

Comparative Study of Digital Terrain Models (DTM) Using DRTK 2 Drone and GNSS Methods

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Abstract

The spatial representation of the Earth's surface, as well as the surfaces of other geometric objects, involves a series of representation models. Digital Terrain Models (DTMs) represent the natural surface of the land without the structures or vegetation that cover it. Today, photogrammetry, with the advent of drone technology, has advanced working methods in precision topography and allows for much more efficient DTMs. However, there are several sources of errors in positioning due to instrumental, procedural, and environmental factors that arise during the process. The objective of this study is to validate the relevance of new drone technology in its application to topography, particularly in the production of DTMs. For this purpose, a DJI Phantom 4 Pro RTK drone was used to acquire 392 images in an area with difficult topography (8 ha), supported by 12 previously established ground control points (GCPs) whose altitudes were determined by a precision direct leveling operation. The processing was carried out using two photogrammetric processing software (Pix4D and Agisoft Metashape) to compare their performance on DTM accuracy. Then, GNSS surveys in real-time mode (RTK) were carried out to produce three-dimensional models to be used for comparison and validation purposes. The vertical error of the three digital terrain models (DTMs) was evaluated by comparing them with direct leveling campaign data on the ground. We found that the result from the GNSS processing method achieved the best performance in terms of absolute error evaluation. Between the results provided by the two software programs, Agisoft offers slightly better results than those obtained with Pix4D.

Keywords

DTM, Drone, GNSS, Pix4D, Agisoft Metashape, Direct Leveling

1. Introduction

The advent of drone technology and its use for civilian applications have given new impetus to photogrammetry. Geographic sciences have benefited greatly in the fields of cartography, topography, land use planning, etc. Drones have become the tools of choice for data acquisition in general, and particularly in areas with difficult access [1]-[3]. They offer many advantages over other data collection tools, such as total stations and GNSS receivers [4] [5]. Indeed, collecting an infinite number of points from the image does not require contact with the terrain to be measured, providing an economical acquisition solution and, above all, high accuracy.

However, it is important to emphasize that both planimetric and altimetric accuracy are dependent on certain parameters such as flight height, focal length, pixel size given by the manufacturer, ground control points, etc. [6] [7].

The aim of this study is to compare, on the one hand, the DTM data resulting from the processing of two photogrammetric software programs (Pix4D & Agisoft Metashape) and, on the other hand, the latter with the DTM obtained from data collected by the GNSS method. The direct leveling technique, which remains the most accurate method for obtaining altitude to date, was used to determine the calibration points and reference points. These latter were used for the comparative study of the different DTMs. The entire methodological approach is summarized in **Figure 1**.

2. Presentation of the Study Area

Senegal is located in the far west of Africa and is bordered by the Atlantic Ocean. It lies between latitudes 12° and 17° North and longitudes 11° and 17° West. Administratively, the country is divided into 554 local authorities, 46 departments, and 14 regions [8]. The city of Thiès is located 70 km from the capital, Dakar, in the region of the same name. With an area of 1,873 km², it is bordered to the north by the department of Tivaouane, to the west by the department of Rufisque and the Atlantic Ocean, to the south by the department of Mbour, and to the east by the department of Bambey [9] (see **Figure 2**).

Our experimental site is located within the Thiès classified forest, east of the Sindia road, and covers an area of 8 hectares.

It is a former laterite quarry, which gives it a good profile for calculating DTMs and, more importantly, for estimating variations in its elevation values.

3. Data Acquisition

This constitutes the fundamental phase for any study project using spatial data. To carry out this work, we used various technological tools. The Leica NAK 80 optical level was used to establish altimetric reference points. For the acquisition of photogrammetric data (point clouds and orthophotographs), many recent aerial imaging drones are equipped with GNSS RTK receivers available on the market [10]. In this study, the DJI Phantom 4 RTK drone was used and a CHCNAV i 50

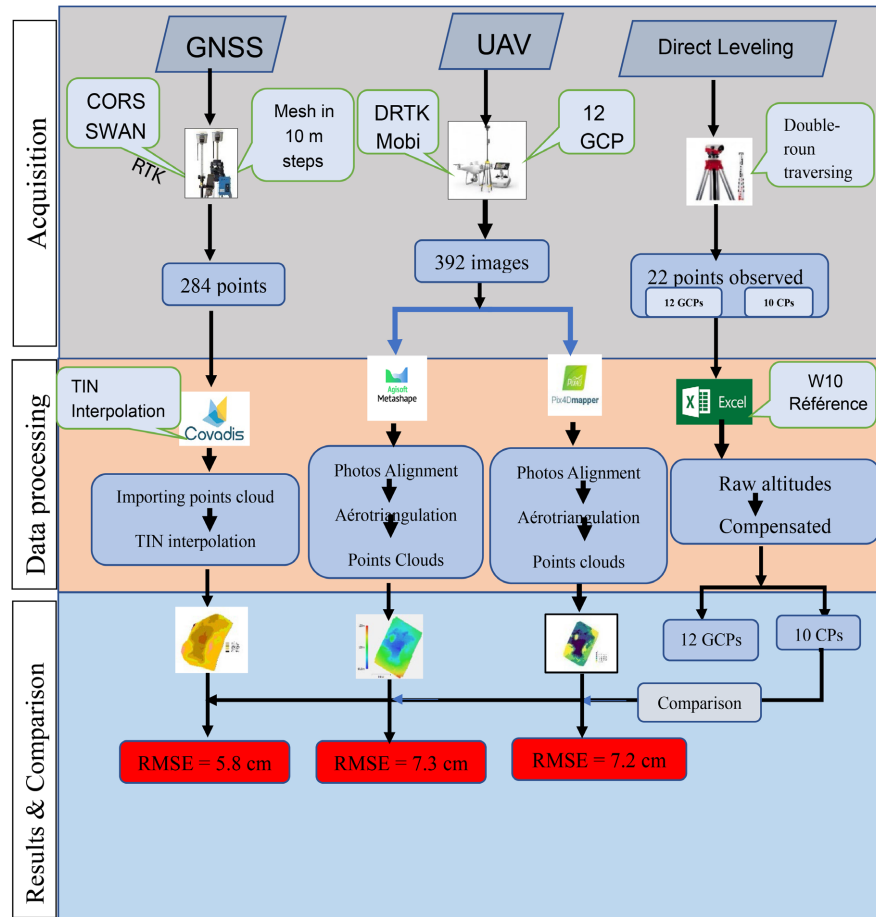


Figure 1. Methodological approach.

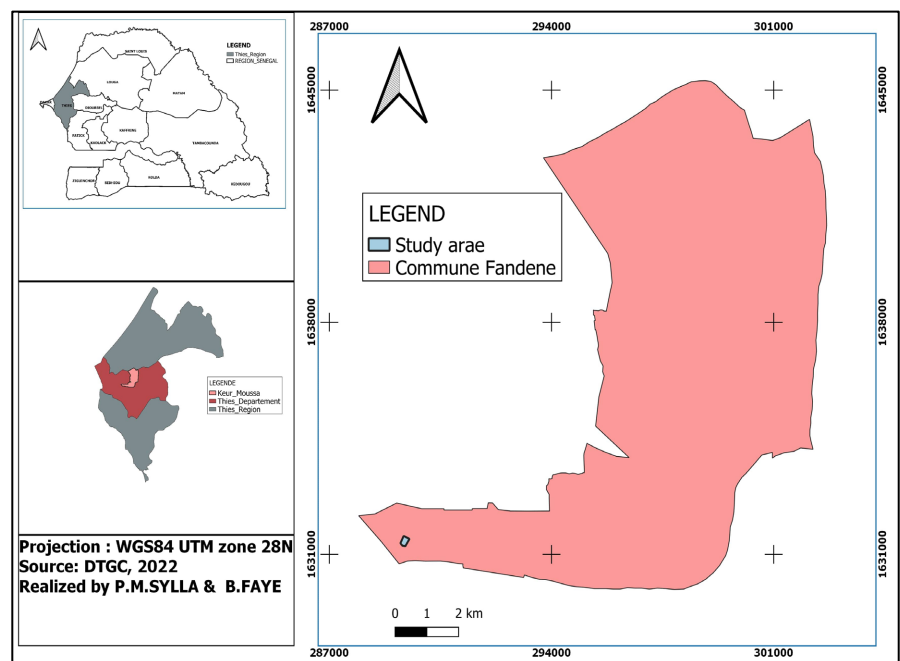


Figure 2. Location of the study area.

dual-frequency GNSS receiver for high-precision point determination (see **Figures 3-5**). It is important to note that GNSS RTK positioning is currently used in various fields, including surveying, mapping, roads, and various networks [11] [12].



Figure 3. DJI Phantom 4 RTK.



Figure 4. GNSS receiver.



Figure 5. Optical level.

1. Image Acquisition

Using the photogrammetric method requires consideration of several parameters that affect data quality and accuracy: flight altitude [13] [14], image overlap [15] [16], drone flight speed [17], flight path configuration (single or double grid) [18] [19], nadir or oblique image acquisition [20]-[22], in addition to the number and distribution of GCPs [23] [24]. In this study, the parameters used are listed in **Table 1**.

Table 1. Image capture program parameters.

Number of pictures	392
Average flight altitude	50 m
Ground resolution	1.35 cm/px
Longitudinal overlap	80%
Lateral overlap	70%
Coverage area	7.99 ha
Flight speed	3.9 m/s
Coordinate system	WGS 84/UTM zone 28N (EPSG: 32628)

Before taking the pictures, it is necessary to carry out the planning stage, which allows delimitation of the study area, definition of the parameters of the flight plan (flight height, overlap, flight speed, etc.), and marking. The latter consists of establishing a set of well-distributed points in clear locations with markers so that they are visible in the images to be taken. These support points will be used during the aerotriangulation, which is a process aimed at determining the transformation (translation and rotation) to be applied to the point clouds in order to convert from local coordinates to the coordinate system of Senegal [25]. As part of this study, the coordinates of these points in planimetry and altimetry were determined using geodetic methods (direct leveling, GNSS survey) to ensure high accuracy. Twelve (12) points were defined in the study area, and the resulting coordinates are shown in **Table 2**.

Table 2. GCP coordinates.

Points	E (m)	N (m)	H (m)
Cr03	289362.006	1631369.93	100.611
Cr05	289273.791	1631326.44	97.353
Cr06	289315.317	1631318.56	98.237
Cr09	289263.39	1631362.92	99.201
Cr12	289408.173	1631274.71	98.674
Cr14	289360.726	1631563.47	103.658
Cr15	289363.968	1631514.92	105.367
Cr16	289422.725	1631512.83	97.387
Cr19	289413.822	1631479.75	97.828
Cr22	289283.648	1631426.38	105.13
Cr24	289381.567	1631416.98	104.201
Cr26	289476.715	1631430.04	103.933

The Senegal West African Navigation (SWAN) permanent station network was used to establish the planimetry points, and a point from the 1953 General Level-

ing of West Africa (NGAO 53) was used to determine the reference altimetry. These Ground Control Points will be used for absolute orientation.

Following this planning phase, the photography mission is carried out, and the order to trigger the shots is automatically sent by the drone's integrated controller, knowing its approximate position thanks to real-time GNSS positioning [26].

2. Acquisition of point patterns using GNSS

Today, GNSS RTK positioning is used in various fields, including surveying, mapping, and civil engineering.

GNSS technology was chosen as the second method for collecting elevation data to create a digital representation of the relief of our study area. Obtaining a Digital Elevation Model (DEM) is based on the interpolation of elevation data to create a surface representing the terrain. As part of this study, it was decided to perform a GNSS measurement mesh to obtain a consistent representation of the relief. Several meshing methods exist, namely the square/rectangular mesh, the hexagonal mesh, the regular triangular mesh, and the arbitrary triangular mesh. Given the morphology of the study area, which is quite hilly with steep slopes, the varied mesh with irregular steps varying from three (03) to ten (10) meters over the entire area was chosen. The surveyed points were attached to the Senegalese Reference Network (RRS04) from point S10 located within the Iba Der THIAM University of Theis, whose coordinates were obtained by the static method. For the densification of the mesh points numbering three hundred and ninety-two (392), RTK GNSS positioning was chosen for its good accuracy. When used correctly, GNSS RTK positioning is an effective measurement method, with errors of approximately 1 cm in terms of positioning accuracy [27].

3. Acquisition by direct leveling

Since the direct leveling method remains the most accurate for determining the altitude of a point [28], it was chosen for the validation of Digital Terrain Models (DTM) produced using new drone technology and the GNSS method. The round-trip method was used from the W10 reference point. This reference point is one of the points in the base polygon attached to the 1953 General Leveling of West Africa (NGAO 53) for the Thiès-Sindia road widening project of the Eiffage Senegal company. To determine the altitudes of the calibration points, two routing methods were used. First, the double-station routing to reach the study area, then a radiation routing taking into account the distribution and proximity of the calibration points (see **Figure 6**).

4. Data Processing and Results

The data processing phase plays a crucial role in DTM acquisition, as a large portion of the results depends on it. Thus, data from drone, GNSS, and direct leveling acquisitions will be successively processed using the existing methodologies we have chosen.

1. Processing of drone-acquired data

Photogrammetric data processing has evolved significantly in recent years. This

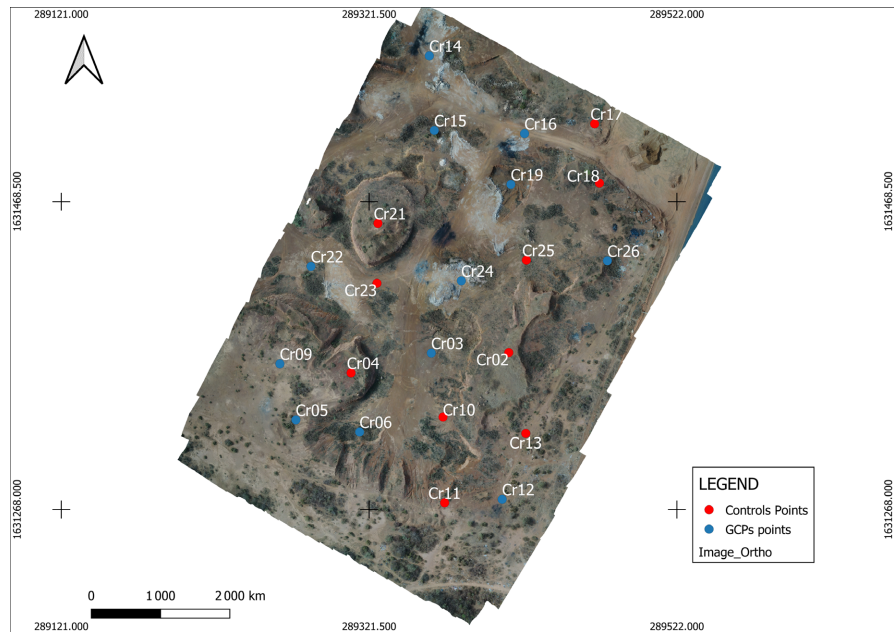


Figure 6. Distribution of GCPs and control points.

evolution has resulted in the existence of more than forty (40) different software programs and photogrammetric tools, both open source and commercial, for processing photogrammetric data [29]. For the purposes of this study, Agisoft Metashape [30] and Pix4D [31] were chosen for processing. Our choice was based on the fact that they are the most well-known and widely used software programs in the professional environment in Senegal. On the other hand, it was necessary to be able to compare the final results of these two software programs. However, we can note that all these photogrammetric processing programs generally follow the same five-step process for generating a DEM: (1) feature detection and matching; (2) triangulation; (3) generation of a dense point cloud; (4) 3D reconstruction; (5) generation of MNS and orthophotos [32] (see **Figure 7**).

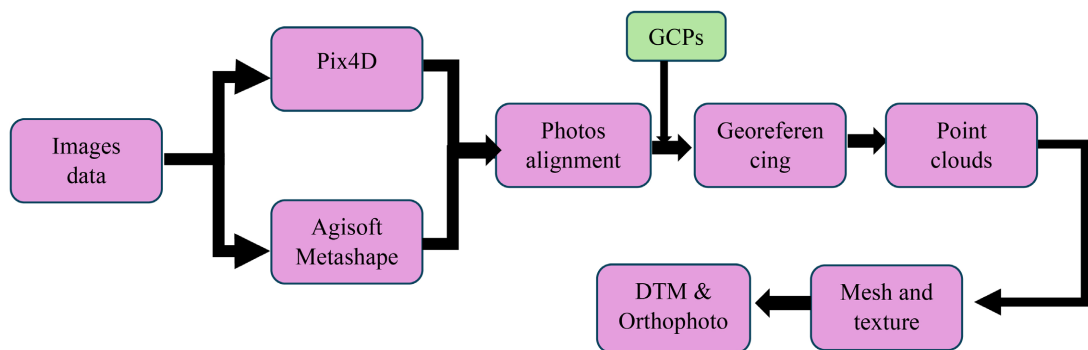


Figure 7. Drone data processing steps.

Figure 8 and **Figure 9** illustrate the results obtained with Pix4D and Agisoft Metashape software, respectively. We can see similar altitudes in the same areas. We note a variation in altitudes from 95,756 m to 107,215 m.

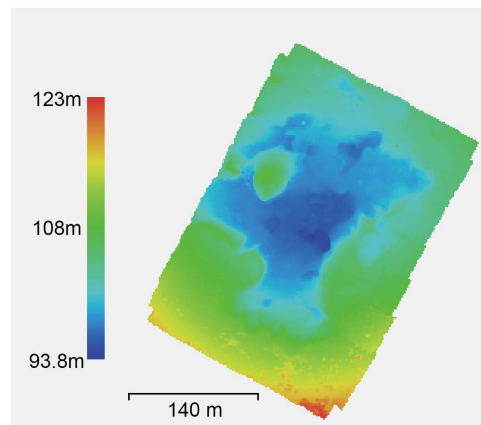


Figure 8. MNT obtenu avec Pix4D.

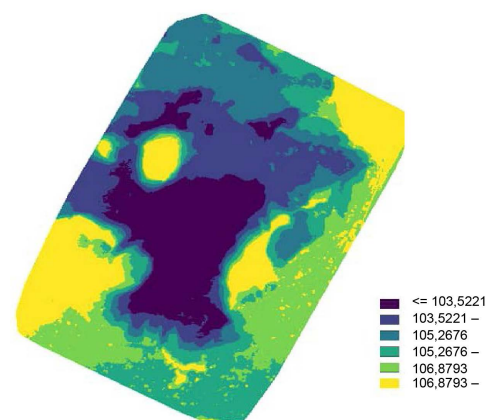


Figure 9. MNT obtenu avec Agisoft.

2. Processing of GNSS data

GNSS data, through automated operation, allow the generation of a DEM for relief modeling. However, the accuracy of this operation depends on the input data, the type of interpolation, etc. After determining the altitudes of the 284 points of the previously created mesh, the Covadis software [33] was used to generate the DEM. The latter uses Delaunay triangulation, which is a local deterministic interpolation method. It constructs the DEM from a mesh of contiguous and non-overlapping triangles from a point dataset [34]. The advantage of this method is that it guarantees that all input points are included, that there are no holes in the mesh, and that the triangles do not overlap. The result obtained is shown in **Figure 10**.

3. Leveling Data Processing

The processing of data from direct precision leveling follows a rigorous approach to determine precise and compensated altitudes of the leveled points. The observations were carried out according to the standards of precision geometric leveling. From the raw data (back and front readings), the raw elevations and then the raw altitudes were calculated. Based on the length of the path and the number of elevations, the tolerance was calculated according to the regulations in force in

Senegal, represented by Equation (1) below [35].

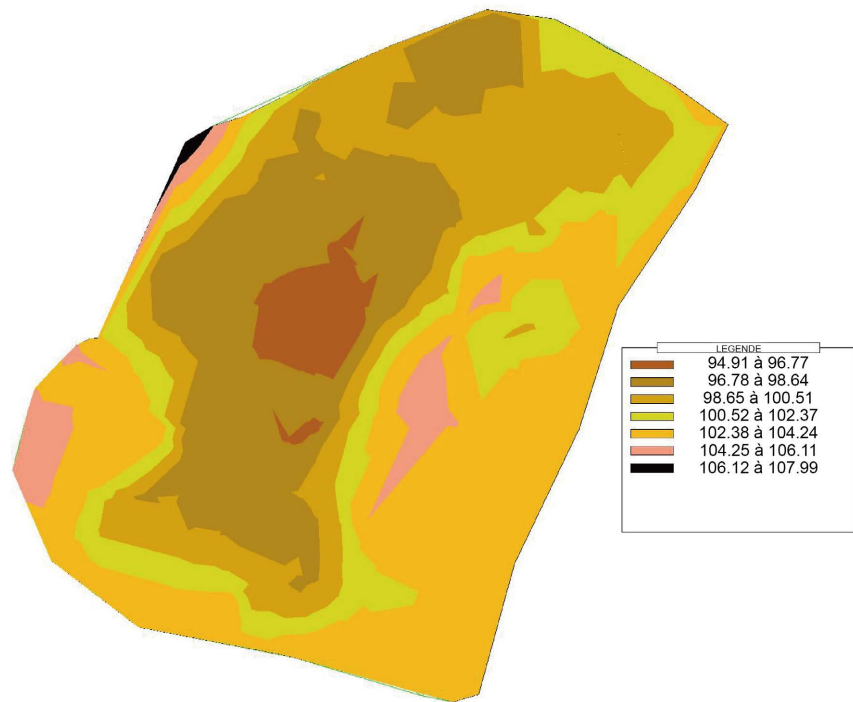


Figure 10. DTM obtained using the GNSS method with Covadis software.

$$T_r = 4\sqrt{(9L + L^2)} \quad \text{pour } n < 16 \quad (1)$$

$$n = \frac{\text{nbre of elevation changes}}{L}; \quad L: \text{path length.}$$

The calculated closure deviation (Raw Altitude – Known Altitude) equals –9 mm. Being less than the tolerance (± 12 mm), we proceeded to compensate the raw altitudes of the 22 points. The altitudes vary between 90.563 m and 105.367 m.

4. Comparative Analysis

The notion of quality is a comprehensive term that must be adapted to the intended purpose or application. This notion of quality encompasses several components or criteria. These include genealogical components, logical consistency, completeness, semantic accuracy, and geometric precision.

For a DEM, quality and precision depend on many variables. The first is related to the size of the area and its morphology [36], land cover types, lighting conditions, and object color contrast [37]. The second is related to the drone data collection systems and their characteristics, the camera and its calibration [38], and the type of drone (multicopter or fixed-wing), which may be a drone equipped with a high-quality GNSS/RTK receiver [39]. However, when comparing two models of a substantially horizontal terrain, a statistic on the deviations along the vertical component z is a simple but sufficient solution [40]. It constitutes the main component when assessing the quality of a DTM. It quantifies the variation

between the points on the ground surface and those obtained by the model. As part of our study, this geometric component was evaluated. Thus, we opted to conduct the comparative study along two axes: first, we analyzed the differences obtained between the two DTMs obtained with the processing software (Agisoft Metashape, Pix4D). Next, we evaluated the quality of the DTMs provided by the photogrammetric method and the GNSS method. The ten reference points whose elevations were obtained by direct leveling served as a reference for comparing the homologous points after processing with the Agisoft Metashape and Pix4D software and those from GNSS receivers. The results obtained are shown in **Table 3**.

Table 3. Differences between the reference elevations and those obtained from the three methods.

Points	Z_Réf	Z_Agisoft	Z_Pix4D	Z_GNSS	ZAgi-ZRef	ZPix4D-ZRef	ZGnss-ZRef
Cr02	97.423	97.43	97.396	97.484	0.007	−0.027	0.061
Cr04	104.412	104.509	104.498	104.309	0.097	0.086	−0.103
Cr10	98.43	98.402	98.412	98.382	−0.028	−0.018	−0.048
Cr11	97.306	97.273	97.275	97.352	−0.033	−0.031	0.046
Cr13	102.265	102.195	102.199	102.228	−0.07	−0.066	−0.037
Cr17	101.569	101.444	101.483	101.547	−0.125	−0.086	−0.022
Cr18	104.926	104.855	104.798	104.853	−0.071	−0.128	−0.073
Cr21	104.668	104.552	104.557	104.6	−0.116	−0.111	−0.068
Cr23	99.246	99.225	99.208	99.24	−0.021	−0.038	−0.006
Cr25	104.041	104.068	104.079	104.099	0.027	0.038	0.058

The analysis of **Table 3** shows that the comparative study between the variations in the altitudes of the selected points reveals fairly small differences between Agisoft Metashape and Pix4D compared to the reference points. For Agisoft Metashape, the differences vary from 7 mm to 12.5 cm, while for Pix4D, the smallest is 1.8 cm and the largest variation is 12.8 cm. From these results, we can affirm that in our case study, the Agisoft software is better suited to the calculation of the DTM. However, it should be noted that the processing time with Agisoft (6 h 55 mn) is relatively longer than the time taken with Pix4D (5 h). However, we note that these variations are not obtained on the same points compared to the different models (**Figure 11**).

Following these results, we opted for the calculation of the EMQ in the different models to better understand the overall precision. The EMQ formula retained after calculating the altitude differences of the sample is given by the following equation:

$$EMQ = \sqrt{\frac{\sum_{i=1}^n (H_i^{drone} - H_i^{level})^2}{n}} \quad (2)$$

With:

H_i^{drone} : Calculated altitude of the i -th point of the sample.

H_i^{level} : Reference altitude of point i of the sample.

n : the total number of samples.

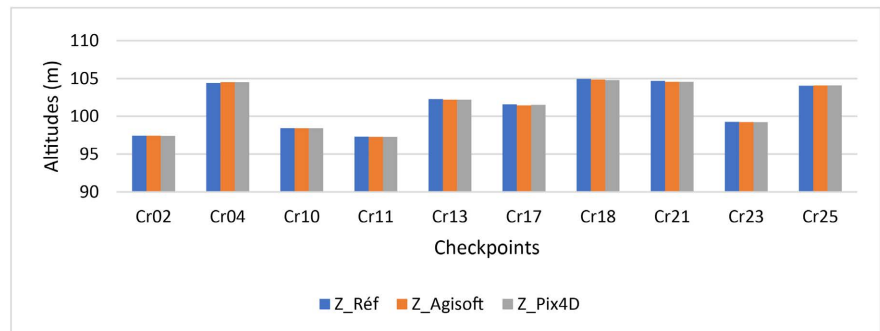


Figure 11. Variations between the altitudes of the drone and the level.

The results obtained are recorded in **Table 4** and show that the differences are slightly smaller between the reference points with the Agisoft software than with the Pix4D software.

Table 4. EMQ calculated for each method.

SOFTWARE	RMSE	Bias	Standard deviation (σ)	LE95
Agisoft	0.0718	−0.0333	0.0670	0.1314
Pix4D	0.0726	−0.0381	0.0652	0.1277
GNSS	0.0583	−0.0192	0.0580	0.1137

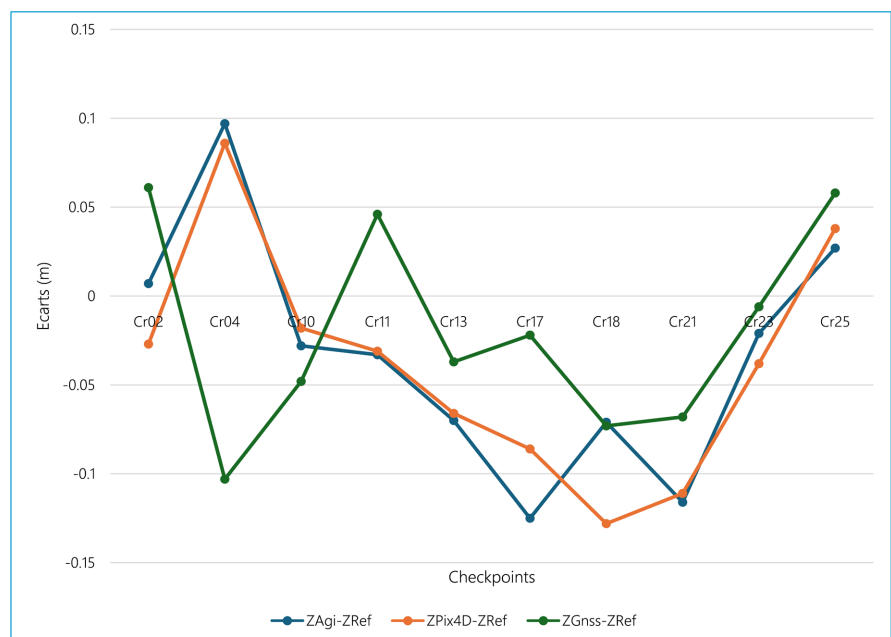


Figure 12. Variations between altitudes with different methods.

We then evaluated these results obtained by the photogrammetric method with those from the GNSS method. The analysis of the altitude differences in **Table 3**, **Table 4**, and **Figure 12** shows us that the results obtained with the GNSS method are closer to the reference values obtained by direct leveling and are therefore more precise than those of the photogrammetric method. Indeed, the differences with the GNSS method vary from 6 mm to 10.3 cm. For the overall evaluation of the different models, the RMSE with the GNSS method is 5.83 cm compared to 7.18 cm for Agisoft Metashape and 7.26 cm for Pix4D.

5. Discussions

The results of this study allowed us to evaluate the different methods used to obtain a Digital Elevation Model. Our study shows that the accuracy of point clouds varies depending on the methodology and tools used. We used a relatively rugged study area, an abandoned quarry, which does not allow us to generalize the results. It would be interesting to conduct the same work with study areas with different morphologies (very rugged, rugged, relatively flat, etc.) to gain a better appreciation of the quality between the different tools and methods used.

The unique feature of our study lies in the fact that the reference points were determined using GNSS planimetry and direct leveling altimetry.

Our results can be considered quite satisfactory compared to work carried out in different areas by other authors. For example, Jaouad El Atiq & Abderrazak El Harti [41] obtained a Digital Terrain Model (DTM) of a mountainous area above the road connecting Demnate to Aït Bouguemez, in the province of Azilal, Morocco, using a DJI Phantom 4 RTK drone and Agisoft Metashape software for point cloud processing. The RMSE of 5 cm obtained for this study, relative to the morphology of the terrain studied, justifies the relevance of our results.

Francisco *et al.* studied the accuracy of Digital Terrain Models on a cut embankment located along the N-340 road, in the province of Almería, southeastern Spain, between the city of Almería and Aguadulce. They used the same flight altitudes (50 m), number of GCPs (10), and software (Pix4d mapper Pro) as our study. Although their study did not use independent measurements to determine the reference altimetry, their result of 4.9 cm RMSE is comparable to ours, which is 7.1 cm for almost the same flight parameters [42]. Dense point clouds from a LiDAR and a UAV in uncovered areas with little vegetation (0 - 20 cm) were used by Salach A. & al [43] to carry out a comparative study of DTMs from reference data surveyed by GNSS-RTK. The results obtained are very close, with 0.11 m for the RMSE of the lidar and 0.14 m for the points of the UAV platform. These results are within the range of the variation of altitudes calculated within the framework of the different methods used in our study and confirm the relevance of our approach.

Yilmaz, C. S. & al [44] studied the generation of high-resolution digital terrain models from point clouds based on drones. The accuracy of the produced DTM was studied using the test points measured by the GNSS RTK technique. These

test points were established in flat areas, sloping areas, and near surface objects; the RMSE obtained is respectively 5 cm, 18.4 cm, and 19.2 cm. The result for the sloping terrain, which is closest to our study area, the abandoned quarry, is twice as high as our calculated RMSE and gives credibility to both our methodology and the results obtained.

6. Conclusions

This study allowed us to assess the benefits of using drone technology in surveying, particularly in producing a DTM for a given area. Indeed, our results are very satisfactory when compared to both traditional and GNSS methods. However, we should remain cautious while waiting to test this new technology in study areas with varied morphologies to develop a definitive solution.

However, given the speed, cost, and efficiency offered by this new technology, and the importance of DEMs, which are currently considered commodities, particularly in design projects (roads, drainage, etc.) and spatial analysis, we recommend its use.

In addition, this study made it possible to combine our conventional surveying practices with modern photogrammetric data processing practices using two software programs (Pix4D and Agisoft), and to quantify the difference between the resulting DEMs.

The production of these results constitutes an encouraging first study for the determination of altimetry and the production of DEMs. Looking ahead, it would be interesting to study them across study areas of different morphologies and sizes using the latest technologies, such as CORS stations and D-RTK2.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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