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EXPERIMENTAL STUDY ON ROAD DEFECT DETECTION

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Abstract : The main objectives of the study are: exerting pressure on the authorities responsible for road maintenance; increasing the level of civic engagement among citizens; calculating a performance score for companies carrying out infrastructure works; raising the level of trust in public institutions. The proposed solutions are: a) use of the accelerometer to assess road quality and detect potholes, including graphical interpretation; b) pothole detection using a camera; c) dimensional analysis of potholes. The study aims to detect defects in images using two methods:1) the automated YOLOv8 model, where some classes (defectType1, defectType2) have very small bounding boxes, while others (defectType3, defectType4) have large boundaries. Real-time operation is achieved (at least 5 Hz on Jetson Xavier), utilizing the SAHI (Slicing Aided Hyper Inference) technique;2) using an instrumental scanning technique with LiDAR. Data were collected and processed, with the measurements interpreted graphically.

Key words : The infrastructure, defect, detection, LIDAR, SAHI, YOLOv8 model.

1. INTRODUCTION

Road defects can be identified through:

- Visual inspections;
- Non-destructive testing;
- The use of automated equipment.

These methods allow for the identification of visible defects such as cracks, potholes, uneven surfaces, and asphalt layer wear.

Methods used to detect road defects include:

- non-destructive testing that analyses the road's structural integrity without damaging it (ultrasonic testing, thermography);
- instrumental techniques utilizing automated equipment (laser scanning systems, integrated data collection systems).

In the current global context, it has been observed that the "Global country average" reflects the mean result for all countries and markets where the survey on transport quality was conducted. It has not been adjusted for the population size of each country or market and is not intended to suggest an aggregate result."[1] There is considerable variation in satisfaction across the 32 surveyed countries (Fig. 1). [2-4]

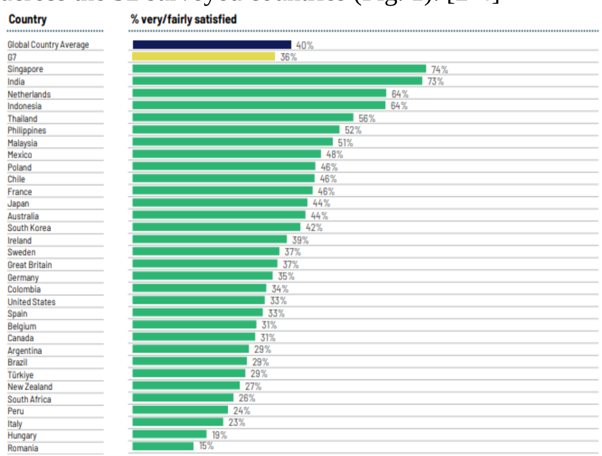

Figure 1 Global infrastructure index as of 2024. [4]

There is variation in how differently the transport sectors are perceived (Fig. 2). [2]:

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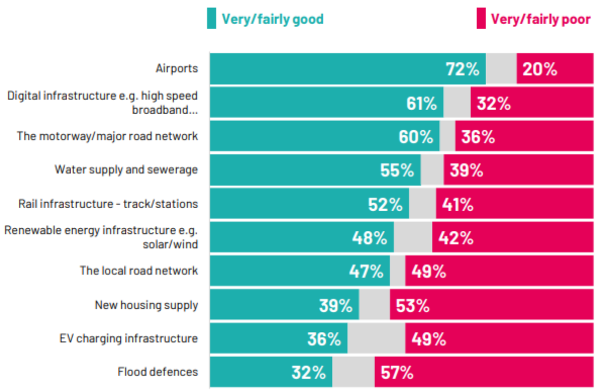

Figure 2 The country's global average [2]

Regarding global statistics, the satisfaction index concerning the mode of transport differs (Fig. 3, Fig. 4)[2].

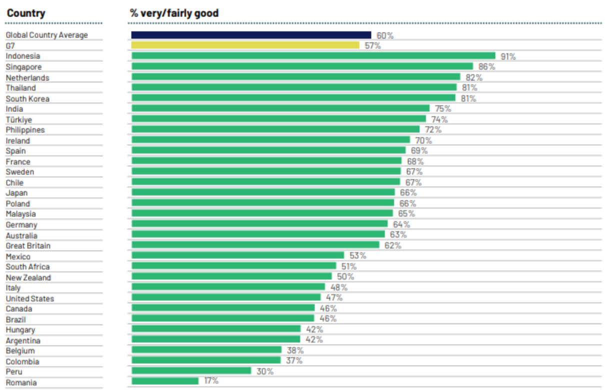

Figure 3 Motorway/major road network assessments. [2]

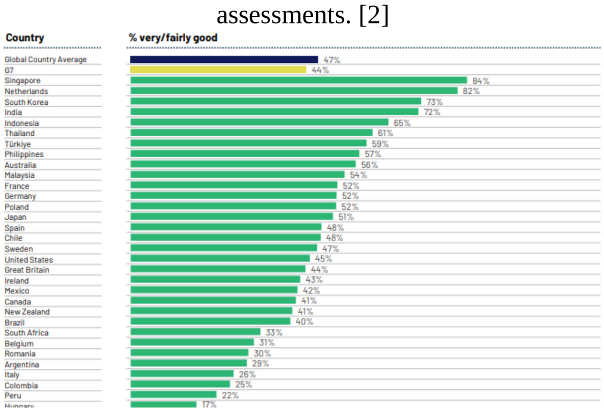

Figure 4 Local road network assessments. [2]

2. MATERIALS AND METHODES

2.1 Objectives of study:

The main objectives of the study are: exerting pressure on the authorities responsible for road maintenance; increasing the level of civic engagement among citizens; calculating a performance score for companies carrying out infrastructure works; raising the level of trust in public institutions.

2.2 The proposed solutions:

a) use of the accelerometer to assess road quality and detect potholes, including graphical interpretation;

b) pothole detection using a camera;

c) dimensional analysis of potholes (Fig. 5, Fig. 6, Fig. 7).

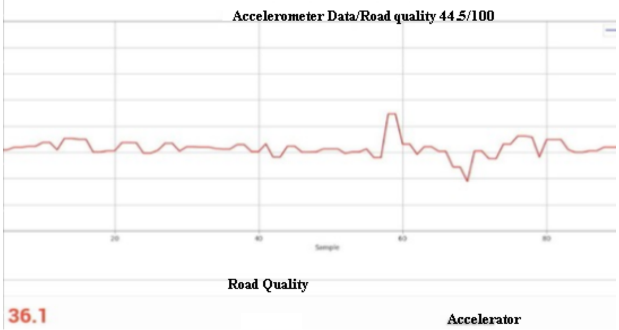

Figure 5 Road quality measured using an accelerometer

Figure 6 Identifying potholes using a camera

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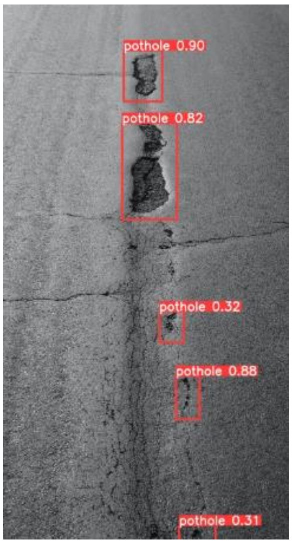

Figure 7 Dimensional analysis of pits

2.3 Defect detection methods :

The study aims to detect defects in images using two methods:

1) the automated YOLOv8 model, where some classes (defectType1, defectType2) have very small bounding boxes, while others (defectType3, defectType4) have large boundaries. Real-time operation is achieved (at least 5 Hz on Jetson Xavier), utilizing the SAHI (Slicing Aided Hyper Inference) technique;

2) using an instrumental scanning technique with LiDAR. Data were collected and processed, with the measurements interpreted graphically.

The steps we follow are:

- we use the SAHI (*Slicing Aided Hyper Inference*) [5]technique, specifically:

1. We attempted iterative learning, first training on smaller image slices (340px x 340px) and then using the trained weights for the next slice size (e.g., 480px x 480px), up to 640px x 640px slices.

2. We also tried training the network on a dataset combining these slices of different sizes [340px, 480px, 640px].

The second method yields the best results. The computational algorithm is shown below (Fig. 8):

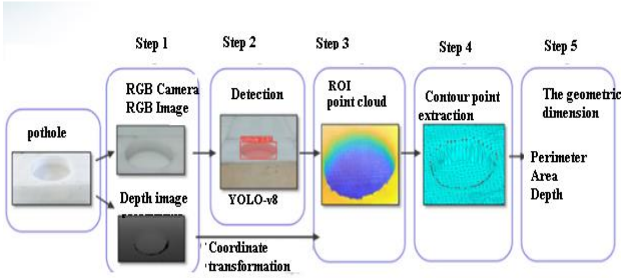

Figure 8 Calculation algorithm for pothole identification

2.4 Selection of the LiDAR instrumental scanning technique

Selecting a LiDAR (Light Detection and Ranging) sensor for pothole detection requires a careful analysis of several key criteria to ensure accuracy and efficiency. The technology utilizes laser pulses to create high-resolution 3D models of the road surface, enabling the automated identification of defects (Fig. 9). [6]

Figure 9 LiDAR – operating principle. [6]

This process, leveraging the constant speed of light, enables the highly precise calculation of the beam's distance from the target. This distance information is combined with X, Y, and Z coordinates to create a three-dimensional point cloud. This point cloud provides a highly detailed model of the scanned area or object.

The LiDAR system consists of:
- a laser scanner,
- a global positioning receiver (GPS system),
- an inertial measurement unit (IMU).

The laser scanner measures distance by transmitting and receiving beams.

The GPS receiver determines the device's location.

The inertial measurement unit measures the angular position—that is, the device's orientation.

Using these three components, a three-dimensional model is created through the precise geo-referencing of the acquired data.

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2.5 Data collection

The LiDAR system employed can be mounted on a platform that presents both advantages and disadvantages. Our LiDAR system is a terrestrial system capable of providing higher-resolution data. When data collection begins, laser beams are continuously directed at the surface to be scanned, and the return times of the reflected beams are recorded. The collected data is subsequently processed and converted into a three-dimensional model. Proper system calibration during the data collection process is essential. The operational stages of the LiDAR system are:

a) emission of the laser beam;
b) detection of the reflected light beam;
c) measurement of the return time of the reflected beams;
d) calculation of the distance;
e) positioning to determine location using GPS and measurement of angular position using an Inertial Measurement Unit (IMU);
f) creation of a 3D point cloud;
g) analysis and interpretation of the collected data.

2.6 Data processing

The collected LiDAR data are processed to make them usable. They undergo several stages: data cleaning, filtering, classification, and modelling.

➢ The data cleaning phase involves removing data deemed useless or erroneous.

➢ The filtering phase entails classifying data based on specific criteria and removing unwanted elements.

➢ The classification phase involves grouping data according to characteristics specific to the study area.

➢ The modelling phase involves creating three-dimensional models using the processed data.

2.7 Method for analysing collected data

The technology for analysing data collected via the LIDAR system is presented in Annex 3. It involves: classification algorithms, segmentation techniques, filtering methods, feature extraction operations, surface modelling, and change detection analyses.

2.8 Equipment used for LiDAR technology

The following LiDAR equipment is used to detect imperfections on national roads (Fig. 10):

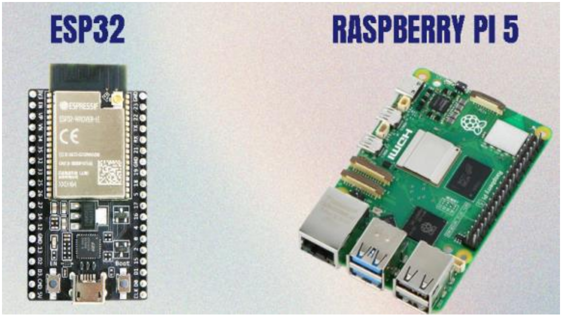


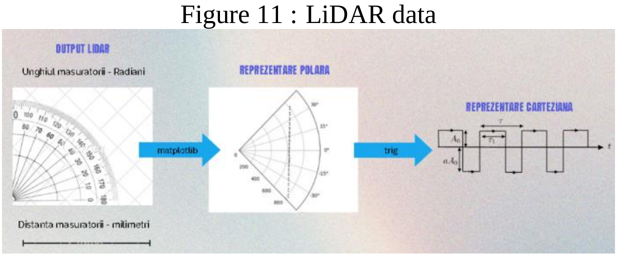
Figure 10 Choosing the processor.[3]

1. A LiDAR laser scanner that measures distances by emitting laser beams.[2]
2. A positioning system (GPS/IMU) required for the geo-referencing of the correct geographic location.[2]
3. A unit for recording and storing the collected data.
4. Equipment for controlling the scanning process and displaying data in real time.
5. A power source to meet the system's energy requirements.
6. Calibration equipment to ensure the accuracy of the LiDAR system. [2]

3. RESULTS AND DISSCUTIONS

The results are: LiDAR data (Fig. 11); Graph conversion and interpretation (Fig. 12) and Mapping (Fig. 13).

Figure 11 : LiDAR data



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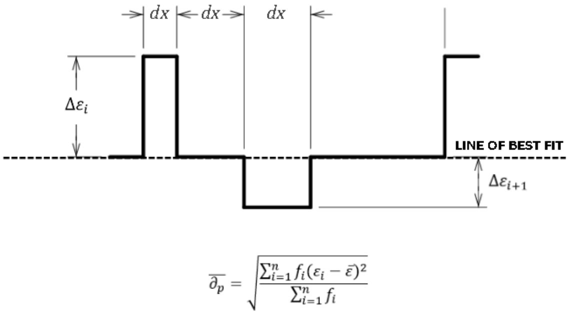

Figure 12 Graph conversion and interpretation

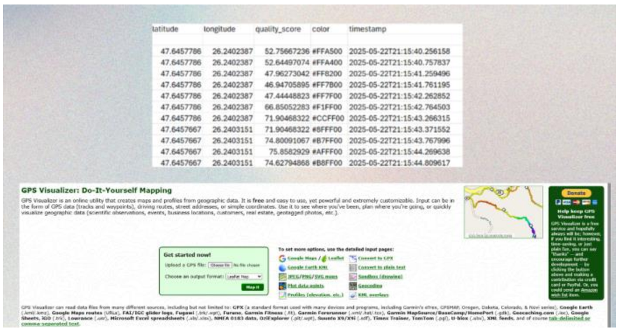

Figure 13 GPS mapping visualization

To examine the practical application of this method, a case study is presented below.

2. 9 Case Study – Lake Tăbăcăriei Neighborhood

GPS, IMU, and a LiDAR system were used to georeference the correct geographical location.

Lake Tăbăcăriei is located north of the city of Constanța and covers an area of approximately 99 hectares.[7]

Its banks have been entirely straightened and reinforced. The western bank rises to an elevation of 6–7 m, while the elevations to the east and south are lower, ranging from 2 to 4 m. In the northern section, the shoreline is very low-lying (1–2 m).

Relatively isolated from natural sources, Lake Tăbăcăriei has a depth varying between 1.5 m and 4.4 m, relying on water inflow from Lake Siutghiol. Excess water is discharged from Lake Tăbăcăriei into the sea via a sluice gate located at the "Pescărie" site.[7]

Google Earth will be used for the Lake Tăbăcăriei location (Fig. 14, Fig. 15).

Figure 14 Studied location

Figure 15 Google Earth’s map representation

. 2. 10 Road defect detection

The LiDAR system employs remote sensing technology, emitting pulsed laser beams and calculating the time required for these pulses to reflect back to the sensor. [26]

The LiDAR scanner generates point clouds—effectively constructing a 3D model—that accurately map the contours of defects on the analysed road.

The distance to the object is calculated using the following relationship:

$$D_{ob} = v_l * t/2 \qquad (1)$$

where:

D_{ob} – distance to the object;

v_l – speed of light;

t – time of flight of the light pulse.

This relationship clearly demonstrates how LiDAR technology utilizes the speed of light and the time of flight of the light pulse.

At the same time, it ensures extremely precise and reliable measurements.

The road defect is captured by the LiDAR system sensor, which measures the 3D depth of the pothole or road defect (Fig. 3.16). The detector captures the light reflected from the road defect (via silicon avalanche photodiodes (APDs) or photomultipliers (PMTs) – Fig. 3.8), while the GPS receiver tracks altitude and location using the coordinates used for mapping (Fig. 3.13).

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Figure 16 Representation of the road defect

An Inertial Measurement Unit (IMU) monitors the vehicle's speed and direction, ensuring precise positioning of the pulsed laser beams on the ground surface—and, by extension, on road defects (potholes) (Fig. 3.16).

A topographic LiDAR is used for mapping land surfaces.

2.11 Analysis of road quality in the study area

Based on information regarding air quality indicators in the study area, it was found (Fig. 17)[8-9].

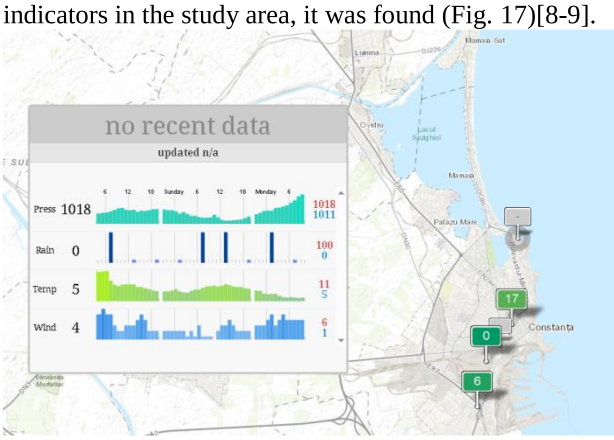

Figure 17 Air quality indices in the Lake Tăbăcărie-Dolphinarium neighborhood area

A comparison with historical data for the area reveals an improvement in air quality resulting from the improved quality of the roads (Fig. 18, Fig. 19, Fig. 20, Fig. 21, Fig. 22) [10]:

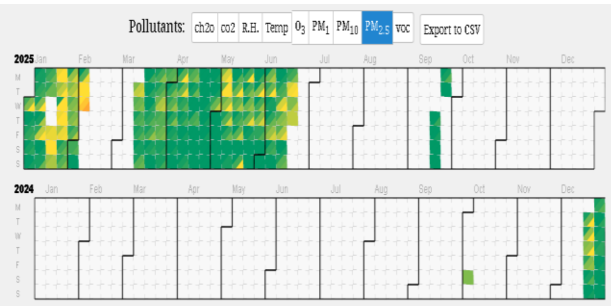

Figure 18 History of pollutants in the study area – PM2.5. [10]

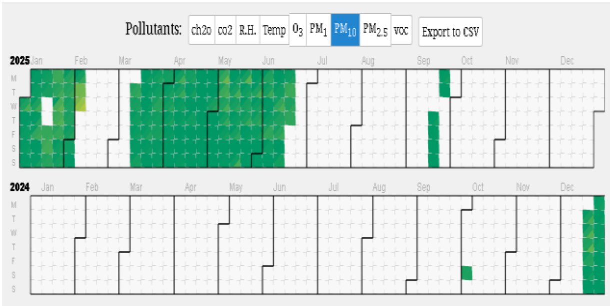

Figure 19 History of pollutants in the study area – PM10. [10]

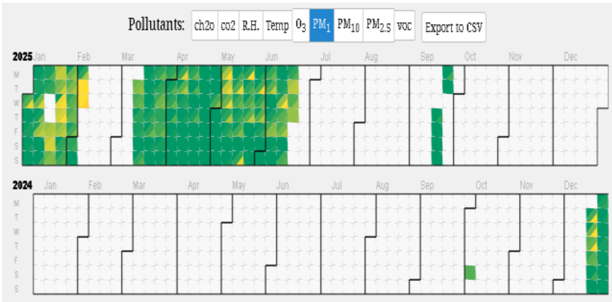

Figure 20 History of pollutants in the study area – PM1. [10]

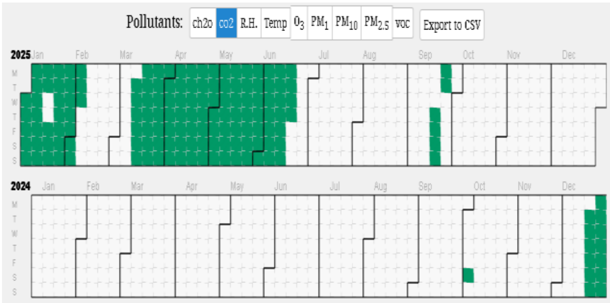

Figure 21 History of pollutants in the study area – CO_2. [10]

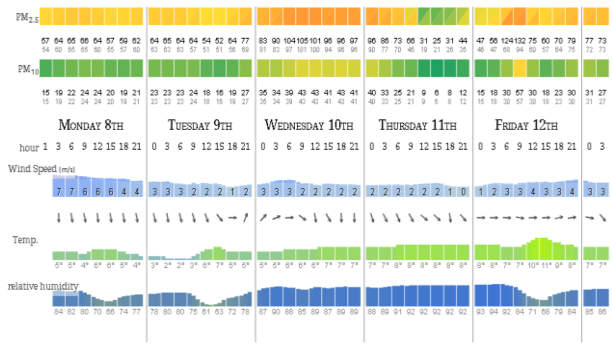

Figure 22 PM2.5 and PM10 air quality index levels as of December 2025. [10]

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A road network reorganization project is currently being implemented in Constanța, under which 28 streets are being converted to one-way traffic to alleviate congestion and improve road quality. In conclusion, the air quality index map for the study area can be analysed in terms of risk as follows (Fig. 23, Table 1, Table 2):

Figure 23 Real-time visual map of the air quality index in the Tăbăcărie Lake – Dolphinarium area.

Table 1. Air risk matrix for the Lake Tăbăcărie-Dolphinarium area

Type of Risk	Probability	Environmental impact	Pollution	Cause
High	Big	Big	NOx, NO_2, suspended particulate matter	Heavy road traffic on Mamaia Bd. and adjacent streets.
Medium	Medium	Medium	Odor pollution (unpleasant odors)	The lake's poor ecological condition (reed beds, waste accumulation, eutrophication)

Table 2 Air quality assessment for March 2026

Pollutant	Level of risk	Environmental and health impact
PM2.5	Moderate	Respiratory discomfort
NO_2	Low/Medium	Traffic on Mamaia Boulevard
O_3	Variable	It grows during warm days.

The implementation of additional traffic-smoothing measures also aims to reduce road surface deterioration caused by large vehicles or by construction work not originally included in the city's urban development plan [9-11].

4. CONCLUSIONS

The Constanța Municipality, through SC Confort Urban SRL, has initiated a traffic management project to reorganize the road layout in the Dolphinarium area, addressing mobility and traffic safety issues along the streets within the perimeter defined by Mamaia Boulevard, Ion Rațiu Street, Tomis Boulevard, Alexandru Lăpușneanu Boulevard, and Soveja Street.

This measure was adopted both to improve traffic flow and to rectify identified shortcomings. Current conditions show that these two-way streets have become difficult to navigate due to the large number of vehicles parked on the roadway; these vehicles impede traffic in both directions and can even block the passage of emergency vehicles when intervention is required.

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This study examined road and air quality in the context of current legislative requirements and modern technologies mandated at the European level.
The durability of asphalt roads is fundamental to ensuring an efficient and sustainable transport network. Our multidimensional approach encompasses the selection of quality materials, advanced construction techniques, and a rigorous maintenance and monitoring program. Selecting high-quality asphalt mixtures is the essential first step in ensuring road durability. Proper asphalt compaction is crucial for maintaining the road's structural integrity. Integrating geo-synthetics into the road structure offers an effective solution for enhancing stability and durability. Geo-synthetic materials, such as geogrids and geotextiles, contribute to uniform load distribution, thereby preventing deformation and cracking. Continuous monitoring and performance assessment are vital components in maintaining and improving road infrastructure quality. Implementing an effective monitoring and evaluation strategy enables us to promptly identify issues and intervene quickly with repairs or improvements, thereby extending the roads' service life and optimizing the user experience.

5. CREdit authors statement

Conceptualization: D.M.-V., P.M., P.F-V.;Data curation; D.M.-V., P.M., P.F-V.;

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Software: D.M.-V.;

Supervision: D.M.-V.;

Validation: D.M.-V.;

Visualization: D.M.-V.;

Writing – original draft: P.M.;

Writing – review & editing: P.M.

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