

UNIVERSIDAD CATÓLICA SANTO TORIBIO DE MOGROVEJO
FACULTAD DE INGENIERÍA
ESCUELA DE INGENIERÍA CIVIL AMBIENTAL



Análisis del riesgo de inundación usando información geográfica y un modelo hidráulico aplicado al río Huancabamba a su paso por el distrito de Pucará

TRABAJO DE INVESTIGACIÓN PARA OPTAR EL GRADO ACADÉMICO DE BACHILLER EN INGENIERÍA CIVIL AMBIENTAL

AUTOR

Anghela Michel Diaz Fernandez

ASESOR

Ronald Esteban Villanueva Maguiña

<https://orcid.org/0000-0002-3707-5503>

Chiclayo, 2023

TIB

INFORME DE ORIGINALIDAD

15%

INDICE DE SIMILITUD

10%

FUENTES DE INTERNET

9%

PUBLICACIONES

6%

TRABAJOS DEL
ESTUDIANTE

FUENTES PRIMARIAS

1

Willians Ribeiro Mendes, Fábio Meneghetti U. Araújo, Ritaban Dutta, Derek M. Heeren. "Fuzzy control system for variable rate irrigation using remote sensing", Expert Systems with Applications, 2019

Publicación

1%

2

repositorio.ucv.edu.pe

Fuente de Internet

1%

3

Submitted to Universidad Nacional del Centro del Peru

Trabajo del estudiante

1%

4

Roberto Moreno López, Rosa Marí Ytarte, Beatriz Estaban Ramiro. "Labour market, education and the specific youth programs: study of perception in Toledo - Spain", International Journal of Adolescence and Youth, 2019

Publicación

1%

5

hdl.handle.net

Fuente de Internet

1%

Índice

Resumen.....	4
Abstract.....	5
Introduction.....	6
Methodology	7
Studio Area	7
Geographic Information System	9
Analysis of maximum extreme flow rates	10
Hydraulic modeling	11
Flood risk analysis	11
Results	14
From the geographic information system	14
From the analysis of maximum extreme flows	14
From the hydraulic modeling	16
From the flood risk analysis	19
Discussion.....	26
Conclusions	27
References	27

Resumen

Las inundaciones son un riesgo permanente a lo largo del tiempo y es allí donde radica la necesidad de estudiarlo, sabiendo que pueden generarse a partir de variaciones climáticas y es muy notorio que influyen los eventos naturales. El objetivo es analizar el riesgo de inundación a partir de información geográfica y un modelo hidráulico aplicado en el río Huancabamba logrando tener posibles prevenciones. Se analizó un tramo de 50000 m del río Huancabamba por ser una zona con mayor probabilidad de inundación. Su metodología es aplicativa y descriptiva, con un análisis de los máximos caudales extremos y un modelo hidráulico con distintos periodos de retorno de 10, 20, 30, 50 y 100 años. Se concluye que la zona estudiada tiene un riesgo de inundación alto con la velocidad máxima de 6.87 m/s, caudal máximo de 1860.20 m³/s y con tirante máximo de 12.56 m, sugiriendo plantear obras de defensas ribereñas tanto en la zona Urbana y Agrícola.

Palabras clave: Riesgo de inundación, cuenca, modelo hidráulico, caudales máximos, información geográfica, prevención.

Abstract

Floods are a permanent risk over time, and this is where the need to study it lies, knowing that they can be generated from climatic variations, and it is very clear that natural events influence. The objective is to analyze the risk of flooding based on geographic information and a hydraulic model applied in the Huancabamba river to have possible prevention. A 50000 m section of the Huancabamba river was analyzed because it is an area with a higher probability of flooding. Its methodology is applicable and descriptive, with an analysis of the maximum extreme flows and a hydraulic model with different return periods of 10, 20, 30, 50 and 100 yr. It is concluded that the studied area has a high risk of flooding with the maximum speed of 6.87 m/s, maximum flow of 1860.20 m³/s and maximum depth of 12.56 m, suggesting the construction of riverine defenses in both urban and agricultural areas.

Keywords: Flood risk, basin, hydraulic model, maximum flows, geographic information, prevention.

Introduction

It is known that floods are a problem that occurs all over the world, it has been studied in the different areas in which it impacts, with the aim of finding solutions that allow a sustainable development of cities both in the field of infrastructure and in the social [1]. It is known that heavy rains have always been considered very destructive and risky for the integrity of a population, since they can cause flooding in the place where they are generated.

It should be noted that the flooding of a river is a natural phenomenon, as long as it is a normal flood that contributes to the fertility of the soil and the transport of water. But when floods are large-scale and more frequent, they can damage the lives of living things, crops and people's habitats.

During the last 60 years it has been possible to catalog a series of multitudes of floods in different parts of the world, this has led scientists to think that these types of phenomena will increase at high speed and that this is not only due to the colonization of flood zones, but to an interannual variability or an immediate climate change in great magnitude that influence the change of rainfall generating In this way disasters of greater magnitude with the passing of the years.

The Ministry of the Environment [2] indicates that in Peru the El Niño phenomenon has been shown in 120 episodes, of which 7 have been shown significantly, and according to SENAMHI the most significant events of El Niño are from the years 1982/1983 and 1997/1998, since large economic losses of US\$ were evidenced. 3283 million and US\$ 3500 million equivalent to 11.6% and 6.2% of annual GDP in 1983 and 1998, respectively.

Given the problem, the objective is to analyze the risk of flooding based on geographic information and a hydraulic model applied to the Huancabamba River as it passes through the district of Pucara. In this way, an adequate flood management would be developed, as well as identifying the areas with the highest risk of flooding in the area under study and obtaining some preventive management strategy [3].

López Rodríguez [4], tells us how dangerous the intense rains are for the populations and their economies, because they can generate human and infrastructure losses. It mentions that the objective of the National Institute of Hydraulic Resources (INRH) is to determine reliably and efficiently the predictions of floods of great intensity and the impacts of floods, this from the use of ArcGIS and HEC-RAS software which perform a hydraulic simulation of the case under study the basin of the Sagua la Chica River, obtaining as a result the graph of the flood zones for a certain flow considered.

There is a history of projects where they make use of ArcGIS and HEC-RAS software, since these facilitate a better integration between both, above all they provide a better hydraulic analysis and because their access is free anyone can use them for the risk analysis of a given area.

Olivares Castillo [5], tells us that through hydraulic simulation with the HEC-RAS application model, the hydraulic behavior of a section under study can be evaluated and analyzed, while allowing to identify vulnerable points when overflow scenarios with different return periods occur. It also mentions that flows, flow hydrographs, velocities, cross sections in flood zones and longitudinal profiles can be established before and after a simulation.

Comparisons of hydraulic behavior can also be conducted between two hydraulic simulation software's such as IBER and HEC-RAS.

According to Belizario Quispe, Pancca Cruz [6], tells us that using rainfall and hydrometric data, Statistical Analysis was conducted for different return periods, as well as the behavior of the riverbed and the calculation of maximum flows. It is concluded that for rivers with a simple geometry it is a better alternative to use the one-dimensional HEC-RAS software, since the introduction of the data is much easier and the results are obtained in less time, and for rivers with greater irregular geometry it is advisable to use the two-dimensional IBER software.

After the search for information, it was observed that in Peru there are very few projects that use software to predict floods, which is why this research will give us a scientific contribution in the analysis and evaluation of risks caused by floods.

Methodology

Studio Area

The project to be carried out is located in the district of Pucara southwest of the province of Jaen at km 117 of the Fernando Belaunde Terry Road.

The Huancabamba River basin hydrographically is part of the Amazon Hydrographic Region, they are part of the Atlantic Slope and flow into the Alto Marañon Interbasin, it should be noted that hydrographically, it belongs to the Chamaya basin. The sample under study is a stretch of 5000 linear meters of the Huancabamba River (figure 1), since this is the area with the most flooding.

For the study of the flows, the historical rainfall records offered by SENAHMI [7] were used, which are the data of the Use of the PISCO Grilled Product (Peruvian Interpolated data of the SENAMHI's Climatological and hydrological Observations), these data cover from 1981 to 2016, that is to say that there are records of 36 years and for a hydrological analysis at least the record of 25 years is needed according to the Ministry of Transport and Communications (MTC) [8], with this the probabilistic analysis of rainfall and the estimation of the maximum flows for the different return periods were carried out.

Subsequently, the investigation was carried out as shown in figure 2, this sequence begins with the investigation of the geographic information of the terrain, then the analysis of the maximum extreme flows is carried out and ends with the hydraulic modeling with which the maps of the most flooded areas will be generated, which is suggested in the investigations according to Meng [9].

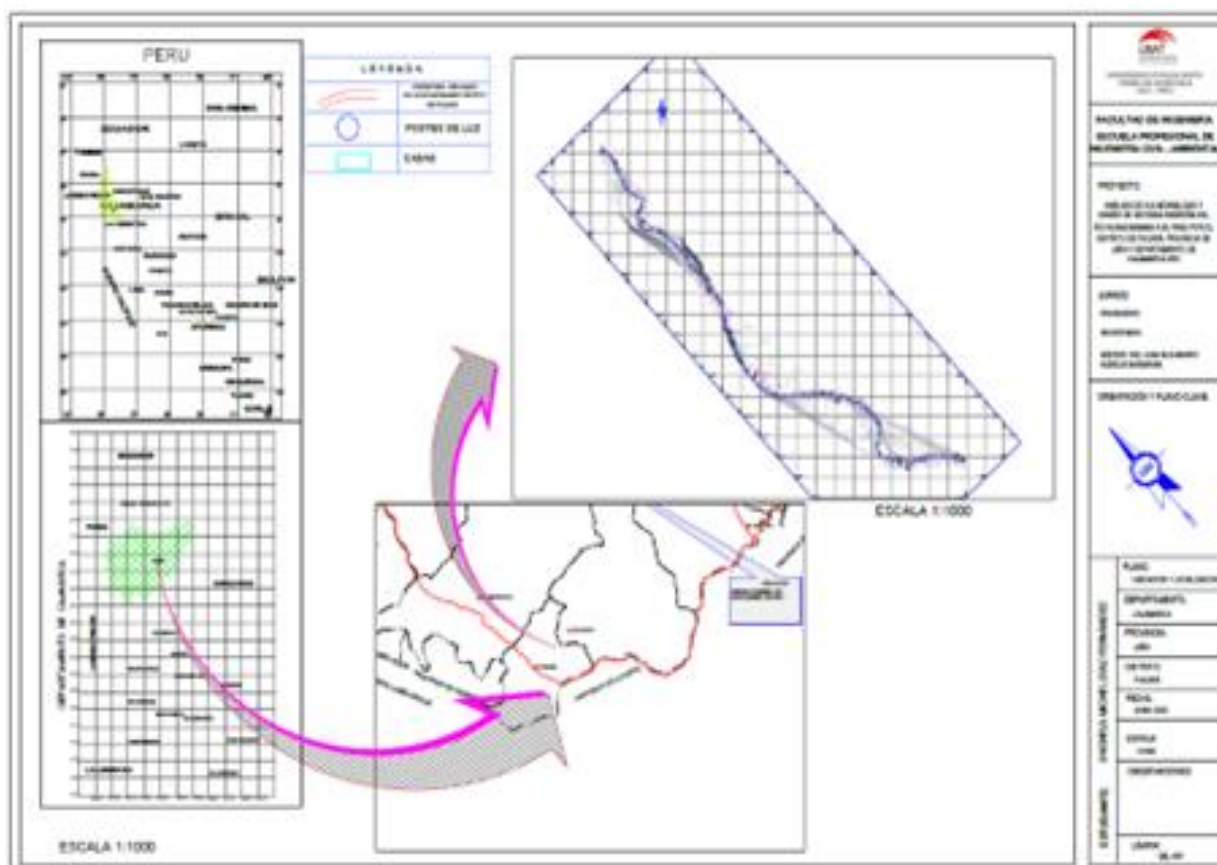


Figure 1: Location of the section under study on the Huancabamba Cueva Chamaya River.

Source: Author's elaboration.

Geographic Information System

To obtain the geographic information of the area under study, georeferential was obtained through the use of Digital Elevation Modeling better known as DEM's, which were obtained from the LAND VIEWER satellite granted by NASA through its website. The DEM's that were used are 5 x5 m, and it was processed in the ArcMap software, these satellite images are downloaded in raster format and in the software, they are passed to the shapefile type in order to export it in dwg format and in this way to be able to align and make the stroke (Figure 3).

It is also worth mentioning that according to [10], he mentions that with the geographic information system you can make predictions of flood patterns and flood risk areas.

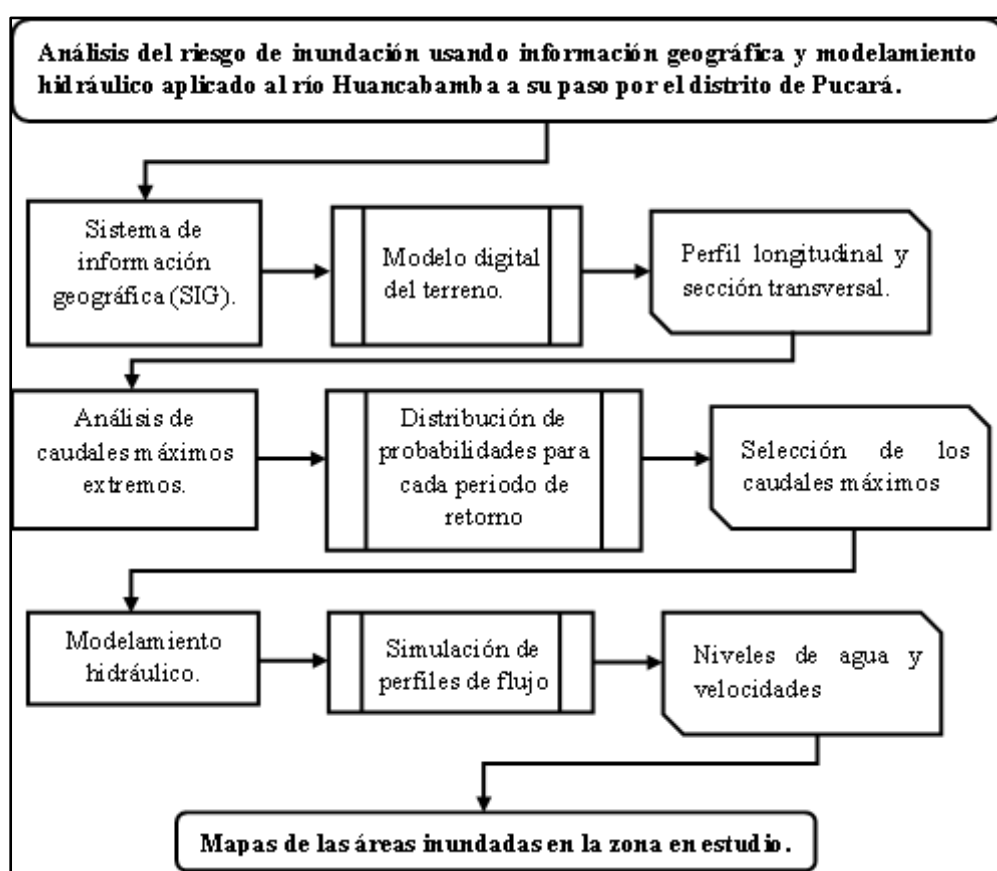


Figure 2: Research flowchart.

Source: Author's elaboration.

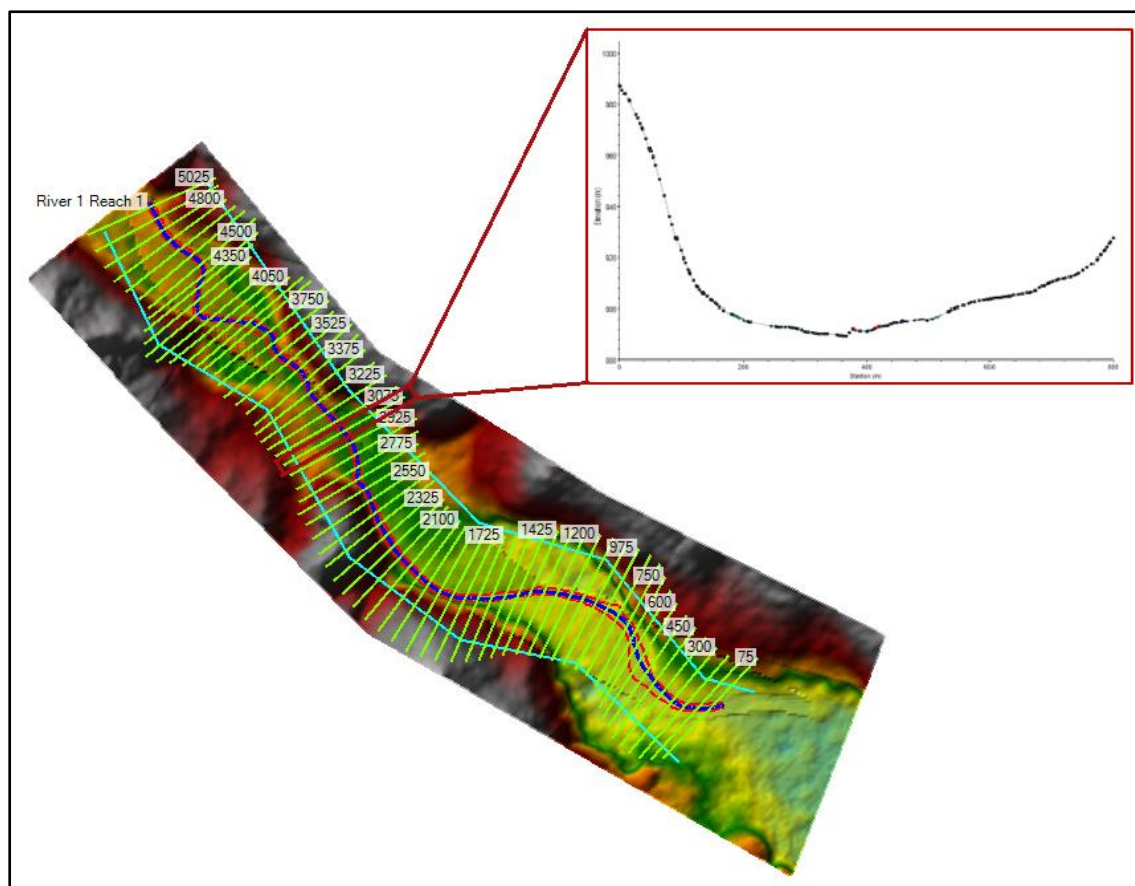


Figure 3: Cross sections and plan alignment of the section under study.

Source: Author's elaboration.

Analysis of maximum extreme flow rates

The analysis of maximum extreme flows is carried out from the data of the historical records of precipitation, in this case the data offered by PISCO, the magnitude of extreme events and the frequency in which they occur are related, making use of probability distributions. The 10 stations with which they worked were determined, and the information was processed with the RStudio software, then the information was exported to Excel and a dynamic table was worked with the maximum rainfall in 24 hours for each year and for each season.

Then the probabilistic analysis of the precipitation data was performed according to the recommendations of the MTC using the following distributions: Normal, Log – Normal, Gumbel I, Pearson III and Long – Pearson III.

The methods mentioned above evaluate whether a range of data fits a distribution for a significance level of 5% or a probability of 95% for either linear or ordinary momentum, which is why using the Kolmogorov-Smirnov method the Goodness of Fit Test is performed for the

11 established stations. It is worth mentioning that according to Guillen Oviedo the criterion for choosing the appropriate distribution will depend on whether the probability distribution queues are associated with the historical rainfall record and, above all, that their trend is constant.

The calculation of the flows in the different return periods was used the HEC – HMS software, for this Juan M. Stella tells us [11], that the calculation of the Curve Number (CN) and the concentration time of each sub-basin must be made, in this case for the Upper, Medium and Low sub-basin. The SCS (Soil conservation Service) method was used, since it is the one that best relates to this project, this method is made from the characteristic curve number, which is calculated by the type of soil presented by the terrain of the area under study and the vegetation cover of the basin studied. To obtain values of the Curve Number were calculated taking into account the guide "Generation of the Thematic Map Curve Number" provided by the National Water Authority.

The ANA provides us with raster maps of Number of Curves for three types of conditions: Normal conditions, Dry conditions and Wet conditions. With the help of ArcGIS, data needed from the Huancabamba River basin were extracted, mentioning that we worked with the Curve Number map under normal conditions.

Hydraulic modeling

Here the simulation of a one-dimensional hydraulic model of the area under study of the Huancabamba river basin is carried out using the HEC-RAS v.6.1 software, in order to have the sections, simulate the flow profiles, know the water level throughout the section and the speeds. In the hydraulic model, the delimitation of the axis and the margins of the river and the maximum flows for the different return periods that are being analyzed were considered.

Flood risk analysis

To carry out the flood risk analysis based on the hydraulic model carried out, the tables provided by INDECI were used [12], here they teach you what steps you must follow to achieve the elaboration of hazard, vulnerability and risk maps produced by a flood.

According to INDECI it indicates that the danger can be determined from the intensity (depth and speed of the water) and the probability of occurrence, in Table 1 you can see how the intensity is calculated, in Table 2 the flood intensity ranges are observed, in Table 3 you will

see the probability that exists for a flood to be generated and Table 4 shows the probability ranges.

Intensity levels	Depth of flow (H) (m) (static flooding)	Depth x flow velocity (m ² /s) (Dynamic flooding)
Very high	H > 1.50 m	H*V > 1.50 m
Alta	0.50 m < H < 1.50 m	0.50 m < H*V < 1.50 m
Media	0.25 m < H < 0.50 m	0.25 m < H*V < 0.50 m
Baja	< 0.25 m	H*V < 0.25 m

Table 1: Table for the calculation of intensity product of a flood.

Source: River flood risk estimation manual.

Intensity Level	Ranges
Very high	0.75 < NI ≤ 1
High	0.50 < NI ≤ 0.75
Half	0.25 < NI ≤ 0.50
Low	0 < NI ≤ 0.25

Table 2: Table for flood intensity ranges.

Source: Manual for River Flood Risk Estimation.

Intensity levels	Return period in years (Tr)
Very high	1 < T < 5 years
High	5 < T < 15 years
Half	15 < T < 50 years
Low	50 < T < 200 years or more

Table 3: Table for calculating the probability of a flood.

Source: Manual for River Flood Risk Estimation.

Frecuencia	Ranges
Very high	0.75 < F ≤ 1
High	0.50 < F ≤ 0.75
Half	0.25 < F ≤ 0.50
Low	0 < F ≤ 0.25

Table 4: Table for flood probability ranges.

Source: Manual for River Flood Risk Estimation.

With regard to the flood vulnerability analysis, the different vulnerabilities presented by INDECI used [12] were taken into account, which are: physical, environmental and ecological, economic, social, educational, cultural and ideological, political and institutional and scientific and technological vulnerability. For each of these INDECI it offers us a series of tables to determine them. Once the ranges of each of the vulnerability types are established, INDECI tells us that the total vulnerability is the average of the vulnerabilities analyzed.

Already with that value of the total vulnerability we will look in table 5 in which values is the vulnerability that was calculated, and in this way, we will determine the degree of the vulnerability.

TOTAL VULNERABILITY			DEGREE
0.75	$< V \leq$	1	Very high
0.50	$< V \leq$	0.75	High
0.25	$< V \leq$	0.50	Half
0	$< V \leq$	0.25	Low

Table 5: Total vulnerability table.

Source: Manual for River Flood Risk Estimation.

With regard to flood risk, INDECI offers us a probabilistic equation, where it tells us that risk equals danger due to vulnerability. But to calculate the level of risk, the double-entry matrix (Table 6) was used, where it relates the level of danger and vulnerability, to finally determine with that value in what range the level of danger generated by the flooding of the Huancabamba River is (Table 7).

Very High Danger 1	Medium Risk 0.25	High Risk 0.5	Very High Risk 0.75	Very High Risk 1
High Danger 0.75	Low Risk 0.19	Medium Risk 0.38	High Risk 0.56	Very High Risk 0.75
Medium Danger 0.5	Low Risk 0.13	Medium Risk 0.25	Medium Risk 0.38	High Risk 0.5
Low Danger 0.25	Low Risk 0.06	Low Risk 0.13	Low Risk 0.19	Medium Risk 0.25
	Low Vulnerability 0.25	Medium Vulnerability 0.5	High Vulnerability 0.75	Very High Vulnerability 1

Table 6: Double-entry matrix to determine the level of risk.

Source: Manual for River Flood Risk Estimation.

Risk Level		Ranges		
Very High Risk		0.75	$< NI \leq$	1
High Risk		0.50	$< NI \leq$	0.75
Medium Risk		0.25	$< NI \leq$	0.50
Low Risk		0	$< NI \leq$	0.25

Table 7: Risk level ranges.

Source: Manual for River Flood Risk Estimation.

Results

From the geographic information system

The entire alignment of the section under study was carried out, thus placing the main axis of the river and its margins (left and right), its elevations of the land and the cross sections of the entire section (Figure 4). With all this, the longitudinal profile of the terrain of 5,000 meters and the cross sections that were generated at 75 meters were established and determined, with a strip width of 800 meters at all points.

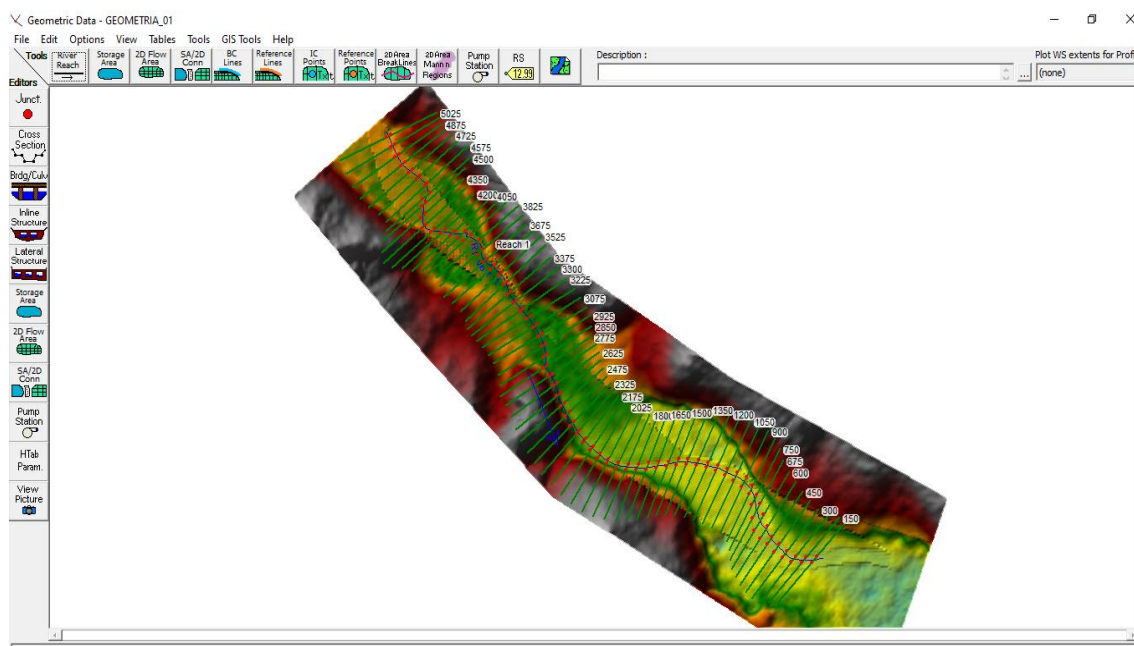


Figure 4: Generation of the archive of the land under study of the Huancabamba River.

Source: Author's elaboration.

From the analysis of maximum extreme flows

In order to establish the maximum extreme flows, a probabilistic analysis had to be carried out at each of the stations, the goodness of fit test - probability distribution graph (Figure 5) was carried out and with the Kolmogórov-Smirnov method the Goodness of Fit Test was carried out, which was applied for each of the established return periods, thus obtaining the maximum rainfall for the 11 stations analyzed (Table 8).

With the precipitation data, the calculation of the flows is carried out with the HEC-HMS software, obtaining the maximum extreme flows for each of the return periods (Table 9).

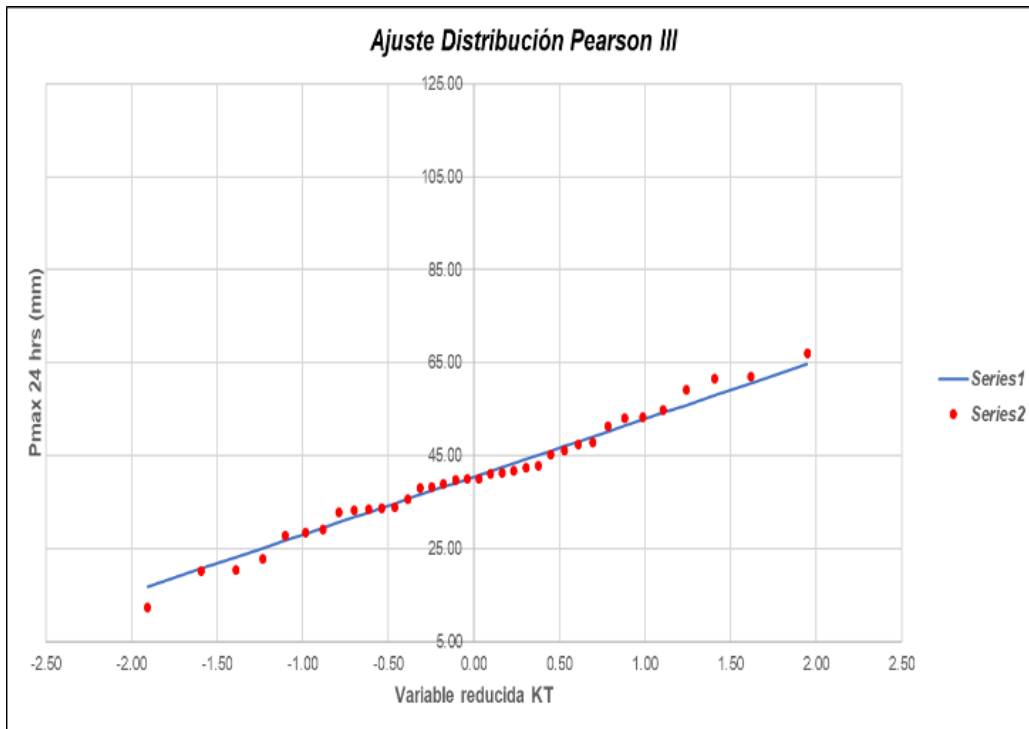


Figure 5: Goodness of fit test - graph of probability distribution of station one.

Source: Author's elaboration.

MAXIMUM ANNUAL RAINFALL IN 24 HOURS						Type of distribution
Tr	10	20	30	50	100	
E1	56.50	61.10	63.51	66.32	69.81	PEARSON III
E2	53.49	61.53	66.37	72.68	81.67	LOG-PEARSON III
E3	47.70	51.46	53.41	55.69	58.51	NORMAL
E4	65.98	76.01	81.82	89.13	99.11	LOGNORMAL
E5	62.51	70.46	74.99	80.63	88.20	LOG-PEARSON III
E6	72.38	80.59	85.08	90.50	97.52	PEARSON III
E7	96.16	116.64	128.66	143.88	164.68	PEARSON III
E8	42.61	48.34	51.62	55.71	61.24	LOGNORMAL
E9	43.82	50.13	53.76	58.30	64.43	EV1-GUMBEL
E10	74.62	87.56	95.24	105.07	118.81	LOG-PEARSON III

Table 8: Maximum rainfall for 24 hours.

Source: Author's elaboration.

Hydrological Element	Drainage area (Km ²)	Maximum Flow (m ³ /s)				
		TR-10	TR-20	TR-30	TR-50	TR-100
Basin (Sink-1)	3605.26	780.50	1034.10	1208.60	1459.20	1860.20

Table 9: Maximum flow rates obtained from the HEC-HMS software.

Source: Author's elaboration.

From the hydraulic modeling

Here the hydraulic model was carried out taking into account the different return periods in order to know from what values a flood will occur, it was possible to know what levels the water reaches during the flood (braces) and the speeds, having a flow of 1459.20 m³ / s in a return period of 50 years (Figure 6) and 1860.20 m³ / s for the 100 years (Figure 7).

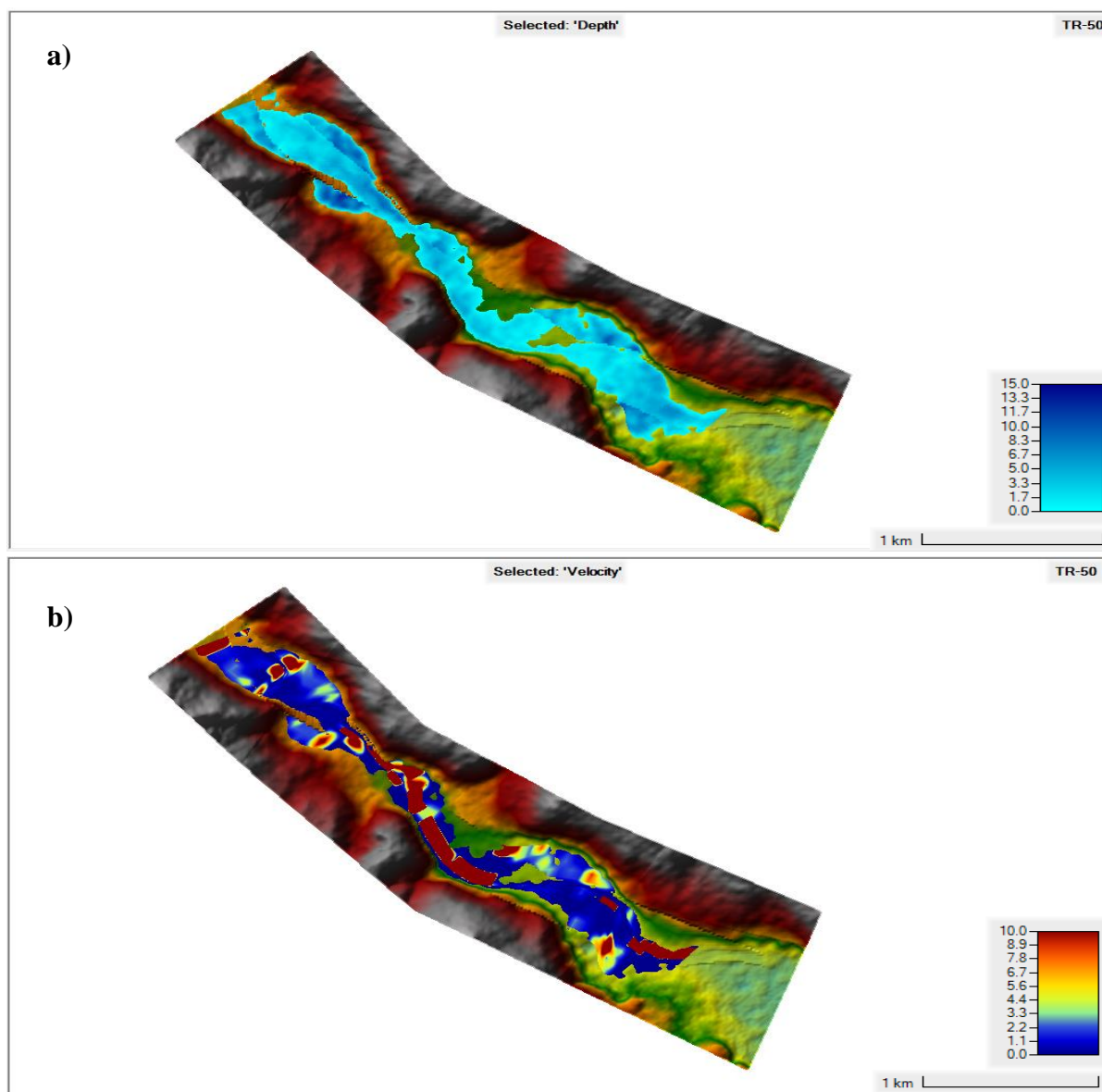


Figure 6: Hydraulic model of the braces (a) and speeds (b) of the Huancabamba River in a return period of 50 years.

Source: Author's elaboration.

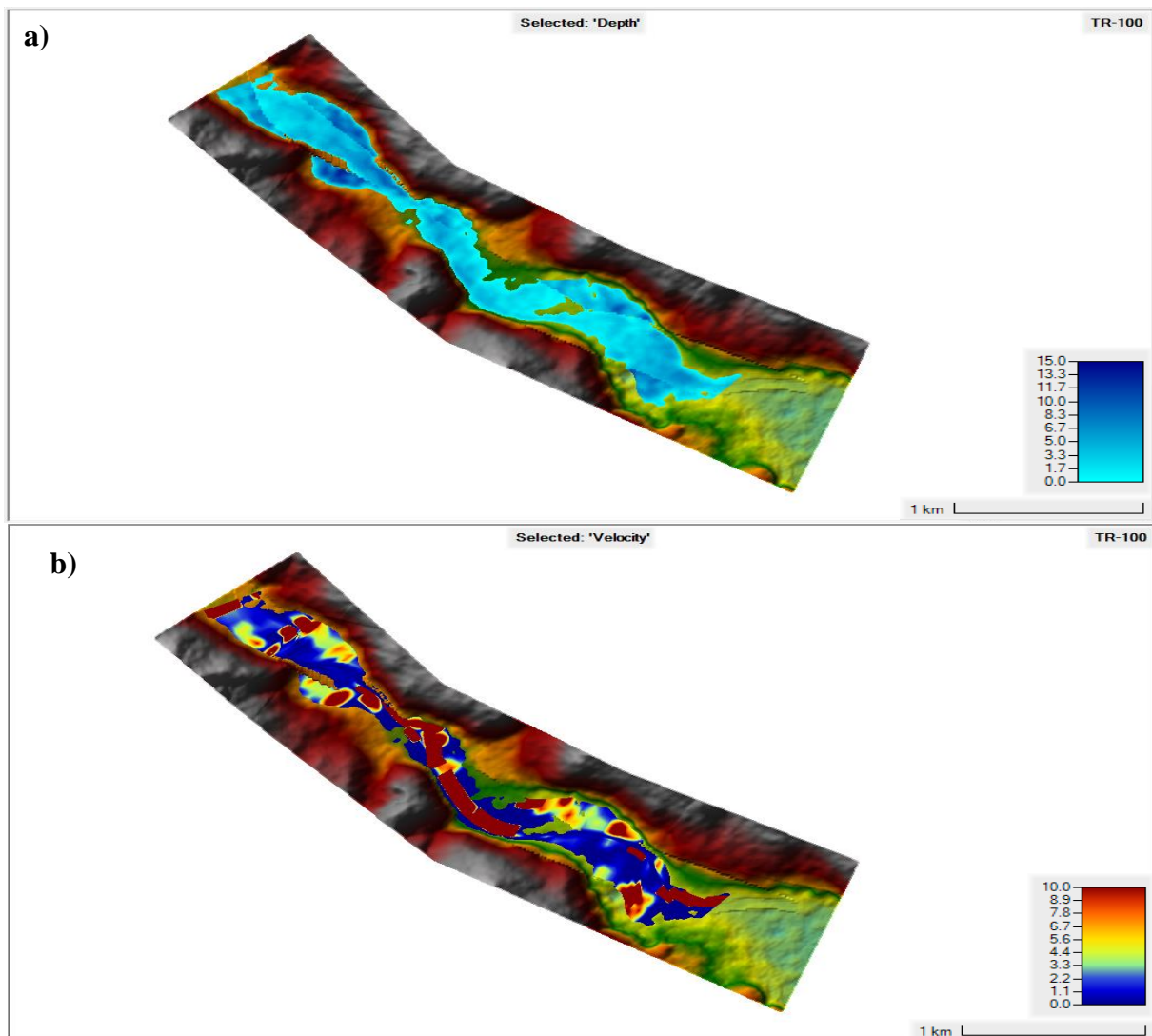


Figure 7: Hydraulic model of the braces (a) and velocities (b) of the Huancabamba River in a return period of 100 years.

Source: Author's elaboration.

As a result, it was had that in a return period of 50 years the maximum water level is 11.85 m and with a maximum speed of 6.29 m/s, in a return period of 100 years it was obtained that the maximum water level is 12.56 m and a maximum speed of 6.87 m/s. After having the maximum water level and the maximum speed for each return period, the maps of a flood were made (Figure 8 and 9).

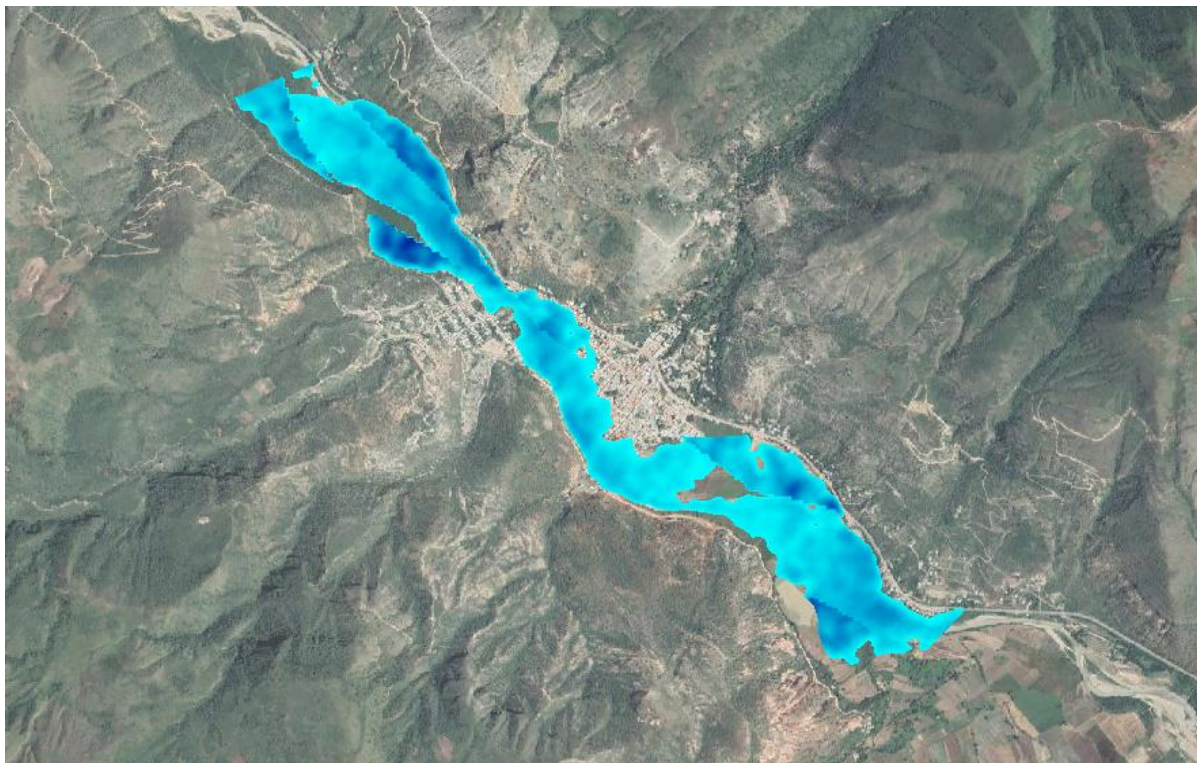


Figure 8: Map of the flooded areas of the Huancabamba River in a 50-year return period.

Source: Author's elaboration.

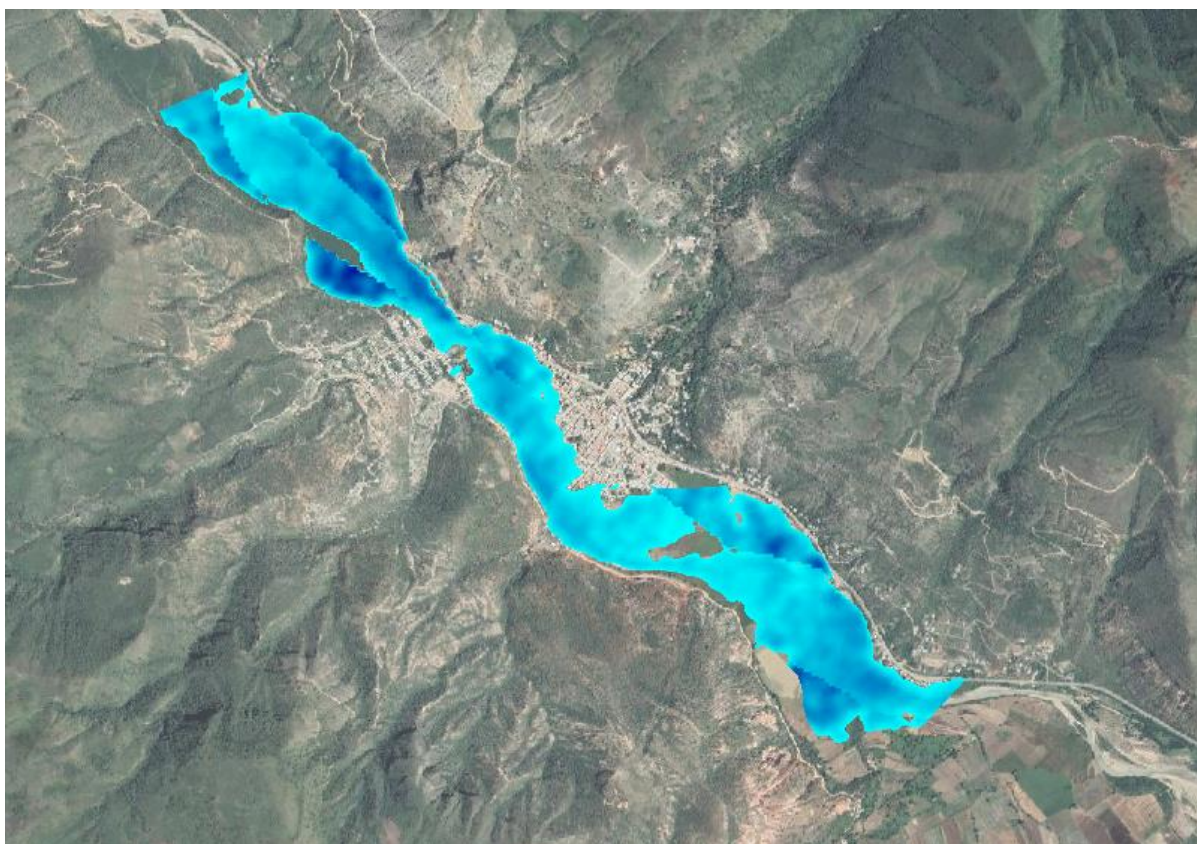


Figure 9: Map of the flooded areas of the Huancabamba River in a return period of 100 years.

Source: Author's elaboration.

From the flood risk analysis

According to the flood risk analysis from the tables offered by INDECI used [12] and the braces and speeds that were obtained with the hydraulic modeling, it was obtained as a result that the most affected areas are rice crops on both the left and right banks, but also in the urban area the houses of the lower part of the district of Pucara are affected. Because these are located less than 1 km away.

The level of danger, vulnerability and risk was quantified, indicating that after making the calculations it was obtained that the area under study will be subject to high degree hazards, a high level of vulnerability and a high-risk level.

Hazard Level

To determine this, the intensity level (Table 10) and the probability level (Table 11) were first calculated. After that, the intensity and probability are related (Table 12), obtaining the level of danger (Table 13).

FLOOD INTENSITY			
Description of the study area	Range	Estimated range	Level
Water level depth	H > 1.5	5.37	Very high
Intensity level		5.37 > 1.5	Very high
Intensity Level	Very high		

Table 10: Flood intensity level of the Huancabamba River.

Source: Author's elaboration.

PROBABILITY OF FLOODING			
Description of the study area	Range	Estimated range	Level
Return period (TR)	15 < T < 50 años	20.50	Half
Frequency of occurrence		21	Half
Probability level	Half		

Table 11: Level of probability of flooding of the Huancabamba River.

Source: Author's elaboration.

Intensity	Very high	Medium danger 0.25	High Danger 0.5	Very High Danger 0.75	Very High Danger 1
	High	Low Danger 0.19	Medium danger 0.38	High Danger 0.56	Very High Danger 0.75
	Half	Low Danger 0.13	Medium danger 0.25	Medium danger 0.38	High Danger 0.5
	Low	Low Danger 0.06	Low Danger 0.13	Low Danger 0.19	Medium danger 0.25
		Low	Half	High	Very high
Frequency (years)					

Table 12: Relationship of intensity and probability.

Source: Author's elaboration.

Flood Danger Level			
Description of the study area	Range	Estimated range	Level
Intensity level (NI)	$H > 1.5$	20.50	Very high
Frequency of occurrence (F)	$0.25 < F \leq 0.5$	0.50	Half
Danger level	0.50		
	High Danger		

Table 13: Flood hazard level of the area under study.

Source: Author's elaboration.

Level of Vulnerability

Physical vulnerability (Table 14), environmental and ecological (Table 15), economic (Table 16), social (Table 17), educational (Table 18), political and institutional (Table 19), cultural and ideological (Table 20) and scientific and technological (Table 21) vulnerability is calculated, these mentioned probabilities are calculated with the average of the aspects considered in each of them and to obtain the total vulnerability (Table 22) the average of all the calculated vulnerabilities is calculated.

HOUSING LOCATION		
<i>Housing Location</i>	<i>Range</i>	<i>Degree</i>
Very close 0.20 - 0 km	1	Very high
CONSTRUCTION MATERIAL IN HOUSING		
<i>Material</i>	<i>Range</i>	<i>Degree</i>
Adobe, stone or wood structures, without structural reinforcements.	0.75	High
GEOLOGICAL CHARACTERISTICS, QUALITY AND SOIL TYPE		
<i>Characteristics</i>	<i>Range</i>	<i>Degree</i>
Areas without faults or fractures, soils with good geotechnical characteristics.	0.25	Low
COMPLIANCE WITH TECHNICAL REGULATIONS		
<i>Indicator</i>	<i>Range</i>	<i>Degree</i>
Con normativa vigente sin cumplimiento.	0.75	High
Physical vulnerability	0.69	
	High	

Table 14: Calculation of physical vulnerability of the area under study.

Source: Author's elaboration.

EXPLOITATION OF NATURAL RESOURCES		
<i>Indicator</i>	<i>Range</i>	<i>Degree</i>
Practices of degradation of the riverbed and banks of the river or other water continent (deterioration in the consumption / indiscriminate use of soils and forest resources) without trained technical advice. But the activities are of low intensity.	0.50	Half
FUENTES EMISORAS DE SUSTANCIAS O MATERIALES PELIGROSOS		
<i>Indicator</i>	<i>Range</i>	<i>Degree</i>
The study area does not have equipment or establishments that emit polluting and/or toxic substances or materials, so the population is not affected.	0.25	Low
Environmental and ecological vulnerability	0.38	
	Half	

Table 15: Calculation of environmental-ecological vulnerability of the area under study.

Source: Author's elaboration.

ECONOMIC ACTIVITY		
Indicator	Range	Degree
The production system has some points that present competitiveness. Some economic activities carried out by the population show a certain level of profitability. There are some investments that begin to energize the area under study. There is a significant level of informality in economic activities. The area under study is located at a distance that provides a certain fluidity (daily) in the areas of production and the markets of exchange and consumption (local, national and / or international).	0.50	Half
Economic vulnerability	0.50	
	Half	

Table 16: Calculation of economic vulnerability of the area under study.

Source: Author's elaboration.

ORGANIZATIONAL LEVEL		
Indicator	Range	Degree
The political or social organization of the population is ephemeral or never works. There are internal disputes between these organizations. They present some cases of corruption in their ruling class and popular discredit. There is a low interest of the population to participate in some kind of social organization. The participation of the population, in the generation of development strategies or management of the territory, due to its level of disorganization has little force in decision-making. There are neighborhood committees of social organization (civil defense, citizen security, glass of milk, among others), but they are very deficient in their management. There are no organized guilds.	0.75	Alta
DEGREE AND TYPE OF RELATIONSHIP AND INTEGRATION BETWEEN THE INSTITUTIONS AND ORGA. LOCAL		
Indicator	Range	Degree
There is a partial relationship and integration between local institutions and organizations.	0.50	Media
Social vulnerability	0.63	
	High	

Table 17: Calculation of social vulnerability of the area under study.

Source: Author's elaboration.

EXISTENCE OF TRAINING IN SCHOOLS ON ISSUES CONCERNING CIVIL DEFENSE		
Indicator	Range	Degree
They do not have or develop any type of training program on issues concerning Civil Defense.	1.00	Very high
EXISTENCE OF TRAINING OF THE CIVILIAN POPULATION IN CIVIL DEFENCE ISSUES		
Indicator	Range	Degree
The population is poorly trained in issues concerning Civil Defense, and its dissemination and coverage is scarce.	0.75	High
DISSEMINATION CAMPAIGNS		
Indicator	Range	Degree
There is no media coverage of civil defence issues for the local population.	1.00	Very high
Educational vulnerability	0.92	Very high

Table 18: Calculation of educational vulnerability of the area under study.

Source: Author's elaboration.

POLITICAL AND LEGAL		
Indicator	Range	Degree
The legal support of the territory that helps to reduce the risks of the territory (local, regional or national) in which the area under study is located, are not enforced. There is little interest in the planned development of the territory. The disorder in the territorial configuration of the area under study occurs in almost all the territory where the area under study is located.	0.75	High
ORGANIZATION AND INSTITUTIONAL CAPACITY		
Indicator	Range	Degree
Local and regional governmental institutional organizations have little effectiveness in their management. They begin to generate discredit and popular disapproval. Government institutions at the sectoral level show some efficiency management indices, but in isolated cases, there is some intersectoral coordination. There is no political maturity. Private institutions generate isolated conflicts, show a relative interest in the local reality, some of them contribute to informality, are integrated into the territory in which they are located. There is low institutional and inter-institutional support and ownership.	0.75	High
Political and institutional vulnerability	0.75	High

Table 19: Calculation of political and institutional vulnerability of the area under study.

Source: Author's elaboration.

COLLECTIVE KNOWLEDGE ABOUT PAST OCCURRENCE OF HAZARDS		
<i>Indicator</i>	<i>Range</i>	<i>Degree</i>
The majority of the population is knowledgeable about the causes and consequences of disasters.	0.50	Half
LOCAL RISK PERCEPTION		
<i>Indicator</i>	<i>Range</i>	<i>Degree</i>
The majority of the population has a real perception about the occurrence and consequence of disasters.	0.50	Half
ATTITUDE TO RISK		
<i>Indicator</i>	<i>Range</i>	<i>Degree</i>
Hardly forward-looking attitude of the majority of the population.	0.75	High
Cultural and ideological vulnerability	0.58	
	High	

Table 20: Calculation of vulnerability, culture and ideology of the area under study.

Source: Author's elaboration.

INFORMATION AND TECHNICAL SUPPORT		
<i>Indicator</i>	<i>Range</i>	<i>Degree</i>
There are studies on the site, which can serve tangentially to the estimation of the Risk of the Site under study. Research centers and / or state agencies have information some type of information isolated from the place. The area does not have technological equipment that can monitor and analyze the hazard. Nor do you mitigate it. There are no qualified technicians who can advise on disaster risk management (prevention and mitigation).	0.75	High
KNOWLEDGE AND COMPLIANCE WITH RECOMMENDATIONS		
<i>Indicator</i>	<i>Range</i>	<i>Degree</i>
The population has a basic knowledge about the studies carried out in the urban or rural center of the most recurrent dangers, not complying with the recommendations given.	0.75	High
Scientific and technological vulnerability	0.75	
	High	

Table 21: Calculation of political and institutional vulnerability of the area under study.

Source: Author's elaboration.

Flood Vulnerability Level		
Types of vulnerability	Range	Level
Physical vulnerability	0.69	High
Environmental and ecological vulnerability	0.38	Half
Economic vulnerability	0.50	Half
Social vulnerability	0.63	High
Educational vulnerability	0.92	Very high
Political and institutional vulnerability	0.75	High
Cultural and ideological vulnerability	0.58	High
Scientific and technological vulnerability	0.75	High
Total Vulnerability	0.65	
	High	

Table 22: Flood hazard level of the area under study.

Source: Author's elaboration.

Risk Level

To determine the level of flood risk (Table 24), a double-entry matrix offered by INDECI was used, which relates the level of danger and vulnerability (Table 23) previously determined.

Very High Danger 1	Medium Risk 0.25	High Risk 0.5	Very High Risk 0.75	Very High Risk 1
High Danger 0.75	Low Risk 0.19	Medium Risk 0.38	High Risk 0.56	Very High Risk 0.75
Medium Danger 0.5	Low Risk 0.13	Medium Risk 0.25	Medium Risk 0.38	High Risk 0.5
Low Danger 0.25	Low Risk 0.06	Low Risk 0.13	Low Risk 0.19	Medium Risk 0.25
	Low Vulnerability 0.25	Medium Vulnerability 0.5	High Vulnerability 0.75	Very High Vulnerability 1

Table 23: Relationship of hazard level and flood vulnerability of the area under study.

Source: Author's elaboration.

Risk Level		
	Range	Level
Danger level	0.50	High Danger
Total Vulnerability	0.65	High
Total Risk	0.56	
	High Risk	

Table 24: Flood risk level of the area under study.

Source: Author's elaboration.

Discussion

The analysis of the risk of a flood of a given area is very complicated when there is no geographic information to correctly locate the area under study, but with the use of freely accessible satellite images, satellite georeferencing has been facilitated, as mentioned by Albano [13] in his research.

Guido Borzi [14], tells us that you can use geographic information from satellite images in this case I use those of Landsat, and I apply it in the Samborombon river basin (Argentina), demonstrating the efficiency in the flood study. In the same way Alimi S.A [15], says that floods are identified as a threat due to climate change worldwide, that is why the flood study of a certain area is done, for this geographic information is needed that was obtained from the digital elevation model (DEM) of Landsat 8 achieving in this way georeferencing the area under study and therefore carry out the elaboration of flood maps correctly.

Regarding the analysis of the maximum flows there are many methods to calculate them, but Paola Duque [16], recommends that to evaluate the hydrological behavior of the tropical basin of Ecuador made use of the SCS Curve Number method that were applied in the HEC-HMS software with respect to the different return periods obtaining in this way the correct extreme flows, It is worth mentioning that the use of this software is very good and more if in the area where the study is carried out there is no hydrometeorological information.

For Juan Cabrera the use of [17] the HEC-HMS model, this is a method widely used today, especially because it is very good since it can correctly and satisfactorily simulate the runoff flows of a basin under study, the use of this method agrees with the methodology used in the study area of the Chamaya basin of the Huancabamba River, since in this way the maximum extreme flows that can produce a risk from flooding in relation to the different established return periods were determined.

With regard to hydraulic modeling, it was possible to see that there are several studies and investigations where the use of HEC-RAS software is recommended for one-dimensional models since this type of modeling is simpler and especially because it is easy to handle data, as Roland Lowe says [18]. Thanks to this type of modeling, we can determine the flood areas and therefore propose alternative solutions, while Ben Khalfallah [19] indicates that the HEC-

RAS software is suitable for a simulation of a flood, which was reflected in the study he carried out in the Medjerda basin of Turkey.

Also, Devanand [20], in his article mentions the ease of the HEC-RAS software to import a GIS or DEM thus allowing its free use worldwide, which is why the application of the software in the Huancabamba River gave us correct results and allowed us to identify the areas with more flood danger of the entire section under study.

Conclusions

This article makes a contribution since it determines the factors that influence the flooding of a Huancabamba River basin. It is concluded that the hydrological information base of PISCO provided by SENAHMI can be used if there is no complete information in the stations near the study area. It is emphasized that having the geographic information of the area under study requires free access satellite images. It should be noted that after performing the flood risk analysis through the development of a hydraulic model it was observed that the maximum flows that affect more are those of the return period of 50 and 100 years, with flows of 1459.20 m³ / s and 1860.20 m³ / s respectively, the maximum speed is 6.87 m / s and the maximum water level is 12.56 m for a return period of 100 years, that is why it is recommended to plate alternative solutions such as riparian defenses for the right and left bank of the Huancabamba River in the 5000 meters of the section under study so that in this way crops and homes near the banks of the river can be protected.

References

- [1] A. S. & J. A. Leonardo Mancusi, "FloodRisk: un software colaborativo, gratuito y de código abierto para el análisis del riesgo de inundación," *Geomática, Peligros Naturales y Riesgo*, p. 22, 2017.
- [2] S. N. d. M. e. H. d. P. – S. (. G. d. M. -. D. d. Climatología), "Reducir la vulnerabilidad de la población y sus medios de vida ante riesgo de desastres.," Depósito Legal en la Biblioteca Nacional del Perú N° 2014-08286, Lima, 2014.

- [3] N. a. K. G. Kourgialas, "Flood management and a GIS modelling method to assess flood-hazard areas—a case study.," *Hydrological Sciences Journal–Journal des Sciences Hydrologiques*, vol. 2, p. 56, 2011.
- [4] L. R. Lianet, "Procedimiento para la simulación hidráulica a partir de los software ArcGIS y HEC-RAS para eventos extremos máximos.," Universidad Central Marta Abreu de Las Villas, Santa Clara (Cuba), 2017.
- [5] G. M. G. Olivares Castillo, "Determinación de zonas inundables mediante simulación hidráulica bidimensional aplicando HEC – RAS 5.0 en un tramo del río Huancabamba, desde la quebrada Chula (KM 2.42) hasta la quebrada Lungulo (KM 5.51), provincia de Huancabamba, departamento de Piura", " Universidad Nacional de Piura, Piura, 2018.
- [6] M. Belizario Quispe and Y. G. Pancca Cruz, ""Comparativo del comportamiento hidráulico de zonas inundables con el software y HEC-RAS del río Coata C.P. Almosanche", " Universidad Nacional del Altiplano, Puno, 2020.
- [7] S. N. d. M. e. H. d. Perú, "Uso del Producto Grillado PISCO de precipitación en Estudios, Investigaciones y Sistemas Operacionales de Monitoreo y Pronóstico Hidrometeorológico," SENAMHI, Lima, 2017.
- [8] M. d. T. y. Comunicaciones, "Manual de Hidrología, Hidráulica y Drenaje," Laboratorio DEE, Lima, 2011.
- [9] M. Z. ., J. W. S. D. ., H. X. L. W. a. Y. Y. Xianhong Meng, "A Simple GIS-Based Model for Urban Rainstorm Inundation Simulation," *Sustainability*, vol. 11, no. 10, p. 19, 2019.
- [10] G. S. B. ., P. P. ., A. C. M. ., D. G. ., P. K. Raja Majumder, "Assessment of flood hotspot at a village level using GIS-based spatial statistical techniques.," *Arabian Journal of Geosciences*, vol. 12, p. 13, 2019.
- [11] J. M. Stella¹ and E. N. Anagnostou, "Modeling the flood response for a sub-tropical urban basin in south Florida," *Tecnología y ciencias del agua*, vol. 9, no. 3, p. 15, 2018.
- [12] I. N. d. D. Civil, "Manual de Estimación del riesgo ante Inundaciones Fluviales," Biblioteca del Instituto Nacional de Defensa Civil, Lima, 2011.
- [13] R. S. A. A. J. P. A. & I. A. Albano, "Using FloodRisk GIS freeware for uncertainty analysis of direct economic flood damages in Italy.," *International Journal of Applied Earth Observation and Geoinformation*, vol. 73, pp. 220-229, 2018.
- [14] F. C. C. T. E. M. & E. C. Guido Borzi, "Methodological proposal for the study of floods in plains areas with," *DYNA*, vol. 1, no. 1, p. 8, 2020.

- [15] T. A. O. O. S. S. V. A. O. A. ., L. O. Q. M. S.A. Alimi, "Flood vulnerable zones mapping using geospatial techniques: Case study," *The Egyptian Journal of Remote Sensing and Space Sciences*, vol. 25, pp. 841-850, 2022.
- [16] D. M. P. y. X. E. L. Paola Duque-Sarango, *Información Tecnológica*, vol. 30, no. 6, pp. 351 - 362, 2019.
- [17] L. M. T.-C. P. J. C.-S. Juan José Cabrera-Balarezo, "Evaluation of the HEC-HMS model for the hydrological simulation of a paramo basin," *DYNA*, vol. 86, no. 210, pp. 338 - 344, 2019.
- [18] R. Löwe, C. Urich, N. D. F. Sto. Domingo, O. Mark, A. Deletic and K. ArnbjergNielsen, "Assessment of Urban Pluvial Flood Risk and Efficiency of Adaptation Options Through," *Journal of Hydrology*, vol. 550, pp. 355 - 367, 2017.
- [19] S. S. Ben-Khalfallah, "Spatiotemporal floodplain mapping and prediction using HEC-RAS-GIS tools: Case of the Mejerda river, Tunisia," *Journal of African Earth Sciences*, vol. 142, pp. 44-51, 2018.
- [20] M. & K. S. Devanand, "Flood inundation mapping of Harangi river basin, Kodagu, using GIS techniques and HEC-RAS model.," *Lecture Notes in Civil Engineering*, vol. 99, pp. 665 - 678, 2021.