Remote monitoring of urban flooding based on the warning system of INEA-RJ, Brazil

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Abstract: The purpose of this article is to analyse the flood-warning systems through remote management to the risk of extreme hydrological events carried out by the State Institute for the Environment (INEA-RJ). The methodology involves selecting hydrological monitoring stations located in the region of the Fluminense Lowlands, Rio de Janeiro-RJ, with the observed data of the water levels of the river and rainfall. The results suggested there was a period of about 2 hours and 15 minutes from the time the river reached an 80% spillover rate until the complete overflow of the volume of water in the section monitored, in the town of Duque de Caxias-RJ-Brasil. The remote management of the rain recommended by the INEA will make it possible to broaden its range of measures for planning and response to urban risks, and in particular to provide an instant response to the civil defence of the town.

Keywords: prevention; urban flooding; disasters; extreme hydrological events; flood-warning; Rio de Janeiro; Duque de Caxias; Brazil.

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1 Introduction

The total number of people affected by natural disasters, like floods and mudslides, make up about 34% of all the cases reported, while dry seasons and droughts cause the types of disasters that most affect the Brazilian people and make up 51% (Brazil, 2013). Of this total, approximately 1,460 deaths were recorded between 1991 and 2012, owing to the landslides in the South-East region, with about 78% of them occurring in the State of Rio de Janeiro (Brazil, 2013). These inundations, mudslides and flood damage in the 'hydrological nature' group as defined are catalogued in the Codificação Brasileira de Desastres [Brazilian disaster code] (Brazil, 2012). Basically, they all take place because of the incapacity of the drainage system to withstand heavy rainfall on occasions when there is a sudden downpour. These events lead to the plains being submerged, with a sudden rise in the torrent of water in the outlets and gullies causing an accumulation of water in the urban regions situated in the lowlands.

The irregular settlements, in particular those beside of the watercourses, are more susceptible to disasters of a hydrological nature because people occupy these dangerous areas. In the region of the Fluminense lowlands in the State of Rio de Janeiro, among the plains, there can be found a rugged terrain with hills and steep slopes. This together with an intense use of the land for urban occupations means that the hydraulic-hydrological features increases the vulnerability and exposure to extreme events and thus increases the likelihood of disasters. The sharp difference in level between the mountain peaks and the plains accelerates the speed of the surface runoff, which results in high pluviometric degrees of intensity that have powerful impacts, especially in urban areas.

Owing to the constraints imposed by the lack of monitoring data in the lowlands, there is less chance of alleviating the adverse effects of the extreme events and managing the climatic conditions to mitigate the risks of natural disasters. However, a number of different structural and non-structural measures can be taken in an integrated way, to reduce the material and human damage caused by these extreme phenomena. The flood warning system (SAC) encompasses a set of components responsible for giving information about rainfall and river flow metrics automatically. Since it is coupled with particular electronic systems for the collection and transmission of data through various sensors, the SAC is abled to give an advance warning of the risk of the occurrence of an extreme natural phenomenon, it is thus able to assist in the decision-making of the policymakers, such as environmental committees and the towns civil defence (adapted from Kobiyama et al., 2006).

The increase in the number of reported cases of natural disasters in the Fluminense lowlands thus can be partly explained by the evaluation of the hydrometric network in the State of Rio de Janeiro. The inventory of pluviometric and fluviometric seasons in the region shows the inefficiency of the information systems used in the hydrological platform, in so far as there is a clear discontinuity in monitoring with numerous gaps in the datasets. In addition, there is a ¨depersonalisation¨ of the network controls which leads to deactivation and is largely caused by the obsolescence of the equipment, discontinuity of the budgetary control, the termination of projects, the lack of technical qualifications for the operation of the networks, among other reasons (INEA/COPPETEC, 2014).

The State Institute of the Environment (INEA-RJ) of Rio de Janeiro, which is affiliated to the Secretary of State for the Environment, is the environmental management body that plays a strategic role in providing mechanisms of control and monitoring for the socio-environmental requirements and sustainable development of the State. Apart from having other powers, it is also the responsibility of the INEA to monitor the hydrological events reported by the SAC. The flood warning system, which has been in operation since 2012, is designed to provide information to the authorities and public about forecasted heavy rain that is capable of causing serious human losses and material damage.

The purpose of this article is to analyse the rainfall warning system (SAC) by remote management for the prevention and mitigation of the risk of extreme hydrological events in the Fluminense lowlands, carried out by the State Institute of the Environment (INEA-RJ).

2 Methodology

The hydrographic basins that belong to the municipality of the Duque de Caxias form a part of the metropolitan region of the city of Rio de Janeiro and are situated in an extensive region of lowlands known as the Baixada Fluminense. Despite a large number of structural and non-structural measures that have been taken since the 20th Century (and more recently with the drawing up of the Master Plan for Hydric Resources in the Basin of the Rio Iguaçu-Sarapuí River) (SERLA, 1994), there are still natural disasters occurring in the region which directly affect more than 180,000 people (Kelman et al., 1995).

With an area of 467.6 km^2, the town of Duque de Caxias-RJ has about 99% of the residential population in the urban area (IBGE, 2010). Although it experiences all types of rainfall, the Duque de Caxias region, has orographic rain with an annual average of 1,300 mm and temperature of 23.2°C. The Basin of the River Capivari occupies about a quarter of the municipal area of Duque de Caxias, and includes approximately 22% of the local population. Its average annual temperature is 22°C, and the average annual rate of rainfall is 2,300 mm (see Table 1).

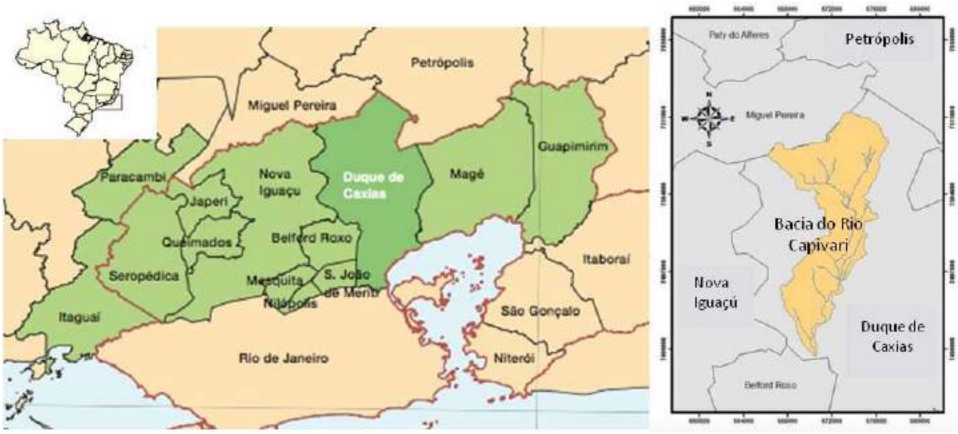
Table 1 Features of the town of Duque de Caxias, Baixada Fluminense, Rio de Janeiro

Municipality	*Area* (km^2)	*Population*	*Climate*	*Average annual rainfall*	*Average annual temperature*[2]
Duque de Caxias-RJ	467.6	882.729[1]	Tropical	1,300 mm[2]	23.2°C
Bacia do rio Capivari	104.8	40.220[?]	Tropical	2,336 mm[3]	22.0°C[4]

Notes: [1]Estimate IBGE 2015; [2]http://pt.climate-data.org/; [3]Station of Xerém; [4]Basin of the River Iguaçu.

The aerial surveys that are conducted take place in the Baixada Fluminense region. The flood warning system warning system involves hydrological monitoring, surveillance and the management of environmental conditions, particularly in the basin of the River Capivari, which is a tributary of the River Iguaçu, in the town of Duque de Caxias, RJ (Figure 1).

Figure 1 The Fluminense lowlands and the Basin of River Capivari, are situated in the town of Duque de Caxias, RJ (see online version for colours)



Source: PUC (2009) and Neves and Sousa (2014) adapted

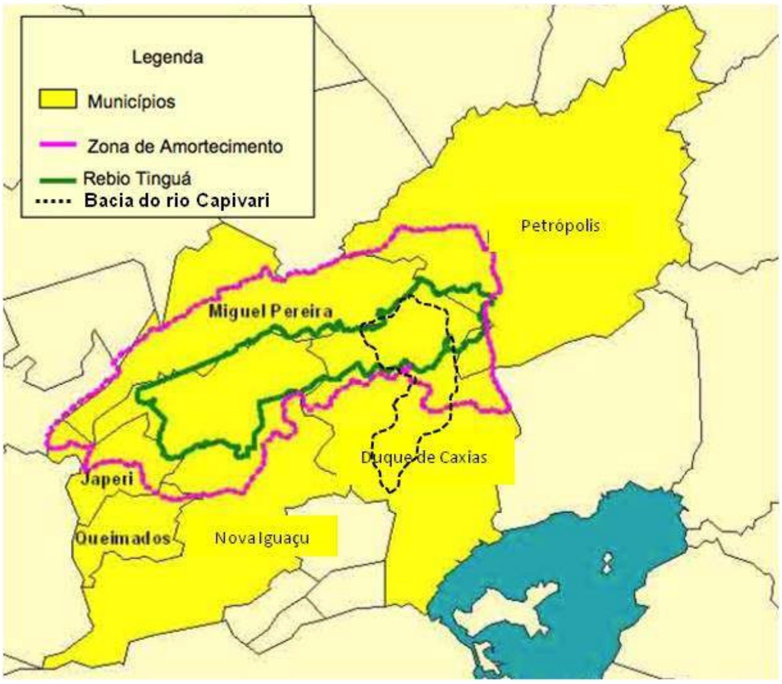
Table 2 Classification of land use in the basin of the River Capivari

River Basin of Rio Capivari/Area	km^2	*Hectares*	*%*
Forest c/secondary vegetation	73.103	7,310.29	69.73%
Pastureland and exposed soil	26.527	2,652.75	25.30%
Urban occupation	4.233	423.26	4.04%
Agriculture	0.744	74.42	0.71%
Rocky outcrops	0.197	19.74	0.19%
Water	0.032	3.20	0.03%
Total	104.837	1,0483.66	100.00%

The basin of the River Capivari comprises a total area of 104.8 km^2 and is an integral part of the Xerém district. About 69.8% of this area is preserved for forests, 25.3% is made up of pastureland, meadows and exposed soil and 0.71% is used for cultivation (Table 2). The remaining part of the basin which covers 4.23 km^2 (4.0%) is formed of urban settlements. 0.2 km^2 (0.2%) consists of rocky outcrops. Stretches of water fill 0.03 km^2 of the area of the basin (Neves and Sousa, 2014).

Although there is a serious lack of geological data and there have been considerable alterations to the climatic conditions of the region, the classification of the use of the land and occupations of the people in the basin of the River Capivari shows that more than 95% of the area is green (or with exposed soil), which suggests there is a high capacity for infiltration. In these conditions, only limited structural interventions can be made in the basin, especially because it includes locations for sustainable conservation practices and protective measures – the Environmental Protection Area of Alto Iguaçu and the Biological Reserve of Tinguá. The REBIO of Tinguá covers about 37% of the town of Duque de Caxias (IBAMA, 2006), this town is directly to the north of the Xerém district and in the upper part of the basin of the River Capivari (Figure 2).

Figure 2 Boundaries of the biological reserve of Tinguá and buffer zone (see online version for colours)



Source: Adapted from IBGE (2000)

In these conditions, areas susceptible to climatic variations are extremely vulnerable to the occurrence of disasters (especially in regions characterised by hills and urban settlements), that have their own particular features. This is a factor that justifies re-evaluating the current management model for hydric resources and taking measures to install or renew surveillance and flood warning systems capable of forecasting the risk of an extreme natural event occurring (adapted from Kobiyama et al., 2006). Thus, since the historical records of extreme natural phenomena are fairly recent, the advent of application systems for monitoring information is also a comparatively new kind of technology (in a situation where there are no systems that can be integrated with voluntary services). A wide range of data can be produced in an automatic and continuous form combined with humanitarian logistics. The conditions for meeting the needs of communities in areas susceptible to changes in climate and the occurrence of extreme events, have become even more complex since the region affected by the catastrophe is full of obstacles that make communication difficult with the people concerned, such as between the rescue teams and the command centre (Albuquerque et al., 2014).

3 Results and discussion

Currently, the rainfall warning system of the government of the State of Rio de Janeiro in the region of the town of Duque de Caxias, makes use of hydrological stations installed in the Xerém district, namely

1 Ponte Ferro Capivari [Capivari Iron Bridge], in the basin of the River Capivari.

2 Santa Cruz da Serra, situated in the basin of the River Saracuruna (Table 3).

There is also a pluviometric station situated upstream of the basin called Xerém-Mantiquira (Vianna et al., 2009). The hydrological stations record data about the water levels of the river and rainfall, and the pluviometric posts only provide data about rainfall. Both stations are discretised for upgraded intervals every 15 minutes (Figure 3).

The rainfall distribution in the basin is much greater in the mountainous regions in so far as they allow a greater concentration and release of water to the plains below where the Xerém district is located (Figure 4).

The study of the list of stations in the monitoring system of the INEA includes a hydrological network at Ponte Ferro-Capivari (INEA/COPPETEC, 2014), the information data have not been updated to proved a historical sequence since April 2012. For this reason, data on rainfall and river flow metrics have been compiled in accordance with the records available in the period corresponding to the event being analysed.

Figure 5 shows the pattern of the hydrological data obtained from a critical event observed on 3 January 2013 that was done to assess the flood warning system in the basin of the River Capivari. During this event, the Mayor of the town of Duque de Caxias issued a Declaration of a State of Emergency in the 4th District of Xerém, under authority granted him by Decree No. 6259 of 3 January 2013. It was an abnormal situation in wich there was the need to request assistance from the Government of Rio de Janeiro or the Federal Government to enable the affected region to more fully recover. The event which took place at the beginning of the year was catalogued as a natural hydrological disaster and classified as a landslide by the Brazilian disaster code (COBRADE). It carried a very high volume of surface runoff at great speed and energy, becaused of the torrent of concentrated rainfall, particularly at the upper part of the basin. The disaster which occurred on that day was in the region of the basin of the River Capivari, a tributary of the River Iguaçu, in the 4th District de Xerém-Mantiquira, in Duque de Caxias and affected about 100,000 people, with more than 1,400 displaced and made homeless, 60 injuries and two deaths (Carvalho and Domingues, 2013). The data observed at the Xerém-Mantiquira station recorded a rainfall of about 200 mm in less than 12 uninterrupted hours. The IDF equation of Region 3 of Xerém (CPRM, 2000) estimates a pluviometric intensity with a 2% rate of frequency in a given year, corresponding to a return period of approximately 50 years.

Table 3 Monitoring network in the hydrographic region of the Capivari

Station	*Exact location*	*Measurement*	*Latitude*	*Longitude*
Hydrological	Ponte Ferro Capivari	Level and rain	22°40’03”S	43°20’03”W
Hydrological	Santa Cruz da Serra	Level and rain	22°38’35”S	43°17’28”W
Pluviometric	Xerém-Mantiquira	Rain	22°35’06”S	43°18’20”W

Figure 3 Location of the monitoring network in the basin of the River Capivari (see online version for colours)

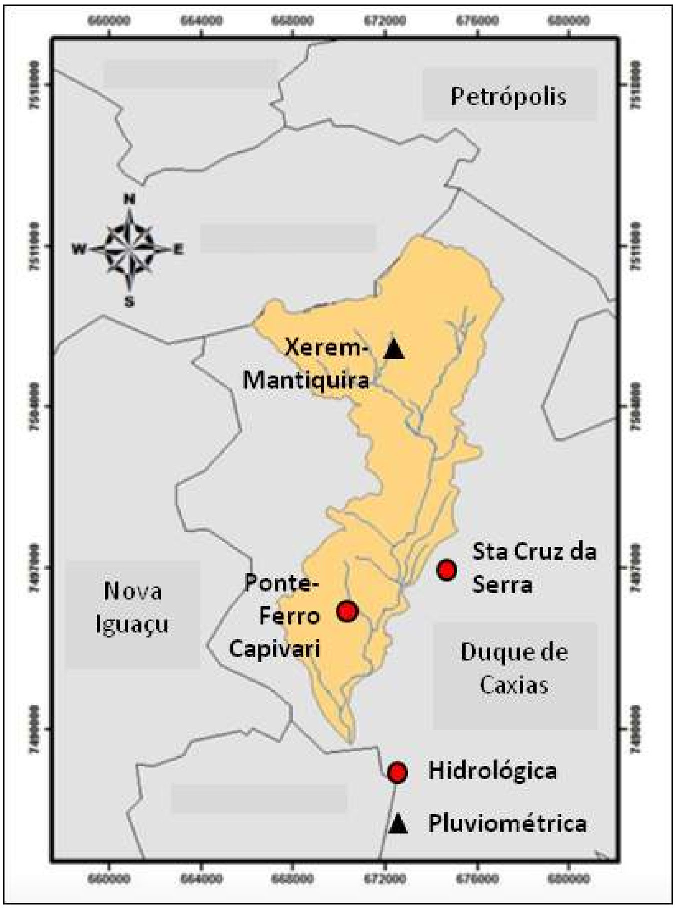
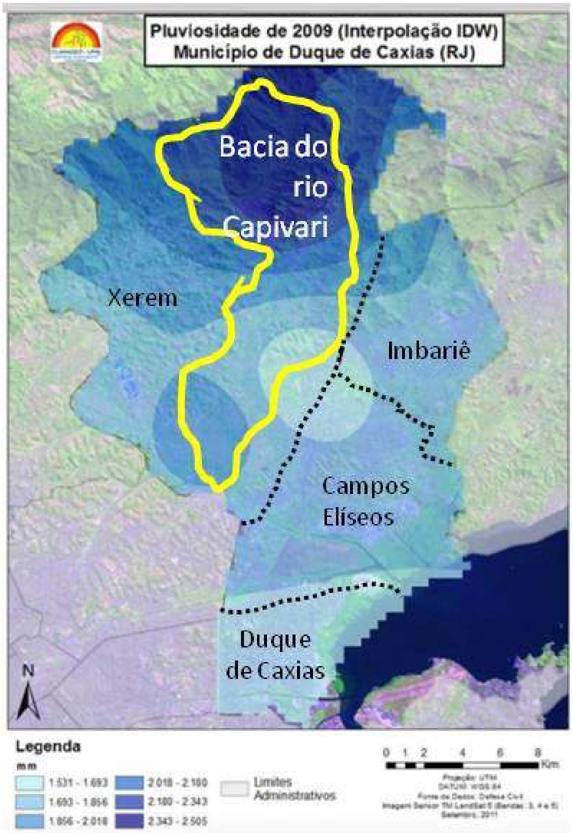
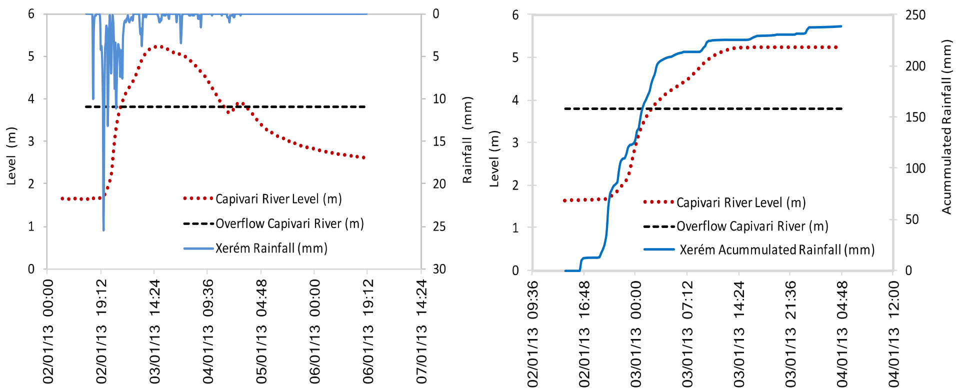


Figure 4 Rainfall in the basin of the River Capivari (see online version for colours)



Source: adapted from Oscar and Brandão (2012)

Figure 5 Hydrological data observed in the basin of the River Capivari (see online version for colours)



Although significant advances have been made in the management of hydrologial information in the region, the flood warning system installed in the State of Rio de Janeiro has serious failings with regard to connectivity, its inability to disseminate the information provided by the data from the rainfall and from the river flow metrics, as well as inconsistency in the representation of hydrological processes. This particularly applies to the following: measurement of flows, meteorological data, the spatial variability of rainfall, distributed modelling of shifts in the direction of the rain, the absence of discharge measurements corresponding to the key curves that were traced and little representation of the records of the data that had been collated. The short period of observation also had an adverse effect on the reliability of the results of the analysis, particularly in the most affected areas and the risks of hydrological disasters.

4 Conclusions

There are different factors involved in this scenario, even despite the systematic attempt by government bodies and entities to cover them all. There are also areas that currently show weakneeses and constraints that hamper any search for solutions or answers to the problem of how to avoid the occurrence of catastrophes related to adverse natural phenomena which have a corresponding effect on hydric resources. The lack of hydric security and the effect of changes in the climate on the region of Baixada Fluminense and in Brazil generally, is revealed by the historical records which show an increase of more than 40% in the occurrence of sudden natural events between the decades of 1990 and 2000 (Brazil, 2013).

The peculiar environmental features in the region of the lowlands, intensified by possible changes in climate and anthropic factors, are conducive to the occurrence of natural disasters, especially of a geological or hydrological order. The heavy torrents of rain that have fallen on the upper parts of the basin have caused significant changes in the runoff especially when they reach the plains, in so far as they lead to a greater frequency of mass movements of earth, soil erosion, inundations, mudslides and flood damage.

It is recommended that in future studies, an attempt should be made to extend the existing monitoring network, as well as to investigate the patterns of heavy rainfall in the basin, with regard to the time of concentration and response to critical events.

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