A METHOD FOR ESTIMATING TIME AND WATER VELOCITY: CASE STUDY OF THE PIURA RIVER, PERU

Oscar Peña-Cáceres [1*], Eduardo Arbulú-Gonzales [2], Manuel More-More [3], Rudy Espinoza-Nima [3] and Henry Silva-Marchan [4]

1. Universidad César Vallejo, Piura, Perú.
2. Municipalidad Distrital de Veintiséis de Octubre, Piura, Perú.
3. Universidad Nacional de Piura, Piura, Perú.
4. Universidad Nacional de Tumbes, Tumbes, Perú.

*Corresponding author: ojpenac@ucvvirtual.edu.pe

ABSTRACT

The “El Niño” phenomenon periodically affects the Piura region in Peru, causing heavy rains that increase the flow of the Piura River and, in some cases, lead to overflows, as occurred in 2017. This event poses a latent risk to the inhabitants of the districts of Piura, Castilla, Catacaos, and Cura Mori. The objective of this study was to estimate the surface flow time and velocity in four segments of the Piura River. To achieve this, the float method was used, which consisted of measuring the time it takes for a floating object to move between established points. Measurements were taken at the Andrés Avelino Cáceres, Eguiguren, Sánchez Cerro, San Miguel, and Bolognesi bridges. The experimentation was limited to low-magnitude flow rates, in accordance with the hydrometeorological conditions present during the months of March in 2019 and 2021, which gives the results an estimated character. The findings indicate that as the flow rate (m^3/s) increases, the travel time of the water masses decreases, and the surface velocity increases proportionally. For example, a flow rate of 422 m^3/s was associated with a velocity of 1.14 m/s, meaning that the water takes approximately 28 minutes to travel across the four evaluated segments.

KEYWORDS

“El Niño” Phenomenon; Piura River; Flow; Meteorology; Surface velocity; Peru

UN MÉTODO PARA ESTIMAR EL TIEMPO Y LA VELOCIDAD DEL AGUA: ESTUDIO DE CASO DEL RÍO PIURA, PERÚ

RESUMEN

El fenómeno “El Niño” afecta periódicamente a la región de Piura, en Perú, provocando fuertes lluvias que incrementan el caudal del río Piura y, en algunos casos, generan desbordamientos, como ocurrió en 2017. Este evento representa un riesgo latente para los habitantes de los distritos de Piura, Castilla, Catacaos y Cura Mori. El estudio tuvo como objetivo estimar el tiempo y la velocidad superficial del flujo de agua en cuatro segmentos del río Piura. Para ello, se utilizó la técnica del flotador, que consistió en medir el tiempo que tarda un objeto flotante en desplazarse entre puntos establecidos. Las mediciones se realizaron en los puentes Andrés Avelino Cáceres, Eguiguren, Sánchez Cerro, San Miguel y Bolognesi. La experimentación se limitó a caudales de magnitud baja, de acuerdo con las condiciones hidrometeorológicas presentes durante los meses de marzo de 2019 y 2021, lo cual otorga un carácter estimativo a los resultados obtenidos. Los hallazgos indican que, a medida que el caudal (m^3/s) aumenta, disminuye el tiempo de recorrido de las masas de agua y la velocidad superficial se incrementa proporcionalmente. Por ejemplo, un caudal de 422 m^3/s se asoció a una velocidad de 1,14 m/s, lo que implica que el agua tarda aproximadamente 28 minutos en recorrer los cuatro tramos evaluados.

PALABRAS CLAVES

Fenómeno “El Niño”; Río Piura; Caudal; Meteorología; Velocidad superficial; Perú

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INTRODUCTION

The Piura River basin, located in the northernmost part of Peru and ranging from 0 to 3600 meters above sea level, is geographically situated between coordinates 04° 46–05° 43' S and 99° 33–80° 58' W. It covers parts of the provinces of Piura, Sechura, Morropón, Huancabamba, and Ayabaca, with an approximate area of 12,220.7 square kilometers and a river course spanning 280 kilometers in length. The river flows in a south-to-north direction, curving from the San Francisco ravine to the Curumuy Falls and then veering southwest until it reaches its mouth in the Pacific Ocean via the Virrilá Estuary. However, as of the year 2023, this natural outflow is obstructed due to sedimentation and the overgrowth of vegetation in the major infrastructure drains (Maza-Sócola, 2019). In this context, the Piura River is a crucial part of the Piura region, which is consistently affected by the "El Niño" Phenomenon between the months of January and March (Son et al., 2020) on many occasions, the causes of "El Niño" impact on the region are attributed to the increase in sea surface temperatures in the Niño 1+2 area and the trade winds (Jiménez-Carrión et al., 2018), which disrupt the hydrological patterns of the Piura River's course (Alvarado-Ancieta & Ettmer, 2008). With the occurrence of the "El Niño" event in 1983, precipitation records in the Piura region indicated a significant climate change, marked by more frequent and intense rainy years (Waylen & Caviedes, 1986). It's important to note that the extraordinary events that occurred in 1983, 1998, and 2017 (Farias de Reyes & Ruiz, 2018) were similar in nature to the ones that took place in 1925 (Takahashi & Martínez, 2019).

The "El Niño" Phenomenon of the years 1982 and 1983 triggered heavy rainfall, ranging from 1,000 to 2,000 mm in the lower and middle basins of the Piura River. In the Upper Piura, rainfall reached levels of 3,000 to 4,000 mm. This impact began to pique the interest of the population in understanding more about this event. However, during the years 1997 and 1998, the Piura region once again experienced this phenomenon, with rainfall accumulations reaching up to 4,000 mm. The "El Niño" event of 1998 had significant impacts, particularly in the Piura River course, where it reached a maximum discharge of 4,424 m^3/s. This data was recorded at the hydrological station located at the Sánchez Cerro Bridge (Ejidos Dam), a discharge never recorded and surpassing the one in 1983, which was 3,200 m^3/s. The presence of this phenomenon brings about various positive aspects, including the formation of vast green areas, increased water availability, higher production of beekeeping products, and abundant carob production.

In the livestock sector, there has been an increase in production, particularly of goats, which has led to a higher supply of milk and the commercial production of cheese. Additionally, a recovery of native species in the dry forests has been observed. However, the negative effects of the "El Niño" phenomenon are mainly associated with crop flooding, which poses a direct risk to the population and fosters the spread of vector-borne diseases such as dengue, Zika, and chikungunya (Hijar et al., 2016), especially in the lower Piura region. As a result, healthcare centers are often overwhelmed by the high demand. Added to this are damages to homes, public buildings, and sewer networks in districts like Piura, Chulucanas, Catacaos, and Sechura, where existing infrastructure is not built to withstand events of this magnitude. The most vulnerable families are in the middle and lower sections of the Piura River, including Chulucanas, Tambogrande, Castilla, and Cura Mori, where many homes are made from fragile materials such as adobe, wattle and daub, and reed mats, with roofs of corrugated metal or tiles, making them highly susceptible to collapse.

This level of vulnerability worsens in low-lying areas, where the rising river flow causes various types of flooding, particularly in populated zones along its course. The consequences include losses in social, productivity, irrigation, and drainage infrastructure. In Piura's urban center, heavy rainfall creates puddles and temporary lagoons, known as "blind basins," which render streets and main avenues impassable for both pedestrians and vehicles. Although in some cases these blind basins drain into the Piura River through the city's drainage systems, in recent years the infrastructure has suffered from collapses and poor maintenance. This highlights that, if the drainage systems operated at full capacity, the volume of water discharged into the river would increase significantly, heightening the risk to low-lying urban areas. Furthermore, bridges such as Andrés Avelino Cáceres, Eguiguren, Sánchez Cerro, San Miguel, and Bolognesi (Hídricos, 2001) would also be at structural risk, affecting population mobility.

This situation became especially evident during the 2017 "Coastal El Niño" event (Rodríguez-Morata et al., 2019), a phenomenon characterized by a sustained rise in sea surface temperature in the Niño 1+2 region 2 (Martinez & Takahashi, 2017). Extreme rainfall led to the overflow of the Piura River on March 27, causing catastrophic damage, particularly in the districts of Piura, Castilla, Catacaos, and Cura Mori (French et al., 2020). The most severely affected areas were low-altitude zones such as Catacaos and Cura Mori (French et al., 2020), with elevations not exceeding 50 meters above sea level and flat topography (Ramirez et al., 2018). According to the Centro de Operaciones de Emergencia Nacional (COEN), over 100,000 people were affected in northern Peru. It is likely that a more effective and controlled response could have been achieved if approximate information had been available regarding the time water masses take to travel between different sections of the Piura River, which would have helped mitigate the impact of the overflow on the population.

In response to this reality, institutions such as the Servicio Nacional de Meteorología e Hidrología del Perú (SENAMHI) – Zone I (Piura) and the Proyecto Especial Chira Piura (PECHP) are responsible for issuing meteorological and hydrometeorological forecasts, especially during the rainy season. This work intensifies between January and April, with updates every two hours. However, these entities face logistical and technological limitations that hinder the exploration of new areas and the implementation of more effective preventive strategies. The Centro de Operaciones de Emergencia Provincial (COEP Piura), affiliated with the Municipalidad Provincial de Piura, supports these efforts by monitoring the Piura River through video surveillance systems and technical-scientific sources. Nevertheless, these resources are at times insufficient for comprehensive risk monitoring.

To date, the surface flow time and velocity of the Piura River between the Andrés Avelino Cáceres, Eguiguren, Sánchez Cerro, San Miguel, and Bolognesi bridges remain undocumented, information that is relevant for authorities to respond promptly to potential increase in the level of the Piura River. Given the lack of initiatives, economic constraints, and technological limitations, this study aimed to estimate the surface flow time and velocity in these sections using the float method as an empirical alternative. The analysis considered hydrometeorological conditions (m^3/s) observed in March of 2019 and 2021. It is important to note that the experiment was limited to low-magnitude flow rates, consistent with the hydrometeorological conditions prevailing during the study periods. Section 1 presents the study context, Section 2 reviews related work, Section 3 outlines the research methodology, Section 4 presents the results, Section 5 discusses the findings and implications, and Section 6 states the conclusions of the research.

RELATED BACKGROUND RESEARCH

In this section, a literature review of relevant alternatives related to the study's topic is covered. In Jyoti et al. (2023), drones, video imagery, and state-of-the-art optical flow algorithms were used to measure river velocity. This system was applied along the Menomonee River in Wauwatosa, WI. To remotely detect river flow, a DJI Matrice 210 RTK drone equipped with a Zenmuse X5S camera was used to capture video footage. River velocity was measured directly at specific locations using a handheld velocimeter. The authors Bacharidis et al. (2018) presented a video-based method for river discharge tracking. To estimate velocity, they calculated optical flow using a series of video frames, combining information from camera views. Their contribution lies in estimating river discharge using two-dimensional imagery. Research Stone & Hotchkiss (2007) reveals that accurate flow measurements in shallow rivers are essential for various applications, including biological research and numerical model development. Unfortunately, river velocity data is challenging to obtain due to traditional velocimeter limitations. However, the use of instruments like the Acoustic Doppler Velocimeter and Acoustic Doppler Current Profiler makes it possible to gather relevant data for this purpose.

Thorne & Zevenbergen (1985) highlight the need to estimate average velocity in ungauged mountain rivers, which typically feature coarse beds, steep slopes, and shallow depths. Despite ongoing efforts, a reliable flow resistance equation tailored to these conditions remains lacking. Orellana et al. (2023) underscore the importance of aquifer monitoring to better understand groundwater dynamics. Similarly, Hudson et al. (2023) point out that river flow management and alterations in channel geometry can disrupt natural conditions, creating critical zones of sediment deposition and erosion. Meanwhile, Mdegela et al. (2023) note that flood prediction in poorly gauged basins remains a major challenge, especially in developing countries with limited hydrological data.

The literature review reveals the diversity of methods employed to measure water flow velocity in rivers, and it underscores the importance of selecting the most suitable approach for this task. The application of advanced technology such as drones and cameras could be effective and relevant in obtaining precise and detailed measurements. However, the current reality in the Piura region, marked by economic limitations, political gaps, and high corruption rates, makes it challenging to carry out this task using high-end instruments. As of now, institutions in the region do not have access to equipment that can fulfill the study's objectives. It is essential to highlight that such measurements for water resource management contribute to a better understanding of river dynamics, emphasizing the potential contribution of this study to improved management in the Piura region. The difficulty in measuring velocity in rivers, as mentioned in the literature review, underscores the need to address specific challenges that may arise in the context of the Piura River. We firmly believe that this study represents an opportunity and an alternative to demonstrate that challenges can be overcome and solutions can be found to achieve a goal. Finally, the data scarcity in developing regions further emphasizes the relevance of the proposed research, as it could help fill this data gap and contribute to the mitigation of flood-related risks in the Piura region.

MATERIALS AND METHODS

Fig. 1 represents the study area, where the aim is to estimate the time and surface velocity of the movement of water masses within the course of the Piura River, between the Andrés Avelino Cáceres, Eguiguren, Sánchez Cerro, San Miguel, and Bolognesi bridges.

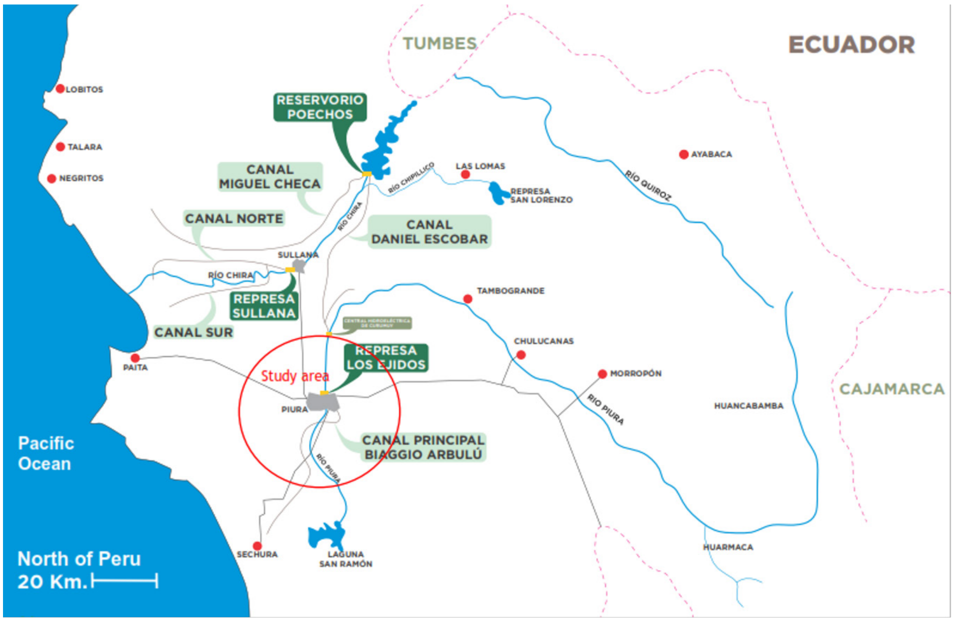

Figure I. Geographic study area
Source: PECHP (2021).

Location of the Study Area

The study area was chosen to encompass the right bank of the Piura district and the left bank of the Castilla district due to their higher population density and accessibility provided by the bridges connecting these two districts. This choice of study area is also driven by the need to address a critical and current issue in the Piura region. Growing concerns about climate variability and global climate change make it essential to understand how extreme climate events, such as "El Niño Costero", can influence hydrology and water management in this area. The increasing frequency and intensity of these phenomena underscore the importance of conducting research to help predict, mitigate, and adapt to potential impacts on local communities and ecosystems. It's worth noting that during the period from December 2016 to May 2017, the presence of "El Niño Costero" rendered the main bridges in the mentioned districts impassable, and its impact was associated with heavy rainfall and flooding (Guzman et al., 2020). It's also relevant to mention that "El Niño Costero" represents the third most intense event recorded in the last 100 years in Peru (Carrasco et al., 2019).

Bridges Located in the Piura River Channel

In the Piura River channel, several bridges are of great importance for the communication and mobility of the local population. These bridges play a crucial role in both vehicular traffic and pedestrian movement in the area. In line with the focus of our research, a carefully selected set of bridges has been chosen to estimate the time and surface velocity of water mass displacement. The selection of these bridges is based on their relevance, as they are the most commonly used and frequented by the community. Detailed information about these bridges is presented in Table 1, providing a solid foundation for our assessment of risks and challenges related to river flow in this critical area of regional infrastructure.

N°	Bridges	Coordinates Latitude and Longitude	Google Earth Linear Extension
1	Andrés Avelino Cáceres	-5.182, -80.6254	145 m
2	Eguiguren	-5.188, -80.6241	125 m
3	Sánchez Cerro	-5.193, -80.6238	130 m
4	San Miguel	-5.197, -80.6242	125 m
5	Bolognesi	-5.200, -80.6255	150 m

Table 1. Bridges between the Piura and Castilla districts
Source: Authors, 2025.

Method and Definition of Sections

In this section, key hydrometeorological parameters that influence the choice of the study method are introduced. It's important to highlight that rainfall, especially during the months of January to March, plays a fundamental role in the increase of the Piura River's flow. This information is essential for understanding the context in which the research is conducted. In an initial approach, the goal is to obtain data on the time and surface velocity of water masses in the mentioned river channel. This data has a significant impact on the development of forecasts (Ramírez & Briones, 2017) and strengthens urban planning (Schroeder, 2020) by local authorities and professionals responsible for formulating contingency plans (Chantavilasvong & Guerrero, 2019), particularly in preparation for extreme weather events.

To achieve this objective, the decision has been made to use the float method, a choice supported by the lack of access to more advanced measurement instruments such as current meters or flow meters (Bladé et al., 2014). It's relevant to note that there are various float alternatives available today, including buoys, corks, pieces of wood, or weighted bottles, which can be successfully employed to gather the required information (Franquet-Bernis, 2005). Furthermore, it is crucial to mention that this method is applied in situations where the presence of foreign objects in the water hinders the use of conventional instruments or when there is a risk to the physical integrity of the person responsible for taking measurements and the operation of conventional measuring instruments.

Table 2 represents the detailed planning of the execution sections for the deployment of buoys, which will allow for precise estimation of both time and surface velocity of water masses in the Piura River channel. This methodological approach provides a solid foundation for the research and will significantly contribute to the understanding of hydrometeorological patterns in the region, subsequently enhancing the capacity to respond to adverse weather events.

N°	Initial Section Bridge(a)	Abbreviation Starting	Point Bridge(b)	Abbreviation of Arrival	Distance (m)
1	Andrés Avelino Cáceres	(A1-I)	Eguiguren	(B1-F)	560
2	Eguiguren	(A2-I)	Sánchez Cerro	(B2-F)	607
3	Sánchez Cerro	(A3-I)	San Miguel	(B3-F)	373
4	San Miguel	(A4-I)	Bolognesi	(B4-F)	401

Table 2. Sections assessed in the Piura River channel
Source: Authors, 2025.

Human Talent and Logistical Resources

During this phase, the human and logistical resources required to estimate the surface flow time and velocity of the Piura River were defined, specifically for the section between the Andrés Avelino Cáceres, Eguiguren, Sánchez Cerro, San Miguel, and Bolognesi bridges. The operation was supported by a team of five trained operators equipped with one hundred 3-inch buoys, two 400 ml spray paint cans in red and yellow used to differentiate the buoys during their movement along the river one camera for visual recording, five stopwatches for time measurement, five VHF radios for remote coordination, five registration boards for manual data collection, and ten pens (black and red) as complementary materials.

Execution and Data Recording

Based on the complementary aspects identified in the previous sections, this stage consisted of the implementation and data collection through the flotation method. Figure 2(A) highlights four selected segments of the Piura River. These segments are located within the urban areas of the Piura and Castilla districts, where the riverbanks are densely occupied by infrastructure. Among the landmarks highlighted is the Bolognesi Bridge, distinguishable by its blue-coloured structure that sustains high vehicular traffic.

Figure 2. Study area - Sections of the Piura riverbed
Source: Authors, 2025.

In order to improve the visualization of the sites and ensure accurate spatial reference, Google Earth was used as a geospatial support tool. This platform allowed the delineation of the four selected river sections and, at the same time, the generation of a panoramic view for operational planning. As shown in Figure 2(B), the aerial perspective allows an assessment of the physical conditions of the river environment, allowing for the anticipation of possible logistical and technical constraints at each location. This visualisation was especially useful to identify structural elements and natural barriers that could alter the surface dynamics of the flow or affect the development of the experiment, particularly during the buoy launching manoeuvres.

Logistic resources have been crucial at this stage, especially the means of communication among the collaborators located on the bridges. Each buoy launch has been timed to determine the launch and arrival times. These timed data provide a more comprehensive view of the Piura River's dynamics in each section and possibly allow for a more precise assessment of variations in surface velocity over time. In Figure 3, you can see the buoy launches, which were painted red and yellow to differentiate them.

In this stage, it was ensured that the meteorological conditions were normal, allowing the buoy launches to proceed without obstruction or difficulties. On the other hand, parts (A) and (B) of Figure 3 show that the buoy launches were made in the center of each bridge. These details were essential because, at the time of the launch, the Piura River channel had a certain amount of sediment due to the transport of natural elements such as tree branches and vegetation growing on its banks. The use of VHF radio communication equipment has been vital in this work, as it effectively allowed communication with operators located in each section and provided information that could either support or restrict buoy launches.

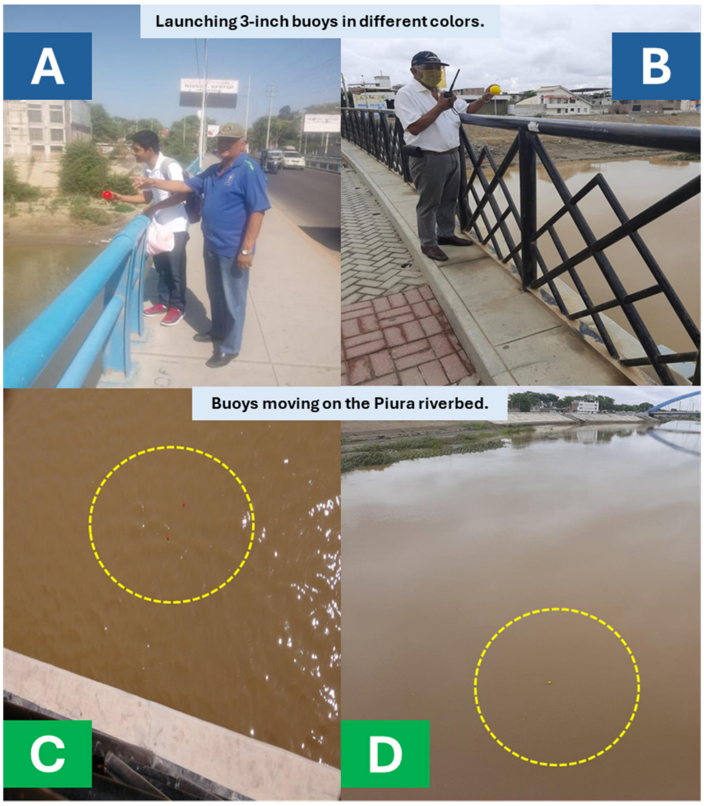

Figure 3. Launching and displacement of 3-inch buoys in the Piura riverbed
Source: Authors, 2025.

Fig. 3 shows how the buoys move between the different sections. On some occasions, it has been necessary to launch more than three buoys at similar times because they were obstructed during their movement by the plant elements located in the riverbed, as observed inside (D) of Fig. 3, corresponding to the left bank of the river. All the information obtained from each launch has been recorded in Table 3. In it, you can find details ranging from the date to the flow rate in m^3/s. The simulations were conducted in two different years due to the initial hydrological deficit experienced in the Piura region. The simulated years are 2019 and 2021.

N°	Date	Launching Point	Launch Time	Arrival Point	Arrival Time	Time (s)	Flow Rate (m^3/s)
1	27-03-2019	A1-I	10:00:00	B1-F	10:13:10	790	83
2	27-03-2019	A1-I	10:20:00	B1-F	10:32:05	725	83
..	…	…	…	…	…	…	…
99	27-03-2019	A2-I	10:40:00	B2-F	10:54:15	855	83
100	12-03-2021	A2-I	10:40:00	B2-F	10:49:41	581	422

Table 3. Data logging of the launches carried out
Source: Authors, 2025.

As shown in Table 3, the data records consist of 100 entries, corresponding to the years 2019 and 2021. Initially, these records were manually collected and later processed digitally. To obtain the surface velocity, Equation (1) was employed, defining the velocity of an object (3-inch buoys). This equation states that velocity is the distance traveled divided by the time taken (Olmo, 2021), or it can be interpreted as displacement divided by time (Fernández, 2021). This formula establishes a mathematical foundation for calculating and understanding the motion patterns of water masses in the Piura River's channel. By applying this equation in the context of our study, an effective methodology was employed to gather precise data and gain a deeper understanding of the hydrological dynamics of the Piura River's channel.

Equation 1. Distance-time relationship

$$V = \frac{d}{t}$$

RESULTS

This section presents the research results, organized into three subsections. Subsection 4.1 presents the results related to time and average velocity obtained from three different flow rates: 83 m³/s, 111 m³/s, and 422 m³/s. These low-magnitude flow rates were recorded during the empirical experimentation stage, based on the prevailing climatic conditions at the time of sampling. Subsection 4.2 presents the results of the correlation heat map, whose purpose is to show how the variables of distance, time, and velocity are related. The final subsection (4.3) illustrates the average estimated values of time and velocity during the flow movement along the Piura River channel.

Time and average speed results

The information provided in Table 4 represents a significant milestone in the study as it shows the initial results of estimating the time and surface velocity of water masses in the Piura River. These results were based on a flow rate of 83 m³/s, a crucial data point provided by the daily report from the Special Chira Piura Project on a specific date, March 27, 2019. One notable finding is the minimum average time recorded, which was 685 seconds, equivalent to 11 minutes and 41 seconds. This time period corresponds to the displacement of water masses between the Sánchez Cerro (A3-I) and San Miguel (B3-F) bridges. The average velocity calculated in this section was 0.54 m/s, and the linear length of this segment was estimated to be 373 meters. On the other hand, the maximum average time is found in the last section, between the San Miguel (A4-I) and Bolognesi (B4-F) bridges, with a value of 18 minutes, a velocity of 0.37 m/s, and a linear length of 401 meters. This initial data provides an essential insight into the variability in time and surface velocity in different sections of the Piura River, serving as a fundamental starting point for more detailed analysis and decision-making.

Initial Section Bridge(a)	Final Section Bridge(b)	Distance (m)	Average Time (s)	Velocity m/s
Andrés Avelino Cáceres	Eguiguren	560	790	0.71
Eguiguren	Sánchez Cerro	607	903	0.67
Sánchez Cerro	San Miguel	373	685	0.54
San Miguel	Bolognesi	401	1080	0.37
Total		**1941**	**3458**	**2.29**
Average		**485.25**	**864.5**	**0.572**

Table 4. Time and mean surface velocity at a flow rate of 83 m³/s on March 27, 2019
Source: Authors, 2025.

On March 9, 2021, the second study exercise was carried out, this time with a significantly higher flow rate in the Piura River channel, reaching 111 m³/s. This volume of water exceeded the previously analyzed flow rate. The results revealed an interesting pattern in the movement of water masses in the section between the Andrés Avelino Cáceres, Eguiguren, Sánchez Cerro, San Miguel, and Bolognesi bridges. It was observed that with the increase in flow rate, there was a noticeable decrease in the time required for movement and a corresponding increase in velocity, as detailed in Table 5 – section (A). This change in the relationship between time and velocity emphasizes the significant influence of the flow rate on the dynamics of the Piura River and underscores the importance of this data for understanding and managing hydrological risks.

The third and final exercise, carried out on March 12, 2021, presented a considerably high flow rate of 422 m³/s, the result of increased rainfall in the upper and middle basins of the Piura River. This event allowed us to validate some key statements regarding the hydrodynamic behavior of the river. It was confirmed that as the flow rate increases, the average time required for the displacement of water masses decreases significantly, while the velocity experiences a marked increase due to the greater force of the current, as detailed in Table 5 – section (B). These findings support the importance of considering the flow rate as a determining factor in river dynamics and highlight its relevance in water resource management, decision-making in urban planning, and risk management associated with extreme weather events in the Piura River basin.

Time and mean surface velocity at a flow rate of 111 m³/s on March 9, 2021 (A)				
Initial Section Bridge(a)	**Final Section Bridge(b)**	**Distance (m)**	**Average Time (s)**	**Velocity m/s**
Andrés Avelino Cáceres	Eguiguren	560	731.4	0.77
Eguiguren	Sánchez Cerro	607	733.8	0.83
Sánchez Cerro	San Miguel	373	518.1	0.72
San Miguel	Bolognesi	401	575.7	0.70
Total		**1941**	**2559**	**3.02**
Average		**485.25**	**639.75**	**0.755**
Time and mean surface velocity at a flow rate of 422 m3/s on March 12, 2021 (B)				
Andrés Avelino Cáceres	Eguiguren	560	582.3	0.96
Eguiguren	Sánchez Cerro	607	491.4	1.24
Sánchez Cerro	San Miguel	373	336.9	1.11
San Miguel	Bolognesi	401	321.6	1.25
Total		**1941**	**1732.2**	**4.56**
Average		**485.25**	**433.05**	**1.14**

Table 4. Time and mean surface velocity at a flow rate of 83 m³/s on March 27, 2019
Source: Authors, 2025.

Correlation heat map

The correlation heat map in Fig. 4 shows how the variables of distance, time, and velocity are related. In the case of section (A) of Fig. 4, the relationship between distance and time is very low, indicating that these two variables are not strongly connected in this dataset. However, there is a strong positive relationship between distance and velocity, meaning that longer stretches tend to have higher velocities. On the other hand, the relationship between time and velocity is moderately negative, suggesting that as time increases, velocity tends to decrease. In general, if two variables have a positive correlation, they tend to increase together. If the correlation is negative, when one variable increases, the other tends to decrease. Values close to 1 or -1 indicate a strong relationship, while values near 0 indicate a weak relationship. In this regard, it is important to note that the maximum linear distance between the four bridges is found between Eguiguren Bridge and Sánchez Cerro Bridge. The results in this section corresponded to a travel time of 15 minutes and 05 seconds and a velocity of 0.67 m/s. This indicator offers a new perspective on this experiment, as it expands the possibility of conducting further expeditions and simulations along different sections of the Piura River channel. Despite the lack of uniformity and the obstruction caused by external elements such as vegetation, this does not diminish the interest in continuing with further tests to obtain valuable information for the benefit of the community.

On the other hand, the correlation analysis in Fig. 4, section (B), shows how the variables of distance, time, and velocity are related. The relationship between distance and time is very strong, with a correlation value of 0.981, indicating that they are highly connected in this dataset. As distance increases, time increases proportionally. The relationship between distance and velocity is also very strong, with a value of 0.935, indicating that longer stretches tend to have higher velocities. The relationship between time and velocity is equally strong, with a value of 0.848, suggesting that as time increases, velocity also tends to increase. In this case, the results from section (B) correspond to a flow rate of 111 m³/s, whereas a previous experiment (A) was conducted with a flow rate of 83 m³/s. When comparing the results, it becomes evident that the increase in flow rate from 83 m³/s to 111 m³/s appears to have influenced the relationships among the variables. The correlation between distance and time shifted from virtually nonexistent to very strong, indicating that with a higher flow rate, the time required to cover a given distance becomes much more predictable. The correlation between distance and velocity increased from moderately positive to very strong, showing that with a higher flow rate, velocities over longer distances increase significantly. The correlation between time and velocity changed from moderately negative to strong and positive, indicating that with a higher flow rate, segments requiring more time also tend to exhibit higher velocities, which could be related to the influence of flow rate on flow dynamics. In contrast, the increase in flow rate from 83 m³/s to 111 m³/s appears to have had a significant impact on how the variables of distance, time, and velocity are related. With the higher flow rate, the relationships between these variables become stronger and more positive, reflecting a faster and more voluminous flow that results in higher and more consistent velocities along the measured distance.

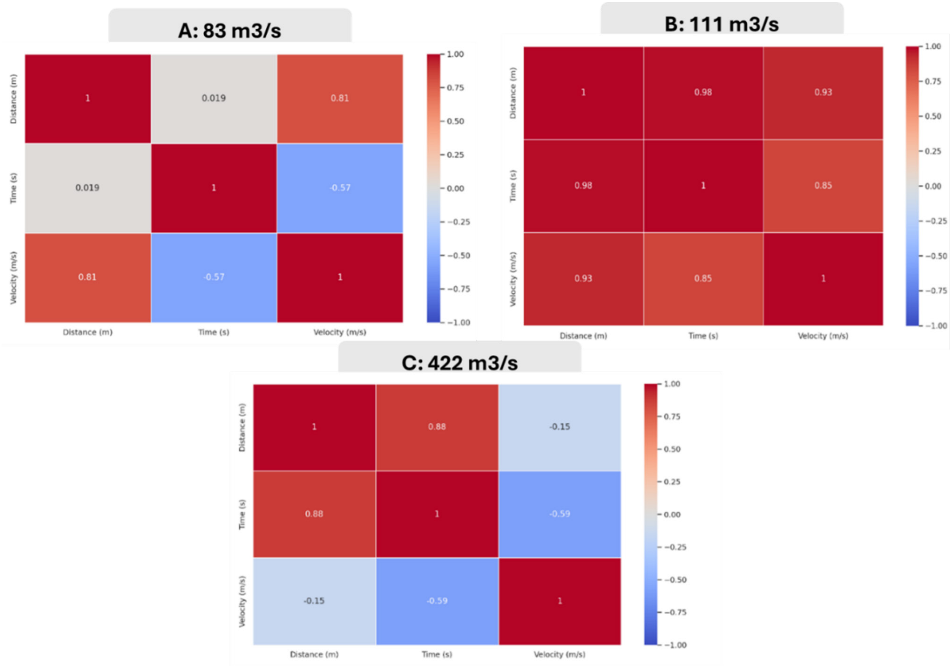

Figure 4. Correlation map of Table 4 and 5
Source: Authors, 2025.

Regarding section (C) of Fig. 4, the relationship between distance and time is strong, with a correlation value of 0.882, indicating that these variables are closely connected in this dataset. As distance increases, time increases proportionally. The relationship between distance and velocity is moderately negative, with a value of -0.152, suggesting that longer stretches tend to have slightly lower velocities. The relationship between time and velocity is also moderately negative, with a value of -0.594, indicating that as time increases, velocity tends to decrease. In this case, the experiment was conducted with a flow rate of 422 m³/s, whereas previous experiments were conducted with flow rates of 83 m³/s and 111 m³/s. When comparing the results, it appears that the increase in flow rate influenced the relationships among the variables. In the experiment with 83 m³/s, the correlations between the variables were weaker and less predictable. With a flow rate of 111 m³/s, the correlations became stronger and more positive, showing that a higher flow rate led to more consistent velocities along the measured distances. However, with a flow rate of 422 m³/s, the correlations between distance and velocity, and between time and velocity, became negative. This indicates that although a higher flow rate may increase velocity in certain sections, it can also lead to significant variations in the time required to cover different distances. Although the experimentation was carried out with low-magnitude flow rates and a visually observed sedimentation index, these initial results could be refined using more sophisticated instrumentation, allowing for more accurate and representative data collection for flow rates exceeding 1000 m³/s.

Evaluation of average travel time and speed

The results obtained from the three exercises are reflected in the illustration in Fig. 5, which shows the estimated average behavior of time (A) and velocity (B) in relation to the movement of water masses in the sections where the empirical experimentation was conducted. Although the experiments were carried out with low-magnitude flow rates, it is important to note that both the estimation and the experimentation are of an empirical nature, and therefore, there is likely a margin of error that could be reduced in the future using more precise hydrological tools. The values presented in Fig. 5 follow an upward trend, clearly demonstrating that as the flow rate (m³/s) increases, the movement of water masses accelerates significantly (Thomas & Marino, 2016).

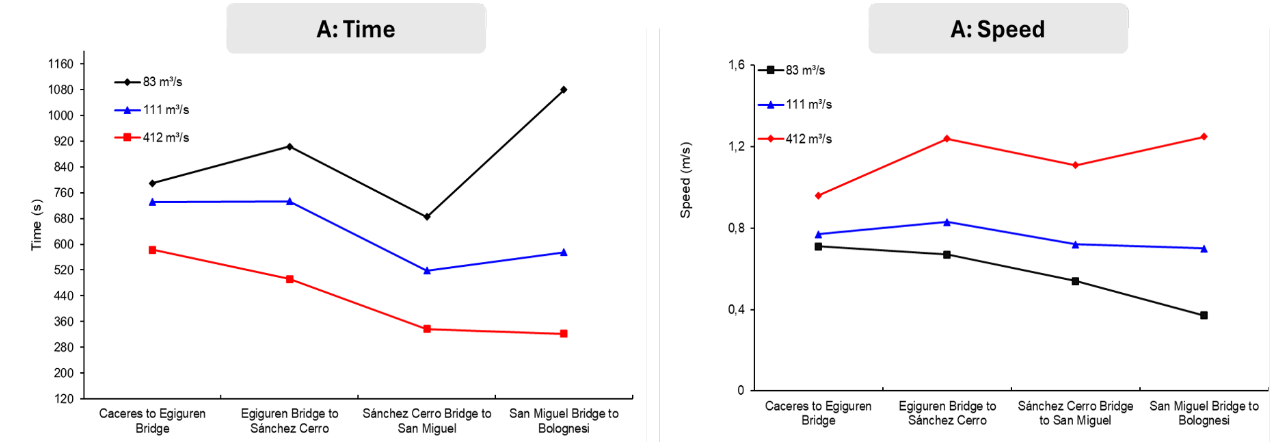

Figure 5. Average estimation of the time and speed of displacement of water masses in four segments of the Piura River
Source: Authors, 2025.

On the other hand, Fig. 5 presents information on the surface velocity (B) obtained from the exercises conducted with flow rates of 83, 111, and 422 m³/s during the months of March 2019 and 2021. Although these results provide a useful preliminary overview, they could be validated and complemented in future studies through the use of high-resolution cameras for surface velocity analysis—such as LSPIV (Large-Scale Particle Image Velocimetry) cameras—and hydrological tools such as acoustic current meters, ultrasonic sensors, and automated hydrometeorological stations. In this regard, we consider that the implementation of a wireless sensor network along the Piura River channel (Guerrero-Ciprian et al., 2020) would enhance monitoring management, similar to the systems used in dams, with the sole purpose of benefiting the population (Toledo et al., 2012).

DISCUSSION

The estimation of time and superficial velocity in the movement of water masses in the Piura River, Peru, represents a crucial element in understanding its riverine dynamics and in decision-making for water resource management, especially in a region prone to extreme weather events. This study, based on the float method, offers results and observations of great significance for the scientific community and the authorities responsible for urban planning and risk mitigation in the Piura River basin.

A notable finding is the unequivocal relationship between the river's flow rate and the superficial velocity of water masses. The data collected in three different exercises reveal a clear trend: as the flow rate increases, the velocity of water mass displacement also proportionally increases. This relationship has important implications, as a sudden increase in flow rate, as evidenced in the third exercise with a flow rate of 422 m³/s, can significantly accelerate water movement, potentially leading to faster and more severe flooding. This finding underscores the need for effective preparation and response to extreme weather events such as the Niño phenomenon. Furthermore, the importance of maintaining up-to-date measurements of river velocity is emphasized, given the dynamic nature of the Piura River channel, which is affected by geomorphological factors and infrastructure construction. These changes can have a significant impact on water flow velocity and, ultimately, on the safety and well-being of populations in riparian areas. Therefore, the continuous implementation of hydrological monitoring and regular data updates are recommended.

Regarding the methodology used, the float method proved to be an effective tool for estimating both time and surface velocity in the Piura River. While it may seem like a simple technique, its applicability and accuracy stand out in this study. However, it is essential to consider that the suitability of the float method may vary depending on the specific conditions of each study site, so a careful assessment of its applicability in particular riverine contexts is suggested. Despite its advantages, the float method presents some significant limitations that need to be discussed. One of the main limitations is the influence of environmental factors, such as the presence of floating vegetation or debris, which can alter the float's trajectory and thus affect the accuracy of surface velocity measurements (Yang et al., 2020). Additionally, the technique assumes that the water surface is representative of the average flow throughout the river, which may not be true in rivers with highly variable velocity profiles (Biggs et al., 2023). Another limitation to consider is the assumption that flow conditions remain constant during the measurement period. In situations where the flow varies rapidly, the float method may not adequately capture these fluctuations, leading to inaccurate estimates (Koutalakis & Zaimes, 2022). In this regard, the accuracy of measurements can be compromised in rivers with high surface turbulence, where the float can be diverted from its ideal path (Corato et al., 2014). Thus, we consider that these limitations can be moderately mitigated by considering meteorological factors, such as wind direction, and by establishing reference points where the float technique has greater functionality, minimizing the risks of variability in its movement.

This study lays the foundation for future research that expands the geographical and temporal scope of monitoring the speed of the Piura River. It is essential to explore other sections of the river and integrate advanced technologies, such as real-time data-based early warning systems (Peña-Cáceres et al., 2024a). Also, the development and use of chatbots would allow citizens to consult the status of the river channel at any time. These chatbots, fed by data updated in real time, would provide accurate and accessible information, helping the community to stay informed and prepared for potential risks (Peña-Cáceres et al., 2024b). These improvements will allow for a more comprehensive and accurate understanding of river dynamics in the region and significantly contribute to risk management and planning in vulnerable areas. Meanwhile, one might ask: How does this study contribute to future research on river dynamics during extreme weather events? This work serves as an accessible reference framework for professionals and institutions with limited financial resources, enabling them to explore river channel behavior. This methodology is not only attractive from an economic perspective but also stands out for its simplicity in data collection, which does not require advanced technical knowledge. In fact, any citizen could carry out this activity, helping to establish thresholds in areas exposed to potential overflows due to river channel increases.

The possibility of involving citizens in the generation of useful data not only democratizes the monitoring process but also reinforces the potential of this information to feed subsequent research with a rigorous approach. In this sense, the transferable value of this research for future studies lies in the analysis of the speed of movement of the riverbed in the sections considered. This information will make it possible to implement and operate early warning systems more effectively, by anticipating more accurately the movement of the water masses of the Piura River. Consequently, it will be possible to issue more precise and timely warnings, based on previously established thresholds, which will significantly increase the capacity to respond to possible overflows. Furthermore, the data obtained will contribute to the construction of a dynamic database that can be continuously updated, which will facilitate permanent monitoring and long-term analysis of river behavior. Beyond the technical benefits, the findings have important social implications by contributing to better community preparedness, reducing the vulnerability of at-risk populations and strengthening the design of public policies aimed at protecting human lives, livelihoods and infrastructure in flood-prone areas.

Future research should focus on developing predictive models that use the data obtained in this work, applying the float method and other technologies such as digital gauges and real-time sensors. These tools will allow anticipating changes in river dynamics during extreme events, especially during the presence of the "El Niño" phenomenon. To improve the precision and effectiveness of these models, Artificial Intelligence (AI) can play an important role (Cáceres et al., 2023). By using machine learning algorithms, large volumes of historical and real-time data can be analyzed, identifying patterns and trends that are not evident at first glance.

These AI-based predictive models could be integrated and synchronized with risk management systems to provide more effective early warnings and mitigation strategies. The implementation of these advanced technologies would enable authorities and local communities to respond more quickly and efficiently to potential overflows and other extreme events. However, for these technological tools to have a truly transformative impact, they must be incorporated within a broader and more articulated risk management framework. In this regard, Sandoval et al. (2023)

propose a framework for Integrated Disaster Risk Management (IDRM), which goes beyond the technical-operational domain and is understood as a dynamic sociocultural process shaped by the historical and social structure of each territory. IDRM requires a multidimensional integration sectoral, spatial/hierarchical, temporal, and external that links risk management with broader structural challenges such as climate change and sustainable development. Therefore, aligning AI-based predictive tools with these integration dimensions proposed by IDRM can foster a more comprehensive, systemic, and context-sensitive approach to risk governance. This would help overcome the current fragmentation in prevention and response strategies, thereby strengthening community resilience in the face of extreme events. Complementing this approach, the promotion of interdisciplinary and cross-border collaborations is essential to address information gaps along the Piura River basin. Establishing networks of cooperation among experts such as hydrologists, computer engineers, meteorologists, and water resource managers can lead to decisive advances in understanding and managing river-related risks within the current context of climate change. In this way, the population will be the main beneficiary of these improvements, through more effective, preventive, and proactive management of risks associated with extreme weather events.

CONCLUSIONS

The float method has proven to be an acceptable mechanism for estimating both time and surface velocity in the movement of water masses between the Andrés Avelino Cáceres, Eguiguren, Sánchez Cerro, San Miguel, and Bolognesi bridges, all located along the Piura River channel. Our results revealed a significant relationship between flow rate (m^3/s) and the displacement velocity of the water mass; as the flow rate increases, velocity increases proportionally. For example, with a flow rate of 422 m^3/s, an average velocity of 1.14 m/s was recorded and the displacement of the four sections took 28 minutes. However, it is important to note that this experimentation was empirical in nature, and the data collected may naturally contain a margin of error due to the methodological limitations of the float technique, as opposed to the use of more sophisticated instrumentation such as acoustic Doppler current profilers or ultrasonic sensors. Despite these limitations, the float method remains a valuable and accessible tool for preliminary assessments. The application of this method should be carried out more frequently, especially considering that the Piura riverbed undergoes geomorphological changes due to sediment content or limitations related to the construction or improvement of infrastructure such as river defenses. Although this study focused on low magnitude flows, it is strongly recommended that future experimentation be carried out under extreme conditions specifically with flows greater than 1000 m^3/s to better understand the behavior of the river during critical hydrometeorological events. Continued generation of this type of data will contribute to the implementation of tangible actions aimed at environmental and hydrological welfare and remediation. It is also suggested that future research focuses on additional explorations, particularly between the Ñacara bridge, in the province of Chulucanas, and the Tambogrande bridge, located in the Tambogrande district. This type of research will complement the data provided in this study and will contribute to the incorporation of new technological tools, such as early warning systems, which will be relevant to safeguard the physical and psychological integrity and livelihoods of the population of the districts of Catacaos, Cura Mori and the areas exposed to the Piura riverbed.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Oscar Peña-Cáceres: Methodology, Writing (original draft), Experimentation, Data Curation, Software and Research Project Management. Eduardo Arbulu-Gonzales: Formal Analysis, Conceptualization, Methodology, Experimentation and Fund Acquisition (original draft). Henry Silva-Marchan and Rudy Espinoza-Nima: Software, Conceptualization and Research (original draft). Manuel More-More: Formal Analysis, Drafting (final review and editing); all authors have approved the final version.

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