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ORIGINAL

Creation of the Geographic Information System for the urban center of the municipality of San José de Ocoa using Digital Photogrammetry (UAV) and Geographic Information Systems

Creación del Sistema de Información Geográfica casco urbano del municipio San José de Ocoa utilizando Fotogrametría Digital VANT y Sistemas de Información Geográfica

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ABSTRACT

The research focused on creating a Geographic Information System (GIS) for the municipality of San José de Ocoa, Dominican Republic, using digital photogrammetry with drones. The study area was delimited using Google Earth satellite images, and 4985 georeferenced photos with accuracies of less than 2 cm were obtained using drones. Image processing was carried out in three stages using Agisoft Metashape, generating digital terrain models and contour lines. Urban elements such as buildings and streets were subsequently vectorized using Civil 3D and orthophotos, resulting in a georeferenced plan in shapefile format. The cartography was validated through a walking tour of the municipality, updating the information with data from the UAV survey. The GIS incorporated various layers, including satellite orthoimages from 2013 and 2023, digital models, and shapefiles of buildings and roads. The WGS 1984 datum and the UTM projection system, Zone 19 N, were used with ArcGIS Pro and ArcGIS Online software. The results showed a significant expansion of the urban area between 2015 and 2023, with a 376,97 % increase in educational use and a 245,20 % increase in occupation of risk areas. The research generated a complete GIS, an interactive web application, and a 1:5000 scale cartographic map. It was concluded that the methodology is replicable at the national level, optimizing territorial management in the municipalities of the Dominican Republic.

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

RESUMEN

La investigación se centró en crear un Sistema de Información Geográfica (SIG) para el municipio de San José de Ocoa, República Dominicana, utilizando fotogrametría digital con drones. Se delimitó el área de estudio mediante imágenes satelitales de Google Earth y se obtuvieron 4985 fotos georreferenciadas con precisiones menores a 2 cm mediante drones. El procesamiento de las imágenes se llevó a cabo en tres etapas con Agisoft Metashape, generando modelos digitales del terreno y curvas de nivel. Posteriormente, se vectorizaron elementos urbanos como edificios y calles utilizando Civil 3D y ortofotos, resultando en un plano georreferenciado en formato shapefile. La cartografía fue validada mediante un recorrido a pie por el municipio, actualizando la información con los datos del levantamiento del VANT. El SIG incorporó diversas capas, incluyendo ortoimágenes satelitales de 2013 y 2023, modelos digitales y shapefiles de construcciones y vías. Se utilizó el Datum WGS 1984 y el sistema de proyección UTM, Zona 19 N, con los softwares ArcGIS

Pro y ArcGIS Online. Los resultados mostraron una expansión significativa del área urbana entre 2015 y 2023, con un aumento del 376,97 % en uso educacional y del 245,20 % en la ocupación de zonas de riesgo. La investigación generó un SIG completo, una aplicación web interactiva y un mapa cartográfico a escala 1:5000. Se concluyó que la metodología es replicable a nivel nacional, optimizando la gestión territorial en los municipios de la República Dominicana.

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.[2,3] This technique is based on photogrammetric and stereoscopic principles, taking advantage of the differences between images to calculate objects' depth and three-dimensional shape.[4]

The Urban Design Lab presents a report, 'GIS as a tool for Urban Planning,'[5] which states that GIS provides planners, surveyors, and engineers with the tools they need to design and map their neighborhoods and cities. Visualization, spatial analysis, and spatial modeling are the most commonly used GIS functions in mapping.

With GIS, a city's physical, social, and economic data can be stored, manipulated, and analyzed. Planners armed with this resource can then use the spatial query and mapping functions of GIS to investigate the city's situation. GIS can help identify conflict areas between development and the environment using the map overlay procedure. Using the multi-layer mapping function of GIS, the municipal government can visualize many things, such as quality agricultural land, surface water, flood frequency, and land at high risk from erosion or topographic features.[5]

A work of great relevance and importance for our research purpose is the one that precisely combines the use of drones with GIS, which we refer to below.

The authors, Qiuxi Li and Tracy Deliberty,[6] in their report 'Integrating drones, participatory mapping and GIS to enhance resiliency for remote villages,' explain that Indigenous communities in developing regions are affected by frequent disasters and the erosion of their culture under pressure from modernization. Notably, their efforts to reduce risk have been hampered because these communities lack a detailed map of their territories.

This study uses drone imagery, participatory methods, and GIS to generate the first publicly accessible infrastructure and resource dataset for indigenous communities in Southwest China. The maps produced enable data-poor Indigenous communities to be aware of the fire risk to their dwellings, the state of conservation of historic buildings, and potential economic resources such as tourist attractions.[7,8,9]

The expected end product of these efforts is to build resilience in these communities, which is true for hard-to-reach communities worldwide, for disaster prevention, economic planning, and the all-important cultural preservation that sustains their identity as an ethnic group.[6]

With the possibilities provided by these tools for the capture and presentation of spatial data, it is feasible to create the Dominican Republic's municipal cartographic base and/or update the existing ones. For these reasons, we will take the opportunity to review and/or update the one that was made for the Urban Development Plan of the municipality of San José de Ocoa.

The municipality of San José de Ocoa, which belongs to the new province of the same name, contains the urban center of the same. The town was founded in 1805 by inhabitants from Baní. Fifty-three years later, in December 1858, it was raised to the municipality status and belonged to the province of Santo Domingo. Later, in 1895, it was transferred to the province of Azua de Compostela. However, when the province of Peravia was created in 1944, San José de Ocoa was placed as a municipality of this province.

Law 66-00 made San José de Ocoa a province on 6 December 2000. Therefore, it is the youngest province of the 32 that make up the Dominican Republic. Pedro E. Sosa Veras, the Urban Development Plan of the Municipality of San José de Ocoa, was carried out between 2014 and 2015. In it, all the buildings, roads in the urban area, and waterways, among other information, were inventoried, and 74 municipal development projects were presented.

Currently, the country's municipalities do not have a cartographic base in which they can search with a few clicks for any information related to their productive components, with a complete description of a given unit, such as the use of a given area, whether it is institutional, medical, commercial, surface area, cadastral designation that includes parcel data, cadastral district, registration number, among others.

The only information available to them separately is that provided by Google Maps, and they do not have Geographic Information Systems that provide them with the detailed attributes mentioned in the preceding paragraph. In this sense, the research work will cover this wide range of the urban area's component units, including the mentioned attributes.

The lack of this information among the country's municipal governments diminishes the potential for private investment in suitable locations and also makes it difficult to control the economic and demographic development of these provinces.

Importance

Cartography is an essential tool for the planning and sustainable development of cities and municipalities, as it provides detailed information on the geographical location of natural resources, existing infrastructure, and urban and rural areas, among other relevant aspects. However, on many occasions, existing cartographic information is outdated, incomplete, or inaccurate, which hinders decision-making and the efficient implementation of public policies. According to our experience, 95 % of the municipalities in the Dominican Republic lack a cartography that would allow them to develop their municipal development and territorial management plans.

The collection and updating of urban cartography is essential for the effective planning and management of territorial development in the municipalities of the Dominican Republic.[10,11,12] A workflow model that integrates Unmanned Aerial Vehicle (UAV) technology and Geographic Information Systems (GIS) can significantly improve cartographic data collection and update efficiency and accuracy.[13]

The Urban Development Plan of San José de Ocoa is a concrete case representing the common challenges in urban management and the need for accurate and up-to-date base mapping. Studying this specific case will allow us to evaluate the effectiveness of the proposed workflow model and its applicability in other municipalities in the Dominican Republic.

By applying digital photogrammetry with UAV and GIS in the case of the Urban Development Plan of San José de Ocoa, it is expected to obtain updated and accurate information on topography, existing infrastructure, green areas, access roads, risk areas, among other elements relevant to urban planning. This information will allow decision-makers in San José de Ocoa to have a reliable and updated cartographic base, which will facilitate the identification of priority areas for intervention, designing more effective public policies, and implementing sustainable development projects.[14]

It should be noted that the municipalities of our country can autonomously take this work as a basis for developing their cartography with the integration of Geographic Information Systems (GIS).

Using UAVs makes it possible to obtain high-resolution geospatial data and coverage in urban areas, overcoming the limitations of traditional topographic survey techniques.

Conversely, GIS provides tools for processing, analyzing, and visualizing cartographic data, facilitating decision-making based on up-to-date and accurate information.

After 9 years have passed since the base cartography of the municipality of San José de Ocoa was carried out as part of the Urban Development Plan, it is a priority to review and update this information to show the evolution of the urban area, taking advantage of these mapping tools.

Objective

Create a Geographic Information System for the urban area of the municipality of San José de Ocoa.

METHOD

Contour lines were generated using Global Mapper software based on the digital terrain models obtained from processing the photographs. This whole process is framed within the quantitative method.

Research Technique

The GCP adjustments and verification of the accuracy of the center coordinates of the GCP photographic images were carried out using the TBC software. As a result of the UAV flights, 4985 georeferenced photos were obtained.

The process of vectorization of the geo-referenced orthophotos, which involves the identification and tracing of elements such as buildings, street axes, and watercourses, i.e., gullies and rivers, was carried out with the participation of three independent teams, simultaneously using Civil 3D software through which they inserted the orthophotos that allowed them to make precise drawings on them.[15]

This process resulted in a georeferenced plan that accurately reflects the traces of the buildings, the axes of the streets, the gullies, and the river that borders the urban center of the municipality studied.

The export of this plan in shapefile format, with its subsequent integration into the Geographic Information System (GIS) previously established for the study, guarantees the data's interoperability and facilitates its

interpretation, analysis, and management within the study area's geospatial context. This process has generated a systematized and robust product for producing accurate and quality cartographic maps of the municipality of San José de Ocoa.

Hypothesis

The municipality of San José de Ocoa's cartography underwent significant changes in terms of the expansion of the urban area from 2015 to 2023.

The occupation of river courses by people who have built their homes there is greater in size than that observed 8 years ago.

The use of digital photogrammetry technologies with UAVs and GIS in the design of a municipal cartographic mosaic will make it possible to obtain accurate, updated, and higher-quality information, thus improving the local government's decision-making in developing its urban plans and managing the territory of San José de Ocoa.

The conservation of roads has not changed since 2015 regarding their physical state of consolidation, deterioration, and/or intervention.

Explanations of the Use of the 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 demonstrating 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

When considering 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.

We adjusted the GCPs (Ground Control Points) and processed the photographic images using Agisoft Metashape software using the SFM (Structure from Motion) digital photogrammetric technique. This allowed 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.

RESULTS AND DISCUSSION

Creation of the Geographic Information System for the urban hull of the municipality of San José de Ocoa

The Geographic Information System (GIS) for the urban area of San José de Ocoa is an essential component in developing an integrated approach to spatial analysis and decision-making. A GIS is defined as a set of tools that integrates various components, allowing the storage, organisation, manipulation, modification, analysis and dissemination of large real-world geospatial data sets. This approach facilitates efficient information management and incorporates cultural, social, economic, and environmental aspects, thus enriching the decision-making process.

Georeferencing emerges as the central element in a GIS, as all its components (points, lines, polygons, raster images) must be linked to a typical frame of reference. In the context of the Dominican Republic, this reference frame is defined by the WGS 1984 Datum and the UTM Cartographic Projection System, with Zone 19 N corresponding to the country.

At present, ArcGIS Pro and QGIS are two of the most prominent software packages in the field of GIS.

QGIS is open-source software that offers a free solution designed for various platforms. With more than 20

years of experience and a growing worldwide adoption due to its free, open-source format and ease of learning, it is a trusted choice.

ESRI developed ArcGIS Pro, a market-leading desktop software recognized for its ability to create and work with geospatial data in multiple formats. ESRI also offers ArcGIS Online, a powerful cloud-based tool for creating and sharing interactive web maps. ESRI's educational training structure has helped to consolidate its position as a leader in the geospatial world.

In the framework of this work, we chose to use ArcGIS Pro and ArcGIS Online software, taking advantage of the educational license held by the Autonomous University of Santo Domingo (UASD), to which we proudly belong as part of its faculty. This choice is based on the robustness and constant development of these programs, thus supporting the quality and accuracy of our Geographic Information System for the urban area of San José de Ocoa.

Layers that integrate the GIS created

- A satellite orthoimage of the polygon that covers the urban area of the municipality of San José de Ocoa in 2013 with a resampled GSD of 0,50 m was obtained from the company DigitalGlobe: Satellite GeoEye-1, optical sensor, multispectral and panchromatic, panchromatic resolution 0,41 m, multispectral resolution 1,65 m. This image comes from a composition of RGB bands that represent the actual color and was used by Eng. Pedro E. Sosa Veras for elaborating the Urban Development Plan of the Municipality of San Jose de Ocoa in 2015.
- Georeferenced orthophoto resulting from the photogrammetric flight we carried out for the present research work in September 2023 with a GSD of 0,05 m.
- Digital terrain and surface model, obtained from processing the images of the photogrammetric flight detailed in the previous point with a GSD of 0,30 m.
- Shapefile of construction polygons vectorized on the Orthoimage 2023.
- Shapefile of street axes, gullies, and the Ocoa River obtained from the 2023 Orthoimage.
- A shapefile of historical and positional georeferenced cadastral parcels is available in the Virtual Office of the Real Estate Registry as of July 2023.
- The plans in .PDF and AutoCAD format, derived from the Urban Development Plan of San José de Ocoa in 2015, have been refined and improved for more efficient integration into the Geographic Information System (GIS) database. It is essential to note that a georeferencing process was necessary to incorporate these plans into the GIS database. This specific task was carried out using the Global Mapper software and the satellite image originally used to vectorize the plans of the Urban Development Plan. The georeferenced plan obtained was exported in shapefile format to efficiently integrate it as a layer within the Geographic Information System of the urban area of the municipality of San José de Ocoa. This action facilitates the direct comparison between two points in time, specifically the plans corresponding to 2015 and 2023.

The operations described above aim to carry out a detailed visual analysis of the changes experienced in the urban area of the municipality under study over time. By integrating these two maps into the geographic information system, a solid basis is established to evaluate and contrast the urban elements, infrastructures, and any other transformations that have taken place between 2015 and 2023.

This comparative approach will effectively identify urban patterns, evolutions, and trends, thus providing valuable information for urban planning decision-making and sustainable development in San José de Ocoa.

Shapefile of provinces and municipalities of the Dominican Republic. The origin of this layer is the National Statistics Office (ONE).

The generation of contour lines is to be integrated into the cartographic map of the urban area of the Municipality of San José de Ocoa

From the Digital Terrain Model (DTM) obtained by processing the photographic images, we used the geoprocessing tools of the ArcGIS Pro software to generate the contour lines that will be integrated into the cartographic map of the urban area of San José de Ocoa.

The choice of the equidistance between curves, set at 2 meters, is based on the peculiar topography of the town center, which extends along the mountain slopes and is crossed by four streams. It is also on the banks of the Ocoa River.

It is important to highlight that the choice of equidistance in this context is directly related to the final scale of the cartographic map that we are developing in the framework of this study, which will be 1:5000. The decision of this scale is based on the consultation of the municipal cartographic maps produced by the National Geographic Institute José Hungría Morel (IGN). However, thanks to the exceptional quality of the Orthoimage we have generated, with a remarkable resolution (GSD) of 0,05 meters, we can produce maps at even more

detailed scales.

This higher resolution guarantees optimal detail and clarity in the final representation. It also enables the generation of smaller-scale plans, consolidating valuable geospatial information. These plans are essential for various purposes, from urban planning to detailed geographic analysis of the metropolitan area of San José de Ocoa. In this sense, our ability to generate maps at more minor scales adds precision that significantly enriches the usefulness of geographic information for various applications.

Generation of the Table of Attributes for the Layer of Buildings and their Uses in the Urban Area of the Municipality of San José de Ocoa

As an integral part of the Geographic Information System (GIS) that is the subject of this study, after defining the layer that covers all the buildings and constructions in the urban area of the municipality of San José de Ocoa, we proceeded to create an exhaustive table of attributes.

We focused our attention on detailing the specific use of each of the polygons, which are classified into various categories, such as:

Table 1. Attributes of the polygons by categories of the layer buildings and constructions of the urban area

Commercials	Commercial premises and establishments.
Sports	Areas used for sporting activities.
Educational	Educational institutions and training centres.
Medical Facilities	Facilities related to health services.
Residential	Residences and housing.
Institutional	Spaces for public and private entities.
Religious	Places of worship and religious activities.

Additionally, we provide detailed information on the number of levels of each building, adding a vertical dimension that enriches the three-dimensional representation of the urban environment. We also include significant names of governmental and municipal institutions that contribute to identifying and contextualizing geospatial information.

This table of attributes constitutes an essential component of the Geographic Information System, strengthening the study's capacity to comprehensively analyze and manage the diversity of uses in the urban fabric of San José de Ocoa.

Information Gathering and Digitalisation in the Creation of the Geographic Information System of the Urban Centre

In the process of compiling the aforementioned data, we printed maps of the urban area at a detailed scale of 1:1000. Accompanied by duly trained auxiliary personnel, we meticulously explored every corner of the central polygon selected for the creation of the Geographic Information System (GIS) of the municipality's urban center as an integral part of the present study.

The observations and data collected in the field were subjected to digitization. This step is essential to feed the attribute table that forms the backbone of the GIS. It should be noted that ArcGIS Pro software provides advanced digital tools to facilitate the automated capture of field data. This technology streamlines the process and improves the accuracy and quality of the information incorporated into the GIS.

Importantly, the ArcGIS Pro digital tools were valuable not only in the GIS creation stage but also provided an effective solution for the ongoing maintenance and updating of the system. This automated capability ensures the currency and accuracy of the GIS generated by our team, consolidating its usefulness over time.

Products Resulting from Current Research

- Geographic Information System (GIS) of the urban area of the municipality: the development of this GIS represents a valuable tool for planning and managing the territory of the urban planning office of San José de Ocoa. Our team is available to install the system and train staff in its use and maintenance. This GIS provides a comprehensive and detailed view of the urban environment, facilitating informed and strategic decision-making at the municipal level.
- Computer application (APP) of the municipal cartography of the urban area of the municipality of San José de Ocoa. Accessible through the link: https://experience.arcgis.com/experience/95eb46522bea4943a895054fe3886cbd.
- Municipal Cartographic Map of the urban area of San José de Ocoa at Scale 1:5000 in PDF Print

Format: we present the link to enter the Municipal Cartographic Map of the urban area of San José de Ocoa, elaborated with a detailed scale of 1:5000. Available in PDF format at the following link: https://drive.google.com/file/d/1lUUg0EWpVj1lx49aL_nBBF9ogOcN4nfb/view?usp=drive_link.

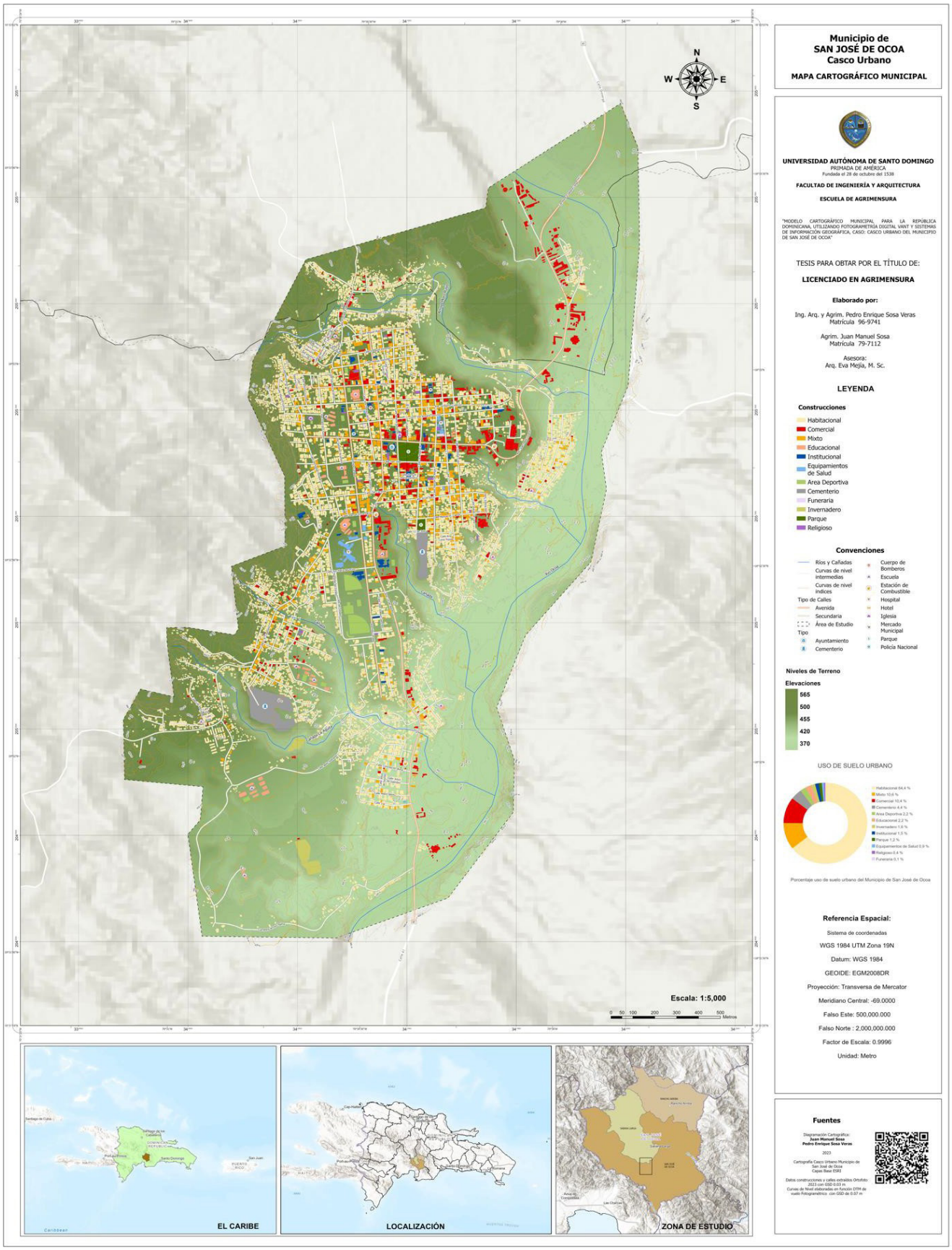

Figure 1. Municipal Cartographic Map of the urban area of San José de Ocoa

This interactive app is presented as an extraordinary tool that allows users to perform searches, queries, and geospatial analyses of the urban area of San José de Ocoa. Available on computers, tablets, or mobile devices through the web, it offers various functionalities, such as:

- Measurement of distances and surfaces.
- Visual comparison of the changes experienced in the urban area between 2015 and 2023.
- Printing of personalized maps.
- Activation or deactivation of map layers for personalized visualization.
- Change the base map to match the user's needs.
- Display of map legends for a detailed understanding.

These tools represent the fruits of current research and offer significant resources for measurement science professionals, the community, municipal authorities, and anyone interested in exploring and understanding the geospatial dynamics of San José de Ocoa's urban area.

This map provides an accurate and detailed cartographic representation of the urban environment, highlighting significant elements and offering a clear view of the urban fabric. The 1:5000 scale provides an optimal balance between detailed information and geographic coverage, making it a valuable tool for various purposes, from urban analysis to local project planning. This resource is available for download and consultation, facilitating access to key geospatial information for residents, researchers, and urban planners interested in the development and management of the metropolitan area of San José de Ocoa.

Images of the Different Products of the GIS Interactive APP

We implemented a comprehensive GIS for the urban area of San José de Ocoa using ArcGIS Pro and Digital Photogrammetry with UAV (Unmanned Aerial Vehicles), with the supervision of the teacher Eva Mejía. This GIS includes layers such as orthoimages, digital terrain models, shapefiles of buildings, street and river axes, and cadastral information currently available in the archives of the Real Estate Jurisdiction.

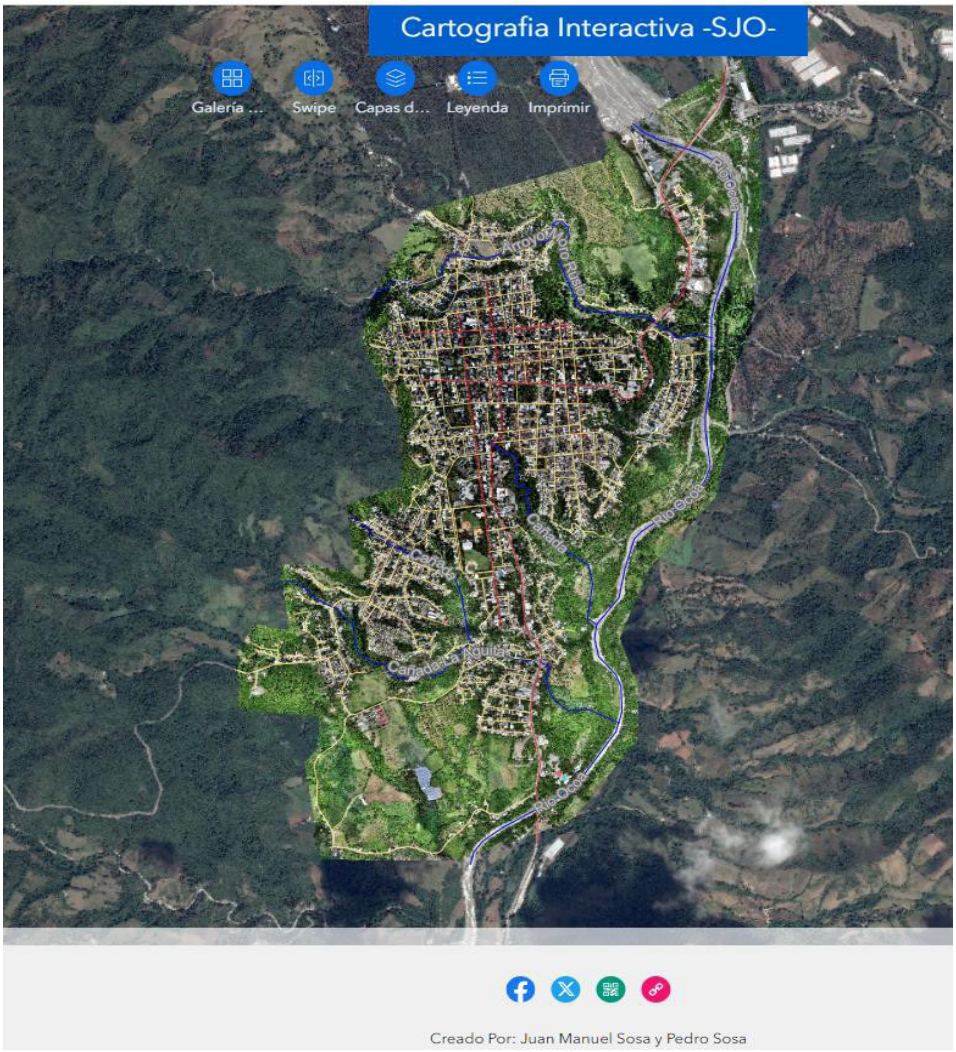

Figure 2. APP screenshot showing the Interactive Cartography San José de Ocoa

Regarding Contour Line Generation

The generation of contour lines with an equidistance of 2 metres, based on the Digital Terrain Model, enriches the cartographic map, adapting it to the local topography. In addition, we create a detailed attribute table for the buildings, classifying them by specific uses.

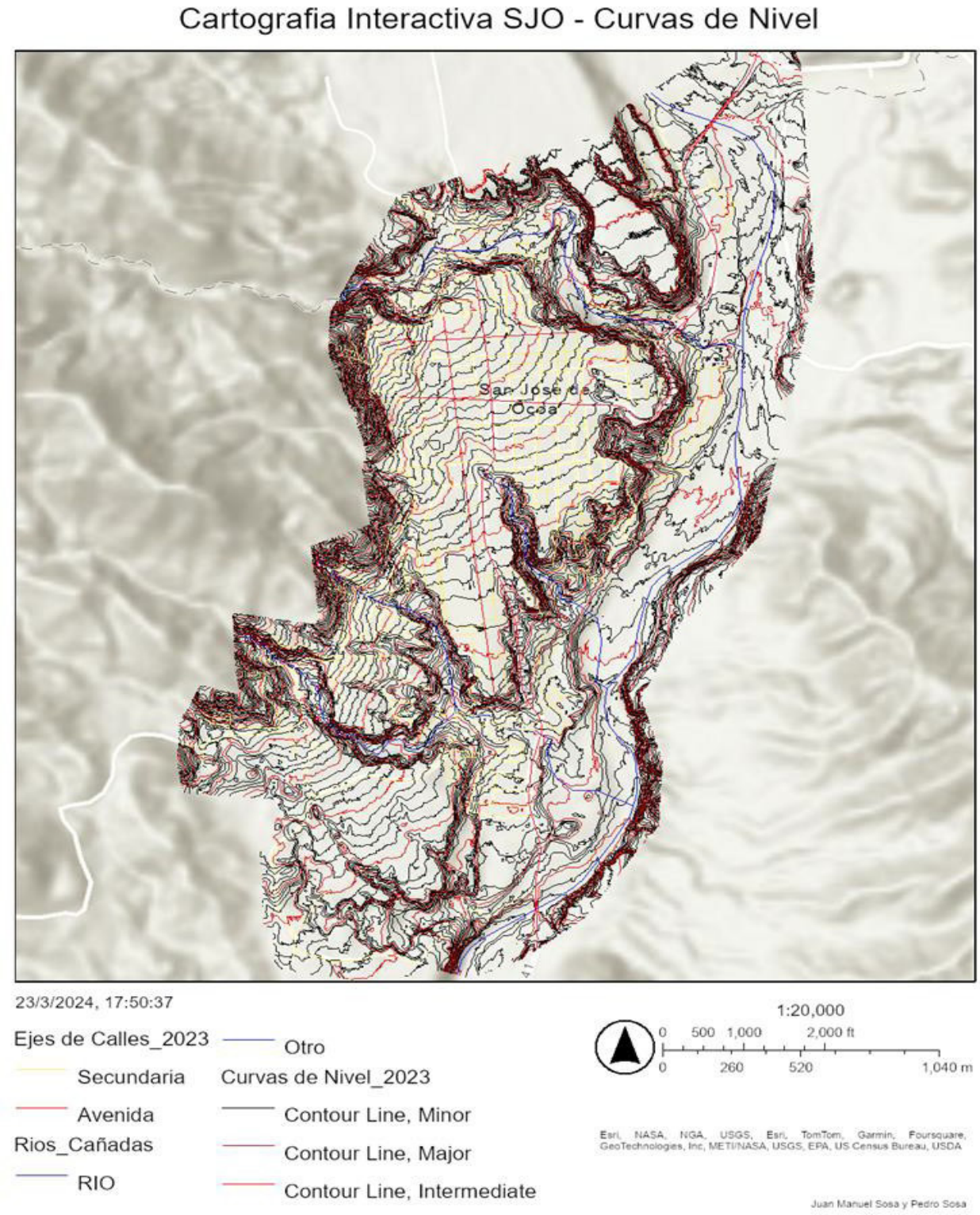

Figure 3. Printout from the APP of the contour map of the urban area of San José de Ocoa

About Layers

The survey of information on the ground, followed by digitization, feeds the attribute table and ensures the validity of the GIS. The layers that make up the GIS include orthoimages, digital terrain models, shapefiles of buildings, street and river axes, and georeferenced plans obtained by Digital Photogrammetry with UAV.

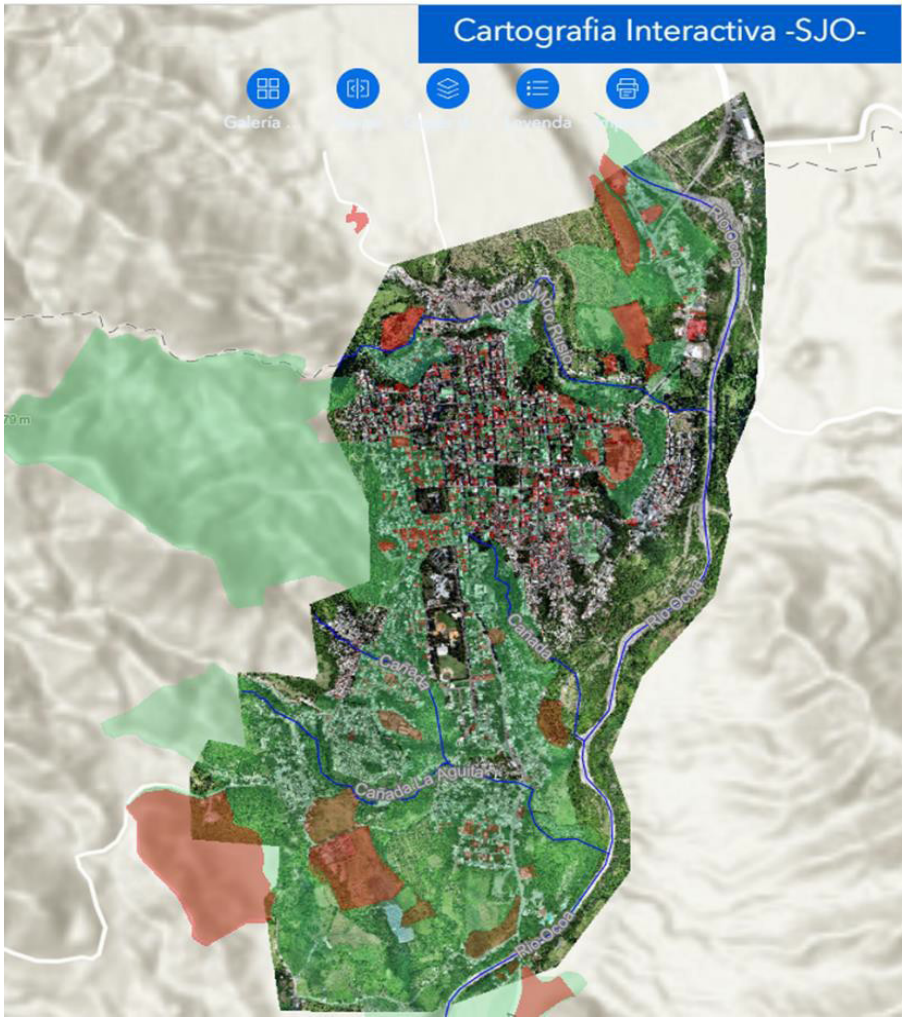

Figure 4. PPP display of historical and positional plots

Concerning Orthophoto and Urban Environment

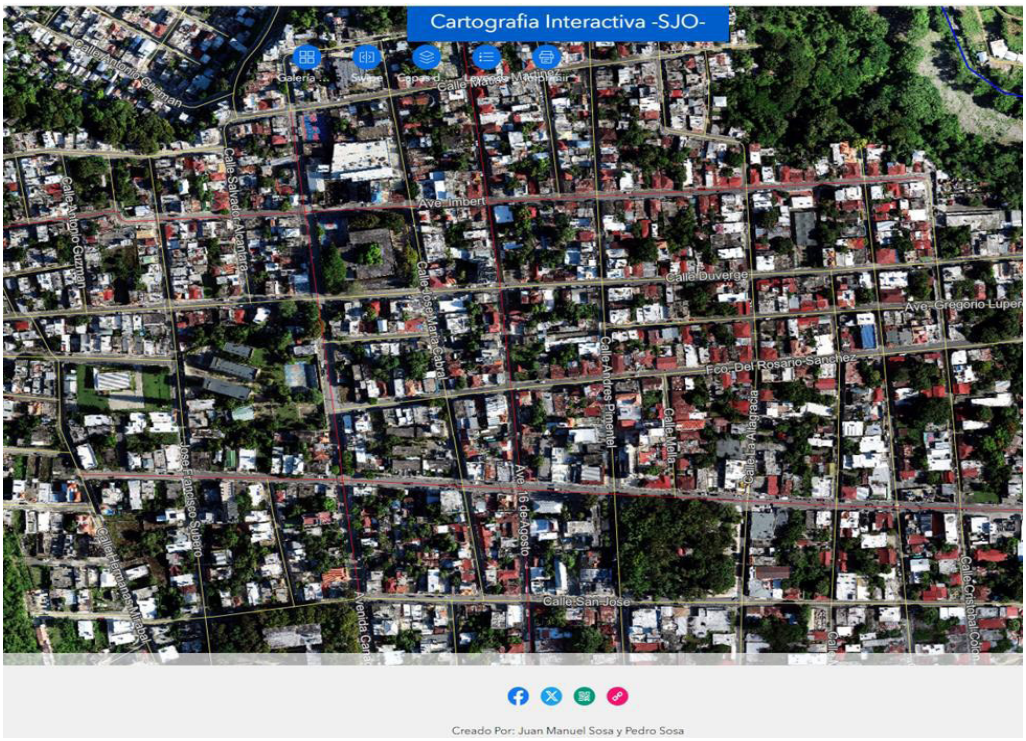

Figure 5. Visualisation in the APP of streets and Orthophoto of the urban area of San José de Ocoa

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The products resulting from this project include a GIS, a Geographic Information System (GIS) application for mobile devices (APP), and a printed map at a scale of 1:5000. These resources are essential tools for planning and decision-making at the municipal level, providing a detailed and up-to-date view of San José de Ocoa's urban environment.

In Relation to Buildings and Watercourses

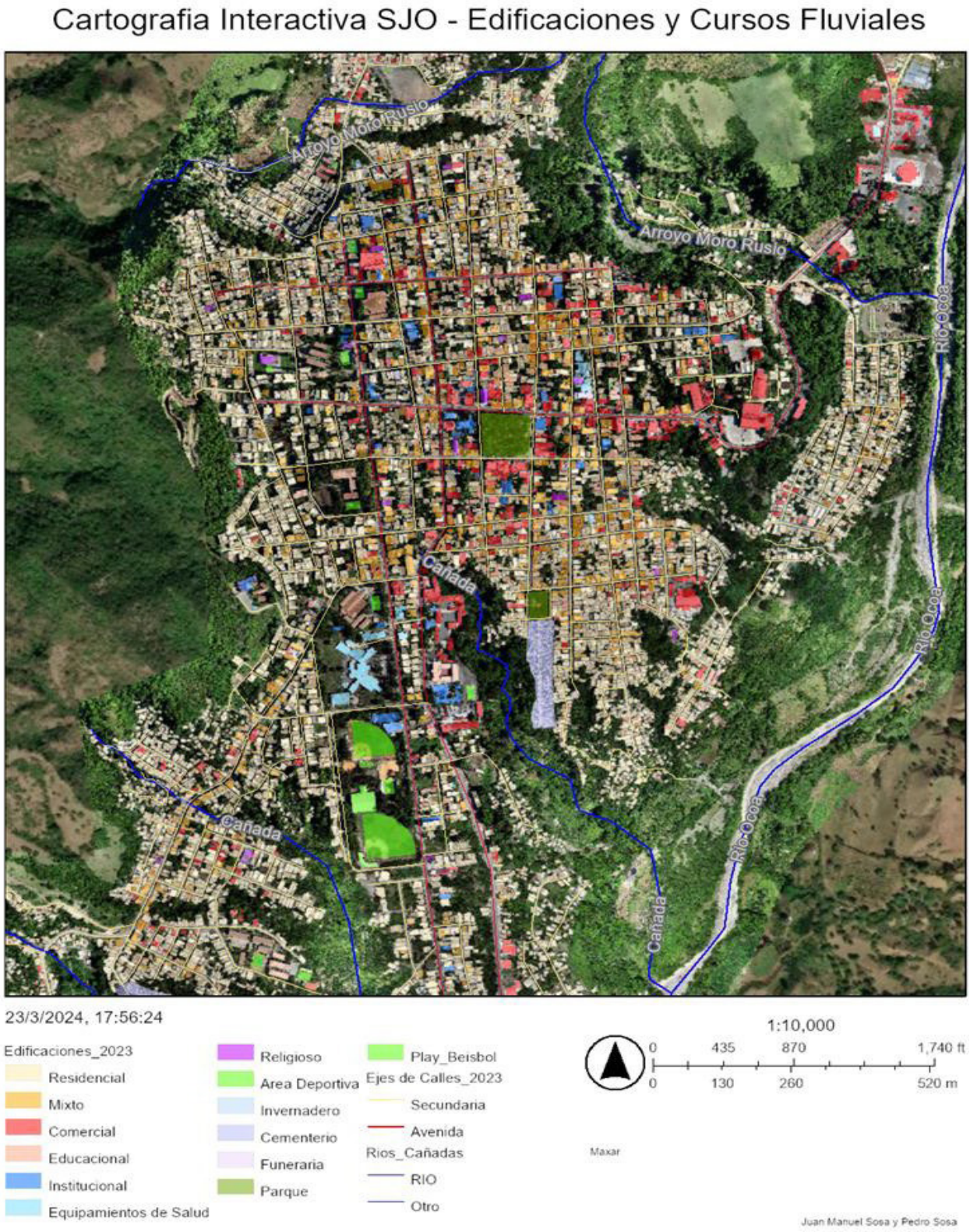

Figure 6. Printout of map of buildings and watercourses from the interactive PPP

Regarding the Use of the Swipe Tool

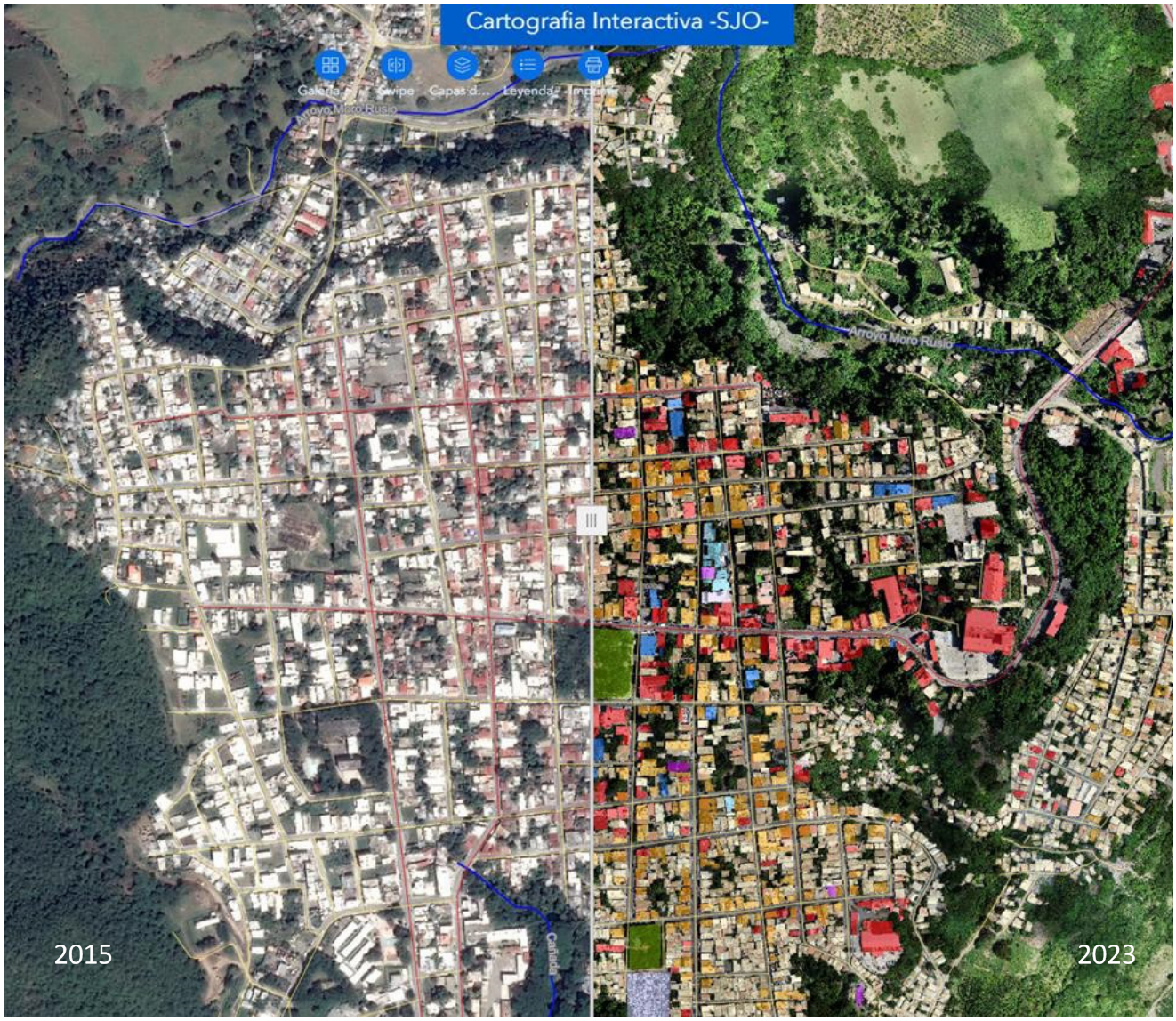

Figure 7. Swipe tool, hover over the 2015 and 2023 mapping to make comparisons

Verification of the cartography

Verify the cartography through personnel who traveled around the municipality throughout the mapped area, provided with the plans, and validated and/or updated the cartography's vectorized information generated with the UAV survey information.

Table 2. Comparative intended land uses 2015-2023

Land uses for	Year 2015 (m^2)	Year 2023 (m^2)	Percentage increase
Sports area	18 353	18 989	3,47
Cemetery	31 802	37 361	17,48
Commercial and Mixed	115 842	177 544	53,26
Educational	3956	18 869	376,97
Health facilities	4632	7529	62,54
Housing	361 733	544 433	50,51
Institutional	9307	12 252	31,64
Religious	3015	3716	23,25

The mapping of the municipality of San José de Ocoa has undergone significant changes in terms of the expansion of the urban area from 2015 to 2023.

When analyzing the evolution of the urban area of the municipality of San José de Ocoa from 2015 to December 2023, we can observe an expansion generated by the increase in the built-up area of the types of land use; the evidence can be seen in the cartographic map, while the quantification of the phenomenon is shown in the comparative table of land use (table 2), for the years 2015 versus 2023.

The corroboration of these results supports the hypothesis's initial premise, confirming that there have indeed been changes in the expansion of the urban area in the municipality of San José de Ocoa during the period studied. This confirmation provides solidity to the hypothesis, ratifying its validity.

For a more detailed understanding and visualization of these changes, it is recommended that you explore the PPP created by this research, available at https://experience.arcgis.com/experience/95eb46522bea4943a895054fe3886cbd.

The construction of buildings in risk areas near the ravines shows the evolution of this phenomenon. It increased in 2023 compared to 2015 when it was registered in the Urban Development Plan of San José de Ocoa.

According to the 2015 San José de Ocoa Urban Development Plan records, the construction occupation in the 30-meter risk zone measured from the center of the ravines (as established by Law 64-00) was 22 530 square meters. By December 2023, when the fieldwork for this research was completed, this area had increased to 55 242,85 square meters, representing a total increase of 32 712,85 square meters and a percentage value of 245,20 %. Table 3 below analyses the behavior of the two most relevant uses in the referred occupation by Destined Land Uses.

Table 3. Comparative land uses 2015-2023

Land uses for	Year 2015 (m^2)	Year 2023 (m^2)	Percentage increase
Commercial	4796	6000	25,10
Residential	17 601	43 790	248,79

These data support the validity of the hypothesis, demonstrating that occupation in the ravines' risk zone has grown over the last eight years.

The evidence provided by the results of the comparison of the occupied areas supports the hypothesis's assumption, confirming its veracity.

The use of digital photogrammetry technologies with unmanned aerial vehicles (UAV) and geographic information systems (GIS) in the design of a municipal cartographic mosaic will allow the local government to obtain accurate, updated, and higher-quality information, thus improving its decision-making in developing its urban plans and managing the territory of San José de Ocoa.

With the tools and information such as high-resolution orthoimages, digital elevation models, satellite images, geospatial databases, global positioning technologies (GPS), and cadastral parcel data, which we developed in this research work and the geographic information system that we jointly designed, the local government will be able to increase its response capacity, which in turn will enhance decision-making in planning, civil defense against disasters, natural risk assessment, natural resource management and land use planning, which are crucial elements for the sustainable development of the region.

These resources are fundamental to creating and feeding a Geographic Information System (GIS) that has been developed in conjunction with the Cartographic Map as the overall objective of this thesis. The GIS is a comprehensive platform that enables geospatial data collection, storage, analysis, and visualization, facilitating informed decision-making in various areas. By making this GIS available to the local government of San José de Ocoa and previously training the personnel in charge of its use, a valuable tool has been provided to address specific challenges in territorial management. The ability to visualize geographic information in a digital environment allows for more efficient and strategic decision-making.

In the development of this research, it has become evident that the hypothesis's assumption was correct. Implementing and using GIS has yielded positive and tangible results, satisfactorily demonstrating its effectiveness in territorial planning, natural disaster response, and resource management. These findings support the relevance and usefulness of the proposed approach, highlighting the importance of geospatial technology as a key component in local development and decision-making.

Since 2015, the growth of the road network and the preservation of roads in terms of their physical state of consolidation, deterioration, and/or intervention have undergone changes.

A comparative analysis for the years 2015-2023 shows an increase in the entire road network, including consolidated, intervened, and non-intervened roads. We quantify this phenomenon below.

Table 4. Comparative land use growth on roads 2015-2023	
Total track length in 2015	52 775
Total track length in 2023	56 991,46
Total increase over the period	4 215,74
Percentage change	8 %

This supports the fact that the road network has experienced measurable growth, including the evolution of its state of consolidation.

CONCLUSIONS

The implementation and use of the GIS have yielded positive and tangible results. The methodology developed is not limited to San José de Ocoa but is replicable nationally. The combination of digital photogrammetry using UAVs and GIS can be applied in all municipalities of the Dominican Republic.

The methodology creates maps and allows for continuous updating of municipal cartographic bases. Its replicability promotes resource optimization, distributing the initial investment in technologies among multiple municipalities and allowing for more effective management of government resources. This work has laid the groundwork for a robust and replicable methodology that can be implemented throughout the country, resulting in a comprehensive tool for the development and territorial management of each municipality in the Dominican Republic.

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CONFLICT OF INTEREST

Authors declare that there is no conflict of interest.

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