Towards the Building of a Resilient City able to Face Flood Risk Scenarios

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ABSTRACT

Despite the efforts that have been made to inform the community about the possible environmental risks, there is still a general lack of information. Currently, we are working on a flood risk scenario focused on a proposal towards a resilient culture together with the support of Information Technologies (IT) as a way to manage information. The goal is twofold: (i) on the one hand, to manage data in a small scenario to analyze and process the data collected from sensors in different sites in a micro-basin. Data get from data processing such as flow and velocity will then be the input data for hydraulic models to predict floods downstream; (ii) on the other hand, to publicize the predictions and the data already processed means people can benefit from information on flood risks, and the different participants may change their perception and consider cooperating in improving resilience.

Keywords
Risk Management, Floods, River Morphology, Resilience, IT.

INTRODUCTION

Ecuador is at a high risk of disasters due to its geo-location (SNGRE 2019). Specifically, we have taken as a study scenario the city of Cuenca, the third-largest city in Ecuador. Cuenca has different types of natural risks with a high incidence of earthquakes, forest fires, landslides and rains, and floods caused by heavy rains or climate change. The Cajas National Park (CNP) is a protected high-altitude area at the south-west Ecuadorian Andes west of Cuenca in Azuay province. In general, from the map overview, the CNP provides some water sources which are distributed between two oceanic slopes: the Amazon River (Atlantic Ocean) and the Pacific slope. From the local map of Cuenca, the CNP is the source of the Tomebamba, Yanuncay, and Machangara rivers. The CNP has micro basins such as the Mazán River (17.74%), Llaviuco River (16.39%), Soldados River (15.29%) and Quinuas River (11.41%). The other micro basins are below 10% (Astudillo et al. 2015).

Flood risk depends on a confluence between two components: hazard and vulnerability, which can be a combination of natural and human factors that create flood risk (Komori et al. 2012). Flood risk management allows communities and cities to control floods through preparedness and minimizing their impact. Information Technologies play a key role in flood risk management and disaster risks can be monitored with the support of sensors and computer tools, among others (Degrossi et al. 2014). Concerning the flood scenario, Cuenca can prepare for disaster based on information obtained after the analysis of flows and velocities from the sources in the micro basins in both winter and summer to monitor their impact at different times of the year. In this paper, we present the first step towards a complex analysis of how floods can be studied at source with the support of computer tools. The data have been collected in the work-field corresponds to three morphological types (Cascade, Step-pool, and Plane Bed) present

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at different sites on the Quinoas River (see Figure 1). We processed the data to obtain mean-flow and velocity and finally present these on a map. In the second step, data related to flow and velocity are the inputs of specialized flood prediction models. We also think that it is necessary to incorporate resilience with an emphasis on preparedness. We must consider as the first objective the different stakeholders’ viewpoints, the general information of the city studied, how it may face a flood emergency or disaster, and include this in emergency management activities (Ganji et al. 2019).

Figure 1. Location of the Quinoas River in the geographic map

Sustainable development and climate change are a great leap forward in Risk and Disaster Management history (UNISDR 2005). In this context, the first global framework, called Marco Hyogo, MAH (2005-2015), pursued objectives such as increasing disaster resilience and promoting Disaster Risk Reduction (DRR). The Sendai Framework is in force until 2030, and among its goals are highlighting the construction of resilience and encouraging science and technology. Although certain means have been established to manage risks and disasters, there is still a lack of information. Accordingly, incidents may arise when it is too late to prepare or prevent an emergency or disaster. In many cases, people think that an incident won’t happen to me or here (Peters et al. 2017). Hence, analyzing different risk scenarios in cities is an objective of resilience in cities (Gonzalez et al. 2016).

This paper is organized as follows: Section 2 describes the background on resilience in disaster management and the importance of community participation in risk scenarios such as floods. Section 3 describes the study area in a small scenario and the conceptual model conceived within a flood risk scenario. Section 4 details the steps followed in data processing including the presentation of the data on a map. Section 5 shows how information can be managed, while Section 6 concludes the paper and outlines future work.

BACKGROUND

Resilience has many aspects that can be adapted to various contexts and study domains, such as ecology, sociology, psychology, and engineering, among others (Alexander 2013). Regarding the disaster management domain, the United Nations International Strategy for Disaster Risk Reduction (UNISDR) provides the definition: “The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.” (UNISDR 2009). Resilience focuses on the ability of a system to deal with perturbations linked to concepts of vulnerability, innovation and adaptation, and appears to reduce practices that can increase risk vulnerability and improve the implementation of sustainability, sustainability being one of the main solutions for climate change (Rego et al. 2018). Anthropogenic actions are useful tools to study resilient strategies and measure environmental and social resilience, which means all members of the community are involved in resilience and participate in disaster preparedness (Cumming et al. 2013).

The participation of those involved, known as stakeholders (e.g., governments, communities, organizations, academic institutions, responders, volunteers, and citizens) is important in the challenge to find a new approach (Almoradie et al. 2015; Gonzalez et al. 2016). In other words, the stakeholders’ involvement must be committed to the different activities involved in community participation and a continuous learning process in flood risk assessment, as well as in planning and implementation of risk management measures, as all are key to the success of flood risk management plans (Tingsanchali 2012). The stakeholders’ participation and collaboration in flood risk management are useful in the decision-making process when a disaster or emergency strikes (Almoradie et al. 2015). Flood risk management,
including prevention, preparation (pre-disaster phase) and flood recovery (post-disaster phase) make countries more flood resilient (Hegger et al. 2016). The main objective of the pre-disaster phase is to reduce risks through early warning systems and preventive measures to minimize the impact of a flood (Degrossi et al. 2014).

Information Technologies are present in each one of the phases of disaster or emergency management (pre-disaster, response, and post-disaster (Aligne 2009)). In this sense, a few years ago, the UNISDR presented a list of technologies and tools for the Disaster Risk Reduction, which was released with a clear vision towards a resilient future in this domain (Fakhruddin 2016). For instance, in the preparedness stage, many tools have been created to simulate or train stakeholders. During the response stage, the knowledge gained from different sources is relevant for decision making support. At the recovery stage, many data collected in the response are analyzed and studied (Canós et al. 2010).

Considering the flood risk scenario in Cuenca was considered an interesting laboratory in which to experiment on building resilience on local and global scales. Cuenca citizens have to adapt to a changing climate, precipitation, drought, and floods, but there is an absolute lack of a holistic approach focused on city resilience. There is a need for better collaboration, so as to strengthen city resilience. Community involvement is a relevant issue to create social resilience. Additionally, there is a lack of education among citizens about territorial development and land use planning, as well as construction restrictions in flood and landslide risk areas, and sometimes the protection of the environment and the cultural heritage is ignored.

THE STUDY AREA

Morphological types are widely present in mountain rivers. The Quinuas river has three study morphologies: Cascade, Step-pool, and Plane Bed (Torbizadeh et al. 2018). The data collected in each one of these morphologies were measured by the dilution-gauging method by NaCl (Hudson and Fraser 2005). Each reach was divided into three to five cross-sections, with a staff gauge where the water level was measured with a measuring tape. Velocity was obtained by the traveling time obtained from the conductance curves upstream and downstream of the reaches. The traveling time was determined by the Harmonic methodology (Waldon 2004).

For each experiment, conductivity sensors were used. The first one was placed upstream or downstream of the reach in a place with a steady flow. The remaining sensors were sited on the opposite reach at the cross-section of points with different hydraulic conditions, which potentially can influence the conductance curve. The effects of those conditions can be assessed through a comparison of discharge or velocity results.

The study area of the Quinuas river involves seven sites. However, in this experiment, we have seen it necessary to collect data only in four sites, the most representative according to the study morphologies. Thus, four conductivity sensors were used together with three sensors situated at the opposite reach limit. The experiment was carried out on 5 December 2019, and we measured mean-flow and velocity behavior at points along the cross-section, such as turbulent or calm areas. Two of the sites are shown in Figure 2.

Figure 2. Excerpt of points taken along the cross-section at Quinuas River sites
• **Plane-Bed 2 Site**: boulder wave area, ridge area, calm area

• **Step-pool 2 Site**: turbulence area, preferential area, calm area

• **Cascade 2 Site**: turbulence area, preferential area, closest to the staff-gauge

• **Step-pool 1 Site**: farthest from the staff-gauge, closest to the staff-gauge, preferential from the center of the river

### The Conceptual Model

We summarized our model on flood risk scenario with a UML class diagram (see Figure 3). The main entities of the model are represented as classes, and their dependencies as different types of relation (associations, aggregations and compositions). In this regard, different sites (**Site class**) has a location (**Location class**) in a map represented on the geographic coordinate system, where each location contains attributes such as latitude and longitude. The data measurement collected in the field (**FieldMeasurement class**) belongs to a Site, where the measurement corresponds to date, water-level, wetted-width, mass, and salt-concentration. The water-level corresponds to Water Surface Elevation obtained by the sum of the meters above sea level (m a.s.l.) and height(m) of the data collection sites in different morphologies. The wetted-width is related to river width minus objects which block the flow of the river (e.g., stones). From the different custom views of stakeholders (**Stakeholder class**) the results and measurement can be deployed (**Result class**), which belong to a site and staffgauge.

**Figure 3. The Conceptual Model on flood risk scenario**

### DATA PROCESSING FLOW

Our proposal was to process the data from that collected at different sites to show the results, where the first step is the preparation of data from sensors. The next step is related to the processing of the collected data. The last step is to presented data obtained on a map.

### Data Preparation

First of all, we prepared data collected in each one of the morphologies obtained from the HOBO v21-v001 sensor though **HOBOware v3.7.17** tool. The data collected were measured following the dilution-gauging method by using NaCl (Hudson and Fraser 2005). Data was exported from each one of four selected sites in the CSV file.
Data Processing

Once the data had been obtained, we executed R scripts by steps, through RStudio IDE\(^2\), a tool that was created for statistical computing and graphics support. As a first step, we read the data from the CSV file and checked the conductance curve of each site through graphics to determine whether or not these were correct. In other words, when there are significant jumps or noises, we proceeded to eliminate them. In the second step, we processed the data to calculate mean-flow and velocity. In the third step, we exported the data to a database applying Postgres v4.11 based on our conceptual model, and created a view that was exported to CSV. In the fourth step, we executed a python script with support from the Jupyter Notebook application from Anaconda Distribution\(^3\). According to the python script, we took a view from the database and geometry data extracted from the qGis\(^4\) file. Finally, we have exported it in Html. The results can be seen in the map plot.

Data Presentation

The map generated shows each georeferenced point on the Quinuas River with a pop-up message with information on the site, mean-flow and velocity. We used some libraries, such as geopandas, folium, pandas, and numpy, and these allowed us to visualize the data on an interactive map and made working with geospatial data in python easier. An example of information from Step-pool 2 is shown in Figure 4.

\[\text{Figure 4. Map obtained after data processing}\]

Results by Sites

The results from four selected sites, according to morphology (Plane-Bed 2, Step-pool 2, Cascade 2, and Step-pool 1), are shown in Table 1. The mean-flow (Q) is represented in liters per second (lps) and velocity (U) is represented in meters per second (mps). The preferential area is the ideal point and is the reference data. The other points or areas

\[^2\]R Studio (https://rstudio.com/)
\[^3\]Anaconda Navigator v1.9.7 (www.anaconda.com)
\[^4\]qGis (https://www.qgis.org)
evaluate the variability from a sensor is incorrectly placed to obtain the velocity and flow by the dilution-gauging method using NaCl. Variability thus depends on the morphology and affects both variables, flow (Q) and velocity (U), as shown in Figure 5. Concerning the flow results, in Cascade morphology the flow value of the turbulence area is higher than 100% from its reference point, where the variability is clearly shown related to the preferential area. In the other morphologies, the flows related to the preferential area are closer to each other (see Figure 5a).

Regarding the velocity results, in Step-Pools morphology we can see that there may be under- or overestimation of the calculated variables, reaching an extreme case in which Step-pool 2 yields a value higher than 100% than the preferential area. In Cascade 2 morphology the effect is shown to a lesser extent, and in Plane-Bed morphology, the values for each point are closest because the flow is more regular (see Figure 5b).

Table 1. Results obtained in sites selected

<table>
<thead>
<tr>
<th>Morphology</th>
<th>Mean-flow (lps)</th>
<th>Velocity (mps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step-pool 1</td>
<td>244.820</td>
<td>0.161</td>
</tr>
<tr>
<td>Cascade 2</td>
<td>246.748</td>
<td>0.293</td>
</tr>
<tr>
<td>Step-pool 2</td>
<td>239.642</td>
<td>0.463</td>
</tr>
<tr>
<td>Plane-Bed 2</td>
<td>226.398</td>
<td>0.011</td>
</tr>
</tbody>
</table>

Figure 5. Results by Morphology

The sensitivity results were obtained at points along the cross-section for each morphology with different hydraulic conditions to produce different curves. These conditions influence how they affect the work-field data, which are then the input data for different hydraulic models. For example, in a 1-D HEC-RAS steady model flow and Manning roughness are compulsory to run the data while water depth can be used as boundary condition or for validation. In this context, the input data are taken from our database to apply to the hydraulic models, including velocity, flow, height, river width, and water level, for information on flow resistance through Manning (n) (Arcement and Schneider 1989). This can have a high incidence effect on a flood risk scenario.

MANAGING INFORMATION IN A FLOOD RISK SCENARIO

The data from our database, as well as the information generated after applying the data to these hydraulic models for flood prediction, can be managed and given to stakeholders through custom views and access permissions by roles defined for each stakeholder, as shown through the mockup in Figure 6. In the study of downstream flood...
predictions, factors such as the flow travel time must be considered to give early warning in good time, so that the information can be disseminated to the different risk management agencies responsible.

The benefits to a city and community of knowledge of the latent risks in their environment and how climate change can affect them are one of the key points in building resilient cities. So, there is important the participants’ knowledge about floods, their perception of flood management, and collaborations between community members (e.g., researchers, citizens, and organizations), government, and responders team (Desportes et al. 2016). Also, the collective culture of resilience in the community allows sharing knowledge from experience, which leads citizens to give us information from their location. The formal knowledge enables us to train through guides and emergency plans, and contextual knowledge allows obtaining information from different sources, such as computer systems, social networks, mobile applications, etc. This is the challenge involved in creating a collective resilience culture in the different phases of disaster management.

Community members can collaborate with relevant information. Thus, volunteers as researchers and citizens can act as human sensors in monitoring the risks and assessing hazards from recent information which provides the parameters of local conditions likely to result in a natural disaster. In a flood scenario, parameters such as water level, the flooded area, and location are vital information to provide an adequate response. So, we will also work on the participation of different stakeholders in flood risk activities to analyze their observations.

CONCLUSIONS

The proposal presented in this research is aimed to contribute to a resilient culture in the flood risk scenario in Cuenca (Ecuador). In this context, we introduce a conceptual model to manage information with the support of IT. The first step was collecting data from the work-field in a small scenario, then processing it, saving it in a database, and presenting it on a map, with the help of computer tools such as R and Python. Regarding the second step, we pursued the objective that the data from our database be input data in existing hydraulic flood prediction models considering precipitation sensors and the travel time upstream from the micro basin towards downstream in large rivers.

We consider resilience is necessary for reaching long-term sustainability. For this reason, we are currently establishing continuous contact with experts in the emergency management domain to involve the community in a resilient culture for risks in their environment. Also, we think the support of IT is key to managing information from different sources. Although in this work we have taken a small scenario, the Quinoas River, this micro basin has an impact on the other rivers in the Cuenca city valley. Therefore, studying a smaller scenario first will allow our model to be taken to larger rivers in the future.

As for further work, we intend to keep working on our flood risk model and we will collect more data from the work-field for processing and analysis at different times of the year. We intend to implement an IT-based tool to manage the information obtained from the processed data and flood prediction.
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REFERENCES


