The Influence of Land Use Planning on Disaster Risk Due to Natural Hazards: Bogotá, Case of Study

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Key words: Metronamica, ArcGIS, land distribution, land management, land readjustment, risk management, spatial planning.

SUMMARY

Disaster risk is derived from the combination of natural threats and anthropogenic influence. Consequently, the social and economic impact that natural hazards have on urban areas may be massive depending on the exposure that communities in a situation of vulnerability have. For a city as Bogotá, it denotes a problem due to the high percentage of illegal urbanization that, according to the Colombian National Administrative Department of Statistics - DANE, represents 21% of its area. It reflects a problematic because of uninformed expansion in exposure, and therefore vulnerable, zones of the capital of Colombia.

This paper aims to provide insights of the influence that land use planning has on disaster risk owing to natural hazards. The analysis is supported by two software: A geographic information system: ArcGIS; and a Spatial Decision Support System (SDSS) for urban and regional planning applications: Metronamica. Based on the information obtained, it was possible to compare two scenarios, in which the exposure variation was identified according to the behavior of the land uses between 2016 simulated real uses – that considers hazard areas, and 2016 actual land uses.

The tendency obtained will be shown in the results section along with the conclusions and recommendations. It is expected to extend this study to analyze future behaviors of the land use to mitigate disaster risk consequences in Bogotá. This investigation will develop and improve the knowledge in risk assessment, to support the community and decision makers in the understanding of the impact that land administration's public policies have on the magnitude of disastrous events, based on the found tendency.
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1. INTRODUCTION

In view of the world population rapid growth and given the necessity of society to develop different territorial activities, land use planning has become a main concern for governing leaders, in both rural and urban areas. Considering that space is limited and over the years the demand for land has increased, it has become imperative to develop a good planning. For ensuring this, it is essential to consider social, political, economic, cultural and environmental aspects, which make more complex the decision-making process. In the same way, given the lack of space, many communities have settled down in exposure areas to flood, landslide and so on, causing disasters and claiming many lives. This is why many countries have adopted disaster risk management into land use planning (GIZ, 2011).

The first case of territorial ordering (OT) was presented in the United States in the 1930s. The economic recession of the time increased the need for a better organization of the land in the cities. On the other hand, in Europe, the first countries that adopted a system of OT were: The Union of Soviet Socialist Republics (USSR), as a response to large urban complexes and massive housing plans for workers, and France, where began as a response to the adequate reconstruction of the cities after the Second World Ward (Pérez, 2014). Likewise, the first attempts of territorial ordering in Latin America were presented during the 1970s in Argentina, Mexico, Cuba, and Venezuela. In 1992, countries such as Colombia, Uruguay, Bolivia, Costa Rica, Chile, Ecuador, El Salvador, Nicaragua and the Dominican Republic joined these efforts to improve territorial ordering. These efforts were a response to the concern of the governments to take a global position on the problem of the environment and development (Marley, 2008).

Although many countries welcomed OT into their government priorities, it was not until huge disasters started to happen around the world, when leaders beginning to take actions over that problem. In 2005, 168 United Nation (UN) member states adopted The Building the Resilience of Nations and Communities to Disasters – Hyogo's Framework for Action (HFA), with the purpose of increase disaster risk reduction and create resilience. Even though HFA worked well, vulnerability never stopped to decrease, leading the creation of a new action: the Sendai Framework for Action (SFA: 2015-2030), this time adopted by 187 UN member states. The UN Office for Risk Reduction set with this a stronger emphasis on risk management instead of disaster management. The SFA determined four specific priorities for action and seven different global targets to reduce disaster risk (Camacho, 2016).

Nevertheless, these efforts are almost starting to be considered in many OT, and many countries continue paying the consequences of a poor planning.

The aim of this study is to show the large-scale consequences of uncontrolled, in terms of risk, growth of human settlements in Bogotá, to support the community and decision makers in the understanding of the impact that land administration has on the magnitude of a disaster risk. By the length of this article, will be present the general context of the city, its territorial ordinance plan, the methodology used to prove the importance of including risk studies into land use planning, accompanied by the used analysis tools and the procedure, the results and the conclusions. It is expected to extend this study and improve risk layers with help of the Capra-GIS software, to simulate the behavior of Bogota's land uses under different scenarios to 2040.

2. CASE STUDY: BOGOTÁ

1.1 General Context

Bogotá D.C., the capital city of Colombia, has an area of 1.587 km2 with a population of approximately 8,1 million, making it one of the densest cities in the world. Most of the universities, schools, and business centers are located on this city, generating more than 25% of the National GDP, reason why it has continued growing at a rate of approximately 1.1% per year (DANE, 2017).

Figure 1. Bogotá, Colombia (Schibsted, 2018).

As said before, Bogotá is characterized by being a dense city, but also for a having high mixture of uses. One of the principal concerns is the illegal settlement because of their location in high disaster risk areas. This situation has worsened moving from being 813 hectares in 2003 to 3.690 hectares in 2015. Which is not surprising since 20% of the urban area comes from an illegal origin. A solution for this is to legalize the land under the condition that it must be located in low disaster risk areas or out of protected areas due to their environmental importance, other ways it should be relocated (POT, 2004).

1.2 Territorial Ordinance Plan

Nowadays, Bogotá is governed by the 2004's territorial ordinance plan (POT, for its acronym in Spanish), a basic instrument which contains politics, strategies, goals, programs, and rules, essential to achieve an adequate territorial development (Secretaría de Planeación, 2015). However, 2004's POT version, did not consider a detailed disaster risk management plan until its modification in 2014. In fact, 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 years, as noted further.

In Bogotá, the POT is updated every 12 years, which means that a new version of it was scheduled to be completed in 2016. Even though 2016's version has not been published yet, it is possible to access to a summary of the general diagnosis where a clear s inclusion of disaster risk management is made. It specifically incorporates mitigation of flood risk caused by the Bogotá River, areas with hazards or risks due to a landslide, areas signaled with hazard or risk due to flood, among others (SDP, 2017).

It is also important consider that currently, the Colombian government has ensured new guidelines for the inclusion of disaster risk management for each municipal POT. In 2016, the National Planning Department (DNP, for its acronym in Spanish) published the 3870 CONPES (National Council of Economic and Social Policy), which describes the National Program for Formulation and Updating of Land Management Plans, and establish that the government must support each municipal with the necessary instruments which allow facing the different challenges among those, disaster risk management (DNP, 2016).

2. METHODOLOGY AND PRACTICAL APPLICATION

2.1 Analysis tools

For the purpose of this study, two principal tools were used: Metronamica, which is a Spatial Decision Support System for land planning and its urban and regional applications that works with cellular automata LUCC mode. Its objective is to simulate the spatial land use changes over time under different scenarios and based on external inputs such as policy options, biophysical and socio-economic factors, among others. This tool allows planners to gain insights into probable future land use developments and the effects of different policy actions (RIKS BV). On the other hand ArcGIS, a geographic information system, useful for analyzing geographic information and represent it through maps. Geographic information is represented by a series of geographic datasets that model geography making use of generic data structures (ESRI, 2004).

2.2 Development

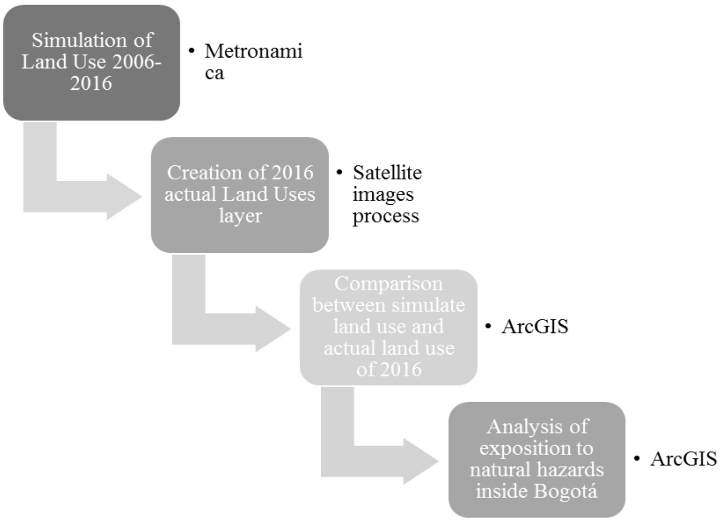


Figure 2. Followed Steps

2.2.1 <u>Simulation of Land Use 2006-2016</u>

The first step was to simulate land use changes in Bogotá and its surrounding areas, from 2006 to 2016 using Metronamica. To achieve this, six principle inputs as layers, created by the Urban and Regional Sustainability research group (SUR), were considered:

i. **2006's Land Uses:** For the creation of this layer, 2006 satellite images of Bogotá were processed to obtain the "urban trace" and then land uses were assigned to those traces. Land uses were categorized into 15 groups:

Table 1. Land uses categories (SUR, 2017).

No.	Category of Land Use	Definition
0	Available	Land available for its occupation
1	Residential low stratum	Residential with occupation higher than 60% of 1 y 2 stratums
2	Residential medium stratum	Residential with occupation higher than 60% of 3 y 4 stratums
3	Residential high stratum	Residential with occupation higher than 60% of 5 y 6 stratums
8	Water bodies	Wetlands, rivers, reservoirs and lakes
9	Services	Transportation services, funeral services, etc.
10	Dotacional	Public services, cultural, welfare, educational, defense, health, security
11	Airport tracks	El Dorado and Guaymaral airport tracks

4	Industrial	Industrial use (including agroindustry)
5	Commercial	Commercial use (Stores, malls, etc.)
6	Mix	Residential between 40% to 60% of occupation
7	Parks y clubs	Parks y clubs
12	Lanes	Principle lanes of the region
13	Landfill	Landfill
14	Mining	Mining areas according to mining titles and Corine

ii. **Environmental Aptitude:** This layer has been crucial during this study, since it describes the exposure areas to natural hazards in Bogota. For the creation of this layer, three biophysics variables were considered:

- Landslide: hazard that can derive from weathering, precipitation, runoff, earthquakes and anthropological events. This layer was obtained at "Visor Datos Geográficos" (SGC) in raster format.
- Flooding areas: consider dry areas adjacent to any body of water susceptible to flooding in high precipitation seasons (Agreement 06 of 1996, Article 139). This information was provided by The SDP.
- Forest fires: phenomenon that may come from natural or anthropogenic causes. This layer was provided by The SDP as well.

The environmental aptitude layer is represented in values between 0 - no accurate to settle down because of the exposure to hazards, to 10 - totally accurate.

iii. **Zoning:** This layer was constructed as of POT regulation, establishing three **Zoning:** This layer was constructed considering the POTs different regulations, establishing three categories: urban land, protected land, and rural-expansion land.

iv. **Infrastructure:** This layer includes the main regional lanes, public transport network, traffic network and bicycle network.

iv. **Accessibility:** This layer is categorized into four types: a) zonal, based on the generalized cost of traffic; b) local, reflects the need to have or not have access to a transport network; c) implicit, reflects the fact of when an area is being occupied by urban land, it has ensured its accessibility; d) explicit, has on count the inaccessible lands as lakes or water bodies.

v. **Neighborhood curves:** This dynamic layer makes a relationship between land uses and consists in attraction or repulsion rules of each cell.

*The model was calibrated, with help of Map Comparison Kit 3 Software, before extracting the final 2016 land use layer.

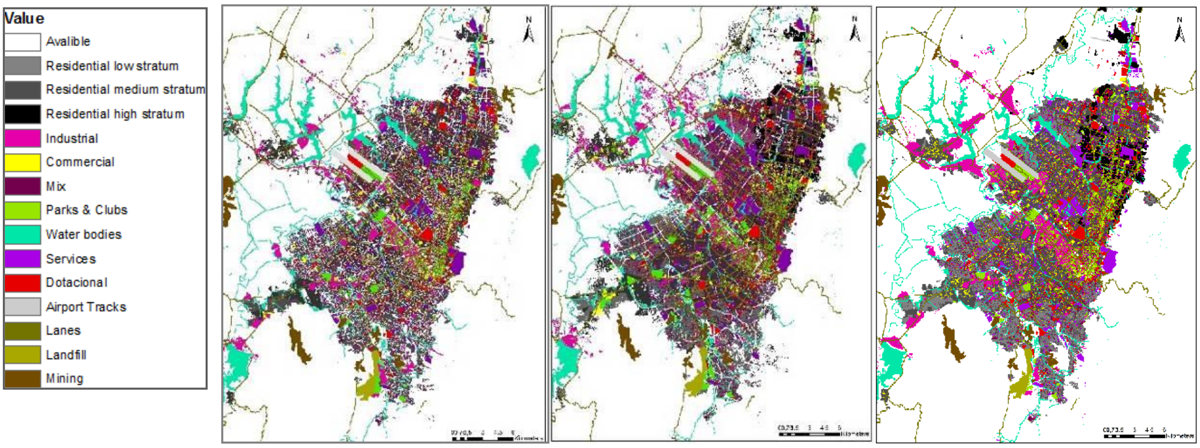
2.2.2 Creation of 2016 actual Land Uses layer

The creation of the 2016 Land Uses layer was made using the same procedure described above for the creation of the 2006 layer, only this time a 2016 satellite image was used.

2.2.3 Comparison between simulate land use and actual land use of 2016

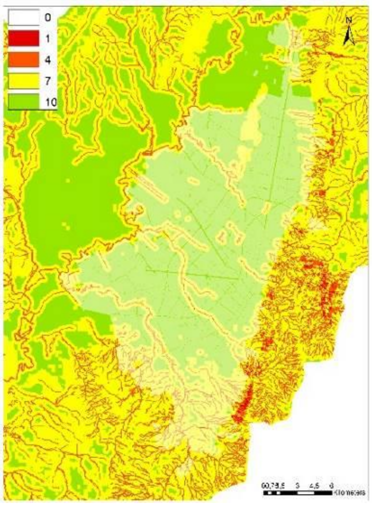
Once the Land Use Layers were ready, an analysis using ArcGIS was made. For this procedure, the used data was the following:

- Land Use: Actual 2006, Actual 2016, 2016 Simulated



Maps 1, 2, 3. 2006 Land Use, Actual Use Land, Simulated Use Land.

- Aptitude:



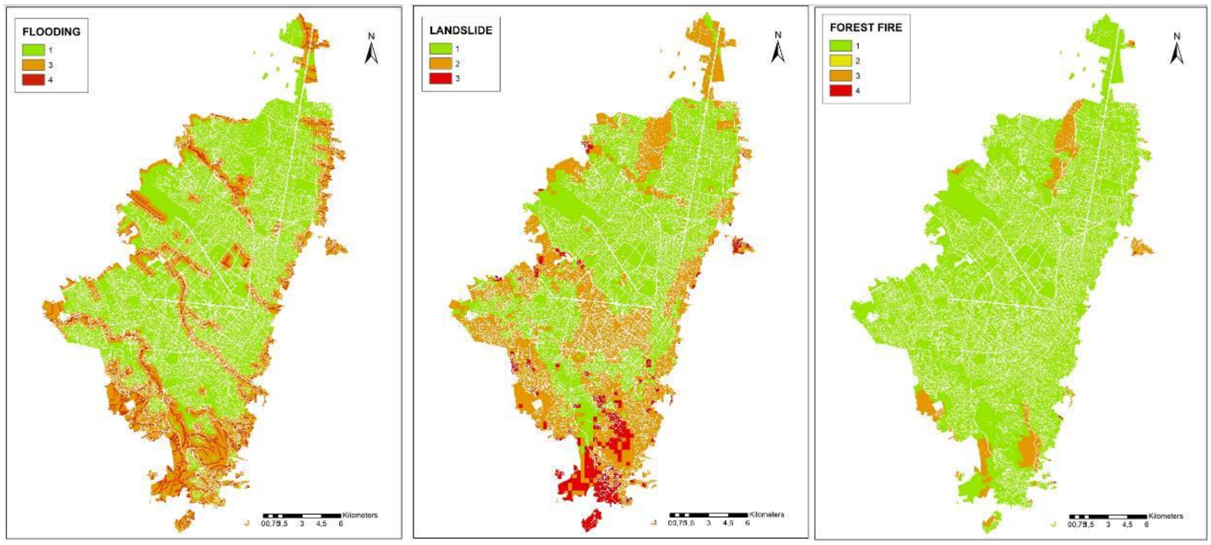
Map 4. Aptitude

Notice that surrounding areas of Bogotá had to be taken into account to observe a possible future growth of the city. To obtain precise calculations after collect the information, each layer must be projected into MAGNA_Colombia_Bogotá.
The tool *zonal statistic* was primordial on this step to calculate statistics on values of a raster within the zones of another dataset. In this case, land use information within aptitude.

2.2.4 Analysis of exposition to natural hazards inside Bogotá

For this procedure, the used data was the following:

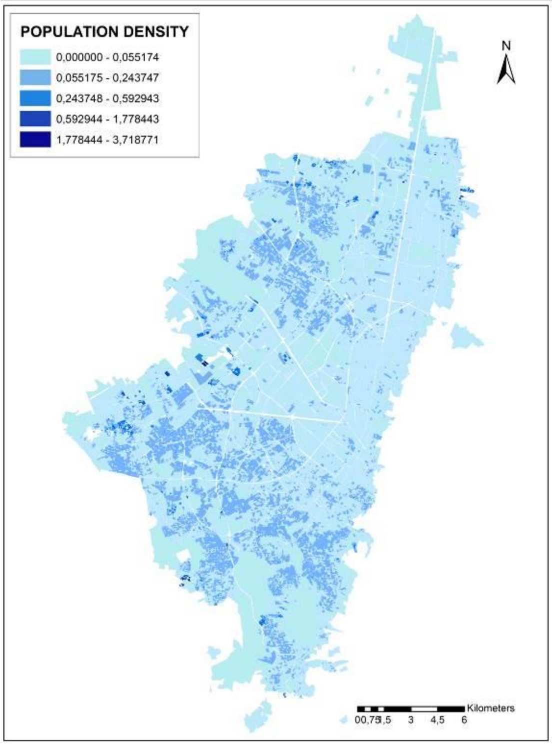
- Hazards: Flooding, Landslide, Forest Fire



Map 5, 6, 7. Flooding, Landslide, Forest Fire. (Source: DNP).

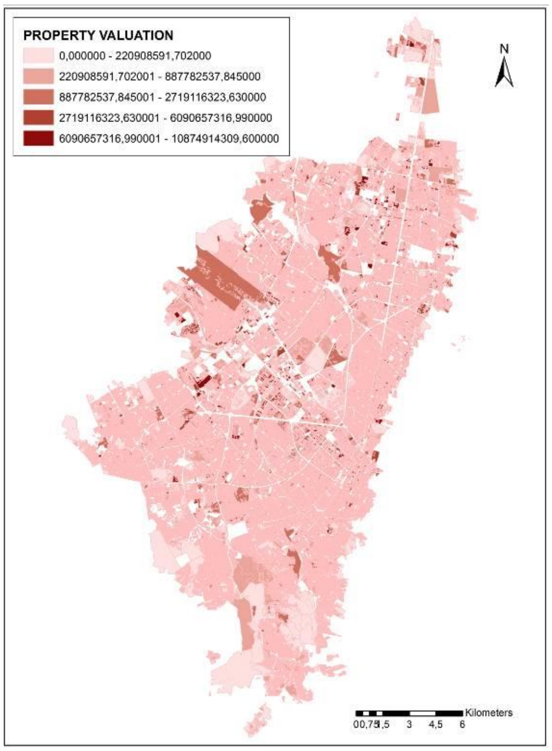
*In each layer the value 1 represents a lower and 4 a higher hazard.

- Population:



Map 2. Population density. (Source: DANE).

- Property Valuation:

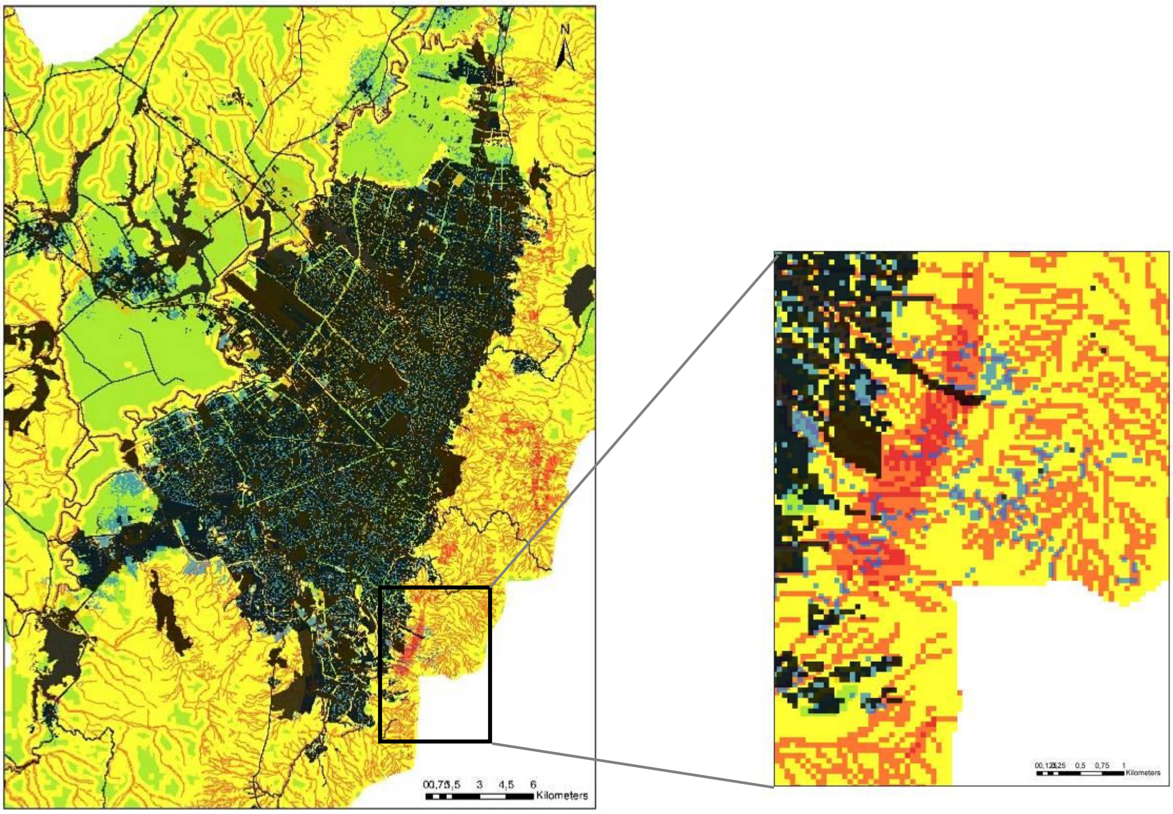


Map 3. Property Valuation. (Source: IGAC).

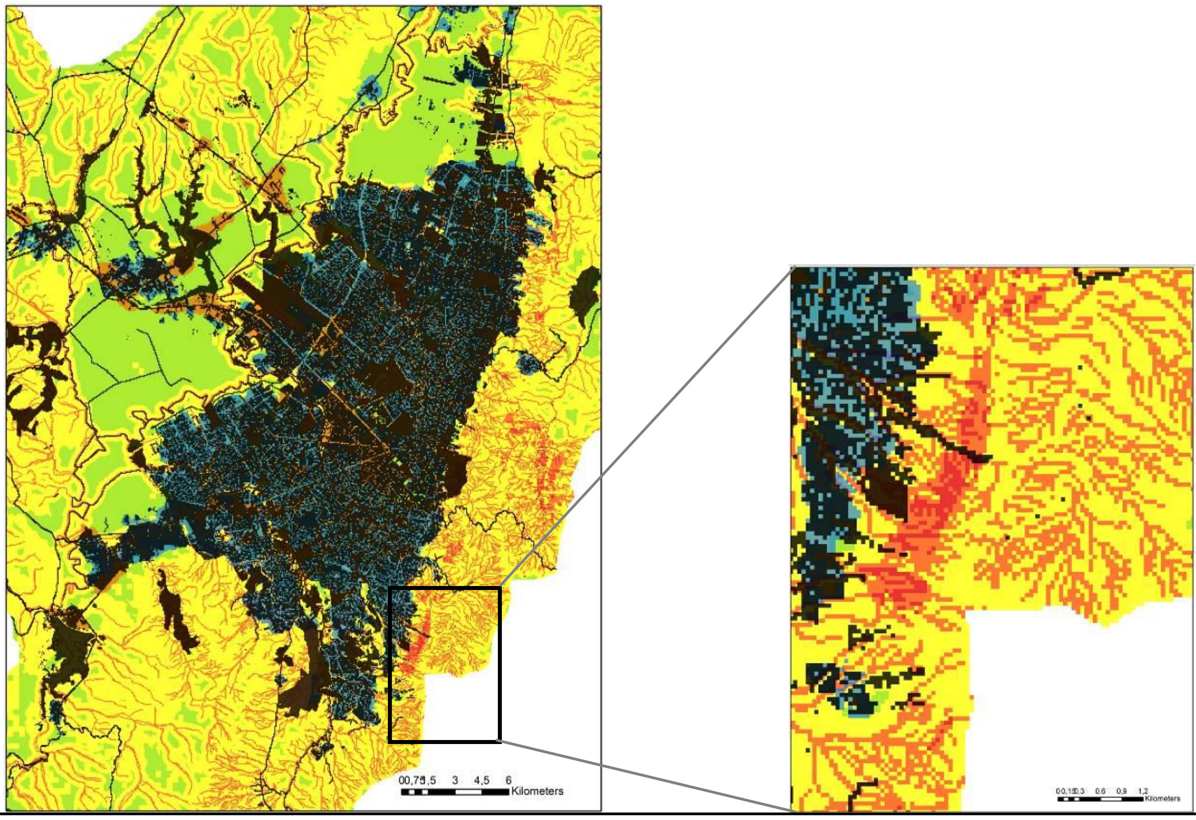
To obtain precise calculations, each layer must be projected into MAGNA_Colombia_Bogotá. For the analysis of this information, it was necessary to use tools as *Feature to point, Raster to Layer, Join Data*, *Spatial Join* and *Project.*

3. ANALYSIS AND RESOULTS

Thanks to ArcGIS it was possible to appreciate the variations between the different scenarios: Actual land use of 2006, actual land use of 2016, simulate land use of 2016. Below are shown two maps, where 2016 land uses are shown in blue for residential uses and orange for the others; actual land use of 2006 in black; and aptitude is classify between red for most high hazard areas and green for low hazard areas.



Map 5. 2016 Actual Land Use



Map 6. 2016 Simulated Land Use

Roughly it does not seems to be any important difference between bought scenarios. However, in a more detail view –as the shown example above- the actual land use layer shows a land growth in highest hazard areas. Then, how much did exposure in hazard areas changed between scenarios?

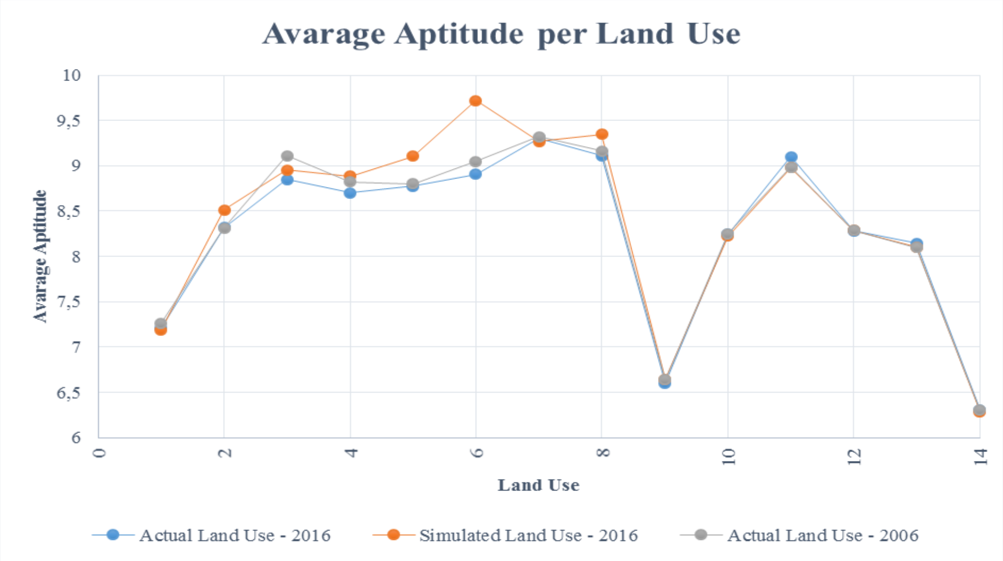


Figure 3. Avarage Aptitude per Land Use

As Figure 3 shows, in most of the different land uses, aptitude is higher for the simulated layer. On the other hand, actual land use of 2016 has the lowest aptitude avarages in most of the uses. This means that currently land is growing in areas more exposed to hazard zones, and so the aptitude is lower than expected. The results are particularly worrying in view of the distribution of the land, which shows a higher percentage of growing area in resident uses:

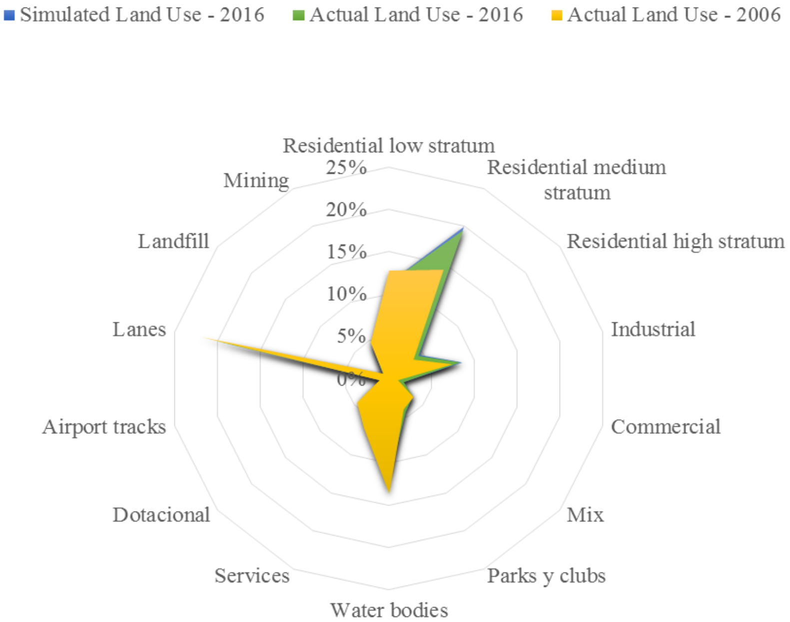


Figure 4. Occupied Area per Land Use

As part of the study, population and property valuation were analyze, as shown below:

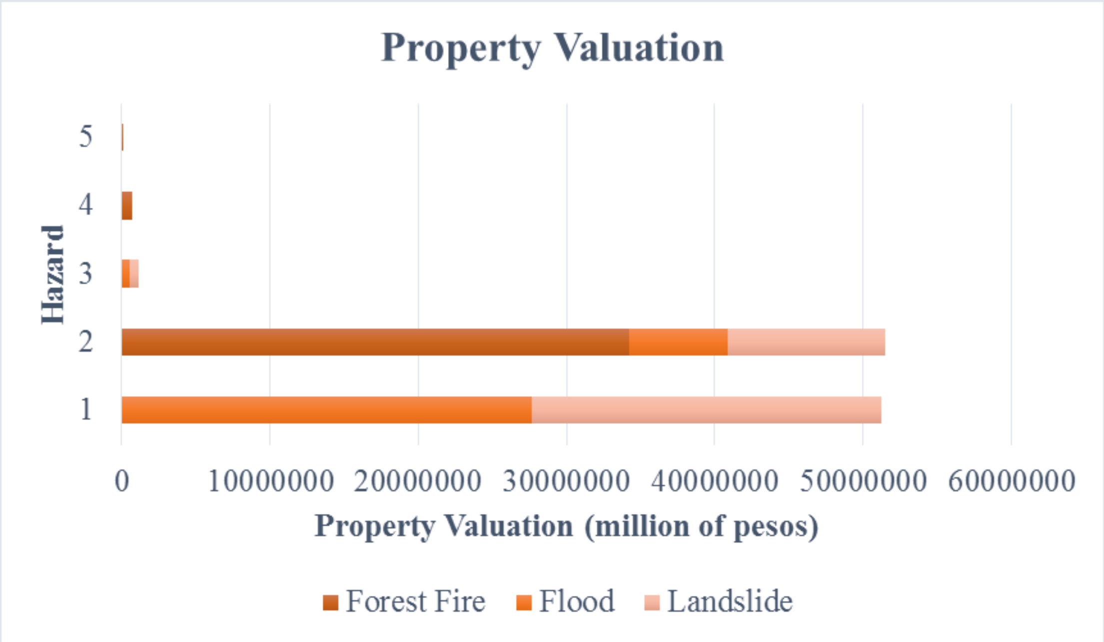


Figure 5. Property Valuation

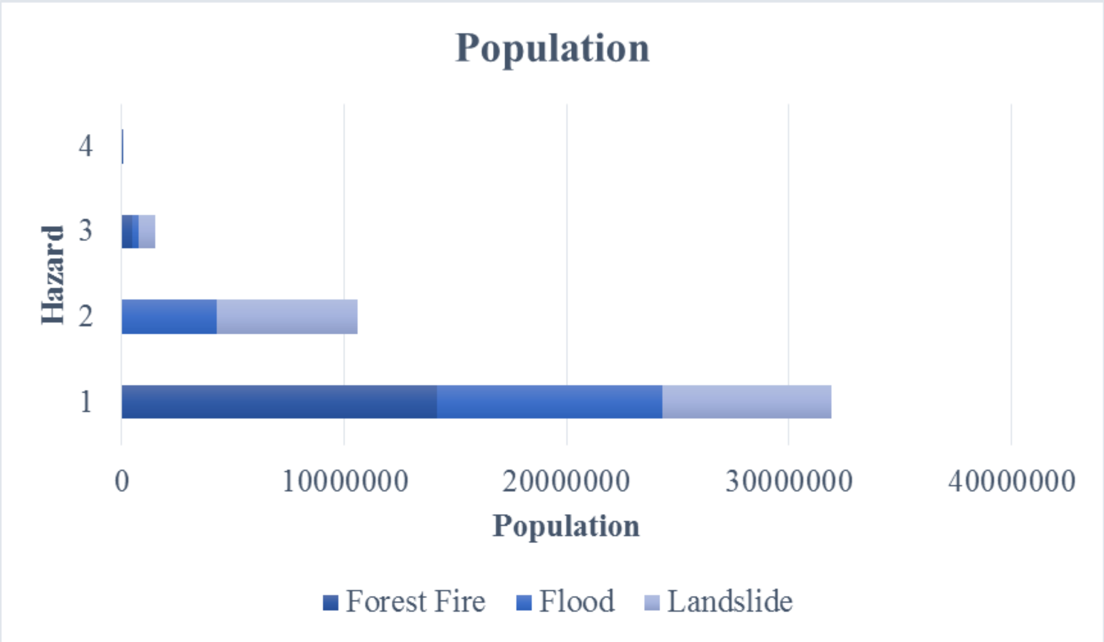


Figure 6. Population

Most of the property valuation is exposed in forest fire hazard areas. Meanwhile, landslide represents a lower exposition for that value. Nevertheless, the majority of population exposed in the worst hazard is because of landslide. This means that infrastructure exposed to landslide could be from a low socio-economic stratum, and so from an illegal human settlement. These are not determine values, is necessary to study them in greater depth.

4. CONCLUTIONS AND RECOMMENDATIONS

Bogotá is in constant growth both spatially and in term of its population, the question we must ask is, it growing in a correct way? With what was demonstrated in this study, it can be inferred that the answer is no. Residential use area are increasing more than the other uses, and people is settling down into high hazard areas. Therefore, it is pertinent to avoid it at all cost, as SDP stipulates. It is expected that with the new version of the POT, the distribution of exposition decreases, or at least kept at the same level trough time. For that matter, Bogotá leaders must take action on land use planning, so vulnerability parameters can be modified to reduce risks.

Tools like Metronamica and ArcGIS are fundamental for this kind of studies, since mapping both the information of hazard and exposition can support decision takers and policy makers on where and how to locate and distribute human settlements. Nevertheless, lack of information may be a limitation and hence, to take action on mitigate risk disasters, is necessary to improve databases.

It is expected to extend this study, in order to analyze future behaviors of the land use to mitigate disaster risk in Bogotá. This investigation will develop and improve the knowledge in risk assessment, to support the community and decision makers in the understanding of the impact that land administration's public policies have on the magnitude of disastrous events, based on found tendency.

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BIOGRAPHICAL NOTES

Lina María González, prior to completing her master at civil engineer with emphasis in transport Universidad de Los Andes of Bogotá (Colombia), is a civil engineer from the same university (2017). She currently works as a teaching assistant in the same university, and is part of the Regional and Urban Sustainability research group (SUR).

Luis Ángel Guzmán is a civil engineer and master at civil engineer (2003) from Universidad de Los Andes of Bogotá (Colombia), and Ph.D. on Civil Engineering Systems, Urban Transport Planning (2011) from Polytechnic University of Madrid. He is currently associated with Los Andes University as an assistant professor with the department of civil and environmental engineering. Is director of the Regional and Urban Sustainability research group (SUR). World Bank consultant, advisor of the Urban Development Institute of Bogotá on issues of value capture instruments for the financing of transport infrastructure. Advisor to the District Planning Department of Bogotá in the reformulation of the Land Management Plan, on the subject of the mobility system. Author of several articles published in international journals related to the evaluation of transport policies, poverty, equity and urban structure. He is part of COLCIENCIAS as a junior researcher.

Luis Eduardo Yamín is a civil engineer and master at civil engineer (1983) from Universidad de Los Andes of Bogotá (Colombia), a Master of Sciences (1985) from Stanford University, and Ph.D. Of Structural Analysis (2016) from Polytechnic University of Catalunya. He is currently associated with Los Andes University as an associated professor with the department of civil and environmental engineering. Is director of Cimoc (Center for Research in Materials and Civil Works). His areas of expertise are the analysis and modeling of hazard phenomena, especially earthquakes, winds and landslides, the assessment of vulnerability and the risk of all types of civil works components, as well as the analysis and design of infrastructure works before all types of requests. His professional life has been framed in teaching, research and consulting. He is the author of more than thirty articles published in national and international journals, and several chapters of specialized books, documents and technical publications of various kinds, including the book: "Probabilistic Modeling for Disaster Risk Management - The Case of Bogotá, Colombia". He is part of COLCIENCIAS as an associate researcher and of the Colombian Association of Seismic Engineering (AIS).

Ricardo Camacho is a civil and environmental engineer from Universidad de los Andes in Bogotá, Colombia. He has a Master of Science in Civil Engineering for Risk Mitigation from Politecnico di Milano (2016). Currently Mr. Camacho works as Instructor Professor at Universidad de Los Andes Civil and Environmental Engineering Department where he leads the Geomatics area and course and is part of the Regional and Urban Sustainability research group (SUR). His research focuses on land use planning and remote sensing for disaster risk reduction.

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