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COB-2021-2278 Appling the Large-Scale Particle Image Velocimetry with drone images for determining the hydrokinetic potential in rivers

Felipe Ribeiro de Toledo Camargo
Reginaldo Nunes da Silva
Rafael Castilho Faria Mendes
Tayogara Oliveira
Antonio Brasil Junior
UnB - Brasilia, Federal District, 70910-900
felipertc@gmail.com, profreginaldo.n@gmail.com, rafael.cfmendes@gmail.com, taygoara@unb.br, Brasiljr@unb.br

Abstract. *The hydrokinetic potential in rivers is proportional to the flow rate, where it crucial to find high velocities to make it viable to install hydrokinetic turbines. In some cases, due to the large scales, the velocity measuring is a problematic process and demands expensive equipment, like acoustic Doppler current profiles (ADCP). In this view, this work intends to demonstrate a low-priced methodology of Large-Scale Particle Image Velocimetry (LSPIV) with drone images for measuring the velocities on the river's surface. The tests were carried on Rodeador river in Federal District, Brazil. The presence of trace-marks also was analyzed, where some sawdust was deployed on the river to improve the LSPIV results. The measurements were compared to traditional ADCP results.*

Keywords: *Large-Scale Particle Image Velocimetry, acoustic Doppler current profiles, Hydrokinetic potential.*

1. INTRODUCTION

Increasing the supply of renewable and clean energy is a global demand. Energy use and GDP (Gross Domestic Product) are positively correlated so is extremely important that a country like Brazil can expand it energy matrix to increase the GDP and improve the quality of life of Brazilians.

Aware of this global need to increase energy supply in a clean and renewable way and aware of the situation of the Brazilian energy matrix, which is mostly composed of hydroelectric plants, this work proposes to analyze a methodology to determine the hydrokinetic potential in rivers using the LSPIV technique.

Hydrokinetic energy is defined as the energy associated with the movement of water in rivers, coastal areas and oceans, whose primary energy sources are of origin gravity, associated with surface drainage in a relief of a hydrographic, tidal effects or ocean currents on a planetary/regional scale. This water mass movement in water currents provides a potential relevant energy, which can be used for conversion into electricity by means of suitable electromechanical devices. In this sense, this bias of energy restraint has been the object of an important development axis of technologies over the last decade (e.g. (Yuce and Muratoglu, 2015), (Sood and Singal, 2019)).

New methods that can help in the hydrological characterization is totally necessary, mostly in a country like Brazil. The benefits of this method if compares to usual ones, like bathymetry, sonar and ADCP (Acoustic Doppler Current Profiler) is that LSPIV is a non-intrusive instrument, so it does not need to be in contact with the fluids. Ensuring more safety for the operator of the system and possibility to records measurements in extreme events, without the risk of losing or breaking the equipment during "(Camargo *et al.*, 2020).

The LSPIV method derives from the PIV (Particle Image Velocimetry) method, that was typically adopt to solve mechanics fluids problems in the early eighties. PIV found great acceptability of the scientific community for being a cheap and efficient method and at that time were expected that with technologies advances this method become even more efficient, cheaper and reliable (Fincham and Spedding, 1997).

PIV is an experimental technique that allows the acquisition of velocity field data of a flow in fractions of seconds. The working principle of PIV is based on measurements of the displacement of particles present in the fluid, carried out by capturing multiple images. Small diameter particles are generated and dispersed in the flow by a seeder. A plane of light, formed by a set of optical lenses and a laser, as shown in Figure 1, is generated to illuminate the area of interest, managing to highlight the particles and allowing them to be visualized by the camera. The image capture process is done multiple times and very quickly, where in the interval between photos, it is possible to visualize the path taken between the particles. The entire PIV process is synchronized such that the system fires the first laser pulse, takes the first photo, then fires the second pulse and takes the second image capture. The time between photos will depend on speed and data transmission. After acquiring the images, a pair of subsequent photos is compared in order to compute the displacement of the particles. The PIV methodology results in the measurement of the velocity field in the captured image area, being able to even distinguish the two velocity coordinates in the plane.

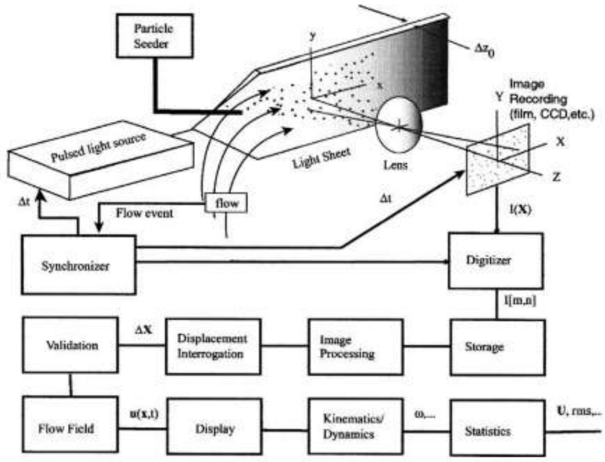

Figure 1: PIV Setup (Adrian 2005)

Fujita (Fujita *et al.*, 1998) is the first author to use the name LSPIV (Large Scale Particle Image Velocimetry) for large scale PIV experiments. The first time this technique was applied to measure the velocity of a river was in Japan and as the studied area was larger than that traditionally area used for PIV experiments, the name LSPIV become more adequate (AYA *et al.*, 1995). It could be experiments in hydraulic laboratories, rivers, channels or floods events. Measuring the surface velocity of a water course is a very important factor in the hydrological characterization.

The LSPIV technique employs the same principle as the classic PIV, but applied to larger length scales, normally found in situations external to laboratory situations, such as river surface velocity calculation applications. From this point on wards, the main distinction between PIV and LSPIV cases are the orders of magnitudes found in the problems, in which, generally, the large length scales are accompanied by smaller scales of times and characteristic speeds found in the cases of LSPIV. Thus, the application of the LSPIV methodology is less costly than the classic case of PIV, not depending on sophisticated equipment to capture images quickly.

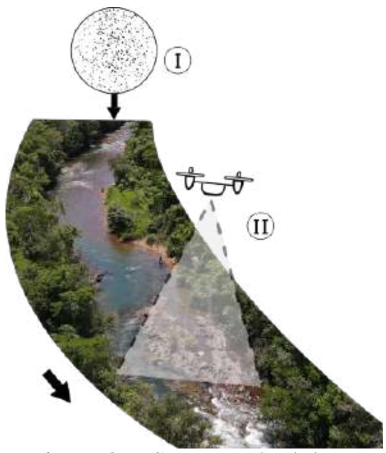

Figure 2: LSPIV Methodology

Generally, the LSPV technique is applied in cases of water runoff, with great emphasis on surface runoff. The standard LSPIV technique is illustrated in Figure 2 and is based on standard PIV elements, with the exception of laser and synchronizer elements. These reservations are based on low speeds and the natural presence of a flat surface. Returning to the illustration in Fig 2, the methodology can be described as two steps: I) dissemination of particles on the river surface and II) image acquisition, which in the case of this work was performed by a drone, but there are acquisition options through fixed cameras.

The experiment was conduct at the Rodeador River, that is located at Federal District the capital from Brazil. The River is in the administrative region of Brazlândia, a predominantly rural region. The Rodeador River is the main tributary of the Descoberto reservoir, the primary water reservoir in the Federal District. Using a DJI Mavic Air 2 Drone the images of the river flow were capture and processed at PIVLAB, a open source PIV tool. Also an ADCP measure was performed at the River so it could be possible to compare both techniques.

2. Methodology

This work methodology is divide in two steps. The first step is the field data collection, where the site location, the ADCP equipment operation and the image acquisition with the drone are gone be presented. The second step is the processing phase, with the support of the software RIVeR (Patalano *et al.*, 2017) to correct the displacement from the drone that capture the images and the PIVLab (Thielicke and Stamhuis, 2014) to process the frames from the videos.

2.1 Field Data Collection

As mention before, the images were collected at Rodeador River. The river is barred to form the Rodeador Channel, the region's major irrigation channel (ADASA, 2018), see Fig 3. The flow from both river and channel are monitored by the ADASA, the water agency from Brasília.

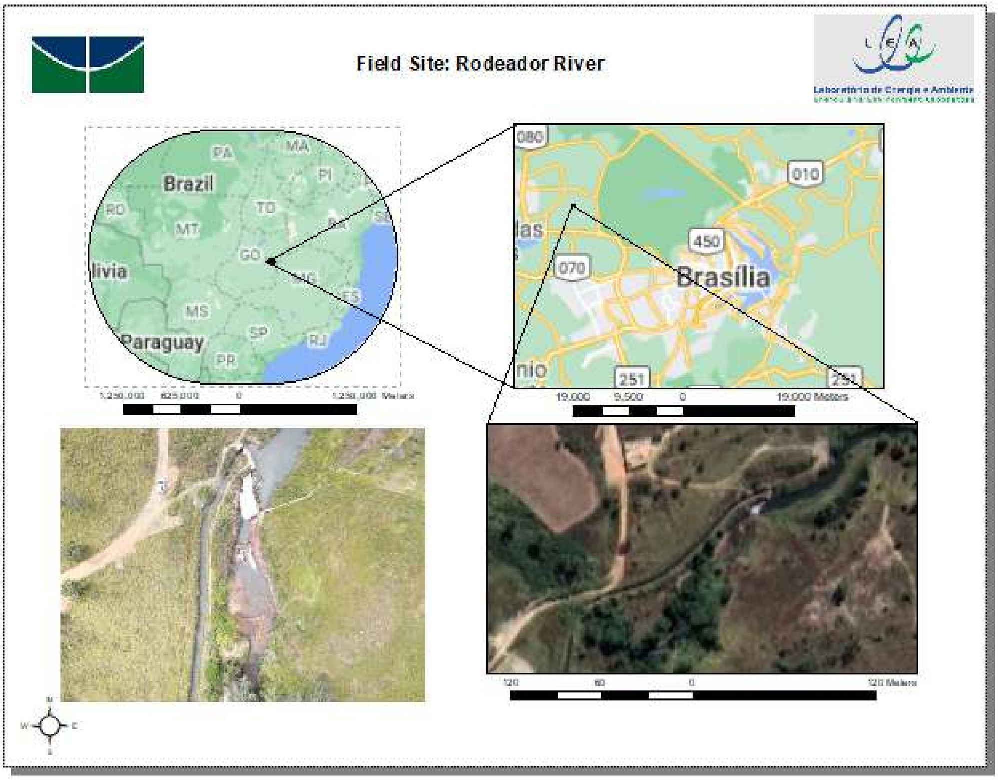

Figure 3: Location map

The ADCP equipment is the M9 ADP from Sontek that is a nine-beam system with two sets of four profiling beams and one vertical beam, see Fig 4a 4. The M9 has a velocity profiling range of up to 30 m and a discharge measurement of 80 meters. It measures water currents with sound, using a principle of sound waves called the Doppler effect. The ADCP works by transmitting "pings" of sound at a constant frequency into the water. As the sound waves travel, they ricochet off particles suspended in the moving water, and reflect back to the instrument.

A boat was design and construct to remotely operate the M9 sensor through the river, see Fig. 4b. Were printed 60 pieces by a 3D printer and glued together, a glass resin was also added and the electronic part was installed. The boat traveled through a region of interest to collect information on both the river's bathymetry and velocity profiles. With these information gathered the flow of the river was calculate and compared with the flow measured by the hydroelectric.

The drone took off in a flat region away from any type of vegetation and was manually driven to the area of interest, previously measured by define the M9 sensor. Positioned 6 meters above the water level and with its camera positioned orthogonally to the direction of the river's flow. Sawdust was added to the flow to work as a natural tracer.

2.2 Processing Phase

As the field data collection is completed. The processing phase starts. The M9 sensor has it own software to extract and visualize the results. The Sontek offers a interface called River Survey live that is possible to analyze the path the sensor has taken and extract information from both bathymetry and velocity profiles into a format compatible with matlab files. The LSPIV method were processed with the support of two software. First the PIVLAB (Thielicke and Stamhuis, 2014) is used to extracted the frames from the videos, then with the RIVeR program (Patalano *et al.*, 2017) the displacement

(a) M9 ADP by Sontek

(b) Boat design and built to remote operate the M9

Figure 4: Detail from the M9 sensor and the Boat

from the drone is corrected to each frames previously extract.

The video was recorded at a rate of 60 frames per second, with a Δt of 10 seconds the RiVER program extracted 600 frames and we used a tool from the same program to calibrate and correct the instability of the Drone's flight. The Δt of 10 seconds was define after an analyse of the convergence of both mean and standard deviation from the velocity's results obtain from the processing phase. With the 600 frames extracted and corrected, the image correlation analysis procedure begins.

The technique basically consist of an image matching pattern. Each pair of frames will be analyze together. The program works defining a region of interest (ROI) in the first frame of the pair. In this ROI is define some searching areas (SA), grid box that decreases in size proportionally. The idea is to characterize the pixel inside these boxes, calling this characterize pixel of interrogation point, and search for this same pattern in the next frame of the image pair "(Camargo *et al.*, 2020). This characterization and search for pattern is the most sensitive part of the LSPIV. This analyze is made by a cross correlation algorithm. In essence, the cross-correlation is a statistical pattern matching technique that tries to find the particle pattern from interrogation area A back in interrogation area B (Thielicke and Stamhuis, 2014). This statistical technique is implemented with the discrete cross correlation function, see equation 1:

$$C_{m,n} = \sum_{k=i}^{n} \sum_{k=j}^{n} A(i,j)B(i-m, j-n) \tag{1}$$

Where A and B are corresponding interrogation areas from frame A and frame B. There are two common approaches to solve equation 3. The most straightforward approaches is to compute the correlation matrix in the spatial domain, this approach is called direct cross correlation. The other approach is to compute the correlation matrix in the frequency domain, and is called Discrete Fourier Transformation (DFT). Both approach are available at PIVLab, and both have their advantages and disadvantages. For this work the discrete Fourier transformation was used because it demand a lower computational cost to solve the cross correlation. After defining the ROI and the SA in the first pair of frame, we expand the selection to all the frames extract from the videos and through DFT the surface velocity vectors of the channel are obtained "(Camargo *et al.*, 2020).

3. Results

The M9 Sensor collected data from the region of interest determined, see Fig. 5. From this area three cross-section were extracted from the LSPIV method and from the ADP equipment to compare the velocity and flow results that were obtained, which are represented by the dashed lines in the Fig 5. Some parts of the area analyse were too shallow for the M9 sensor to be able to collect information, therefore some pieces of the section went unmeasured. The bathymetry and the velocity profile from the section are showed in Fig 6.

The PIVLAB results are 600 text files that contain the velocity measured from each ones of the frames evaluate. To inspect this results and that could be perform a good comparison with the ADP method, the mean velocity value were extracted from all the 600 frames inspect and plot thought the cross-section, see Fig 7.

The velocity that are presented at Fig 7 are corresponding to the superficial velocity from the river. To compare the profile velocity measure by the M9 sensor with the superficial velocity measure by the LSPIV a index-velocity value will be assign to estimate the discharge measurements. A value of $k = 0.85$ is generally accepted for river flows and used in conjunction with other measurement techniques (Costa et al., 2000). The value of the index-velocity coefficient is based on the assumption that the vertical velocity distribution is logarithmic (Muste *et al.*, 2008).

Figure 5: Drone view from the Rodeador River, with the region of interest define

Now with the velocity's values corrected by the index value, the method can be relate, see Fig 8. Some results can be pointed out from this graph. The behavior of increasing speed through sessions remained present in both methods. The difference in the final speed value remained below 10%.

The discharge was calculate using the mean area measured by the M9 sensor. The value from the areas are show below and they units are in m^2:

Area 01	Area 02	Area 03
1.568	1.542	1.369

The value from the calculate discharge can be seen at Fig 9. The units of the discharge are m^3/s and the kept the difference between each methods preserved below 10%.

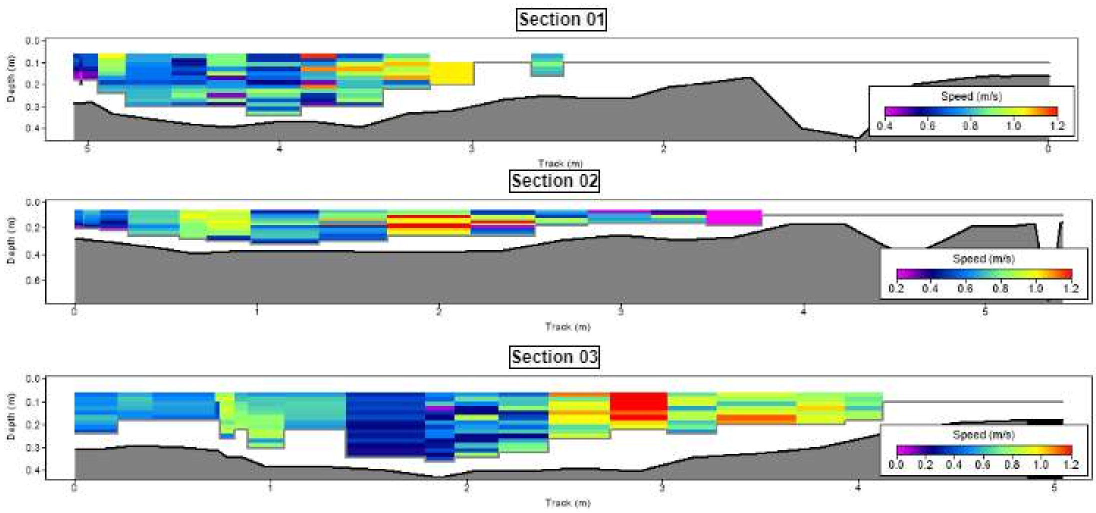

Figure 6: Bathymetry and Velocity from each section measured by the ADP equipment

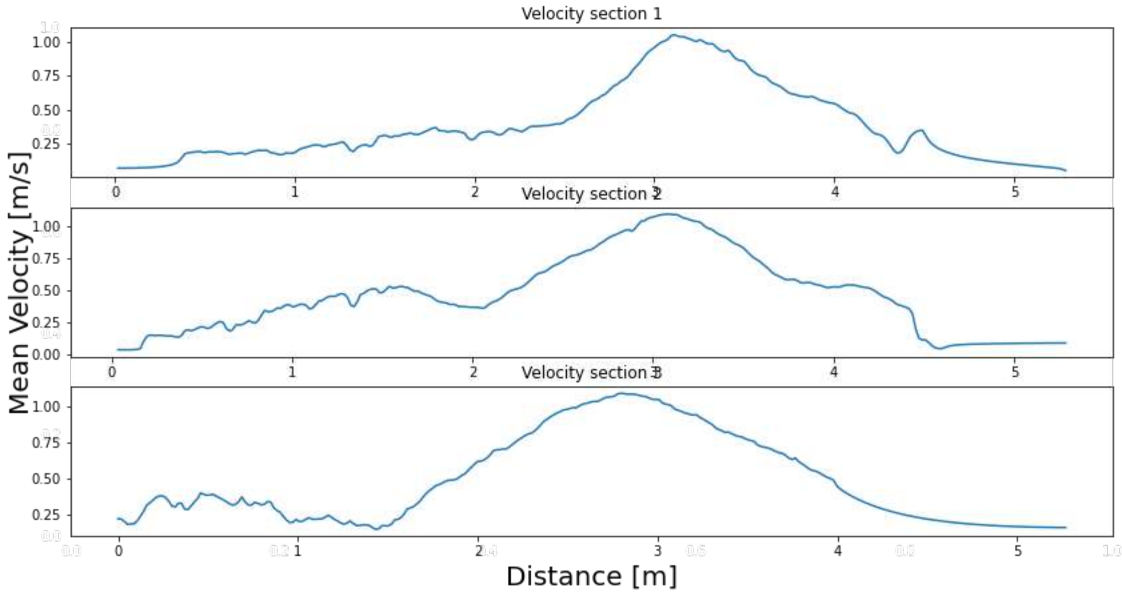

Figure 7: Superficial Velocity from the LSPIV method

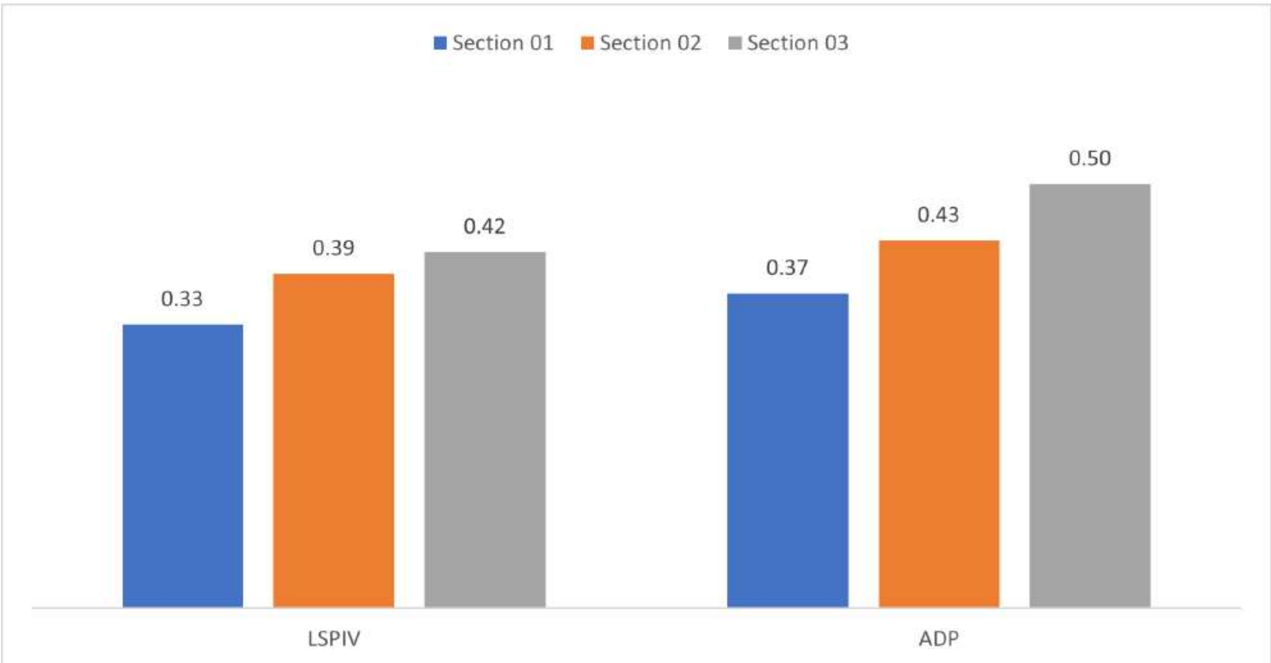

Figure 8: Mean velocity's value from each method and section

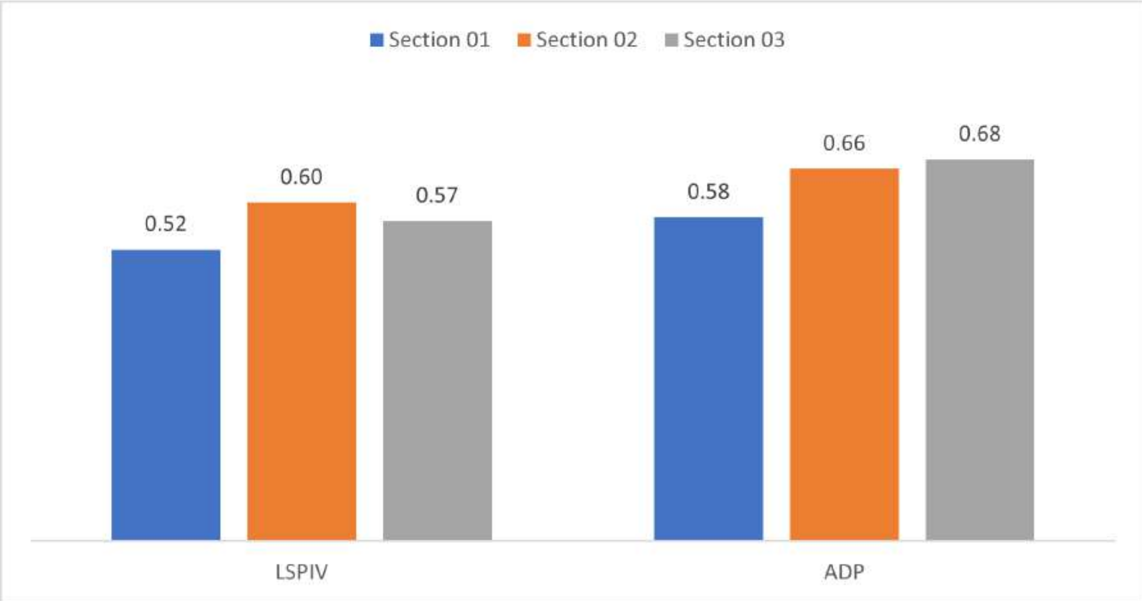

Figure 9: Discharge value from each method and section

4. Conclusion

New measures techniques are extremely important for river characterization. The LSPIV is a safe, fast and reliable technique to perform superficial velocity's measures. The difference between the values from each method was more than the expect but that can be cause as a result of the location that the video were record. There were a lot of shadow from tress that affects the image analyses. Despite the fact that the location could not physically receive the installation of an hydrokinetic turbines, the experiment was able to determine the hydrokinetic potential in the Rodeador river that was the prime objective of this work.

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