Migration Letters

Volume: 21, No: S6 (2024), pp. 1693-1706

ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online)

www.migrationletters.com

Evaluation Of The Flow Discharge Of The Quillcay River Sub-Basin – Peru In The Face Of Climate Change

Flor Jara[1,2*], Alexzander Santiago[1], Abel Mejía[2], Pedro Colonia[1], Teófanes Mejía[1] , Gerardo Revelo[1]

Abstract

In recent decades, climate change has had an impact on meteorological alterations, so in many places they are leading to the high rainfall and droughts manifested by ENSO (El Niño Southern Oscillation). Geospatial technologies, together with hydrometeorological information, have made it possible to make hydrological studies more accurate and detailed. In this research, a methodology for flow discharge is proposed using HEC-RAS (Hydrological Engineering Center – River Analysis System) and flow data modeled by SWAT (Solid and Water Assessment Tool) and HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System). 4 evaluation periods were determined during 1986 to 2016; In addition, 2 February dates of high occurrence of ENSO were determined, 1998 and 2016. The average results obtained for the depth time series are a mean of 3.75 m and a standard deviation of 3.19, minimum of 0 and maximum of 26.24m. The results in ENSO were depth ranging from 0 to 15 m, velocity from 0 to 2 m/s and WSE is from 837 to 902 m.

Keywords: *HEC-RAS, SWAT, DEM, drone, orthomosaic.*

Introduction

Climate change has im[1]posed challenges on studies of water resources in urban areas (Ávila, 2012). It has been reflected in the constant changes of the hydrological cycle with fluctuations in the parameters of precipitation, evapotranspiration, soil moisture and discharge of river flows. Changes or intensifications of the hydrological cycle will increase exposure to water resource stress and consequently to the risk of floods and droughts. Research has shown that many of the global impacts such as climate change and the El Niño phenomenon are directly related to water sources and that rivers are ecosystems sensitive to climate extremes (Gómez, 2022).

The importance of water resources lies in the relationship with climate change in atmospheric changes and precipitation processes such as evaporation that occur in the short and long term (Duque-Sarango et al., 2019). Global changes involving simultaneous and rapid changes in both land surface temperature and vegetation and soil cover are implying significant and evident changes in the water balance (Aber et al., 2001).

[1] Universidad Nacional Santiago Antúnez de Mayolo (UNASAM), Av. Universitaria s/n, Independencia, Huaraz, Ancash, Perú.
[2] Programa de Doctorado en Recursos Hídricos, Universidad Nacional Agraria La Molina (UNALM), Lima, Perú.
*Correspondence:
Flor Ángela Jara Remigio, PhD Program in Water Resources, Universidad Nacional Agraria La Molina (UNALM), Lima, Peru.
Professor at the Faculty of Agrarian Sciences of the Universidad Nacional Santiago Antúnez de Mayolo (UNASAM), Huaraz, Ancash, Peru.

The identification in the field of flood-prone sectors or the evaluation of flow discharges must be previously oriented. This is where hydraulic simulation becomes important through the use of specialized software and Geographic Information Systems. These facilitate the management of spatial data and its representation, providing a more integrated and detailed view of the region under study. They also make it possible to represent the information generated by the running of mathematical models in the form of maps, which constitutes an important support for work in Hydrology and Geomorphology (Garrido et al., 2013).

In the Quillcay sub-basin, the water network is crisscrossed by the melting of part of the Cordillera Blanca, the seepage of the lakes at the head of the basin and the effective precipitation, the resulting flow crosses the city of Huaraz and flows into the Santa River. At the same time, the volume of glaciers in the sub-basin has been decreasing, this quantification of glacier volume shows that tropical glaciers in the sub-basin lost 2.73 percent of volume, which represents an average of 36% of glacier melt in the last 35 years. (Jara et al., 2023a)

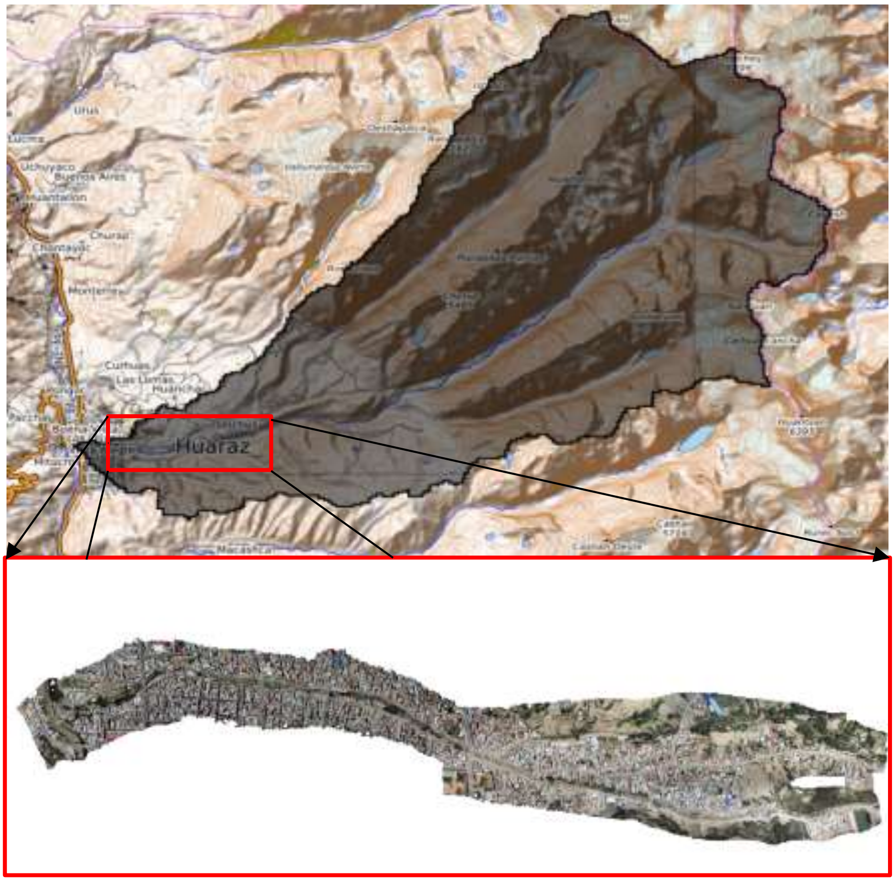
Methodology

2.1 Case study and localization

The study area comprises a segment of the sub-basin of the Quillcay River, exactly in the section of the city of Huaraz, which runs from the confluence of the Auqui and Paria rivers, and ends its discharge into the Santa River.

The sub-basin of the Quillcay River is located between the districts of Independencia and Huaraz, both districts in the northeastern part of the province of Huaraz. It borders the provinces of Huari and Carhuaz. It has an area of 247.38 km2, a perimeter of 110.10 km and an average altitude of 4232.24 meters above sea level. (Jara et al., 2023a; Jara et al., 2023b). The waters drain along the right bank of the Santa River basin and have their origin in the Cojup Creek, form the Paria River, down the course and after the formation by confluence of the Auqui River, take the name of Quillcay. The river runs through the main city of Huaraz and flows into the Santa River (Meza et al., 2016).

Figure 1: Study area, Quillcay River sub-basin



Source: (Jara et al., 2023a)

2.2 Data Source and Software

Flow data

The flow data source was obtained from the application of the SWAT and HEC-HMS models. The SWAT model is entered sequentially into the ArcSWAT interface within the ArcGIS software. The results obtained are based on meteorological data from PISCO (Peruvian Interpolation Data of the Climatological and Hydrological Observations of SENAMHI) such as precipitation, maximum and minimum temperature. The model establishes a monthly scale period for the period 1983-2016 where the first 3 years were used as a test period for the model, to eliminate unknown initial biases. From the 9 hydrographic subunits delimited by SWAT from the Digital Elevation Model (DEM), it was carried out from January 1986 to December 2016 and daily flows were generated in^{m3}/s. (Jara et al., 2023b)

As for the model in HEC-HMS, the 12.5m DEM is processed and the division of the hydrographic subunits is obtained. The time period of the model spans from 1986-2016, in which meteorological data from PISCO (Peruvian Interpolation Data of the Climatological and Hydrological Observations of SENAMHI) were considered with daily precipitation data and average monthly evapotranspiration data.

Table 1: Average flow from 1986 to 2016

Date	SWAT	HEC-HMS	Average flow rate (m3/s)
1/01/1986	13.76	37.40	25.58
1/02/1986	19.70	27.30	23.50

1/03/1986	8.56	18.50	13.53
1/04/1986	19.41	34.10	26.76
1/05/1986	3.62	2.10	2.86
1/06/1986	1.44	0.00	0.72
1/07/1986	0.43	0.00	0.22
.	.	.	.
.	.	.	.
1/08/2016	0.01	0.00	0.01
1/09/2016	1.59	0.00	0.80
1/10/2016	2.94	8.20	5.57
1/11/2016	0.35	1.20	0.78
1/12/2016	9.56	23.10	16.33

The average generated by the two models, the SWAT and HEC-HMS (Jara et al., 2023b), was used in the simulation of the flow discharge in the section of the lower Quillcay River that runs from the junction of the Auqui and Paria rivers to the mouth of the Santa River.

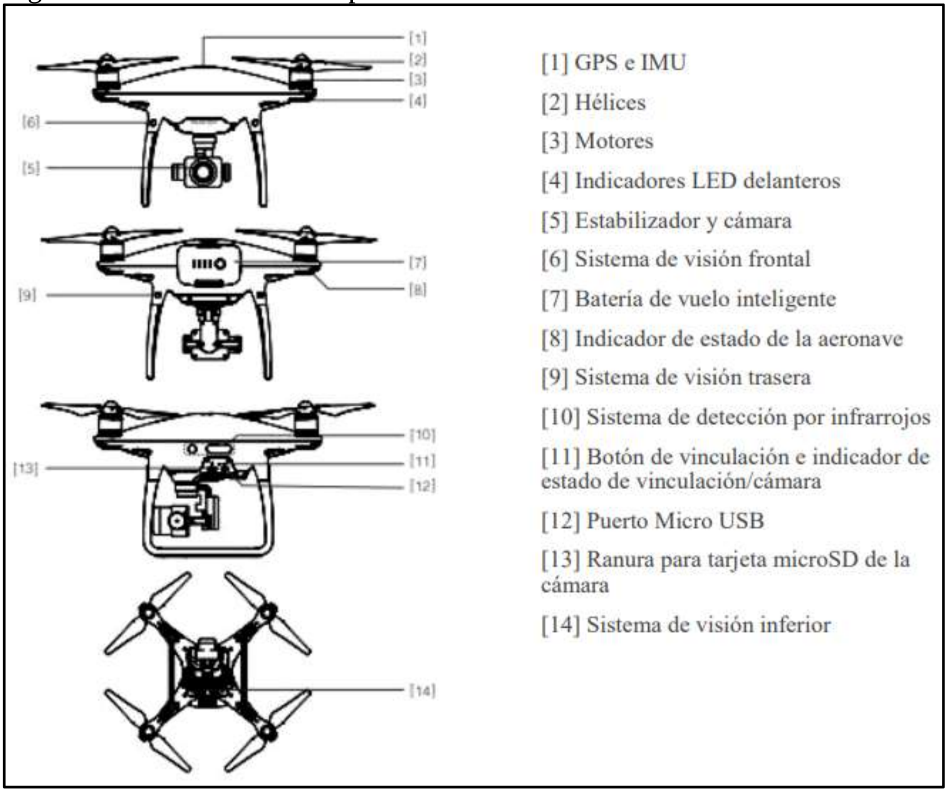
Dem and Orthomosaic

The Digital Elevation Model (DEM) of 0.25m spatial resolution using the Phantom 4 pro drone. The DEM generated from the earth's surface contains information about the altitude or elevation of the earth at different points, it will be used for research in the simulation of flow discharge. The Phantom 4 Pro drone is a high-quality photography and video drone produced by DJI. It has the ability to take a set of high-quality images and videos and can be used to capture aerial imagery to create orthomosaics.

The DJI Phantom 4 Pro is a high-quality photo and video drone with the following features:

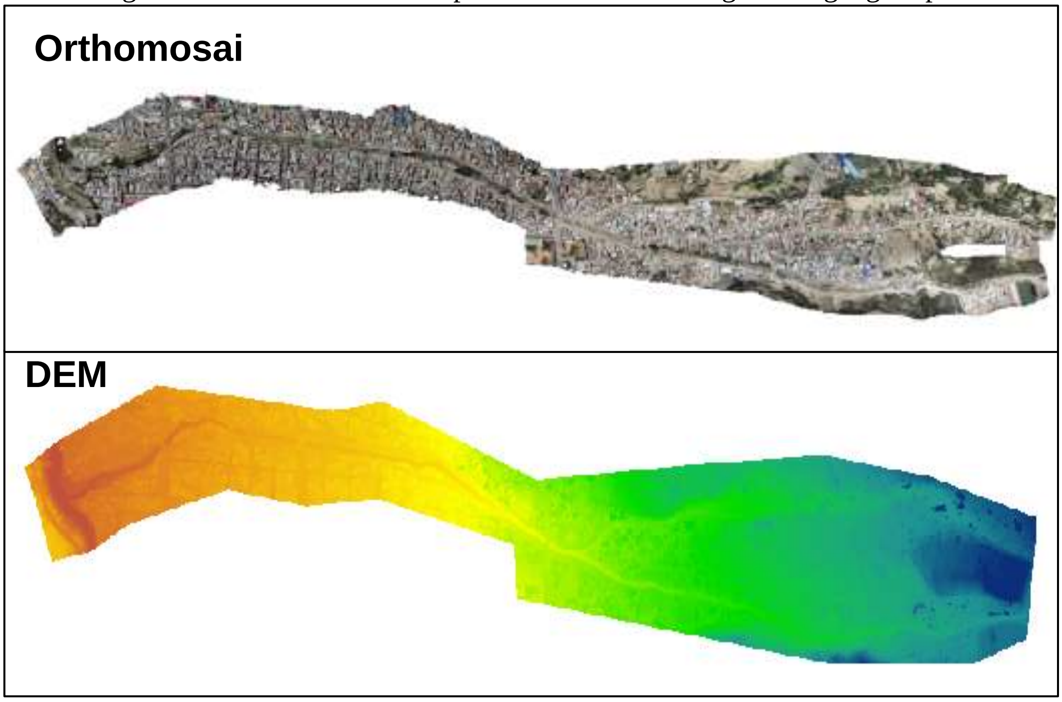
- 20-megapixel camera with image stabilization: The Phantom 4 Pro's camera is capable of capturing high-resolution images and 4K videos at 60 frames per second. It has an f/2.8 aperture lens and a mechanical image stabilizer to minimize the effect of motion and improve image quality.
- Fast Flight Speed: The Phantom 4 Pro can fly at a maximum speed of 72 km/h and has a maximum flight time of 30 minutes.
- Advanced Navigation System: The Phantom 4 Pro has a navigation system that includes vision and laser sensors to avoid obstacles and maintain stable flight. It also has a "follow me" flight mode that allows the drone to follow and film the user.
- Flight Control and Real-Time Video Streaming: The Phantom 4 Pro comes with a remote control that allows the user to control the flight and view the video in real-time through a built-in display. It also has a real-time video streaming feature over a WiFi connection, allowing you to watch the video on a mobile device or computer.
- Weight & Dimensions: The Phantom 4 Pro weighs 1.38 kg and measures 29.8 x 8.3 x 20.8 cm.

Figure 2: Parts of Phantom 4 pro



Source: Excerpted from (Phantom 4 Pro/ Pro + User Manual, 2020)

Figure 3: Georeferenced orthophoto and DEM. In original language: Spanish



Software

HEC-RAS (Hydrological Engineering Center – River Analysis System). The software is capable of performing calculations of water surface flows, uniform and varied flow calculations, sediment transport, steady-state and non-steady-state flow modeling, sediment transport modeling, and water quality analysis (Cartaya, 2016).

As Cartaya (2016) points out, HEC-RAS is a software used for the analysis and simulation of water flows in rivers and canals. There are several types of simulations that can be performed with HEC-RAS, including:

- One-dimensional flow simulation: This simulation analyzes the flow of water in a canal or river in a single dimension, i.e., on the horizontal axis. It is used to predict the depth, velocity, and distribution of current along the channel cross-section.
- Two-dimensional flow simulation: This simulation analyzes water flow in two dimensions, i.e., on the horizontal axis and on the vertical axis. It is used to predict the distribution of current in the cross-section of the channel, as well as the distribution of velocity and depth in the cross-section.
- Three-dimensional flow simulation: This simulation analyzes the flow of water in three dimensions, i.e., on the horizontal axis, on the vertical axis, and on the longitudinal axis of the channel. It is used to predict the distribution of current across the entire cross-section of the channel, as well as the distribution of velocity and depth across the entire cross-section.
- Flood simulation: This simulation analyzes the flow of water in a flood zone and predicts the water level in the area during a flood. It is used to assess flood risk and to develop flood management plans.

2.3 Procedure and application of the methodology

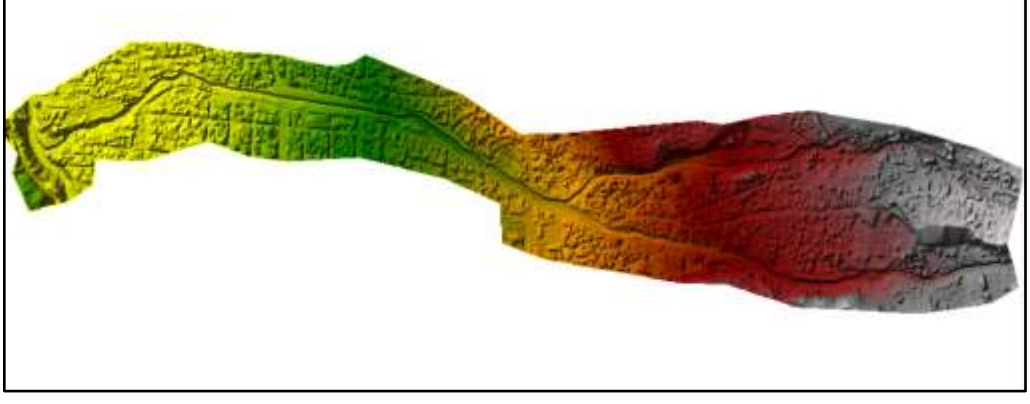
We start with obtaining high-resolution terrain data to perform the simulation. To do this, a flight plan is made with the Phantom 4 Pro drone that consists of:

- The flight area selection of the section comprising the Quillcay River in the city of Huaraz which is located from the confluence of the Auqui and Paria rivers to the Santa River.
- Monitoring the flight area and ensuring that it is free of obstacles and restrictions.
- The flight was made at an altitude of 80m with a constant flight, with the right weather conditions and light between 10am and 2pm.
- The drone was configured to take the images for mapping.
- Download the flight images.

Once the flight plan for taking drone images has been made, post-processing is carried out for the generation of the orthophoto and the point cloud. Agisoft Photoscan software was used to import the images and make parameter adjustments for processing. In this processing, low-quality images are removed and correlation sensitivity is realized.

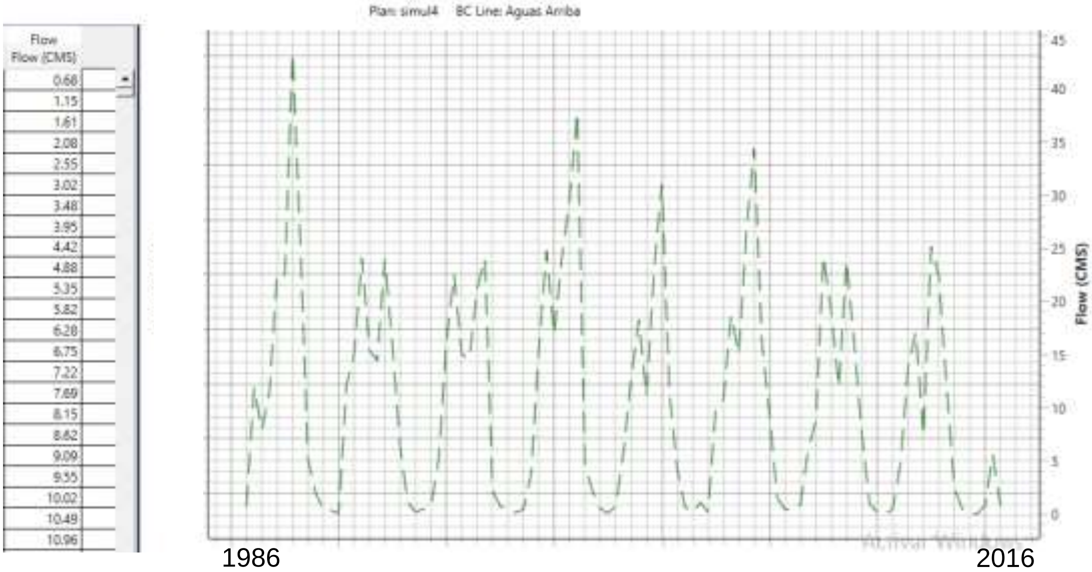
From the point cloud, the Digital Elevation Model (DEM) with a spatial resolution of 0.25m was generated.

Figure 4: RAS Terrain of the DEM



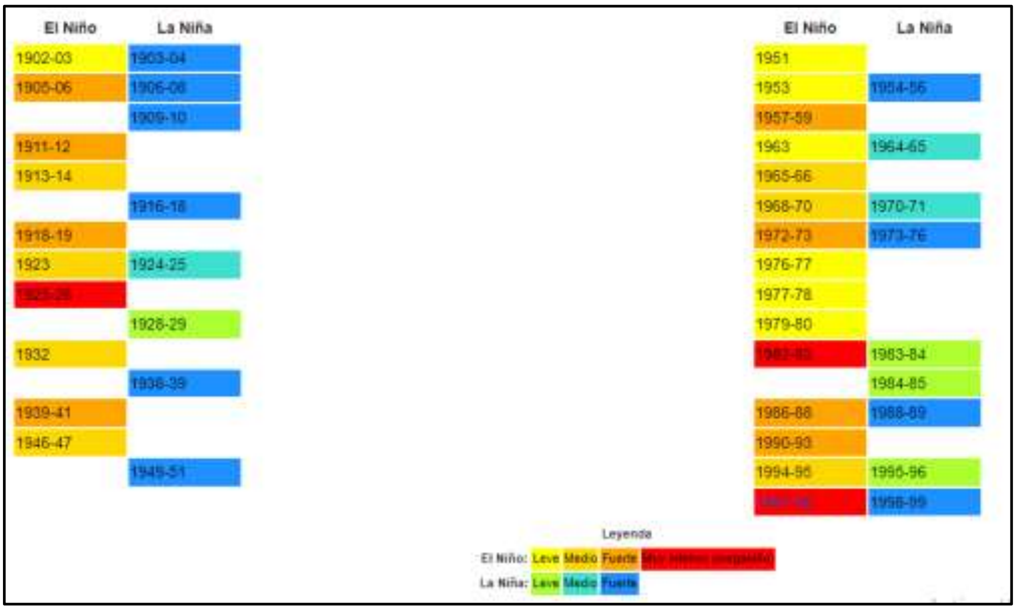
Taking the data provided by the SWAT and HEC-HMS model of subunits 9 and 4 respectively of the Quillcay River subbasin (Jara et al., 2023b), and averaging the data from both models, periods of climate change analysis were established to perform the simulation in HEC-RAS.

Figure 5: Average flow of the Quillcay River from 1986 to 2016



Source: Authors' own creation

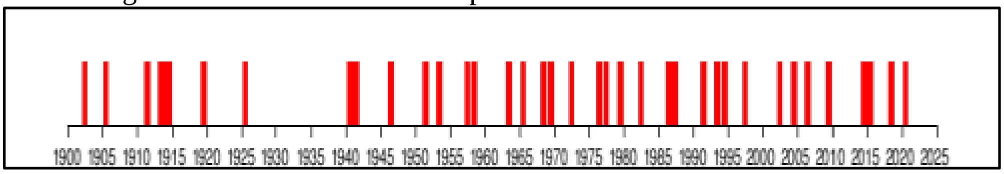
Climate change occurs when an anomaly arises in one of the components of the ocean-atmospheric system of sufficient magnitude to alter its balance. There are three major oscillations that inversely relate the atmospheric pressures at various locations: the North Atlantic Oscillation, the North Pacific Oscillation, and the Southern Oscillation. The most important of these, due to its impact on the global climate, is the Southern Oscillation (Fuentes, 2000).



Source: (Wikipedia, 2021)

Mainly El Niño-Southern Oscillation, ENSO or ENSO is part of climate change and some of the events classified as very strong children or historical megachildren would be the following: 1891 Niño, probable coastal El Niño (local event with no major global influence), 1925-26 El Niño (begins with the 1925 coastal El Niño), 1982-83 Niño, 1997-98 Niño and 2014-16 Niño (ends with the 2017 coastal El Niño); 10 Very Strong Events in 475 Years (Wikipedia, 2022).

Figure 7: Timeline of El Niño episodes between 1900 and 2020.

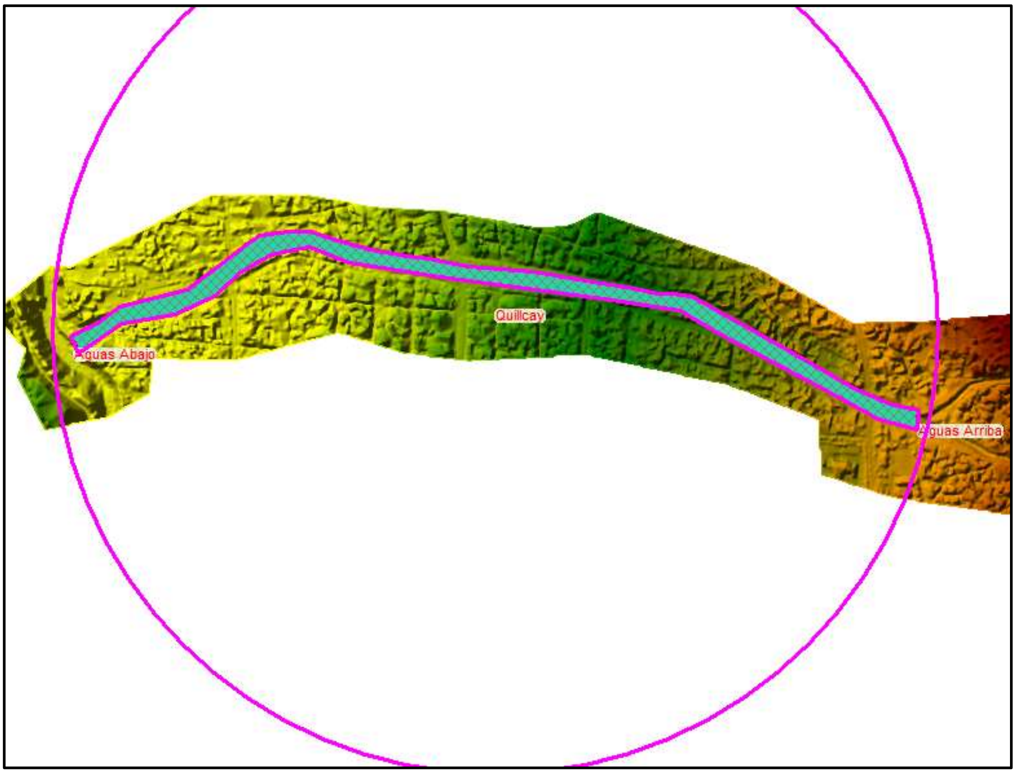


Fountain: (Wikipedia, 2022)

For the present research, the periods of Niño 1997-98 and Niño 2014-16 were chosen based on flow data from 1986 to 2016. In addition, periods of absence from El Niño were taken.

The mesh simulation in HEC-RAS was performed using a network of 10 x 10 separation cells to model the discharge into the Quillcay River. Establishing the "Upstream" and "Downstream" direction baseline.

Figure 8: Mesh geometry in HEC-RAS

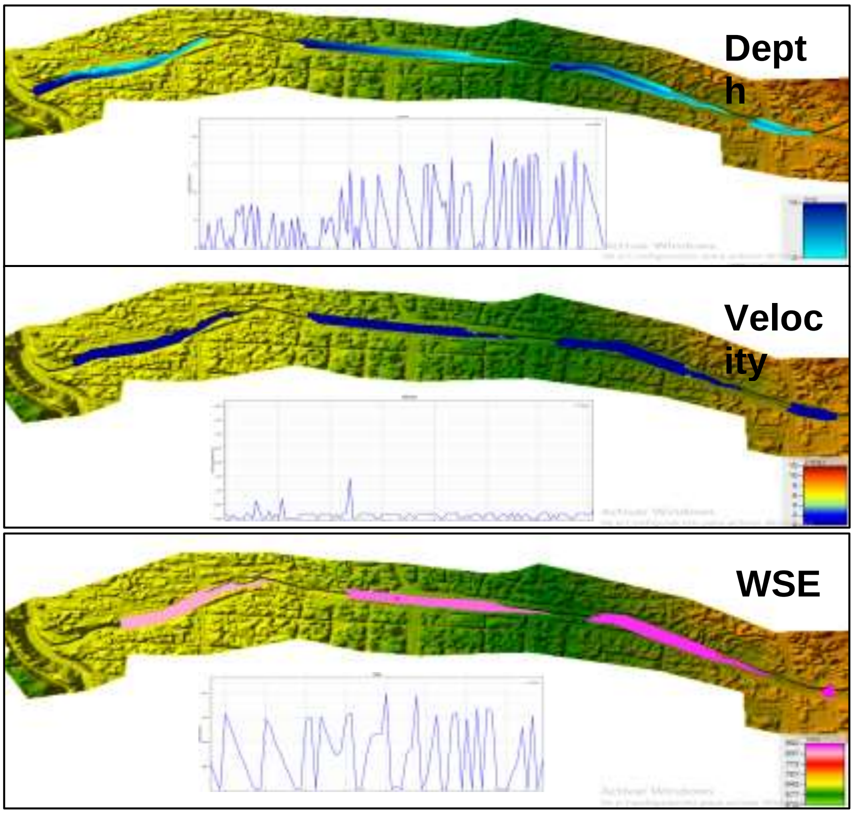


"Unsteady Flow Data-Flow" in HEC-RAS was chosen for flow discharge because this method is unstable flow that changes over time and is characterized by fluctuations in water velocity and height. The unstable simulation was performed specifying the time flow data per month from 1986 to 2016 and the flow rate for each date. In addition, the frequency of output of the results of each month with which these data are updated was established. This allows HEC-RAS to calculate the flow through the river at different points in time and show how the flow changes over time. In short, unstable flow data is flow data that varies over time and is used to simulate unstable flow in HEC-RAS.

Results and discussion

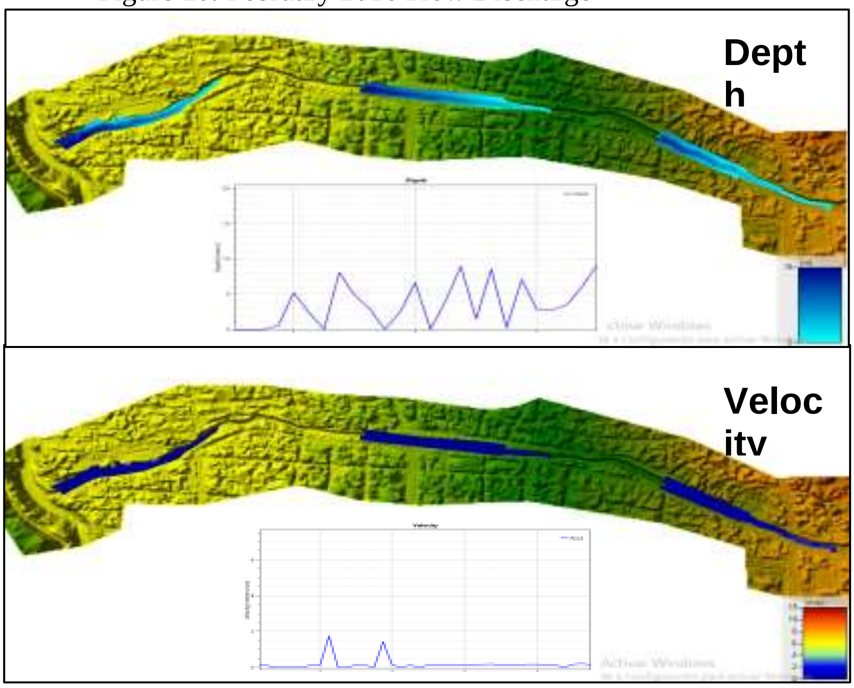
The visual representation of the dynamics of the flow discharges in the Quillcay River in the face of climate change is possible by performing an analysis of the ocean-atmospheric disturbances caused by the El Niño phenomenon at a global and regional level due to the alterations of rainfall and consequently the level of flow in the main rivers of Peru. The results obtained for February 1998, the season of high rainfall throughout the Peruvian highlands, the depth varies from 0 to 15 m deep.

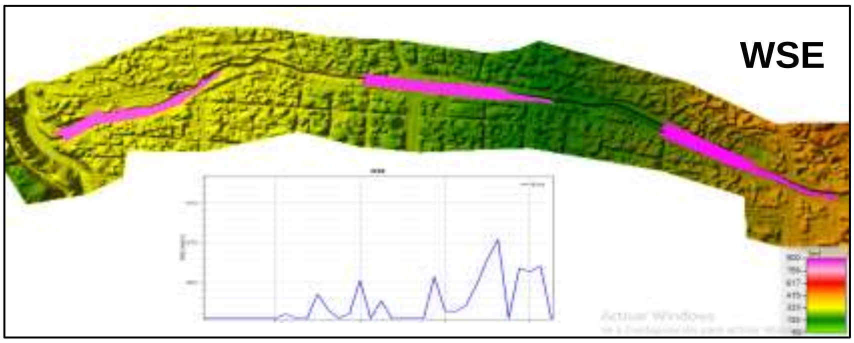
Figure 9: February 1998 flow discharge



The velocity of the amount of water flowing into the Quillcay River in a given period. The average results obtained vary from 0 to 2 m/s and at some points on the banks of the river that are adjacent to the buildings the speed is from 4 to 15 m/s. As for the elevation of the water surface, which refers to the height of the water surface, it is 837 to 902 m. WSE results may vary over time due to factors such as precipitation, evaporation, and infiltration.

Figure 10: February 2016 Flow Discharge





The results obtained for February 2016 show that the depth varies from 0 to 15 m deep. The velocity in the Quillcay riverbed in a given period, the average results obtained vary from 0 to 2 m/s. As for the elevation of the water surface it is from 758 to 900 m.

Depth, Velocity, and WSE Time Series

The results obtained from the time series for the discharge of flow by depth (Depth), for the first period from 01/01/1986 to 01/04/1994, have a mean of 3.7 and standard deviation of 3.15; The minimum is 0 and the maximum depth of discharge is 24.31m. In the period from 01/05/1994 to 01/08/2002, there was a mean of 3.9 and standard deviation of 3.34, the minimum value is 0 and the maximum depth is 22.45. For the period from 01/09/2002 to 1/12/2010, there is a mean of 3.6 and standard deviation of 3.06, the minimum value is 0 and the maximum depth is 23.04m. Finally, for the period from 01/09/2008 to 31/12/2016, there is a mean of 3.8 and standard deviation of 3.21, the minimum value is 0 and the maximum depth is 26.24m.

Figure 11: Flow discharge by depth from 1986 to 2016

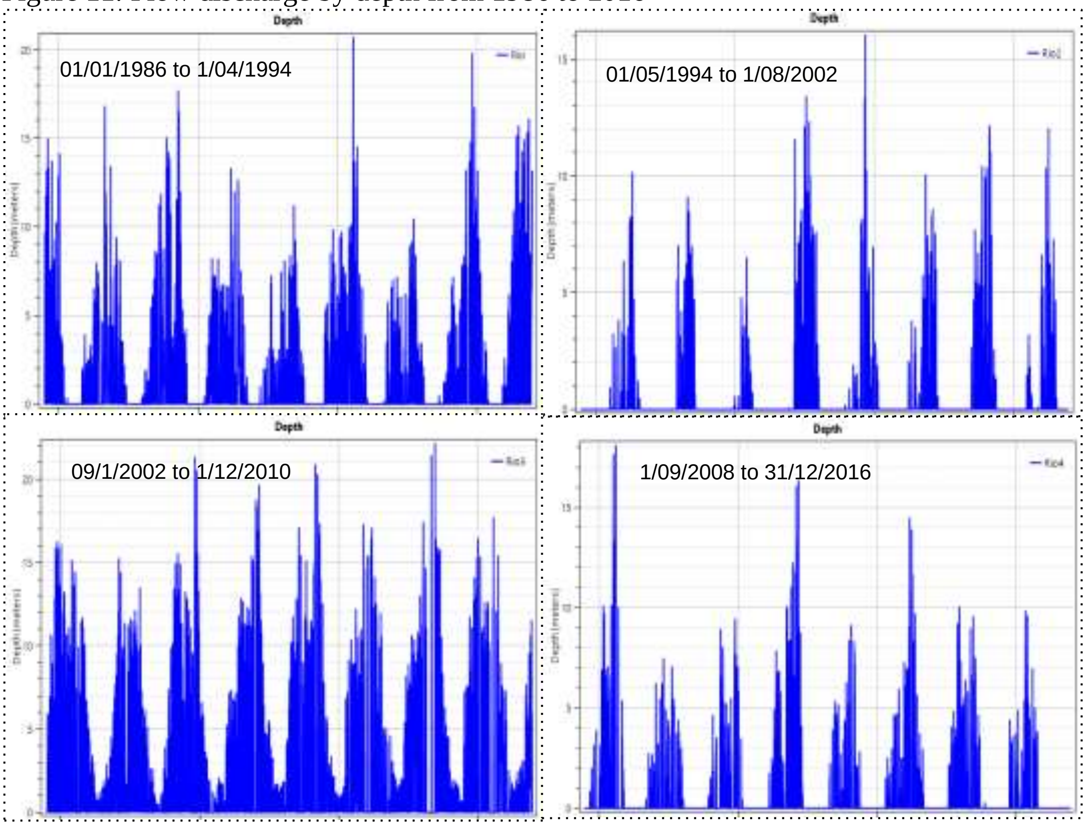


Figure 12: Download speed from 1986 to 2016

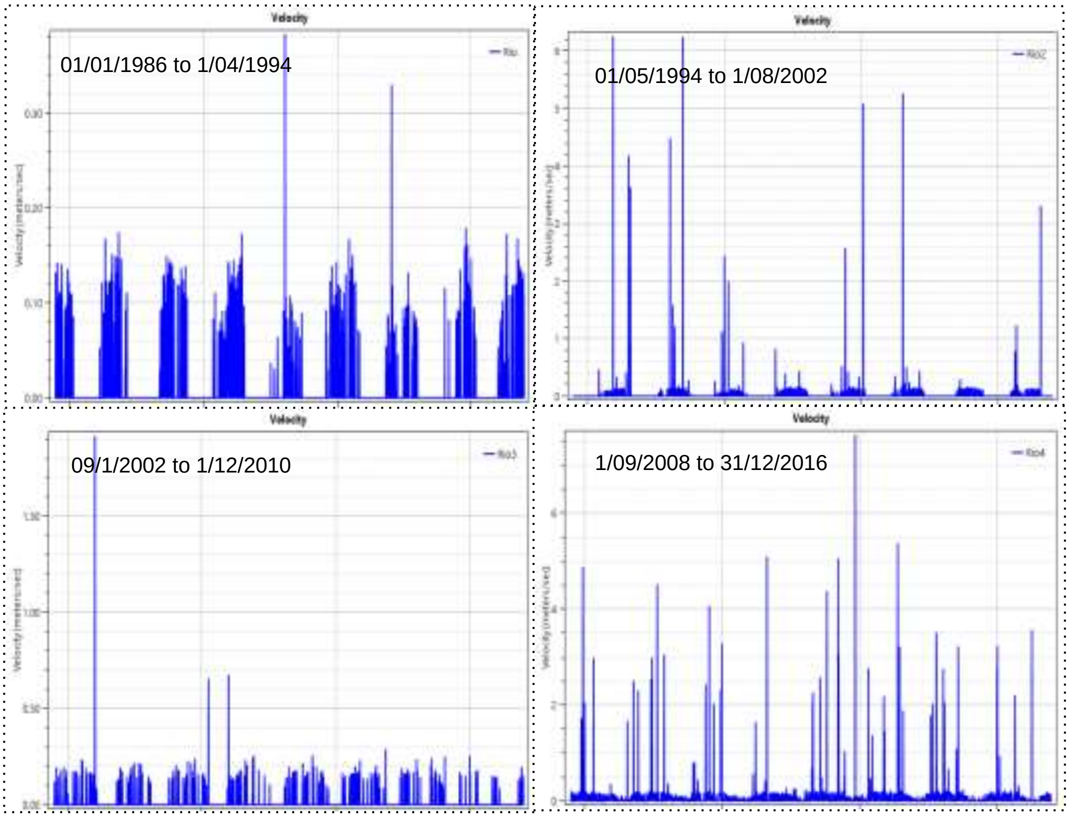
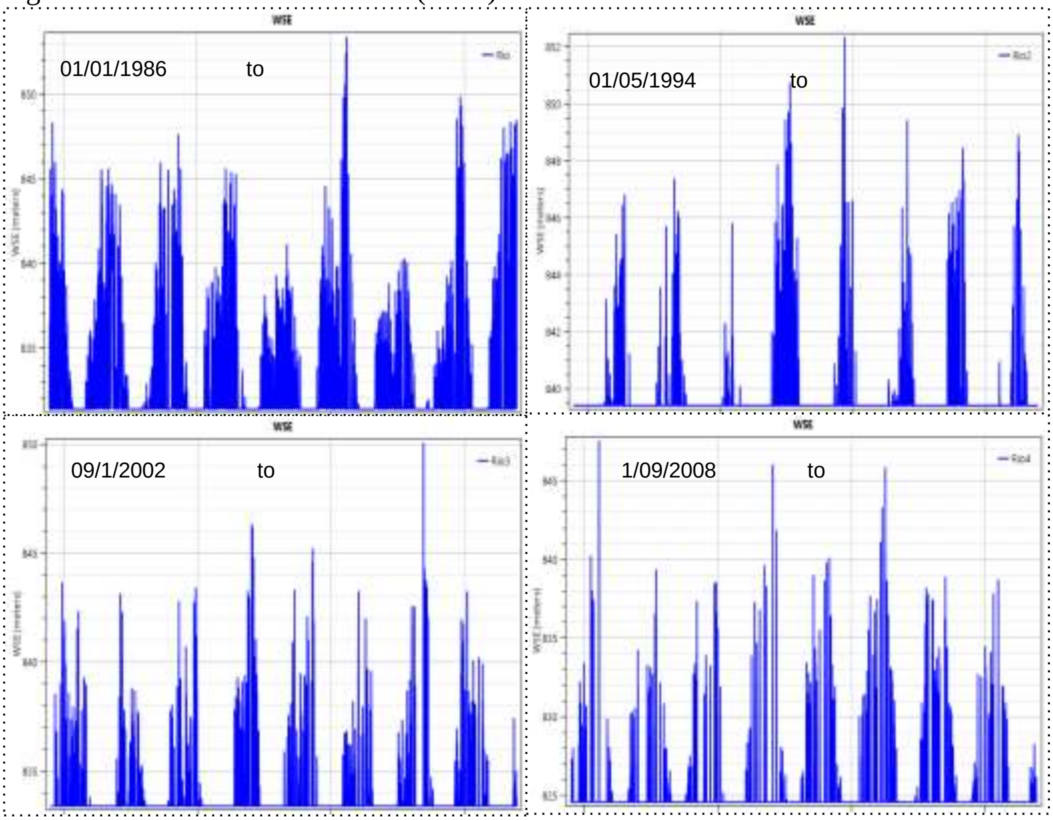


Figure 13: Water surface elevation (WSE) from 1986 to 2016



The results obtained are highly variable and the ocean-atmospheric alterations that have an impact on the atmospheric conditions with the El Niño phenomenon in Peru. There is a particularity of the occurrence of ENSO (El Niño Southern Oscillation) in 2016, which caused the prolonged absence of snow cover in the snow-capped mountains of Yanapaccha and Shallap of the Cordillera Blanca compared to previous years, even during the months of highest precipitation from December to April (Sánchez, 2019). With respect to this research carried out by Sánchez (2019), it can be confirmed that there was no variability of the flow discharge in the Quillcay sub-basin.

In the research carried out by Cartaya in 2016, they obtained results from affected areas of 18.7 km2. Simulated annual river flood patches with HEC-RAS provide information on the location of overflow zones and potential agricultural land that is at risk. Establishing the flow discharge for the identification of areas at risk of flooding through hydraulic simulation in a segment of the Pescadillo River, Manabí, Ecuador (Cartaya, 2016).

The research carried out by Briongos in 2016 shows that the modelling of the advance of the wavefront in the Salce dam break has given very similar results with the two sizes of the calculation mesh. It has been influenced by having modified the time interval from 10s to 1s in the 15x15m mesh, since with the passage of time of 10s the results were quite different. Therefore, some inconsistencies are observed in the combination of 1D/2D modelling (Briongos, 2016).

Conclusion

The data generated are useful because they provide information on the extent, depth, and location of the modeling sections in the Quillcay River, with very good accuracy with the DEM and having hydrological flow data for discharge. The information obtained can be validated with the on-site data.

In future research, the research carried out on flow discharge in the Quillcay River sub-basin will allow the further development of flood risk studies, as well as calibration, as problems are solved in future versions of HEC-RAS. And the very new numerical model applied, of which there is very little experience, adjustments were made to different elements necessary for hydraulic modeling.

The methodology developed can be applied to other high Andean sites with similar characteristics with the necessary information and hydrological data.

References

Aber, J., Neilson, R. P., McNulty, S., Lenihan, J. M., Bachelet, D., & Drapek, R. J. (2001). Forest Processes and Global Environmental Change: Predicting the Effects of Individual and Multiple Stressors: We review the effects of several rapidly changing environmental drivers on ecosystem function, discuss interactions among them, and summarize predicted changes in productivity, carbon storage, and water balance. BioScience, 51(9), 735-751. https://doi.org/10.1641/0006-3568(2001)051[0735:FPAGEC]2.0.CO; 2

Ávila, H. (2012). Perspective of storm drainage management in the face of climate change - case study: City of Barranquilla, Colombia*. Journal of Engineering. https://doi.org/10.16924/revinge.36.10

Briongos, G. (2016). Two-dimensional modelling of free-sheet water flow using the new tool Hec-Ras 5.0 [Bachelor thesis, Universitat Politècnica de Catalunya]. https://upcommons.upc.edu/handle/2117/104694

Cartaya, S. (2016). Identification of areas at risk of flooding through hydraulic simulation in a segment of the Pescadillo River, Manabí, Ecuador. Article 40.

Duque-Sarango, P., Patiño, D. M., & López, X. E. (2019). Evaluation of the HEC-HMS Hydrological Modeling System for the Hydrological Simulation of a Tropical Andean Microbasin. Technology Information, 30(6), 351-362. https://doi.org/10.4067/S0718-

07642019000600351

Fuentes, J. L. (2000). Introduction to meteorology and climatology. Mundi Prensa Libros. https://dialnet.unirioja.es/servlet/libro?codigo=67429

Garrido, M., Gómez, M. R., & León, A. (2013). Automated flood hazard early warning system. Hydraulic and Environmental Engineering, 34(3), 30-43.

Gómez, A. C. (2022). Methodological proposal for the estimation and analysis of the impact of climate change scenarios on the water quality of tropical mountain rivers. Case Study: Bogotá River - Colombia. https://repositorio.uniandes.edu.co/handle/1992/54570

Flor Jara, Abel Mejía, Teófanes Mejía, & Gerardo Revelo. (2023). ESTIMATION OF DEGLACIATION IN THE SUB-BASIN OF THE QUILLCAY RIVER –PERU, IN THE FACE OF CLIMATE CHANGE. Ann. For. Res, 66(1). https://doi.org/10.5281/zenodo.7860578.

Flor Jara, Abel Mejía, Pedro Colonia, Teófanes Mejía, & Gerardo Revelo. (2023). Evaluation of hydrological models in SWAT and HEC-HMS with potential application to the particular characteristics of the sub-basin of the Quillcay River-Peru . Migration Letters, 20(S8), 534–547. Retrieved from https://migrationletters.com/index.php/ml/article/view/4629.

Meza, H. M., Balabarca, H. V., Pereda, J. R., Rosario, A. M., & Vidal, D. O. (2016). CHARACTERIZATION INFORMATION OF THE QUILLCAY RIVER SUB-BASIN. https://www.inaigem.gob.pe/wp-content/uploads/2019/05/Informe-Quillcay.pdf

Phantom 4 Pro/ Pro + User Manual. (2020). Phantom 4 Pro—Download Center—DJI. DJI Official. https://www.dji.com/downloads/products/phantom-4-pro

Sánchez Rodríguez, W. E. (2019). Impact of black carbon on the melting of the Yanapaccha and Shallap glaciers of the Cordillera Blanca, period 2014–2016.

Wikipedia. (2021). List of El Niño and La Niña events in the 20th century. On Wikipedia, the free encyclopedia. https://es.wikipedia.org/w/index.php?title=Anexo:Eventos_de_El_Ni%C3%B1o_y_La_Ni%C3%B1a_en_el_siglo_XX&oldid=133602698

Wikipedia. (2022). El Niño (phenomenon). On Wikipedia, the free encyclopedia. https://es.wikipedia.org/w/index.php?title=El_Ni%C3%B1o_(fen%C3%B3meno)&oldid=147783960