Monitoring and Control System for Flood Forecasting Forehead of Climate Change and the "El Niño" Phenomenon

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Abstract

Floods are natural phenomena that develop due to natural and/or anthropic factors actions. Floods are the most expensive environmental hazard in property damage costs and loss of life. El Niño-Southern Oscillation (ENSO) is an atmospheric phenomenon in the eastern equatorial Pacific Ocean. Scientific evidence shows that ENSO is decisive in Ecuador's climatic behavior. GESTINA (GESTión INtegral del Agua) software is introduced. GESTINA is an early warning system for flooding. This software was designed for flood forecasting in extraordinary rainfall episodes. Its primary purpose is warning flood beginning based on rainfall intensity data registered. GESTINA was coded, including a geostatistical module to estimate flood flows for different return periods. The code was linked to HECRAS software to get additional hydraulic information. GESTINA receives precipitation data from a weather station in a constant increment time (5 min). Precipitation data is used for GESTINA to get runoff flow, water depth, flow velocity, and other hydraulic information. Every new precipitation data entered automatically updates hydraulic basin information. The comparison allows for forecasting the time at which a flood will occur. The software was applied in the Loja basin (Ecuador). Loja basin digital hydrological model was made. It was calibrated with historical city flood data. The difference between measured and calculated data is from 2 to 7%, and a 5% difference in flows measured at the Ecuadorian National Institute of Meteorology and Hydrology gauging station. GESTINA is a universal tool that will help predict floods in real time, avoiding the possibility of human and economic losses.

1 Introduction

Floods are a natural phenomenon associated with extraordinary rain events that are repeated with a period of return. The "El Niño" phenomenon, climate change, and the creation of large impervious surfaces due to the growth of paved urban areas or obsolete drainage networks contribute to increasing flood episodes. This entails an increased risk of floods that usually have economic consequences, loss of human life, destruction of property, roads, etc. (Fortnam et al., 2021).

In Ecuador, phenomena such as "El Niño" generate extraordinary rain events that cause flooding in cities and fields. It is necessary to design a tool that quantifies and anticipates floods, to increase the quality of life (Aguirre et al., 2019).

Among the strategies, the development of computer tools in real time is proposed, aimed at forecasting floods with enough time to allow an immediate reaction in the decision-making of the competent authorities (Bhardwaj et al., 2021). Furthermore, the generated information makes it possible to analyze the risk of flooding (Nicholls, 2001).

The application of the software in the control basin of the city of Loja allowed us to calibrate the generated software's results and know the main threats related to the flood episodes that affect the studied area (Huang et al., 2020).

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2 Methods

The project was divided into five phases:

(1) The **project's first phase** corresponds to the collection of information that includes maps and plans of the sector, general data of the study area, and hydrometeorological information from the National Institute of Meteorology and Hydrology (INAMHI).
(2) In the **second phase**, the geomorphological parameters of the Loja city basin were determined.
(3) In the **third phase**, the Gumbel method determined precipitations for different return periods. Likewise, a conventional hydrological analysis estimated the maximum flood flows for the same return periods.
(4) In the **fourth phase**, the hydrological model was developed from the information generated in the previous phases using Hec-Ras. The results were calibrated with historical flood information, flow data from INAMHI, and measures taken "in situ". The results of risk and flood zones are visualized in ArcGis.
(5) In the **fifth phase**, the GESTINA software was coded and linked to a city rain gauge that sent precipitation data every 5 min. GESTINA estimates every 5 min the values of flow and intensity of rain, among others, and compares them with the results obtained in the fourth phase. The comparison allows for forecasting the time in which a flood could occur.

3 Results

The basin of Loja comprises three rivers: Malacatos, Zamora Huayco, and Zamora. The Malacatos River basin has an area of 62.33 km^2, while the Zamora Huayco and Zamora River basins are 40.59 km^2 and 130.95 km^2, respectively. The maximum precipitation varies between 43.25 mm for a return period of 25 years to 76.94 mm for a return period of 1000 years. In addition, the surface flow values range according to the values indicated in Table 1.

Four critical checkpoints (reach) have been established in Loja city. In each checkpoint, the flow was measured in situ. These data were compared with results calculated by GESTINA in real time (Table 2).

Table 3 shows some estimated values during phase 3 of the investigation, the estimated values with GESTINA, and the differences in percentage.

Once the software has been calibrated, the model anticipates the time a flood could occur if precipitation intensity is maintained following a linear progression.

Table 1 Differences (%) between maximum rainfall, flow for different return periods, and values estimated with GESTINA

T_r (years)	R_{max} (mm)	Malacatos F (m^3/s)	Zamora Huayco F (m^3/s)	Zamora F (m^3/s)	Differences with GESTINA (%)
25	43.25	84.96	177.14	144.89	0.01
50	49.64	109.93	227.62	189.54	0.03
100	55.98	136.07	280.26	236.59	0.02
500	70.64	200.27	408.94	353.10	0.02
1000	76.94	229.10	466.53	405.74	0.03

Table 2 Differences (%) between flow data measured "in situ" and values estimated with GESTINA

Stretch of river	Day 35 F (m^3/s)	Day 41 F (m^3/s)	Day 55 F (m^3/s)	Day 73 F (m^3/s)	Differences with GESTINA (%)
Malacatos (M). Reach 13	12.9	15.6	11.1	16.3	1.5 – 3.0
Zamora Huayco (ZH). Reach 1	26.5	28.4	24.7	29.1	4.3 – 6.6
Zamora. Reach 7	20.8	23.4	18.2	23.7	2.2 – 2.7
Union (M–ZH). Reach 20	40.1	45.3	37.2	46.6	1.9 – 3.4

Table 3 Differences (%) between some parameters estimated in phase 3 and the values estimated with GESTINA

Parameter	Estimated data	GESTINA values	Difference (%)
Precipitation (mm). Input data	4.8	4.800000000	0.00
Effective precipitation (mm)	2.04	2.038081308	0.02
Peak flow ($m^3/s/m$)	5.41	5.415614124	0.09
Total flow (m^3/s)	10.49	10.49375049	0.04

4 Discussion

GESTINA has been coded in Python and Java. A script has been developed to connect the software to Hec-Ras. GESTINA accumulates precipitation data, while the value entered is greater than 0 (zero). The precipitation counter returns to 0 (zero) value when the time with precipitation 0 (zero) equals basin concentration time. At this point, accumulated rainfall is restarted when new precipitation data is registered in GESTINA (Waseem et al., 2021). The software recalculates the flow values with each information input and compares them with those previously estimated in phase 4. For example, suppose the flow values estimated by GESTINA for the intensity of precipitation that generates them are less than the flood flows estimated in phase 4. In that case, GESTINA projects the result linearly and estimates when a flood could occur if the precipitation intensity is maintained (Pagano et al., 2016).

In the case of the city of Loja, the response time to flooding is 2.5 h, corresponding to the time of the flood. It is a short time because Loja is located at the head of the river sub-basins. The response time to flooding is variable. It depends on the locations of the basin's point of interest and the rainfall that causes the flood. Implementing a climate operation model in GESTINA would increase the response time to a flood (Jin et al., 2015).

The differences between the flow data measured, those provided by INAMHI, and the values estimated by GESTINA are reasonable, considering that in all cases, the flows calculated with GESTINA are higher than those measured (Waseem et al., 2021). The generated code was also linked to Hec-Ras software to get additional hydraulic information. The results obtained can be viewed in Hec-Ras in real time (Pagano et al., 2016). GESTINA is a universal tool. Hydrological knowledge of the study area is required to enter the flow parameters for different return periods into the software, concentration time, and connection with rain gauges.

5 Conclusion

It is necessary to develop computer tools to forecast floods with enough time to make decisions that avoid human and economic losses. GESTINA (GESTión INtegral del Agua) software has been developed as an Early Warning System for floods. GESTINA receives precipitation data from a meteorological station and obtains the flow and additional hydraulic information to anticipate a possible flood. The software was calibrated in the Loja basin (Ecuador) with historical flood data, data from INAMHI, and measured data. The difference between the measured and calculated data is 2–7%. The software can be used in other parts of the world by entering specific parameters of the studied basin.

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