AGORA-GeoDash: A Geosensor Dashboard for Real-time Flood Risk Monitoring

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ABSTRACT

Flood management is an important approach to reduce damage caused by floods. In this context, technological architectures which work in real-time are needed. However, Brazil has faced many structural difficulties in obtaining updated information on the current state of its rivers. To address this problem, this paper outlines a geosensor dashboard called AGORA-GeoDash, which processes data streams from wireless sensor networks and makes them available in the form of a set of performance indicators that are essential to support real-time decision-making in flood risk monitoring. The dashboard was built on open-source frameworks, made use of geoservices that comply with the standards of Open Geospatial Consortium, and established a Wireless Sensor Network which monitors the rivers of São Carlos/SP in Brazil. The analysis of the indicators available in two rainfall events revealed that the dashboard can provide the key information required for the decision-making process involved in flood risk management.

Keywords

Flood Risk Monitoring, Geosensor Dashboard, Wireless Sensor Network, Flood management, Hazard Index.

INTRODUCTION

The recent floods in Queensland between 2010-11, Thailand in 2011, China in 2012 and Germany and Hungary

in 2013, make clear that these disasters are causing significant losses in social, economic, structural and political spheres (Degrossi et al., 2013). In the past few years in Brazil (following severe damage to towns and cities in the states of São Paulo, Rio de Janeiro and Santa Catarina), the government, official agencies, and the general community have all had to tackle the problem of dealing with floods. Flood management is also an important adaptation measure for dealing with climate change, since there is expected to be an increase in the frequency of extreme weather conditions that can lead to flooding (Albuquerque et al., 2013).

Hence, there is an increasing need to investigate what measures can be taken to provide resistance against flooding and extreme events (Norris et al., 2008). In this area, digital dashboards are a type of technological tool that can support real time decision-making by emergency services. They can operate by monitoring the variables related to disaster preparedness (including the structural and social policies of the affected region) which appear in the form of performance indicators for the operational, tactical, and strategic activities of the safety organizations (Bharosa et al, 2010).

This paper sets out a geosensor dashboard called AGORA-GeoDash which processes the data streams of wireless sensor networks and makes them available in the form of a set of performance indicators that are required to support real-time decision-making in flood risk monitoring. In this way, it is hoped that this paper can make an addition to the existing literature on flood risk monitoring by providing a geosensor dashboard based on concepts of service-oriented architecture linked to a wireless sensor network, together with a set of key performance indicators, and examining the experiences derived from its evaluation through an analysis of two real flood events.

The remainder of the paper is structured as follows: Section of *Background* defines the concepts used. Section of *Research Context and Methods* provides a detailed account of the context of the research and the methodology used to develop the dashboard, which is shown in Section *AGORA-GeoDash*. Section of *Deployment and Analysis* examines two rainfall events used to evaluate the dashboard. Finally, Section of *Conclusion and Final Remarks* summarizes the conclusions and makes recommendations for future work.

BACKGROUND

Flood Management

The growing occurrence of natural disasters has highlighted the need to adopt measures that increase the resilience, and adaptability of the people within the communities affected (Mendiondo, 2010). The activities involved in the management of floods can be grouped into three phases: pre-flood planning, emergency management and post-flood recovery (Ahmad and Simonovic, 2006). During the planning phase, activities are carried out to reduce the extent of the damage caused by a flood, e.g. they involve defining evacuation plans and simulations to optimize the use of land around the rivers. During the event, the emergency management undertakes the tasks defined in the planning phase. Following this, in the recovery phase a set of activities is put into effect to enable the affected communities to return to their normal lives and to adapt to any new developments (Simonovic, 1999).

In view of the many variables involved, flood management is a complex "cycle" which requires specific activities to be carried out before, during and after a flood (Simonovic, 1999). In the case of Brazilian floods, there are a lot of technical factors that make it difficult to obtain updated information about the current state of the rivers, especially when there is flash flooding caused by heavy rain or the overflow of streams and narrow gullies, which seriously damages the local infrastructure. These problems hamper the task of flood risk monitoring and as a result, slow down the decision-making of the emergency agencies. In response to this problem, the next section sets out the digital dashboard as an alternative means of providing relevant and essential information through a simple user interface.

Digital Dashboard and Related Work

A Digital Dashboard is a type of information system which is available for use on a single screen. It provides the most important management information needed to support strategic activities, such as goal setting, planning and forecasting, and tracking performance in strict accordance with organizational objectives (Few, 2006; Liang and Miranda, 2001). In addition, it can be understood as a type of information system that is usually used to support decisions at the strategic level of organizations (Hosack et al., 2012). In these kinds of decisions, the systems still handle a large number of parameters and relationships but also attempt to alleviate the effects of any unknown or shifting parameters and relationships (Hosack et al., 2012).

There are several essential features that these digital dashboards must include to achieve their objectives. First of all, they must be customizable and adaptive so that they can carry out the specific objectives of their users e.g. the managers. Furthermore, they are characterized by the use of drill-down capabilities that provide quick access and allow them to identify the root cause of a problem (Vasiliu, 2006). Finally, they must provide an overview of everything that is currently going on in the business by means of simple charts, key performance indicators (KPIs), and forecasting capabilities (Vasiliu, 2006; Liang and Miranda, 2001).

Examples of digital dashboards can be found in several application fields (Mahendrawathi et al., 2010; Mitchell and Ryder, 2013). With regard to disasters, Zheng et al. (2010) produced a set of dynamic dashboards to provide a quick view of the user's interests i.e. the aim is to predict the information that is most needed by different users and to display that information directly. These dashboards are a part of a project which seeks to provide disaster recovery information for a community network, and improve collaboration and information exchange. Bharosa et al. (2010) developed a dashboard that is used for data visualization of key performance indicators for multi-agent emergency preparedness. With this end in mind, they undertook an action research project with the aim of evaluating the indicators of simulation game performance with 36 relief agency managers. The results of the evaluation showed that most of the participants were satisfied with the dashboards and intended to make practical use of them.

RESEARCH CONTEXT AND METHODS

As stated earlier, floods in Brazil have been a particular cause of alarm to society and the news of flooding in urban centers has become routine during the rainy season (Albuquerque et al., 2013). This has resulted in a weakening of the risk management and decision-making process. Hence, the monitoring of rivers is essential. In this context, digital dashboards can be an alternative means of monitoring the variables related to the state of the river in an easy and straightforward way, by enabling the decision-making process to be carried out more quickly. However, most of the dashboards available fail to monitor the environmental variables in real-time or employ its communication geoservices, which impedes the reusability, scalability, and interoperability of the systems. In addition, the performance indicators identified on the analyzed dashboards are not sufficient to support decision-making in a flood situation, mainly, because they are static, inflexible, unable to calculate the degree of risk in dangerous situations, and inoperable in real-time. As a result, these methods often fail because they disregard important variables in the analysis, such as vulnerability and exposure to natural phenomena.

To achieve its objectives, this paper extends the prototype for flood monitoring shown in (Degrossi et al., 2013) which proposes an approach which aims to monitor the rivers in Brazil using Wireless Sensor Network (WSN) with ZigBee motes as a hardware component and Sensor Observation Service (SOS) with GeoExtAPI/OpenLayers for the software implementation. In previous work, the user interface software provides simple indicators of the water level but without any indicator to help in the analysis of a flood situation. Moreover, the approach has not been evaluated in a real case study and does not provide any indicators which can be used to give a warning of a flood risk. In contrast, this paper adapts the approach proposed in the previous work to a new approach composed of a structure of layers aimed at making it more flexible and scalable. Additionally, on the dashboard it includes the flood measurements in the water level charts and the Hazard Index (HI) value (Rotava et al., 2013) as potential indicators that can assist in flood risk monitoring, together with an analysis of two case studies which made use of the dashboard in October and November, 2013. This study forms a part of the AGORA project (Albuquerque and Zipf, 2012) and project called "*Assessment of Impacts and Vulnerability to Climate Change in Brazil and Strategies for Adaptation Options*" supported by FAPESP (no 2008/58161-1).

The research method that was employed involved four activities. First of all, we identified the requirements and performance indicators (such as HI) used to monitor the flood risk. This activity was carried out with the help of hydrologists, and involved conducting semi-structured interviews and holding regular meetings. With the aid of these research methods, we defined the elements required to compose the interface of the Geosensor Dashboard. After this had been completed, we introduced a software prototype to monitor the rivers of São Carlos/SP in real-time, using data obtained from a WSN composed of three sensors located at strategic points of the rivers. Finally, an analysis was conducted to evaluate the usability and efficiency of the Geosensor Dashboard.

AGORA-GEODASH

This section examines AGORA-GeoDash, a geosensor dashboard for real-time flood risk monitoring based on performance indicators (such as Hazard Index).

Layer Structure

The main objective of this dashboard is to allow members of emergency services or official agencies - e.g. fire, police or civil defense – to make quick decisions based on accurate geographic information collected in real-time by sensor networks and displayed in a simple interface that can be easily interpreted. As can be seen in Figure 1, the AGORA-GeoDash is composed of three layers to make this possible. In the next section, each of them will be outlined in detail.

The first layer, called *DataSource,* is composed of wireless sensors connected to a WSN and is designed to collect data from the river, e.g. its height, speed, temperature, level of pollution, etc (Lewis, 2004). The communication also complies with Open Geospatial Consortium (OGC) Sensor Web Enablement (SWE) standards (Botts et al., 2008); so as to enable the collected data to be shared in an interoperable and flexible manner with the new layer called *ServiceLayer*.

The *Service Layer* comprises several routines for fusion, as well as for transforming and sharing the data provided by the previous layer; this group of routines is called AGORA (Albuquerque and Zipf, 2012). In addition, other routines analyze the quality of these data in terms of their accuracy. Here, "quality" can be understood as referring to accuracy, the degree of similarity between the data produced and the real world (Flanagin and Metzger, 2008). This layer provides integrated data by employing a set of services based on the concepts of Service Oriented Architecture (SOA) and the SWE specifications (Botts et al., 2008).
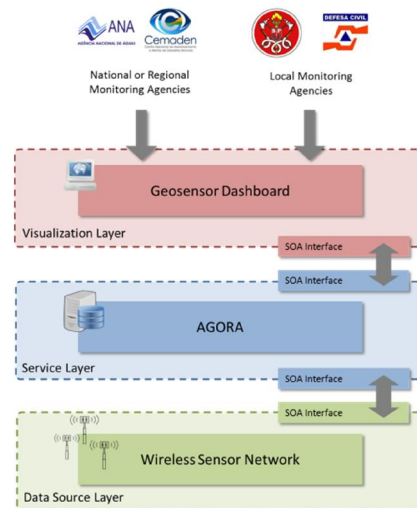

Figure 1. Layer Structure of AGORA-GeoDash

Finally, the third layer, called the *Visualization Layer* consists of the geosensor dashboard which draws on the data provided by the *service layer* to create a simple and unique dashboard with performance indicators that are essential to assist decision-making of several types of official agencies. The layout was created to be simple and easily interpreted because the visualization of geographic data requires several visual resources to allow a correct interpretation of the dataset (Oliveira and Baptista, 2012). In the following section, this dashboard will be described in detail.

The Geosensor Dashboard[1]

The geosensor dashboard of AGORA-GeoDash displayed in Figure 2 is composed of eight elements - a map, a report generator, five performance indicators, and a photo - as described in the following section.

Element 1 is a map showing the monitoring zone and positions of the sensors– highlighted by red or green circles – which are at the critical points of the analysis; these are the locations which need to be monitored because they have been affected by floods. *Elements 2*, *3* and *4* are indicators, the blue line represents the depth of the river for the last eight hours - in real-time and at three specific and critical points of the river. As well as

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[1]This dashboard is shown on the following link: http://www.agora.icmc.usp.br/geodashboard/

this, there is a red line which represents the bank of the river (its max height), i.e. if the blue line crosses the red line, it means a flood may occur at that location. Through an analysis of these visual charts, emergency agencies can make a decision (e.g. if roads must be closed, how many people will need to be evacuated and sheltered, which hospitals are available etc). *Element 5* is a report generator which creates a simple report that shows the depth of the selected sensor in a given period of time. This feature is essential for the analysis of the historical data.
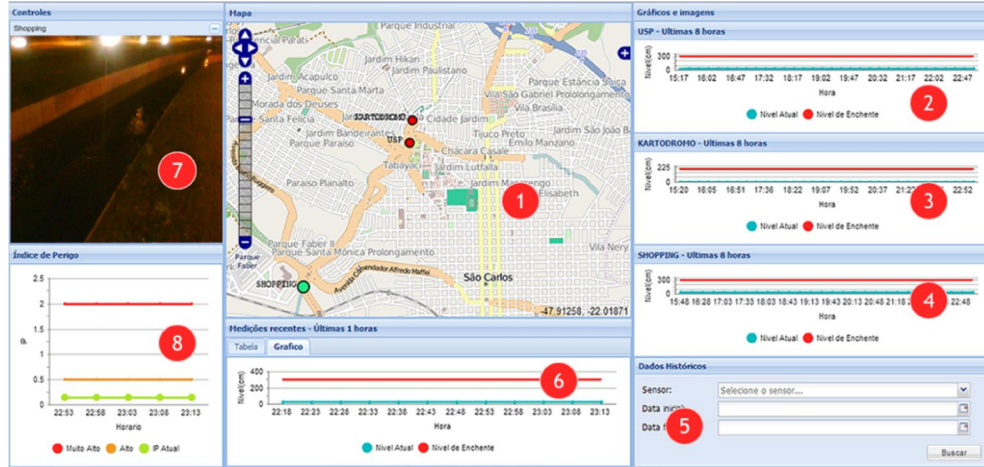

Figure 2. Geosensor Dashboard of AGORA-GeoDash

In addition to these elements, when the user selects each one of the three sensors highlighted on the map (Element 1), two other performance indicators are shown on the dashboard. *Element 6* shows the depth of the river for the last hour in the same way as *Elements* 4, 5 and 6, e.g. the blue line represents the depth of the river and the red line represents the bank of the river. Furthermore, *Element* 7 displays a simple photo taken by a camera installed in one of the sensors which can be used to monitor the height of the river or the presence of people living close to the river bend, in visual terms. Finally, *Element* 8 is an important supplementary performance indicator, called the Hazard Index (HI), which also helps in the planning of the activities carried out by an official agency. The functions of this performance indicator will be discussed in detail in the next subsection.

The Hazard Index

The Hazard Index (HI) is calculated from the water level, as measured by the selected sensor in real-time. This index represents vulnerability to loss with regard to human stability in flood flows. The HI used in this paper derives from the previous work of (Jonkman and Penning-Roswell, 2008) that shows how flood depth and flood water velocity are combined in a dynamic equilibrium. An example of this index is shown in Figure 3.
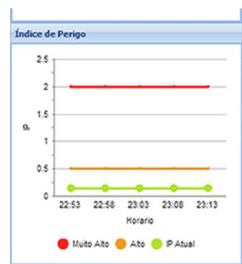

Figure 3. Example of Hazard Index (HI)

As shown in Figure 3, this component has three lines, the HI is represented by a green line and the other two lines represent a high level (orange) and very high level (red) which are features of a flood. On the basis of this information, the emergency services can support their decision-making activities by making the following analysis: when the green line crosses the orange line, there is a high potential risk and when the green line crosses the red line, this potential threat changes from high to very high risk.

The water velocity is calculated by the Gauckler-Manning Equation:

$$V = \left[\frac{1}{n} R_h^{2/3} S_f^{1/2}\right] \tag{1}$$

As we see in Equation (1), V is the cross-sectional average velocity; R_h is the hydraulic radius defined by the Area ($B \cdot D$) divided by the wet perimeter ($2D + B$); S_f is the slope of the water surface; n is the Gauckler-Manning coefficient. Assuming that the cross sections of rivers and canals are uniform and rectangular, then the flow Q is the product of the average velocity V and the cross-sectional area A_t. The Hazard Index (HI) is the product of the depth D and the average speed, B being the width of the channel (Rotava et al., 2013). We thus have the relationship:

$$Q = \underline{V} \cdot A_t = \underline{V} \cdot B \cdot D \tag{2}$$

$$H \cdot I = \underline{V} \cdot D = \frac{V \cdot B \cdot D}{B} = \frac{Q}{B} \tag{3}$$

This relationship is very significant because, HI is more representative than the use of flow measurements in studies of disaster management. In this methodology, we propose either replacing, or making a comparative study of, the flow parameter by HI, because the hazard index provides risk levels that are proportional to the study site, and this allows us to make a comparison with situations in other river basins of different sizes. It also describes the vulnerability of the area more clearly (Fava *et al.* 2013).

DEPLOYMENT AND ANALYSIS

Deployment of AGORA-GeoDash in the Floods of Brazil

When evaluating the AGORA-GeoDash, each of its layers was implemented in accordance with the specifications and details proposed for them. The *data source layer* was composed of three wireless sensors that were designed to obtain a good range of wireless communications between the nodes, with a good cost/benefit ratio (Degrossi et al., 2013). ZigBee technology was employed to ensure long-range communication, together with low-cost transmission, in terms of battery usage and physical size (Hughes et al., 2011). A base station was also established which receives (via JSON requests) all the data collected by these sensors and sends them through a call to a RESTful web service located in the *service layer*.

In the *service layer*, the data server is based on a database management system (PostgreSQL) and its extension to a geographic database (PostGIS)[2] while the routines that are used to transform, merge and share the data, are developed using Java Server Pages (JSP). In addition, the communication between this layer with the *visualization layer* component, occurs through the operations defined in the SOS specification (Botts et al., 2008) using the framework provided by 52 North German initiative for Geospatial Open Source software (52n)[3] (Jirka et al., 2012). In our case, we used three of them: *GetCapabilities* which makes metadata available for the service in a general way, *DescribeSensor* which supplies metadata regarding the sensor and *GetObservation* which supplies observation data from a particular sensor. Finally, two key libraries were used for the development of the *visualization layer*: GeoExt API[4] an open source library that is employed to create geographic web layout using javascript and OpenLayers[5] which is responsible for executing essential visualization features, handling geographic data and integrating it with OGC services. Figure 4 illustrates the scenario of the deployment.

As can be seen in Figure 4, the deployment scenario is located in the 'downtown' district of São Carlos/SP and its purpose is to monitor the basins of Monjolinho (highlighted by the blue line) and Santa Maria Madalena (the brown line). This is largely because these are frequent flood points which affect both the infrastructure of the city and also its inhabitants. For this reason, we installed three wireless sensors – called SN1, SN2, and SN3 – at strategic points, on the basis of information supplied by hydrologists in interviews and meetings held during the research study. This group of wireless sensors formed the *data source layer* as a kind of WSN of the AGORA-GeoDash.

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[2] http://postgis.net/
[3] http://52north.org/downloads/sensor-web/sos
[4] http://www.geoext.org/
[5] http://openlayers.org/

Figure 4. Layout of an urban flood-prone area in the Monjolinho river basin, Sao Carlos/SP, Brazil

We carried out routines in the *service layer* to calculate the HI and identify the danger level for each point of the basins, by means of the data provided by the previous layer. In this study, we decided to analyze the HI by using the data provided by the SN1 that is located at the Monjolinho basin. Since there was a wide range of measurements in different parts of the basin, we went to the field to collect specific measurements (the height, slope of the water surface, velocity, and width of the channel), which are described as follows: $S_f = 0.005$ (m/m), B = 9 (m), D = 0.2 (m), and n = 0.016.

On the basis of these measurements, the first routine calculates the water velocity through the theoretical equation (1). After this, a second routine calculates the HI that applies to Equation (3), together with the previous measurements and calculated data. Finally, the danger level is defined by using the HI and refers to the classification of ranges provided in Table 1, (e.g. if the HI calculated is 0.7, its danger level is medium), i.e. there is a medium degree of probability that someone in the river will be dragged along by the water.

HI (m2/s)	Classification	River Height (m)
> 1.4	Very High	0.7
1 < HI< 1.4	High	0.6
0.5 < HI< 1	Medium	0.5
0 < HI< 0.5	Low	---

Table 1. Classification of the height for the HI ranges of the river basin under study.

These classifications were calculated for a person weighing 75 kg (165lb), and 1.75 m tall (5.74 feet) by (Rotava et al., 2013). In addition, it should be noted that this is an indicator of a fall risk, i.e. someone unable to cross the channel. This index is not concerned with assessing the likelihood of flood occurring, or assessing the danger to people walking outside. In the next section, there will be an analysis of the data collected by the SN1 about two flood events that occurred in October and November, 2013 to estimate the usefulness of HI in assisting the decision-making process of the civil defense department of the city.

Event 1: Flood event that occurred on October 22-23, 2013

There was heavy rainfall in the city of São Carlos/SP on October 22, 2013. According to the Civil Defense department, the rain lasted 2h20min. During this period, the amount of rain was 105mm, which is what is normally expected for the entire month of December. Vehicles were swept away and houses and shops were flooded. On the basis of the data supplied by SN1, from the afternoon of October 22 to the afternoon of October 23, the AGORA-GeoDash provided the HI by applying Equation (3), and also showed the height of the river. Figure 5 shows both indicators.

On the basis of an analysis of the graph and assuming: (1) a uniform distribution of the rainfall and (2) a predominant surface runoff, it is clear that there was a large peak representing the two hours (from 18 p.m. to 20 p.m.) of heavy rainfall on October 22 followed by a less pronounced peak. In this period of time, the HI achieved an index of 3.27 which represents a very high risk for people who live close to the river, while the height of the river reached 327cm, 27cm above the river edge.
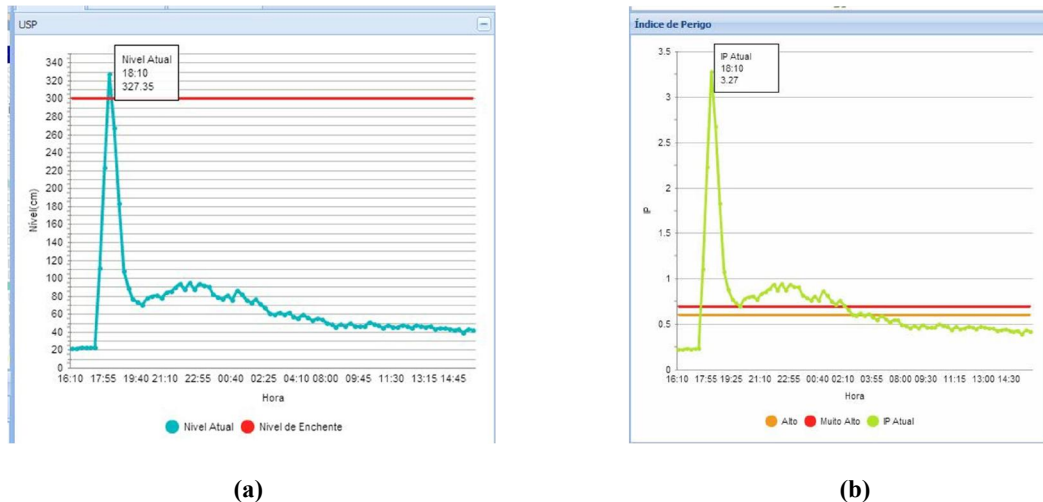
(a)	(b)

Figure 5. Indicator (a) for the height of the river and Hazard Index (b) shown by Geosensor Dashboard during the period of the flood recorded in São Carlos/SP on October 22-23, 2013.

The effect of the basins on the tributaries, i.e. the highly urbanized Tijuco Creek of ca. with a drainage area of 5.8 km^2 and a short flood concentration time, had the greatest impact in a very short period of time and there was a high order of magnitude from the maximum flow sensor. In this case, the Upper Monjolinho Basin, ca. with a drainage area of 30 km^2 and with mixed land-uses in the urban areas, (with some agriculture and the remains of a riparian forest), produces a slow, second flood pulse that can be seen in the Chart (from 20 p.m. to 04 a.m.).

Event 2: Rainfall on November 4, 2013

In addition, we also analyzed the data collected by the SN1 on the heavy rainfall which occurred on November 4, 2013. Figure 6a shows the HI index and Figure 6b shows the height of the river, both based on the data collected by the wireless sensor.

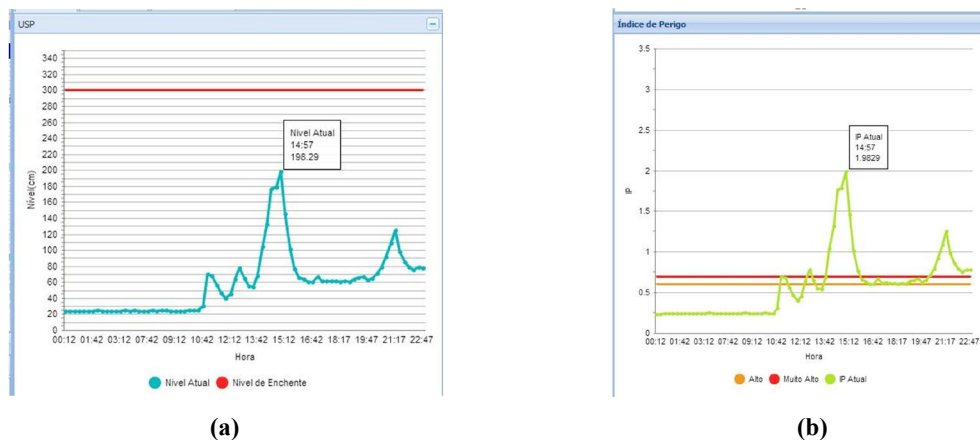| (a)	(b)

Figure 6. Indicator (a) of the height of the river and Hazard Index (b) illustrated by the Geosensor Dashboard during the period of floods recorded in São Carlos/SP on November 4, 2013.

As can be seen in Figure 6, this rain event was milder than that described earlier. Although the river did not overflow the banks of the channel (as shown by Figure 6b), it reached a height of 198cm, far from the river edge. However, the HI was very high, and attained an index of 1.98 (as shown in Figure 6a) which represents a dangerous situation for people how live close to the river.

CONCLUSION AND FINAL REMARKS

The seriousness of recent flood damage has encouraged the development of systems that are not only designed to support their management and assist the community in its response and preparedness but also to improve the decision-making activities of the official emergency services. In the case of Brazil in particular, there are many technical factors that make it difficult to obtain updated information about the current state of rivers and as a result, the effectiveness of risk management and resilience of the communities are weakened. However, there is a lack of state-of-the-art studies on the development of dashboards which are supported by real-time information and concerned with flood risk monitoring. In this context, this paper has sought to show that a digital dashboard can be used to overcome these problems through a simple system comprising a set of performance indicators combined with the measures required for flood management.

With regard to this, the main value and innovative feature of this paper is to devise a geosensor dashboard which has been developed by an interdisciplinary group (consisting of information systems researchers, sensor networks, and hydrologists), and aims to support the decision-making of emergency services and allow real-time flood risk monitoring (called AGORA-GeoDash) to be carried out. Another key factor in this study is the evaluation of the dashboard which was tested through its deployment in a real flood scenario in Brazil using data collected during two heavy rainfall events in October and November, 2013. The results showed that this dashboard can be used to assist real-time flood risk monitoring and also to support the decision-making process. This was shown through the analysis of the charts displayed in Figure 5 and Figure 6. This provides the HI and river height indicators in real time, and can be used to assist the decision-making of members of official agencies by determining when the river will overflow, as well as the risk of an adult weighing 75 kg (165lb) losing balance and being dragged along by the water.

Additionally, this paper showed that HI is a performance indicator which can also be used to assist flood risk monitoring. It employs a simple equation that can be easily applied to monitor a river in Brazil that flows through a critical flood site and provide valuable information that can be used to help emergency agencies to carry out their activities e.g. warning heavy vehicles or the traffic of the local community not to cross a nearby bridge even though the river has not yet overflowed its banks. Thus, another key component of this paper is to provide a multilayer structure based on the concepts of wireless sensor networks and digital dashboard, to introduce the HI as a means of supporting the activities of emergency services, and to analyze real experiences as a means of demonstrating how the dashboard can be deployed and evaluated in practice.

In future studies, we seek to undertake an action research with specialists in the field; the purpose of this is to investigate other essential indicators which have been used in flood risk monitoring and use volunteered information combined with sensor data, to increase the amount of information and extend its range (Horita and Albuquerque, 2013). In addition, we intend to conduct a "usability analysis" with specialists, by adopting an experimental approach to evaluate its quality. Finally, we will also use some data mining techniques to improve the analysis of the data, especially with in-situ collected data of B (width of the channel), n (Gauckler-Manning coefficient), S_f (slope of the water surface) to compose a hydraulically-based HI, and thus provide support for decision-making.

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