River Velocity through LSPTV Technique using UAVs[*]

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Abstract

This research analyzes the difference between two techniques for measuring the velocity of water flows, using the non-intrusive large-scale particle tracking velocimetry technique (LSPTV), and intrusive techniques such as electromagnetic windlass and propeller windlass. A fluvial characterization of the river is conducted to classify it in relation to various fluvial parameters. The technique is applied in the stretch of the river, using two types of Unmanned Aerial Vehicles (UAVs): DJI Inspire II and DJI Spark, using two types of tracers, to obtain velocity fields in the study section. Comparing the two techniques it is evident that the tracers that best adapted to the model are the orange peel with the Spark drone with a reliability of 91 %, compared to the tracers of plastic covers with the same vehicle with a reliability of 81 %. The LSPTV technique has higher reliability compared to conventional methods, even more when depth corrections are made; therefore, it would reduce the risks for operators and/or damage to equipment that needs to be introduced to the fluid.

Keywords: velocimetry of particles; surface velocities; drone; tracers; LS PTV; mean velocity.

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Velocidad de río mediante la técnica LSPTV con VANT

Resumen

En este estudio se analizó la diferencia entre dos técnicas de medición de velocidad de cuerpos de agua, utilizando la técnica no intrusiva de velocimetría por seguimiento de partículas a gran escala (*LSPTV*) y técnicas intrusivas como molinete de hélice. Se realizó una caracterización fluvial del río con el fin de clasificarlo en relación con diversos parámetros fluviales. Se aplicó la técnica en el tramo del río, utilizando dos tipos de Vehículos Aéreos No Tripulados (VANT); DJI Inspire II y DJI Spark, usando dos tipos de trazadores, para obtener campos de velocidad en el tramo de estudio. Realizando la comparación de las técnicas, se evidenció que los trazadores que mejor se adaptaron al modelo son la cáscara de naranja con el dron Spark con una fiabilidad de 91 %, en comparación con los trazadores de tapas plásticas con el mismo vehículo con una fiabilidad de 81 %. La técnica *LSPTV* posee una fiabilidad alta en comparación con los métodos convencionales, más aún cuando se realizan correcciones de profundidad, por lo tanto, disminuiría los riesgos para operarios y/o daños en equipos que requieren ser introducidos al fluido.

Palabras clave: velocimetría de partículas; velocidades superficiales; dron; trazadores; LS PTV; velocidad media

INTRODUCTION

The speed quantification in superficial watercourses have great importance in numerous engineering applications such as pollutants dispersion in a river, sedimentation rate, problems associated with the behavior of a watershed (erosion, flood, droughts, among others), hydraulic works designs, water supplies, landfills in water purification plants [1] speed of debris flow, flow measurement, creation of early warning systems (EWS), validation of flood modeling, among others. Nowadays, the speed measurement of waterways is performed by non-intrusive and intrusive (conventional)methods the latter group requires to be introduced into the fluid, putting at risk the operator's life and the measurement equipment, because the sensors can suffer damage (corrosion and/or incrustation problems) [2].

One of the most widely used non-intrusive methods for measuring velocity fields is large-scale particle image velocimetry (LSPIV), being an effective, instantaneous, and non-intrusive method [3]. LSPIV uses Euler's principle, observing particle patterns and by cross-correlation of images determines the most probable displacement with too small a time interval occurring between successive images. On the other hand, the LSPTV method, based on Lagrangian motion, consists of obtaining the velocity of surface currents through digital images, thus detecting the change of position of tracers previously seeded in the surface current [4]. Having the basis of the captured images and in a known time interval, we proceed to detect the position changes and subsequently its individual vector for each of the tracers by means of specific algorithms and the help of computer programs developed by Dr. Brevis together with his research group and Dr. Patalano, respectively [5].

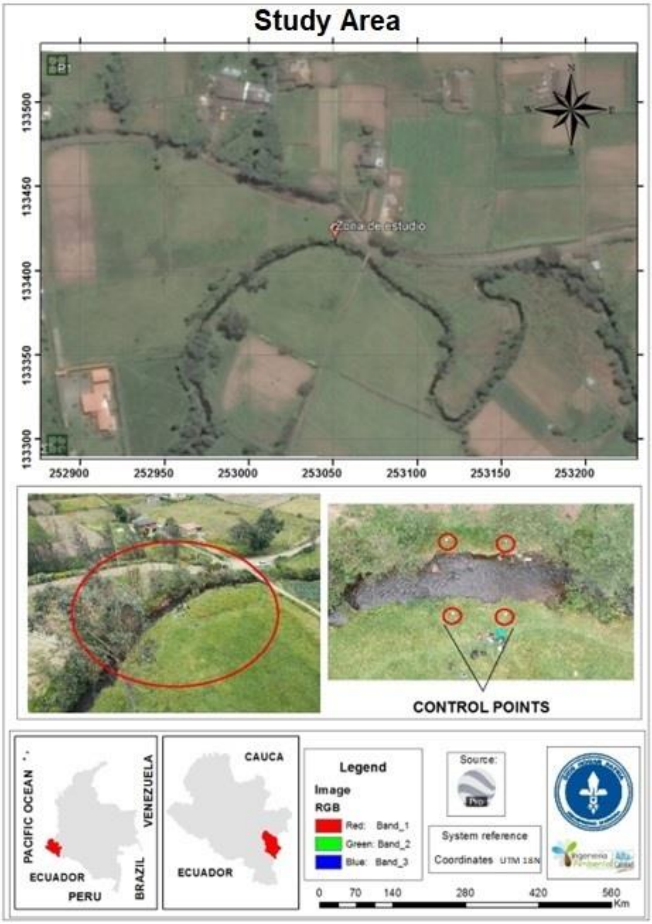
PTV techniques have a greater advantage than PIV when the concentration of particles in the fluid is lower; additionally, its installation is much simpler and cheaper because PTV does not require any type of laser. Finally, better results have been observed in the PTV technique because of its higher spatial resolution [6].

The present study aims to evaluate the reliability of speed measurements through conventional methods and the LSPTV technique in mountain rivers, characteristic of the Colombian Andean Region, in the Department of Nariño. The conventional equipment used were electromagnetic windlass and propeller windlass, while the images to be processed were obtained by two types of drones DJI Spark and DJI Inspire II, with a tripoidal function to avoid strong movements that could disturb the position of the tracers and generate errors in obtaining velocity fields.

1. MATERIALS & METHODS

The study was evaluated in the upper basin of the Pasto River, selecting a representative fluvial section of the area. It is in the village of La Laguna, municipality of Pasto, Department of Nariño (Figure 1). When evaluating the section under study for the fluvial characterization, an average depth of 0.36 m, a maximum depth of 0.63, and a representative width of approximately 5 m were found; it was established that the adequate length for the characterization of the section under study is 100 m, taking into account that it should be 20 to 30 times the representative width of the river [7], likewise, fluvial parameters such as slope, river bottom material, width-depth ratio, boxing ratio, and sinuosity were determined. The measurement conditions were developed in mid-water times.

Figure 1. Location of the study area



Source: own elaboration.

The average slope was determined along the longitudinal profile of the channel by measuring the difference in elevation of the bank surface per length unit of the channel, using a Topcon AT-22A automatic laser level. Slope measurements were taken every ten meters, estimating the difference in height between the different sections.

Five transverse profiles of the river, related to its length, were selected to facilitate the determination of all the application parameters. The width/depth ratio was obtained by determining the average depth of the channel and the width of the bank full. The average depth is obtained from the ratio between the profile area/stream width. Finding the area, using the depth measured every 50 cm across the width of the river. The bank full ratio is determined through the channel width obtained with an elevation of two times the maximum bank full depth and the bank full width [7].

The speed measurement of the river section by intrusive methods was performed with two types of windlasses, one with a propeller and one electromagnetic, the first corresponds to a universal windlass with basic operation, where the current rotates the propeller of the windlass and a magnet that rotates with the propeller drives the sensor that transforms the revolutions per minute to speed information in m / s. The electromagnetic windlass used was reference OTT MF pro [8], consists of a magnetic-inductive flow meter to measure speeds at points in different water currents, and it consists of a magnetic-inductive flow meter to measure velocities at points in different water currents. On the other hand, the electromagnetic windlass used was reference OTT MF pro [8], it consists of a magnetic-inductive flux meter to measure speeds by points in different water currents. It consists of a light and compact sensor made of glass fiber reinforced ABS material, also of a robust handheld controller, and works reliably even under difficult conditions. Both system components are designed for mounting on conventional measuring rods. The measuring range is from 0 m/s to 6 m/s with an accuracy in 0 to 3 m/s of ±2% of the measured value ±0.015 m/s and in 3 to 5 m/s: ±4% of the measured value ±0.015 m/s.

In relation to the non-intrusive LSPTV technique, two types of tracers were selected to characterize the surface velocity field based on the study of Patalano *et al.* [9]. The tracers used were 8 cm diameter orange peel and 11.8 cm diameter plastic caps (figure 2 and figure 3.) coated with white tape to improve visibility. Both tracers comply with adequate characteristics, related to their surface tension, density, and buoyancy, in addition, they are low cost, and their acquisition is not restricted, highlighting that the tracers were collected at the end of each test avoiding alterations in the ecosystem.

Figure 2. Tracers' plastic lids of approximately 11.8 cm diameter

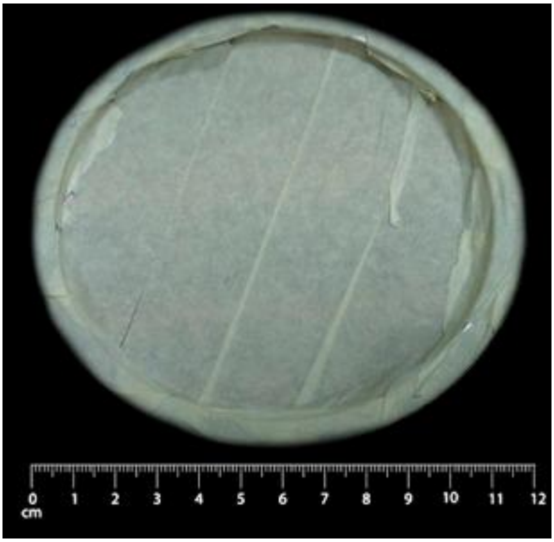


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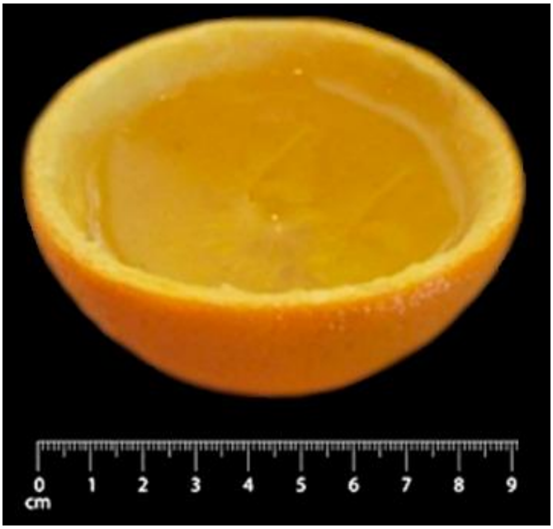
Figure 3. Tracers of orange peel approximately 8 cm in diameter



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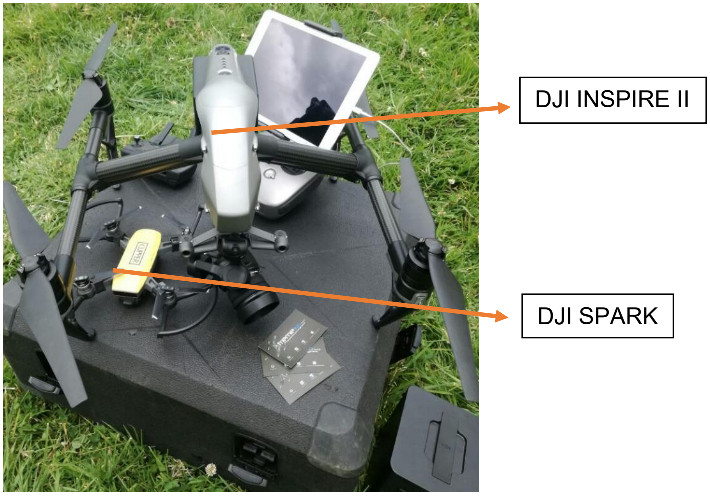
To carry out the filming, two types of drones —DJI Inspire II and a DJI Spark— (Figure 4) with different physical and functional characteristics were used, taking into account that they have excellent stability in the wind through the tripod function, following the recommendation that the camera should not have any movement [10], likewise, that the minimum resolution of the camera is 640x480 pixels [11]. The first one has a weight of 3440 g, including propellers and two batteries, videos were captured using the UAV's default CMOS 4/3'', 20 MP camera (15 mm focal length), at a native resolution of 4 K (3840 × 2160) and a frame rate of 59.94 frames per second (fps). The videos were shot at a flying height of 25 m, with a ground sampling distance (GSD) of 0.74 cm/pixel.

Figure 4. Comparison of VANTS DJI Inspire II and DJI Spark used in the study area



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The DJI Spark is a mini drone with a weight of 300 g, and a dimension of 143×143×55 mm. The videos were captured using UAV's default CMOS 1.2/3'', 12 MP camera (6.6 mm focal length), at a native resolution HD (1280 × 720) and a frame rate of 29.97 frames per second (fps). videos were shot at a flying height of 19 m, with a ground sampling distance (GSD) of 135 cm/pixel.

The camera of each of them is located at an angle of 90° formed by the vertical of the lens, all the area remaining within the focus of the camera was cleared and proceeded to start filming, also attributed to the tripod function where the movement in the control is reduced so that the movements are smoother and controlled in-flight, which was evidenced in the field control points observed in the (figure 1).

To reduce the mistakes presented during the flight where turbulences occurred and affected the tripod function of the vehicles, the videos were edited using the Adobe Premiere Pro CC 2017 software, considering the vertical rotation, cropping, light reduction (opacity), and the stability without movement of each frame in the video. In this way, image extraction and processing were performed through the PTVlab software, determining the flow speed of each test performed.

In the PTVlab software, a preprocessing, processing and extraction of the flow velocity in time and space by cross-correlation was performed. Initially, we have input data corresponding to the sequence of images and minimum allowed correction coefficients, then the particle detection is performed by filters that are used on the images so that the particles are white, until they have a black background [9]. Finally, a processing of the coordinates of the detected particles and extraction of the flow velocity in time and space by cross-correlation was performed [12].

Finally, to make a comparison between the average surface speed provided by the LSPTV technique and the average speed collected in the field with the windlasses, a conventional method called surface speed index (α) is used. The variability of α values is in the range of 0.70-0.90, however, due to variations in channel geometry it is difficult to select an appropriate value. In the literature there are methodologies that use numerical methods where the measurement of speed in different cross sections and at different depths is required, for more detail on this type of methodologies we recommend the review of the study by C. Masafu, *et al.* [13].

For this study, the α factor was extracted through literature review finding that authors such as Cheng, *et al.* 2004 [14], performed estimation of this coefficient using ADCP for flow velocity measurements at water depth and velocimetry through radar to evaluate surface velocities. These authors suggest that it is feasible to use surface velocities since the value of α always falls in the same range of the theoretical value ($\alpha \approx 0.85$), this was corroborated with the study [13], which used a nonlinear generalized reduced gradient optimization algorithm (Solver), obtaining as a result $\alpha = 0.89$.

2. RESULTS

The values obtained in the fluvial characterization are the product of a morphological classification of the river, which plays a very important role because it allows ordering the observations and field data collection, facilitating the interpretation of the forms and processes analyzed and leads to the formulation of empirical and theoretical laws that explain the differences in the structure and functioning of the classified objects [15].

The values of the fluvial characterization of the river section under study are presented in Table 1.

Table 1. Results of fluvial characterization parameters of the Pasto River section

Parameter	Amount
Slope of water surface (%)	1.50
Entrenchment ratio	1.05
Width/depth ratio	17.53
Sinuosity	1.30

Source: own elaboration.

Also, a distribution of materials from the river bottom was conducted, finding rocks, gravel, sand, and clay (Table 2).

Table 2. Results of bottom material of the Pasto River section

Type of material	Size
Boulder	Large > 508 mm Small 254- 508 mm
Gravel	2.032- 63.5 mm
Sand	0.062 a 2 mm
Clay	< 0.062 mm

Source: own elaboration.

Subsequently, the comparison between the two intrusive techniques, propeller windlass and electromagnetic windlass with the LSPTV technique with several types of tracers and unmanned vehicles in a section of the Pasto River was demonstrated (Table 3). In this way, it is evident that the tracers that best adapted to the technique were the orange peel with a diameter of 8 cm, using the DJI Spark drone obtaining a speed with depth correction of 0.33 m/s and with the DJI Inspire drone a speed of 0.42 m/s.

Table 3. Results of the relative error obtained by comparing the flow velocity measurement between the LSPTV techniques with different tracers in the Pasto River

Tracer type	Electromagnetic velocity meter (m/s)	Digital water velocity meter (m/s)	Speed PTV (m/s) Inspire II		Speed PTV (m/s) Spark		Relative error Inspire II		Relative error Spark	
			α=1	α=0.85	α=1	α=0.85	α=1	α=0.85	α=1	α=0.85
Plastic lids	0.36	0.31	0.51	0.43	0.52	0.44	29 %	17 %	31 %	19 %
Orange peel	0.36	0.31	0.49	0.42	0.39	0.33	27 %	14 %	8 %	9 %

Source: Prepared by the authors.

Figures 5 and 6 show that the trajectory of the orange peel tracers presented a more significant distribution, as well as the field of speeds (Figures 7 and 8), corresponding to the orange peel tracers with the DJI Inspire II and DJI Spark equipment respectively, although these tracers presented a difficulty in the detection of the particles compared to the plastic caps, these were distributed in a larger cross-sectional area, probably associated with the fluvial parameters and the river type classification according to the river characterization that was performed, as well as due to the riffle-pool behavior in the river, with stagnation zones and "waterfalls" that fit the type of tracers used (Figures 7 and 8).

Figure 5. Flow lines of the Pasto River obtained with PTVlab. Drone DJI Spark. Tracers: oranges

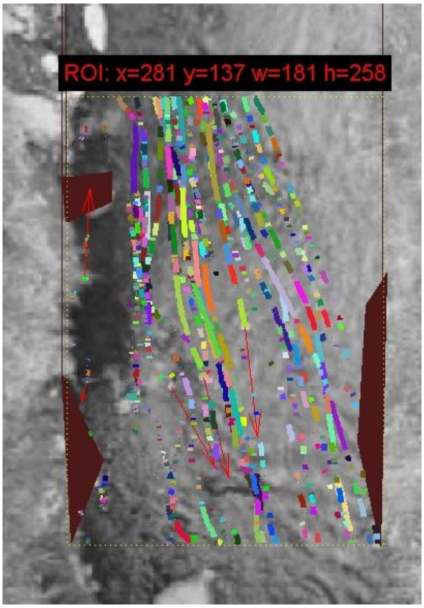

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Figure 6. Pasto river flow lines obtained with PTVlab. Drone DJI Spark. Tracers: plastic covers

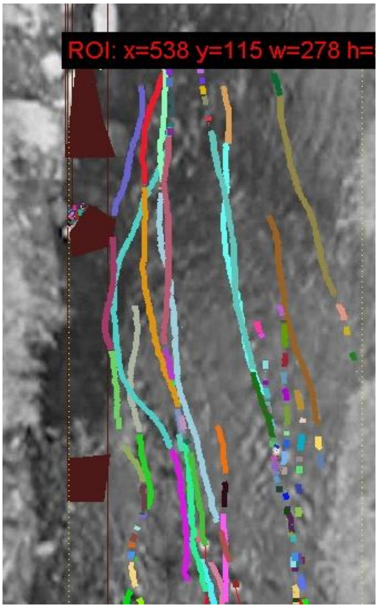

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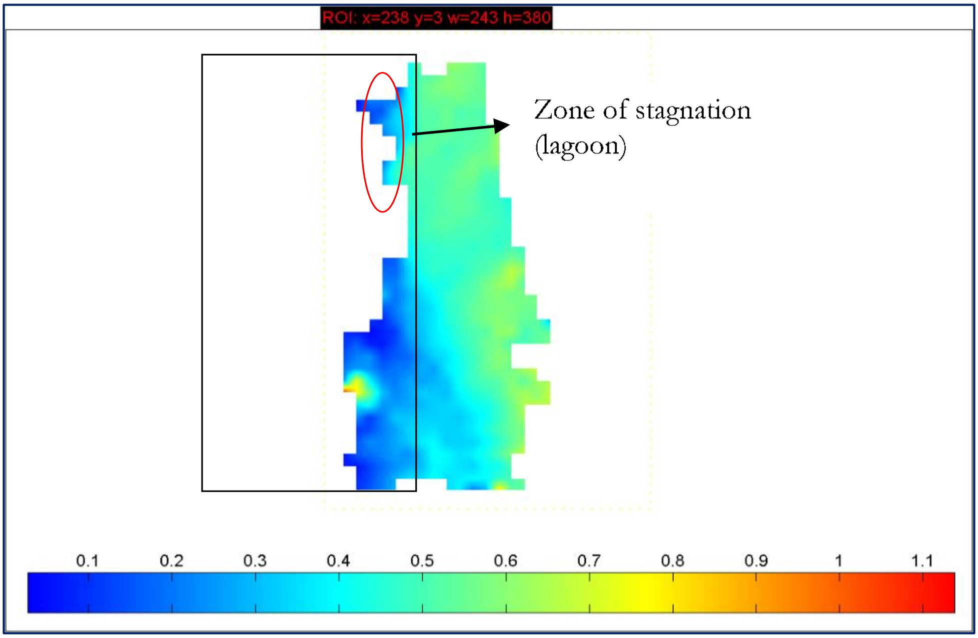
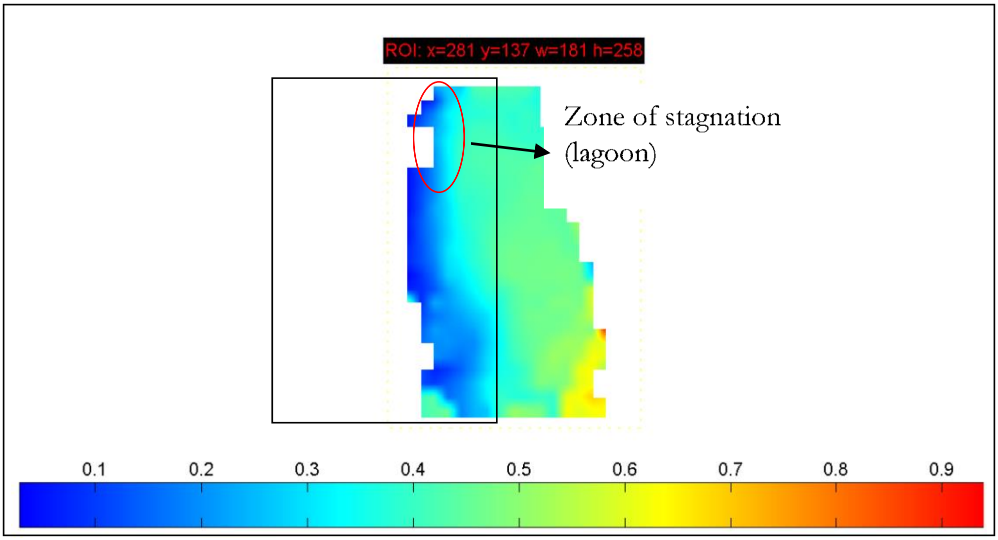
Figure 7. Field of Pasto River speeds obtained with PTVlab. Drone DJI Spark. Tracers: oranges



Source: own elaboration.

Figure 8. Field of Pasto River speeds obtained with PTVlab. Drone Inspire II. Tracers: oranges



Source: Prepared by the authors.

3. DISCUSSION OF RESULTS

According to Sánchez [16], the results presented in Table 1 correspond to a river of type C classification, with valleys developed on alluvial deposits, so that they have a well-developed and slightly embedded floodplain, with an embeddedness ratio greater than two; a high width/depth ratio in the channel, with a value greater than twelve, in addition, they are sinuous rivers (sinuosity greater than 1.2) and have slopes below 2 %, the characteristic longitudinal sequence of the bed is the riffle-pool.

In this way, the essential morphological characteristics of type C rivers are sinuosity and low channel relief, aggradation and lateral meandering processes are usually remarkably active, although they depend on bank stability, upstream basin conditions, both flow and sediment regime. Type C rivers can be easily and rapidly destabilized by bank instability or changes in flow and/or sediment flows [16].

In Table 2, the headwater sectors of the riverbeds are made up of large blocks of colluvial origin, which determine the formation of small "waterfalls". Downstream, the average size of these blocks decreases, and the current can organize small "stairs", where one can recognize an alternation of pools and small jumps that respectively affect the entire cross-section [17].

As the longitudinal slope decreases, downstream sections of "continuous riffles" are formed, with gravels and boulders, and the small dams organized by the larger stones that constituted the upstream steps disappear. Similarly, Alonso [18] mentions that, in this type of river, the bed is organized longitudinally in a sequence between steps formed by clusters of larger sediments and pools formed by finer particles. The predominant sources of sediment input are the same as in the case of the cascade (*i.e.,* in addition to fluvial, hillslope, and torrential lava) but the primary sedimentation occurs in the bottom forms.

In addition, Arellano [19] reports that the "riffles" accumulate thick bottom material and are subject to a flow with a higher water speed due to the high longitudinal slope. The pools consist of a bed of material finer than the "riffles", with water flowing at a slow speed compared to the "riffles", which was demonstrated in the achieved results.

The results obtained in Table 3, in relation to the relative error in each vehicle, show that in comparison with other research performed by [4], [9], [11], [13], and [20] where recordings with fixed support cameras were used, a higher percentage of relative error was obtained. The error could have occurred because the drones have vibration effects due to the propellers, or momentary wind currents, characteristic in mountainous areas.

The recognition of the particles in each image requires that their size is adequate to be detected by the processing software. If the particles are smaller than 2 pixels, their detection is difficult [11], on the contrary, if the particles are too large, they are detected as the union of several particles, due to the changes in luminosity that occur in the field, generating uncertainty when determining the velocity field.

According to the GSD found for each drone, in the case of Spark, a GSD = 1.35 cm/px was found, it is inferred that to detect the plastic caps tracers, approximately 8 px were required and to detect the orange peels, approximately 6 px were required. In the case of the DJI Inspire 2, a GSD = 0.74 is obtained, which means that 15 px is required to detect plastic lids, and approximately 11 px is required to detect orange peels.

According to the above, it is inferred that in the case of DJI Spark, the pixels of the tracers especially orange peels, are close to the size recommended by several authors such as Vaschalde, 2013 [11], where better particle processing is achieved in the software used (PTVlab). With the 1 megapixel resolution of the camera, the diameter of a particle in the images covers about 6 pixels. The 6-pixel coverage used here was found to be sufficient to allow the detection of the central position of the particle with sub-pixel resolution. Achieving sub-pixel resolution becomes important when small displacements are considered [21].

Another author refers that it is also advisable that the particle size has a diameter between 3 and 4 pixels so that the position of the particle can be accurately recorded [22].

On the other hand, according to the results presented in Figures 5, 6, 7, and 8, Tang [23] mentions tha, the performance of the particles depends on their shape, to obtain better results he recommends the search for tracers of ellipsoidal shape, because they can float on the water surface, even if the water is very shallow they tend not to accumulate with each other, because their major axis is much longer than their minor axis. [20] He mentions that a disadvantage of using spherical particles is that they tend to agglomerate, which could be evidenced with the tendency of plastic caps, being a cause of confusion in the detection of the displacement of each particle, affecting the result of surface speed.

Plant [24] mentions that the surface speed correction factor at average speed always tends to decay at $\alpha = 0.85$ calculated empirically, applying the factor decreases the relative error difference between the intrusive technique and non-intrusive LSPTV technique.

From the literature review, it specifies the value $\alpha = 0.85$,which is typically proposed for natural waterways and has become standard practice within the hydraulic community, the same being strictly valid when the mean longitudinal flow velocity profiles at any section follow the standard logarithmic law distribution [25].

Estimation of surface flow velocity fields determined with LSPTV on a large scale in a non-intrusive manner requires defining the relationship α between the measured values of mean flow speed in the water column and the values of surface speeds [9]. This relationship depends on the bottom geometry, roughness, secondary currents, and wind effect.

According to Patalano *et al.* [9], sources of different errors that could occur in the tests performed; the type of illumination (the reflection of sunlight on the water surface can disturb the particle detection algorithms) and the wind (directly influences the speed of the particles) are two of the physical phenomena of the environment that most noticeably influence the measurements.

Also, it should be noted that there were difficulties in obtaining the speed values at some points of the study section, taking into account the type of river studied, presenting a behavior according to the geometry of the channel of “riffles and pools” that causes the particles sown upstream of the measurement section to tend to enter in the areas of higher speeds and leave the areas of stagnation or lower speeds.

Additionally, the accurate determination of the correction factor is one of the main uncertainty factors when evaluating mean velocity from surface velocity measurements, since it causes a multiplicative and systematic error. It has been previously mentioned that the factor $\alpha = 0.85$ proposed to quantify velocity using the LSPTV technique, is typically proposed for natural channels and presents an error of the order of ±5 % in velocity determination [25].

Finally, there are also uncertainties in the quantification of the flow rate by using hydrometric windlass that lie mainly in the proper calibration of the equipment and the way the technique is performed *in situ* (measuring the depth of the channel in the progressive, placing the velocimeter perpendicular to the current, number of measurement points, etc [22]).

4. CONCLUSIONS

When performing the fluvial characterization, taking into account the various fluvial parameters studied, slope, sinuosity, width-depth ratio, boxing ratio, and channel bottom material, it is observed that they are of great importance to obtain a classification of the water body studied, related to the behavior of the water current, pertaining to rapids and pools, which are directly attributed to the spatial variability of speeds along the waterway.

The correction factors α from surface speed to deep velocity are important to being able to compare the results obtained with non-intrusive techniques. These can be estimated through numerical methods for each specific river and with previous planning; however, if there is no way to obtain them, the ones recommended by the literature in studies of rivers with similar fluvial characteristics can be used.

Although the non-intrusive technique evaluated requires the use of round, high-contrast tracers that are difficult to find in the natural environment, algorithms are now available that detect tracers of any shape, which has the advantage that it is no longer necessary to seed particles in the water body.

According to the study, it is inferred that a device that specifically does not have a high resolution can be used, but it is important to take into account other factors such as the stability of the drone and to observe that at the time of recording the video the wind conditions are adequate, in order to avoid errors at the time of processing the videos. Additionally, it is essential to calculate a ground sampling distance (GSD) in order to find an adequate flight altitude.

The measurement of water current speeds by non-intrusive methods is a technique that is gaining increased strength as technology advances along with the implementation of improvements in the algorithms for PIV and PTV techniques, even with a drone it is possible to monitor places that are difficult to access.

Non-intrusive techniques show immense potential in measurements of water bodies, making it a more accessible method for some entities that wish to monitor water bodies and have difficulties such as access to the terrain, scarce resources to acquire intrusive techniques, inaccessibility due to floods in the channel, among others. This study allowed observing that the necessary characteristic of a drone for speed measurement in water bodies is its stability against disturbances due to wind and vibrations while it is operating.

5. ACKNOWLEDGEMENT

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