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Application Of Remote Sensing And GIS To The Mapping Of The Settlements Exposed To Flooding And Runoff Hazards In The City Of Bohicon, Benin

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Abstract – In recent years, several rainwater drainage works have been implemented in the city of Bohicon through the support of various technical and financial partners. Despite these efforts, the city of Bohicon still experiences runoff and flooding phenomena which have heavy socio-economic and environmental consequences. This research aims to determine the settlements exposed to flooding and runoff hazards in the city of Bohicon by 2030. The main methods used were diachronic land use mapping based on Landsat images from 2006, 2011, 2016 and 2021, hydrological modelling and land use modelling. The results revealed that the area of the settlements exposed to runoff hazards has increased from 568.36 ha in 2006 to 1051.30 ha in 2021; this area could reach 1066 in 2030 ha if the current trend continues. The area of the settlements exposed to flooding has increased from 45.37 ha in 2006 to 85.03 ha in 2021. If this trend continues, this area could reach 95 ha by 2030. The evolutionary trend of the settlements exposed to flooding and runoff hazards remains the same as that of the overall settlements. It is important to reduce investments in the stormwater facilities construction and then declare areas at risk of flooding as unbuildable areas. Appropriate construction measures should be promoted in areas exposed to runoff.

Keywords – Runoff, flooding, mapping, evolutionary trend, Bohicon.

I. Introduction

Flooding and runoff are major environmental problems the world is facing. These environmental problems are exacerbated by climate change (Wallez, 2010). In recent decades, floods have been a danger to properties and people in most parts of the world, with huge economic losses (Koumassi *et al*., 2014). Runoff is a major contributor to soil degradation in rural areas and to infrastructure and facilities in urban areas. Confronted with these worrying environmental problems, the society is asking many questions which, they hope, could find clarifications from the scientific world and solutions from decision-makers.

Cities in West Africa have been increasingly experiencing intense flooding in recent years (Wallez, 2010 ; Mounirou, 2012). From Dakar region in Senegal, to Cotonou in Benin, via Niamey in Niger, some neighbourhoods are increasingly flooded every year despite the large investments made in stormwater drainage (Wallez, 2010). These floods have immeasurable environmental and socio-economic effects. Flooding has therefore become a serious development problem.

In 2010, Benin experienced the most disastrous floods in its history (Godonou, 2013). They affected 55 out of 77 municipalities, directly affected at least 8% of the population, destroyed 55,000 settlements and invaded 128,000 ha of crop fields (Gouvernement de la République du Bénin *et al*., 2011). The number of municipalities affected by the floods is increasing yearly.

Most municipalities have started taking measures to contain this phenomenon without having an exhaustive mapping of floods and runoff. The mapping of these phenomena is therefore a major challenge.

In Benin, the city of Bohicon, which is not crossed by a major river, nevertheless experiences flooding and runoff. It is a city that is almost located in the middle of the Lama sub-basin. It receives a significant part of the rainwater coming from the upstream part of this sub-basin, particularly from the sub-municipalities of Mougnon (Djidja District), Passagon (Bohicon municipality) and the city of Abomey. During the rainy seasons, run-off and flooding leading to the degradation of infrastructure are increasingly recorded; they often lead to human life losses (G2C Ingénierie & LHA, 2016). Over the last few years, the city has built several rainwater drainage structures with the support of several technical and financial partners. A study carried out by the French consultancy G2C and the Laboratory of Applied Hydrology (LHA) revealed that the city of Bohicon has 4,850 linear metres of gutters (G2C Ingénierie & LHA, 2016). An impressive ridge collector that should intercept rainwater coming from the upstream part of the sub-basin is currently being built in the north of the city of Bohicon. In total, to fight against flooding and runoff, large investments have been made by the Bohicon City Council and by several projects, notably the Urban Development and Decentralisation Support Project (PAURAD), the project to build a ridge collector in Bohicon, the Cities Climate Change Support Project, etc. In spite of these heavy investments, the city of Bohicon still experiences runoff and flooding phenomena that have serious socio-economic and environmental consequences. It is therefore essential to quantify the areas exposed to flooding and runoff in order to make projections into the future.

The frequency and increasingly complex nature of these crises requires a holistic approach that integrates actions to strengthen crisis preparedness, prevention and mitigation through effective and timely responses (Koumassi *et al.,* 2014). Remote sensing and Geographic Information Systems (GIS) are powerful geospatial technologies that allow a holistic analysis of floods and runoff to disentangle the interactions between these spatial phenomena. They help to make objective diagnosis of floods and runoff through mapping in order to find appropriate solutions (Tchotsoua *et al*., 2007 ; Khalil, 2018 ; Ndour, 2020) that take into account spatial components (Antoine *et al*., 2008; Leumbe Leumbe, 2015; Lagadec, 2017). The mapping of flood and runoff prone the settlements in the city of Bohicon used satellite images and hydrological modelling outputs.

The objective of the present research is to determine the settlements exposed to flooding and runoff in the city of Bohicon in order to make projections into the future.

II. GEOGRAPHIC AREA OF THE RESEARCH

Bohicon is a city located in the heart of the Province of Zou with extensive stormwater networks (Figure 1). Its development dates from the beginning of the 20th century. The appearance of the city was linked to the development of purely commercial activities, which still gives it the status of a commercial centre on the national level. Indeed, the urbanisation of the city was initially crystallized around the central market and the railway station (Mairie de Bohicon, 2012). The city then developed from these structural facilities according to a plan of subdivision dating from 1937 and updated in 1977. This plan of subdivision is thus at the origin of the grid pattern with a few radial roads.

The spatial expansion of Bohicon could have a knock-on effect on these areas. More broadly, all these together constitutes an important relay at the crossroad of two structuring road axes for national land use (Beninese coast - hinterland countries, Togo - Nigeria). The proof is that the majority of goods and people that circulate nationally take by the city of Bohicon.

In this context, the city of Bohicon has been undergoing a major spatial transformation for several years. The extension of the current and future urban space is characterised by two main phenomena. Firstly, there is an urban sprawl organised in a concentric manner around the central municipalities. On the other hand, embryonic urban nuclei, in full composition, are developing along the structuring axes of the national road network. Also, the opening of the bypass, by allowing certain peripheral zones to be brought closer to the central municipalities of Bohicon, has generated new dynamics in terms of urbanisation. The structuring of these embryonic urban nuclei around the main roads suggests the creation of "street agglomerations" on the margins of the existing urban centre.

Nowadays, there is a major factor which constrains urbanisation and generates conflicts of use. This is the geographical configuration of the site. The city of Bohicon is located in the heart of a depression which represents the outlet for part of the runoff water from the Municipalities of Abomey and Djidja (Mairie de Bohicon, 2012). This phenomenon causes heavy flooding in the built-up areas during the rainy season. The various channels (gutters, ditches, etc.) for the evacuation of rainwater do not always follow the natural path of the water. This results in serious flooding and runoff problems caused fundamentally by the configuration of the site and the various developments carried out here and there without respecting the various land use plans. These developments have created urbanised areas with roofs, streets, car parks and roads, all of which are waterproofed surfaces that eliminate any water infiltration. Urban catchment areas create an urban hydrology. The city of Bohicon generates its own flooding and runoff through the impervious surfaces (G2C Ingénierie & LHA, 2016).

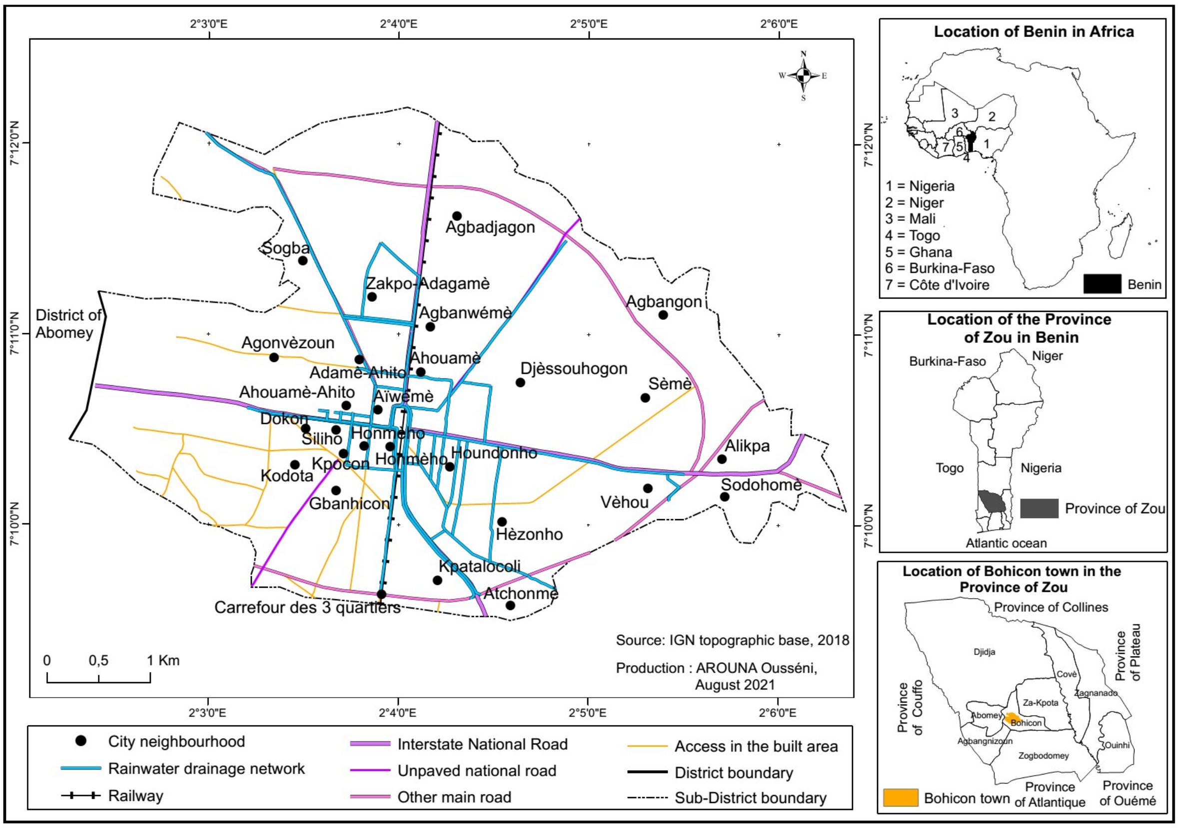

Figure 1. Study area

The figures 2 and 3 show the monthly average and the interannual average of rainfall during the period 2004-2017, which corresponds to the study period.

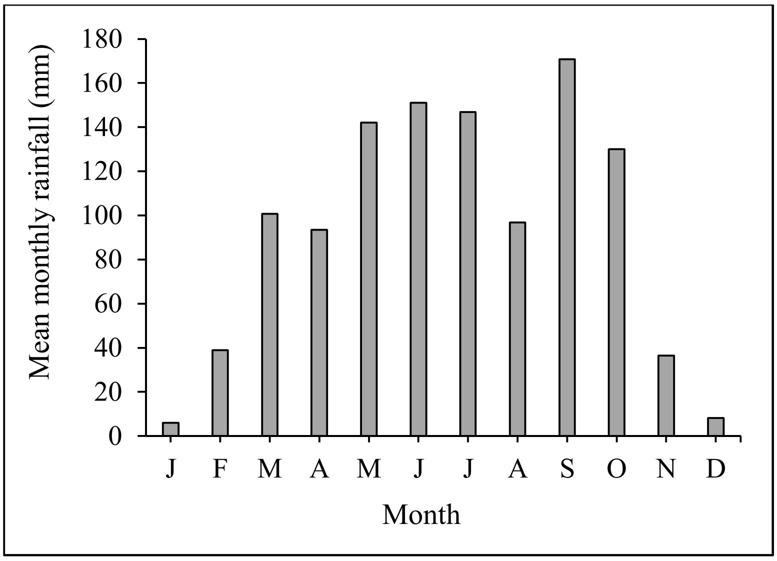

Figure 2. Mean monthly rainfall in Bohicon (2006 - 2017)

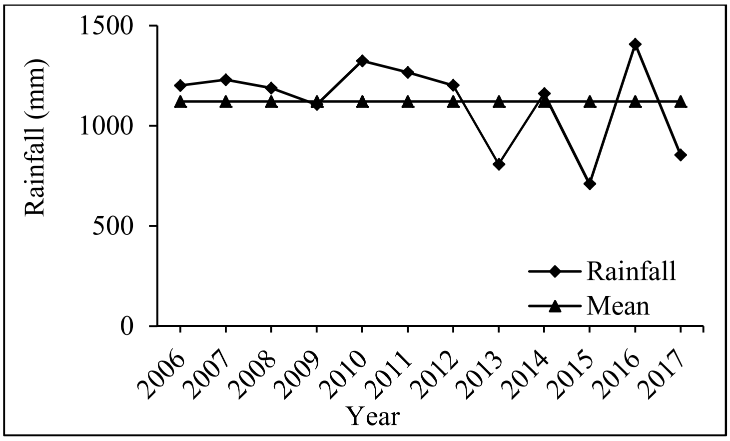

Figure 3. Interannual rainfall variability in Bohicon (2006 - 2017)

The analysis of the average monthly rainfall (Figure 2) and the interannual variability of rainfall (Figure 3) in Bohicon shows that the city hasn't received significant amounts of water in recent years which are different from previous years. Therefore, the cause of the increase in flooding and runoff should be found elsewhere.

III. Materials and methods

3.1 Materials used

The material used consists of:

- ✓ Landsat images from 2006, 2011, 2016 and 2021 with a spatial resolution of 30 m;
- ✓ SRTM data at a rate of 1 arc/s, i.e. a resolution of 30 m in X and Y.

3.2 Methods

3.2.1 Hydrological modelling

The hydrological modelling consisted of simulating a ten-year return period rainfall (i.e. a rainfall of 2 hours duration with an intensity of 50 mm/h) according to the recommendations of the Laboratory of Applied Hydrology of the University of

Abomey-Calavi in Benin (G2C Ingénierie & LHA, 2016). The HEC RAS 2D modelling software was used. Climatological data (rainfall) from the Bohicon synoptic station were used. NASA's Shuttle Radar Topography Mission (SRTM) data was used because knowledge of the topography is essential for the characterisation of flooding and runoff (Drouin, 2008). The output of this modelling displayed on Landsat images background was used to indicate the areas exposed to flooding and runoff hazards (Figure 4).

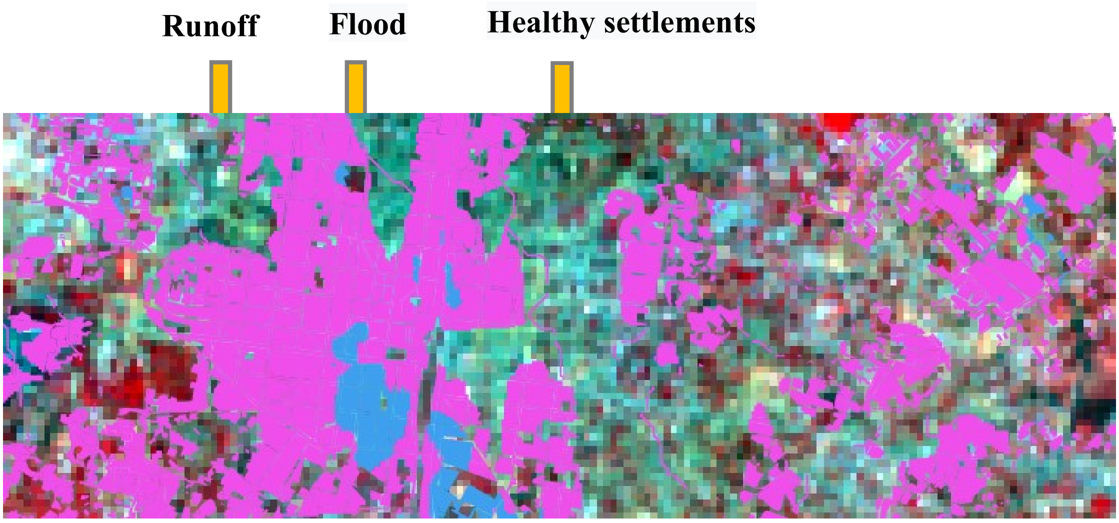

Figure 4. Modelling outputs displayed in colour composition of Landsat images

3.2.2 Interpretation of the 2006, 2011, 2016 and 2021 Landsat images

In order to identify the dynamics of areas prone to flooding and runoff, the Landsat images from 2006, 2011, 2016 and 2021 were interpreted through the pixel-by-pixel classification method using Envi software. These images were interpreted on the same methodological basis. The training areas were first selected. These sites are representative of the numerical characteristics of the classes that allow defining the spectral signatures of each land use unit. These training areas were delineated away from the transition zones in order to avoid including mixed pixels, i.e. pixels that could be classified in two distinct classes. On the images, the training areas were drawn to the nearest pixel. The training areas were well dispersed throughout the research area, representative of the diversity of each land use class. The more heterogeneous the class, the greater the number of training areas.

Supervised Maximum Likelihood Classification has been implemented. It is a pixel-by-pixel classification based on the assumption that the spectral signature of each pixel is representative of the land cover class it is located in. The supervised maximum likelihood classification consisted in assigning to each group of pixels the most plausible class based on the spectral similarity between the pixels and the class signature. The set of pixels in each satellite image was classified using the maximum likelihood algorithm extrapolating the spectral characteristics of the training areas to the rest of the image. The pixels were assigned to the most likely class based on a previously determined probability. Pixels that could not be assigned to a land use class were classified as rejects and then identified during the field test. Land use units such as settlements, urban vegetation areas, bare ground, plantations and savannahs were identified.

3.2.3 Validation of satellite image interpretation

Any interpretation of remotely sensed data must be validated by a field check. The verification of the accuracy of image interpretation is done on a quantitative basis. The error matrix or confusion matrix is the standard way to present the results of a verification study in a satellite image interpretation process. The verification of the accuracy of the interpretation of the remote sensing data was done using the GPS data collected in the field. These collected data and the data from the interpretation of the remote sensing data were used to calculate the accuracy of the maps. The interpretation is correct if the overall accuracy is at least 80% (Arouna, 2017).

3.2.4 Modelling urban expansion to 2030

Spatial modelling of land use requires the use of software capable of taking into account the analysis of non-linear evolutionary trends by integrating change factors (Arouna, 2017). The "Land Change Modeler" program used in ArcGIS was also used in this research. This modelling was carried out for the year 2030 considering the time horizon of urban planning documents which is 10 years in Benin, i.e. 2021-2030 (MDGLAAT, 2013). Indeed, the results of this research can be used to achieve rational urban planning taking into account flooding and runoff. The land use maps of 2006, 2011, 2016 and 2021 were the basic inputs for this modelling. From these maps, the transition probabilities between 2006-2011, 2011-2016, 2016-2021 of the land use units were calculated by the "Run Transition" sub-module of the "Land Change Modeler" programme.

The probable evolution of land cover was estimated from the matrix of transition probabilities of the land cover units according to the Markov chains integrated in the Land Change Modeler programme. Markov chains study, from the transition probabilities, the evolution process of a set of states evolving in the space-time domain. The Markov chains integrated into the "Land Change Modeler" programme were used to model land use for the year 2030.

3.2.5 Mapping of areas exposed to flooding and runoff

The "Flood" and "Runoff" layers from the hydrological modelling and the "Land use" layers from 2006, 2016 and 2030 from the interpretation of the 2006 ortho-images, the 2016 aerial photographs and the 2030 predictive modelling were cross-referenced using the QGIS "Intersect" tool. The results of this cross-referencing were the settlements exposed to flooding and runoff hazards in 2006, 2016 and 2030 in the city of Bohicon.

IV. Results

The settlements exposed to runoff and flooding hazards were identified in 2006, 2011, 2016, 2021 and 2030. The overall accuracies of the maps of land use and land cover of 2006, 2011, 2016 and 2021 are 86,5%, 89,2 %, 90,3% and 92,1% respectively. These percentage indicate that the results of the image interpretation have good accuracy.

4.1 Settlements exposed to flood and runoff hazards in 2006

Figure 5 shows the settlements exposed to flood and runoff hazards in 2006 in the city of Bohicon.

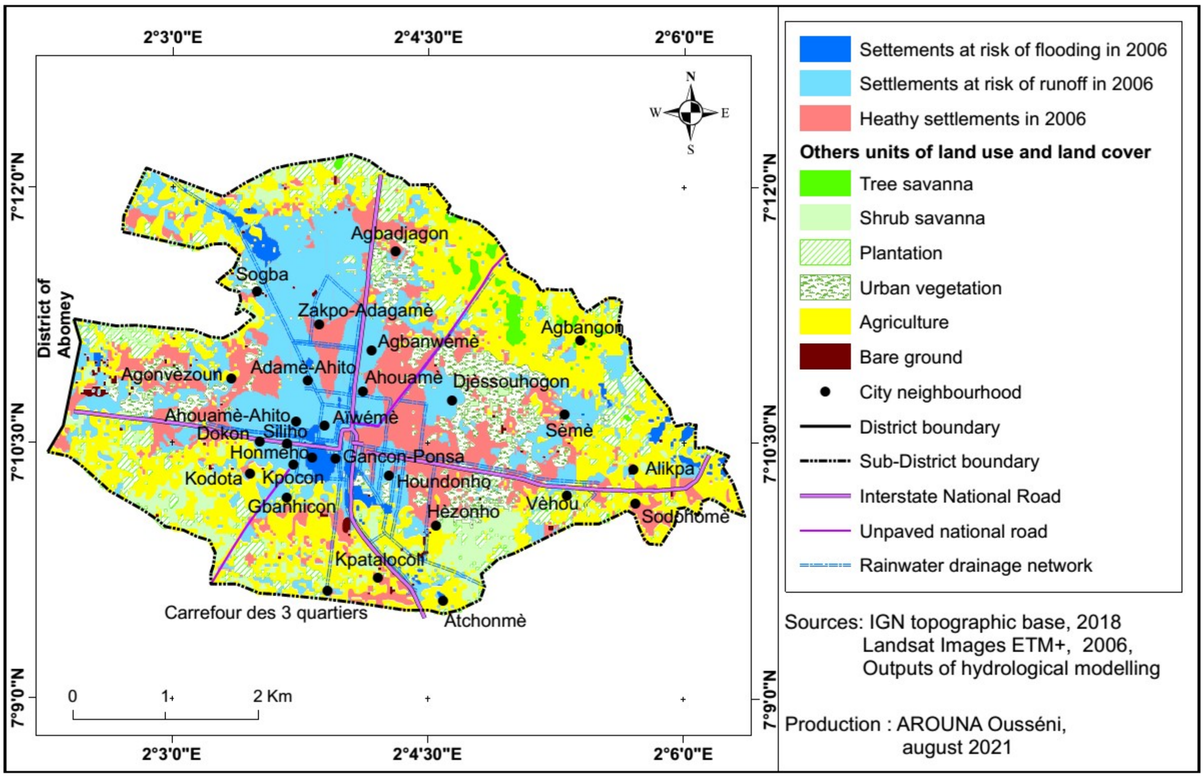

Figure 5. The settlements exposed to flooding and runoff hazards in 2006 in the city of Bohicon

The examination of figure 5 shows that the areas exposed to flooding in the city of Bohicon in 2006 are found in the city centre, particularly in the Gancon-Ponsa neighbourhood, and towards other peripheral neighbourhoods such as Ailipka and Sogba. In total, these areas exposed to flooding occupy a surface area of 45.37 ha. Assuming that each inhabited plot has a surface area of 500 m^2, we can deduce that about 907 plots are affected by flood hazards. Assuming that a plot is inhabited by 5 people, it can be deduced that 4535 inhabitants would be impacted by flooding in 2006.

Observing figure 5, it is clear that runoff hazards affect practically all neighbourhoods of the city of Bohicon, except for a few peripheral neighbourhoods such as Agbangon, Sodohomé and Hèzonho to a lesser extent. The settlements exposed to runoff hazards in 2006 cover an area of 676.33 ha, i.e. 11,367 plots of approximately 500 m^2 with a population of 5837 inhabitants exposed.

Healthy settlements that are not exposed to either flood or runoff hazards occupy an area of 350.32 ha or 36.33% of settlements. The number of plots of 500 m^2 concerned is 7006 which host a population of 35030 inhabitants.

In total, in Bohicon city, 4.70% and 58.95% of settlements were exposed to flooding and runoff hazards respectively in 2006.

4.2 Settlements exposed to flood and runoff hazards in 2011

Figure 6 shows the settlements exposed to flooding and runoff hazards in 2011.

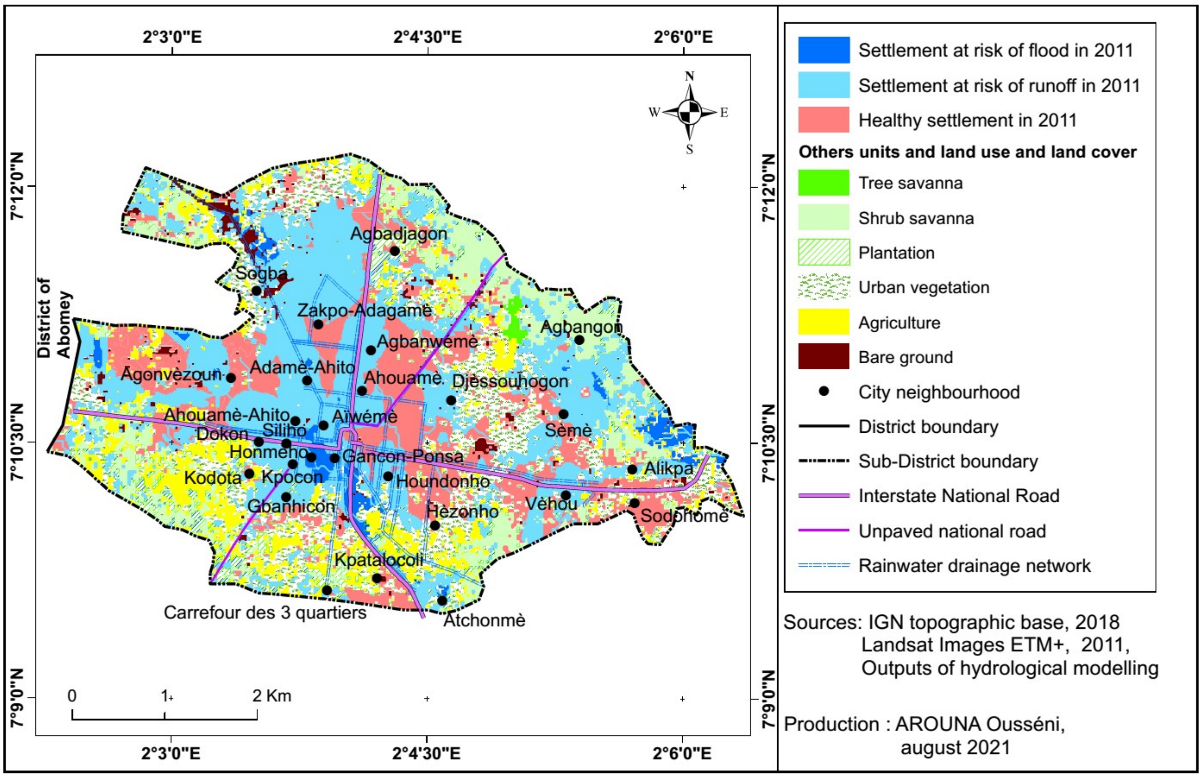

Figure 6. The settlements exposed to flooding and runoff hazards in 2011 in the city of Bohicon

Examination of figure 6 shows that apart from the neighbourhoods exposed to flood hazards in 2006, other neighbourhoods such as Sogba, Sèmè are exposed to flood hazards in the city of Bohicon in 2011. In total, 50.27 ha of settlements are exposed to flood hazards, i.e. 1105 plots of 500m^2. Assuming furthermore that a plot is inhabited by 5 people, it can be deduced that 5025 inhabitants would be impacted by flooding in 2011.

By examining figure 6, it appears that runoff hazards affect practically all the neighbourhoods of the city of Bohicon apart from the Sodohomé neighbourhoods. The settlements exposed to runoff hazards in 2011 cover an area of 659.84 ha, i.e. 13197 plots of about 500 m^2 with a population of 65985 inhabitants exposed

In 2011, healthy settlements occupied an area of 408.52 ha or 36.51% of settlements, i.e. 8171 plots of 500 m^2 with a population of 40855 inhabitants.

In 2011, 4.49% and 58.99% of settlements are exposed to flooding and runoff hazards respectively. Healthy settlements represent 36.51% in the city of Bohicon. These flooding and runoff hazards affect more than half of the city of Bohicon.

4.3 Settlements exposed to flood and runoff hazards in 2016

Figure 7 shows the settlements exposed to flooding and runoff hazards in 2016.

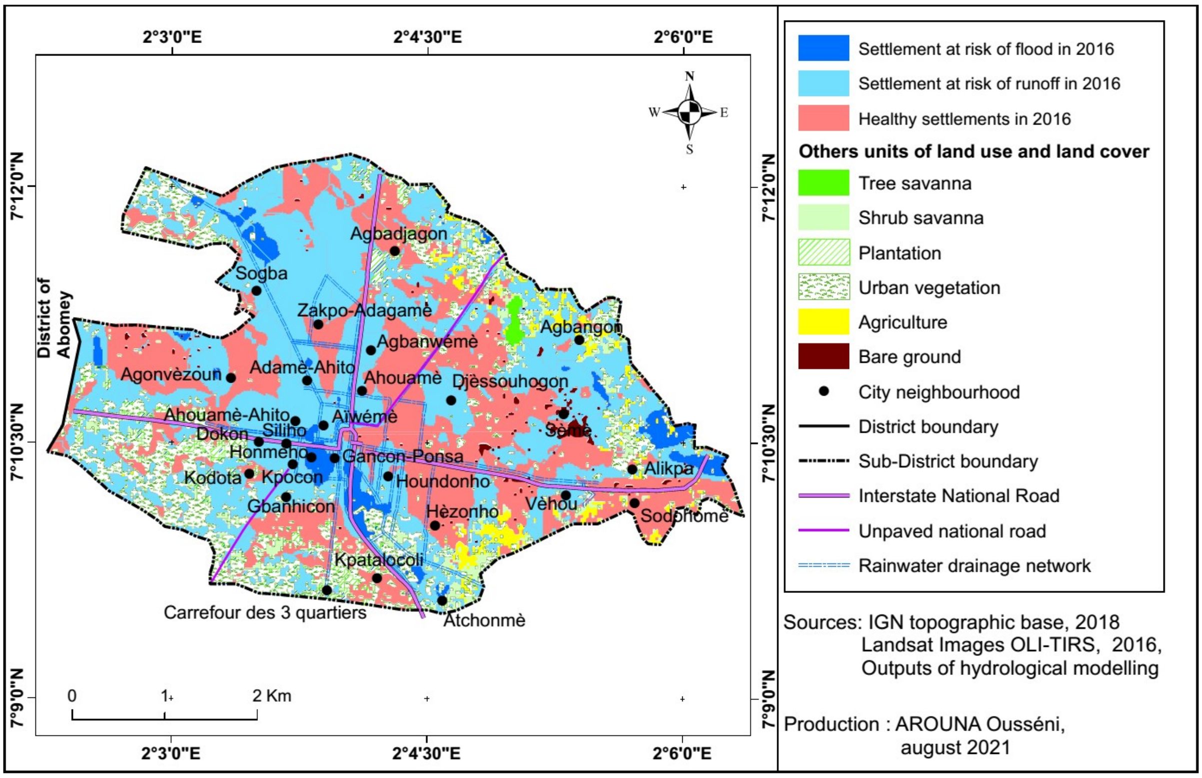

Figure 7. The settlements exposed to flooding and runoff hazards in 2016 in the city of Bohicon

Examination of figure 7 shows that apart from the neighbourhoods exposed to flood hazards in 2011, other neighbourhoods such as Sogba, Atchonmè are exposed to flood hazards in the city of Bohicon in 2016. In total, 77.63 ha of settlements are exposed to flood hazards, i.e. 1553 plots of 500m^2. Assuming furthermore that a plot is inhabited by 5 people, it can be deduced that 7765 inhabitants would be impacted by flooding in 2016.

By examining figure 7, it appears that runoff hazards affect practically all the neighbourhoods of the city of Bohicon apart from the Sodohomé neighbourhoods. The settlements exposed to runoff hazards in 2016 cover an area of 938.70 ha, i.e. 18774 plots of about 500 m2 with a population of 93879 inhabitants exposed

In 2016, healthy settlements occupied an area of 445.02 ha or 35.77% of settlements, i.e. 1288 plots of 500 m^2 with a population of 64039 inhabitants.

In 2016, 4.68% and 56.66% of settlements are exposed to flooding and runoff hazards respectively. Healthy settlements represent 35.77% in the city of Bohicon. These flooding and runoff hazards affect more than half of the city of Bohicon.

4.4 Settlements exposed to flood and runoff hazards in 2021

Figure 8 shows the settlements exposed to flooding and runoff hazards in 2021.

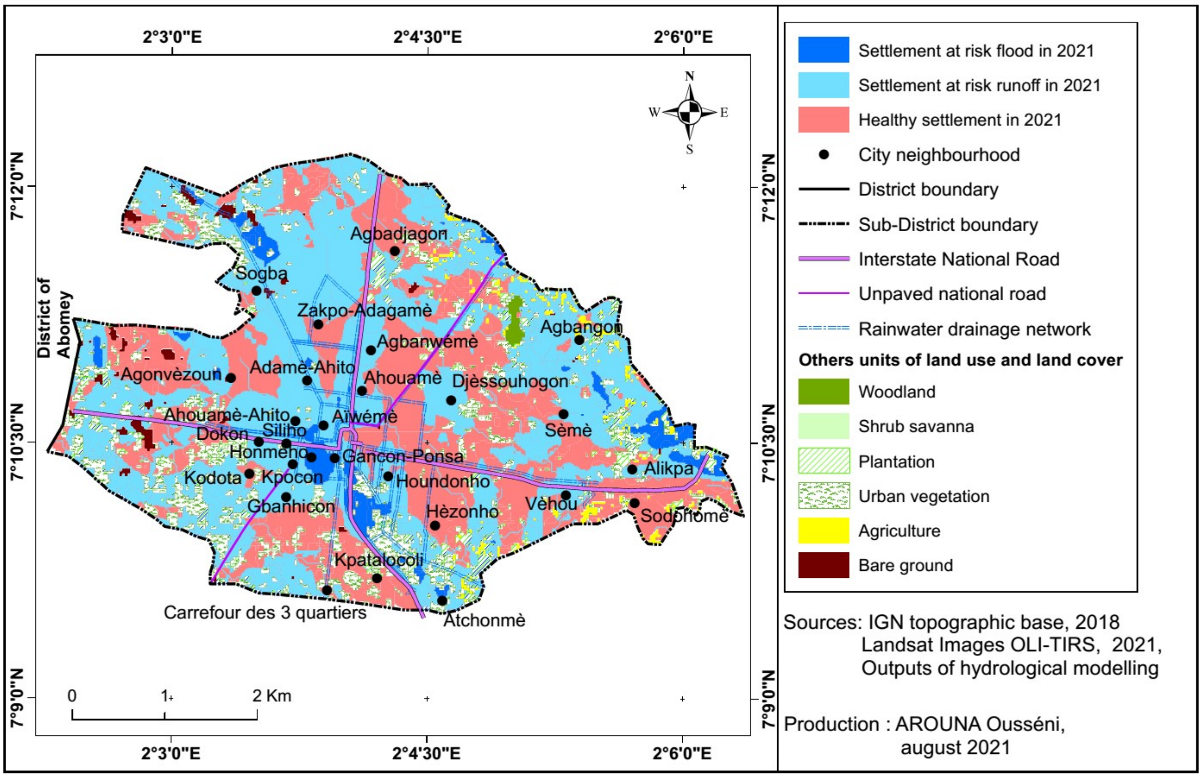

Figure 8. The settlements exposed to flooding and runoff hazards in 2021 in the city of Bohicon

Examination of figure 8 shows that all the neighbourhoods are exposed to flood and runoff hazards in 2021. In total, 85.03 ha of settlements are exposed to flood hazards, i.e. 1701 plots of 500m^2. Assuming furthermore that a plot is inhabited by 5 people, it can be deduced that 8505 inhabitants would be impacted by flooding in 2021.

By examining figure 8, it appears that runoff hazards affect practically all the neighbourhoods of the city of Bohicon. The settlements exposed to runoff hazards in 2021 cover an area of 1051.30 ha, i.e. 21026 plots of about 500 m^2 with a population of 105130 inhabitants exposed

In 2021, healthy settlements occupied an area of 665.68 ha or 36.94% of settlements, i.e. 13314 plots of 500 m^2 with a population of 66570 inhabitants.

In 2021, 4.71% and 58.34% of settlements are exposed to flooding and runoff hazards respectively. Healthy settlements represent 36.94% in the city of Bohicon.

4.5 Urban areas exposed to flood and runoff hazards in 2030

Figure 9 shows the settlements likely to be affected by flood and runoff hazards in the city of Bohicon in 2030.

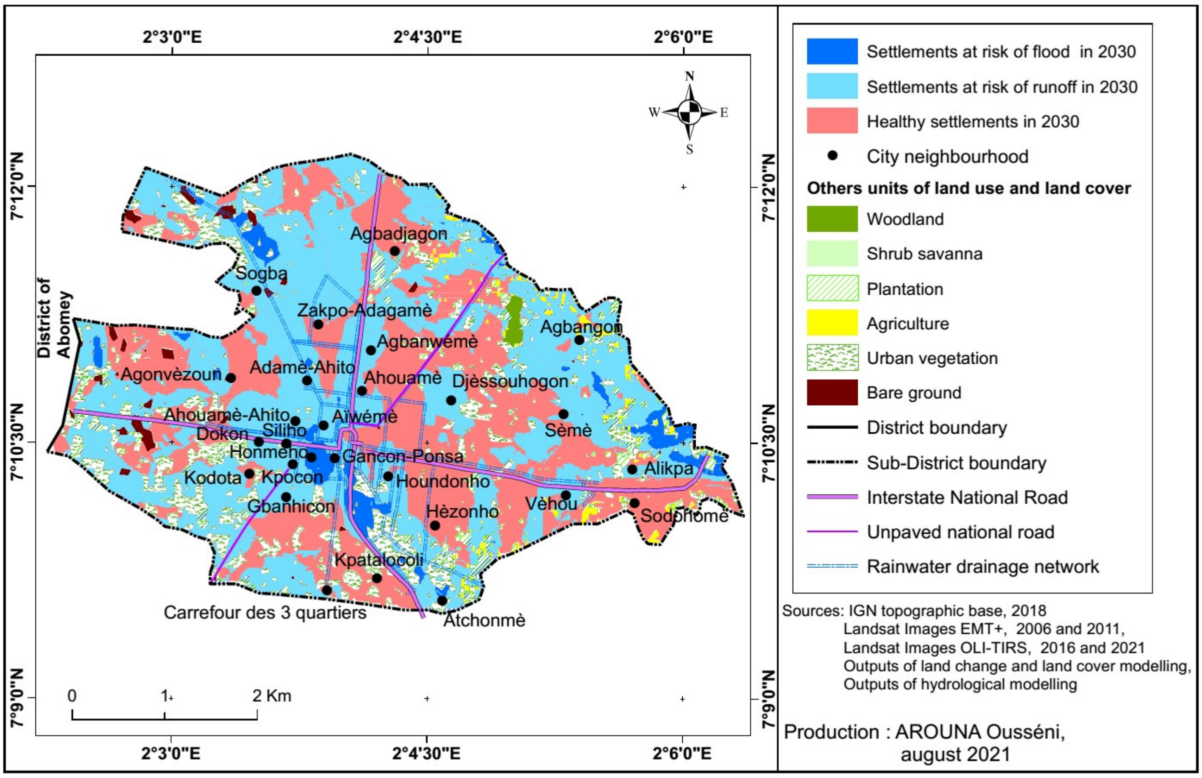

Figure 9. The settlements exposed to flooding and runoff hazards in 2030 in the city of Bohicon

Looking at figure 9, it appears that the city centre and some peripheral neighbourhoods such as Sogba, Agonvèzoun, Kpatalocoli, Atchonmè and Alikpa will probably be exposed to flood hazards in the city of Bohicon in 2030. These settlements will occupy an area of 95.95 ha or 1919 plots. A population of 9595 could be impacted by these flood hazards in 2030.

The hazards of runoff will be observed on practically all the neighbourhoods of Bohicon. The affected settlements will occupy an area of 1066.71 ha, i.e. 21334 plots of 500 m^2 each, which can accommodate a population of 106670 inhabitants in 2030.

The healthy settlements will probably occupy an area of 649.72 ha in 2030, i.e. 12974 plots that can house a population of 64870 inhabitants.

In total, in 2030, flooding and runoff hazards will occupy 5.29% and 58.85% of the settlements respectively. Healthy settlements will represent 35.85% of all settlements.

4.4 Dynamics of areas exposed to flooding and runoff

Figure 10 summarises the area of the settlements exposed to flooding and runoff hazards and the healthy settlements from 2006 to 2030.

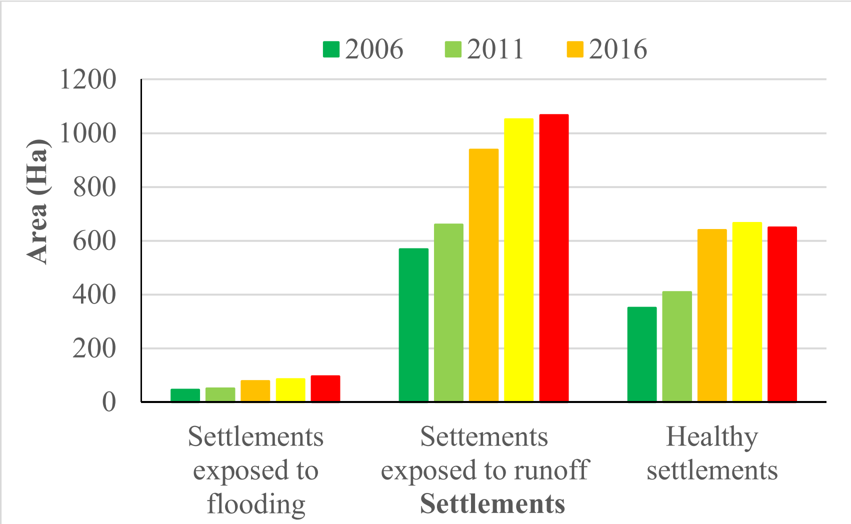

Figure 10. Summary of settlements at risk of flooding and runoff

Examination of Figure 10 reveals an increasing trend in each category of settlements. The settlements exposed to flood hazards have increased from 45 ha in 2006 to 95 ha in 2030. The settlements exposed to runoff hazards have increased from nearly 600 ha in 2006 to 1066 ha in 2030. Healthy settlements have also increased from 350 ha in 2006 to 650 ha in 2030. In total, the area of the settlements exposed to flood and runoff hazards follows the same trend of increase as that of settlements overall.

V. Discussion

5.1 Data and methods

The main data used are the Landsat images from 2006, 2011, 2016 and 2021 with a spatial resolution of 30 m and the Digital Elevation Model with a step size of 1 arc/s with a resolution of 30 m in X and Y. The method of change detection used is the post-classification comparison or classification difference. Post-classification comparison is a robust change detection method successfully used by several authors (Lu *et al.*, 2004 ; Arouna, 2017; Kahangwa *et al.*, 2020). Furthermore, flooding and runoff phenomena which are objects to be detected on satellite images cover large areas. In addition, several authors (Twumasi *et al.*, 2020; Khalil, 2018) have successfully used SRTM data at 1 arc/s (30 m X and Y resolution) available from the United States Geological Survey (USGS) to map floods and runoff. The data and methods used can therefore ensure the quality of the results obtained. The accuracy of the maps, which is around 90%, attests the high quality of the data and the robustness of the methods used (Awuh *et al.*, 2018; de Oliveira *et al.*, 2020). This is an indication of almost a perfect agreement (Awuh *et al.*, 2018; Kahangwa *et al.*, 2020). The transition probabilities used to predict the land cover by 2030 show evidence of the robustness of the modelling method used (Kahangwa *et al.*, 2020).

5.2 Dynamics of the settlements exposed to flooding and runoff

The results revealed that from 2006 to 2021, the proportions of the settlements exposed to flooding and runoff hazards have increased despite the significant investments made in the construction of stormwater facilities in the city of Bohicon. The area exposed to runoff hazards increased from 568 ha in 2006 to 1051 ha in 2021; this surface area could reach 1066 ha in 2030 if the current trend is maintained. The area of housing exposed to flooding has increased from 45 ha in 2006 to 85 ha in 202. More than half of the city is affected by flooding and runoff hazards. If this trend is maintained, this area could reach 95 ha by 2030. The results also revealed that the area of the settlements exposed to flood and runoff hazards follows the same trend of increase as that of settlements in general. The natural axes of rainwater concentration and runoff remain areas susceptible to flooding (Kangah et Alla Della, 2015).

Several factors can explain the increase of areas exposed to flooding and runoff hazards in the city of Bohicon. Firstly, there is the reduction of infiltration through soil sealing (Leumbe Leumbe *et al.*, 2015) following the increase in urbanised areas with roofs, streets, car parks and roads. This is a remarkable phenomenon in the city of Bohicon. This reduction of rainwater infiltration due to soil sealing is reinforced by a low vegetation cover. Indeed, rainfall is not intercepted efficiently because of the low intensity of vegetation cover (Armand, 2009). In the city of Bohicon, the low urban vegetation cover can explain the persistence of flooding and runoff hazards. Indeed, the denudation of the soil favours an increase in the volume of runoff water (Kangah et Alla Della, 2015). Other specific forms of land use can also be the cause of flooding and runoff. In the case of the city of Bohicon, this is the obstruction of water paths by human settlements, infrastructures, equipment and the presence of household waste in the storm drainage system (G2C Ingénierie & LHA, 2016).

Aside from land use, other geomorphological, hydrological, topographical and meteorological factors can also explain flood hazards (Antoine *et al*., 2008). The examination of these factors shows that the city of Bohicon is located in a depression which receives part of the runoff water from the Municipalities of Abomey and Djidja. This phenomenon partly explains the flooding and runoff in the built-up areas of the city of Bohicon. The topographical configuration of the site is an important factor in the flooding and runoff hazards as it is the case of the District of Sampathè in Senegal (Ndour *et al*., 2020). According to these authors, Sampathé has been confronted with many urban flooding problems which became recurrent due to the configuration of its settlement.

The analysis of the interannual variability of rainfall in Bohicon shows that there is no significant difference in the annual rainfall totals recorded in recent decades (2006-2017). The climatic factor does not play a determining role in the occurrence of flooding and runoff in the city of Bohicon.

The anarchic land use marked by the obstruction of water paths, the reduction of infiltration caused by the sealing of soils and the filling of rainwater drainage structures are factors that determine the occurrence of floods and runoff in the city of Bohicon. The anarchic land use is pointed as one of the important causes of flooding (Dembélé et Ouattara, 2019). These authors specified that floods are caused both by the occupation of flood-prone areas by the population and by a disruption of river and rainfall regimes, caused by climate variability. To cope with these phenomena, urban planning based on the application of remote sensing and GIS tools with the consideration of the stormwater dimension is needed (Twumasi *et al.,* 2020).

5.3 Implications of flood and runoff area dynamics

Flood and runoff mapping is an excellent decision-making tool for planners (Yésou *et al*., 2015; Khalil 2018). On the basis of this detailed knowledge of floods and runoff, informed decisions can be made.

The resolution of flooding and runoff problems must then be based on preventive solutions, as the curative measures taken by the Bohicon City Council and various projects have not been able to solve these problems (G2C Ingénierie & LHA, 2016). These preventive solutions involve taking into account the "rainwater management" dimension in urban planning. As the plan of subdivision is the first urban planning operation, it is then necessary to clearly identify and materialise the natural water paths in the housing estates in order to declare these zones as *non aedificandi* zones through a Municipality decree. A mechanism for the execution of the resulting planning should be put in place, with the local council being responsible for the implementation of the planning (Arouna, 2017). An efficient way to reduce its effects is preparing flash flood mapping to identify zones at risk due to flood and runoff.

VI. Conclusion

Remote sensing, GIS and hydrological modelling were used to map the dynamics of the settlements exposed to flood and runoff hazards in the city of Bohicon. The area of the settlements exposed to flood and runoff hazards has increased from 2006 to 2021. The area of the settlements exposed to flood and runoff hazards increases with the spatial extension of the city. Topographically, these are areas exposed to flooding and runoff that should not be occupied by housing. This clearly shows that the measures taken by the Bohicon City Council through the investments made in the construction of rainwater treatment facilities are not effective. This trend will probably be maintained if things remain the same until 2030. The anarchic land use characterised by the obstruction of natural water paths and the filling of stormwater facilities with rubbish are the main causes indexed.

Based on these results, it is appropriate to implement an urban planning model that takes into account the dimension of stormwater management. The maps generated could be used to declare areas at risk of flooding as unbuildable areas and appropriate construction measures should be promoted in areas exposed to runoff.

The limitations of this work may stem from the low X and Y resolution of the digital terrain model used to implement the hydrological modelling. A higher resolution digital terrain model could provide a more accurate result that takes into account all the particularities of the terrain, especially the role played by streets and urban developments in the problem of runoff and flooding. It is nevertheless an interesting and exhaustive first analysis at the city scale which quantifies the flood and runoff hazards for a first consideration of stormwater in the framework of urban development plans. The future research lines could deal with the evaluation of the contribution of urban streets and urban developments to flooding and runoff.

CONFLICTS OF INTEREST

The author declares no conflicts of interest regarding the publication of this paper.

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