve all the problems which local actors face. This calls into question the relevance and effectiveness of prevention and fight against floods. Consequently, it is essential to develop a comprehensive program that highlights a transversal approach both in terms of actors that point of view the proposed solutions. The feedback and expert missions insist that within ten years, the consideration of risk must necessarily pass through the revaluation of vulnerability studies as the basis necessary for setting goals for management regionalised risk [24-25-26]. Several work on the assessment of vulnerability to flooding in the region are based on a quantitative approach and focus on specific areas. Efforts, however, remain to be deployed on studies based on modeling across the region through advanced hierarchical techniques, given the mass of heterogeneous information to take into account. Today the Advanced techniques have revolutionized their mechanisms of decision making and are used in a large number of area agriculture for example [27-28-29-30-31]. It is therefore necessary to develop tools to aid the decision on vulnerability knowledge locally for risk prevention. Vulnerability to flooding depends, among other factors of importance and frequency of flood factors such as rain, soil type, geology, topography, hydrology, land use, structuring housing, population density. This research proposes to use the operational and scalable tools to aid in evaluation and decision in management of urban flooding. The assessment of urban vulnerability is based on the fullest possible identification of issues of territory and a method for decision support, based on expert judgment, allows to assess their vulnerability. The results are transcribed in the form of maps, through GIS, using geo-processing operations. This is to develop analysis and evaluation grids enabling decision makers to increase their knowledge of local vulnerabilities. These vulnerability assessment grids are implemented in order to meet a specific demand facing the risks of urban flooding.

II. STUDY AREA AND DATA

The region of Dakar is located in the extreme west of Senegal between longitude 17 ° 10 'and 17° 32'W and latitude 14° 53' and 14° 35 'N (Fig1.). It covers an area of 550 km², representing 0.28% of the total area of the country. Administratively, the region of Dakar is divided into four departments (Dakar, Guediawaye, Pikine, and Rufisque) and 10 districts. It houses 53 local authorities: a region, 6 towns, 43 district municipalities and 2 rural communities. It is bounded to the east by the Thies region and the north, west and south by the Atlantic Ocean [32]. It has several distinctive physically. Geomorphology is characterized by a dune terrain, topography is low [33], geology leaves appear several formations such as dune sand, clay and organic sandy clays. It is characterized by a coastal type of microclimate due to its advanced position in the Atlantic. This is strongly influenced by maritime trade winds and the monsoon which respectively set from November to June and from July to October in directions N-NW and S-SE. It is characterized by two seasons, a rainy season from June to October and a dry season from November to May.The average annual rainfall is estimated at 400mm [34]. The minimum temperatures range (12° to 20° C), maximum temperatures range from (28° C to 36° C). The average temperature is between (20° C and 28° C). The data used in this study are of map and satellite natures. These include mapping a geological map of the Dakar region 1/50000 [35], a map of the deep web as points [36], a map of the inequality of wealth [37] and a population density map [38-21]. For remote sensing satellite data, we have a Landsat image of 2014 (OLI) for the extraction of wetlands, a TRMM and SRTM image, for the extraction of rainfall and DEM data.

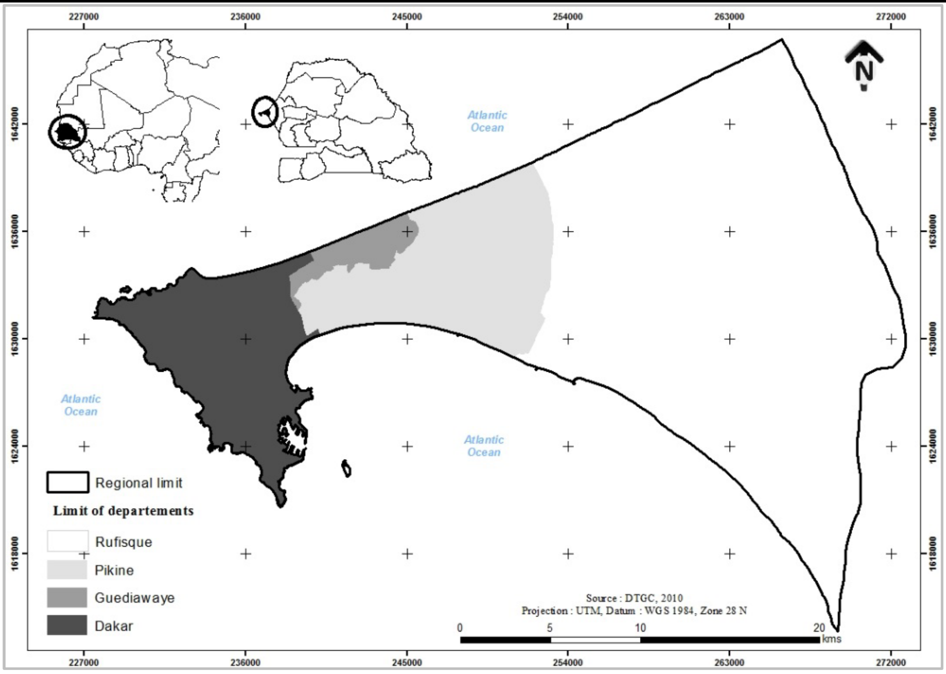

Fig.1: Location of the study area

III. MATERIALS AND METHODS

3.1. Data processing

Map data is initially georeferenced and projected into the system WGS 1984 UTM Zone 28 N, before being converted to raster mode. The pixel size of the images is homogenized at 30 m. We also use the interpolation method, the IDW method for spatial point data of the depth related to the web for their spatialization to compare to the rest of the database. For remote sensing data, we have georeferenced the TRMM images and then converted into ASCI format before proceeding with their interpolation. We then extract wetlands (lakes and flood zones) from the Landsat image classification of 2014. Euclidean distances are performed on these areas to determine the different levels of vulnerability. Regarding the DTM, we first defined a projection him prior to the correction of missing pixels from the Arc Hydro tool. Thereafter we have calculated the TIN that have been reclassified to get the DEM of the Dakar region.

3.2. Multi-criteria analysis

Multi-criteria analysis allows a choice between several solutions by breaking an analysis grid in several criteria, each weighted coefficient or a relative weight. A criterion is a function defined on all shares representing the preferences of the user according to his point of view; in our case they concern the most vulnerable to flooding factors. We conducted an identification of criteria that will be based analysis and their assign weights according to their relative importance. These weights are obtained by the pair comparison approach defined by [39-40-41].

3.2.1. Criteria identification

A criterion is a judgment factor based on which measured and evaluated an action [42-43]. The criteria are of two types, constraints and factors. Constraints allow to single out vulnerable areas deemed those are not factors as are criteria that define a certain level of fitness or alternative solutions for all regions [44]. Based on the data available to address the problem of flooding in Dakar, we have identified eight criteria that allude to "factors" layers. These are: topography, water table level, population density, housing type, wetlands, wealth inequality, rainfall and geology of the region.

3.2.2. Standardization of criteria

The standardization is to harmonize different criteria layers involved in the analysis system. We performed the treatment in three steps: (i) all layers were reduced to raster format with the same number of row and column. To this, we used a boundary layer in the region in 2014, which served to extract all the other information on the mapping; (ii) the pixel size is 30 m resolution; (iii) all criteria layers were reclassified into 5 sub-criteria according to their level of vulnerability. After this normalization, we got 8 layers criteria (or factors) that will be translated to a stage of weighting and aggregation leading to the establishment of a decision-making board.

3.2.3. Weighting factors

The weight is a relative percentage, and sum of the weights of influence percentages must equal 100. If the number of factors is high, it is often difficult to estimate the relative weight of each of them (Soto etRenard 2001; Kêdowidé, 2010). One solution is to compare each factor with the other, a paired comparison (Table 2) and then deduct the total weight resulting from statistical calculation. This method was adopted, given the number of factors in play in the conduct of the CMA set at 8. The assessment of flood vulnerability criteria based on the judgment of 13 experts involved in the field of management of urban and flooding issues such as planners, managers, actors, local authorities, civil engineering engineers , sanitation and surveyors, etc. The objective here is to bring the maximum judgment of actors and have a wide viewing angle on the vulnerability of the site to flooding. Factor analysis by pair has generated a weighting matrix and to perform the calculation of the weights on the basis of these weights (Table 3). A 1 to 5 rating scale is allocated to the diaper criteria, in increments of 1 (1 is the lowest and 5 the appropriate is more). Table 4 shows the 5 classes identified for each criterion, starting from the low vulnerability class to the very high vulnerability class. In each class, we assign a weight in an arithmetic progression system for more originality in the classification.

Table .2: Scale of [39-40] for weighting factors in pairs

Intensity of importance	Description
1	Equal importance
3	Moderate importance
5	Strong or essential importance
7	Very strong or demonstrated importance
9	Extreme importance
2-4-6-8	Intermediate values
Reciprocals	Values for inverse comparison

Table .3:Weighting factors in pairs according to the scale of Saaty with the weight of the resulting factors

	Rainfall	DEM	Water level	Density population	Quality of life	Wetland	Geology	Type housing
Rainfall	1	1/5	1/3	3	3	1/2	1/3	3
DEM	5	1	3	5	5	5	5	3
Water level	3	1/3	1	3	5	1/3	1	3
Density population	1/3	1/5	1/3	1	2	1/3	2	2
Quality of life	1/3	1/5	1/5	1/2	1	1/2	1/5	2
Wetland	5	1/5	3	3	2	1	5	3
Geology	3	1/5	1	1/2	5	0/5	1	3
Type housing	1/3	1/3	1/3	1/2	1/2	1/3	0,33	1
Weight	**8,425**	**32,674**	**13,180**	**6,902**	**4,561**	**19,484**	**10,450**	**4,324**

3.3. Aggregation of the layer

Aggregation involves combining all the criteria layers to obtain because of vulnerability of the region to urban flooding. The weighted linear combination allows complete aggregation and generates a vulnerability map, on which each pixel is the weighted sum of all the criteria taken into account. The value of the cells obtained is added to give a result as raster. This is a decision support tool in terms of assessment, intervention for better management of the problem of flooding.

IV. RESULTS

The aggregation of various factors according to their level of influence expressed by relative weight has helped develop a vulnerability map with floods in the Dakar region (Fig. 2). Table 2 shows the areas and the corresponding percentages at each level of vulnerability. The analysis of the map of vulnerability of the Dakar region floods indicates a trend range and to assess the best level of vulnerability of the region; we can distinguish them in very high risk areas (4.14%), the high vulnerability areas (40.36%), areas with low vulnerability (50.33%) and very low vulnerability (1.67%).

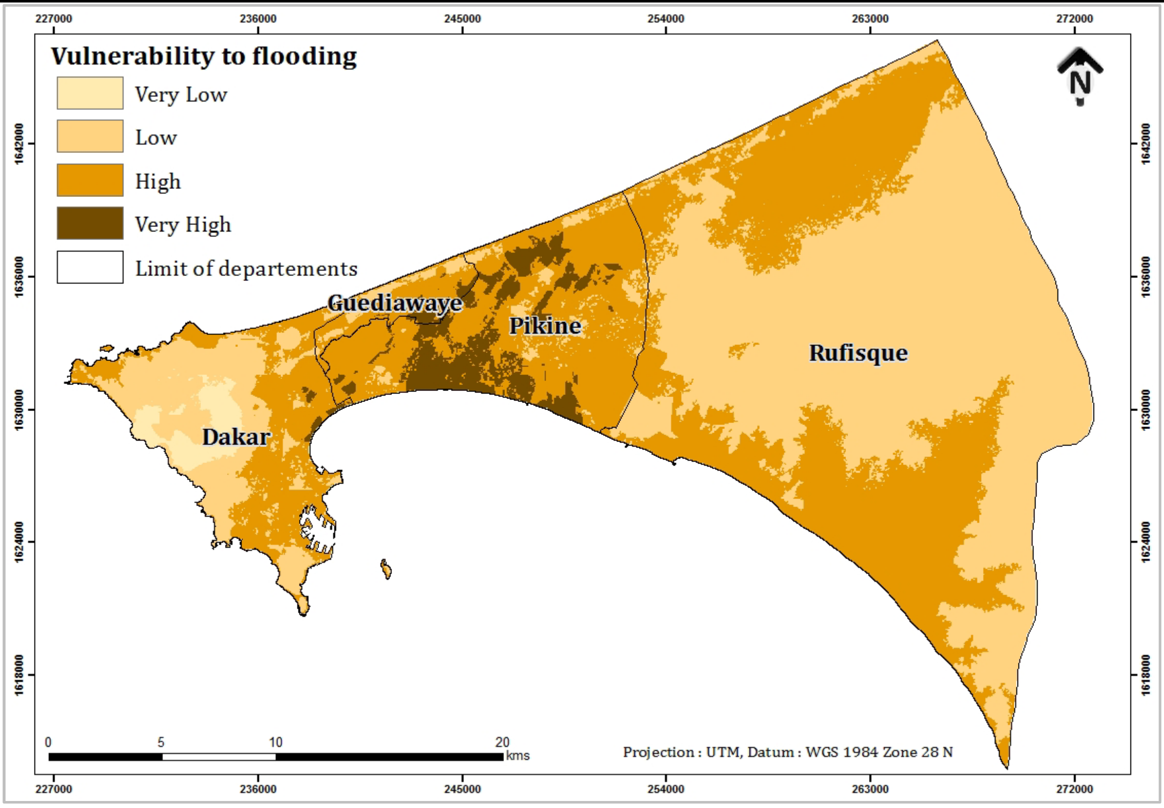

Fig. 2: Vulnerability to flooding in the Dakar region

Table.1. Vulnerability ranks for flooding in Dakar urban area

	Vulnerability Rank	Area km²	Area Percent %
1	Very Low	9.185	1.67
2	Low	277.915	50.53
3	High	240.130	43.66
4	Very High	22.77	4.14
	Total	**550**	**100**

In the vulnerability map, the areas to the heart of the Dakar region, specifically in the municipalities located in the departments of Pikine and Guediawaye seem most vulnerable to flooding (Figure 3 and Table 2). From Figure 4, the very high vulnerability areas primarily concern the department of Pikine at 91%, followed Guediawaye to 5.88% and 3.12% in Dakar. The high vulnerability relates against the four departments with Rufisque respectively (58.04%), Pikine (24.88%), Dakar (13.49%) and Guediawaye (3.59%). The low vulnerability is recorded in the departments of Rufisque (83.86%), Dakar (13.49%), Pikine (2.16%) and Guediawaye (1.01%). The very low vulnerability to flooding is recorded exclusively in the department of Dakar close to 100%. This situation of high vulnerability to high vulnerability and respect mainly Pikine and Guediawaye is justified through the different factors used in their identifications. Each individual factor shows a significant vulnerability in these two geographical areas. Lower altitudes, the lowest levels of water, high population density, the lowest standard of living, lack of rainwater drainage network,..., characterize these municipalities in the region. This explains their relatively high vulnerability compared to the rest (Dakar and Rufisque).

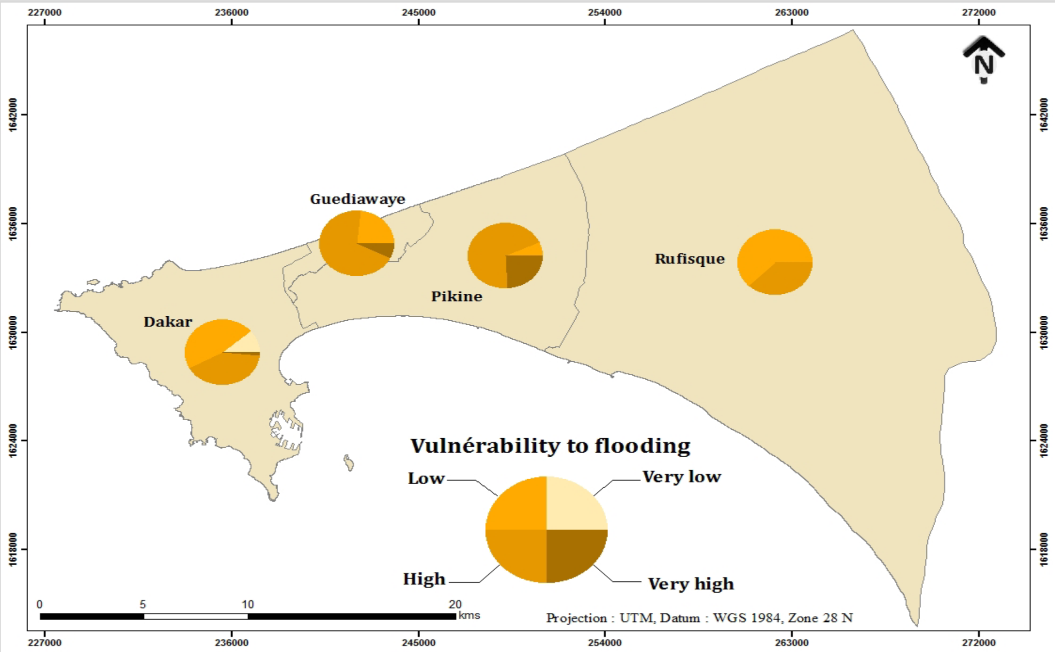

Fig. 3:Proportion of vulnerability by department

Table 2:Vulnerability levelby department (km² and %)

Vulnerability Rank	Rufisque		Guediawaye		Dakar		Pikine		Total	
	Km²	%	Km²	%	Km²	%	Km²	%	Km²	%
Very Low	0	0	0	0	9,18	1,67	0	0	9,18	1,67
Low	233,25	42,38	2,81	0,51	36,09	6,56	6,00	1,09	278,15	50,53
High	139,49	25,34	8,62	1,57	32,43	5,89	59,78	10,86	240,32	43,66
Very High	0	0	1,34	0,24	0,71	0,13	20,72	3,76	22,78	4,14

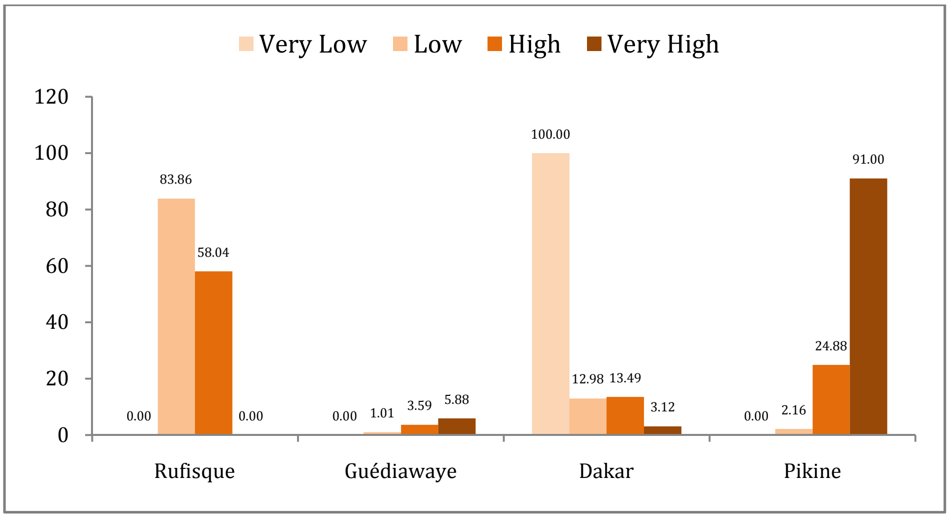

Fig. 4:Vulnerability to flooding across the departments in the Dakar region (percent)

V. DISCUSSION OF RESULTS

The GIS-AMC coupling wants adamant in resolving issues concerning urban flooding. In this study, we have from this approach, spatial flooding and risks to Dakar to locate the most vulnerable areas. This step is essential for the authorities in measuring the priority intervention. The vulnerability was illustrated by 05 levels (very low, low, medium, high and very high). Approximately, 50% of the Dakar region area (270km²) are vulnerable to flooding. Analysis of the results reveals that the departments of Pikine and Guediawaye, as the most vulnerable. This shows that these departments are home to lower altitudes, the lowest levels of water, high population density, lack of development, the lowest standard of living, lack of rainwater drainage network and sanitation... These conclusions make available to the authorities and decision makers an operational tool for managing urban floods in 14 regions of Senegal in general and particularly in the Dakar region.

VI. CONCLUSION

Our motivation through this study is to provide basic knowledge to decision makers through powerful tools in the fight against floods. In this study, we have conducted by identification of vulnerability factors, its processing, evaluation and aggregation.The results reveal that about 50% of the Dakar region are vulnerable to flooding. Analysis of results has showed that Pikine and Guediawaye remain the most vulnerable areas to flooding. This study has therefore showed the relevance of GIS-MCSA coupling in the detailed characterization of the areas at risk. It is an important decision support for urban planning and environmental management.

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