08-002

MODELOS HIDRÁULICOS Y CAMBIO CLIMÁTICO PARA EVALUAR RIESGO A INUNDACIONES EN LAS ZONAS URBANAS DE LA CIUDAD DE CUENCA, ECUADOR

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Cuenca, es una ciudad andina, de gran importancia dentro del manejo de los recursos hídricos y gestión ambiental, pero el riesgo en general y el cambio climático en particular no encuentra aún un nicho efectivo de estudio. Existen experiencias históricas como el desastre de La Josefina en 1993, el de Marianza en 2022, o el propio caso icónico del río Tomebamba, cuyo comportamiento hidrodinámico derivado de la variabilidad climática global convierte al territorio por el que discurre en altamente riesgoso. Dentro de este cauce de río es importante estudiar y analizar el patrón típico de los efectos de precipitación elevada e inundaciones repentinas. A partir del escenario climático RCP 8.5 se evalúa la respuesta del río y posibles afectaciones a los bienes de la ciudad que se concentran en la zona de afección. Se determina que inicialmente 180 bienes se afectarían, entre los cuales destacan inmuebles de valor ambiental y valor arquitectónico emplazados en las orillas norte y sur. En el primer caso destacan las acciones de contingencia asociadas a efectos colaterales, y en el último las incidencias sobre el 2%, 8% y 17% de los bienes en escenarios de riesgo a 50m, 250m y 500m del eje del río.

Palabras clave: riesgo; inundaciones; cambio climático

HYDRAULIC MODELS AND CLIMATE CHANGE TO ASSESS FLOOD RISK IN URBAN AREAS OF THE CITY OF CUENCA, ECUADOR

Cuenca is an Andean city of great importance in the management of water resources and environmental management, but risk in general and climate change in particular has not yet found an effective niche for study. There are historical experiences such as the La Josefina disaster in 1993, the Marianza disaster in 2022, or the iconic case of the Tomebamba river, whose hydrodynamic behavior derived from global climate variability makes the territory through which it flows highly risky. Within this riverbed, it is important to study and analyze the typical pattern of the effects of high precipitation and flash floods. Based on climate scenario RCP 8.5, the response of the river and possible effects on the city's assets concentrated in the affected area are evaluated. It is determined that initially 180 properties would be affected, including buildings of environmental and architectural value located on the north and south banks. In the first case, contingency actions associated with collateral effects stand out, and in the latter case, impacts on 2%, 8% and 17% of the assets in risk scenarios at 50m, 250m and 500m from the axis of the river

Keywords: risk; floods; climate change

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1. Introduction

The Andes mountain range spans over 7,000 kilometers, covering seven countries and serving as the source of many major rivers in South America. However, this region is also known for its susceptibility to extreme weather events, particularly floods. Climate change is exacerbating the frequency and severity of these floods, posing significant risks to the communities living in the Andes. This paper will explore the causes of flooding in the Andes and its impact on the region's ecology, economy, and society.

The Andes region experiences flooding due to several natural and human-made factors. One of the significant natural factors is the region's topography, characterized by steep slopes and narrow valleys. These features make it easier for water to flow downhill, leading to an increase in the velocity and volume of water during heavy rainfall (Baraer et al., 2012) (Mark et al., 2017). In addition, the Andes region is also prone to landslides and rockfalls, which can further exacerbate the effects of flooding.

Human activities have also contributed to the increased risk of flooding in the Andes. Deforestation, mining, and agricultural practices have altered the natural landscape and disrupted the region's water cycles. Deforestation, for instance, has led to reduced vegetation cover, which hinders the ability of the soil to absorb water, leading to an increase in surface runoff (Buytaert et al., 2006). Mining activities have also resulted in soil erosion and contamination of water bodies, further exacerbating the risk of flooding.

Flooding has significant impacts on the Andes region's ecology, economy, and society. The region's fragile ecosystem is particularly vulnerable to the effects of flooding, with soil erosion and landslides leading to the loss of biodiversity and degradation of habitats (Favier et al., 2008). The impacts of flooding are also felt on the region's economy, with damage to infrastructure, disruption of transportation, and loss of crops and livestock leading to significant economic losses (Emerton et al., 2016). Flooding also poses a significant risk to the region's population, with the potential for loss of life and displacement of communities.

In the southern zone of Ecuador, the risks mentioned above have been a repeated constant in recent years, the effect that a flood event can cause with an unfavorable climatic scenario is analyzed.

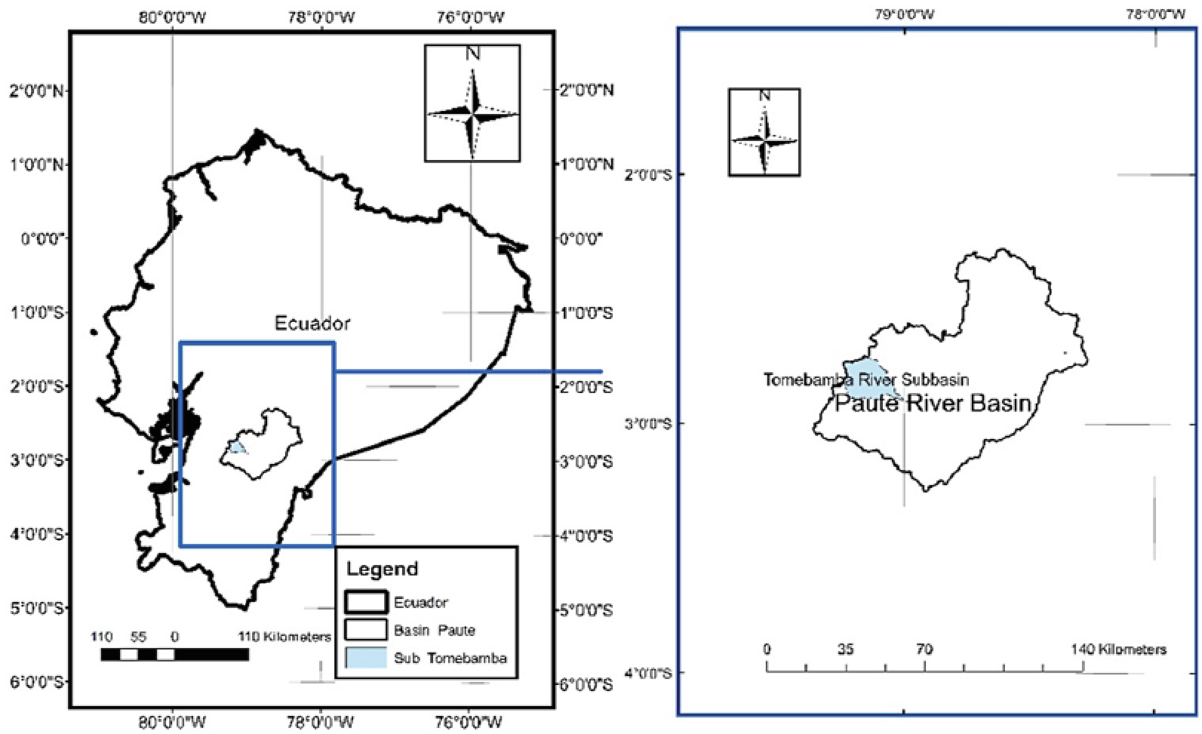
2. Study Area

The flood risk analysis process was carried out in the Tomebamba river sub-basin (Fig. 1), which is located in the southern Andes of Ecuador and belongs to the Paute river basin. It has an area of 327 km2, and whose water resource is used for human consumption, irrigation areas, preservation of aquatic life, forestry, among others activities.

The altitude limits range from 2476 to 4428 m.a.s.l., so the study area is a subbasin that varies significantly in its altitudinal characteristics, which could condition its behavior due to the high climate variability, as shown in different studies (Morán-tejeda et al., 2013)(Ohmura, 2012). The presence of the Andean moorland and the presence of ecosystems typical of these areas should be highlighted.

In particular, the analysis was carried out in the final stretch of the Tomebamba River, which is the area most vulnerable to flooding, since it has the most assets that can be affected.

Figure 1: Tomebamba river sub-basin location.



3. Methodology

The methodological proposal has been divided into three phases: 1 the climate model, 2 the hydrological and hydraulic model and 3 the flood risk analysis in the areas of influence.

Climate change manifests itself as a phenomenon that exacerbates already existing social problems (Soares & Sandoval-Ayala, 2016), and therefore needs to be studied from a quantitative therefore, it is necessary to study it from a quantitative point of view. In order to understand extreme precipitation events and flash floods due to climate climate change-related extreme precipitation and flash flooding events, specifically their effect on floods in the lower zone of the Tomebamba river basin, three models were developed, adjusted and validated. A climate scenario model, a hydrological model to obtain point events and a hydraulic model that simulates floods.

This research is based on the fifth IPCC report, in which four climate scenarios were estimated. The four RCP trajectories comprise a scenario in which mitigation efforts lead to very low forcing (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6.0), and a scenario with very high forcing (RCP6.0). (RCP4.5 and RCP6.0) and a scenario with a very high level of GHG emissions (RCP8). GHG emissions (RCP8.5).

Because hydrologic modeling is performed on a daily scale, in order to simulate to be able to simulate external precipitation events, future climate change scenarios must external precipitation events, future climate change scenarios must be at the same scale. be on the same scale. For this reason, global and regional climate models and regional climate models at monthly scales are eliminated from the selection process, and with the and thus, only regional climate models provided by the Ministry of Environment are used provided by the Ministry of Environment and Water of Ecuador are used, since they have historical and future information on a daily scale (Table 1). From them, it is possible to observe information on the variables of relative humidity (RH/H), precipitation and relative humidity (RH/H), precipitation (PR/P), radiation (RAD/R), maximum temperature (TMAX/TX), mean temperature (T), minimum temperature (TN temperature (T), minimum temperature (TN) and wind speeds on their x and y axes (U, V).

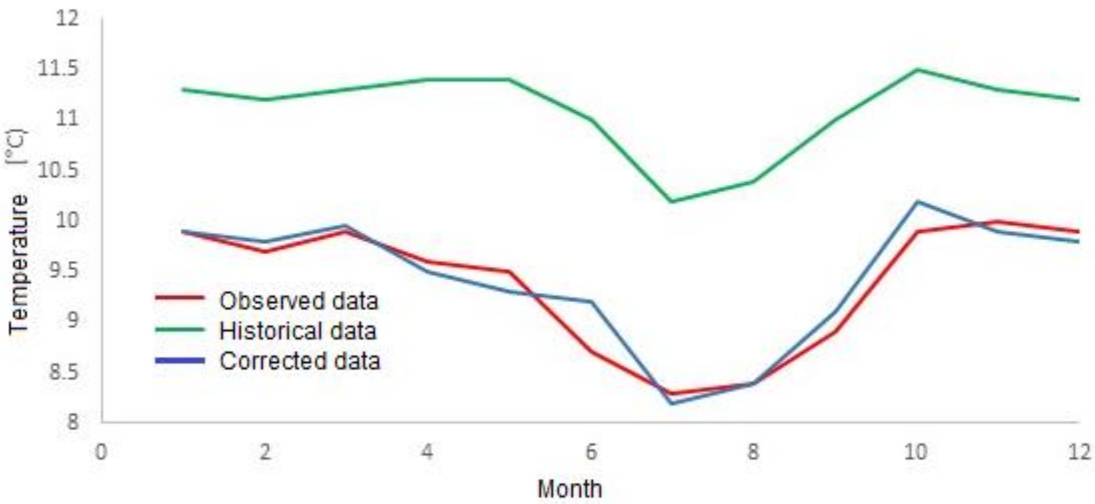
Tabla 1. Climate models obtained by the third climate change communication of Ecuador.

ID	Model
1	IPSL-CM5A-MR
2	MIROC-ESM
3	GISS-E2-R
4	CSIRO-Mk3-6-0
5	Ensamble

In order to carry out a flood study on a smaller scale to analyze the risk generated by floods, it is necessary to carry out a downscaling process is necessary, for reduce the size of the cells of the climate model. Several downscaling, statistical and downscaling processes, statistical and geo-statistical (Homsi et al., 2020), are performed and carried out, which allows to evaluate which of these processes gives the best results and apply them to obtain the variables of interest.

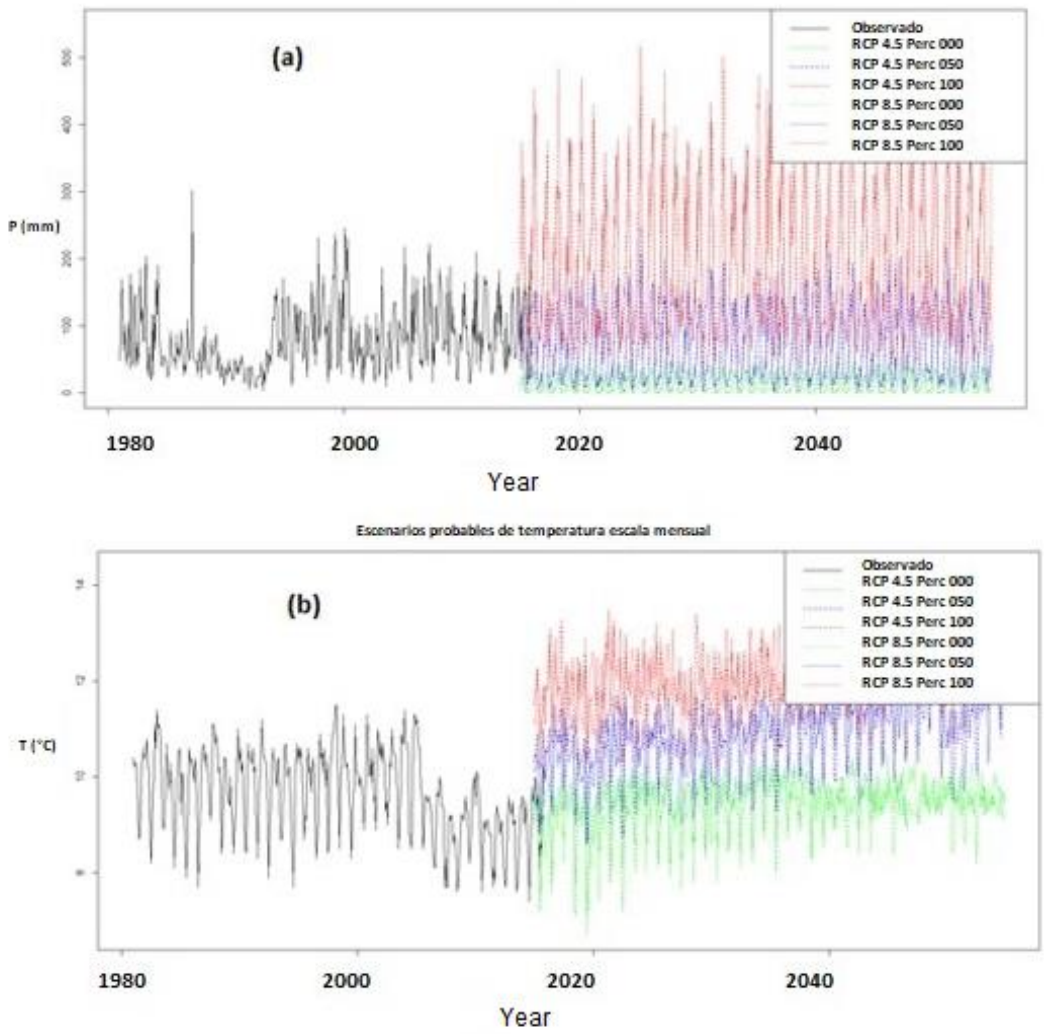
The methodology applied that gave the best result is based on a bias correction of the regional model data using the observed data as a correction reference. In this way, it is possible to have a corrected historical series to apply in the climate models. Once the analysis to be used is clear, we work with the meteorological data of the Tomebamba river basin, in order to obtain the data for hydrological and hydraulic modeling. Meteorological data of the Tomebamba river basin, in order to obtain the data for the hydrological and hydraulic modeling. In this way, the precipitation and temperature variables are obtained in the RCP 8.5 scenario, three probable models corresponding to the 0, 50 and 100 percentiles (Figure 2).

Figure 2: Historical Observed Data Vs Observed Data



For the case of precipitation, several future scenarios can be analyzed according to the percentile to be evaluated. In the 50th percentile scenarios precipitation tends to decrease, in the 100th percentiles precipitation increases (Figure 3a). In the case of temperature, all scenarios tend to increase, maintaining cold and warm periods (Figure 3b).

Figure 3: Probable rainfall and temperature scenarios



For this purpose, the HEC-HMS free license hydrological model is used to introduce the watershed with its components, including the current land uses. Once the model has been calibrated, we proceed with an event simulation, i.e., we model the most unfavorable precipitation in the simulated probable future obtained from the climate model. In order to introduce the highest precipitation event into the hydrological model, a synthetic storm is constructed using the IDF equations of the analyzed stations.

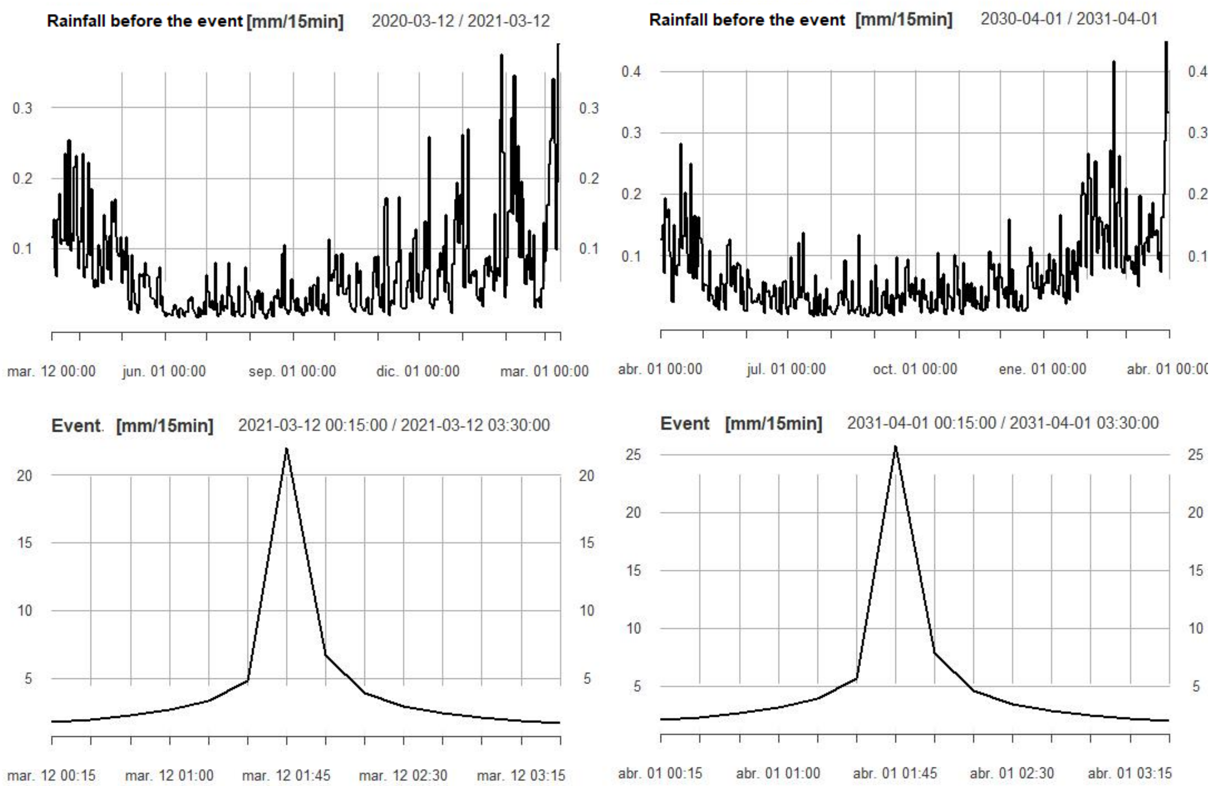
Table 2 shows the scenario and precipitation values of the storm chosen for the event that generates a flood with climatic incidence.

Table 2. Maximum daily precipitation value per meteorological station for the RCP 8.5 scenario.

Scenario and date of maximum event	Weather station P (mm)		
	M417	M0427	M429
RCP 8.5: 2031_04_01	64.24	84.30	67.56

The hydrologic model is used to model the event and its transformation to flow. It is necessary to obtain the precipitation and evapotranspiration values for each 15 minutes of the year prior to the event. Once this process is completed, the RCP 8.5 climate scenario, i.e., the unfavorable one, is modeled. In this way, the highest flood event is considered (Figure 4). The cumulative rainfall event of 84.3 mm in a 210-minute storm is observed, which generates a flood event with a simulated maximum flow of 27.5 m3/s. This is sufficient to generate a flood event with a simulated maximum flow of 27.5 m3/s. This is sufficient flow for water levels of more than 3 meters, considering the accumulated rainfall on the ground during the previous days.

Figure 4: Rainfall events.



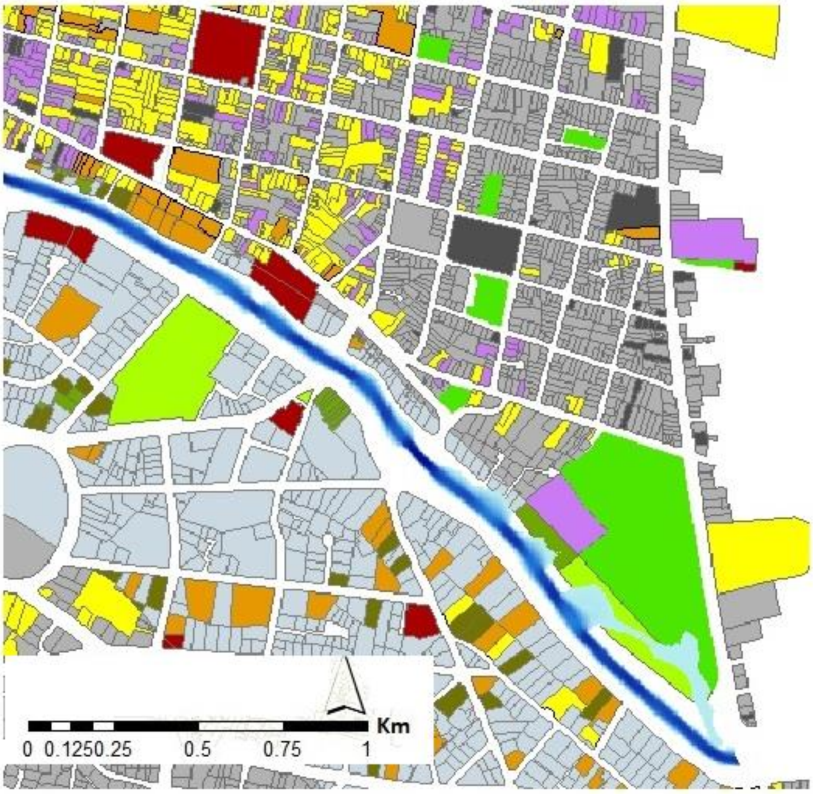
4. Results and discussion

Flow prediction and forecasting is one of the problems of greatest interest in modern hydrology (Quichimbo et al., 2013). The climatic, hydrological and hydraulic models are used to generate the areas to be flooded in the event analyzed. The data on changes in climate, precipitation and topographic surveys of the riverbed and nearby areas at risk allow refinement of the projection to establish potential flood maps.

The case of Tomebamba is an urban flood (Piperno et al., 2015), and corresponds to a global problem typical of climate change. Its persistence causes, under extreme conditions, significant impacts on biodiversity, local economies, the dynamics of urban settlements, etc.

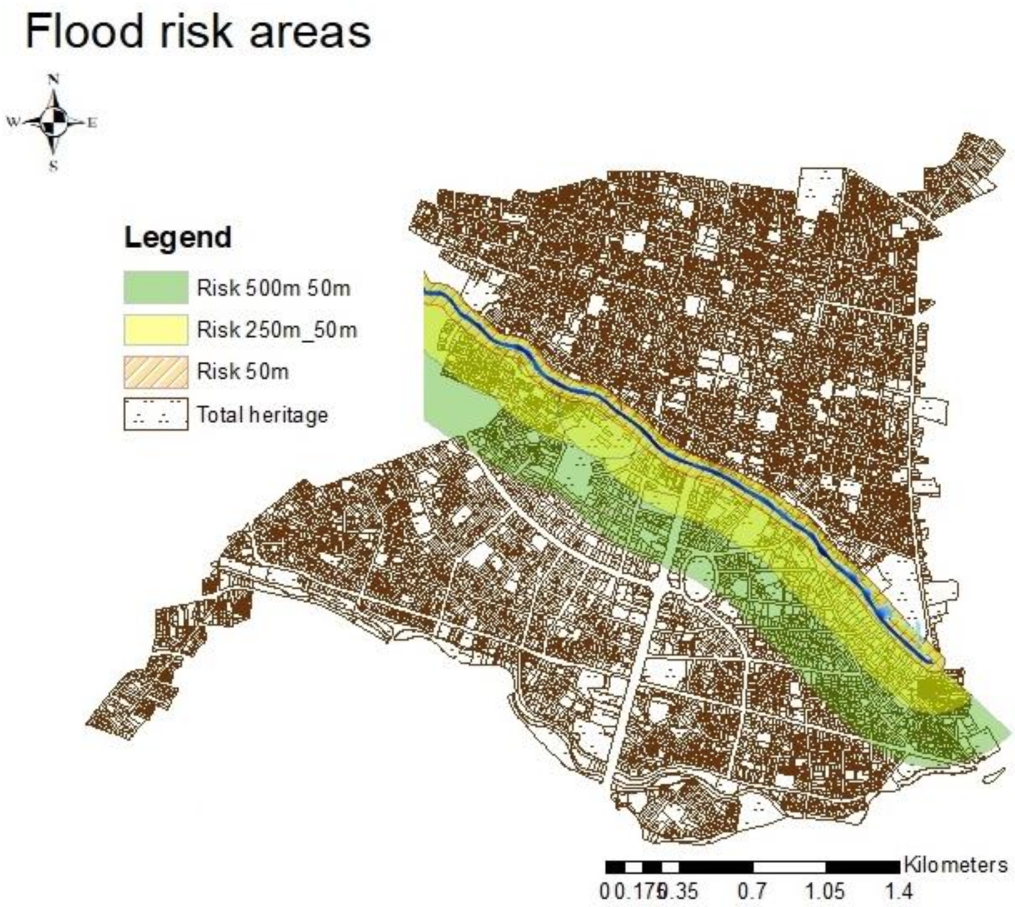
In particular, and in direct relation to the 84.3 mm event during a 210 minute (3.5 hours) rainfall, there would be an effect of at least 1%, that is, 180 assets of the 14,880 recorded. According to the hydraulic model, the greatest impact was observed in the lower zone of the Pumapungo Archaeological Complex (Figure 5).

Figure 5. Approach to flood zones


0 0.1250.25 0.5 0.75 1
Km

Under a broader and more precise perspective, three risk levels (50, 250 and 500m) are established according to the influence that flooding can have, and according to the condition of the river's cross profile. In the latter case, the right bank (south), also known as the modern city (Rey Perez, 2017) or El Ejido, is the most vulnerable to flooding because of its lower slopes. To compensate for the topography of the study area and depending on the behavior of the river, a risk level of 50m is proposed for the left (north) bank, and for the right bank the initial levels.

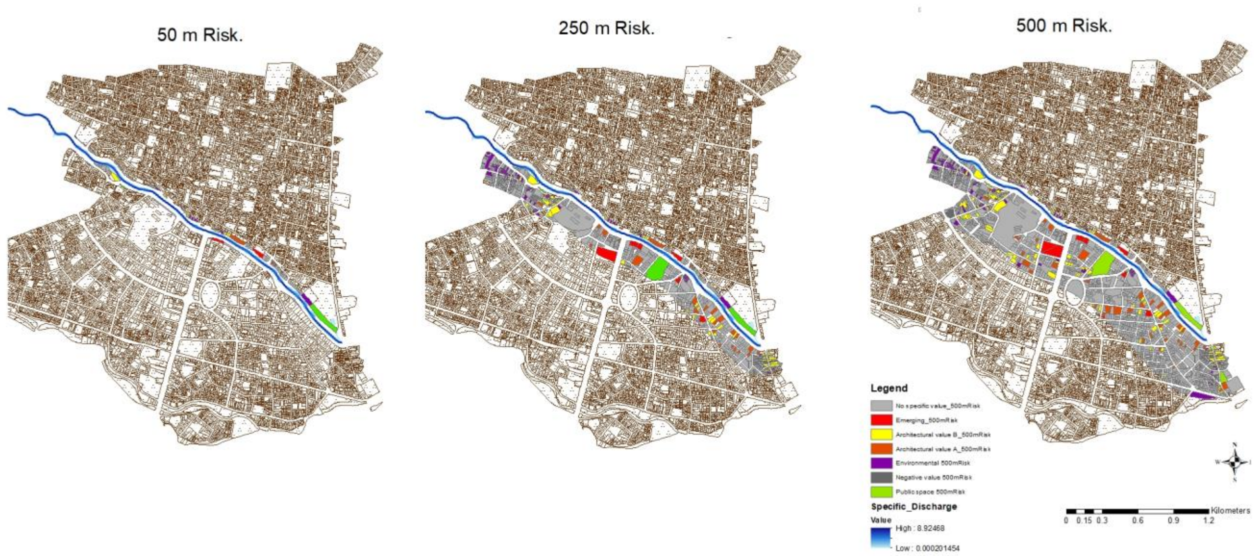
Figure 6. Flood risk areas.



On the other hand, although the direct impact of flooding on the north shore may be considered minor, the effects associated with horizontal static pressure, upward hydrostatic pressure, dynamic currents, soil compaction or fill, saturation of materials, biological or chemical contamination of materials due to the buoyancy of waste, etc., are probable (Holick & Skora, 2010) (Kelman & Spence, 2004).

In the first risk scenario (50m), 2% of the assets are affected, while in the second and third risk scenarios, 8% and 17% of the assets are affected. In the second and third scenarios, 8% and 17%, respectively and progressively, are affected. At a specific level, recurrence is determined on multiple levels, with special representation in those of environmental and architectural value.

Figure 7. Affected buildings at different risk levels.



5. Conclusions

Examining the results of the models and flood scenarios, it is impossible not to examine three situations, the first being the accumulation of affected assets, the second, the clustering of assets near the river axis, and the third, the capacity to adapt and mitigate the associated risk.

Initially, the construction of adequate theoretical models to predict future flood flows and extensions contributes to the preparation of protection measures for different return periods; however, it is clear that there is still no link between the risk and disaster reduction sectors. and disaster reduction sectors, to which predictions in isolation can contribute little.

Likewise, the capacity to adapt and mitigate the associated risk is practically nil under current conditions. In the same sense, two dilemmas of interest for future research emerge; the first, the construction of resilience in risk areas and measures for adaptation to climate change, as a technical-social-administrative problem, linking all the institutions in charge of risk management.

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