A Proposed Methodology to Assess Disaster Risk within a Land Use Cover Change Model, contributing to SDGs - Case Study: Bogota, Colombia

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Keywords: Geographic Information System (GIS), Land Use Cover Change (LUCC), Risk management, Land planning, Sustainable Development Goals

SUMMARY

Disaster risk is derived from the combination of natural hazards and anthropogenic influence. Consequently, the social and economic impact that natural hazards have may be massive depending on the communities' vulnerability and exposure. Therefore, the way a city develops can determine its potential losses due to disaster risk, which is the reason why an understanding of hazards impact and urban growth tendencies are fundamental to reduce risk and should be considered by the decision makers. This study aims to develop a disaster risk assessment within a land use cover change model to analyze different scenarios of land development plans in Bogota, Colombia.

A Land Use Cover Change (LUCC) Model for urban and regional planning applications (Metronamica) is used to determine future land use scenarios for Bogota. Then, a risk assessment is conducted to demonstrate the opportunity for long-term risk planning by combining state-of-the-art urban modeling and risk assessment methodologies. In addition to the advanced urban model growth, this analysis is supported by a mapping and analytics Software (ArcGIS). Based on the different scenarios, it is possible to compare the behavior of disaster risk and forecast it by the year 2030.

As a result of this analysis, risk maps have been obtained for each scenario and are shown along with the conclusions and recommendations. Furthermore, this investigation is aligned with the Sustainable Development Goal (SDG) 11 (make cities inclusive, safe, resilient and sustainable) and will develop and improve the knowledge in risk assessment, to support the community and decision makers in the understanding of the impact that land development plans have on the magnitude of disastrous events, based on the found tendencies. It is intended to extend this study in the future to incorporate its findings into city resilience policy development.

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1. INTRODUCTION

In light of the world population rapid growth, which has doubled in less than 50 years, reaching 7.5 billion in 2017 (The World Bank, 2018), and given the need of society to develop different territorial activities, land use planning has become a primary concern for governing leaders, in both rural and urban areas (Yamin, Ghesquiere, & Ordaz, 2013). Considering that space is limited, and over the years the demand for urban land has increased, it has become imperative to develop proper planning. For ensuring this, it is essential to consider social, political, economic, cultural, and environmental aspects, which increases the complexity of the decision-making process. In the same way, many communities have settled down in flood and landslide-prone areas, causing disasters and claiming many lives. Therefore, many countries have adopted disaster risk management (DRM) into land use planning (GIZ, 2011).

With the increasing impact of disastrous events, caused by the combination of natural phenomena and anthropogenic action, governmental and intergovernmental agencies have acted through several global frameworks. For instance, the United Nations International Strategy for Disaster Reduction (UNISDR) was established to support and coordinate this movement in 2000. Shortly afterward, the 2005 World Disaster Reduction Conference led to the Hyogo Framework for Action (HFA), which was endorsed by the United Nations (UN) General Assembly. This Framework aimed to increase disaster risk reduction and resilience; however, vulnerability never stopped to rise, leading the creation of a new action: the Sendai Framework for Action (SFA: 2015-2030), this time adopted by 187 UN member states. Short after, the 17 Sustainable Development Goals (SDGs) were approved by all the UN Member States in 2015, with the objective to 'produce a set of universal goals that meet the urgent environmental, political and economic challenges facing our world' (UNDP, 2018). One year later, as support of the SDGs, especially SDG 11 (Sustainable Cities and Communities), the New Urban Agenda (NUA), an urbanization action blueprint, was declared in the UN-Habitat's 3rd conference (UNDP, 2018). Nevertheless, these efforts are almost starting to be considered in many countries, leaving a large amount of the world population paying the consequences of a previous lack of development planning (UNISDR, 2015a).

This study aims to support the community and decision makers in the understanding of the impact that land use planning has on the magnitude of disaster risk. This is achieved through the development of a disaster risk assessment based on land use cover change (LUCC) model's simulations. Furthermore, this study is aligned with the SDG 11 with the aim of "make cities inclusive, safe, resilient and sustainable" (UNDP, 2018). The paper is organized as follows. Section 2 briefly reviews the research context and relevant literature. Section 3 presents the methodology used to achieve the main objective. Section 4 shows the results. Section 5 makes a discussion on the main findings. Section 6 concludes and presents recommendations. It is intended to extend this study in the future to incorporate its results into city resilience policy development.

2. RESEARCH CONTEXT AND LITERATURE REVIEW

To understand the connection between Disaster Risk Reduction (DRR) and sustainable development in urban areas, two global frameworks are discussed. Moreover, a literature review is made along with methodological approaches taken in this study.

2.1 Disaster Risk Reduction and Sustainable Development

In 2018, the CDMPS pointed, in the Blueprint for Disaster Management RD&D Supporting the SDGs, the existing relationship between disaster management and each SDG. Ensuring that ‘with the rapid growth of urban populations, disasters can cause significant losses at national and global levels since the risk exposure is highest there […]. The incorporation of DRM in urban planning and policies can significantly reduce the negative impact of disasters on cities and urban communities and ensure inclusive, safe, resilient, and sustainable cities and human settlements for all’. Therefore, the purpose of this study is aligned with the SDG goal number 11, specifically targets 11.3, 11.5, and 11.b.

These targets have been adopted by several organizations to ensure fulfilling the SDGs achievements. For instance, the NUA adopted them, and it sets a global standard for a sustainable urban development, representing a shared vision for a better and more sustainable future, recognizing the linkages between sustainable urbanization and, among others, sustainable development, DRR, and climate change, and providing a guide for achieving the SDGs.

The relationship between the SDG 11 indicators and the NUA priority areas is illustrated in Figure 1 where can be noticed that national urban policies are related to three of the indicators, meaning it is a strong area in relation with the DRR. Besides, indicator 11.3.1 (ratio of land consumption rate to population growth rate) (UNDP, 2018) is relevant for three of the four priority areas, including urban planning and design. This means that to improve this indicator and focus it on a sustainable development, land use planning must consider DRM, and urban extensions must be controlled, among other considerations (UN, 2017).

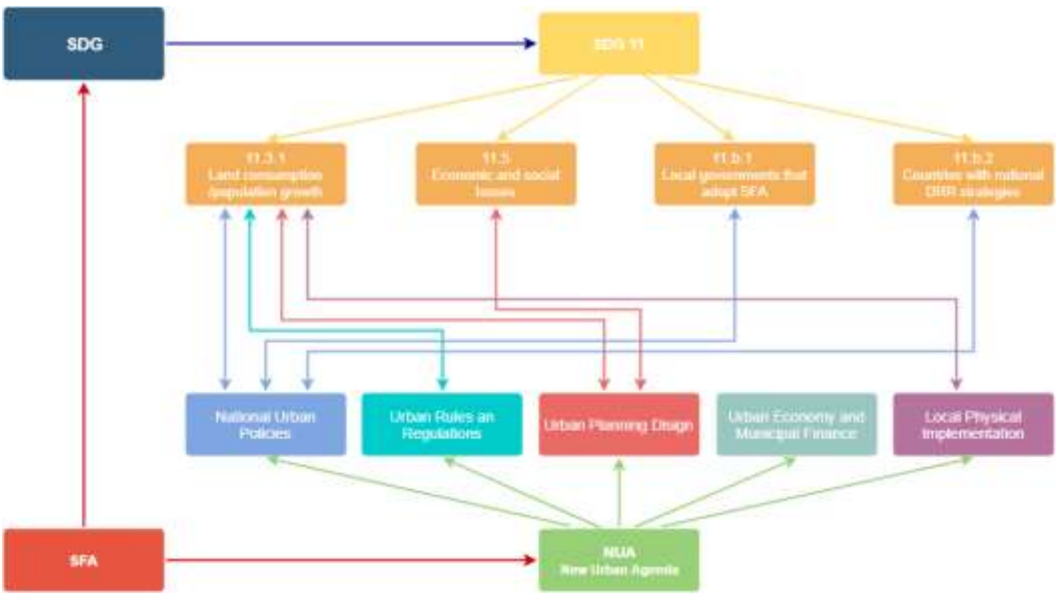

Figure 1. Linkages between SDG 11 indicators and NUA priority areas. Source: Prepared by the authors based on the UN-Habitat report (2017) and CDPMS SDGs Blueprint (2018).

Regarding one of the NUA's transformative commitments for environmentally sustainable and resilient urban development, it is intended to strengthen resilience in cities, to reduce the risk and the impact of disasters, by implementing measures as improving urban planning and local responses (UN, 2017). Specific commitments aligned to this study sought to promote DRR and management through strategies and periodical assessments (par. 65) (UN, 2017).

On the other hand, as a practical implementation measure for 'planning and managing urban spatial development,' NUA seeks to integrate DRR and climate change adaptation to territorial planning processes, encouraging collaboration across sectors to develop and implement DRR and formulate adequate response plans (UN, 2017).

These frameworks indicate the importance of implementing DRR strategies in land use planning to increase resilience and decrease vulnerability. Understanding the impact that land use changes of urban and rural areas have on disaster risk, could help decision makers to achieve that aim.

2.2 Methodological Approaches

This study is multi-disciplinary, with the involvement of major domains such as urban land use planning, and disaster risk assessment, in which SDGs and NUA apply. While the focus is on using geographical information systems (GIS) as a platform and enabler to perform analytics in this study, it is still necessary to evaluate the methodological approaches of the domains mentioned above separately. As such, the rest of this sub-section is divided into two areas.

2.2.1 Land Use Planning

Through history, land use planning has been understood as a social process that conduces to environmental sustainability, social justice, and economic balance. Since the 1990s, there has been a proliferation of technologies applied to land use planning, such as GIS and remote sensing, which can be used to monitor land cover changes (GIZ, 2011).

Because of the impact of accelerated urbanization, LUCC models have become an essential topic for local and regional land use planning research and practice (Liu, X., et al. 2017; Yu, W., 2011). LUCC based on Cellular Automata (CA) models has been used in recent studies because of its flexibility, simplicity, and capability to incorporate spatial and temporal dimensions of urban growth processes (Sante, G. et al., 2010).

An example of a CA-LUCC model is Metronamica[1], which is a Spatial Decision Support System for land planning (RIKS BV, 2012). This software has been used successfully in several developing countries, including Colombia. Some benefits of this model are the facility to link to GIS, the freedom to run different future scenarios, and the capability to ''learn'' the characteristics of a defined area (Paez, D., & Escobar, F., 2018).

The calibration of the model is made through a cell-by-cell comparison between the simulated land-use and the observed land-use using Map Comparison Kit 3 Software (MCK), where a Kappa similarity index is evaluated (SUR, 2018). Even though some authors recommend different methods to calibrate models for more accuracy, Kappa index has been primarily used in the literature showing good results (Pontius and Millones, 2011). Due to the limitations of CA, two main assumptions are made in this model: (i) population density remains constant in time, (ii) occupation demand is homogeneous for the entire study area (RIKS BV, 2012).

[1] http://www.metronamica.nl/

2.2.2 Disaster Risk Assessment

Disaster risk is derived from the combination of natural hazards and anthropogenic influence. It can be measured through risk assessments by determining hazard, exposure and vulnerability, where hazard is defined as harmful events such as flood, bushfire, earthquake, and landslide, that could result in loss, exposure represents the economic assets, physical goods and population on potential loss due to hazard impacts, and vulnerability is related to the susceptibility of exposed assets (Simmos, D. et al., 2017).

As result of risk assessments, an estimation of possible social, economic, and infrastructure impacts from a particular hazard or multiple hazards can be done with the aim of developing a DRR action planning (GFDRR, 2014b). This is relevant because the integration of DRR into investment decisions contributes to strengthening resilience and therefore to the accomplishment of sustainable development (UNISDR, 2017). A proper risk analysis is directly related to the aim purposed, the available data, and its quality. Therefore, a global risk assessment does not exist (Simmos, D. et al., 2017).

To support disaster risk assessment, the most common technology used is GIS because of its accuracy into the analysis of multiple and complex datasets, and its capability to reveal trends and patterns over defined areas (Esri, 2018). Tools available in GIS packages such as ArcGIS[2] and Q-GIS[3] have been frequently used in several recent types of research related to disaster risk assessment, especially those related to the flood risk analysis (Nur, W., 2018; Azizat, N., 2018; Liu, C. & Li. Y., 2017). Raster analysis in a GIS environment is commonly used to obtain more accurate and spatially enabled risk assessment (Liu. Chunlu, Li. Yan, 2017). Higher accuracy can be achieved because raster format is useful in describing continues elements or phenomena such as density, topography, and land-use (Paez, 2012).

To support complex decision-making processes, a general framework called Multicriteria Decision Analysis (MCDA) had been broadly used in GIS analysis (Matori, A., 2014). The most commonly used MCDA for risk assessment is the Analytic Hierarchy Process (AHP), as it is considerate by many researchers as the most reliable method to determine the weights of variables. This method was introduced by Thomas Saaty (1980), and it has been largely applied in making decisions in, among other things, transportation, planning, economics, education, resources allocation, and more recently in risk management (De Brito, 2016). The evaluation of criteria can be based on a direct judgment of an expert group (Kokangül, A., 2017) using a pairwise comparison matrix with a nine-point scale (Diop et al., 2017). To verify the trustworthiness of the matrix, a consistent ratio (CR) is calculated (Bathrellos et al., 2017).

Different variables are used to develop a risk assessment. In the case of flood hazard, there are some variables used frequently by researchers, which can be seen in Table 1.

Table 1. Variables' literature review

Factor	Inputs	**Literature Review**
Hazard	Elevation	Ghosh, A., & Kar, S. K. (2018), Seejata, et al. (2018), Siddayao, G. (2014).
	Slope	Ghosh, A., & Kar, S. K. (2018), Seejata, et al. (2018), Matori, et al. (2014).
	Distance from rivers	Ghosh, A., & Kar, S. K. (2018), Seejata, et al. (2018), Liu. Chunlu, Li. Yan (2017), Nasim Yeganeh and Soheil Sabri (2014), Siddayao, G. (2014), Derwan A. (2013).

[2] ESRI's Software. https://www.arcgis.com/index.html
[3] https://www.qgis.org/es/site/

	Historic floods	Febrianto, H., et al. (2016)
	Rainfall pattern	Ghosh, A., & Kar, S. K. (2018), Seejata, et al. (2018), Febrianto, H., et al. (2016), Matori, A. N., et al. (2014).
Exposure	Land-Use	Seejata, et al. (2018), Bathrellos (2017), Liu. Chunlu, Li. Yan (2017), Khosravi (2016), Nasim Yeganeh and Soheil Sabri (2014).
	Population density	Liu. Chunlu, Li. Yan (2017), Pittore et al. (2016), Nasim Yeganeh and Soheil Sabri (2014), Siddayao, G. (2014), Yamin et al. (2013), Derwan A. (2013).
Vulnerability	Economic income level	Liu. Chunlu, Li. Yan (2017), Yamin et al. (2013).
	Primary road density	Liu. Chunlu, Li. Yan (2017)

Among the variables presented in Table 1, the most compelling to this study are elevation, slope, distance from rivers, land-use, population density, economic income level, and primary road density because of the availability and quality of this data.

2.3 Study area

Bogotá, the capital city of Colombia, is located in the western Andes range of the country. This city is exposed to a high-moderate seismic hazard. In fact, through history there has occurred three large-scale seismic events., with an intensity of 8 degrees in 1785, 1827 and 1917 (IDIGER, 2018). Besides, because of its topographic conditions, the city is also susceptible to floods and landslides (Yamin, Ghesquiere, & Ordaz 2013).

Furthermore, this city has an area of 307,4 km2 with a population of approximately 8,1 million, housing 21% of the urban population of the country, and making it a highly dense city (The World Bank, 2012). Most of the universities, schools, and business centers are located on this city, generating more than 27% of the National GDP, the reason why the population has continued growing at a rate of approximately 1.24% per year (DANE, 2017).

Due to the rapid urbanization, in recent years, risk management has been a main concern for the government, since it represents an indispensable development policy to ensure the sustainability and territorial safety (Colombian Ministry of Foreign Affairs, 2014). Consequently, the Colombian government has ensured new guidelines for the inclusion of DRM for each Municipal Development Plan (POT[4], in its Spanish acronym), and has created normative support of DRM. (The World Bank, 2012).

Nowadays, Bogotá is governed by the 2004's POT, which did not consider a detailed DRM plan until its latest updates (Yamin, Ghesquiere, & Ordaz, 2013). It was not until 2012 when the Law 1523 established a National Policy on Disaster Management. Consequently, the land use of Bogotá was being developed, ignoring the exposition to natural hazards for several years (SDP, 2015). Also, poor practices in the urbanization and development processes, and deficiencies in construction techniques as well, increase the vulnerability of the communities, and therefore its risk (The World Bank, 2012).

In view of this, the Cities' Institute of Risk Management and Climate Change (IDIGER) was created in Bogota in 2013, and its main objectives are to ensure the execution and continuity of risk management processes, and to control the execution of Bogota's risk management plans, guaranteeing sustainable, safe and resilient territories (IDIGER, 2015).

[4] A basic instrument which contains politics, strategies, goals, programs, and rules, essential to achieve an adequate territorial development (SDP, 2015).

Colombia, as Member State of the UN, adopted the SDGs in 2015. However, it was not until this year (2018), when the country defined specific goals to guarantee the achievement of the SDGs at a national level. In this respect, and regarding the SDG 11, Colombia set the goal to decrease quantitative housing deficit[5] from 6.7% (2015) to 2.7% by 2030 at a national level. For that, 1.5 million of homes were delivered by the government between 2015 and 2018, of which 750,000 were social interest housing, and it is intended to continue the construction of households led by the government for the next years. The methodology to measure this index, however, does not considers houses located in high-level disaster risk areas (DNP, 2018). Therefore, the SDG 11 goal set in Colombia does not take DRM into account. This does not mean that the POTs do not consider it, as previously mentioned. Indeed, Colombia implements national disaster in line with the SFA (UN, 2017).
In conclusion, while NUA has provided directions for implementing SDG 11, it has not been fully considered in both Bogota and Colombia. The methodology developed in this study intends to provide support for the implementation of both SDG11 and NUA priority areas in Colombia through the connection of DRR and Land Use Planning.

3. METHODOLOGY

This methodology is developed with the aim of aligning disaster risk assessments with land use planning, contributing to SDGs and NUA, using a CA-LUCC model as a basis. Because of different research communities have different concepts for vulnerability and risk assessment data and method (Nur, Wawan Hendriawan, Kumoro, Yugo, Susilowati, Yuliana, 2018), this study is based on the integration of a series of processes to achieve the primary objective, as noticed further. The workflow of this study is developed into four different stages: Definition of scenarios, Definition of Inputs, Data Processing, and Risk Assessment. The steps for each stage are described in Figure 2. This workflow can be adapted in different contexts.

[5] Housing quantitative deficit estimates the amount of housing that must build so to have a one-to-one relationship between adequate housing and households that need housing. (DANE, 2009)

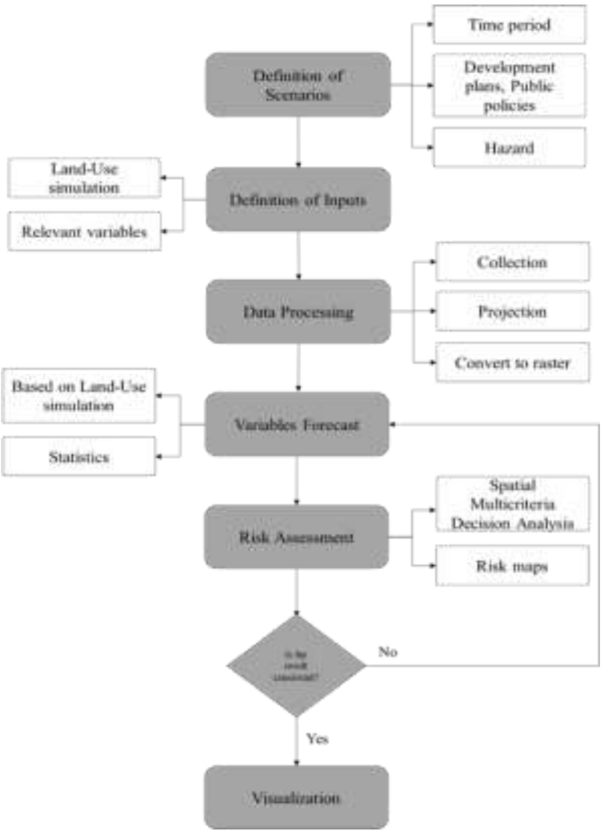

Figure 2. Proposed workflow of research methods. Source: Prepared by the authors.

3.1 Definition of scenarios

Definition of scenarios involves time period, development plans, and public policies that wants to be studied in the CA LUCC model simulations, and the hazard under which risk assessment wants to be made.

Three different scenarios are proposed. The first scenario is 2016 observed land-use, the second is 2030 simulated land-uses without modifications on the inputs (business as usual), and the third is 2030 simulated land-uses under the implementation of different development plans and public policies. Definition of second and third scenario is based on a project developed by Grupo de Sostenibilidad Urbana y Regional (SUR, group of urban and regional sustainability), from la Universidad de Los Andes, Colombia (SUR, 2018).

The third scenario contemplates an important urban renewal of the north of the city[6], and two other development plans[7] proposed by the district as well. Besides, projects for new transport infrastructure are also considered: modal interchange centers[8], Bus Rapid Transit (BRT) networks[9], road networks[10], aerial tram[11], metro[12], and Light Rail Transit (LRT)[13]. These projects are expected to be done by 2030.

[6] *Lagos de Torca*
[7] *Ciudad Río, Ciudad Tunjuelo*
[8] *Centros de intercambio modal (2024)*
[9] *Transmilenio fase 4 y 5 (2023, 2027)*
[10] *Proposed regional and ciudad Norte road networks (2023)*
[11] *Transmicable fase 1 y 2 (2023, 2027)*
[12] *Metro linea 1 (2023)*
[13] *Regiotram Occidente y Norte (2021, 2023)*

The Hazard chosen for this research is flooding, as the available data and the methodologies approaches are more aligned to this.

3.2 Definition of inputs

Definition of inputs depended on the context and the availability of the data, as the literature review as well. Variables used for this study case are the terrain parameters, such as slope angle, and elevation derived directly from the digital elevation model (DEM), built-up areas, population density, distance from rivers, economic income level, and first road density.

3.3 Data processing

Data processing includes georeferencing, projection of every layer to the same coordinate system, and harmonization of criteria by rating the ranges of each variable from 1 to 4 based on literature review. In this research, the study area is represented as a continuous raster grid with a cell size of 60 x 60 meters (3600 square meters), as an approximation of a block area in Bogota, and all the information is projected to *MAGNA_Colombia_Bogota* coordinate system.

3.4 Variables Forecast

The CA-LUCC model is used to simulate land use changes between 2016 and 2030 under different development plans and policies of Bogota and the region[14]. Layers use as inputs for these simulations are: (i) 2016 land uses, (ii) environmental aptitude, related to biophysical variables as landslide, flooding areas, and forest fires, (iii) zoning, which represents a policy that allows or restricts the development of land uses, (iv) traffic infrastructure, (v) accessibility, and (vi) neighborhood curves. Resultant land-uses are divided into 15 categories, including available land, low residential, medium residential, high residential, industrial, commercial, mix, transport services, water bodies, parks, health, education and security services. Information sources for Bogota are the cadastral bases of the Secretaría Distrital de Planeación (SDP).

Based on land-use simulations' results, it was possible to obtain 2030 population density, built-up areas, and economic income. For population density, a Kernel density method of 2016 population is applied in GIS and the assumption of population density remaining constant in time is made to 2030 forecast. Inputs chosen along with its data source and the analysis method used for each are summarized in Table 2.

Table 2. Inputs for risk assessment.

Inputs	**Data Source**	**Method of Analysis**
Elevation	NASA (2018).	Digital Elevation Model (DEM)
Slope	NASA (2018).	Slope
Distance from rivers	IDECA.	Euclidean distance
Land-Use	SDP (2007), SDP (2014), SUR (2018).	CA-LUCC
Built-up areas	Land-use simulation result	
Population density	DANE (2916), Land-use simulation result	Kernel Density
Economic income level	Land-use simulation results	
Primary road density	SDP.	Line Density

[14] Although spatial extension for land-use simulations includes information of seventeen municipalities and Bogota, the risk assessment is made only for the city of Bogota.

After forecasting the variables, a data processing is made again for the new layers of 2030.

3.5 Risk Assessment

Once the inputs are well defined and processed, each variable is classified into hazard, exposure, or vulnerability factors, where slope, elevation, and distance from rivers classify as hazard, population density and built-up areas as exposure, and road density and economic income level as vulnerability.

As part of the disaster risk assessment, AHP method is conducted to generate weights. For this, a classification of the variables relative importance was made by 5 experts. Afterwards, Equation 1 is applied through Raster Calculator in GIS to calculate each disaster risk factor (DRF).

$$DRF = \Sigma W1 * R1i + \Sigma W2 * R2i + \ldots + \Sigma Wn * Rnj$$

Equation 1

Where W is the weight of the variable and R are the given ratings. Finally, disaster risk maps are resultant from the factor's combination, as done in the studies of Yamin, Ghesquiere, & Ordaz (2013) and Luu & von Meding (2018):

$$\textit{Disaster risk} = \textit{Hazard} * \textit{Exposure} * \textit{Vulnerability}$$

Equation 2

Once applied these equations, a risk map is generated for each scenario.

4. IMPLEMENTATION AND RESULTS

4.1 Forecasts

Land-Uses

Simulation of land-uses for scenario 2 and 3 are shown in Figure 3**,** as so the observed land-uses of scenario 1. Bogota area is shown inside the grey shade. It can be noticed that if the city adopts the proposed development plans, it is going to grow especially in the northern area. As opposite way, in scenario 2 the changes are not going to be notable, even for existing land uses, the development will be focused on rural areas.

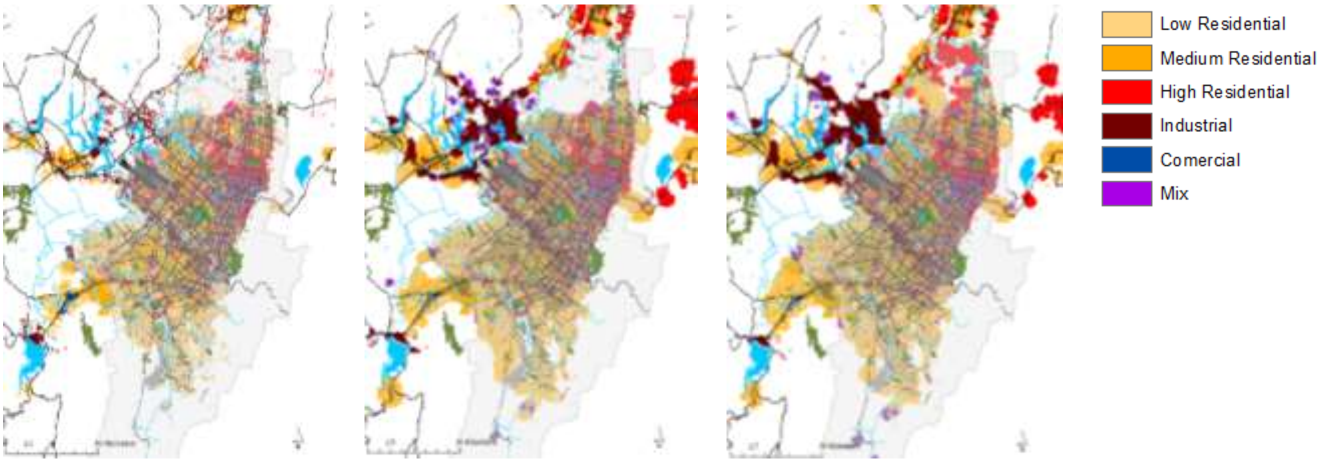

Figure 3. Land-Uses. (1) Scenario 1, 2016. (2) Scenario 2, 2030 business as usual. (3) Scenario 3, 2030 development plans.

Based on the simulations, it can be observed that scenario 3, differently as scenario 2, will have a more spread population with the planned development, as shown in Figure 4. Additionally, scenario 2 shows a densest city not only in terms of population but also in infrastructure, as shown in Figure 5. As for economic income level, the tendencies are going to remain in time with the difference of a new low-income level area located in the north result of social housing, as shown in Figure 6.

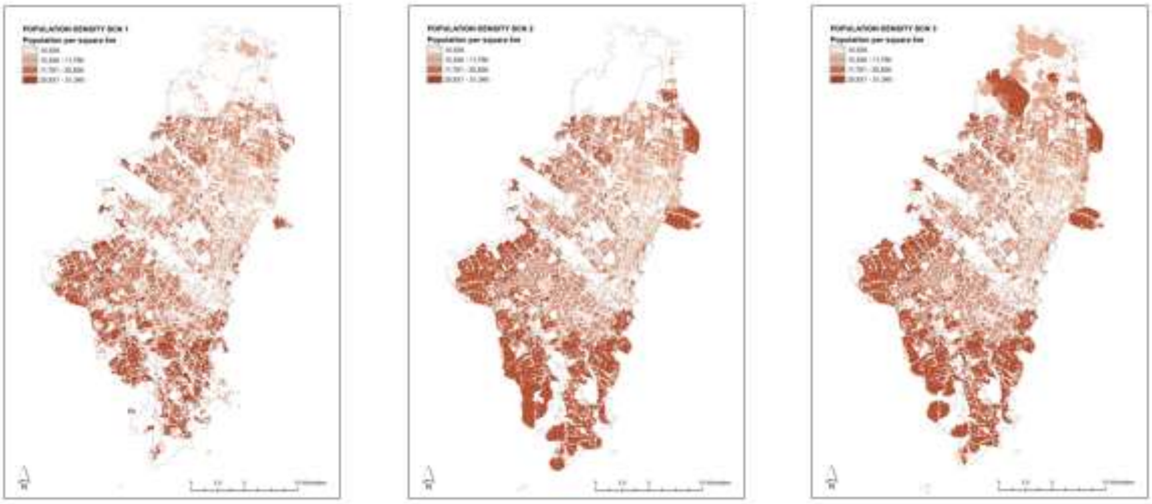

Figure 4. Population density (1) Average density scenario 1. (2) Average density scenario 2. (3). Average density scenario 3.

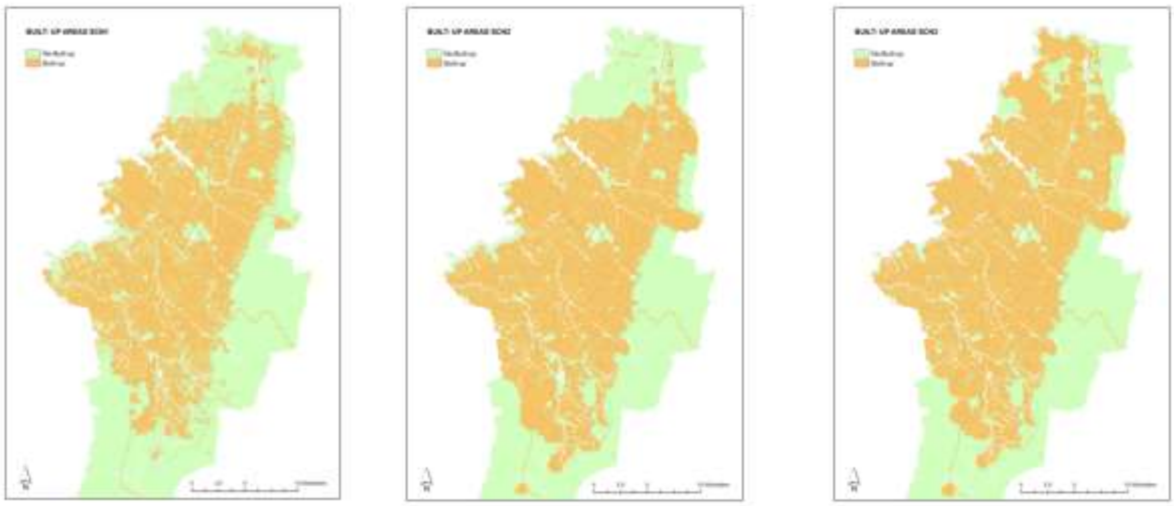

Figure 5. Built-up areas. (1) Scenario 1. (2) Scenario 2. (3). Scenario 3.

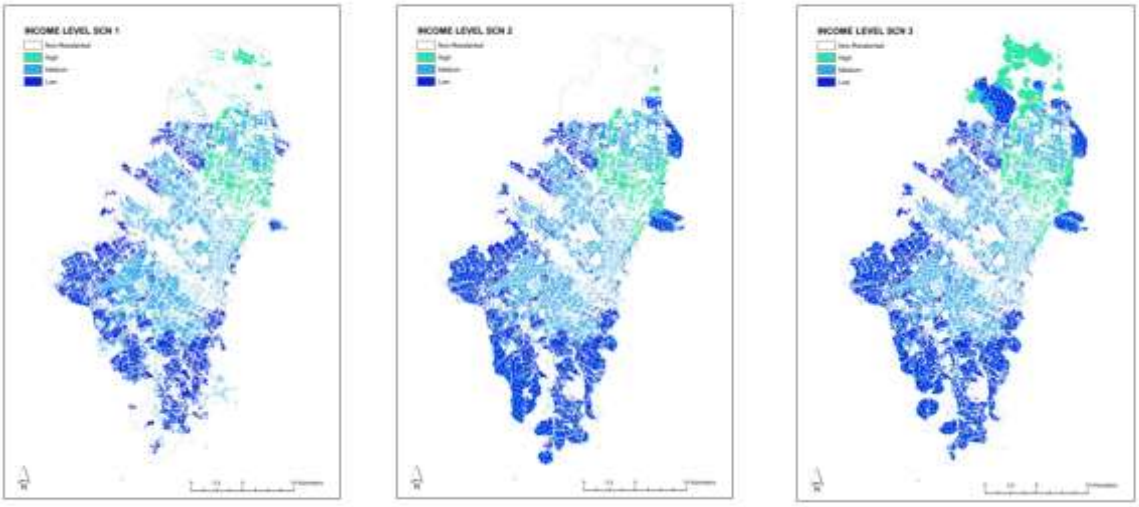

Figure 6. Economic income level. (1) Scenario 1. (2) Scenario 2. (3). Scenario 3.

Primary road density is the same for scenario 1 and 2, as it was set on the CA-LUCC for business as usual. Nonetheless, it can be observed a higher density in scenario 3, meaning a decrease of vulnerability because of the high accessibility, as shown in Figure 7.

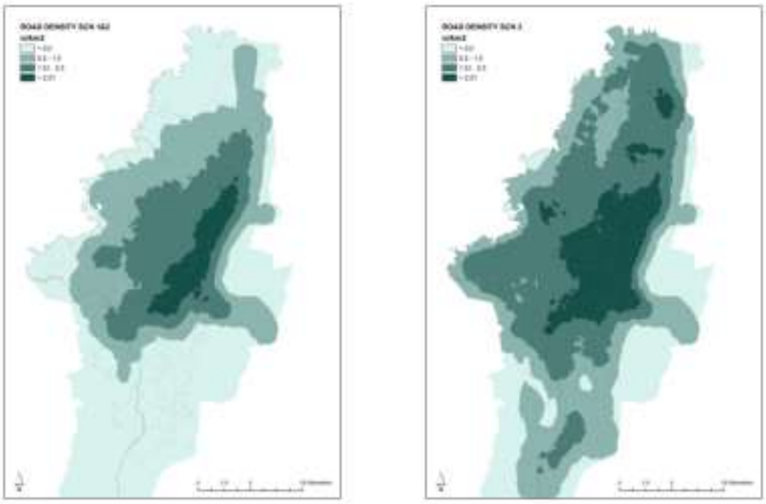

Figure 7. Principal road density. (1) Scenario 1 and 2. (2). Scenario 3.

Finally, terrain characteristics are observed in Figures 9 and 10, as the distance from the river in Figure 8. A lower slope, elevation, and distance from the rivers mean higher risk, hence, the western area of the city is more susceptible to flood hazard according to these characteristics.

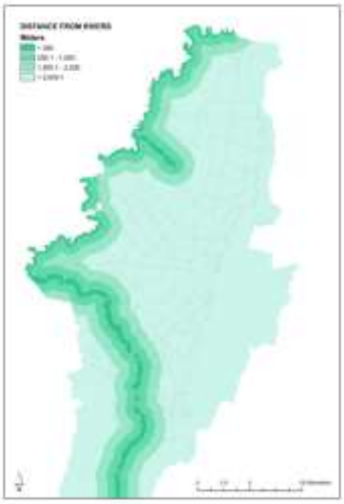

Figure 8. Distance from rivers.

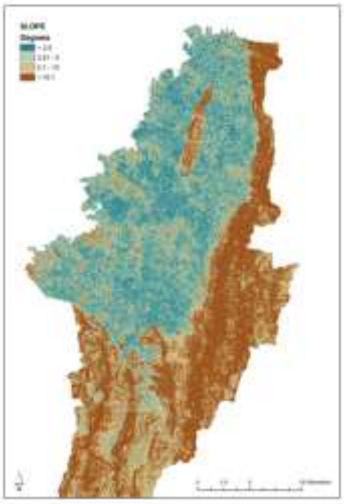

Figure 9. Slope.

Figure 10. Elevation.

4.1 Risk assessment

As a result of the AHP, different weights were calculated for each variable. After figuring a Consistency Radio (CR) smaller than 0.1, it can affirm that these results are reliable. Results are shown in Table 3.

Table 3. Variables rating and weights

Factor	Criteria	Functional relation	Rating	Rating
Hazard	Elevation	Inverse	2301-2600 m	4
			2600.1 – 2700 m	3
			2700.1 – 3000 m	2
			3000.1 – 4065 m	1
	Slope	Inverse	< 2.5	4
			2.51 – 5	3
			5.1 – 10	2
			< 10.1	1
	Distance from rivers	Inverse	< 250m	4
			250.1-1000 m	3
			1000.1–2000 m	2
			> 2000.1 m	1
Exposure	Population density (p/km2)	Direct	0	1
			0.1-10539	2
			10540-11790	3
			> 11790	4
	Built-up areas	Direct	Not-Built	1
			Built-up	4
Vulnerability	Economic income level	Inverse	Low	4

		Medium	3
		High	2
Primary road density (m/km2)	Inverse	<0.5	4
		0.51-1.5	3
		1.51-2.5	2
		> 2.51	1

Finally, the flood risk map (Figure 11) is resultant from the integration of hazard, exposure, and vulnerability maps.

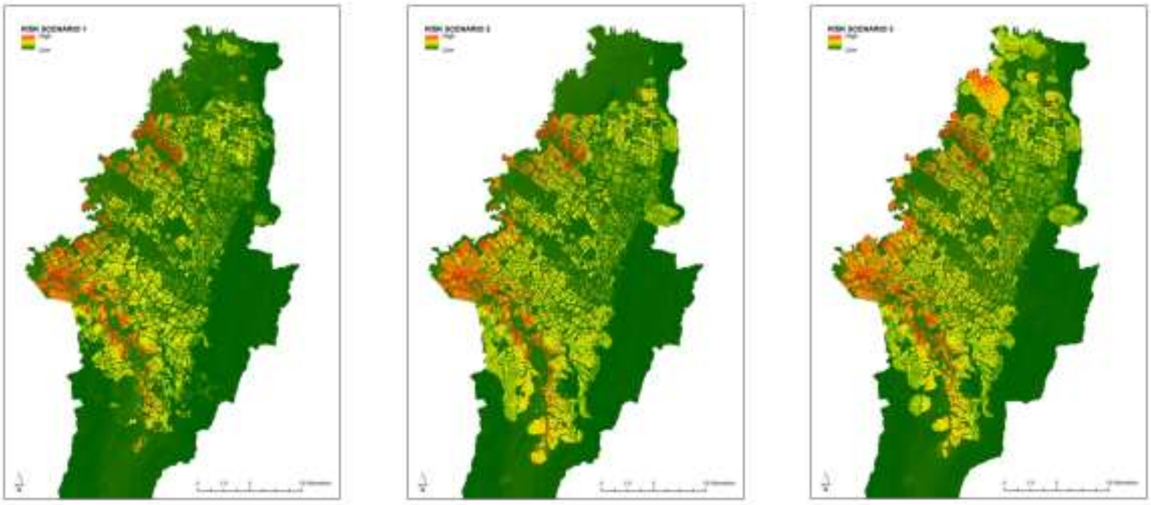

Figure 11. Risk maps. (1) Scenario 1 (1), Scenario 2 (2). Scenario 3 (3).

As shown, higher risk areas are located near the river and are more notable in low-income level areas, and higher population density areas as well, since more people are exposed to this hazard. Scenario 2 is not too different than scenario 1, meaning that a lot of infrastructures located on susceptible areas remain there. As for scenario 3, even though an increase of the primary roads decreases the risk, a development of the city increases it.

5. DISCUSSION

Global frameworks such as the 17 SDGs are set to support community and decision makers to address the urgent challenges that the world is facing. Accordingly, domain-specific frameworks such as NUA and SFA support SDGs, with focus on specific areas including land use planning and disaster risk management, respectively. NUA highlights the importance of implementing DRR strategies into land use planning to increase resilience and decrease vulnerability. Understanding the impact that land use changes in urban and rural areas have on disaster risk, by developing regular assessments, can guide decision makers to achieve sustainable development. CA-LUCC models bring an improvement of urban planning by representing the behavior of land under specific development plans and are useful to forecast future disaster risk scenarios contributing to DRR. Additionally, problems dimensions can be easily understood, and politic, economic and social priorities can be justified, by using technology as GIS because of its accuracy into the analysis of multiple and complex datasets, and its capability to visualize patterns over defined areas.

The applicability of this approach is demonstrated in a case study of Bogota, Colombia for different scenarios. In this study, flood risk is assessed with the integration of variables as terrain characteristics, distance from rivers, population density, built-up areas, economic level income, and primary road density, using spatial analysis techniques and AHP. The proposed workflow can be adapted to different contexts, and its results will directly depend on the quality of the available data. However, the result is interpretable exclusively in Bogota.
Several researches (Liu & Von, 2018; Gosh & Kar, 2018; Sabri, 2014) have shown accurate results by using MCDA for disaster risk assessment, highlighting the reliability of methods as AHP. Additionally, studies based on the CA-LUCC model used in this research (Paez, 2018; Gantiva, 2018), have shown valid results, demonstrating the efficacy of the model. Finally, studies made in Bogota by Yamin et al., (2013) and IDIGER (2016) shows similar flood risk behavior as the obtained in this study.
The resulting maps show an increased risk for the scenario that contemplates development plans, because an urban grown in vulnerable areas, therefore it is fundamental to pay special attention to mitigate the impact of flood hazard. It was also noticed that several settlements are remaining near to high-risk areas through the time, the reason why it is necessary either to re-locate them or improve mitigation plans. It's essential to highly that this study was made with the aim of providing a useful workflow for decision makers to contribute the achievement of goals proposed in the mentioned global frameworks, the quality of the results are directly connected to the quality and availability of the data.

6. CONCLUSION

This research provides a workflow to assess disaster risk for Bogota, supporting sustainable development. The analysis is presented on a GIS-based map, the product of the combination of simulations made on a CA-LUCC model, and a MCDA. Through mapping techniques in a GIS environment, three resultant maps were used to illustrate the impact that the land-use changes may have on flood risk magnitude. The conclusion can be stated as follows:

- First, CA-LUCC models are able to give reasonably reliable possible future scenarios, useful for decision making. Which results can be used as a basis for disaster risk forecast.
- Second, after comparing the maps, it can be seen that an urban development implies an increase in disaster risk magnitude; hence, an appropriate control must be put in place over developing areas, as so as the existing exposed settlements.
- Third, an understanding of disaster risk can be significant regarding sustainable development since it gives insights into the priority areas that must be treated, preventing future catastrophes and creating resilience.

Overall, the proposed workflow is capable of giving insights about the impact that different development plans and public policies may have regarding disaster risk, providing an alternative for more comprehensive land use planning strategies. This study supports the community and decision-makers and contributes on the understanding of the impact that land development plans may have on the magnitude of disastrous events. The workflow could be applied under different contexts, and its accuracy will directly depend on the quality of the data.

It is intended to extend this study in the future to incorporate its findings into city resilience policy development.

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