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ORIGINAL

Municipal map model for the Dominican Republic, using drone-based digital photogrammetry and GIS. Case study: San José de Ocoa urban area

Modelo Cartográfico Municipal para República Dominicana, Utilizando Fotogrametría Digital VANT y Sistemas de Información Geográfica; caso: Casco Urbano del Municipio San José de Ocoa

Juan Manuel Sosa[1], Pedro Enrique Sosa Veras[1], Eva Mejía[1]

[1]Facultad de Ingeniería y Facultad de Ciencias. Universidad Autónoma de Santo Domingo (UASD). Santo Domingo, República Dominicana.

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Corresponding Author: Pedro Enrique Sosa Veras

ABSTRACT

Updating urban cartography is essential for territorial development planning and management in the Dominican Republic, where municipalities lack Geographic Information Systems (GIS) that detail local productive components. To address this need, a municipal cartographic model was proposed using digital photogrammetry with a UAV and GIS, focusing on the municipality of San José de Ocoa. The study area was delimited using Google Earth satellite images and a flight was conducted with a Phantom 4 RTK drone, employing RTK/PPK techniques to ensure the accuracy of the geographic coordinates. GNSS observations were stored in RINEX 3,02 format for possible subsequent adjustments. Nine flights were conducted, obtaining 4985 georeferenced photos with accuracies of less than 2 cm. Image processing was performed in three stages using Agisoft Metashape, generating digital terrain models and contour lines with Global Mapper. Subsequently, urban map elements, such as buildings and street axes, were vectorized using Civil 3D and orthophotos as reference. The result was a georeferenced plan including the footprints of buildings and bodies of water, exported in shapefile format. Finally, the cartography was validated by a walk through the municipality, updating the vectorized information with data from the UAV survey.

Keywords: Cartographic Mosaic; Photogrammetry; UAV (Unmanned Aerial Vehicle); GIS (Geographic Information System); Municipality.

RESUMEN

La actualización de la cartografía urbana es esencial para la planificación y gestión del desarrollo territorial en República Dominicana, donde los municipios carecen de Sistemas de Información Geográfica (SIG) que detallen los componentes productivos locales. Para abordar esta necesidad, se propuso un modelo cartográfico municipal utilizando fotogrametría digital con un dron (VANT) y SIG, enfocado en el municipio de San José de Ocoa. Se delimitó el área de estudio a través de imágenes satelitales de Google Earth y se realizó un vuelo con el dron Phantom 4 RTK, empleando técnicas RTK/PPK para asegurar la precisión de las coordenadas geográficas. Se almacenaron observaciones GNSS en formato RINEX 3,02 para posibles ajustes posteriores. Se llevaron a cabo nueve vuelos, obteniendo 4985 fotos georreferenciadas con precisiones menores a 2 cm. El procesamiento de imágenes se realizó en tres etapas usando Agisoft Metashape, generando modelos digitales del terreno y curvas de nivel con Global Mapper. Posteriormente, se vectorizaron elementos del mapa urbano, como construcciones y ejes de calles, utilizando Civil 3D y las ortofotos como referencia. El resultado fue un plano georreferenciado que incluye las huellas de construcciones y cuerpos de agua, exportado en formato shapefile. Finalmente, se validó la cartografía mediante un recorrido por el municipio, actualizando la información vectorizada con datos del levantamiento realizado con el VANT.

Palabras clave: Mosaico Cartográfico; Fotogrametría; VANT; SIG; Municipio.

INTRODUCTION

The use of SFM(Structure From Motion) digital aerial photogrammetry in engineering and spatial design is a technique that facilitates the capture of geospatial information. It evolved from aerial photogrammetry, which was carried out in airplanes from the 1950s onwards.[1]

Digital Photogrammetry SFM is an advanced technique that uses computational algorithms to reconstruct objects and landscapes from digital images taken from different angles and positions in three dimensions. This technique is based on photogrammetric and stereoscopic principles, exploiting the differences between images to calculate objects' depth and three-dimensional shape.

A crucial aspect of SFM Digital Photogrammetry is identifying and matching visual features between images, such as corners or edges, and then calculating the three-dimensional position of characteristic points in the scene and the position and orientation of the cameras used to capture the images. This is achieved through triangulation and optimization algorithms.[2,3]

Once the three-dimensional structure has been reconstructed, dense point clouds representing the object's or landscape's surface are generated, allowing the creation of accurate and detailed 3D models. This technique is applied in various areas, such as topographic mapping, environmental change monitoring, documentation and reconstruction of archaeological sites, urban planning, and infrastructure design.[4]

Stereo triangulation is a fundamental aspect of SFM Digital Photogrammetry. It is based on the principle of parallax to calculate the three-dimensional position of points in a scene from two-dimensional images captured from different locations and angles. Control points whose three-dimensional coordinates are known are established and used to calculate the position of other points in the scene.

To implement stereo triangulation, various algorithms, and computational methods are employed, such as feature matching algorithms to identify corresponding points in the images and 3D reconstruction algorithms to calculate the three-dimensional coordinates of points in the scene from the two-dimensional coordinates of corresponding points in the photos. The combination of GIS Geographic Information Systems software with this SFM technology allows for a relatively fast mapping of the area under study, including all its typology, such as relief, vegetation, watercourses, etc.[5]

This resource is currently being used in many parts of the world because it allows information to be obtained precisely and with considerable time savings. In the following, we will present several examples of the use of these technologies.[6,7]

The authors Rubén Sancho Gómez-Zurdo, David Galán Martín, Beatriz González, Rodrigo Miguel Marchamalo Sacristán, and Rubén Martínez Marín[8] in their report 'Application of DRONE Photogrammetry to Deformational Control of Structures and Terrain'. study the feasibility of using drones, analyzing the resolution, accuracy, and validation with other techniques. They present in detail the photogrammetric technique Structure From Motion, which is used to produce accurate orthophotographs and 3D models without prior knowledge of the positions and angles of incidence. They also use precise control points, and their drones have an integrated RTK system. This guarantees them a high degree of accuracy. The example taken is the monitoring of an arc-gravity dam. Their results show a deformation accuracy of ±2 mm for the structure. This confirms that drone photogrammetry can be applied to the deformation monitoring of concrete dams.

For their part, Felipe Buil Pozuelo, M. et al.[9] in their study 'Influence of 3D Modelling on the Determination of Discontinuity Families in Rock Massifs', nine focus on the characterization of discontinuities in the rock massif, to identify the potentially unstable outlet volume, necessary for the evaluation of the danger of rock falls. The study area is Pala de Morrano (Aiguestortes NP). Through photogrammetric flights from aerial platforms (RPAS and helicopter), two 3D models were generated, and a third one from ground coverage. The data were completed with a TLS (Terrestrial Laser Scanning), which was assumed as ground truth. The characterization was performed with the Fast Marching plugin of Cloud Compare on these models.

The generated models have significant completeness, above 95 %, where the combination of terrestrial and helicopter, without occlusions (98 %), stands out. They concluded that, for the set objective of obtaining the families of discontinuities, all the photogrammetric models are valid, with the terrestrial photogrammetric model showing the most significant similarity to the one obtained with the TLS, being the optimal one on a cost-benefit basis, followed by the one generated by multicopter photogrammetry.[10]

In the report 'Topography of a Physical Model of Urban Drainage using the Structure From Motion Photogrammetric Technique,' the authors Regueiro-Picallo et al.[11] from the University of Coruña, Water and Environmental Engineering Group (GEAMA), A Coruña, Spain, present visualization techniques as an innovative tool to solve some complex problems of experimental hydraulics in a simple and generally low-cost way.

This study presents a case of the SFM technique being applied to reconstruct the surface of a physical model of urban drainage. A detailed surface mesh with a resolution of 5 mm and a relative error of ±2,5 % concerning conventional topographic techniques was obtained from an image sweep for use in 2D rainfall-runoff transformation models.

The research work of the authors Yandri José Lalangui Jaramillo and Belizario Amador Zárate Torres, on 'Evaluation of the Digital Terrain Model Obtained Using Photogrammetry Techniques with UAV and GNSS Techniques Applied to Road Projects in Medium Vegetation Areas,'[12] had as its objective to obtain a digital surface model of mountain roads using an uncrewed aerial vehicle (UAV). At an altitude of 100 m, a UAV took images every two seconds and these were processed in SFM software.

A digital terrain model was configured using photogrammetric techniques, and the results were compared with the differential GPS-derived digital terrain model.

The digital models turned out to be similar because there is variation where vegetation is dense. They would reduce the margin between these two types of survey so that topographic surveys can be achieved without cost to the environment.

The research paper by authors Chaudhry et al.[13] on 'Impact of Unmanned Aerial Vehicle Topographic Parameters on Urban Land Mixed Use Surface Modelling' argues that uncrewed aerial vehicles (UAVs) as a surveying tool are mainly characterized by a large amount of data and high computational cost. However, this research explores the use of a small amount of data with less computational cost for more accurate three-dimensional (3D) photogrammetric products by manipulating UAV surveying parameters, such as flight line patterns and image overlap percentages.

In Pix4DMapper, 16 photogrammetric projects were processed with perpendicular flight plans and a 55 % to 85 % lateral and frontal overlap variation. For georeferencing and accuracy assessment of the UAV data, 10 ground control points (GCP) and 18 control points (CP) were used. The comparative analysis incorporated the median of tie points, the number of 3D point clouds, the horizontal/vertical mean square error, and large-scale topographic variations.

The results indicate that a higher frontal overlap increases the median number of tie points and that an increase in lateral and frontal overlap results in a higher number of point clouds. It was also found that the horizontal accuracy of 16 projects varies from ±0,13 m to ±0,17 m, while the vertical accuracy varies from 0,09 m to ±0,32 m. The lowest vertical mean square error did not correspond to the highest percentage overlap.

The trade-off between UAV topographic parameters can result in high-accuracy products with less computational cost.

Importance

Cartography is crucial for the planning and sustainable development of cities, but in the Dominican Republic, 95 % of municipalities lack accurate and up-to-date cartographic information, which hinders decision-making. Updating urban mapping is vital, and a model that combines Unmanned Aerial Vehicles (UAVs) and Geographic Information Systems (GIS) can improve the efficiency of data collection. The Urban Development Plan of San José de Ocoa illustrates the need for reliable mapping to identify priority areas and design effective policies. It is proposed that municipalities use this methodology to develop their mapping. It is highlighted that using UAVs allows for obtaining high-resolution geospatial data, overcoming the limitations of traditional techniques. Furthermore, it is suggested that the Dominican Republic adopt practices such as those of Madrid, which updates its cartography every four months, proposing annual updates in fast-growing urban areas and every two years in areas of slower development.

Problem statement

The Dominican Republic's legislation on municipal issues and urban development itself dates back some 80 years, starting with Law 675 of 14-8-1944 on Urbanisation and Public Decoration, followed by Law 3455 of 18-12-1952 on Municipal Organisation and Law 3456 of 29-1-1953 on the Organisation of the District of Santo Domingo, through Law 6232 of 25-2-1963 on Urban Planning, to the more recent Law 176-07 of 17-7-2007, on the National District and the Municipalities.

Until recently, practically no municipality, except San José de Ocoa, had a complete municipal cartography that included an inventory of all urban spaces, such as buildings by type of use, roads, waterways, and projects to be developed for modernization and municipal development.

The National Geographic Institute José Hungría Morel (IGN), during the second quarter of the year 2023 with its project called Survey of the Cartographic Base 1:5 000 and 1:25 000 of the Dominican Republic began to make available to the public cartography of part of the national territory, such as Monte Cristi, Dajabón, Santiago Rodríguez, Santiago, Valverde, Puerto Plata, Espaillat, La Vega, Monseñor Nouel, Sánchez Ramírez, Duarte, Hermanas Mirabal, María Trinidad Sánchez and Samaná. The products that can be downloaded at the time of writing, which is the first quarter of 2024, are the Orthophoto 1:5 000 and 1:25 000, as well as the DTM digital terrain models. Topographic sheets 1:5 000 and 1:25 000 will be available in the future.

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This mapping has been developed using satellite imagery; as we have heard, nothing has been done with UAVs.

Although the IGN delivers the Ocoa cartography, our design of the cartography with the UAV resource and the application of Geographic Information Systems (GIS) focuses on the fact that our purpose is to maintain the updating of each of the municipal cartographies at the national level with the tools that we use in our research. Therefore, no conflicts of interest or repetitive actions lead to duplication of efforts on our part.

Our project seeks that the municipalities of the Dominican Republic, with the establishment of a Geographic Information System based on an updated cartographic base with the VANT resource, can advance to a level of response that allows them to address issues such as urban development, public safety, health, recreation, and other municipal matters, to bridge the gap that they have been subject to for historical reasons framed in the development of the capital city, which were leaving behind the possibilities of progress of the remaining towns of municipalities headwaters of the provinces of the country.

In the Latin American model of development, established in the decades between 1940 and 2000, two critical aspects are characterized, firstly: generalized dependence on the agricultural sector, but dominated by archaic mechanization systems, in some cases almost non-existent and consequently not very productive, and secondly, the growth experienced by these cities due to migration from the countryside to the city, where 42 % lived in urban areas in 1950, rising to 76 % in 2010.[14]

A similar situation occurred in our country some two decades before 2000; the increasing concentration of population in the cities of the central provinces, together with the lack of mechanisms for the control of new urbanizations, has left local governments virtually prostrated in terms of planning and control of these settlements.

These realities show that urban development controls have never been articulated under an integral development concept for the country's cities. This could be due, in part, to the fact that adequate tools have not been available during all this time.

There has not been an operational agenda for growth with real long-term execution.

Each local government, i.e., mayors' offices, 'works' according to their political and economic possibilities. Our GIS mapping can also be used for other critical municipal issues, such as tax collection, which can be permanently monitored, for example, in cases such as the collection of municipal taxes handled in each locality.

The green area is a municipal issue of high importance, which can be ideally monitored with our tool. Despite being in the 21st century, the municipalities of the Dominican Republic do not have a cartographic base and a geographic information system (GIS) that serves the purposes of urban development for which they are responsible.

Objective

To create a municipal cartographic model for the Dominican Republic, using UAV digital photogrammetry and Geographic Information Systems, case: Urban centre of the municipality of San José de Ocoa.

METHOD

In this research, we have used the quantitative method because the data collection was based on measurements. For example, we used a DJI Phantom 4 RTK uncrewed aerial vehicle (UAV) for the flight over the study area.

The technique used for executing this flight was simultaneous RTK/PPK, for which a WIFI connection was established between the Phantom 4 RTK UAV and the Comnav N3 GNSS receiver, previously linked to the CORS FCOC (belonging to the FUNDCORSRD Network), to determine the georeferenced coordinates of the base point of each flight.

The GNSS receiving equipment was configured to store the static observations every second in RINEX 3.02 format. This ensured that, in the event of failure of the real-time connection to the UAV, the data could be used for Post Process Kinematic (PPK).[15,16,17]

The company TRIMBLE's TBC software was used to perform the Ground Control Point (GCP) adjustments and verify the accuracy of the center coordinates of the photographic images. As a result of the nine flights, 4985 georeferenced photos were obtained, all with an accuracy of less than 2 cm.

The photographic images were processed in three stages using AGISOFT METASHAPE software. Using the digital terrain models obtained from the processing of the photographs, contour lines were generated using Global Mapper software. This whole process is framed within the quantitative method.

Research Technique

The research technique used in this work can be classified as descriptive since it is based on measurement. This characteristic is reflected in the field activities, which range from the placement and georeferencing of ground control points (GCPs) to the flight carried out. Adjustments were made to the GCPs, and the accuracy of the center coordinates of the GCP photographic images was verified using the TBC software. As a result of the UAV flights, a total of 4 985 geo-referenced photos were obtained.

Three independent teams vectorized the geo-referenced orthophotos, which involves identifying and tracing elements such as buildings, street axes, watercourses, gullies, and rivers. They simultaneously used Civil 3D software to insert the orthophotos, which allowed them to make precise drawings on them.

This process resulted in a geo-referenced plan that accurately reflects the traces of the constructions, the axes of the streets, the ravines, and the river that borders the urban center of the municipality studied.

Use of Variables and Indicators

The variables we will analyze in our research will be simple since we do not need composite variables to develop them. For the same reasons, we will not need dimensions in the table below showing the variables and indicators.

The indicators refer to specific elements of the municipal cartography of San José de Ocoa, that is, particular characteristics that allow us to measure or evaluate each of the variables of interest in our research.

Indicators are specific elements of reality that help us measure or evaluate the variables of interest in our research. Each indicator provides a concrete measure that allows us to better understand changes and trends in the study area.

Analysis of the Variables to be Considered in the Study

The first variable, the Base cartography of San José de Ocoa, is of the dependent type because it is a function of the changes that the components of this cartography undergo, such as the expansion of the urbanization of the polygon that makes up the urban area.

The second variable, Typology of Uses, is a dependent variable. It is a function of the municipality's potential economic development, and this currency mobilizing factor will mark the trend of uses, regardless of the existence of the Land Use Plan (POT).

The third variable, Damage to watercourses due to humans' presence on their banks, is a dependent variable, as it is a function of the demographic explosion in these areas.

The fourth variable, Conservation of Waterways, is a dependent variable, as it is a function of the intervention carried out on the waterways.

Analysis of the Indicators to be considered in the Research

The indicators are the unit of measurement of the variable, so for the first variable, Municipal Cartography of San José de Ocoa, an indicator to be tested to measure it is the residual surface that results from comparing the current cartography with the previous one.

For its part, variable two, Typology of Uses, has as an indicator to test the percentage measurement of the positive increase in uses, especially the commercial uses determined when carrying out this study.

The indicator for testing variable three, Damage to watercourses due to the presence of humans on their banks, is the result of the comparative analysis of the current state concerning 2015.

The indicator used to measure variable four, the Conservation of Waterways, is the result of the comparative analysis of the current state with respect to 2015.

Table 1. Variables and indicators

Variables	Indicators
	Residual area resulting from the overlay with the new mapping carried out in the research.
Base mapping of the municipality of San José de Ocoa	Percentage measurement of the positive increase in uses, especially the Commercial Uses determined by this study.
Typology of uses	Numerical result of the comparative analysis of the current state, with respect to that presented in 2015.
Damage to watercourses due to the presence of humans on the river banks	Numerical data obtained from the analysis of the current state, with respect to that presented in the 2015 SJO PDU.

Explanation of the Study Methodology

The methodology of this research is composed of two fundamental parts:

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Fieldwork in which the following actions were carried out

Placement and georeferencing of the ground control points (GCP) and survey of the urban area of the head municipality of San José de Ocoa through the use of digital photogrammetry with the unmanned aerial vehicle (UAV), or DRON, which means Aircraft that flies without a human crew on board. Another name is UAS (Unmanned Aerial System) or UAV (Unmanned Aerial Vehicle), with which high-resolution aerial images are captured.

Office work

We adjust the GCP (Ground Control Points) and process the photographic images using Agisoft Metashape software using the SFM (Structure from Motion) digital photogrammetric technique. This allows us to obtain accurate three-dimensional models of the study area. In addition, we vectorized the orthoimage of the urban center of the municipality of San José de Ocoa using AutoCAD Civil 3D software.

Finally, we integrated the data obtained from the digital photogrammetry into a Geographic Information System (GIS) using ArcGIS Pro software. This allows us to generate an updated and high-quality cartography of the urban area of the municipality of San José de Ocoa.

From these two large blocks, we have seven execution stages, as shown in table 2.

Table 2. Implementation stages

1	Documentary study	
2	Analysis of the information contained in the documents	It consists of reviewing the inventory of documents included in the bibliography of the project.
3	Instruments used	This activity precedes the others, as it constitutes the starting point of the work.
4	Fieldwork	We analysed all the documentation contained in the bibliography of the project, in order to be able to orientate where the attention should be directed, to the questions that could be relevant in the changes and evolution of the cartography object of study that we proposed to update.
5	Situational Analysis and/or Diagnosis	Since we applied technological tools such as data capture and processing software, the instruments used were the respective softwares and hardwares.
6	Drafting of the preliminary document	No other instruments were designed in the fieldwork, such as questionnaires and interviews. Photographic resources were used.
7	Formulation of the final document of the research results.	It was carried out with the help of support staff in accordance with the sample selected from the universe.

Methodology Employed in the UAV Flights

Flights over the studied area

Flight Planning. In order to plan the flights over the urban area of the municipality of San José de Ocoa, it was necessary to delimit the polygon under study, which we did with the help of a Google Earth satellite image, as can be seen in figure 1.

RESULTS AND DISCUSSION

The area selected to cover the entire urban area of San José de Ocoa has an approximate extension of 5,42 square kilometers. The delimitation did not follow any specific institutional criteria; however, we established the limits as follows: to the north, the bridge that connects with the municipality of Sabana Larga; to the east, the course of the Ocoa River; to the south, the bridge at the entrance to the city of San José de Ocoa; and to the west, the line of the mountainside up to the point where the buildings end.

The UAV used for the flight of the study area was the DJI Phantom 4 RTK, which consists of a camera with a 1" CMOS sensor, a mechanical trigger(Global Shuter), and a resolution of 20 Megapixels.

The Phantom 4 RTK includes a fully integrated RTK module that provides real-time centimetre-level position information for excellent image geo-referencing accuracy. It also stores satellite observation information for kinematic post-processing, better known as PPK.

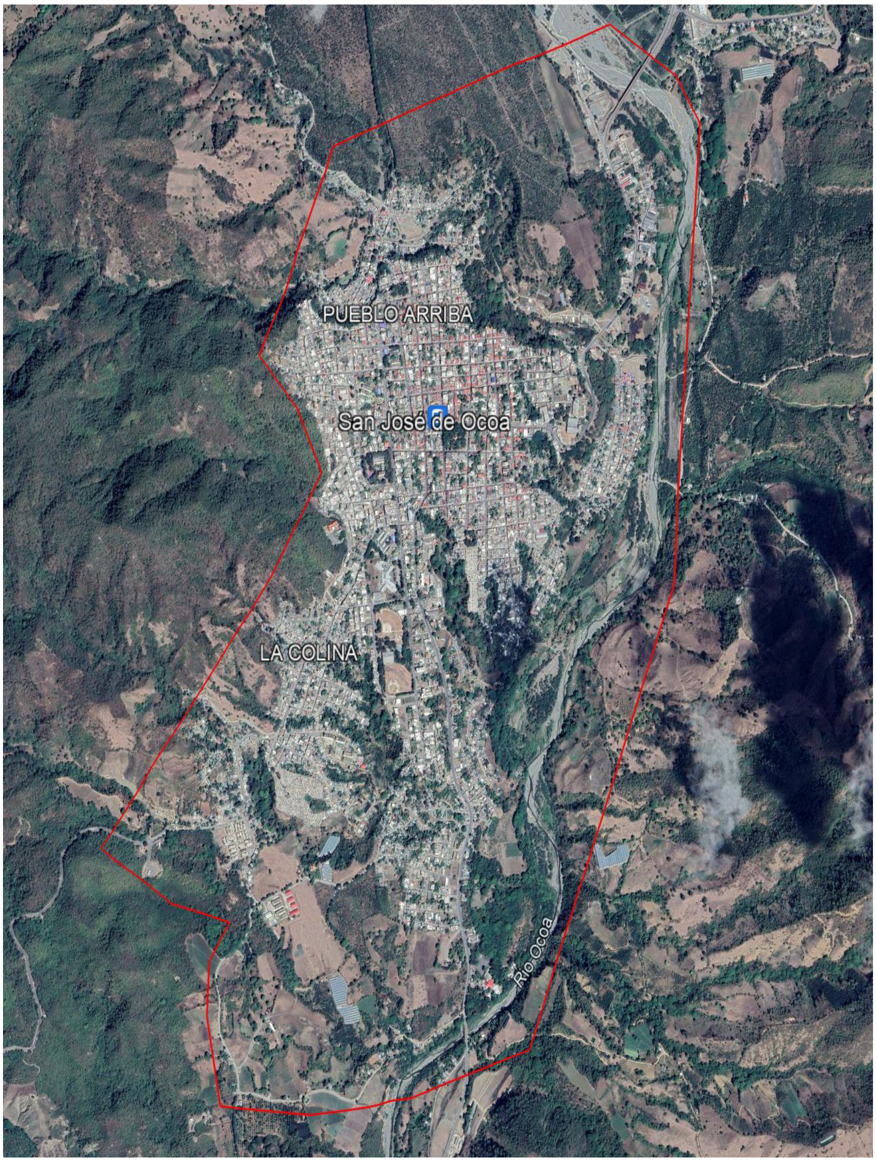

Figure 1. Polygon of the urban area of San José de Ocoa on Google Earth satellite image of September 2023

Table 3. UTM coordinates Zone 19N

Vert.	This	North
1	341286,38	2049219,21
2	340810,39	2049047,64
3	340412,36	2049007,44
4	340051,50	2049041,03
5	340002,97	2049349,55
6	340014,80	2049536,93
7	340096,36	2049669,93
8	339864,61	2049737,24
9	339604,47	2049936,25
10	340293,92	2050856,81
11	340438,37	2051118,68
12	340478,97	2051188,56
13	340386,25	2051401,72
14	340244,97	2051573,01
15	340533,07	2052285,79
16	341633,66	2052704,29
17	341898,31	2052527,20
18	341991,22	2052367,03
19	341871,96	2050802,62

Figure 2. PHANTOM 4 RTK UAV flying over the town of Ocoa

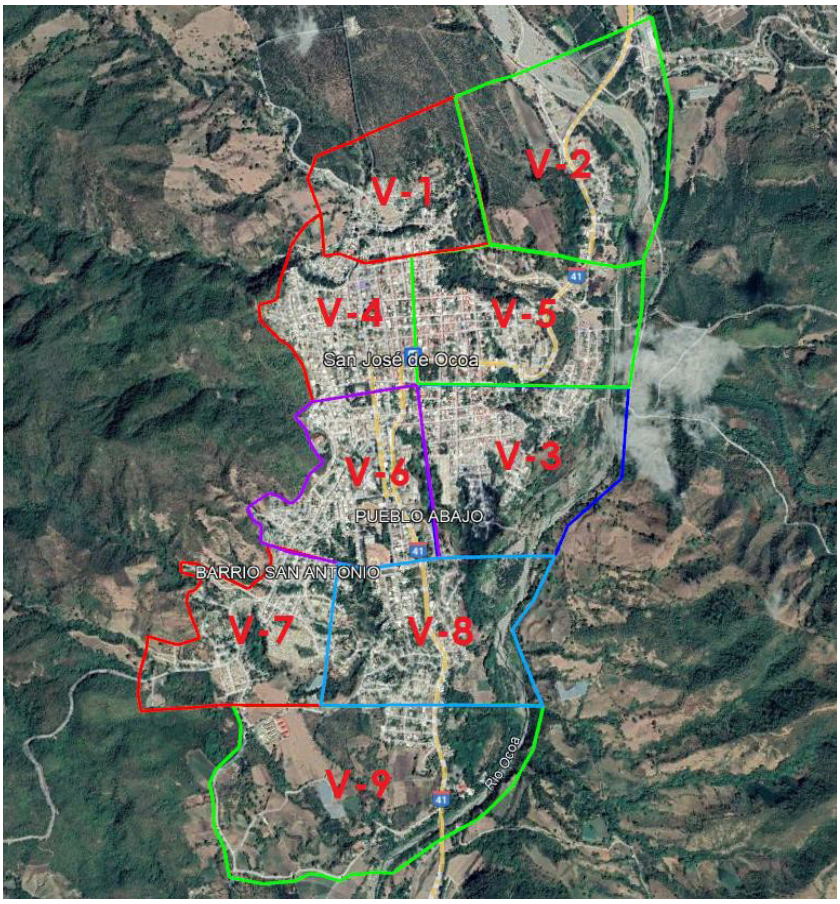

Figure 3. Flight plans over the urban area of San José de Ocoa

The flight tool used was DJI GS RTK, an application specifically designed to integrate with Real-Time Kinematic (RTK) positioning systems. It offers an intuitive interface that facilitates planning and executing accurate and efficient flights to capture geospatial data. To better control the UAV during the flights, we divided the study area into nine flight plans, allowing us to have the UAV in sight during the whole mission and ensure that the UAV did not move more than 1 km away from the take-off point.

The flight height was 120 m with respect to the UAV's take-off point, so we obtained a GSD of less than 5 cm/pixel. The UAV speed for all missions was set at 9,5 m/s, and the horizontal and vertical overlaps were 70 % and 80 %, respectively, to obtain a good stereo model.

Placement and Georeferencing of the GCP Control Points

The Ground Control Points (GCP) provide reference points to verify the accuracy of the results obtained in the photogrammetric process. By comparing the coordinates measured on the ground with the coordinates estimated from the imagery, it is possible to assess the quality and accuracy of the final product.

Figure 4. NTRIP Ground Control Point GCP survey is performed

The satellite receiver was the Comnav N3 GNSS, capable of tracking the four satellite constellations visible from the Dominican Republic: GPS, GLONASS, GALILEO, and BEIDU. The georeferencing methodology we used was the NTRIP cellular correction connected to the CORS FCOC belonging to the FUNDCORSRD Network, which is located in the urban area of San José de Ocoa. As shown below, 27 ground control points (GCP) were geo-referenced and used only as checkpoints.

Flight Plan Execution

Figure 5. UAV radio control screen during execution of flight plan

Before the execution of the flight plans, the possible take-off points were determined, taking into account the elevation of the terrain, so that the planned mission could be executed without putting the UAV at risk and ensuring that the resulting GSD was less than 5 cm/pixel. The technique used for the execution of the flight was RTK/PPK simultaneously, for which we linked via WIFI the UAV Phantom 4 RTK with the Comnav N3 GNSS equipment, which we previously connected with the CORS FCOC to determine the georeferenced coordinates of the point used as a base.

The GNSS receiver is configured to store the static observations every second in RINEX 3,02 format. This is done in anticipation of any failure in the UAV's real-time connection. In case a connection problem occurs, this data will be used to carry out the Kinematic Post Process, known as PPK. The field works, which included positioning and georeferencing the GCPs and executing the flights, were carried out on 9, 17, and 22 September 2023.

These activities were carried out to cover the entire urban area of the Municipality of San José de Ocoa.

Figure 6. GNSS Receiver at Base Point on the roof of the Altagracia Brito School

Adjustments of the Ground Control Points GCPs

To adjust the GCPs and verify the accuracy of the coordinates of the center of the photographic images, we use the TBC software of the company TRIMBLE, whose reports are included as part of the annexes.

Number of Georeferenced Photos Obtained

The nine flights resulted in 4985 georeferenced photos, all with a precision of less than 2 cm. This verification was done by loading the pictures into the image processing software Agisoft Metashape.

In the flights made from the roof of the Basic School Altagracia Irma Brito Sánchez, for the processing of the images, we were forced to use the PPK methodology because we made a mistake in the field by introducing the ellipsoidal height of the base erroneously, This error can only be detected by checking the GCPs in the office, hence the importance of placing them and registering the RINEXs in the GNSS receiver, so that when these cases occur we can use the PPK method to geotag the photographic images with the corrected geo-referenced coordinates.

For the PPK calculation, we use the Red toolbox software. This program allows us to introduce the photographic images, the RINEX data and the time records of each photo taken stored by the UAV, the RINEX data stored by the GNSS equipment used as a base, and the geographic coordinates of the point with its ellipsoidal height. After matching the photos, this software performs the corrected calculation of the center of each of the photographic images.

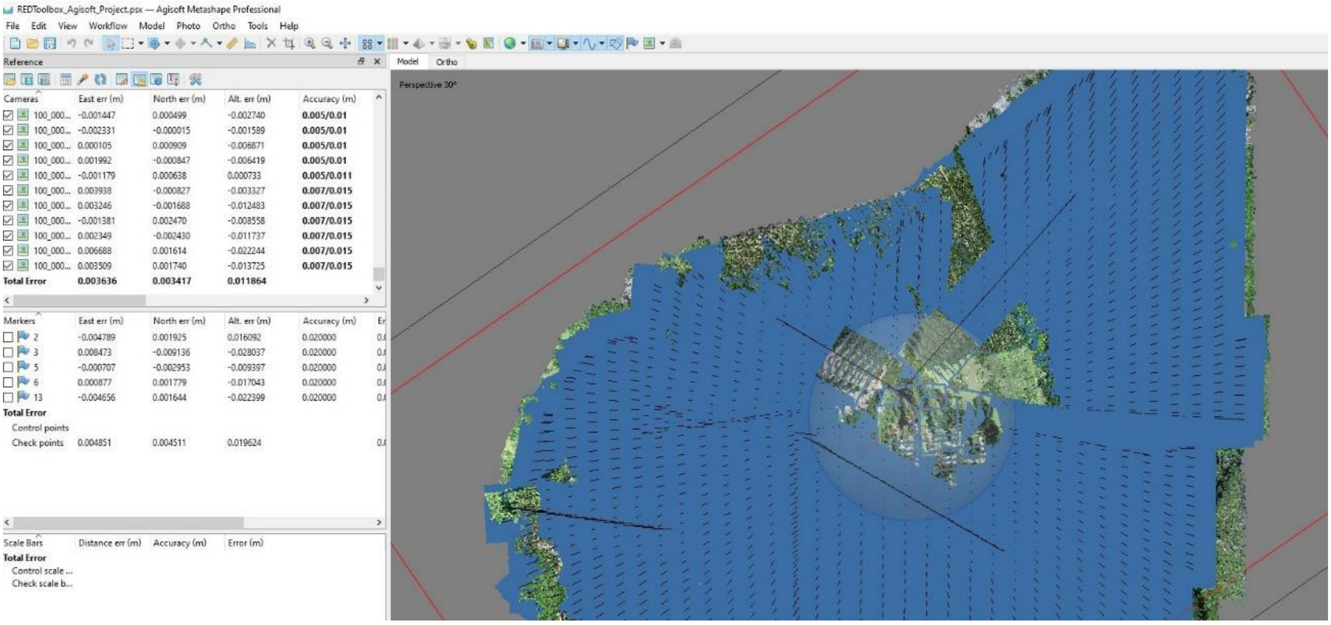

Figure 7. Agisoft Metashape software interface during photo processing

Processing, Curve Generation and Vectorization Photo Processing

We processed the photographic images using the Agisoft Metashape software. Given the number of photos, we decided to divide the processing into three (3) parts, as processing the 4,985 pictures in a single project would require a computer with greater processing capacities than the one we have.

The specifications of the computer used are as follows: AMD Ryzen 9 5900X 12-Core Processor 3,70 GHz, 64 GB RAM, and GEFORCE RTX 2080 video card.

Summary Results Obtained from Each of the Processes

First Processing

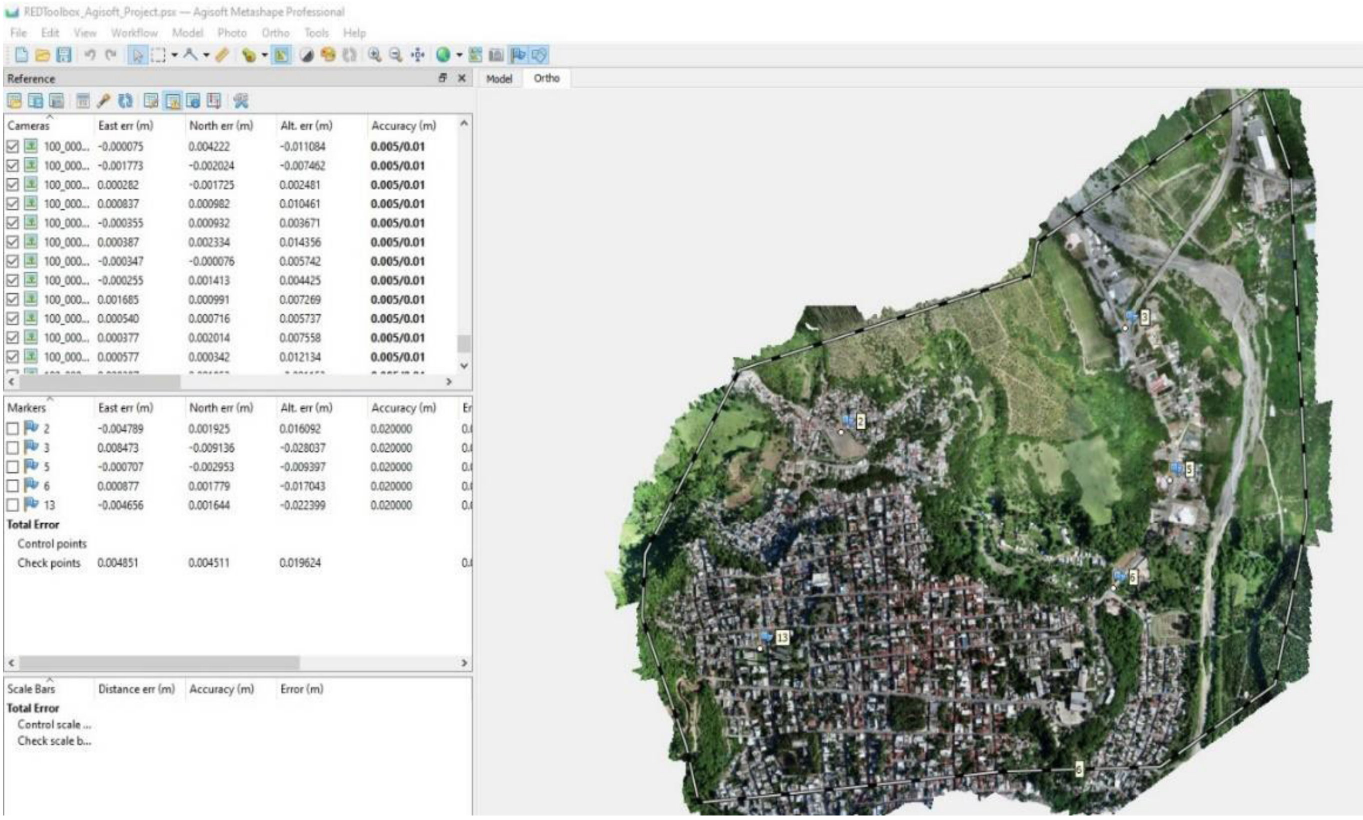

Figure 8. Agisoft Metashape software interface showing Ground Control Points and their resulting errors in the first processing

Number of photos processed... 1 966 photos
Processing time Depth Map.................................. 2 hours 19 minutes
Processing time Dense Cloud.. 5 hours 7 minutes
Processing time Terrain Point Classification......................... 1 hours 5 minutes
Digital Surface Model Processing Time.................. 14 minutes 12 seconds
Digital Terrain Model Processing Time..................... 15 minutes 24 seconds
Orthophoto Processing Time with a GSD of 3,61cm/pix................... 1 hour 48 minutes
The GSD of the DTMs and DSMs was 7,23 cm/pixel. For this processing, 5.
GCP only as checkpoints yielding the following results:

Table 4. UTM coordinates of the GCP Ground Control Points in the first processing

GCP	This	North	Raising
M2	340818,399	2052045,062	460,164
M3	341602,428	2052316,919	436,875
M5	341726,521	2051918,002	427,238
M6	341570,024	2051633,437	432,894
M13	340596,588	2051476,495	490,198

Errors when assigning GCP Ground Control Points to a maximum of 10 photographs:

Table 5. Digital Model errors when assigning GCP Ground Control Points to 10 photographs in the first processing

GCP	Error This	Error North	Error Elevation
M2	-0,004	0,003	0,016
M3	0,009	-0,008	-0,028
M5	-0,000	-0,003	-0,009
M6	0,001	0,002	-0,017
M13	-0,004	0,002	-0,023
Average error	0,005	0,004	0,020

Note: RMS = 0,021

Second Processing

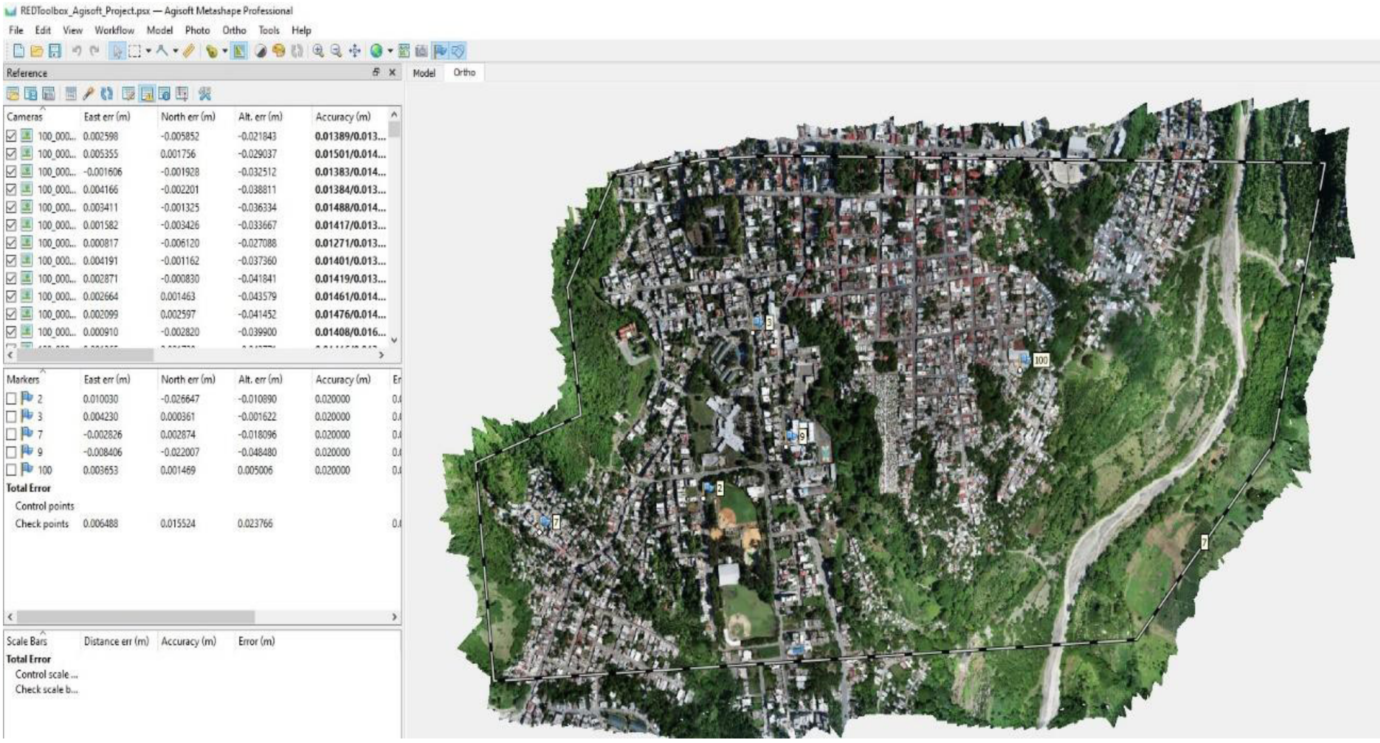

Figure 9. Agisoft Metashape software interface showing Ground Control Points and their resulting errors in the second processing

Number of photos processed...1,339 photos
Processing time Depth Map...1 hours 25 minutes
Processing time Dense Cloud...3 hours 44 minutes
Processing Time Terrain Point Classification ....40 minutes 10 seconds
Digital Surface Model Processing Time..7 minutes 27 seconds
Digital Terrain Model Processing Time....................................... 9 minutes 20 seconds
Orthophoto processing time with a GSD of 3,91cm/pix....................50 minutes 11 seconds.
The GSD of the DTM and DSM was 7,83 cm/pix.
For this processing, 5 GCPs were used as checkpoints only and the results were as follows:

Table 6. UTM coordinates of the GCP Ground Control Points in the second processing

GCP	This	North	Raising
2	340679,354	2050699,775	459,532
3	340784,246	2051003,508	467,571
7	340333,356	2050637,132	479,616
M9	340854,714	2050794,822	459,254
100	341351,077	2050935,447	455,623

Table 7. Digital Model errors when assigning GCP Ground Control Points to 10 photographs in the second processing

GCP	Error This	Error North	Error Elevation
2	0,011	-0,027	-0,011
3	0,004	-0,000	-0,002
7	-0,002	-0,003	-0,018
M9	-0,008	-0,022	-0,048
100	0,005	0,001	0,006
Average error	0,007	0,016	0,024

Note: RMS = 0,029

Third processing

Number of photos processed...1,956 photos
Processing time Depth Map...1 hour 46 minutes
Processing time Dense Cloud...4 hours 09 minutes
Processing time Terrain Point Classification...1 hour 24 minutes
Digital Surface Model Processing Time...15 minutes 1 second
Digital Terrain Model Processing Time..16 minutes 34 seconds
Orthophoto processing time with a GSD of 3,04 cm/pix...1 hour 35 minutes
The GSD of the DTM and DSM was 6,07 cm/pix.

For this processing, 6 GCPs were used as checkpoints only and the results were as follows.

Table 8. UTM coordinates of the GCP Ground Control Points in the third processing

GCP	This	North	Raising
4	340251,640	2049746,815	454,530
5	340041,388	2049980,366	471,360
6	340265,629	2050216,685	471,790
M10	341025,798	2049849,949	412,379
M11	340973,008	2049308,782	393,814
M15	340255,079	2050304,634	476,102

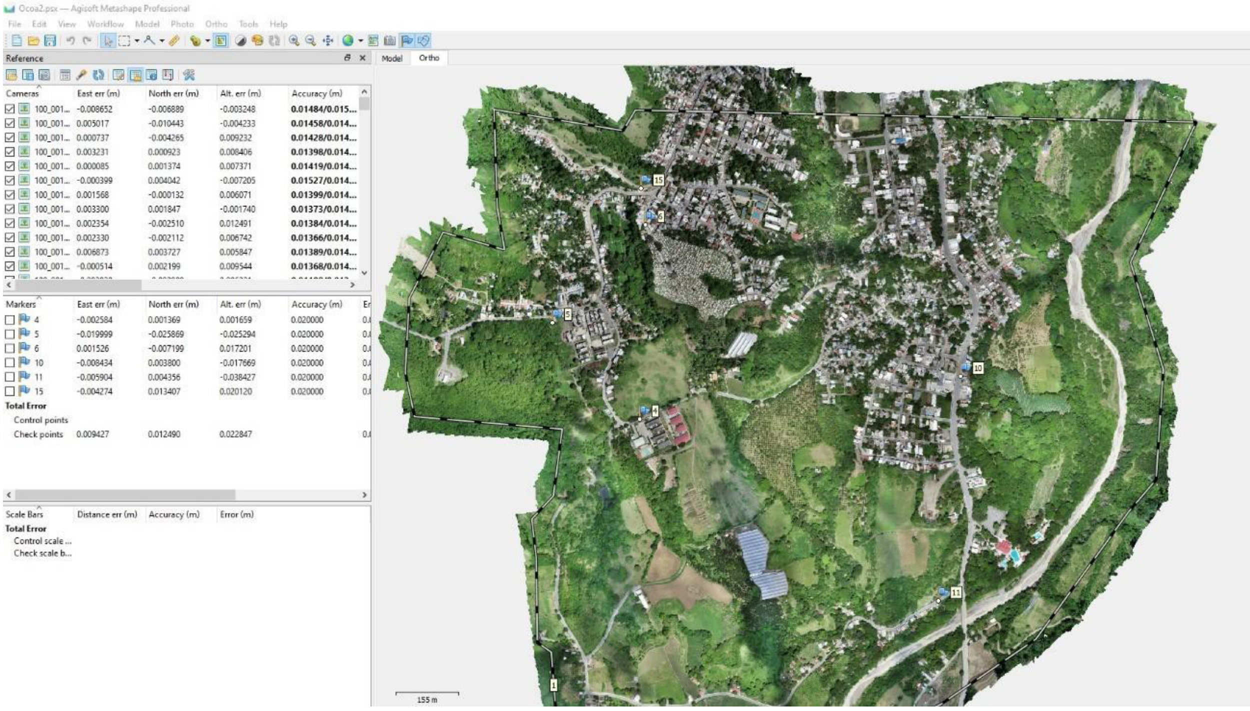

Figure 10. Agisoft Metashape software interface showing Ground Control Points and their resulting errors in the third processing. Note: Although the GCP ground control points are not clearly visible in the printed image of the document, these and any other details can be seen accurately and clearly by zooming in on the digital image in each case

Table 9. Digital Model errors when assigning GCP Ground Control Points to 10 photographs in the third processing

GCP	Error This	Error North	Error Elevation
4	- 0,012	0,001	0,002
5	-0,013	-0,023	-0,025
6	0,002	-0,007	0,017
M10	-0,008	0,004	-0,018
M11	-0,005	0,005	-0,039
M15	-0,004	0,013	0,020
Average error	0,007	0,012	0,023
RMS = 0,027			

After processing the images, we obtained Digital Surface Models (DSM), Digital Terrain Models (DTM), and georeferenced orthophotos of the entire area of interest.

Generation of contour lines in the urban area of San José de Ocoa

Based on the Digital Terrain Models obtained from the processing of the photographic images, we proceeded to generate the contour lines using Global Mapper software, a software used to analyze and process digital models obtained from photogrammetric or Lidar surveys.

Given the rugged topography of the study area, the contour lines were generated at an interval of 2 m. This process made it possible to accurately capture the variations in the elevation of the terrain, providing detailed information on the urban area's topographic configuration. Once the plane of curves was generated, we exported it in shapefile format to load it as one of the layers that would make up the Geographic Information System of the cartography of the urban area of the municipality of San José de Ocoa.

This choice of format ensured the dataset's compatibility with the Geographic Information System (GIS) for mapping the urban area of the municipality of San José de Ocoa. The inclusion of these curves in the GIS enriches the cartographic representation by providing a detailed and essential layer for the area's topographic analysis.

This contour line generation process, supported by specialized technologies and an accurate focus on local topography, is crucial in constructing a comprehensive and detailed cartographic map of San José de Ocoa's urban area.

Vectorisation of the orthophotos

To create the cartographic map of the urban area of the municipality of San José de Ocoa, a process of vectorisation of the geo-referenced orthophotos was carried out. This process involved the identification and tracing of crucial elements, such as buildings, street axes, and stream and river courses.

Three independent vectorization teams were implemented using Civil 3D software. This program allowed the insertion of orthophotos to make precise drawings of them. Each team was in charge of exhaustively vectorizing the elements above, taking advantage of the advanced tools provided by the software.

Subsequently, the results obtained by each team were consolidated. This combination process resulted in a georeferenced map that accurately reflects the footprints of the buildings, the axes of the streets, the ravines, and the river that borders the urban center of the San José de Ocoa municipality.

The next step was exporting this plan in shapefile format, thus ensuring its compatibility and effective integration with the Geographic Information System (GIS) previously established for this study. The use of this technology not only ensures the data's interoperability but also facilitates its analysis and management within the study area's geospatial context. This robust and systematized working approach contributes significantly to the production of accurate and quality cartographic maps for the municipality of San José de Ocoa.

CONCLUSIONS

A digital cartographic mosaic was created for the urban area of San José de Ocoa, using VANT digital photogrammetry and Geographic Information Systems (GIS) as all urban development specifics.

Integrating advanced technologies, such as high-resolution ortho imagery, digital elevation models, satellite imagery, geospatial databases, global positioning technologies (GPS), and cadastral parcel data, has generated a robust and detailed cartographic product.

The cartographic information generated has practical applications in urban planning, civil defense against disasters, and natural resource management. It is also a significant element for the region's sustainable development.

BIBLIOGRAPHIC REFERENCES

1. Delgado García, Jorge. Fotogrametría Digital. Universidad de Jaén. https://coello.ujaen.es/Asignaturas/fotodigital/descargas/FD_tema1.pdf.

2. García Vinces JJ, Ross Lopera CU, Solórzano Villegas LE. Research trends related to road innovation in civil construction of public spaces. Salud, Ciencia y Tecnología - Serie de Conferencias 2024;3:1328. https://doi.org/10.56294/sctconf20241328.

3. Jha A, Chandra Gupta N, Dey B. Morphometric Analysis of Gandak River Drainage Basin Using Geographic Information System (GIS) And SRTM-DEM. Salud, Ciencia y Tecnología 2022;2:189. https://doi.org/10.56294/saludcyt2022189.

4. Alonso Sarría, F. Sistemas de Información Geográfica. Universidad de Murcia. España. 2015. https://www.um.es/geograf/sigmur/sigpdf/temario.pdf

5. Galbán, EM. La cartografía en la Era Digital: Desarrollo y Perspectiva. Universidad Nacional de Luján. Argentina. 2018. https://repositoriosdigitales.mincyt.gob.ar/vufind/Record/REDIUNLU_bc804bf616fbfd875935825e0afbfcc6

6. Vélez Duque P, Centanaro Quiroz P, Juan Javier Martillo JJM, Alvarado Barzallo A. Preparation of a thematic map of agroecological crops using Google Earth. Salud, Ciencia y Tecnología 2024;4:1018. https://doi.org/10.56294/saludcyt20241018.

7. Abood MY, Aljanabi KR, Sayl K. Abood MY, Aljanabi KR, Sayl K. Using GIS Tools for the Prediction of Bearing Capacity of shallow footing (qu)and Undrained Shear Strength (Su) values for Falluja City's Soils. Salud, Ciencia y Tecnología - Serie de Conferencias. Salud, Ciencia y Tecnología - Serie de Conferencias 2024;3:843. https://doi.org/10.56294/sctconf2024843.

8. Gómez Zurdo, Rubén Sancho et al. Aplicación de la Fotogrametría con Drones al control deformacional de estructuras y terreno. 2021. https://iopscience.iop.org/article/10.1088/1755-1315/169/1/012003/meta

9. Buill Pozuelo, Felipe; Núñez Andrés, M. Amparo; Ruiz Carulla, Roger; Lantada Zarzosa, Nieves. Influencia de los Modelos 3D en la Determinación de Familias de Discontinuidades en Maciozos Rocosos. 2021. https://georisk.upc.edu/es/shared/2021/20211115_articulo_geoeuskadi2021_buill_et_al.pdf.

10. OCW UPCT. Introducción a la Geodesia. Universidad Politécnica de Cartagena. Colombia. 2001. https://ocw.bib.upct.es/pluginfile.php/10143/mod_resource/content/4/unidad_didactica_1.pdf

11. Regueiro-Picallo, M et al. Topografía de un Modelo físico de drenaje a partir de la técnica. Grupo de Ingeniería del Agua y del Medio Ambiente (GEAMA). 2018. https://www.revistahidrolatinoamericana.com/_files/ugd/d728aa_1cda10437fa9468cb82a6d88d62ba1c0.pdf?index=true

12. Lalangui Jaramillo,Yandri José; Zárate Torres, Belizario Amador. Universidad Técnica Particular de Loja, Loja, Ecuador. Evaluación del modelo digital de terreno obtenido mediante técnicas de fotogrametría con VANT y con técnicas GNSS aplicados a proyectos viales en zonas de mediana vegetación. 2020.

13. Chaudhry, Muhammad Hamid et al. Geoformation Faculty of Built Environment & Surveying, Universiti Teknologi Malaysia. 2020. https://www.mdpi.com/2220-9964/9/11/656

14. CEPAL Perspectivas de Urbanización Mundial: Revisión 2010. https://www.cepal.org/notas/73/Titulares2#:~:text=Am%C3%A9rica%20Latina%20es%20la%20regi%C3%B3n%20m%C3%A1s%20urbanizada%20del%20mundo%20en%20desarrollo

15. Pacheco, Henry et al. Uso de un Vehículo Aéreo no Tripulado como Alternativa para Generar Información Topográfica. Universidad Técnica de Manabí, Ecuador. 2023. https://www.redalyc.org/journal/5722/572273150005/html/

16. Ojeda-Bustamante, Waldo, et al. Aplicaciones de los Vehículos Aéreos no Tripulados en la Ingeniería Hidroagrícola. Scielo Tecnología y Ciencias del Agua. Instituto Mexicano de Tecnología del Agua. 2017. https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-24222017000400157s.f.

17. Li, Qiuxi; Deliberty, Tracy. Integrating drones, participatory mapping and GIS to enhance resiliency for remote villages. 2022. https://onlinelibrary.wiley.com/doi/abs/10.1111/tgis.12886

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AUTHORSHIP CONTRIBUTION
Conceptualization: Juan Manuel Sosa, Pedro Enrique Sosa Veras, Eva Mejía
Data curation: Juan Manuel Sosa, Pedro Enrique Sosa Veras, Eva Mejía
Formal analysis: Juan Manuel Sosa, Pedro Enrique Sosa Veras, Eva Mejía
Drafting - original draft: Juan Manuel Sosa, Pedro Enrique Sosa Veras, Eva Mejía
Writing - proofreading and editing: Juan Manuel Sosa, Pedro Enrique Sosa Veras, Eva Mejía