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COMPARATIVE ANALYSIS OF AERIAL PHOTOGRAMMETRIC AND REAL-TIME KINEMATIC (RTK) METHODOLOGIES IN TOPOGRAPHIC SURVEYS FOR DESIGNING A POTABLE WATER SYSTEM IN UYUNTZA, SUNTSUNTZA, AND PIKIUR COMMUNITIES, SEVILLA DON BOSCO PARISH, MORONA SANTIAGO CANTON, ECUADOR

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ABSTRACT

The aim of this study is to compare the results of two topographic survey methodologies in the design of a potable water system for the communities of Uyuntza, Suntsuntza, and Pikiur in the parish of Sevilla Don Bosco in the Morona Santiago canton, Ecuador, with an intervention area of 468 hectares. In this context, the results were compared between the methodology e9mploying an unmanned aerial vehicle (drone) and the second utilizing a Real Time Kinematic (RTK) GNSS receiver or kinematic differential GPS; the analysis involved post-processing the information collected with the drone and differential GPS, contrasting parameters such as cost, time, and precision through statistical tests. The outcome of this method comparison demonstrated that the drone-based process is secure, feasible, and efficient in terms of time and cost; however, significant differences in altimetry precision (Z-axis) were found. Therefore, local ground control points (GCP) will continue to be crucial in studies of environments incorporating data collection with airborne sensors.

KEYWORDS: Topographic survey; drone; GPS; RTK; kinematic

1 INTRODUCTION

The initial stage in a civil engineering project is the topographic survey [1], which aims to study methods necessary to accurately represent the terrain surface [2]. Hence, the importance of handling instruments and understanding new technologies used for this task, which provide faster data acquisition and processing, generating multiple high-quality products with impressive detail [3].

Technological advancements have contributed to improving the precision and quality of data, thus advancing various branches of engineering [4], including topography, a field that has seen significant progress with the emergence of sophisticated technical and technological equipment such as electronic total stations, dual-frequency GNSS RTK, optical theodolites, electronic theodolites, distance meters, semi-total stations, total stations, unmanned aerial vehicles (drones), among others [5].

Traditionally, this activity is carried out using a total station or a Global Positioning System (GPS) differential with the Real-Time Kinematic (RTK) method, where GPS signals are transmitted and corrected in real-time from a base receiver with known coordinates to other receivers called rovers [6].

The use of differential GPS receivers in the real-time kinematic (RTK) method for point collection is widespread because it allows for obtaining precise point positions in a relatively short time [6].

The principle of GPS RTK is similar to that of Differential Global Positioning System (DGPS), except that the RTK method uses and processes carrier phase observations for positioning. Since carrier phase observations produce more precise positions than code measurements, spatial positions obtained with GPS RTK are of better quality, with an accuracy on the order of centimetres [7].

In the last decade, photogrammetric processes have evolved, emphasizing the importance of computer science in photogrammetry by combining hardware and software [8]. Aerial photogrammetry and direct, fast, and precise georeferencing are much more accessible technologies and methods [9], where thanks to the emergence and use of unmanned aerial vehicles (UAVs), also called drones, they have been considered useful for tasks such as infrastructure supervision, construction monitoring, rapid response mapping, search and rescue, cadastral surveying, among others [10]. In this regard, aerial photogrammetry based on drones has become a common tool for topography used in multiple environments ranging from polar regions to tropical ones [11], demonstrating that the cost of acquiring topographic data with traditional techniques is comparable to the cost of photogrammetry; therefore, drones are becoming standard surveying tools where following a few steps, high-resolution data acquisition is accurate, safe, simple, and cost-effective [12].

In this context, the objective of this study is to compare the two methodologies, conducting statistical tests in the post-processing of information according to the following parameters: cost, time, and precision.

2 METHODOLOGY

In the case of a topographic survey, the methodology used considers everything from planning, analysis, and information processing to the generation of a final topographic product [13]. This is for the design of a drinking water system where the intervention area ranges from 1069.59 meters above sea level to 1137.06 meters above sea level, covering an approximate area of 2000 hectares (Figure 1). This includes a distribution zone that starts at the site designated for collection up to the point designated for the construction of a reserve tank and a distribution area that will benefit three communities covering an area of 468 hectares.

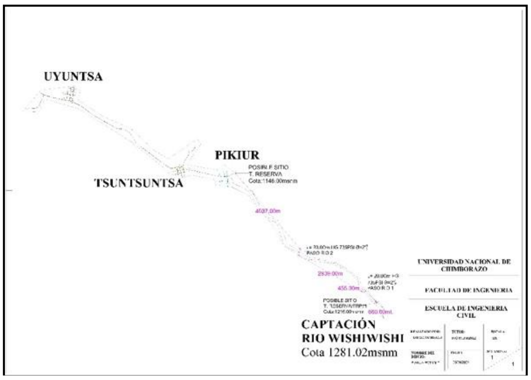

Figure 1. Proposed area for the design of potable water.

The definition and evaluation of variables such as cost, time, and accuracy were carried out in the study area designated for distribution, as it has a partially flat topography with few undulations and the presence of topographic features such as rivers, streams, and slopes, contrary to the conditions found in the conveyance study area, which corresponds to a mountainous area with dense vegetation and significant topographic features such as rivers, mountains, and streams with a natural slope greater than 75% (Figure 2), making it nearly impossible to conduct topographic surveys using traditional methods.

Two types of topographic surveys were conducted: the first using a drone and the second using real-time kinematic differential GPS (RTK).

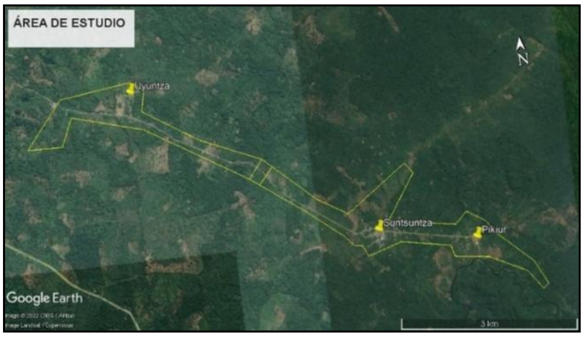

Figure 2. Study area obtained from Google Earth Pro

2.1 Aerial Photogrammetric Method

The workflow carried out with the drone involved using a DJI equipment from the Phantom 4 Pro V2.0 series, equipped with a 20-megapixel aerial camera, a maximum range of 7 km, and a 30-minute autonomy. The workflow and processing steps are summarized into three stages (Figure 3).

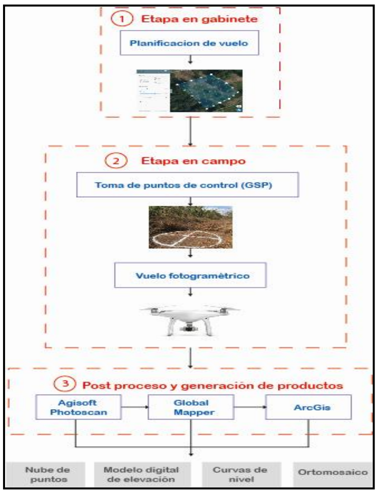

Figure 3. Workflow for an Aerial Photogrammetric Survey.

2.2 Desk Stage

Based on the "Project Parameters (PP)" and with the assistance of software used for flight planning and execution such as Google Earth, ArcGIS, AutoCAD, and Pix4D Capture, a total of three flights were configured to cover 468 hectares. Attributes were defined and modified, including longitudinal and transverse overlaps to avoid perspective distortions, flight altitude from the takeoff point thus defining the size of the pixel on the ground (GSD), flight speed, and starting point (Table 1).

Table 1. Flight Parameters Configuration.

Flight Parameters	Values
Longitudinal Overlap	85%
Transverse Overlap	70%
Flight Altitude	200 m
Ground Sampling Distance (GSD)	4,5 cm/pixel
Flight Speed	9 m/s

2.3 Field Stage

A visual inspection was conducted on-site to define the location of 18 Ground Control Points (GCPs) that were used on the ground for georeferencing. These points were distributed every 500 meters and measured using an RTK GNSS system. Before conducting the scheduled flights, the drone underwent an inspection (Figure 4) to ensure that all components were correctly installed. Subsequently, it was positioned on the takeoff runway, where it was powered on and linked to the remote control to initiate the programmed automatic flight planned during the desk stage.

Figure 4. UAV inspection before the scheduled flight.

2.4 Post-processing and Product Generation

The images from each planned flight were processed in separate batches, with a total of 222 aerial photos per batch. Subsequently, a fusion of the three processes was generated following the processing protocols of the Pix4dMapper software used for the generation of products such as: point cloud, digital surface model, digital terrain model, orthophoto, and contour lines (Figure 5). Ground control points (GCPs) were marked in the photos for geometric rectification linked to a projected coordinate system (WGS-1984, UTM17S).

Figure 5. Products generated after image processing.

2.5 Real-Time Kinematic (RTK) Cinematic Method

For the second Real-Time Kinematic (RTK) cinematic method, a differential GPS E300 Pro-GNSS receiver was used. This receiver operates with a fixed (base) receiver with known coordinates obtained after a correction process calculated with respect to the MAEC reference station located in the provincial council of the city of Macas. The location of this base point was selected to provide maximum performance by being as unobstructed as possible from obstacles and having a clear line of sight to the sky to capture all possible satellites covering the maximum work area. Additionally, a mobile receiver (rover) was used to collect GPS points with a fixed solution in real-time correction sent by the base via a radio link.

CivilCad 2017 software was used for processing the points collected in the field, generating a point cloud (Figure 6) to create a surface and obtain equidistant contour lines (1 meter between minor contours and 5 meters between major contours) according to the regulations (NTE INEN 2542.2006) for hydraulic projects (Figure 7).

Figure 6. Point cloud generated from the RTK survey

Figure 7. Contour lines generated with Civil Cad

3 RESULTS

Below are the results of the comparison of the two topographic survey methods that identify differences in the variables time, cost, and precision, taking into account the atmospheric and environmental limitations of each method.

3.1 Evaluation of the Time Variable

For the evaluation of the time variable in both types of topographic surveys using drone and differential GPS, the time spent on generating control points for the photogrammetric aerial survey and as known coordinates (base) for the Real-Time Kinematic (RTK) method was considered (Table 2).

Table 2. Time spent on collecting control points and base.

Activities	Time in hours
Equipment setup, positioning, and leveling	1
Point collection (including transportation)	5
Post-processing	2
Total	8

The time spent on the survey with the unmanned aerial vehicle and the post-processing of the captured information was 21.3 hours, as described in Table 3.

Table 3. Time spent on the Aerial Photogrammetric Survey.

Activities	Time (hours)
Control point generation	8
Photogrammetric flight	2
Fieldwork	10
Flight stage planning	2
Data processing	8
Initial configurations	1,53
Desk work	11.53
Time spent on surveying	21,53

In (Table 4), the time used in the real-time kinematic (RTK) kinematic surveying method in the study area is described, considering the effective hours that may vary depending on the climatic conditions of the area.

Table 4. Time spent on real-time kinematic RTK surveying.

Activities	Time (hours)
Base point acquisition	8
Positioning, leveling, and equipment setup	1,5
Point collection (including transportation)	36
Station or base change	2
Fieldwork	47,5
Data processing	16
Office work	16
Total survey	63,5

The time elapsed in both types of surveys was compared, both in fieldwork and office activities, finding that the time spent on post-processing in both cases (office work) is less than that used in fieldwork (Figures 8 and 9).

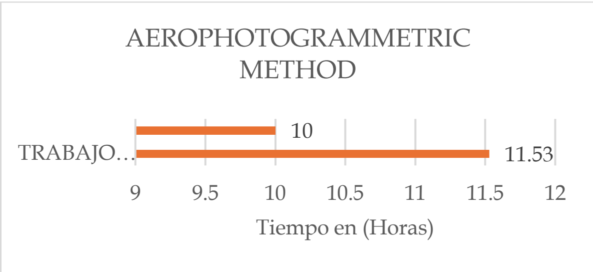

Figure 8. Aerophotogrammetric Method Time

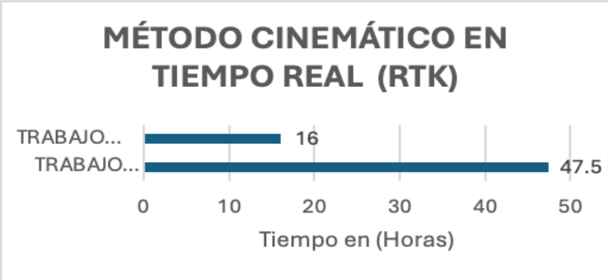

Figure 9. Real-Time Kinematic (RTK) Method Time

3.2 Evaluation of the cost variable

To carry out the cost evaluation of this project, it was necessary to obtain the performance. Botero [14] defines performance as the amount of work of any activity executed and completed by a team composed of one or several operators of different professions and specialties per unit of human resource. In this sense, it was necessary to calculate the performance in both types of topographic surveys, for which the time used for each method worked was considered, that is, the time needed to survey 1 ha of land (Tables 5 and 6), thus obtaining the performance: time used (hours) / Area surveyed (hectares) [15].

Table 5. Aerophotogrammetric Survey Performance

Aerophotogrammetric Survey Performance	
Aerophotogrammetric Survey Performance	21,53
Area surveyed (ha)	414,59
Performance = Time/Area (h/ha)	0,05

Table 6. Real-Time Kinematic Survey Performance.

Survey Performance with Real-Time Kinematic Method	
Time spent on the survey (h)	63,5
Area surveyed (ha)	269,39
Performance = Time/Area (h/ha)	0,24

According to Tables 5 and 6, it was determined that there is a considerable difference in yield values between the aerial photogrammetric method and the real-time kinematic (RTK) cinematically method. Specifically, for topographically surveying 1 hectare of land, the first method required 3 hours of work, whereas with the second method, it required 14.4 hours of work. Thus, cost evaluation was conducted based on labor, materials, equipment, and transportation categories.

It can be inferred that the approximate price per hectare surveyed using the aerial photogrammetric method ($4.12) is more economical than that achieved by the real-time kinematic (RTK) cinematically method ($12.02).

3.3 Evaluation of the precision variable

3.3.1 Planimetric precision

For the evaluation of planimetric precision, the coordinates obtained with the differential GPS used for the ground control points (GCP) were compared by placing them on the orthophoto, thus obtaining the difference between both coordinates. It was observed that the majority of the data are below 5 cm (RMSE ± 5 cm) (Table 9).

Table 7. Planimetric Difference of Both Methods.

	Difference in Coordinate (North)	Difference in Coordinate (East)
Mean	0,024	0,021
Standard Error	0,005	0,005
Median	0,022	0,011
Minimum	0,002	0,002
Maximum	0,071	0,064

3.3.2. Altimetric Precision

In planimetric surveys, standards for measurements along the z-axis or vertical plane are established by the Federal Geodetic Control Committee (FGCC) and depend on the type of engineering project [16]. In this regard, for the height component, the RMSE values found are ± 7 cm. These were evaluated at points used as ground control points (GSP) and compared with the digital terrain model (Table 10).

Table 8. Altimetric Difference of Both Methods

	Difference (meters)
Mean	0,07
Standard Error	0,06
Median	0,07
Minimum	0,06
Maximum	0,07

In this sense, the results obtained in this research indicate that the performance in an aerial photogrammetric survey is far superior to a real-time kinematic (RTK) cinematically survey. With the aerial photogrammetric method, more area can be surveyed in less time and with planimetric differences of ± 5 cm and altimetry differences of ± 7 cm. It is important to emphasize that nowadays there are drones with RTK technology that incorporate high-precision GNSS antennas, which could reduce differentiations in the x, y, z axes.

Furthermore, fieldwork is less laborious compared to cinematically surveying with differential GPS, as it is an indirect methodology where it is not necessary to travel across the entire study area, thus utilizing fewer resources.

4 CONCLUSIONS

The drone-based aerial photogrammetric method for topographic surveying proved to be accurate, fast, and cost-effective compared to traditional methods involving GPS point surveys.

The equipment used in this study (Phantom 4 Pro V2.0 Drone) exhibited better performance compared to traditional methods. The differences observed in elevations were within an acceptable range of variation, considering the geographic irregularities present in the study area.

Drones are now widely used for topographic measurement in various environments due to their precision, speed, and low cost. With appropriate methods and equipment configurations, vertical accuracies ranging from a few millimetres to a few decimetres can be achieved.

The accessibility and flexibility of low-cost drones offer advantages over conventional surveying methods. These platforms have the capability to access environments that may be difficult to traverse using ground-based methods.

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Ethics There are no ethical issues with the publication of this manuscript.

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