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Application Of Geotechnologies For Flood Risk Analysis In The Pumahuasi - Huamancoto Sector, Department Of Huánuco

Elizabeth Luz Segovia Aranibar[1] , César Alejandro Chumpitasi León[2] , Katherine Pamela Peralta Calderon[3] , Carolina Lucia Vásquez Aliaga[4]

[1]Faculty of Geographic and Environmental Engineering, National University of Federico Villarreal, Lima, Peru.

[2]Faculty of Geographic and Environmental Engineering, National University of Federico Villarreal, Lima, Peru.

[3]Faculty of Geographic and Environmental Engineering, National University of Federico Villarreal, Lima, Peru.

[4]Faculty of Geographic and Environmental Engineering, National University of Federico Villarreal, Lima, Peru.

Abstract

The objective of this research is to analyze the risk of flooding in the Pumahuasi - Huamancoto sector, district of Daniel Alomía Robles, department of Huánuco. Floods are a devastating event that causes serious consequences for people, affecting the productive zone, the urban and natural area, the environmental impact is direct since the flooded area is difficult to recover, it also affects the fauna because they are displaced from their habitat which leads to migration; the social impact is given because the affected inhabitants may choose to stay in place and rebuild their homes, experiencing a financial burden; the economic impact is that these events affect the district since the productive chain is broken. To determine the risk, geotechnological tools were used such as: HEC-RAS, for hydraulic modeling; ArcGIS, a well known Geographic Information System for the processing and representation of flood risk. As a result, it is shown that, in flood risk mapping, the predominant unit is high risk. The vulnerability analysis, developed based on the established methodology, indicates that there are crop lands with very high, high and medium levels of vulnerability to the occurrence of river flooding.

Keywords

Geotechnologies, Flood, River, Precipitation, Peru.

Introduction

Among the natural phenomena that stand out in our country and are considered to be one of the most relevant, mainly in the northern coast and the Amazon region, we talk about river floods, we know that these are natural phenomena produced by the increase of the flow caused by heavy rainfall, and it is called a disaster when it causes losses and damages to the population and infrastructure, respectively. A disaster is understood as the materialization of a risk on such a scale that its impacts exceed the response or recovery capacity of the affected environmental system, and therefore requires external support. (Vera y Albarracín, 2017)

Inadequate land use planning and poverty aggravate this situation. Land use planning is a preventive measure to project the organization and forms of occupation of the territory considering the cultural and socioeconomic characteristics, as well as the use of opportunities, the reduction of risks and the protection of resources in the short, medium and long term. (Sánchez et al., 2020) In Peru, poverty, migration and informality have caused many settlers to see as an alternative in inadequate areas, spaces to be inhabited such as hillsides, riverbanks, public sandbanks, places prone to strong landslides, land with fragile compaction, have been invaded and without a technical study and use of adequate construction material have designed houses in precarious conditions. (Sánchez et al., 2020)

Flood-prone areas are those flat areas adjacent to a watercourse or body of water that are covered during a flood, the latter being part of the normal hydrological regime that expresses the hydrological response to excessive water input due to rainfall, rising water tables, etc. They may have the water table close to the surface, making their soils waterlogged. (Caruso, 2020)

In recent decades, a series of computer applications and tools, called Geographic Information Systems (GIS), have been developed from the worldview of quantitative geography, which have become a basic and powerful technology to capture, store , manipulate, analyze, model and present spatially referenced data. . (González et al.,2019).Highlighting its role in the development of flood risk maps; flood damage risk maps are the real risk maps, since they are produced, on the one hand, from cartography that locates and characterizes the physical phenomenon of floods, and, on the other hand, from cartography that locates and characterizes the exposed elements.

The use of GIS, remote sensing, hydrological sensors, among others, represent a potential of great value for the development of flood risk maps, which is, at present, a field open to research. (Ribera, 2004). This research highlights the use of tools such as GIS and

Hydraulic Modeling that represent a potential of great value for the development of flood risk analysis.The flood levels of a river can be calculated due to hydrological and hydrodynamic models, these contain input data such as rainfall, inputs, boundary conditions, among others (Erasun et al., 2019).

A river flood event is represented by computer tools such as the HEC-HMS model that is used to model hydrological factors, while the HEC-RAS and Iber models are used to model hydraulic factors under one-dimensional or two-dimensional flow conditions (Marin and Barros, 2016). This software package integrates several hydraulic analysis programs where the user communicates with the system through a graphical interface. The main objective of the model is to obtain the height of the water in rivers with permanent or discontinuous flow regimes by calculating the wetted area of the cross sections. (Triviño y Ortiz, 2004). Thanks to their approaches, the HEC-RAS and HEC-HMS models have enabled great advances in watershed studies and have been well received by the worldwide community of engineers working in different areas related to water management (Ramos and Pacheco, 2017)

Among several very important reference articles is the Flood risk of the city of Iquitos, Peru (2015), which identifies the areas at risk of flooding through the resulting mapping, explains the use and application of GIS and remote sensing, in order to propose management mechanisms and land use planning (Soria et al., 2015). The National Institute of Civil Defense (INDECI) has reports on overflows of the Tulumayo River in times of large floods that flooded agricultural and urban areas adjacent to its banks, which will complement the data for our study. The knowledge of the areas with different levels of risk (Level of Danger and Vulnerability), is used in the processes of territorial ordering and planning, so these must represent the use that can be given and the potential damages to which this use would be exposed (Manual for estimating the risk of river flooding-INDECI, 2011)

It should be noted that the Manual for the Evaluation of Risks Originated by Natural Phenomena of the National Center for the Estimation, Prevention and Reduction of Disaster Risk (CENEPRED) will be used as a guide, together with the study report presented by the District Municipality of Daniel Alomía Robles, Leoncio Prado, Huánuco. (2020).

As we well know, a flood is a devastating event that causes serious consequences for people, affecting both the productive zone, the urban area and the natural area. The environmental impact is direct since the flooded area is difficult to recover, it also affects the fauna because they are displaced from their habitat which leads to migration; the social impact is that the affected inhabitants may choose to stay in place and rebuild their homes experiencing a financial burden which would lead to abandon the area and start again elsewhere; the economic impact is that these events affect the district since it breaks with the productive chain that existed.

The contribution of this research is the timely identification of risk areas so that both the authorities and the inhabitants of the district of Daniel Alomía Robles are prepared to face an emergency situation due to flooding caused by the overflowing of the Tulumayo River. All of this will contribute to guaranteeing the protection of the inhabitants' lives and livelihoods as well as their infrastructure. The main innovation of the research is the use of geotechnologies such as: hydraulic modeling (HEC-RAS) to estimate or determine the displacement time of flood waves along river channels, Geographic Information Systems (ArcGIS) that are used for the processing and representation of flood risk. All this generates an impact on the user because he will be able to understand the environment he occupies and prioritize measures for the protection of the livelihoods of the population to invest and not to rebuild. The main objective of this research is to identify and evaluate the fluvial flood risk on the right bank of the Tulumayo River through the use of geotechnologies to propose prevention and mitigation measures in the Pumahuasi - Huamancoto sectors, as well as to determine through hydraulic modeling the flood areas of the Tulumayo River.

Research Method

Study area

The Pumahuasi and Huamancoto sector is located on the right bank of the Tulumayo River. Hydrographically, it belongs to the Tulumayo River sub-basin and is bordered to the northwest, west and southwest by the Alto Huallaga inter-basin; to the northeast by the Aguaytía basin; and to the southeast by the Pachitea basin. It has an area of 172.04 hectares and a perimeter of 6141.89 meters. Politically, it is located in the Daniel Alomía Robles district, Leoncio Prado province, department of Huánuco. The study area comprises the right bank of the Tulumayo River.

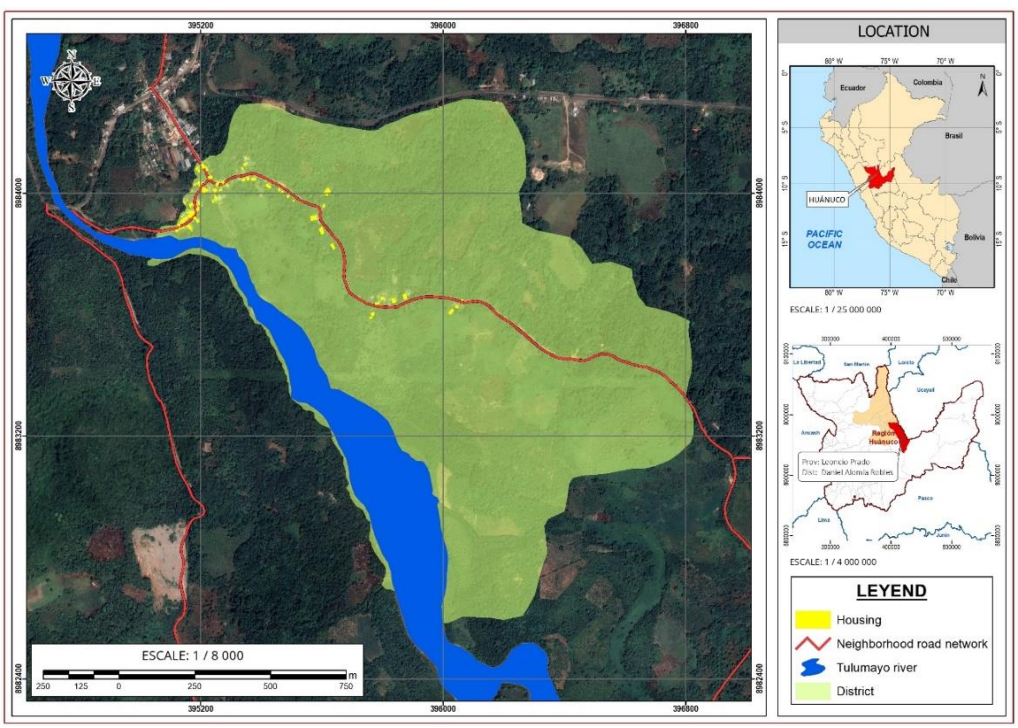


Figure 1. Location map of the study area

Location map of the study area Pumahuasi - Huamancoto sector in the Daniel Alomía Robles district, Leoncio Prado province, department of Huánuco. The study area comprises the right bank of the Tulumayo River.

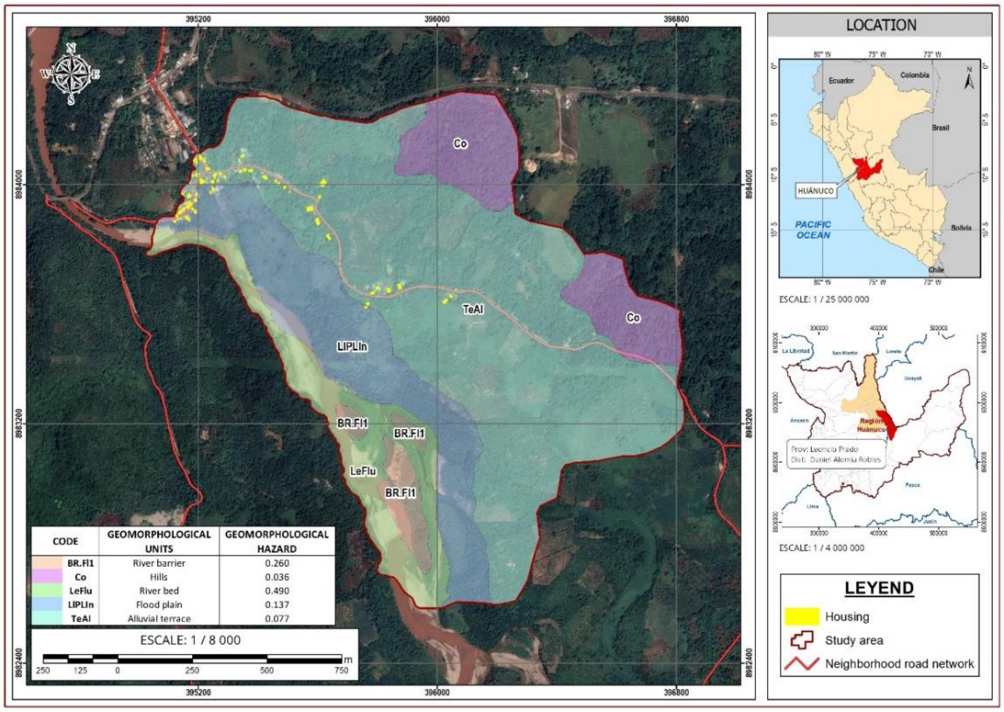


Figure 2. Geomorphological map of the study area.

Pumahuasi - Huamancoto sector in the Daniel Alomía Robles district, Leoncio Prado province, department of Huánuco. It shows the 5 predominant geomorphological units in the study area.

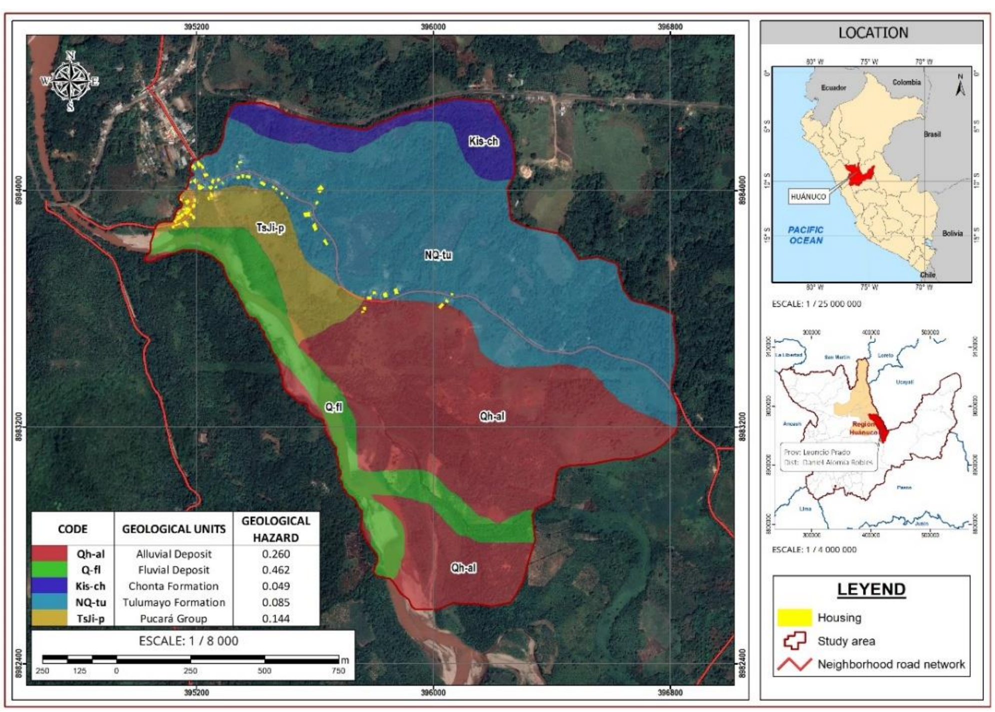


Figure 3. Geological map of the study area.

Pumahuasi - Huamancoto sector in the Daniel Alomía Robles district, Leoncio Prado province, department of Huánuco. It shows the 5 geological units existing in the study area.

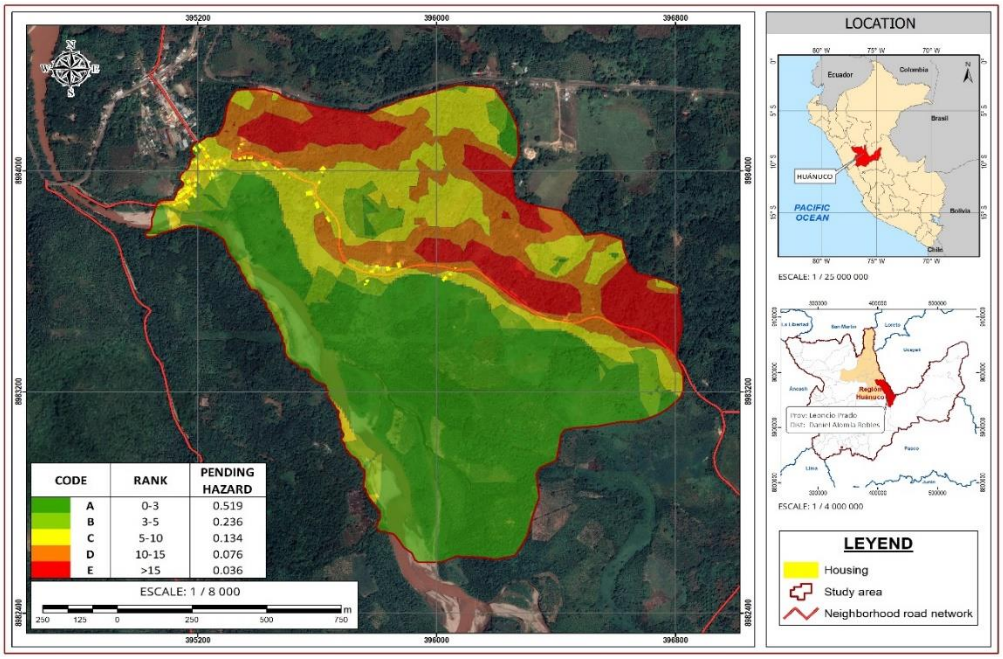


Figure 4. Slope map of the study area

Pumahuasi - Huamancoto sector in the district of Daniel Alomía Robles, province of Leoncio Prado, department of Huánuco. It is classified in 5 ranges.

According to Thornthwaite's classification, the study area is predominantly warm, very rainy and with abundant rainfall in all seasons of the year, and to a lesser extent, warm, semi-warm and with abundant rainfall in all seasons of the year. The climate map was obtained from vector data published by SENAMHI. (Figure 5)

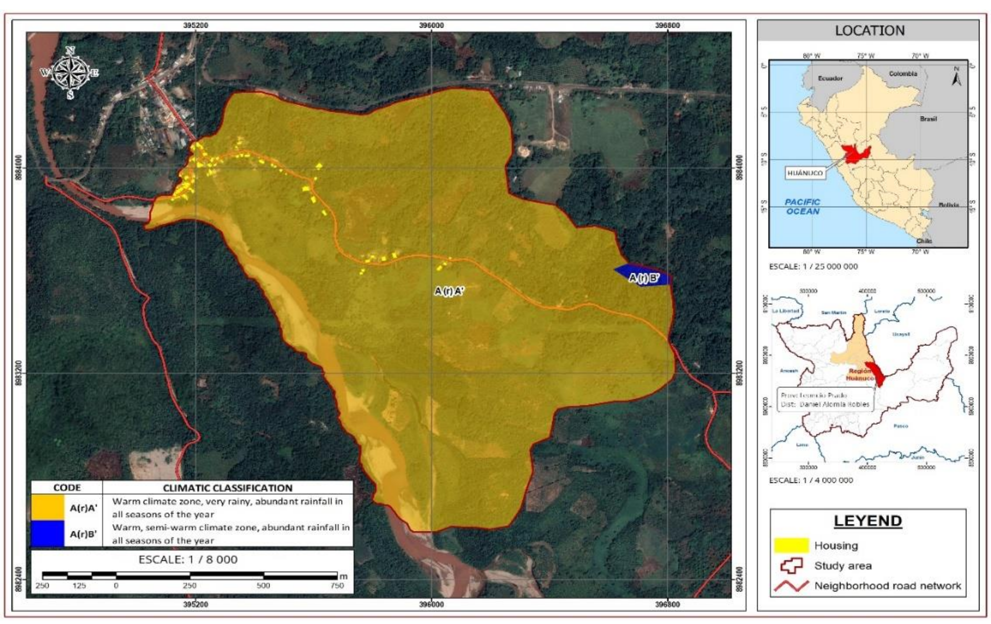


Figure 5. Climate map of the study area.

Method

This work is based on the hierarchical analysis procedure mentioned in the manual for the evaluation of risks caused by natural phenomena, 2nd version (CENEPRED, 2014).
The flood hazard levels of a given area result from the relationship between the evaluation parameter, i.e. flood height and the susceptibility of the territory, for this purpose in the study area the triggering factors (precipitation thresholds) and conditioning factors (geomorphological units, terrain slope, geological units, vegetation cover) were considered (Figure 6).

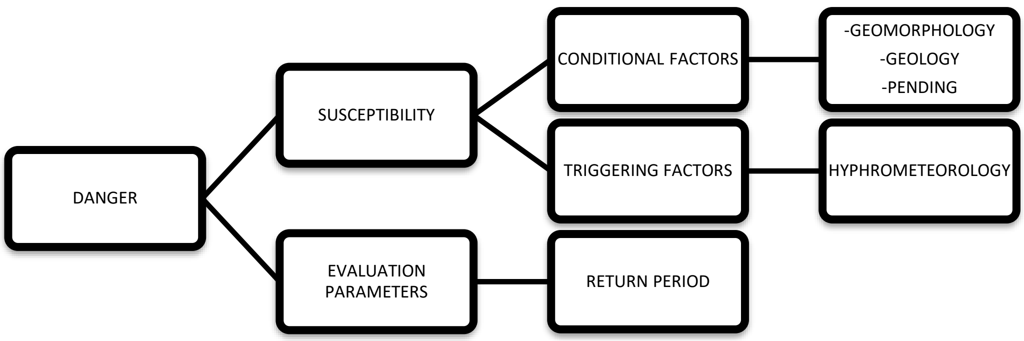


Figure 6. Procedure for determining flood hazard.

This procedure used in the study area is based on the CENEPRED's Manual for the Evaluation of Risks Originated by Natural Phenomena. Thus, for the elaboration of the hazard and vulnerability map, which from the combination of both will generate the risk map.

a) Flood hazard mapping

The flood hazard mapping was carried out based on the analysis and interpretation, in terms of hazard, of the manual for the evaluation of risks caused by natural phenomena, 2nd version (CENEPRED, 2014), using information compiled from studies published by competent technical-scientific entities (INGEMMET, IGP, INEI, SENAMHI, CONIDA, ANA, regional governments, local governments, among others). To obtain the hazard matrix, the starting point was the susceptibility data and evaluation parameters, from which the hazard stratification was obtained through hierarchical analysis, assigning four levels (Table 4).

Table 1. Application of the hierarchical order of the CENEPRED Manual for the evaluation of risks originated by natural phenomena.

SUSCEPTIBILITY (S)		EVALUATION PARAMETERS				**HAZARD VALUE**
		Return period				
(FC VALUE*FC WEIGHT)+(FD VALUE*FD WEIGHT)	WEIGHT	VALUE	WEIGHT	VALUE	WEIGHT	(S-VALUE*S WEIGHT S+(PE-VALUE*PE WEIGHT)
0.476	0.02	0.408	1	0.408	0.98	**0.410**
0.246	0.02	0.300	1	0.300	0.98	**0.299**
0.146	0.02	0.141	1	0.141	0.98	**0.142**
0.093	0.02	0.099	1	0.099	0.98	**0.099**
0.057	0.02	0.051	1	0.051	0.98	**0.051**
						1.000

To obtain the hazard matrix, we conclude with the stratification of hazard levels.

b) Vulnerability mapping

Vulnerability applied to human populations depends not only on external factors such as the existence of resources, but also on endogenous social factors (Córdova, 2020). The vulnerability mapping originates from the analysis of the three vulnerability factors, these factors with their respective social and economic dimensions, each of these dimensions housed exposure, fragility and resilience data. As a result, the vulnerability values and therefore the four levels of vulnerability were obtained. It should be noted that the data provided by the population census and the district cadaster helped in the creation of the vulnerability matrix (Table 5).

Table 2. Application of the hierarchical order of the CENEPRED Manual for the evaluation of risks caused by natural phenomena.

SOCIAL DIMENSION		ECONOMIC DIMENSION		
VALUE SOCIAL DIMENSION	WEIGHT SOCIAL DIMENSION	VALUE ECONOMIC DIMENSION	WEIGHT ECONOMIC DIMENSION	**VALUE OF VULNERABILITY**
0.472	0.70	0.520	0.30	**0.486**
0.267	0.70	0.250	0.30	**0.262**
0.141	0.70	0.129	0.30	**0.138**
0.077	0.70	0.066	0.30	**0.074**
0.043	0.70	0.034	0.30	**0.040**

1.000

To obtain the vulnerability matrix, we conclude with the stratification of vulnerability levels.

c) Risk mapping

Four degrees of risk were established, which will be hierarchized by colors representing the levels of risk. The procedure for determining flood risk in the study area was taken from CENEPRED's Manual for the Evaluation of Risks Originated by Natural Phenomena (Figure 7 and Table 6).

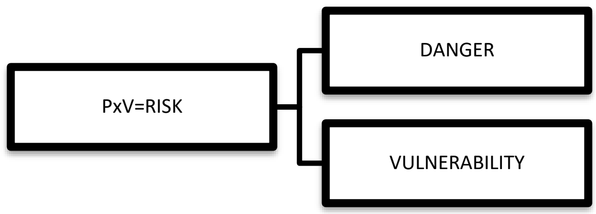


Figure 7. Procedure to determine the flood risk in our study area, taking as a reference the CENEPRED's Manual for the evaluation of risks caused by natural phenomena.

Table 3. Determination of the risk value

HAZARD VALUE	VULNERABILITY VALUE	RISK (P*V=R)
0.410	0.486	0.199
0.299	0.262	0.078
0.142	0.138	0.020
0.099	0.074	0.007
0.051	0.040	0.002

In the table 3 obtain the risk matrix, the risk levels are stratified

d) Hydraulic Modeling

It is often possible to find programs or software designed to carry out hydraulic modeling of rivers or channels along a riverbed, either natural or artificial. In the case of channels in their natural condition, it is essential to have prior information about the configuration of the land that it has. (Rodríguez et al.,2019). According to Prieto et al., (2017) we start with the download of daily rainfall from the Pisco Grid (SENAMHI) with the help of R software and RStudio which was made an analysis of doubtful data by the Water Resources Council Method, after which the goodness of fit test was performed, to prove that the distribution or probabilistic model best fits the existing data with which the maximum corrected rainfall for different return periods is determined.

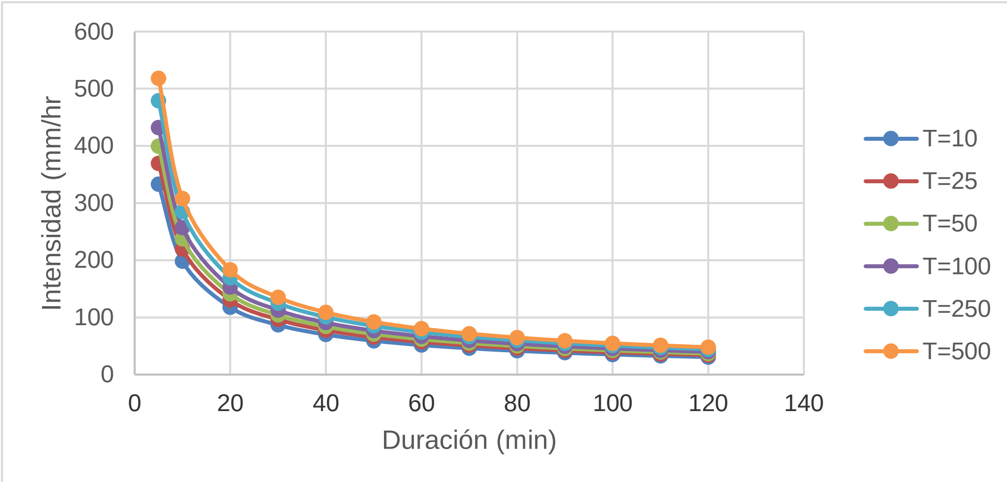
These corrected maximum precipitations will be used in the Dyck and Peschke method to obtain the design precipitations for durations of less than 24 hours. Then we proceed to the calculation of the design intensities for durations less than 24 hours, the results are analyzed to finally obtain the Valid Intensity equation, with the elaboration of the Intensity-Duration-Frequency Curves (IDF) for different return periods, the rainfall hietogram for the 75-year return period was elaborated using the alternating block method, which will be used in the Hec-HMS software (Figure 12).
Hec-HMS was initially developed to simulate rainfall-runoff processes in dendritic basins but was later improved to solve a wide range of problems including: water supply from large basins, flood hydrographs, and runoff from small urban or natural basins. (Cabrera-Balarezo et al., 2019). Historically, the most used tool has been ArcGIS, which can interact with HEC-RAS through its HE Cgeo RAS extension. (Cameron,2005).

Table 4. Maximum rainfall data in 24 hours.

STATION SINGS					
N°	**Year**	**P24 (mm)**	**N°**	**Year**	**P24 (mm)**
1	1981	101,77	19	1999	84,62
2	1982	112,23	20	2000	69,74
3	1983	69,48	21	2001	57,37
4	1984	71,75	22	2002	73,83
5	1985	87,76	23	2003	77,19
6	1986	65,63	24	2004	94,21
7	1987	55,03	25	2005	106,22
8	1988	77,03	26	2006	93,43
9	1989	88,07	27	2007	87,61
10	1990	59,27	28	2008	97,10
11	1991	66,32	29	2009	69,60
12	1992	83,38	30	2010	105,03
13	1993	76,03	31	2011	134,64
14	1994	70,46	32	2012	76,12
15	1995	90,32	33	2013	79,20
16	1996	81,21	34	2014	59,42
17	1997	76,17	35	2015	75,81
18	1998	62,03	36	2016	89,31

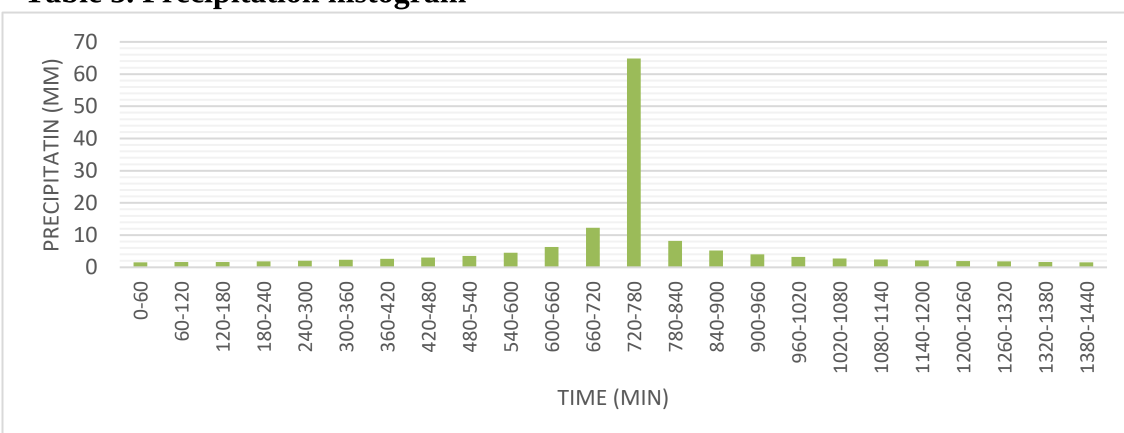
This is 36 years of information obtained from the Pisco grid (SENAMHI) and has been used to determine the maximum flow in the Tulumayo river basin.

Table 8. IDF curve



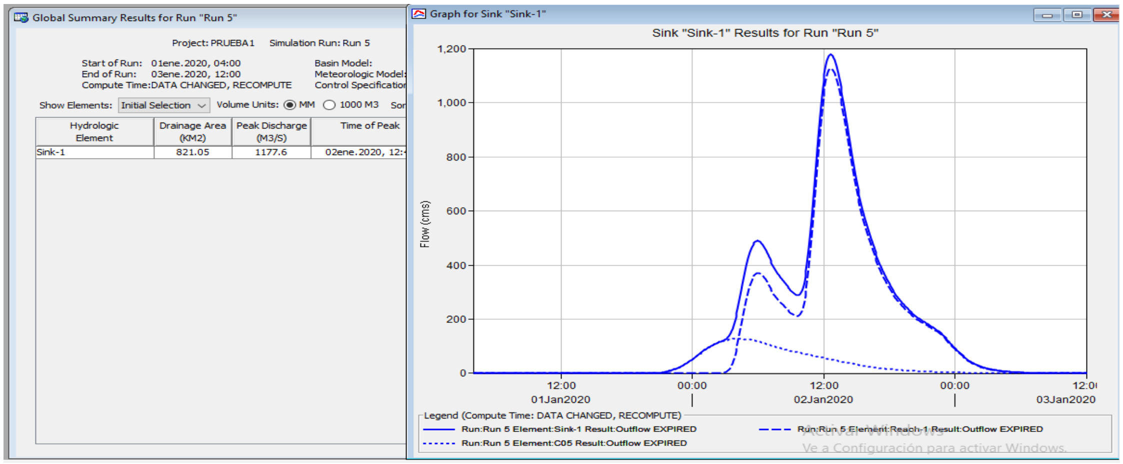
For the construction of the IDF curve, first a design rainfall table was made for durations less than 24 hours using the Dyck and Peschke method. With these intensities for durations less than 24 hours, the Valid Intensity was calculated by regression data analysis.

Table 5. Precipitation histogram



Data entered into the HEC-HMS software to calculate the peak flow at the mouth of the basin.

Table 6. Obtaining the peak flow through the HEC-HMS software.



The values of the hietogram in the software are used, by means of certain processes it determines a peak flow of 1177.6 m3/s for a return period of 75 years.

Using the Hec-HMS software, a flow of 1177.6 m3/s is determined, the Manning's roughness coefficient of 0.030 is determined for the main channel of the river and 0.040 for the cultivated areas, based on table Nº9 Manning's roughness coefficient values, according to the Hydrology, Hydraulics and Drainage Manual of the Ministry of Transport and Communications (2008). Considering Prieto et al., (2017) a DEM and a satellite image of the area are used, the riverbed and river banks are digitized, in addition to the area to be affected before this overflow of the Tulumayo River in the Hec Ras 6.0 software. Cross sections of the riverbed are generated and a mixed regime is considered for the natural channel. This process will result in a raster of flooding, velocity and depth.

RESULTS

- Flood Hazard

Figure 14 shows the flood hazard mapping of the study area. The highest degree of danger (red color) is associated with the geomorphological presence of floodplain, with slopes greater than 10° of inclination, geologically located on fluvial deposits and with precipitation greater than 60 mm/h. The degree of danger is high (orange). There is the geomorphological presence of a fluvial barrier, with slopes between 5° to 10° of inclination, geologically it is located on alluvial deposits and with a precipitation greater than 30 mm/h and less than 60 mm/h. The return period is every 75 years.

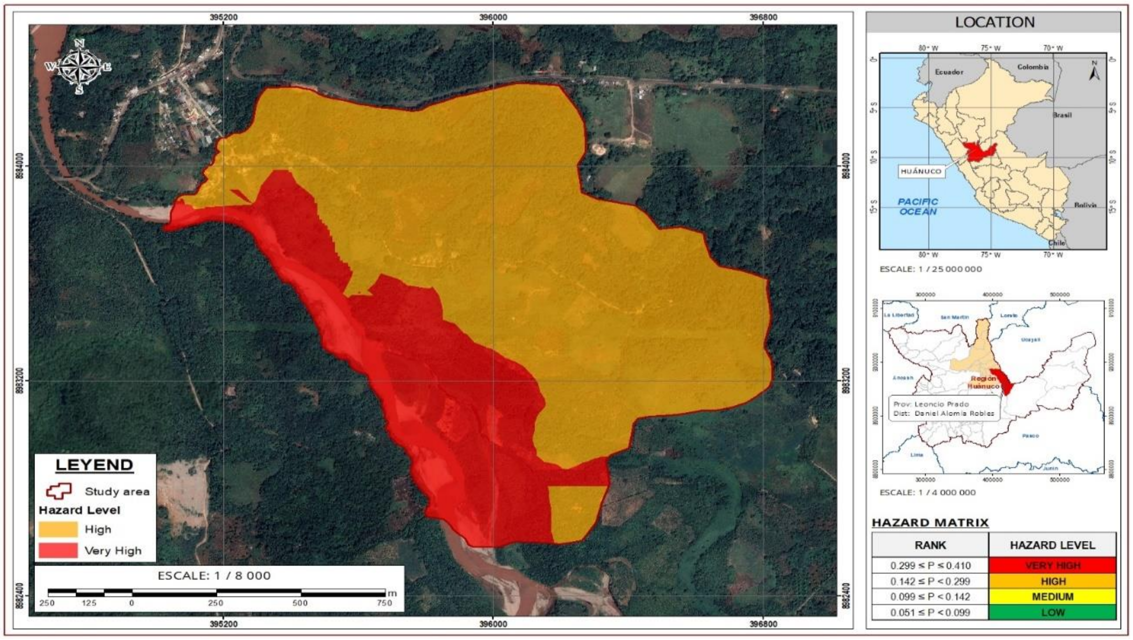


Figure 9. Fluvial flood hazard mapping on the right bank of the Tulumayo river, in the Pumahuasi - Huamancoto sector, Daniel Alomía Robles district, Leoncio Prado province, department of Huánuco.

- **Vulnerability**

The vulnerability map is shown in Figure 15. The high degree represents houses whose built areas are greater than 200 m2 and less than or equal to 300 m2, in addition, only 10% to 25% of the population has access to basic services. The medium level represents homes with a floor area greater than 120 m2 and less than or equal to 200 m2 , where 25% to 50% of the population has access to basic services.

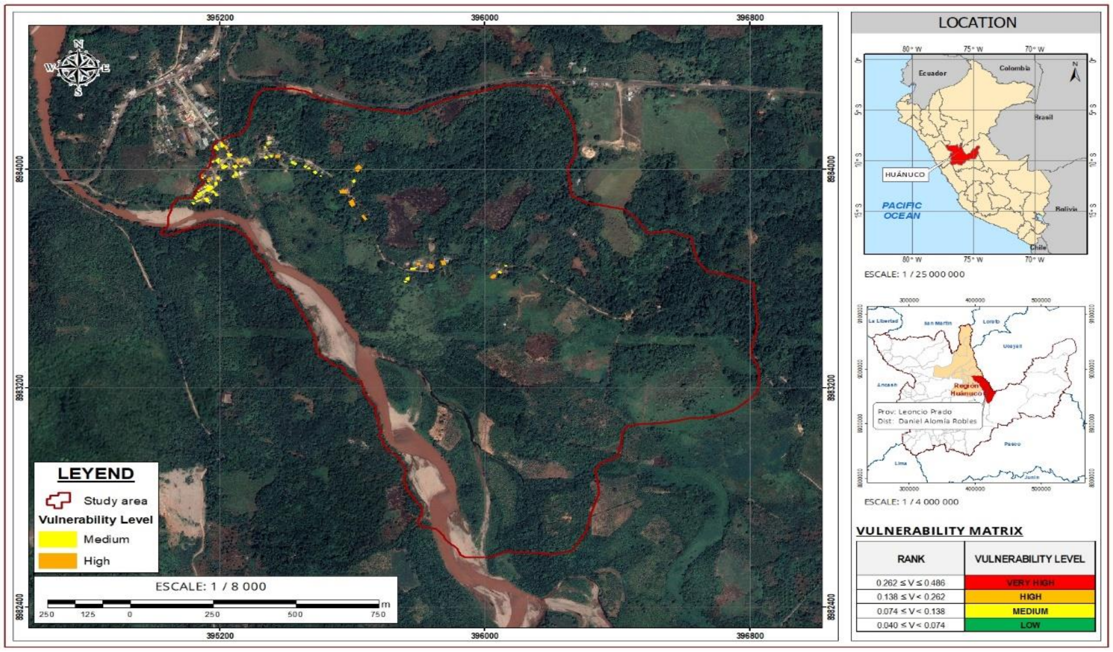


Figure 10. Fluvial flood vulnerability mapping on the right bank of the Tulumayo river, in the Pumahuasi - Huamancoto sector, Daniel Alomía Robles district, Leoncio Prado province, department of Huánuco.

– **Flood risk**

Figure 11 shows the risk of flooding during the Tulumayo river flood season. The high degree is associated with high hazard and vulnerability characteristics. In addition, Figure 17 shows the area to be affected by flooding on the right bank of the Tulumayo River with a total flooding area of 32.01 ha, considering a return period of 75 years.

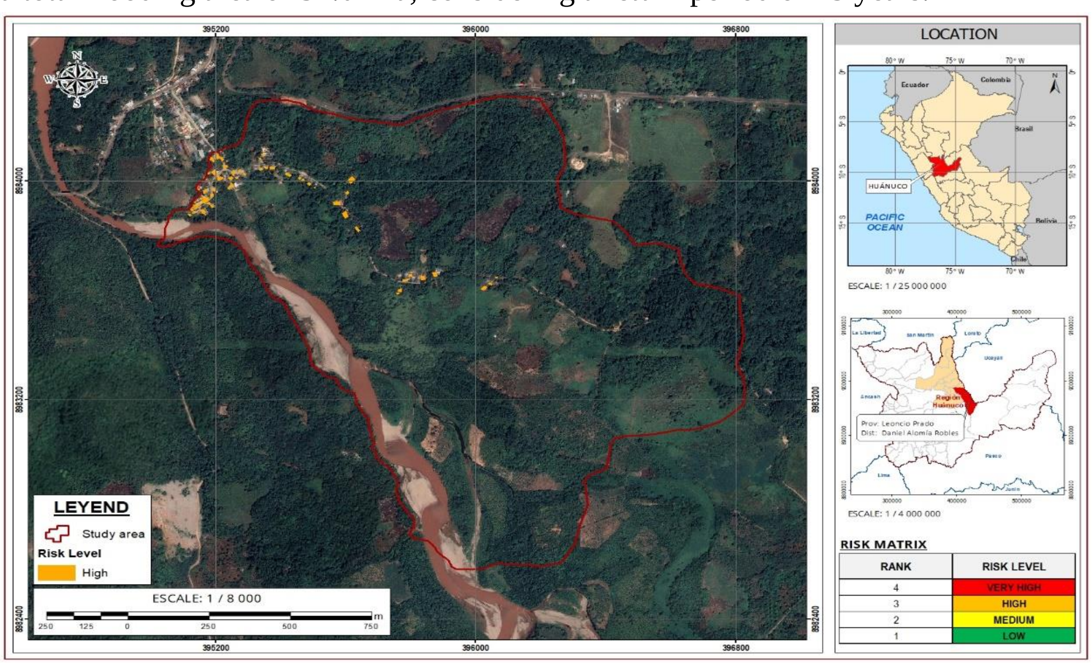


Figure 11. Fluvial flood risk mapping on the right bank of the Tulumayo river, in the Pumahuasi - Huamancoto sector, district of Daniel Alomía Robles, province of Leoncio Prado, Huánuco.

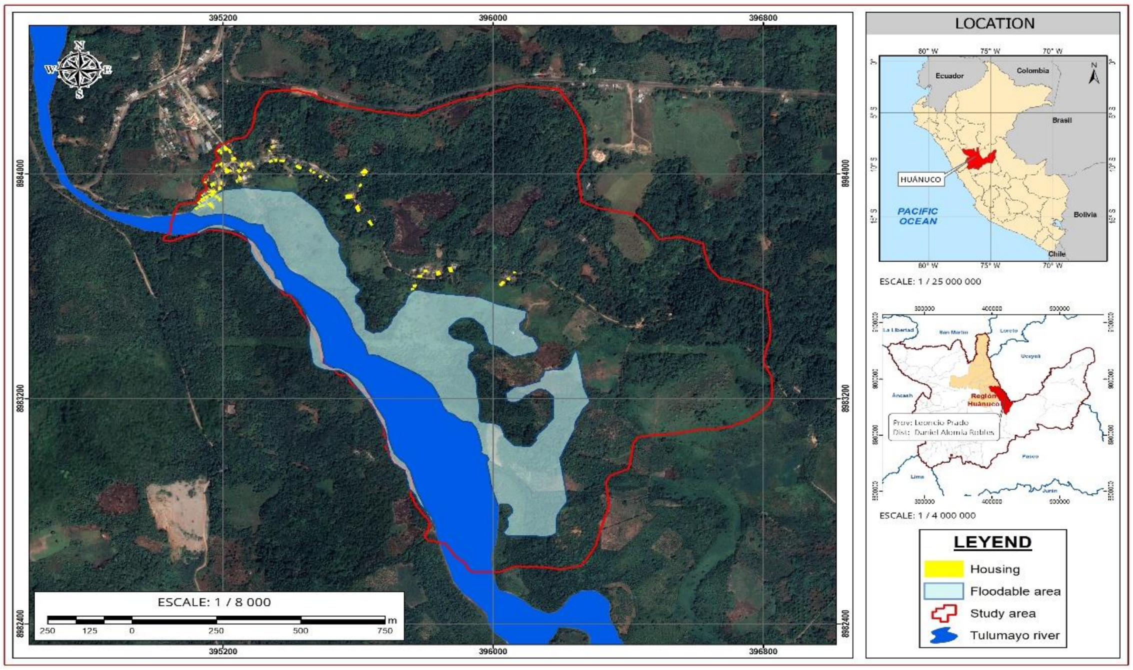


Figure 12. Map of fluvial flooding on the right bank of the Tulumayo river, in the Pumahuasi - Huamancoto sector, Daniel Alomía Robles district, Leoncio Prado province, department of Huánuco.

Discussion

Flood hazard

The flood hazard unit that would be caused by an eventual overflow of the Tulumayo River in the study area is high and very high, due to some factors that would influence the area, one of which is the proximity of the population and cultivated areas to the river, as well as the existence of high precipitation categorized as extremely rainy, and the fact that the area is geomorphologically made up of a flood plain and has a slope of less than 15°. These conditions cause the zones to have these levels of danger.

Vulnerability

The vulnerability to which the population settled in the study area is exposed is between high and medium levels, as can be seen in the vulnerability map (Figure 15). Likewise, we note that the population of the Pumahuasi - Huamancoto sector is unaware of basic emergency and hazard prevention behaviors, therefore, they lack a culture of disaster prevention.

Flood risk

Knowing the risk and representing it through risk mapping makes it possible to avoid, reduce and prepare for the occurrence of a disaster. Thus, in the study area there have been several floods caused by the Tulumayo River; these facts confirm the importance of flood risk management. Therefore, to calculate the flooding area, hydraulic modeling was carried out using Hec-HMS software, where it was determined that the maximum flow that the Tulumayo River would reach would be 1177.6 m3/s, for a return period of 75 years. Therefore, for the intervention zone, the total area affected by an eventual flood would be approximately 32.01 ha, affecting crop and housing areas that would generate large losses for the settled population.

Hydraulic Modeling

According to Prieto et al., (2017) in his research he shows that in order to validate the values obtained in precipitation, the sequence of applying the goodness-of-fit test, the flow regime to be considered and, as in the case of a permanent one-dimensional flow and in a mixed regime, must be followed. In addition to the Manning's roughness factor, which is extracted from tables in use and which are valued according to the morphological and land use characteristics, in the delimitation of the flood zone, a digital elevation model and the TIN type were used. Subsequently, the GIS and HEC-RAS extensions were used to create the spatial files of the model, such as the channel, cross sections, among others. Finally, the result is a raster that allows us to characterize the flooding in the study area and thus confirm that for a given return period the hazard, vulnerability and risk is latent near the banks of the Tulumayo River.

Conclusions

The study was developed mainly according to the provisions of the Manual for the Evaluation of Risk Originated by Natural Phenomena 2nd version, by CENEPRED. The study area is in a high and very high danger zone (Figure 14) for the occurrence of fluvial flooding of the Tulumayo River, all due to conditioning factors such as the slope and the material dragged by the force of the flow.

The vulnerability analysis, developed based on the methodology established by CENEPRED, indicates that there are areas with very high, high and medium levels of vulnerability to fluvial flooding.

The District Municipality of Daniel Alomía Robles together with the vulnerable population should take preventive actions such as avoiding settlement in areas considered high and very high risk; and reducing the existing risk in the study area through structural measures such as riparian defense of the river and non-structural measures such as periodic drills. Another option to take into account is the planting of deep-rooted trees along the entire length of the Tulumayo riverbed environment, in order to create a natural physical barrier that prevents the passage of water without altering the landscape system, as recommended by some technical reports.INGEMMET technicians (2011).

The reduction of risks is directly related to vulnerability and above all to generate resilience in the potentially affected community.

References

Cabrera,J., Timbe,L., & Crespo,P. (2019). Evaluación del modelo HEC-HMS para la simulación hidrológica de una cuenca de páramo. Dyna, 86(210), 338-344. doi: https://doi.org/10.15446/dyna.v86n210.70738

Cameron, A.(2005). HEC-Geo RAS, GIS Tools for support of HEC-RAS using Arc GIS. United States Army Corps of Engineers.https://www.hec.usace.army.mil/software/hec-georas/documentation/HEC-GeoRAS_43_Users_Manual.pdf

Caruso, A. (2020). Producción de riesgo de desastre por inundación, técnicas hidráulicas y urbanización de áreas inundables en la localidad de 9 de Abril, Municipio de Esteban Echeverría. Revista del Área de Estudios Urbanos(13), 162-190. https://dialnet.unirioja.es/servlet/articulo?codigo=7448696

Centro Nacional de Estimación,Prevención y Reducción del Riesgo de Desastres-CENEPRED.
(2014). Manual para la evaluación de riesgos originados por fenómenos naturales.Versión 02.https://sigrid.cenepred.gob.pe/sigridv3/documento/257

Córdova, H. (2020). Vulnerabilidad y gestión de riesgo de desastres frente al cambio climático en Piura, Perú. Semestre Económico, 23(54), 85-112. doi:https://doi.org/10.22395/seec.v23n54a5

Erasun, V., Sapriza, G., Failache, N., Gamazo, P., Arcelus, A., & Nardin, A. (2019). Modelación hidrológica para la gestión del riesgo de inundaciones en subcuencas tributarias al río Uruguay. Aqua-Lac, 11(1), 17-33. doi: 10.29104/phi-aqualac/2019-v11-1-02

Gonzáles, E., & Bejarano, E. (2019). Sistemas de información geográfica y modelado hidráulico de redes de abastecimiento de agua potable: estudios de caso en la provincia de Guanacaste,Costa Rica. Revista Geográfica de América Central, 2(63), 293-318. doi:https://doi.org/10.15359/rgac.63-2.11

Instituto Geológico, Minero y Metalúrgico – INGEMMET. (2011). Peligro de erosión e inundación fluvial en el sector de Ambo. Distrito de Ambo, provincia de Ambo-región Huánuco. https://hdl.handle.net/20.500.12544/1816

Instituto Nacional de Defensa Civil-INDECI. (2011). Manual de estimación del riesgo ante inundaciones fluviales. Cuaderno técnico Nº2.

http://repo.floodalliance.net/jspui/44111/1912

Marín, A., & Barros, J. (2016). Modelamiento de tránsito de crecientes en el río Aburrá-Medellín para una propuesta de su restauración. Revista EIA, 13(26), 153-168. https://www.redalyc.org/pdf/1492/149250081011.pdf

Ministerio de Transportes y comunicaciones. (2008). Manual de hidrología, hidráulica y drenaje. https://www.aguasresiduales.info/revista/libros/manual-de-hidrologia-hidraulica-y-drenaje

Municipalidad Distrital de Daniel Alomía Robles,Leoncio Prado,Huánuco. (2020). Informe de evaluación de riesgos por inundación fluvial margen derecha del río Tulumayo,en el sector Pumahuasi-Huamancoto,distrito de Daniel Alomía Robles,provincia de Leoncio Prado,departamento de Huánuco.

http://sigrid.cenepred.gob.pe/sigridv3/documento/9644

Prieto,J., Martínez-Alegría,R., Taboada, J., Montequi, I., & Sanz, G. (2017). Rotura de la presa de Vega de Tera,simulación hidráulica de la propagación de la avenida (Zamora,España). Dyna, 84(203), 45-54.

doi:https://doi.org/10.15446/dyna.v84n203.60544

Ramos, A., & Pacheco, J. (2017). Análisis hidrológico e hidráulico de la cuenca del Río Frío,municipios de Ciénaga y Zona Bananera,departamento del Magdalena. Revista Logos,Ciencia & Tecnología, 9(1), 156-178. doi:https://doi.org/10.22335/rlct.v9i1.302

Ribera, L. (2004). Los mapas de riesgo de inundaciones: Representación de la vulnerabilidad y aportación de las innovaciones tecnológicas. Documents d' anàlisi geogràfica(43), 153-171. https://raco.cat/index.php/DocumentsAnalisi/article/view/31812

Rodriguez, D., Torrealba, W., & Rincón, J. (2019). Evaluación de herramientas de entorno "SIG" y sus aplicaciones en la modelación hidráulica de ríos. Gaceta Técnica, 20(1), 79-93. doi:10.13140/RG.2.2.14560.94728

Sánchez, S., Carrera, L., & Aguinaga, S.(2020). Vulneración de los derechos humanos ante los desastres naturales en el Perú. EDUCARE ET COMUNICARE: Revista de Investigación de la Facultad de Humanidades, 8(2), 88-95. doi:https://doi.org/10.35383/educare.v8i2.474

Soria-Díaz, H., Camarasa-Belmonte, A., & Carmona-Gonzáles, P. (2015). Riesgo de inundación de la ciudad de Iquitos,Perú. Ciencia Amazónica, 5(1), 11-24. doi:https://doi.org/10.22386/ca.v5i1.86

Triviño,A., & Ortiz, S. (2004). Metodología para la modelación distribuida de la escorrentía superficial y la delimitación de zonas inundables en ramblas y ríos-rambla mediterráneos. Investigaciones geográficas(35), 67-83.

https://www.redalyc.org/articulo.oa?id=17603504

Vera, J., & Albarracín, A. (2017). Metodología para el análisis de vulnerabilidad ante amenazas de inundación, remoción en masa y flujos torrenciales en cuencas hidrográficas. Ciencia e Ingeniería Neogranadina, 27(2), 109-136. doi:http://dx.doi.org/10.18359/rcin.2309