

Geospatial information based on UAV for socio-environmental problems in an urban river

Andrea Nathaly Escobedo Tamez, Fabiola D. Yépez-Rincón *, Yadira Zulema Antonio Durán, Mariana Pérez Martínez, Milena Mesa Lavista, David Clemente López Perez and Carlos J. Ábrego Góngora

Faculty of Civil Engineering, Universidad Autónoma de Nuevo León, San Nicolás de los Garza, Nuevo León, México

Keywords: UAV, point cloud, river, socio-environmental problems.

ABSTRACT:

This study addresses socio-environmental issues affecting the Pesquería River in the Metropolitan Area of Monterrey (MAM), Nuevo León, Mexico, through the integration of unmanned aerial vehicles (UAVs), photogrammetric analysis, and community participation. The river faces critical challenges such as clandestine dumping, illegal wastewater discharges, irregular settlements, and solid waste accumulation, conditions exacerbated by rapid urbanization and weak environmental enforcement. High-resolution RGB and LiDAR imagery was acquired using UAVs, enabling the generation of orthophotos and dense point clouds through Structure from Motion (SfM) techniques. Ground control points (GCPs) ensured spatial accuracy. The methodological approach included citizen engagement through workshops and real-time surveys, which allowed residents to identify and validate environmental problems directly from UAV imagery. This participatory model strengthened community involvement in environmental monitoring. The findings highlight the effectiveness of combining geospatial technologies with local knowledge to document, analyze, and address urban river degradation. This study contributes to a replicable, low-cost framework for socio-environmental diagnostics in complex urban contexts.

1. Introduction

1.1 Monitoring socio-environmental problems in an urban river

Urban rivers are increasingly impacted by unregulated city growth. Flood risks, illegal discharges, and the accumulation of solid waste threaten not only these ecosystems but also the health and safety of surrounding communities. In the Metropolitan Area of Monterrey (MAM), the Pesquería River exemplifies this situation, facing severe socio-environmental challenges that demand urgent and innovative solutions.

The Pesquería River is currently considered the most affected river in the region due to rapid, poorly planned urban expansion (CONAGUA, 2023). As the main watercourse in a sub-basin that supports over 50% of Nuevo León's population, it suffers from poor water management, land-use transformation, and climate-related phenomena such as drought, which have led to prolonged dry periods and disrupted ecological flows (Vega *et al.*, 2024). These changes have significantly altered its hydrology and compromised its ecological services (Torres *et al.*, 2018).

Recognizing its high biodiversity and environmental deterioration, national agencies such as CONABIO and CONAGUA have classified the Pesquería River as a hydrological region of priority intervention. Addressing the degradation of this urban riparian corridor, essential for ecological connectivity between the city and surrounding mountain systems (Castro-López *et al.*, 2019), requires robust tools for monitoring, documentation, and public engagement.

Identifying and monitoring the river's socio-environmental problems pose methodological challenges due to their spatial complexity and the limited accessibility of certain zones. The integration of remote sensing technologies, particularly unmanned aerial vehicles (UAVs), offers a powerful alternative for data collection in urban watersheds (Mohsan *et al.*, 2023). UAVs provide high-resolution imagery, allow access to otherwise unreachable areas, and enable the systematic observation of environmental degradation.

Moreover, involving the local population in problem detection helps link scientific evidence with community experience. Public participation contributes not only to the validation of UAV-derived data but also fosters a shared sense of responsibility and agency in environmental stewardship.

This study aims to identify, document, and spatially analyze the socio-environmental problems of the Pesquería River using UAV imagery, photogrammetric products, and citizen participation. The main contributions of this research include:

- A georeferenced inventory of socio-environmental problems affecting the river corridor through UAV-based image analysis and photogrammetry
- Active community participation through surveys and collaborative image interpretation.
- A replicable methodological framework combining geospatial technology and citizen science for urban river management.

1.2 Background and study site

The Pesquería River is located in northeastern Mexico (within the San Juan River basin, between coordinates 26°38'24"–25°26'24" N latitude and 100°54'00"–98°56'24" W longitude) (Fig. 1). It lies to the north of the Monterrey Metropolitan Area, and its main channel flows through five municipalities: García, Monterrey, General Escobedo, Pesquería, and Apodaca, in the state of Nuevo León (Prat *et al.*, 2019).

The Pesquería river has an average slope of 0.4%, a total length of 288.22 km, and a catchment area of 5,255.56 km², with an annual mean flow of 2.04 m³/s (Ferriño *et al.*, 2016).



Fig. 1. Pesquería River location. (A) Location of the Pesquería River and its neighboring municipalities. (B) Location of the Pesquería River within the state of Nuevo León, northeastern Mexico.

2. Methodology

2.1 Data collection

The analysis of socio-environmental issues was carried out at different scales and with different tools, complemented by the validation of citizen participation. The fieldwork consisted of collecting information for the recognition and characterization of socio-environmental problems.

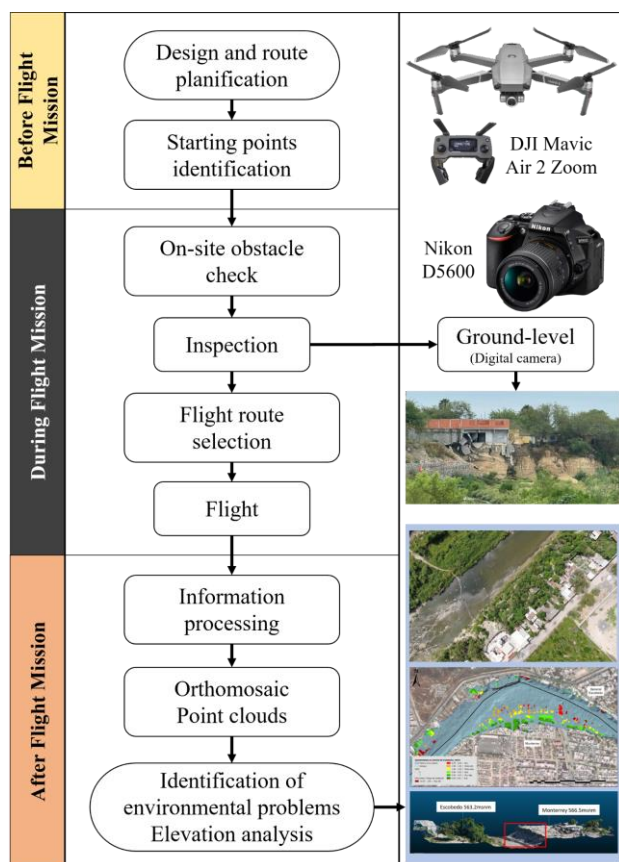


Fig 2. Workflow.

A DJI Mavic Air 2 Zoom multirotor UAV equipped with a 48 MP RGB camera was deployed in the river study area.

The data from UAVs were taken considering 2 types of photos: 1) the videos or photos that were to demonstrate the problem, and that don't really need to have a strict planification and 2) the photos that are serial, and require a software to prepare and make the flight mission. Depending on these needs the flights were selected and the data was collected. The ground view presents georeferenced photographic evidence of the problems seen directly in the field.

Type 1) photographs were taken at different flight altitudes to observe and acquire more detailed images along the river. During these flights, points of interest that were crucial for understanding the socio-environmental issues were detected.

The flight mission for the type 2) photographs was planned in the DroneDeploy software, setting an altitude ___ m and 75% image overlap, yielding higher-resolution orthophotos and point clouds for later analysis.

Additionally, fieldwork included capturing ground-level photographs with a Nikon D5600 digital camera, which were used for detailed site inspection.

2.2 Data Processing

RGB imagery acquired during the UAV mission was processed in Agisoft software using Structure from Motion (SfM) techniques to generate a dense point cloud and orthophotos. Ground control points (GCPs), established through traditional topographic surveys, were used to georeference and validate the UAV-derived outputs.

2.3 Elevation Analysis by Point Clouds

From the point clouds generated by the photogrammetry process, sections of the river with various issues were identified using CloudCompare software. In these areas, the point clouds were sectioned into profiles to obtain the elevations of the riverbanks and existing infrastructure -such as housing, bridges, and avenues- as well as to determine the dimensions of solid waste accumulations on the riverbed, using the volume 2.5D tool (Figure 3).

2.4 Participatory social workshops

Social workshops were conducted to promote the active inclusion of community members, technical experts, government representatives, and civil society leaders in the assessment of socio-environmental issues along the Pesquería River. A total of 36 citizens participated across three workshops held in different municipalities: 9 participants in Monterrey, 17 in General Escobedo, and 10 in Apodaca.

During the sessions, participants analyzed aerial and ground-level images from various sections of the river, with a focus on the boundary between Monterrey and General Escobedo. Using the Mentimeter platform, they marked specific locations on the images where they identified socio-environmental problems.

These inputs contributed directly to the final georeferenced inventory of issues.

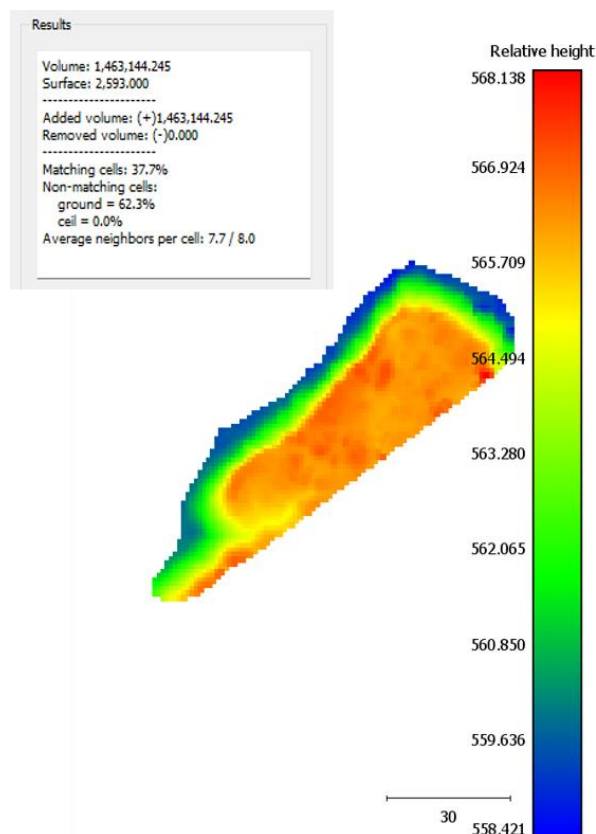


Fig 3. Example of calculating the volume and surface area of a solid waste accumulation using the 2.5D volume tool of CloudCompare.

All three workshops used the same set of UAV and ground-level images. To ensure unbiased interpretation, participants in each municipality viewed the images without any pre-marked points or prior results from other communities.

2.5 Socio-environmental problems classification

To ensure consistency and accuracy in the identification of socio-environmental problems from UAV orthomosaics and aerial imagery, a visual interpretation key was developed. This key guided the manual classification process in QGIS and was based on observable elements such as tone, texture, shape, pattern, and spatial association.

Each orthomosaic generated was visually interpreted to identify zones exhibiting evidence of environmental issues. A point was generated for each zone with any problem. The classification scheme included the following main categories: solid waste accumulation, illegal wastewater discharges, irregular settlements and construction debris (Table 1). Interpretation was performed by trained analysts using QGIS for the visualization and digitization of localization points.

Table 1. Visual interpretation key for socio-environmental problems in the Pesquería River.

Class	Visual indicators	Interpretation elements used
Solid waste	Scattered debris (plastics, tires, furniture), often in clusters along riverbanks or within Pesquería river.	Shape (irregular), texture (coarse), pattern (irregular), association with water.
Wastewater	Dark stains or discoloration in water; pipes or tubes connected to the river; foam or turbidity in the water.	Tone (gray or black), shape (linear), pattern (along walls or riverbanks), and association with water bodies or areas near houses or industrial zones.
Irregular settlements	Informal structures without clear layout, often within the floodplain or very close to the river.	Shape (non-rectilinear), pattern (disordered), association with water.
Construction debris	Rubble piles, bricks, concrete remains, near roads or infrastructure.	Texture (rough), pattern (isolated clusters), shape (angular), and association with urbanized zones.

Additional socio-environmental problems that were not easily identifiable through UAV imagery interpretation, such as site abandonment, animal breeding, decline in fauna, lack of environmental education, infrastructure deficiencies, flooding, disease vectors, industrial waste discharges and other pollutants, were incorporated and georeferenced through ground-level observations and citizen participation gathered during participatory workshops to the geodatabase. The resulting geospatial geodatabase included attributes such as the problem category, geographic coordinates, and associated municipality.

3. Results

3.1 Obtained orthomosaics and point clouds

The surveyed section of the river covers an area of 479 ha, divided into 14 sections of between 30 to 50 ha. Each of the 14 serial photography flights was processed to generate an orthophoto and a point cloud (Figure 4).

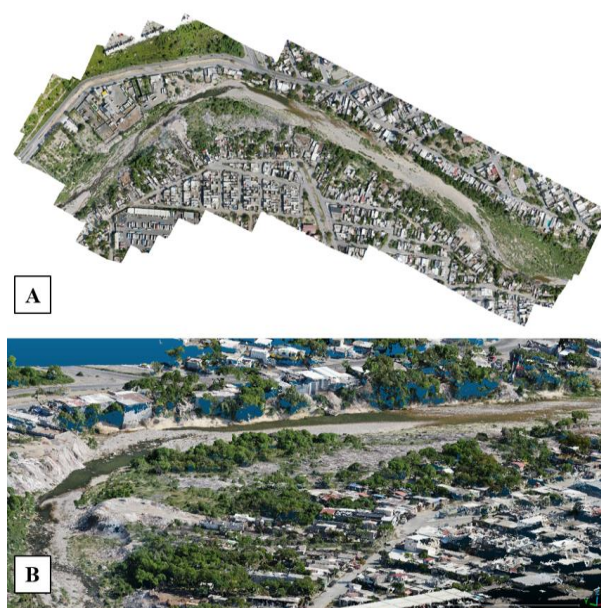


Fig. 4. Products obtained from UAV surveys, A) orthophotos and B) point clouds.

3.2 Point cloud analysis

From the point clouds generated from UAV images, the river sections with the most problems were identified, one of them being the one that divides the municipalities of Monterrey and Escobedo. The point clouds were sectioned into profiles in these problematic areas, in order to obtain the elevation differences of the river shoulders and existing infrastructure, such as houses and avenues (Fig 5).

Within the same sections, five zones of solid waste accumulation were identified, and their respective heights, surface areas, and estimated volumes were calculated. (Fig. 6 and Table 2).

The largest accumulation has a height of 8.5 m, a surface area of 2,874 m² and an estimated volume of 1,627,142.78 m³.

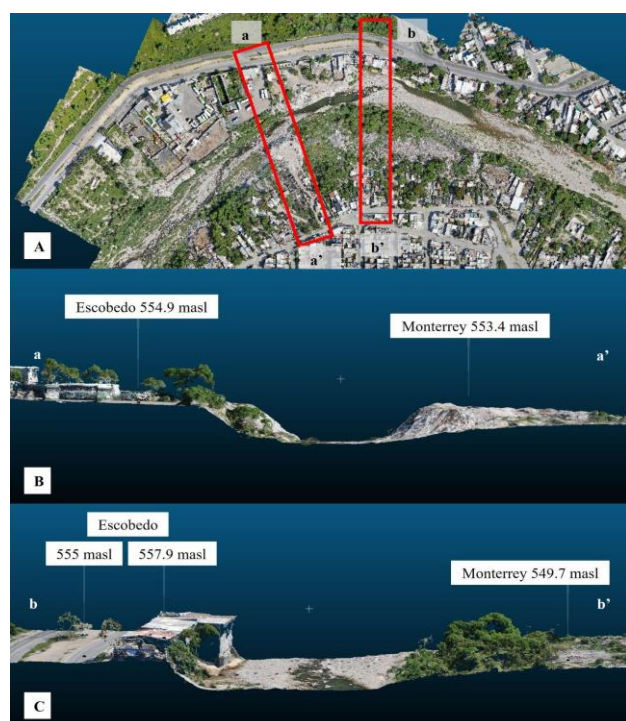


Fig. 5. A) Top view of the evaluated profiles a-a' and b-b'. Elevation differences in profiles B) a-a') and C) b-b'.



Fig. 6. Accumulations of solid waste on the river, showing A) Heights and elevations, and B) Surface area of the waste.

Table 2. Dimensions of solid waste accumulations.

Number of solid waste accumulation	Height (m)	Surface área (m ²)	Estimated volumen (m ³)
1	6.3	1,281.00	717,878.51
2	6.2	384.00	214,619.09
3	8.6	2,794.00	1,571,985.95
4	7.5	2,593.00	1,463,144.24
5	8.5	2,874.00	1,627,142.78

3.3 Social perception of the Pesquería River

This section presents the socio-environmental problems identified by local communities in workshops. The workshops were held with residents from municipalities along the course of the river, who share similar socio-environmental concerns. The participating municipalities included Monterrey, General Escobedo, and Apodaca.

Participants of Monterrey identified the following sources: (1) Illegal dumping sites, (2) Irregular settlements and (3) Illegal discharge of wastewater. The Monterrey's community pointed to urban development as a major cause of environmental degradation affecting the river and its ecosystems.

In General Escobedo participants described the river as very polluted, using terms such as contaminated, abandoned, dirty, and neglected, but also highlighted its value by calling it alive and important. The local community of General Escobedo expressed that current efforts to protect the river are insufficient. The main contributing factors to pollution, as identified by workshop participants, were: (1) Illegal dumping sites, (2) Irregular settlements and (3) construction debris. Additional issues mentioned included illegal wastewater discharge, livestock farms, and intermittent river flow.

In Apodaca, responses reflected a consistent perception: the water quality of the river is very poor, and pollution levels are very high. The river was described as a contaminated, unhealthy, dirty, and forgotten area, with visible signs of residues, vegetation, and biodiversity. Workshop participants in Apodaca agreed that not enough measures are being taken to preserve the river. They pointed to the following main causes of pollution: (1) Illegal dumping sites, (2) Illegal discharge of wastewater and (3) Irregular settlements. Other concerns in the Apodaca community included construction debris, inconsistent water flow, and animal farming activities.

These perceptions, gathered directly from community members during the workshops, demonstrate a shared concern across municipalities (Table 3).

Table 3. Perceived main sources of pollution in the Pesquería River obtained from the community workshops.

Source of Pollution	Monterrey	General Escobedo	Apodaca
Illegal dumping sites	✓	✓	✓
Irregular settlements	✓	✓	✓
Illegal wastewater discharge	✓	✓	✓
Construction debris	-	✓	✓
Animal farming	-	✓	✓
Irregular/intermittent flow	-	✓	✓

The figure 7 presents a visual synthesis of socio-environmental problems identified by the communities during the workshops. Each panel illustrates the participants' observations on specific points along the Pesquería River, providing insight into the lived experience of environmental degradation in the area. Panels A and B show that all three municipalities identified contaminated water, illegal garbage dumps, and human settlements near the riverbed. In panel C, contaminated water, illegal waste disposal, and discarded car tires were identified. Panel D highlights a destroyed house on the riverbank, as well as neglected gabions along the river's edge. In panel E, a large amount of waste dumped in the riverbed is visible, forming clandestine dumping grounds. Panel F shows a tire dump, irregular housing, and waste burning, which also contributes to air pollution.

3.4 Inventory of socio-environmental problems in the Pesquería River

This section outlines the environmental issues identified and georeferenced through field surveys, drone-based aerial photography, and the participatory observations collected during community workshops.

Among the main identified socio-environmental problems identified with ground level imagery are the accumulation of solid waste, such as plastics, cardboard, tires and abandoned furniture, in the riverbed, as well as in green areas and public

spaces, leading to water pollution, soil degradation, and visual deterioration in urban zones (Fig. 8).

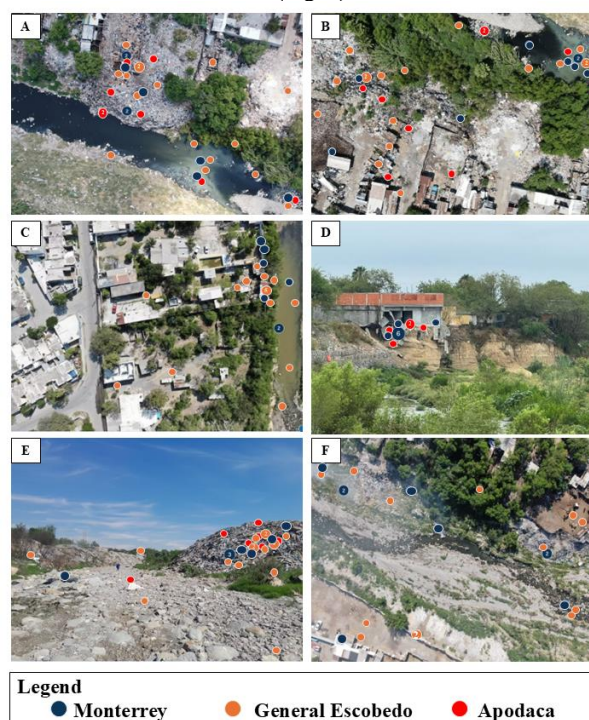


Fig. 7. Aerial and ground-level images of the Pesquería River. The points indicate the location of the socio-environmental problems identified by the communities of each municipality (Monterrey, General Escobedo, and Apodaca). Figure description provided in the text.



Fig. 8. Different problems were recorded with ground-level photos. A) This photograph shows a concrete channel used for river drainage, the wall of which is covered in graffiti, reflecting a possible lack of maintenance and surveillance in the area. Photograph taken from a bridge. B) In this ground-level image, accumulated waste is observed on the riverbed; this accumulation was analyzed using a point cloud. C) On the banks of the Pesquería River, it is common to identify homes that are located within the floodplain; these are usually irregular homes that are not legally registered. Photograph taken from a bridge. D) In this image, accumulations of solid waste are observed on the riverbed; this scene is constant in different areas of the main channel.

Fig. 9 shows socio-environmental problems captured in UAV imagery, including: (A) Irregular settlements where livestock rearing, solid waste accumulation, animal breeding and domestic wastewater discharges occur. (B) Discharges of wastewater from a treatment plant. (C) Collapse of a riverside home due to a landslide, along with improperly constructed gabions by the community. (D) A concrete channel leaking wastewater into the Pesquería River, along with intermittent water flow caused by debris and trash buildup. (E) Accumulation of solid waste on the riverbanks, with large volumes in some sections restricting the river's flow and burning of solid waste. (F) Construction of retaining walls and homes by residents along the river.

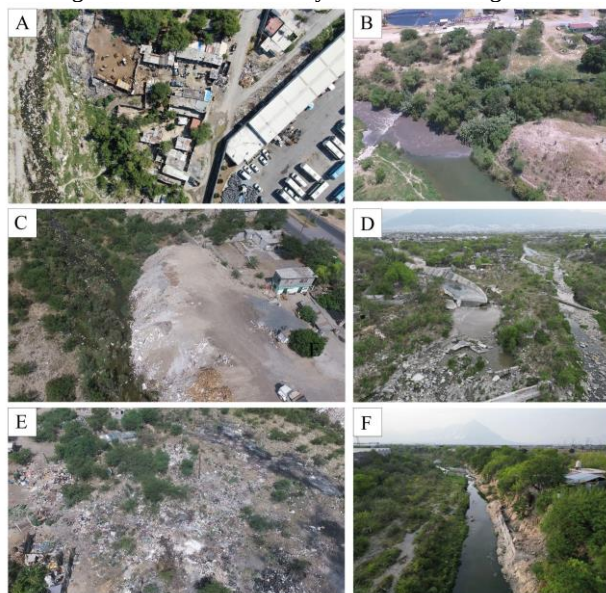


Fig. 9. AUVs imagery over the Pesquería River channel, showing some of the main socio-environmental problems. Description of the figure in the text.

A complete recording of these findings are represented in Table 5 and Figure 10. A total of 91 points with socio-environmental points were detected.

The spatial distribution of these environmental problems highlights a concentration of solid waste and irregular settlements across all municipalities, with Monterrey presenting the highest number of reported problems with 38%. These include wastewater, debris, undefined pollutants, lack of environmental education and industrial discharges. Followed by General Escobedo with 29%. Both municipalities lie along highly urbanized sections of the river. Apodaca and García each reported 16% of the total problems, reflecting a comparatively lower but still significant occurrence of socio-environmental impacts (Fig. 11).

The analysis revealed that solid waste accumulation is the most prevalent problem, accounting for 51% of all recorded problems. This is followed by irregular settlements (23%) and construction debris (11%), highlighting the influence of urban expansion and inadequate waste management on the river. Other issues identified include animal breeding activities (4%), wastewater discharges (3%), and a range of less frequent but relevant problems such as site abandonment, soil erosion, flooding, lack of infrastructure, lack of environmental education, decline in fauna, disease vectors, and industrial waste discharges, each representing 1% of the total number of socio-environmental problems (Fig. 12).

Table 5. Counting of environmental problems identified at the municipal level in the Pesquería River.

Municipality	Socio-environmental problems	Total number of records
García	Solid waste (10)	15
	Irregular settlements (5)	
Monterrey	Solid waste (17)	35
	Debris (5)	
	Irregular settlements (5)	
	Undefined pollutant (4)	
	Abandonment (1)	
	Lack of environmental education (1)	
	Disease vectors (1)	
	Industrial waste discharges (1)	
	Animal breeding (2)	
General Escobedo	Solid waste (15)	26
	Debris (4)	
	Irregular settlements (3)	
	Flooding (1)	
	Animal breeding (2)	
	Wastewater (1)	
Apodaca	Solid waste (4)	15
	Debris (1)	
	Irregular settlements (5)	
	Decline in fauna (1)	
	Wastewater (2)	
	Soil erosion (1)	
	Lack of infrastructure (1)	

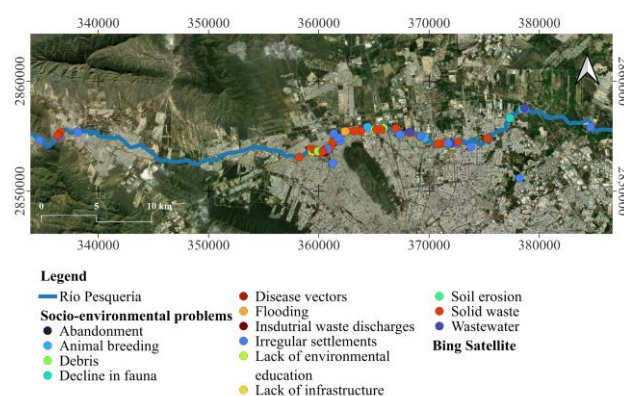


Fig. 10. Map of the socio-environmental problems identified along the Río Pesquería floodplain in the Monterrey metropolitan area, Nuevo León, Mexico. The map displays different issues such as solid waste, wastewater, decline in fauna, and irregular settlements, among others.

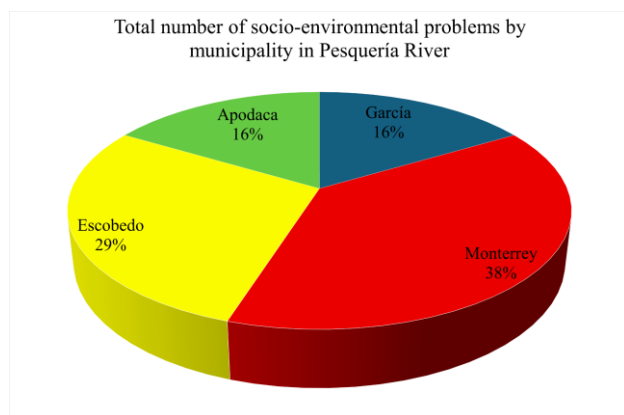


Fig. 11. Distribution of identified socio-environmental problems by municipality along the Pesquería River.

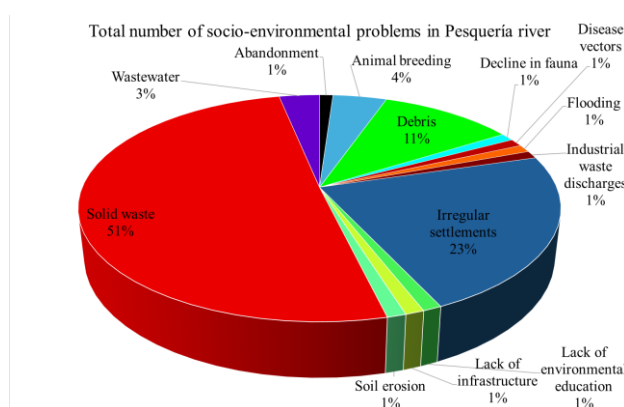


Fig. 12. Distribution of the total number of socio-environmental problems identified along the Pesquería River.

4. Conclusions

Based on the methodologies and strategies applied to understand the context of the socio-environmental issues affecting the Pesquería River, and supported by the use of a low-cost UAV multirotor, it was concluded that the main problems include illegal discharges into the stormwater system, accumulation of urban solid waste and debris, direct discharge of wastewater, irregular settlements, and the intrusion of invasive exotic vegetation. The UAV system allowed for high-resolution aerial monitoring, enabling precise visual documentation and mapping of affected zones, especially in areas with limited accessibility or where on-ground surveys are challenging.

Illegal discharges of wastewater represent a serious environmental issue that affects the river's water quality and public health. These discharges originate from domestic wastewater, industrial effluents, and contaminated stormwater. UAV-assisted observations helped identify several outflow points and discolored water zones indicating contamination. Additionally, direct wastewater discharge contributes to elevated levels of organic matter, fecal coliforms, detergents, heavy metals, solvents, and other harmful compounds in the aquatic ecosystem.

The intrusion of invasive exotic vegetation was another critical factor observed during UAV flights. Aerial imagery revealed dense patches of non-native flora encroaching along the

riverbanks, which disrupts native ecosystems and threatens biodiversity.

The accumulation of urban solid waste and debris remains a major pollutant source for the Pesquería River. UAV flyovers captured significant waste deposits—ranging from domestic packaging and plastics to industrial scraps and construction materials—particularly at informal dumping sites, which reach heights of up to 8.5 m and have an estimated volume of 1,627,142.78 m³. These materials obstruct water flow and create stagnant pools that support the breeding of disease vectors.

This situation is further aggravated by irregular settlements along the river's floodplain. UAV surveys enabled a detailed spatial analysis of these settlements, many of which lack essential services such as clean water, sanitation, and waste disposal infrastructure. This not only increases environmental degradation but also raises the vulnerability of these communities.

The environmental degradation of the Pesquería River reflects a complex interplay of anthropogenic pressures, poor waste management, and limited environmental education and infrastructure—especially in marginalized urban zones. The use of a low-cost UAV multirotor proved to be a valuable tool for environmental monitoring and assessment, offering a scalable and efficient method to identify problem areas, support data-driven decision-making, and promote targeted remediation strategies.

This approach produced a structured and replicable classification of socio-environmental problems, combining high-resolution UAV data with expert visual interpretation and community-based validation and participation.

This work is aligned with the United Nations Sustainable Development Goals (SDGs), particularly Goal 6 (lean water and sanitation), Goal 11 (Sustainable cities and communities), Goal 13 (Climate action) and Goal 15 (Life on land), promoting environmentally responsible development.

5. References

- Arafat, M. Y., Alam, M. M., & Moh, S., 2023: Vision-based navigation techniques for unmanned aerial vehicles: Review and challenges. *Drones*, 7(2), 89. <https://doi.org/10.3390/drones7020089>
- Castro-López, D., Rodríguez-Lozano, P., Arias-Real, R., Guerra-Cobián, V., & Prat, N., 2019: The influence of riparian corridor land use on the Pesquería River's macroinvertebrate community (N.E. Mexico). *Water (Switzerland)*, 11(9), 1–18. <https://doi.org/10.3390/w11091930>
- DOF-Diario Oficial de la Federación, 2020: Programa Nacional Hídrico 2020-2024. Comisión Nacional del Agua. (30/12/2020).
- González-Aguilera, D., Gómez-Lahoz, J., & Sánchez, J., 2008: A new approach for structural monitoring of large dams with a three-dimensional laser scanner. *Sensors*, 8(9), 5866-5883. <https://doi.org/10.3390/s8095866>
- Ferriño-Fierro, A., & Burgos-Flores, D., 2016: Delineation of Federal Zones and Buffer Areas in Rivers Affected by Urban Growth as a Strategy for Flood Prevention. *Epistemos: Ciencia, Tecnología y Salud*, 9(19), 24–33.

<https://biblat.unam.mx/hevila/EpistemusCienciatecnologiaysalud/2015/no19/9.pdf>

González, G., & Eduardo, L., 2020: Resiliencia urbana frente a inundaciones fluviales: factores determinantes en la planificación de ciudades intermedias del valle central de Chile--experiencias entre 1984 y 2017. Tesis Doctoral. Universidad del Bio-Bio, Chile.

Grosel, S., 2021: Numerical analysis of tailing dam with calibration based on genetic algorithm and geotechnical monitoring data. *Studia Geotechnica et Mechanica*, 43(1), 34-47. <https://doi.org/10.2478/sgem-2020-0008>

Mohsan, S. A. H., Othman, N. Q. H., Li, Y., Alsharif, M. H., & Khan, M. A., 2023: Unmanned aerial vehicles (UAVs): Practical aspects, applications, open challenges, security issues, and future trends. *Intelligent service robotics*, 16(1), 109-137. <https://doi.org/10.1007/s11370-022-00452-4>

National Water Commission (CONAGUA), 2023: Water quality assessment of the Pesquería River, Nuevo León, 2012–2022 https://www.gob.mx/cms/uploads/attachment/file/925317/2023_Diagn_stico_r_o_Pesqueria_NL_2012-2022.pdf

Prat, N., & Castro-López, D., 2023: Chironomidae as indicators of water pollution in Pesquería River (México). *Journal of Entomological and Acarological Research*, 55 (1). doi:10.4081/jear.2023.10861

Torres, M., Favela, S., Alanís, G., & González, J., 2018: Land Use Dynamics in a Priority Hydrological Region of the Río Bravo Basin, Nuevo León. *Revista mexicana de ciencias forestales*, 9(46), 54-79. <https://doi.org/10.29298/rmcf.v9i46.136>