ASSESSMENT OF FLOOD HAZARD IN THE CENTRAL ANDES OF PERU: HECRAS SIMULATION CONDUCTED IN MANTARO RIVER VALLEY

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ABSTRACT

The Mantaro River valley is located between the western and eastern cordilleras of the Peruvian central Andes, and is a major agricultural region. The valley is constantly affected by floods associated with heavy precipitation, which cause extensive crop losses. The objective of this study is to assess the floodplain hazard with maximum discharges and at different return periods, using the hydraulic model HECRAS (Hydrological Engineering Center - River Analysis System). The methodology performed includes frequency analysis of discharges and the construction of a detailed digital terrain model (DTM) by stereoscopic methods. Discharge data obtained from the frequency analysis, the DTM and the river geometry based on Quickbird and GeoEye satellite imagery, were used for modeling. The results have allowed us to analyze the floodplain with return period of 1, 10, 25, 50, 100 years, with high accuracy, attributed primarily to the digital terrain model. The results provide the technical basis for an early warning system in the Mantaro Valley. Important information was provided by the valley residents about the flood zones for perform prevention and mitigation purposes.

Keywords: Flood, Hazard, remote sensing.

Introduction

Peru is frequently affected by extreme weather events such as landslides, frost, droughts and floods. Floods are events that in hours and days can generate large economic losses and many victims (Pujadas 2002). The floods in the Mantaro river valley, annually reduces the agricultural production. The valley is approximately 654 km^2, of which 45.5% is directed to permanent agriculture throughout the year and 32.3% in rain-fed crops under irrigation (Zubieta, 2010), therefore, the valley is considered the main supplier of products such as potato, corn, wheat, barley to city of Lima, the capital of Peru.

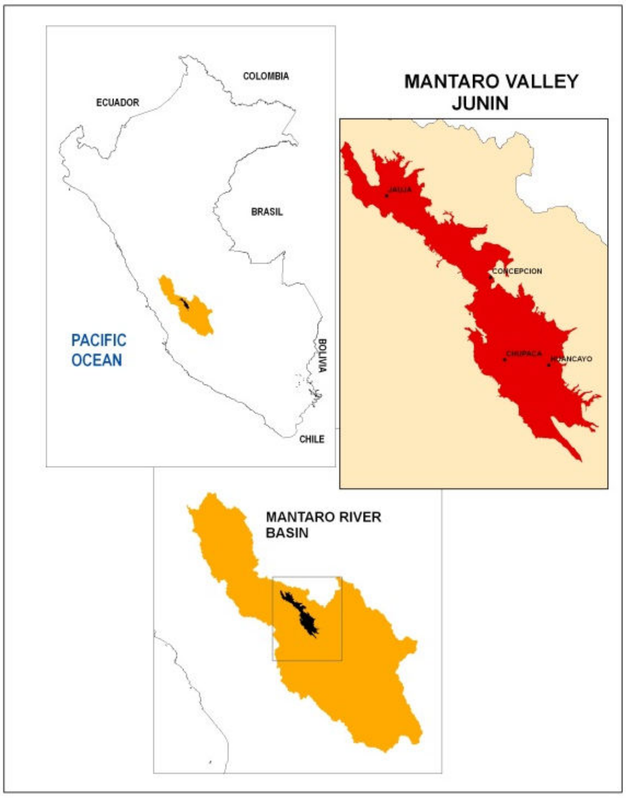
Figure 1: Crop flooding.

Figure 2: Mantaro river overflow.

The study was conducted in the Mantaro river valley, located between the western and eastern cordilleras of the Peruvian central Andes, between 3100 and 3400 masl. The valley has a total length of about 58 km, from Jauja district to Viques district, in north –south west direction.

The Mantaro River basin has abundant water resources; however, the river is polluted by mining activity, in the upper part of the basin. The Mantaro valley contains fifty-nine districts with a total population of approximately

600,000 and is characterized by permanent agricultural production. The average annual precipitation accumulated in the valley is approximately 750-800 mm (IGP 2005). The most important sources of clean water are the 3 main tributary rivers in the valley: Shullcas, Cunas and Achamayo, which provide the water that is used for human consumption and agriculture. The discharges of these tributaries contribute to the water regime of the Mantaro River. The highest recorded inflow of the Mantaro River in the valley amounts to 924 m^3/s in 1979; which caused large-scale overflows and large-scale crop flooding.



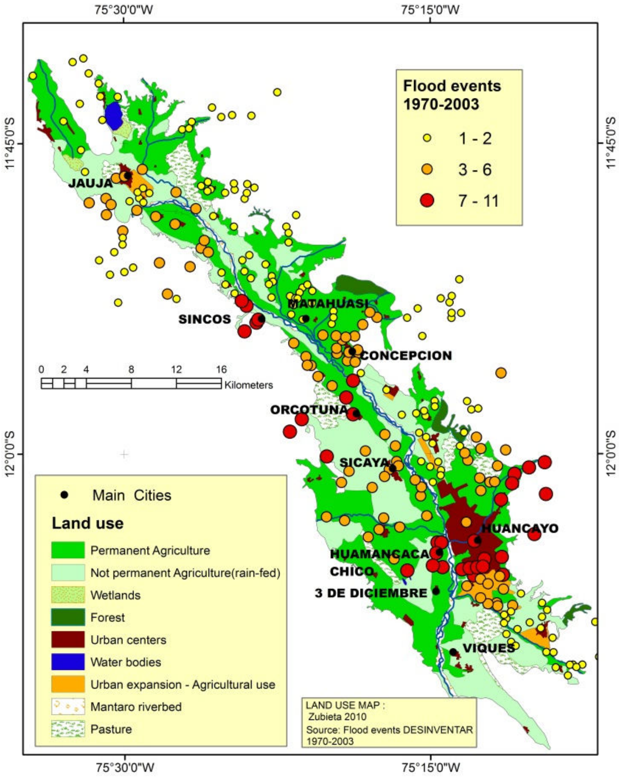


Figure 3: Location

Figure 4: Land use and flooding events

In the past 30 years, the flood occurrences have been consistent over time and spatially distributed throughout the valley, directly affecting irrigated and non-irrigated farming areas. The highest incidence in the right margin, as can be seen in the chart based on historical reports in the DESINVENTAR database (figure 4).

The extraction of natural resources (building material) from the floodplain has increased the hazard and there is a high vulnerability of crops to the flood, mainly due to weather and conditioned by:

• Lack of adequate riparian protections in many districts

• The slope is less than 5% and has facilitated the water surface expansion.

• Poor drainage due to sandy-clay texture, further lateral erosion that is moderate to high.

• A braided river system

METHODOLOGY

The study started with field survey and GPS data collection. We used the Mantaro Valley land use map developed with Landsat images 2002-2008 (Zubieta 2010) and geographic information systems.

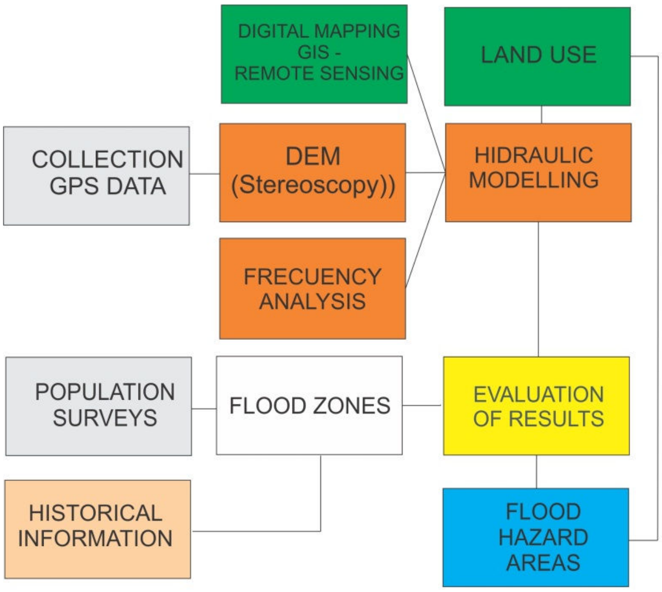


Figure 5: Methodology used in the study flooding Mantaro river valley.

Discharge data include maximum flood records from 1963-2006, which were used for frequency analysis and calculation discharges for return periods of 1, 10, 25, 50, and 100 years.

Fifty-five aerial photographs (scale 1 / 40,000), were acquired for the construction of a digital terrain model DTM for the floodplains and surrounding areas in the Mantaro river valley. A preliminary digital elevation model DEM was extracted by photogrammetric techniques in the Leyca Photogrametry Suite (ERDAS IMAGINE); which consist of applying the collinearity and parallax equations, allowing digital generation stereo pairs.

Aerial photographs were digitized at high resolution (1200 dpi) to detect minimal differential area of 0.0004ha, with a total 70 Ground Control Points (GCP), located on the aerial photos. The same GCP were used for the triangulation process. Forest cover, water bodies and urban centers, were extracted to improve the accuracy of DEM preliminary.

Floodplains and river geometry were mapped in geographic information systems, using Quickbird and GeoEye satellite imagery 2010-2011. The Mantaro River has a variable width that depends on channel geometry and the Floodplain Development. Geometric information of channel was taken in the dry season. To do this we estimate the channel form, taking depth measurements in the main channel on both riverbanks, also the heights riparian protection data (gabions, accumulated material on riverbanks) in Mantaro, Shullcas, Cunas, Achamayo, Yacuy and Chanchas rivers. The data obtained were used to improve the final accuracy DEM and obtaining a final MDT. All cross-sections required from HECRAS, were taken perpendicular to the flow direction.

With the complete digital terrain model DTM (Figure 7), the channel geometry calculations were mapped using ArcGIS and the extensions: 3d analyst and HEC-GeoRAS, which are a set of procedures, tools, and utilities for processing geospatial data in ArcGIS using a graphical user interface. Then, they were used in the HEC-RAS model; which is a computer program that simulates the hydraulic system of water through natural streams or other channels. The model calculates the water surface elevations at all locations of interest for given values. The approach considers the energy and continuity equations, including cross sections for a subcritical system. (Bedient and Huber 2002):

$$\mathbf{Z_1 + Y_1 + \alpha V_1^2/2g = Z_2 + Y_2 + \alpha V_2^2/2g + \Delta h} \quad \text{(energy equation)}$$

Z_1 Z_2 = Benchmark

Y_1 Y_2 = Water surface elevation

V_1 V_2 = Mean Velocity

α = Velocity coefficient

g = gravitational constant

Δh = energy loss among section

All data and spatial information were modeled using HECRAS. The water surface heights resulting with return periods of 1, 10, 25, 50 and 100 years, were used to generate flooding surfaces; which were superimposed on the land use map and analyzed to determine areas with high hazard of flooding.

Additionally, a survey was carried out on 52 farmers living for more than 30 years in the study area, in the towns historically most affected by floods in river floodplain, and the results were used to estimate how far the water surface extends during extreme events.

Finally, the analysis of historical sensitive areas was done by mapping the occurrence of events reported in the DESINVENTAR database, which includes mainly news reports of disasters. This allowed identifying areas affected for recurring floods in the period 1970-2003 (Figure 4).

The occurrences map and surveys were used to create a map of past floods. These scenarios were used in validation for HECRAS modeling results.

RESULTS AND DISCUSSION

Photo interpretation, satellite image interpretation and data collection in the study area improved the accuracy of the land use map, and allowed the identification of potato, corn, and lucerne crops, in the Mantaro river floodplains. The changes in land use were mainly associated with loss of crop area and urban growth on Mantaro riverbank.

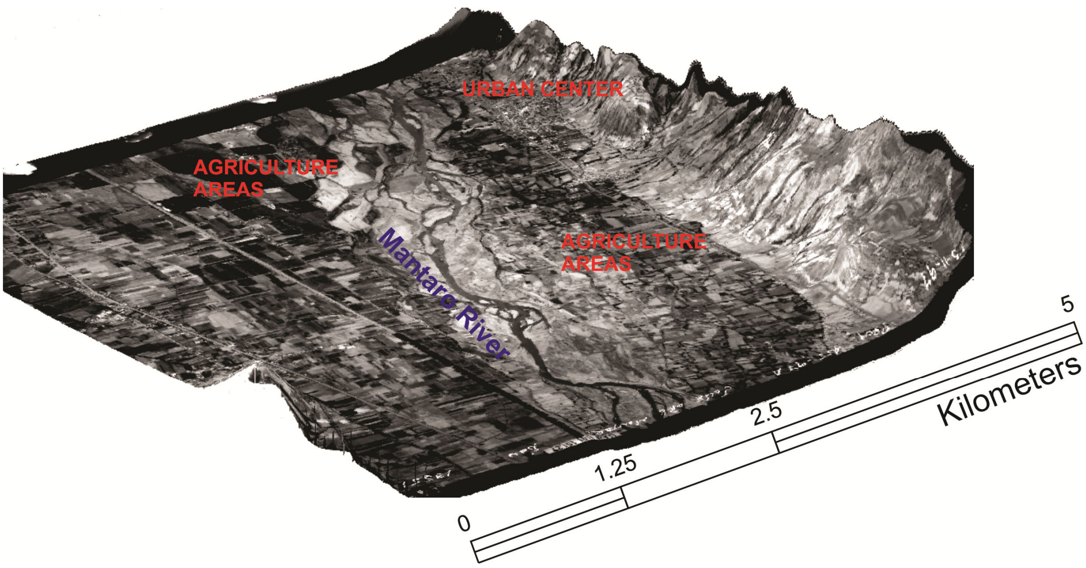


Figure 6: Aero-photo 3D Sincos - Huancaní Cities - Mantaro River Valley.

Digital Terrain Model (DTM)

The digital terrain model DTM developed by stereoscopy and field information, has high accuracy. The Root Mean Square Error (RMSE) is 1.5 meters on the terrace 1 and 2 meters on the terrace 2. However, in some areas as cities, this accuracy decreases due to the brightness, texture in the digital aerial triangulation process; that affects stereoscopic vision and therefore, the final accuracy of the DEM.

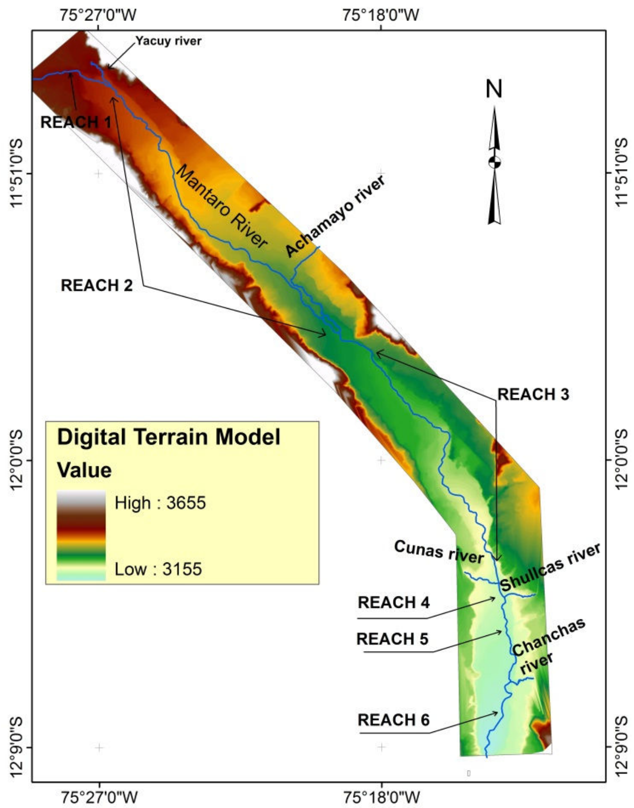


Figure 7: Digital Terrain Model of the Mantaro river valley, obtained by digital aerial triangulation techniques.

Historical events and Survey population

Major floods caused by overflowing of the Mantaro river, were registered in April 1979, March 1981, January 1991, and February 1997. Flooded homes and crops occurred in 70% of the districts, causing economic losses in agriculture (DESINVENTAR 1970-2003).

52 farmers were consulted and interviewed in the floodplain, and flooded areas in the past 30 years were mapped with GPS. According to this population survey, the main causes of losses from these events were identified as:

- Farming too close or on the floodplain.
- Only 30% of the Mantaro River course has riparian protection.
- The extraction of floodplain material (building materials) from rivers and riverbanks is not controlled.
- Mantaro Valley lacks risk management programs.

Frequency Analysis

Probability distribution analysis was performed to correlate discharges with a recurrence at different return period using discharge data ranging from 1963 to 2006 from 4 gauging stations located in the Mantaro, Shullcas, Cunas and Achamayo rivers. With the tabulated data, the hydrological design was performed, estimating discharges with return periods of 1, 10, 25, 50 and 100 years. For this, we used the frequency factor for a Lognormal distribution function of Chow et al. 1995.

RP	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6
1	195	204	213	286	298	306
10	688	713	746	939	996	1011
25	884	929	971	1213	1287	1307
50	1032	1107	1157	1435	1523	1548
100	1180	1310	1367	1681	1783	1813

Table 1: Estimated maximum discharges - Lognormal distribution. (m^3 / s)

Modelling and scenarios HECRAS

The HECRAS model was able to zone flood events with high precision, it should be noted that the accuracy is mainly attributable to the digital terrain model. The simulations were performed with discharges of Table 1.

For maximum discharges at return period RP of 1 year, the map represents, that occurred recently in February 2009, 2010 and 2011. Scenarios at RP of 10, 25, 50, and 100 are due to historical events that occurred in March 1981, February 1997 in the Sincos, Orcotuna, Matahuasi, Sicaya, Huamancaca Chico and Tres de Diciembre districts; which are located on both Mantaro riverbanks.

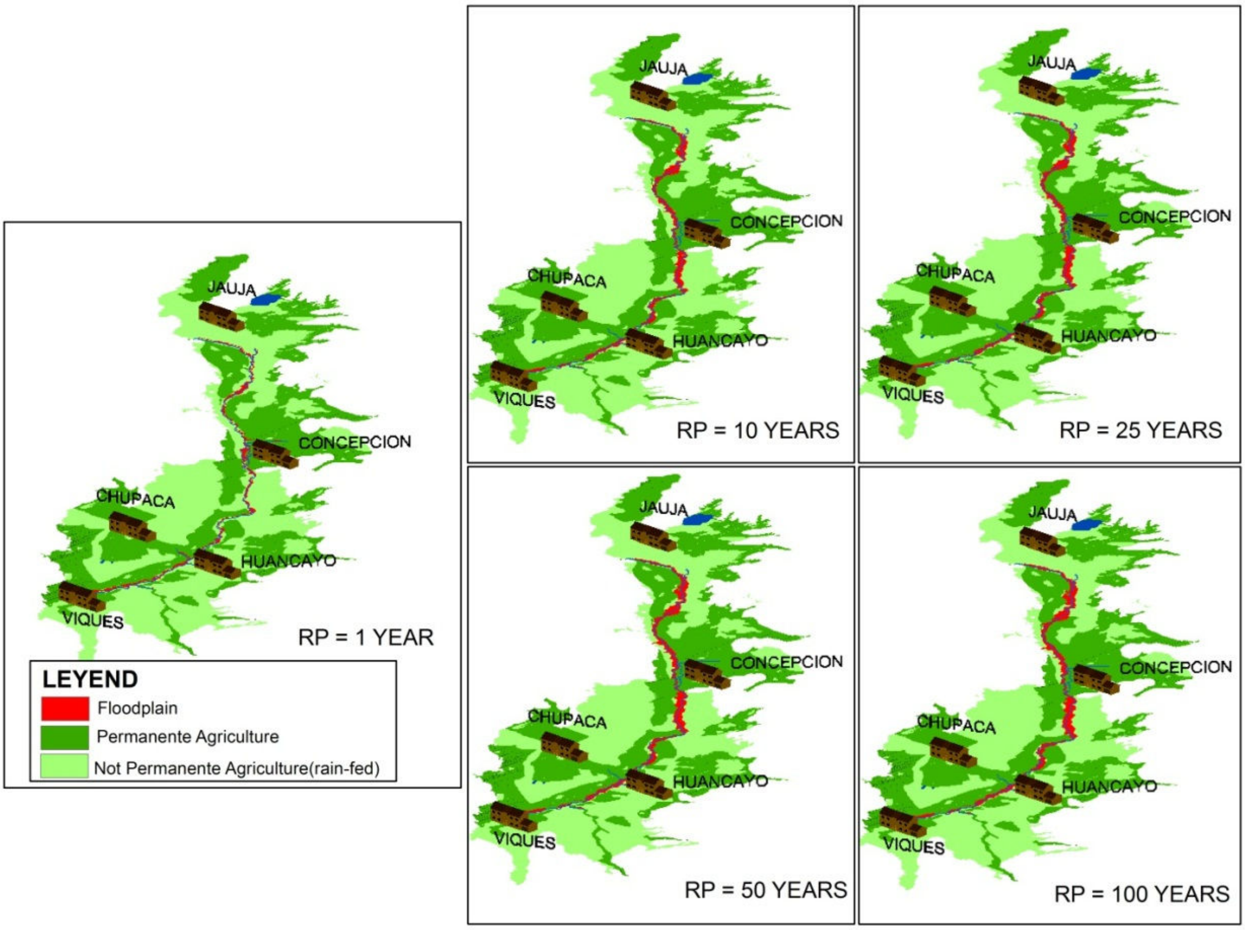


Figure 8: HECRAS Simulations - Return period of 1, 10, 25, 50 and 100 years.

CONCLUSIONS

The simulation steady flow results allowed assessing the floodplain to peak discharges in the Mantaro river valley with high accuracy, primarily attributable to the digital terrain model obtained by stereoscopy. This was verified overlaying with results obtained in the study area, based on surveys about flooded areas in past 30 years. It was also verified using historical records about flood disasters, based on news reports of DESINVENTAR. The maps show the areas that are affected historically in the districts: Sincos, Orcotuna, Matahuasi, Huamancaca Chico and Tres de Diciembre.

The Huamancaca Chico district communities are the most likely to be affected by floods and overflows due to their location a few meters to the Mantaro River (Reach 4). There have been changing agricultural land use to urban use areas from 1997 to 2009.

This article provides the technical basis for an early warning system in the Mantaro Valley. On the other hand, unsteady flow simulations could be used estimate the dynamic behavior of discharges, based on a hydrograph.

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