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Landslide Alarm Sirens: Rio de Janeiro City Leading Experience

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Abstract

In 2011 a siren alarm system was installed in communities in the city of Rio de Janeiro, aiming to reduce or even prevent the loss of human life resulting from landslides caused by heavy and/or prolonged rains. The recurrent deaths caused by rainfall throughout the municipal history, because of geographical characteristics and mainly of inadequate soil use, justified a more incisive action aiming at alerting the residents of communities located in the hills about the risks. In this regard, it should be noted that the siren alarm system has its focus on people. This work aims to report the Rio de Janeiro Municipal Civil Defense experience in the installation and operation of this system, focusing that the siren alarm system represent an initiative of great relevance and success, not only because of the alarm system itself, but also because it has boosted a series of other actions of risk perception and resident's mobilization, especially through the performance of several evacuation simulation practices. Therefore, as it was an innovative project and stimulated the installation of this type of system in several other locations, it can be considered a milestone in the actions of disaster risk education in Brazil and in other countries.

1.Introduction

The city of Rio de Janeiro (CRJ), with about 6.7 million inhabitants [1], is a large economic and tourist center of Brazil. The region of CRJ presents high spatial and temporal variability of meteorological elements. Forest masses influence the regional behavior of the temperature, winds, evaporation, and cloudiness, but mainly precipitation.

The topography of the CRJ is outlined by three mountain ranges: Gericinó-Mendanha hills in the north, Tijuca hills in the east and Pedra Branca hills in the west. The other areas of the city are plain, with an average altitude of 20 m above sea level. To the south is the city bathed by the Atlantic Ocean, to the east to Guanabara Bay and to the west to Sepetiba Bay [2].

The uncontrolled growth of the city and constructions in risk areas, such as hills and slopes, contribute to landslides that often contribute to death and injury. Climate change has also increased the frequency and intensity of heavy and/or prolonged rainfall in the city [3][4].

The CRJ has a history of recurring natural disasters that are result of the expansion of the urban network, which favored the high concentration of people and buildings between hills and the sea, lagoons, and bays, often in areas at risk of flooding and slipping. It is not rare event occurrences that have caused material and economic damage on a large scale and which thus predisposed the population to disease outbreaks and, in extreme cases, victimized people [5].

Since the 60s of the last century, there have been several reports of disasters related to intense rainfall, as the event on January 11, 1966 or, more recently, as the event on April 04, 2010 [6]. In April 2010 disaster event, in which the CRJ was hit by an intense and severe rainfall over several hours, the result was one of the greatest tragedies in the history of the city, certainly the largest of its kind in several decades. There were 67 deaths, all caused by landslides slopes in poor communities [7].

Due to this episode, and several others with lesser extent over several years, in the first half of 2011 a Siren Alarm System (SAS) was installed in 102 communities of the CRJ. The goal was clear and straightforward: reduce or even prevent loss human lives resulting from landslides caused by heavy and/or prolonged rainfall.

This project was conceived by the general coordinator of the Rio de Janeiro Municipal Civil Defense (SUBPDEC) and his team in the second half of 2010. These professionals made it clear that the organization was not complied with the recurring situation in which people living in hills losing their lives slopes because of the rains.

SUBPDEC recognizes that Disaster Risk Reduction (DRR) in a broader context involves series of other actions and projects, structural or structuring, with greater or lesser complexity, some involving several institutions, others practically exclusive competence of SUBPDEC. The hills of the city should not have been irregularly occupied, because these buildings are result of illegal occupation at risk area and/or environmental protection area. However, it is a reality of hundreds of thousands of residents, the result of a social and housing deficit that has been occurring for many decades and various regions of the city, and that unfortunately occurs in many cities of Brazil [8].

Therefore, an eventual resettlement of some families in higher-risk areas (with due care not to cause another social problem) and mainly to hinder the increased occupation of these areas, are fundamental actions that should always be performed regardless of the installation of a SAS. In any case, a Civil Defense organization cannot stop acting to save lives. Therefore, the SAS was designed to warn residents of high geological risk of slope slipping in periods of heavy and/or prolonged rain.

The Paris Agreement [9] emphasizes the need to increase adaptive capacity to adverse impacts of climate change and foster climate resilience. Based on it, this work aims to report the experience of SUBPDEC in the installation and operation of a SAS on the hills of the CRJ, describing some challenges and the complexity of the whole process. It also seeks to emphasize the great success of this initiative, which was unprecedented in Brazil as an alarm for this type of disaster and was a milestone for the DRR actions in the municipality.

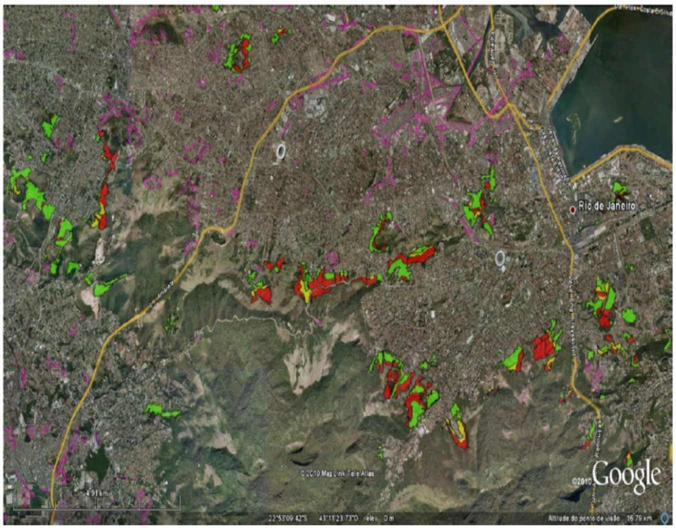
The feasibility of the system installation was facilitated and enhanced by several other issues, but two of which can be considered fundamental:

- Geological-geotechnical risk mapping to understand where the risk was greatest and where SAS installation would be required; and
- Monitoring of rainfall to measure the amount of rain to possible to enable SAS drive decision making.

The conduction of a detailed geological-geotechnical risk mapping by the Geotechnical Foundation of the City of Rio de Janeiro (Geo-Rio) in the second half of 2010 was a great propeller and stimulator for strengthening the idea of SAS. A study carried out in about 200 communities located in the Tijuca hills and their surroundings identified 117 communities with some residences located in areas of high geological risk. The estimate was about of 18000 households in these areas [9].

Figure 1 shows a map of a part of the CRJ and it is possible to verify the large number of covered communities, as well as identify high, medium, and low risk areas (red high-risk areas, yellow medium-risk and green low-risk areas).

Figure 1: Areas with geological risks in the central part of CRJ, including Tijuca hills [10]



The Rio Alert System (RAS) has a large network of automatic rain gauges that send every 15 minutes updated information about how much it is raining in each of the places where this equipment is installed. The RAS, which already had a team of meteorologists 24 hours a day on seven days of the week, gained a significant boost in 2010 by acquiring its own weather radar, previously unheard of for a Brazilian city. Rainfall and weather forecast information is available to the population on an open site and in a free smartphone app.

From the mapping of high geological risk areas and the management of information provided by the Geo-Rio and the RAS, with timely rainfall data, widely shared with the population and municipal managers, the installation of sirens gains viability, which guarantees its operation by the authorities of CRJ.

2. Experiment results

2.1 Installation of sirens

The installation of the sirens was performed by a contractor, with knowledge of systems of this type (even under similar conditions and objectives). Installation contracts for sirens and rain gauges under the responsibility of the Geo-Rio (for technical and financial reasons) and was divided in two phases. The first phase included 67 communities and 117 sound supplies, 58 of them with rain gauge. The second phase included 35 communities and 54 sound supplies, 25 of them with rain gauge. Some communities had only one siren, but several of them needed two or more sound supplies. The installation cost was around US$ 4.9 million (US$ exchange on March 31, 2011).

In 2012, as determined by the Public Prosecution Service, another community was also contemplated. Therefore, there were 103 communities with installed SAS. The primary site selection criteria was technical, as the focus of the message was on the high risk (identified by mapping). Ideally, each of the residences should have its own sound system, to ensure that the message would arrive, even with the natural sounds of a storm. However, for technical and financial reasons, it was necessary to install the sirens at points of the communities that would reach many households. Therefore, the geographic position of the sirens needed to be based on sound range for households located in high geological hazard areas.

There was considerable complexity throughout the installation process for several reasons. The presence of community leaders and Community Health Agents (CHA) in this process was crucial, not just for the relevant importance of involving them in the whole process, but to guide us to the best places for installation equipment (at the top of a house/church/school or even on a street lamppost or residents association). There were many other aspects to be considered, since 103 communities were involved and Rocinha, a community with a population of 100000 inhabitants for example, with its nine sound stations and over 1500 households in high-risk areas, it was just one of these communities.

Concomitantly with the installation, which obviously already required employees of SUBPDEC and/or Geo-Rio to accompany contractor professionals and community leaders on field visits, at least three other main actions needed to be done by the public workers in conjunction with community leadership:

- Equipment test;
- Clarification to residents (with training in a second moment);
- Identification of Support Points (SP), which are locations near (but outside) the high-risk area, to provide temporary shelter during the alarm.

Thus, shortly after installation, SUBPDEC employees visited various locations in the high-risk area (even within some households, with permission and presence of residents) to hear the alarm. With this, the necessary and possible adjustments were made, and the procedure of verification was repeated. In parallel to this sound test, leaflets and explanatory posters were distributed directly to the residents (in their own homes and/or on community roads), as well as placed at concentration points of people in the community, as commercial establishments, and churches.

In the numerous visits to the communities, SUBPDEC agents used to try to identify points that needed to have a minimum of structure (trim coverage and bathroom) to house people temporarily, during the process of preventive eviction of residences (people living in residences located in high-risk areas).

This process was also quite complicated and exhausting for many reasons (inadequate locations in size and/or structural conditions, people who did not want to give up their houses, fear of SP become definitive shelter, among other reasons). Even so, about 200 locations were defined as SP and each community had at least one of these locations. They were identified with standardized SUBPDEC signs.

SUBPDEC employees defined the procedures to be adopted in the process of leaving the houses and disseminated, through a simple, clear and direct message, what should be done by the residents of the hazardous areas after siren sound. The message is:

- Keep calm;
- Get the family together, get your necessary documents and medicine. Turn off the main light switch and close the gas plug;
- Go in an orderly manner to the defined SP;
- Wait for guidance to return to your home.

In parallel to the field installation, technical experts from the SAS developed a Sound Alarm System Triggering Protocol (SASTP), which besides defining the procedures to be performed, also defining the driving criteria and conditions as a function of critical rainfall indices. The triggering criteria in the original protocol consisted of one of the following rainfall volumes:

- More than 40mm/h;
- More than 125mm/24h, and 6mm/h or 10mm/2h;
- More than 200mm/96h and 40mm/24h, and 10mm/h or 16mm/2h or 18mm/3h or 20mm/4h.

These criteria have undergone improvements and/or adjustments over time. Depending on the experience of several sirens sounded without any indication of landslides, a situation that could generate system discredit, adjustments were carried out in the drive protocol. Such inconvenience cannot be disregarded, and even risk of accidents, associated with displacement of residents from their homes to the SP during the rain.

In any case, regardless of the technical criteria defined by SASTP, it should be emphasized that several other factors may or may not cause sliding slopes. Soil type, cohesion particle size, type of construction, vegetation cover and especially soil saturation (which is variable of each region), are heterogeneous characteristics in the different hills of the city.

In addition, it is necessary to remember that the constructions on the hills are irregular and technically inadequate. Therefore, even with small volumes of rain, occasional landslides (from retaining walls and/or houses) can occur and even cause domino effect in downstream constructions.

The audible alarm is a warning that underscores the significant increase in the probability of landslide occurrences. However, cannot be the sole parameter of residents (who that need to have an increase of individual and localized risk perception), as well as does not mean that there will be a landslide, whenever the siren is activated.

3. Resident training and system operation

Since its introduction, the SAS has been part of a larger system, the Community Alarm and Alarm System (called A2C2 System), because it involved besides siren, an alert via SMS [11]-12].

It is worth mentioning that the SMS alert, currently available throughout Brazil by determination of the Federal Government, had been used since in precursor form by the SUBPDEC, in a partnership with mobile operators.

As already mentioned, DRR involves several other actions and projects, and one of the main actions in this sense, which was already being held since the beginning of 2010 by the SUBPDEC (even before the great April disaster), was the training of CHA to act, directly or indirectly, as SUBPDEC collaborators, either before prevention, during (in the dissemination of the alert received via SMS) and later (collaborating in the response) issues related to heavy and/or prolonged rainfall (and also occurrences of other types, as landslides and fires).

Therefore, the CHA were also key players in the SAS. Between 2010 and 2013, around 8000 agents were trained and identified with a specific vest. Conclusion course events were carried out with certificate delivery.

An A2C2 System Evacuation Plan (A2C2 SEP) was prepared, covering several issues, including the conduction of trainings, more specifically the Simulated Evacuation Exercises (SEE). It was necessary a broad promotion, both directly in the community, via media and partners, as well as the mobilization of several actors was fundamental, aiming to stimulate and motivate the participation of the residents in these trainings.

On July 3, 2011 (Sunday) the first SEE was held. At 10:00 am (GMT - 03:00) concomitantly in 20 communities, sirens sounded in a planned way and more than 5000 residents participated. Aiming to stimulate the participation of residents and disseminate SAS after training session, participation shirts were given with the inscription: "Alert and Alarm System - I participate".

Even before the SEE, a theoretical simulation was carried out by the Rio Emergency Operations Centre (COR) at the crisis room, where mobilization, communication, and activation, as well as, as an important result, the participation and involvement of several organizations and partners that would be present in the SEE.

The SEE is also a great training opportunity for remote drive operators, as it requires not only technical knowledge but also tranquillity and emotional control, especially in a crisis. During 2011 and 2012 seven major events were held to cover all communities with installed SAS, with more than 13500 participants. The accomplishment of these trainings it also required a lot of planning, involvement, and commitment from every member of the SUBPDEC.

In figure 2 as an example, the planning of the II SEE (carried out on July 31, 2011) in twelve communities. The organization chart followed the model ICS (Incident Command System).

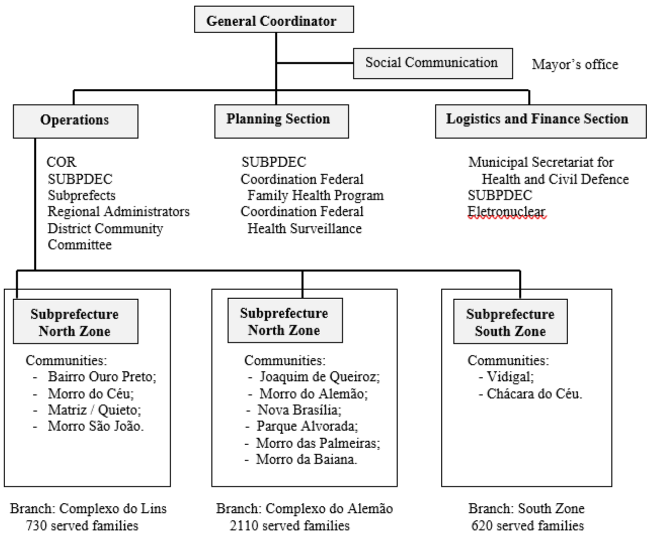


Table 2. The planning of the II SEE

On August 18, 2012, already in the II SEE, after all communities have already been contemplated simulated, an evaluation and satisfaction survey was conducted during the training in one of the communities (Rio das Pedras). A simple and straightforward questionnaire was designed to understand how residents were evaluating the SAS and the training. Four questions were asked, and objective answer options were presented (Table 1).

Table 1: Questionnaire about SAS

	QUESTIONS			
1	What do you think about SAS?			
	( ) bad	( ) fair	( ) good	( ) very good
2	What do you think about performed simulated exercises?			
	( ) bad	( ) fair	( ) good	( ) very good
3	If the siren is triggered in a real emergency, will you leave the house?			
	( ) yes		( ) no	
4	Do you think residents also play a role in reducing community risk?			
	( ) yes, a lot.	( ) yes, a little.	( ) no	( ) I don`t know.

The result of this survey was very positive. Among 104 residents who answered it, over 90% answered "good" or "very good" for both the first and second questions. In the third question, only three people answered no. In the fourth question, 74 residents evaluated that the residents have "yes, a lot" a role in reducing community risks. This survey was informal, conducted by the SUBPDEC employees with the residents who participated in the training. It had no scientific methodology, but it served as parameter of the feeling and perception of the residents.

The systematic day-to-day operation of the SAS involves several questions:

- Integration with COR;
- System coordination (data and information manage-ment);
- Preventive and corrective maintenance of the system;
- Remote trigger logistics (site specific);
- Actual siren trigger events;
- Community mobilization, operational testing, and system dissemination; and
- Integration with schools (simulations in schools and Civil Défense Project in Schools – CDPS).

Integration with the COR is critical to SAS operation. The coordinator of SUBPDEC at COR is responsible for managing the SUBPDEC team present at COR. The team controls the entire drive procedure, as well as interacting with COR coordinator and representatives of the other institutions.

System coordination involves managing data and information from the 103 communities with installed sirens. Activation and Mobilization Plans (AMP) as well as Contingency Plans (CP), are of relevant importance in this regard.

The preventive and corrective maintenance of the system is performed by a contracted company, according to a public bidding process, who is responsible for keeping the system operating 24/7 (twenty-four hour, seven days per week). Teams staff and representative in the COR control room are part of the maintenance team.

The remote drive logistic is based on the use of a specific website, via login and password, for the drive of each sound station or several sound stations at the same time. It is essential that operators are trained and aware of the process, which in real situations involves psychological stress. If this drive does not work for any problem, there is the possibility of manual siren, with specific key (trained residents may be required to do this).

Actual drives are the effective use of the SAS to fulfil the objective of "warn residents of high geological risk areas of the risk of landslides in periods of heavy and/or prolonged rain". Therefore, it is important to keep, registered and updated, the registration of events where the evacuation ring was activated in a heavy and/or prolonged rain.

Community mobilization, operational testing and dissemination of SAS consist of the following activities: (i) visit communities; (ii) talk to community leaders and residents about the system; (iii) run tests; (iv) check nameplates; (v) visit SP, and (vi) continue planning and performing SEE.

Integration with schools is a way of making young people aware of the existence and importance of SAS. It can be highlighted the need for several other activities of DRR [13]. The CDPS, carried out by several years and involving thousands of students, had immeasurable results, making these future citizens more prepared and resilient [14].

4. Results and considerations

Before evaluating the achieved results through SAS, it should be mentioned that the siren is a symbol for stimulating risk perception and behavioural change (self-protection) of the population residing in the areas where this equipment is installed. The implementation of sirens made possible and/or strengthened other DRR projects of SUBPDEC in the CRJ. Training and involvement of CHA, as well as the CDSP, are only two examples of actions were enhanced by sirens.

In the municipal management, the sirens stimulated and provided a broad discussion on DRR in several departments. Actions such as slope containment works, reforestation, resettlement of high-risk area residents, among others, were actions developed posteriorly the 2010 disaster, together or after the installation of the sirens.

In strategic planning, the implementation of the Rio Resilient office, which mobilized organizations and generated two high-level publications, which addressed sirens and other DRR actions.

SAS also stimulated greater discussion in society about the DRR. Media coverage, direct or indirect participation of experts, researchers, academics, involvement of partners, volunteers, and employees of other government agencies in siren-related actions are examples of a greater engagement of society in this theme. There were presentations and lectures at various technical and scientific events, nationally and internationally, mentioning SAS, as well as several scientific articles by SUBPDEC employees or third parties.

The system was mentioned in joining the "Building Resilient Cities" campaign of the United Nations Office for Disaster Risk Reduction (UNISDR), a United Nation component organization related to DRR. Alarm sirens respond to the Hyogo Framework for Action (HFA) the guiding document for global DRR actions at that time, which in 2015 was replaced by the Sendai's landmark for DRR. In both documents, the implementation of Early Warning Systems (EWS) is encouraged [14].

Regarding objective criteria, the first to be questioned is the number of people who were saved due to the existence of sirens. This is an unanswered question, as it is not quantifiable in prevention actions. The issues involved are much broader and immeasurable. To mention an example, due to increased risk perception, some residents may have intentions and given up on deforesting and/or dig slopes or make landfills to expand the households, and this could have prevented landslides.

The SAS of the CRJ represented a milestone in DRR in Brazil. The pioneering and innovative implementation of siren alarm on the hills of the CRJ stimulated similar initiatives in other Brazilian cities.

The SUBPDEC has been carrying out a series of actions and projects aimed at improving the SAS in several aspects. Among other initiatives, it is worth mentioning the 3RD Project "Rio for the Disaster Risk Reduction". This project, which has the partnership of the USTDA (United States Trade and Development Agency) and has among its objectives the "Project for the Modernization of the Community Alert and Alarm System for Heavy Rains". The expansion of the scope to areas that are currently not served by the SAS, in addition to the inclusion of resources that will significantly increase the system's operationality, both in monitoring and issuing alerts. Several videoconferences were held on this topic in the year 2020 and an internal SUBPDEC Commission was appointed to address this project.

Abbreviations

3RD:	Project "Rio for the Disaster Risk Reduction"
A2C2 System:	Community Alarm and Alarm System
AMP:	Activation and Mobilization Plan
AP:	Protocols or specific action plans
CDPS:	Civil Defence Project in Schools
CHA:	Community Health Agents
COR:	Rio Operations Centre
CP:	Contingency Plan
CRJ:	City of Rio de Janeiro
DRR:	Disaster Risk Reduction
EWS:	Early Warning Systems
Geo-Rio:	Geotechnical Foundation of the City of Rio de Janeiro
HFA:	Hyogo Framework for Action
ICS:	Incident Command System
RAS:	Rio Alert System (Rainfall forecasting and monitoring system)
SAS:	Siren Alarm System
SASTP:	Sound Alarm System Triggering Protocol
SEE:	Simulated Evacuation Exercises
SEP:	System Evacuation Plan
SP:	Support Point
SUBPDEC:	Undersecretary of Civil Protection and defence of the City of Rio de Janeiro
UN:	United Nations
UNFCCC:	United Nations Framework Convention on Climate Change
UNISDR:	United Nations Office for Disaster Risk Reduction.
USTDA:	United States Trade and Development Agency.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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