

Assessment of UAV-based Photogrammetry for Bathymetry Measurements in Haiti: Comparison with Manual Surveys and Official data

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Abstract

Updating topographic data in countries such as Haiti, prone to natural disasters where significant morphological changes occur in rivers on a regular basis is quite a challenge. This research proposes simple and relatively cheap solution as an alternative to Lidar measurements, with the contribution of photogrammetry, based on structure from motion, and using a drone for the acquisition of aerial images. The results obtained from the MetaShape software are very promising. In terms of elevation accuracy, the Digital Terrain Model (DTM) obtained from the UAV-based photogrammetry over all sampled cross sections shows a Root Mean Square Error (RMSE) between 5 to 20 cm when compared to the manual survey. In terms of resolution, at the study site of Leogane (Rouyonne River) the pixel size on the obtained orthophoto is 5 cm × 5 cm, which gives a better visualization than the official orthophoto (0.5 m × 0.5 m) of the National Center for GeoSpatial Information (CNIGS) in Haiti. At the Dubreuil site (L'Acul River), the RMSE for the cross-section of the weir is 0.062 m for the MetaShape DTM, and 0.260 m between the CNIGS and DGPS data. For the longitudinal profile, UAV-photogrammetry better represents this situation with an RMSE of 0.058 m against 1.74 meters for the CNIGS DTM that does not include recent morphological changes.

Faster to obtain, easier to update, less expensive and with a better resolution than the official data currently available in Haiti, UAV-based photogrammetry is a promising tool to be promoted for monitoring the morphological evolution of rivers.

Keywords: Bathymetric data; Topographic data; UAV-based photogrammetry; Morphological changes; Haiti

1. INTRODUCTION

During the last decade, the acquisition of aerial images using UAVs has been experimented in many fields. According to Emilien et al. (2021), more than 123 studies have been the basis of a recent research on the use of drones and satellite in synergy for optical remote sensing applications. Photogrammetry has become a widely used technique in many fields requiring land survey (Clapuyt et al., 2015; Colomina & Molina, 2014; James & Robson, 2012; Lucieer et al., 2014; Ryan et al., 2015; Westoby et al., 2012). With a simple camera mounted on an Unmanned Aerial Vehicle (UAV), a large number of aerial pictures can be taken in a short time.

Based on the structure from motion method of Lowe (2004) popularized by Snavely et al. (2008), image processing software become more common and the use of UAV (Unmanned Aerial Vehicle) has enhanced the possibilities offered by photogrammetry. Based on the evaluation of such a solution (Agüera-Vega et al., 2016, 2018; Alfredsen et al., 2018; Ruzgienenė et al., 2015), the accuracy is found to be very satisfactory.

The lack of topographic and bathymetric data in Haiti is one of the major problems that hinder progress in the field of scientific research, hydrology and hydraulics are not exempt from the problem. Indeed, according to Dewals et al. (2011), the modeling of one or two-dimensional flow requires good quality bathymetric data to better reproduce the event studied. In Haiti, it is difficult to model and simulate the situation of the main watersheds due to the lack of recent and accurate data, both topographic and hydrological. The topographic data of the country are managed by the CNIGS, which is an autonomous body created by presidential decree in March 2006 by merging the Service of Geodesy and Cartography (SCG) and the Unit of Remote Sensing and Geographic Information Systems (UTSIG), operates under the Ministry of Planning and External Cooperation (MPCE). The latest available Digital Terrain Model (DTM) is dated 2016 and the measurement campaign was started in January 2014. Considering the various extreme events that Haiti has experienced over the past five years including Hurricane Matthew in 2016 and Tropical Storm Laura in September 2020, relevant questions arise regarding the validity of the currently available data: (1) Is the available DTM still representative

for modeling river flows for hazard anticipation? (2) Can the drone photogrammetry technique be used to build digital terrain models and monitor the morphological evolution of rivers?

In this study, this method is used on two distinct sites: the Rouyonne River in Léogane city (Figure 1) and the Acul River in Dubreuil (Figure 2) which present different characteristics in terms of topographic configuration.



Figure 1. Location of the Rouyonne river in Léogane



Figure 2. Location of the site studied in Dubreuil

The UAV-based photogrammetry method was applied to these two sites with the aim of evaluating the accuracy of the results. The final aim would be to inform local actors about this technique for the update of the topographic, bathymetric data, and the morphological follow-up of the principal rivers, that is based on simple and inexpensive devices such as drones and a Go-Pro camera, to acquire a large amount of information in a short time.

2. MATERIALS AND METHODS

2.1. Data surveying

Data acquired using the UAV-based photogrammetry and a classical manual survey will be compared to the official data available for the entire country at the time of this study. The official survey started in January 2014 by IGN France International, with funding from the World Bank. These are: The Digital Terrain Model (DTM) of mesh $1.5 \text{ m} \times 1.5 \text{ m}$, and the Orthophoto with the pixel size $0.5 \text{ m} \times 0.5 \text{ m}$. Before comparing these three data sets, the UAV-based and the manual survey conducted for this study are described.

2.1.1. Aerial images acquisition

To take images on the sites studied, a UAV “Microkopter Hexa XL¹” was used with a flight height of 40 meters from the ground. The duration of each flight was about 10 minutes, depending on the autonomy of the batteries, with a speed of 5 m/s. A GoPro Hero 4 Silver camera was mounted on this UAV, capturing images at a frequency of one image every 2 seconds. The flight plans were prepared on the Microkopter Tools software, which is adapted to this type of drone. The frontal overlap of the images is 80% and the side overlap is 60% (Agisoft LLC, 2020, 2022), allowing to obtain enough information for the spatial construction of the studied scenes with a total of 300 images on average for a flight plan.

To apply the photogrammetric reconstruction of the topography, Ground Control Points (GCP) are placed on the site before flying over the area. All GCPs are surveyed shortly before the aerial images are taken, using the same differential GPS whose characteristics are given in the previous section. The GCPs are marked with a paper support on which a circular 12-bit image is inscribed. An illustration of the materialized GCP is given in Figure 3.



Figure 3. Example of the materialization of the GCPs (Leogane)

At both sites (Leogane and Dubreuil), 15 GCPs were placed with a representative spatial distribution (Figure 4) to optimize the georeferencing of the image alignment and improve the quality of the results. This number of points is in the range of 10 to 20 GCPs proposed by (Agüera-Vega et al., 2016; Alfredsen et al., 2018; Turner et al., 2012) and Tahar (2013) proposes different spatial configurations depending on the number of GCPs, from 4 to 9, to increase the accuracy of the Orthophoto plan and DTM. And from 8 GCPs to 9 GCPs, good results for the RMSE of the coordinates are obtained.

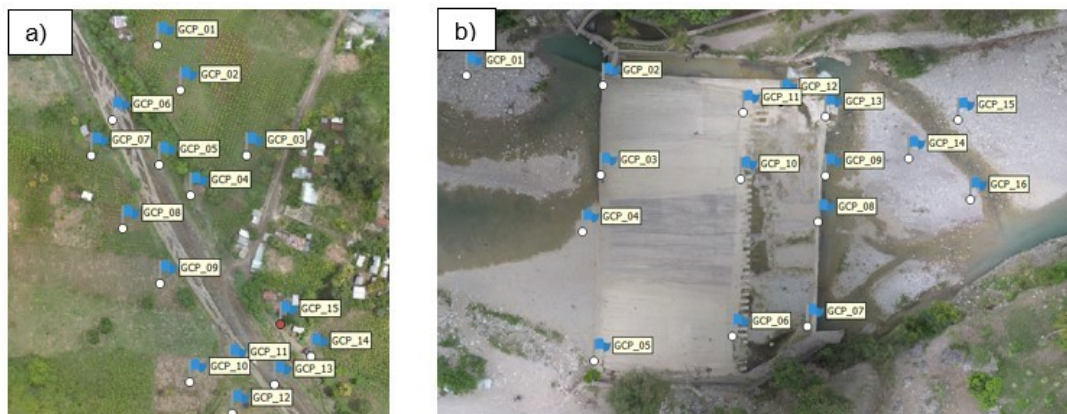


Figure 4. Spatial distribution of GCPs: (a) Leogane site, (b) Dubreuil site

2.1.2. Manual data survey

A manual topographic survey was conducted on both sites using a differential GPS Trimble brand equipped with a receiver R6 model 4, allowing to work in real time Kinematic (RTK) with a nominal horizontal and vertical accuracy, respectively, $\pm 10 \text{ mm} + 1 \text{ ppm RMS}$ and $\pm 20 \text{ mm} + 1 \text{ ppm RMS}$ (Trimble, 2009). Artificial benchmarks are placed at different locations on both sides of the river (upstream to downstream), to link the cross sections to a single topographic benchmark, following the river's path. The altimetric accuracy of these points is assessed by comparing the values recorded by DGPS to those of the official data (Table 1).

¹ <https://www.mikrokopter.de>

Table 1. Benchmark comparison for the Rouyonne river site

Benchmark name	X (m)	Y (m)	Z of the DGPS (m)	Z of official DTM data (m)	Difference (m)
B_01	754289.512	2044423.890	51.341	51.280	0.061
B_02	752844.355	2045717.963	40.981	41.001	-0.020
B_03	751822.359	2046473.839	31.150	31.080	0.070
B_04	750728.474	2047153.500	23.385	23.247	0.138
B_05	750076.080	2047346.444	20.874	20.811	0.063
B_06	749203.935	2048035.191	12.466	12.361	0.105

For the Rouyonne River, a total of 95 Cross-sections were surveyed with the differential GPS from upstream to downstream, following the river channel. Three sections from this survey are located in the photographed scene (Figure 5) and will be used to assess the accuracy of the photogrammetric method. The same process of manual survey was done on three sections on the Dubreuil site (Figure 6): the cross-section of the crest of the weir and finally, the cross-section downstream separated by 100 meters of linear distance.

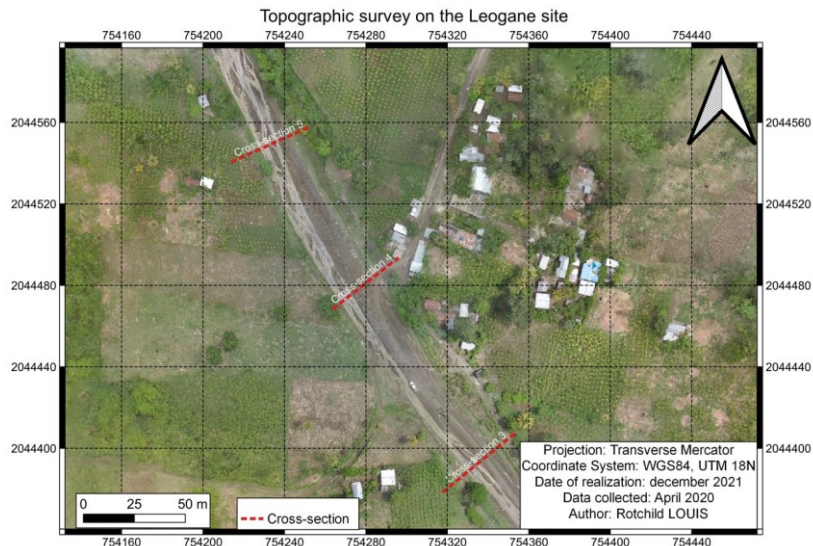


Figure 5. Manuel data survey on the Leogane site

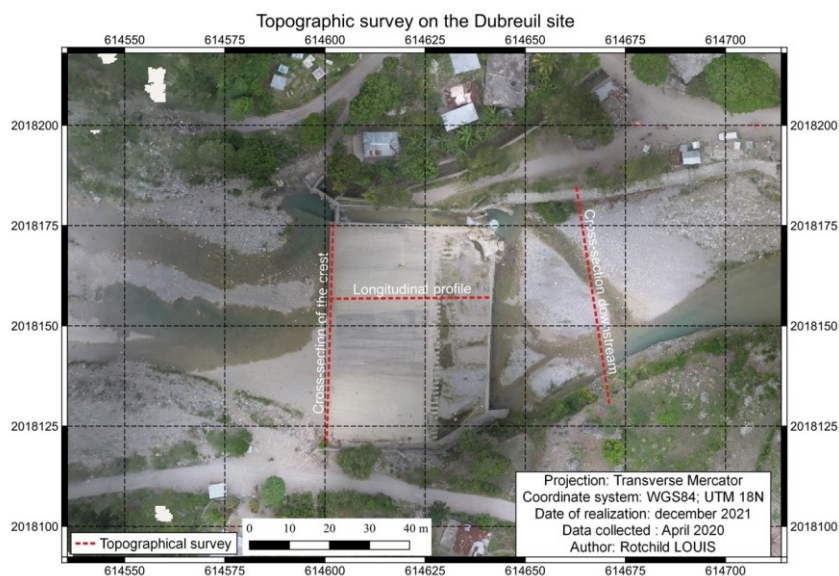


Figure 6. Manuel data survey on the Dubreuil site

2.2. Data processing

2.2.1.DTM and orthophoto computation

The digital terrain model and orthophoto were obtained from Agisoft Metashape Professional software, the recent version of Agisoft Photoscan. The development of Agisoft Metashape is based on the Structure from motion (*Sfm*) algorithm developed by Lowe (2004). For a more detailed description of the *Sfm* technique, see (Lowe, 2004; Snavely et al., 2006, 2008; Westoby et al., 2012).

The first step in image processing is the alignment of the images. This step includes Aerial Triangulation (AT) and Bundle Block Adjustment (BBA) (Agisoft LLC, 2020, 2022). At this stage, Metashape looks for common points on the images and match them from one image to another in tie points. The result of this alignment is a sparse point cloud that can be visualized on the software. The sparse point cloud is needed for the determination of depth maps (based on the sparse cloud of selected stereo pairs) (Agisoft LLC, 2022). The next step is the identification of the GCPs in the individual images in order to scale and geo-reference the dense point cloud that will be obtained, subsequently, based on an estimation of the camera positions and the images themselves. An illustration of sparse and dense point cloud for the Dubreuil site is given in Figure 7.

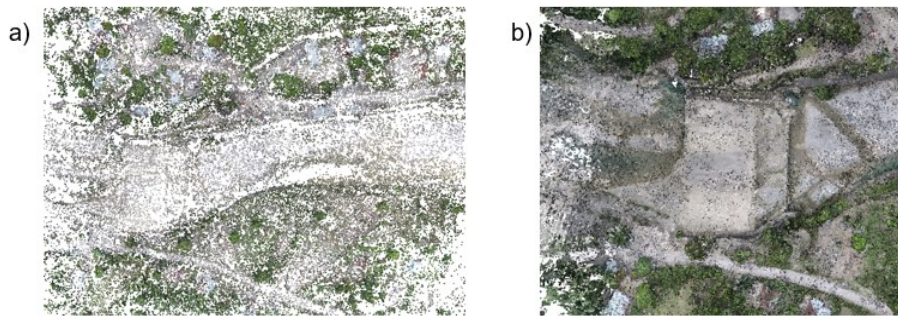


Figure 7. Illustration of the results of the image alignment: (a) Sparse point cloud, (b) Dense point cloud

And finally, the third step is to generate the DTM (Figure 8), then the ortho-mosaic from DTM. A class of terrain points is created before generating the DTM.

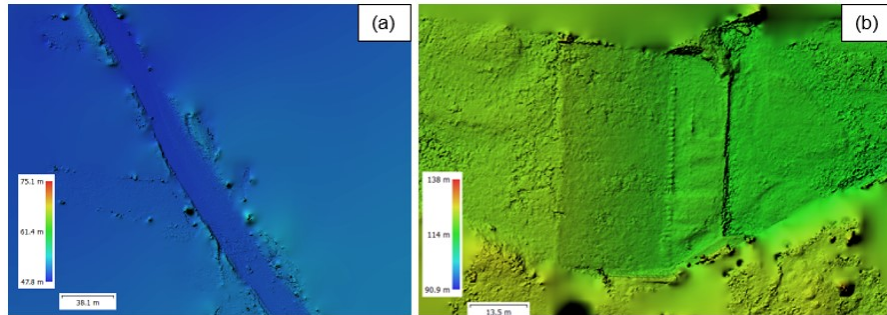


Figure 8. Example of generated DTM: (a) Leogane site and (b) Dubreuil site

2.2.2.DEM accuracy assessment, comparison with official data and manual survey

The quality of the result obtained from the image processing using the Metashape software is evaluated using the mean absolute error Eq. [1] and the root mean square error Eq. [2], considering the differential GPS data as the reference data, because these data are considered to better represent the current topographical situation. Errors are thus computed between the elevation of the points measured using the differential GPS and that obtained from the photogrammetric DTM, and the same assessment is performed between the measured data and the official data.

$$\mu_{\text{abs}} = \frac{1}{n} \sum_{i=1}^n |z_{\text{GPS}} - z_{\text{MNT}}| \quad [1]$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (z_{\text{GPS}} - z_{\text{MNT}})^2} \quad [2]$$

3. RESULTS AND DISCUSSION

3.1. DTM and Orthophoto assessment on Dubreuil Site

The DTM resulting from photogrammetric processing on the Dubreuil site was extracted at a resolution of 0.05 m per pixel using the Metashape software. A total of 97 points are used to evaluate the accuracy of this DTM, including 16 points for the cross-section of the weir, 32 points for the longitudinal profile and 49 points for the cross-section downstream of the weir. The graphic representation of these different situations is given in the following figure (Figure 9).

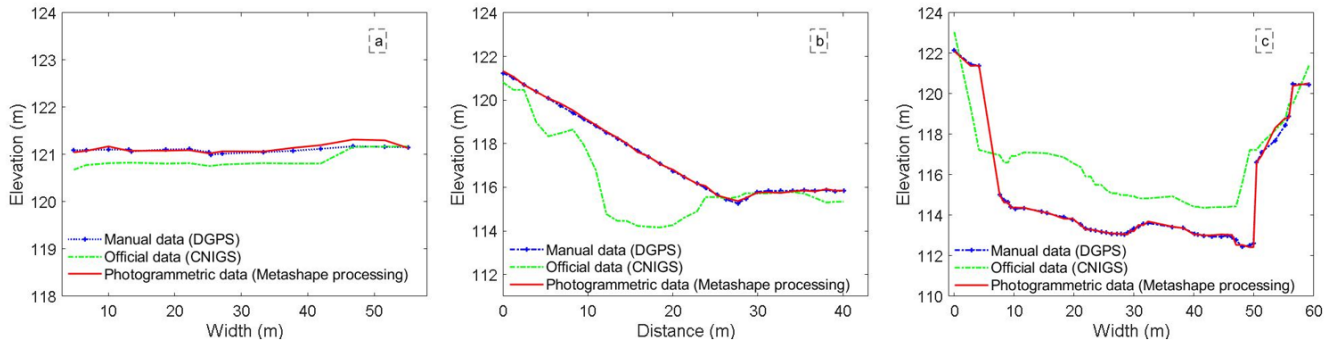


Figure 9. Graphical representation of the DTM assessment at the Dubreuil site: (a) Cross-section of the weir crest, (b) Longitudinal profile of the weir and (c) Cross-section of the downstream section

These representations show first of all the accuracy that can be obtained with the areal processing on Metashape, by comparison with the manual survey. Secondly, a remarkable difference can be observed between the manual data measured in 2020 and the official ones currently available for the entire country, published in 2016 and dating back to January 2014. This tends to show that the official data is not up to date anymore, which is plausible as the region suffered from important morphological events. The errors distribution between the photogrammetry processing DTM and the manual data for all 97 points is given in Figure 10.

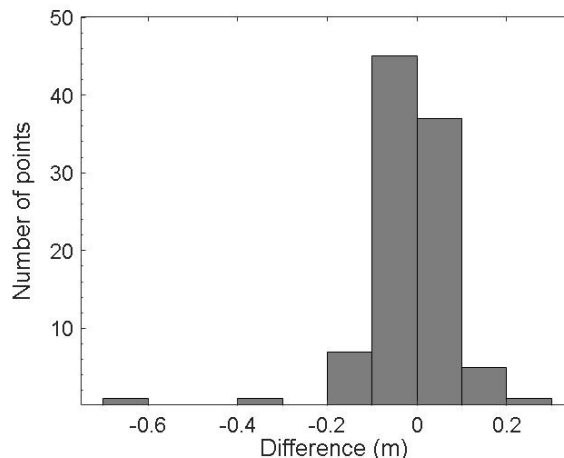


Figure 10. Distribution of the photogrammetric processing errors for all verification points on the Dubreuil site

The average errors range from -0.7 m to 0.3 m. The negative values mean that the elevation of the photogrammetric DTM was overestimated. A similar range of errors can also be found in many studies (Guarnieri et al., 2009; Coneney et al., 2010; Ouédraogo et al., 2014; Hugenholtz et al., 2013). For all the verification points, more than 80% of the points have an error below 0.10 m. The parameters used to quantify the errors are given in Table 2 that summarizes the observations for the different techniques used in this study at Dubreuil.

Table 2. Errors depending on the different topographic surveys in Dubreuil

	Cross-section of the weir		Longitudinal profile of the weir		downstream cross-section	
	Metashape	CNIGS	Metashape	CNIGS	Metashape	CNIGS
MAE (m)	0.048	0.234	0.049	1.229	0.075	1.948
RMSE (m)	0.063	0.260	0.058	1.744	0.127	2.175

The other result obtained from the photogrammetric processing is the Orthophoto plan of the studied site whose size per pixel is 10 cm × 10 cm which is very satisfactory compared to that of the available Orthophoto (50 cm × 50 cm) at the time of this study. An illustration of two orthophotos for the same site is given in Figure 11.

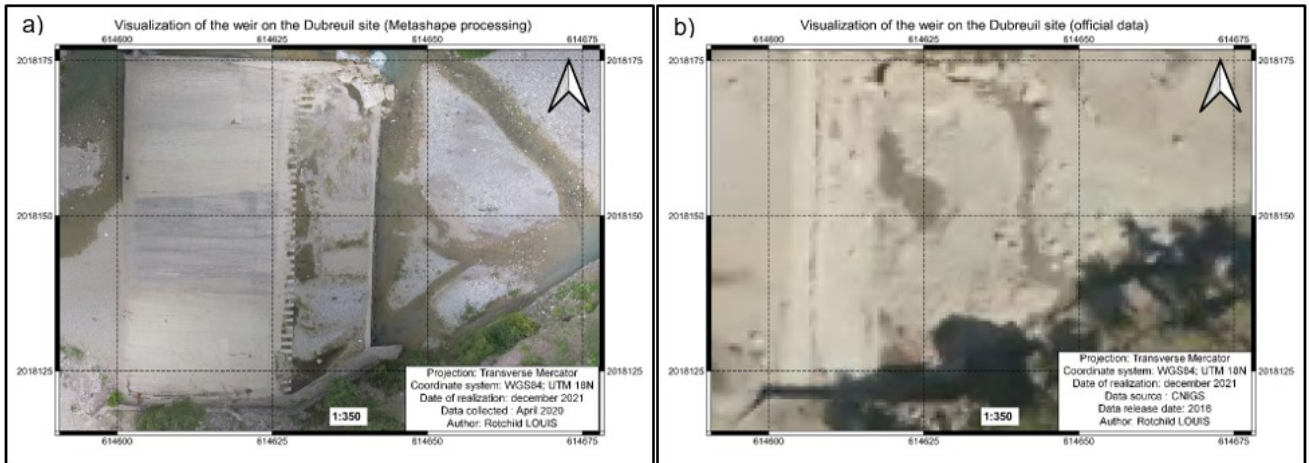


Figure 11. Representation of the weir on the Orthophoto: (a) Photogrammetric processing, (b) Official data

Using the same scale of 1/350, it can be observed that the resolution of the official data is not sufficient and that shape and environment of the weir cannot be properly visualized. It is thus impossible from these images to assess the state of the weir, and to know whether the weir was damaged during the measurement campaign carried out for the construction of the CNIGS database. This emphasizes the importance of updating the topographic data on a more regular basis to monitor the status of land and infrastructures. The UAV-photogrammetry method is interesting and important as it is a low-cost method, allowing to obtain very precise spatial information of the site to be studied.

3.2. DTM assessment on Leogane site

The UAV-based DTM obtained at the Leogane site has the same resolution as the Dubreuil DTM, i.e. 5 cm/px. For the assessment of the accuracy of this DTM, 80 points, surveyed with DGPS, are used and are distributed in three cross-sections on the Rouyonne River. The first section has 26 points, 29 points for the second and 25 points for the last section. The illustrations are given in Figure 12.

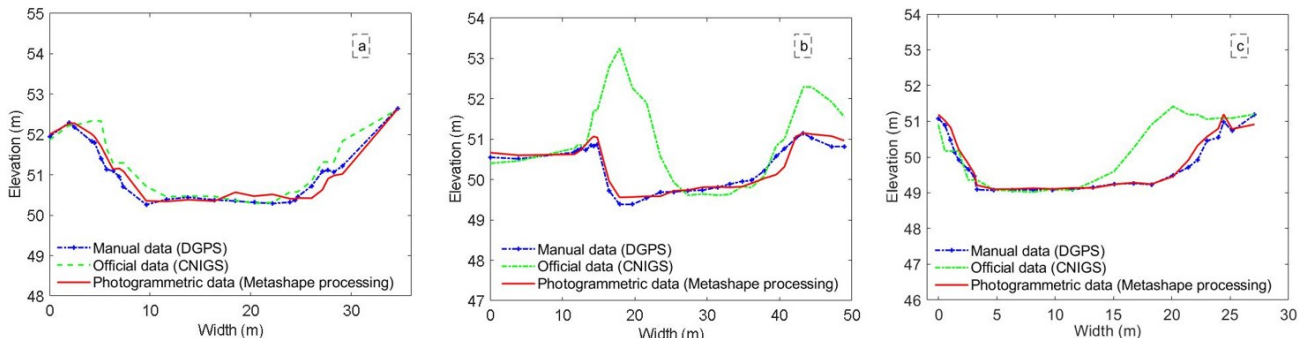


Figure 12. Illustration of the DTM accuracy assessment in Leogane: (a) Cross-section 3, (b) Cross-section 4 and (c) Cross-section 5

Once again, UAV-photogrammetry results in data very close to the manual data. Looking at the official CNIGS data, cross-sections 4 and 5 show significant changes in the channel morphology due to bank erosion between 2016 and 2020. Such morphological changes can have a great influence on the results of flow modeling for flood risk management purposes, depending on the DTM used. This again highlights the importance of updating the topographic data for better flood risk prevention. The errors distribution of all the checked points is given in the Figure 13.

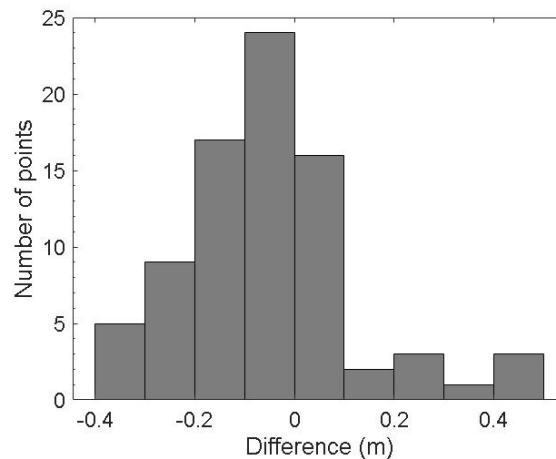


Figure 13. Distribution of the photogrammetric processing errors for the verification points of the Leogane site

More than 73% of the points present an error smaller than 20 cm. The quantification of errors is given in Table 3. Accuracy assessments of DTM are often presented by calculating the RMSE on the verification points, but does not allow highlight the systematic spatial errors (i.e. non-random) (James et al., 2017; Kyriakidis et al., 1999). Such is the case for the vegetation on the banks of the Rouyonne River, which influences the interpolation of the points at these locations and increases the RMSE values.

Table 3. Quantification of errors on the verification points in Leogane.

	Cross-section 3		Cross-section 4		Cross-section 5	
	Metashape	CNIGS	Metashape	CNIGS	Metashape	CNIGS
MAE (m)	0.153	0.251	0.132	0.786	0.135	0.471
RMSE (m)	0.193	0.344	0.173	1.266	0.182	0.724

4. CONCLUSIONS

This study is a contribution to the assessment of the accuracy of high-resolution surface data reconstruction for the updating of topographic and bathymetric data, and for monitoring morphological data of major rivers in Haiti.

For this study, the image processing is performed on the Metashape Pro software. The RMSE obtained for the DTMs of image processing on the studied sites are lower than 0.20 m. The comparison of these results with the official data, shows that the RMSE of the official data is always higher than that of the photogrammetric processing, considering the manual data taken with a differential GPS as reference. A resolution of 10 cm/px and 5 cm/px is obtained, respectively, for the Orthophotos and DTMs of the aerial images processing. Such resolutions are much higher than the official data which are 50 cm/px and 1.5 m/px, respectively, for the orthophoto and DTM.

In view of these results, UAV-photogrammetry based on the development of the *Sfm* algorithm, allows to build DTM and Orthophotos of very good quality. At a lower cost, UAV-photogrammetry is an efficient tool for bathymetric surveys, allows to obtain fast results while offering the possibility to closely follow the morphological evolution of rivers at time interval of episodes.

Future work will be devoted to further assess the influence of the different parameters of the photogrammetry software on the results.

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