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Instrumentation For The Development Of An Early Warning System In The City Of San José De Cúcuta

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Abstract

The acquisition of tools and instruments to quantify the magnitude of climatic phenomena such as rainfall, temperature and seismic activity are necessary for the proper development of studies and extrapolation of data to analyze, identify and mitigate any type of risk to which a society is exposed. This research proposes the necessary instrumentation to establish these risk analyses and develop early warning systems in the city of Cúcuta. The methodology used consisted of an analysis of the existing instrumentation in the country to address this type of risk. Subsequently, the main early warning systems that exist in different cities of the country were identified, emphasizing the emergency response in the department of Norte de Santander and the city of San José de Cúcuta. As a result, a distribution of instruments was obtained based on the relationship that exists in other early warning systems in the country. In such a way that it can be concluded that the use of this proposal is the beginning of a long road, but it will allow establishing a better risk management as well as the development of early warning systems that this city does not currently have.

Keywords: ews, Cúcuta, risk management, seismic

1. Introduction

Given the economic costs associated with various natural or man-made disasters that occur on a global scale and seem to occur with increasing frequency over time, according to studies on rainfall patterns, climate variability and change. Early Warning Systems (EWS), which enable warning, prevention and

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appropriate action while minimizing human and financial costs, are crucial (Domínguez-Calle & Lozano-Báez, 2014).

In Colombia, EWSs have been created in various cities, defining them according to their topography, location, geomorphology, as well as those factors generated by nature and society that influence the triggering of floods, landslides, mass movements and earthquakes (CÁRDENAS GUTIÉRREZ et al., 2021). Due to the different catastrophic events presented worldwide, a system typology began to be defined to develop a response to the correct planning of the territory, as well as the control of the risks generated in each country (de Hyogo, 2005). This territorial planning allows the regulated management of land use, means of mobility, public culture, solid waste management (Cárdenas Gutiérrez et al., 2022), safety and quality of life of all the inhabitants of a city through the establishment of methods to manage, reduce and respond to the effects generated by a natural disaster.

In 1994, the World Conference on Natural Disaster Reduction was held in Yokohama, Japan, where multiple strategies and action plans were defined, which laid the foundations for an initiative that would be known as "A Safer World for the 21st Century", followed by one in the city of Cartagena de Indias, Colombia, which brought together a large number of participants from many countries (Eliasson, 1994).

This series of events would mark a total change of paradigm for the following decade (1990-2000), where governments were called protectors of the citizens of each country, before any type of tragedy unleashed by nature, counting on the support of non-governmental organizations and groups that would leverage international cooperation. Likewise, the more developed countries would support through the contribution of resources, technology and knowledge.

Based on the above information and according to the information collected from the multiple events developed in Colombia, the National Committee for Risk Reduction is in charge of promoting the connection between the knowledge of a risk and the management of disasters that could develop. This policy emphasizes that every city exposed to risk must be aware of it, thus establishing a prompt and appropriate response to the disaster triggered. Therefore, according to the national information system - SINA, in order to activate an early warning system, the following 4 components are required: 1) An organizational structure, 2) Planning tools, 3) Information systems and 4) Financing mechanisms.

The Ley (Ley No. 1523 , 2012) establishes how incidents resulting from a natural or man-made disaster should be planned, managed, prevented and handled in Colombia. At the level of each city it also describes the decision makers, resources and their administration. Due to the associated budget and public institution, along with the support of universities, research institutions and other private entities that support this management, particularly management, there are some changes in the departments in terms of participants in each system. and knowledge. Therefore, it aims to harmonize risk management strategies at the national level and to articulate these systems with the different governmental, national or district entities to support national development as a whole.

The main objective of this research is to propose a seismic early warning system in the city of San José de Cúcuta, because it currently has only two active teams, the methodology to be used consists initially in analyzing the current state of instrumentation in Colombia, then analyze the early warning system of the department of Norte de Santander, then analyze which cities in Colombia have an active EWS, to finally propose an initial scheme on the possible quantity and location of the necessary equipment.

2. Method

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The methodology used for the development of this research consists in

1. Reviewing the current state of instrumentation in Colombia.
2. To analyze the early warning system in the department of Norte de Santander.
3. To review which cities in Colombia have an active EWS.
4. To make a proposal for an initial seismic early warning system.

2.1. Early warning system

The objective of an early warning system is to prevent the loss of human lives and lessen the social and economic effects that could result from the occurrence of a catastrophic event (natural or anthropogenic), which can be anticipated. Each city should implement an EWS based on its geography and environmental factors, such as topography, climate and natural phenomena that are typical of the area (such as tornadoes, cyclones and storms), or changes caused by environmental problems developed by global warming (Vargas-Losada et al., 2016).

The EWS begins to develop in the territories through the knowledge of the various risks to which the community is exposed, with scientific or technological mechanisms, which can be managed by public entities, universities or institutions created for this purpose, which are continuously performing the various readings of data transmissions and the issuance of alarms when appropriate (Guillot et al., 2017). In the case of Colombia, each department has a budget and a public institution that supports this management, likewise, Universities, research institutions and other private organizations also support this management, being the main collaboration in the management and sharing of information (Ley N° 1523 , 2012).

All data collected from the different systems (rainfall, wind speed, river growth, among others) are used to generate an immediate response to alarms, which ultimately requires the support of the government to create response plans that are constantly updated (Coll, 2013)

2.2. Risk management

A risk management system can be defined as a multifaceted social process that has as its general objective the reduction, forecasting and permanent control of disaster risk in society, integrating it with the achievement of human, economic, environmental and territorial sustainable development guidelines (Ordóñez-Diaz et al., 2018). It accepts, in theory, interventions at various levels, from the integral global to the sectoral, macro-territorial, local and family levels. In addition, it requires the existence of institutional and organizational systems or structures that bring together these collective instances of representation operating within predetermined coordination modalities and with predetermined differentiated roles of the various actors and interests that affect the way in which risk is created, reduced, predicted and controlled (Lavell, 2001).

Risk management is mainly structured in 5 phases:

1. The identification and acceptance of risks through probabilistic models, based on historical data and the various climate change studies presented.
2. Risk mitigation strategies adapted to the needs of each region, land-use planning and risk reduction measures.
3. Updating of disaster response teams, improvement of early warning systems and development of organized planning for disaster and contingency response.

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4. Financial security, defining, monitoring and controlling emergency budgets and creating financing tools.
5. Reconstruction through measures to restore damaged structures (including buildings, roads and bridges).

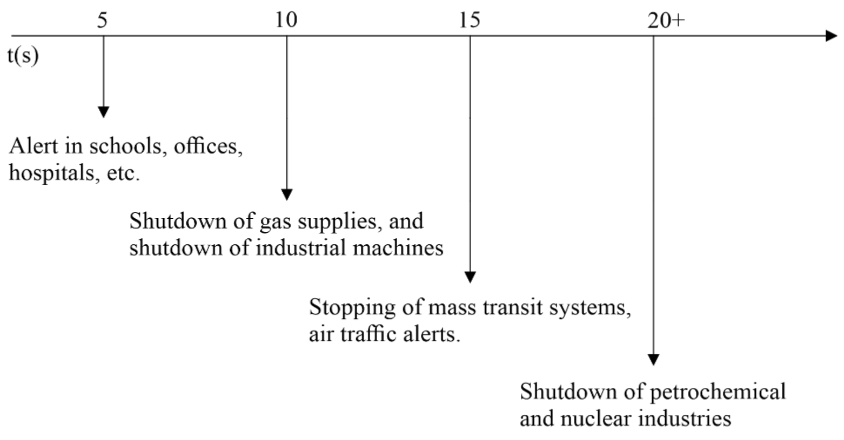
According to this point of view, an EWS is a technique or set of procedures that are implemented in various cities with the objective of preventing the loss of human lives and minimizing the social and economic effects that may result from the occurrence of a catastrophic event (natural or anthropogenic) that is foreseeable; in other words, it is a crucial part of risk management. Early warning systems are important for proper risk management, since the latter must be developed according to the historical data of the various disasters to which each particular city is exposed.

2.3. Early seismic warning system

This type of system is used in destructive earthquakes, these are based on the premise that the signals emitted by P waves, arrive during the first seconds of the event, because this is generated immediately the earthquake occurs, likewise, it is the one that travels at higher speed, today there is the necessary information that allows determining its magnitude, as well as the destructive capacity that the movement has, allowing in this way, to alert before the arrival of the most destructive waves, the S waves (Carranza Gómez, 2016).

The time available to issue an alert can range from a few seconds to a few minutes, and improves decision making, as well as minimizes the damage caused, since it gives enough time to take self-protection measures, reduce the speed of vehicles being transported, allows stopping industrial processes, cutting gas supply (J. A. Cárdenas-Gutiérrez et al., 2020), alerting hospitals, preventing the take-off or landing of aircraft and most importantly, allows preparing emergency bodies to address the situation presented.

Figure 1. Preventive actions in the event of an earthquake



Source: own preparation.

The main objective of early seismic warning systems (ESWS) is to prepare a society to face earthquakes, reducing their damage as much as possible. It is known that an earthquake is a natural phenomenon that is currently impossible to predict or avoid. One of the most advanced tools to achieve this goal, created in the last ten years and which has generated the highest expectations, are the Seismic Early Warning Systems (SAST). The great earthquake that struck Japan in March 2011 confirmed the feasibility of these systems and aroused greater interest in them (Buforn, 2016).

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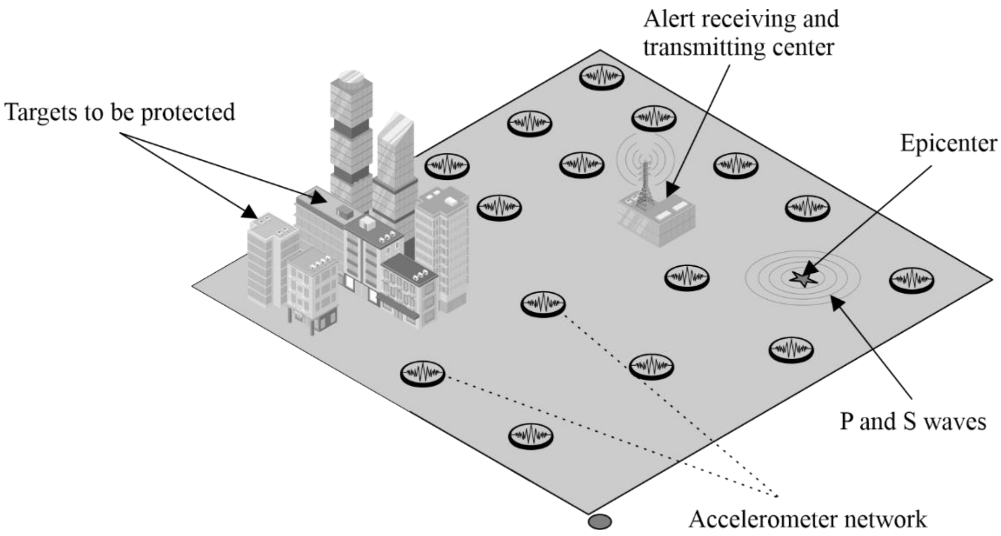
The fundamental premise of a ESWS, as initially discussed, is that there is a record of the P-wave, i.e., the first wave that produced the earthquake, which, in theory, has sufficient data to estimate the magnitude of the motion. The main distinction between this and the classical systems is that the latter calculate the magnitude of an earthquake and, consequently, its destructive potential before analyzing its entire record.

If the earthquake record (seismogram) from a station close to the focus of the seismic movement is recorded, it can be immediately sent to the data processing center via internet, satellite, telephone, etc. As light moves at 300,000 km/s, the information moves at that speed, so sending the information is faster than the most destructive seismic waves, which travel at a speed of 4 km/s for surface waves and transverse waves and 6 km/s for P-waves.

Figure 1. Schematic of a seismic early warning system



Source: own elaboration.

The data center processes these initial seconds of the signal and the SAST can estimate the alert parameters. The ESWS instantly generates an alert if these exceed a predetermined value. The size of the blind zone, or the area surrounding the epicenter where an alert cannot be issued, is one of the most important considerations when proposing a ESWS, as this zone should be as small as possible or not included. The amount of time that can be used to issue the warning depends on how far away the location that needs to be protected is from the station recording the earthquake.

3. Results and discussion

3.1. Seismic instrumentation in Colombia

In Colombia there is a total of 293 functional equipment, which are 167 seismographs and 126 accelerographs, which are responsible for measuring the magnitude of the earthquake and ground motion respectively. These are distributed in 28 of the 32 departments of the national territory, as shown in Table 1.

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Tabla 1. Seismic instrumentation in Colombia

Department	Seismographs	Accelerographs	Department	Seismographs	Accelerographs
Amazonas	0	0	Huila	4	8
Antioquia	11	9	La guajira	22	2
Arauca	2	2	Magdalena	16	2
Atlántico	2	2	Meta	6	3
Bolívar	4	1	Nariño	6	14
Boyacá	4	10	Norte de Santander	2	7
Caldas	4	5	Putumayo	2	1
Caquetá	2	5	Quindío	0	3
Casanare	0	1	Risaralda	0	2
Cauca	6	8	Santander	4	5
Cesar	16	1	San Andrés. Prov. Y Sta. Catalina	2	1
Choco	10	6	Sucre	0	1
Córdoba	4	2	Tolima	6	7
Cundinamarca	22	10	Valle del Cauca	8	7
Guainía	0	0	Vaupés	0	0
Guaviare	2	1	Vichada	0	0

Fuente:(SGC, 2022)

Thus, the departments of Cesar, Cundinamarca and Antioquia, La Guajira and Magdalena have 10%, 13%, 7%, 13% and 10% respectively of the total coverage of seismographs in the country; likewise, the departments of Antioquia, Boyacá, Cundinamarca and Nariño have 7%, 8%, 8% and 11% of the total coverage of accelerographs.

On the other hand, Norte de Santander only has 1% of the seismographs and 6% of the accelerographs, which means 2 and 7 functional equipment respectively, for a department that has an extension of 21.658 km^2, that is, it has one equipment for each 3.094 km^2. Unlike Cundinamarca, a department that has 22 seismographs and 10 accelerographs for an area of 22.633 km^2, one equipment for approximately every 707 km^2 (SGS, 2022).

3.2. Early warning systems in Colombia

Since the National System for Disaster Prevention and Attention was founded in 1989, the conception of risk management has continuously changed. Through the approval of Law 1523 of 2012, the National System for Disaster Risk Management (SNGRD) recently changed its name to reflect this. The National Unit for Disaster Risk Management (UNGRD), is the entity tasked with overseeing the efficient implementation of disaster risk management, as well as coordinating the operation and continued growth and development of the system.

In Colombia, these systems have been evolving; the Hydrology and Meteorology Service of Colombia provided the initial experience in this area in 1976. At present, the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) daily generates technical reports that allow the establishment of any type of climatological and environmental alerts, also elaborating multiple special communications

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for any type of extraordinary event. Therefore, IDEAM provides the largest amount of information in the country regarding hydrometeorological phenomena (Domínguez-Calle & Lozano-Báez, 2014).

In addition to this national system, local early warning systems have also been developed in several regions of Colombia. The main examples are provided below:

- **Early warning system of the Capital District of Bogota:** This system is in charge of the district institute of risk management and climate change IDIGER, and the main objective is to facilitate risk management and attention to any type of emergency within the capital district, this has a network of accelerographs composed of a total of 29 active digital accelerographs, in addition to a hydrometeorological network of 69 active stations (SIRE, 2022).
- **SIATA environmental early warning system:** This system has an impact on the city of Medellín and the Metropolitan Area of the Aburrá Valley. The main objective of SIATA is to quickly inform the public of the probability of a severe event that could potentially lead to an emergency situation. SIATIA, has a particularity and that is that it is a complex system divided into several subsystems that are integrated and reflected in the various networks that compose it, within which are a network of 22 accelerographs, a hydro-meteorological network with a total of 200 functional equipment and has a network of 33 community early warning systems (SIATA, 2022).
- **Agro-climatic early warning system (SAAT) and early warning system for the Combeima river basin:** These systems are located in the upper Cauca river basin and the Combeima river respectively, they are systems that use information from ideam stations and their main objective is to alert the indigenous and peasants of the region of possible agro-climatic risks through the fusion of institutional and cultural knowledge and the participation of all communities (SGC, 2022).
- **Early warning acoustic system in Bucaramanga:** This system consists of a public address system in the Comuna 14 of Bucaramanga that is activated wirelessly by the Municipal Risk Management Committee when the data recorded are extreme in the measuring instruments, so that the 100,000 inhabitants of eight neighborhoods and hamlets of the corregimiento Tres of Bucaramanga are protected by the sound signal, which has a radius of approximately 2 kilometers (Jerez, 2014).
- **Early warning system for extreme weather events in Norte de Santander:** This system aims to bring together multiple types of technical, administrative and financial efforts that allow the design and implementation of an early hydro-climate warning system, before climatic events of flood and drought as a measure of adaptation to climate change, linking the sustainability and expansion of current systems, through the generation and analysis of meteorological information through community participation, as well as the timely response of the different competent agencies in the basins of the Zulia, Pamplonita, Táchira, Chitaga, Algodonal and Tibú rivers. This system has a hydro-meteorological network of 144 active equipment, it also has 2 seismographs and 7 accelerographs, which are not included in the online applications of the warning system, this system is mainly a hydro-meteorological warning system (SATC, 2022).

3.3. Necessary instruments for an early warning system in the city of Cúcuta

The city of San José de Cúcuta is surrounded by 16 surrounding structures, including 9 faults, 4 synclines and 3 anticlines. Likewise, the three closest seismogenic sources are the Boconó and Uribante Caparo

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geological faults and the frontal fault of the eastern mountain range, whose presence is very influential in the seismicity of the city (SGC, 2022).

All these geological structures, establish a high probability of occurrence of seismic events that generate a high impact within the city, in such a way, that this city, could experience telluric movements close to a magnitude of 8.0, as occurred in the year 1875. Therefore, the need to implement seismic microzonation studies and local ground amplitude effects are extremely important to develop a correct and complete risk management within the city.

In such a way, taking into account the early warning systems of the capital district and the environmental early warning system siata we obtain that the ratio of instruments per 100km^2 is:

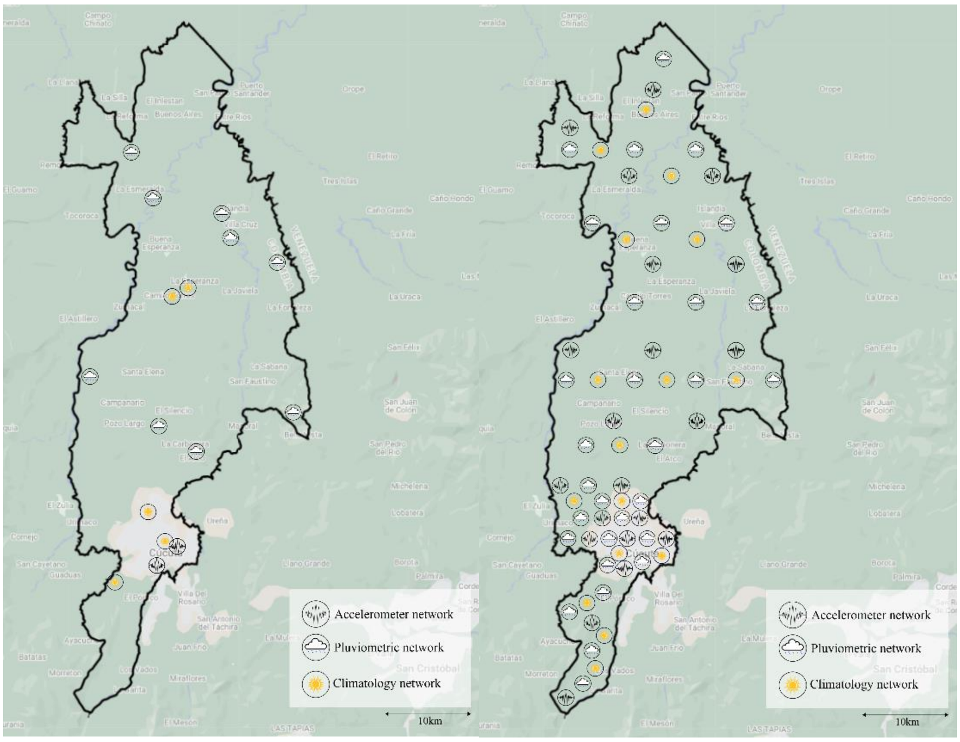
Tabla 2. Instrumentation of the main early warning systems in Colombia

Name	Area km^2	Accelerographs	Hydrometeorological stations	Total, accelerographs km^2	Total, stations km^2
Bogotá D.F.	1.775	29	69	1.63	3.89
Valle de Aburrá	1.157	22	200	1.90	17.28
Cúcuta	1.117	2	14	0.18	1.25

Fuente:(SGC, 2022; SIATA, 2022; SIRE, 2022)

From the table above, it should be noted that the topography of the Aburra Valley is very different from that of the city of Cúcuta, therefore, they cannot be compared. However, Bogota has a more similar topography, so that an average of 2 accelerographs and 5 hydro-meteorological stations per 100 km2 could be established. This gives a total of 22 accelerographs and 56 hydro-meteorological stations, which can be divided into 30 rain gauges and 16 meteorological stations. In Figure 3

Figure. 2 Current and proposed instrumentation for the city of san josé de cúcuta



Source: own elaboration based on Google Maps

The left side of Figure 3 shows the current number of instruments in the city of Cúcuta, highlighting the small number of instruments in the urban area, including only two accelerographs and three

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meteorological stations, which are unable to determine the city's hydro-meteorological conditions locally.

Additionally, the existence of only two accelerographs within the urban area, which are very close to each other, does not allow for rapid response actions in the event of imminent seismic movements.

On the right side of Figure 3, a distribution of instruments is proposed with maximum distances between equipment of 10 km, which allows a radial acquisition of data, facilitating a more accurate and detailed extrapolation of information.

3.4. Benefits and impacts of implementing an early warning system

All the benefits are directly related to the risk management of the city, which is exposed to floods (Gutiérrez et al., 2021), landslides, collapses and telluric movements, therefore, implementing a correct instrumentation will allow the development of rapid action plans by the municipality and competent entities such as firefighters, medical corps, the Colombian Red Cross, among others.

Likewise, such instruments will allow the development of research related to precipitation, such as, for example, a technical consultancy that will allow to definitively solve the current flooding problem of the city, when heavy rainfall occurs, thus determining the necessary corrections on the city's sewage system (Cely Calixto et al., 2022).

Another study that could be developed is that of seismic microzonation. Currently, the city does not have a seismic microzonation study that would allow a correct territorial distribution for the construction of slender buildings, industrial and residential areas (Abril et al., n.d.). Such studies can be developed through the spectral analysis of seismograms, thus determining the fundamental frequency of the ground and subsequently, determine the polarization of the ground and the local effects of seismic amplification, besides being relatively inexpensive (JA. Cárdenas-Gutiérrez et al., 2020).

Finally, thanks to this instrumentation and the analysis of seismic polarization, it would be possible to determine which are the safest areas of the city in the event of a strong seismic event, facilitating the construction of meeting points, development of emergency plans, construction of hospitals, schools, among others.

4. Conclusions

Norte de Santander is one of the departments with the highest threat of floods and seismic events due to its geomorphological and geodynamic conditions, in addition to being in contact with multiple geological faults. Therefore, it would be expected to be one of the departments with more instrumentation and risk management, however, this is one of the departments with the least equipment, thus reducing the capacity to collect and extrapolate the information needed to establish competent emergency plans and early warning systems.

In Colombia, despite the existence of a law that obliges public entities to take responsibility for citizen security, very few cities implement these risk prevention and mitigation measures. The city of San José de Cúcuta is a border city with a population of more than 700,000 people; however, it is one of the least implemented cities in the country despite being located in a high-risk area.

The proposed instrumentation would allow the city to develop multiple risk management studies and emergency plans, as well as early warning systems. Therefore, this research is the starting point to be able to implement these tools that mitigate risks, allow the generation of knowledge that does not currently exist and most importantly, safeguard the lives of the city's inhabitants.

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