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Option: Geomatics

Contribution of geomatics to the study of the road degradation case of the East-West highway, Constantine.

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الشكر والتقدير

نشكر أولاً وقبل كل شيء الله عزّ وجل، الذي منحنا الصحة، الشجاعة، الصبر والقوة اللازمة لإنهاء مشروع تخرجنا.

نود أولاً أن نعبر عن شكرنا العميق لمشرفينا لتفضلهما بالإشراف على هذا العمل، ولملاحظاتهما القيّمة، وتشجيعهما، وتعاونهما الملحوظ، ودعمهما طيلة فترة إعداد هذا البحث.

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إلى أصدقائي: أسامة، عبد اللطيف، منصف... وإلى باقي أصدقائي.

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ملخص:

قبل الشروع في أي عملية صيانة أو إعادة تأهيل لمقطع من الطريق السريع، تُعدّ المعاينة المسبقة لحالة سطح الطريق خطوة ضرورية لا غنى عنها. هذه المرحلة التشخيصية، على الرغم من أهميتها البالغة في تخطيط التدخلات بشكل استراتيجي، تظل عملية مرهقة وتستغرق وقتًا طويلاً، وتُنفّذ تقليديًا من قبل أعوان متخصصين يقومون بعمليات تفتيش ميدانية بصرية لمعرفة وتحديد مواقع عيوب سطح الطريق..

تقترح هذه الدراسة بديلاً مبتكرًا يعتمد على استخدام تسجيلات فيديو ملتقطة بواسطة هاتف ذكي، متزامنة مع بيانات ملاحة مدمجة GPS. ومن خلال التفسير البصري للصور الجغرافية المرجعية، تتيح هذه الطريقة الكشف عن العيوب السطحية وإنشاء خريطة مفصلة للتدهورات. وقد طُبّق هذا التشخيص الجغرافي المكاني على مقطع نموذجي من الطريق السيار شرق–غرب، بين النقطتين الكيلومتريتين 152 و170، الواقع ضمن ولايتي قسنطينة وميلة، ويُعد أداة دعم لاتخاذ القرار من أجل تدخلات مستهدفة ومحسّنة.

تُنفّذ مرحلة الكشف عن التدهورات يدويًا عبر تحليل الصور المستخرجة من مقاطع الفيديو، حيث تُربط كل صورة بموقع جغرافي دقيق. وتوفر هذه المنهجية دقة مكانية دون العشر أمتار، وهي كافية لتلبية متطلبات أنظمة إدارة وصيانة الطرق على المستوى التشغيلي.

Abstract :

Before any maintenance or rehabilitation work is undertaken on a highway section, a prior assessment of pavement condition is essential. This initial diagnostic phase, although crucial for strategic intervention planning, remains a demanding and time-consuming process, traditionally carried out by trained personnel conducting on-site visual inspections to identify and locate surface distresses.

This study proposes an innovative alternative based on the use of video sequences captured with a smartphone, synchronized with embedded navigation data (GPS). Through visual interpretation of georeferenced images, this method enables the detection of surface defects and the production of a detailed degradation map. The geospatial diagnosis was applied to a representative segment of the East–West Highway, between kilometer points 152 and 170, located in the wilayas of Constantine and Mila, serving as a decision-support tool for targeted and optimized interventions.

The anomaly detection phase is conducted manually through the analysis of video-extracted frames, each associated with a precise geographic location. This approach provides sub-decametric accuracy in defect localization, meeting the requirements of operational road maintenance and management systems.

Résumé :

Avant toute opération de maintenance ou de réhabilitation d'un tronçon autoroutier, une évaluation préalable de l'état de la chaussée constitue une étape incontournable. Ce diagnostic initial, bien que fondamental pour la planification stratégique des interventions, reste une procédure exigeante et chronophage, généralement assurée par des agents spécialisés réalisant des inspections visuelles in situ afin d'identifier et de localiser les pathologies de surface.

La présente étude propose une alternative innovante fondée sur l'exploitation de séquences vidéo acquises à l'aide d'un smartphone, synchronisées avec des données de navigation embarquées (GPS). Cette méthodologie permet, par interprétation visuelle des images géoréférencées, de détecter les dégradations de surface et de produire une cartographie précise des défauts. Ce diagnostic géospatialisé a été appliqué à un tronçon représentatif de l'autoroute Est–Ouest, situé entre les points kilométriques 152 et 170, dans les wilayas de Constantine et de Mila, et constitue une base d'aide à la décision pour une intervention ciblée et optimisée.

La phase de détection est réalisée manuellement par analyse d'images extraites des vidéos, chacune étant associée à une position géographique précise. Cette approche permet une localisation des anomalies avec une précision subdécamétrique, compatible avec les exigences des systèmes opérationnels de gestion et d'entretien routier.

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General Introduction

The road network plays a fundamental role in the economic, social, and territorial development of nations. As a basic infrastructure that facilitates the mobility of people and the transportation of goods, it provides cross-sector support to key areas such as industry, agriculture, and services. In Algeria, this strategic function is further emphasized by the vast size of the country (over 2.38 million km²), as well as the complexity of its terrain, the diversity of its geological formations, and its climatic constraints. Consequently, the development, management, and maintenance of the national road network present major challenges for public authorities.

The country has an extensive road network composed of national, wilaya (regional), and communal roads, in addition to major infrastructure projects such as the East–West Highway, which serves as a vital corridor for territorial integration and interregional economic dynamics. However, the increasing demand on this infrastructure due to rising traffic and vehicle loads leads to progressive pavement deterioration, negatively impacting ride comfort, user safety, and the efficiency of transportation networks. This situation calls for regular monitoring and accurate diagnostics of road conditions to ensure effective maintenance planning.

Traditionally, road deterioration assessments rely on visual inspections carried out by specialized teams [1]. While simple to implement, this approach is time-consuming, costly, sometimes dangerous (particularly on highways), and highly subjective in the absence of objective measurement tools. In this context, the integration of geomatics technologies—combining Geographic Information Systems (GIS) and Global Positioning Systems (GPS)—has improved inspection methods by enabling better localization and traceability of defects.

At the same time, more advanced technological solutions such as sensors mounted on specialized trucks, radars, high-resolution cameras, and drones offer excellent performance in terms of precision and speed of data acquisition. However, their

deployment remains limited due to high costs, operational complexity, and the need for qualified human resources—factors that hinder their widespread use, particularly in developing countries or for routine maintenance projects.

In response to these constraints, the use of smartphones has emerged as an innovative, cost-effective, and accessible alternative. Equipped with various sensors (GPS, camera, accelerometer, etc.) [2], smartphones enable automated detection of certain pavement distresses while driving. Their light weight, low cost, ease of implementation, and ability to collect spatialized data with acceptable positioning accuracy (less than 10 meters) [3] make them suitable tools for monitoring road conditions, while also ensuring operator safety.

In this context, the present study aims to experiment with the use of smartphones for the detection and mapping of pavement distresses on a representative section of the East–West Highway, between kilometer points 152 and 170 (in the wilayas of Constantine and Mila). The adopted methodology is based on real-world video recording using a smartphone mounted on the vehicle. Each frame is georeferenced using integrated GPS data, allowing for the identification, localization, and classification of various types of distress (longitudinal cracks, transverse cracks, alligator cracking, rutting). All data is then integrated into a geographic database to generate a digital map of pavement conditions.

This contribution is part of an effort to optimize road diagnostics by exploring simple yet effective tools that can be integrated into low-cost preventive maintenance strategies, particularly suitable for resource-constrained contexts.

This study is structured into four interrelated and complementary chapters, each contributing to a coherent understanding of the research problem addressed.

- **The first chapter** offers a general introduction to road infrastructure. It discusses the various functions of road networks and reviews the main types of deterioration commonly observed, particularly in high-traffic areas.
- **The second chapter** focuses on the technological aspect of the study. It provides a detailed overview of the smartphone's capabilities as a cost-effective tool for assessing road conditions. Special attention is given to the most relevant integrated sensors for monitoring deterioration, such as the

GPS module for geolocation and the camera for capturing visual evidence of defects like cracks, alligator cracking, and rutting. The advantages and limitations of using these mobile devices are also discussed.

- **The third chapter** presents the study area in detail, providing both geographical and functional context. The selected section of the East–West Highway, located between Constantine and Mila, is described in terms of its strategic importance, topography, and known vulnerabilities.
- **The fourth chapter** forms the core of the work. It details the field activities carried out, the data collection protocol using smartphone-recorded videos, and the methodology adopted for processing and analyzing the data. It presents the results obtained, including the identification and classification of different types of pavement deterioration.

Chapter I

General Information on Pavements

1. Introduction

In order to better understand the mechanisms of road deterioration and propose effective diagnostic methods, it is essential to begin with a general overview of pavement structures. This chapter presents the main structural characteristics of pavements, their classification in Algeria, as well as the common surface distresses affecting the wearing course. It also highlights the observation methods used, distinguishing between traditional approaches and modern technologies adopted in developed countries.

2. Definition

Pavements are multi-layered structures (Figure I-1) constructed on a base known as the pavement support platform, which consists of the compacted subgrade soil (referred to as the supporting soil), generally topped by a capping layer [4].

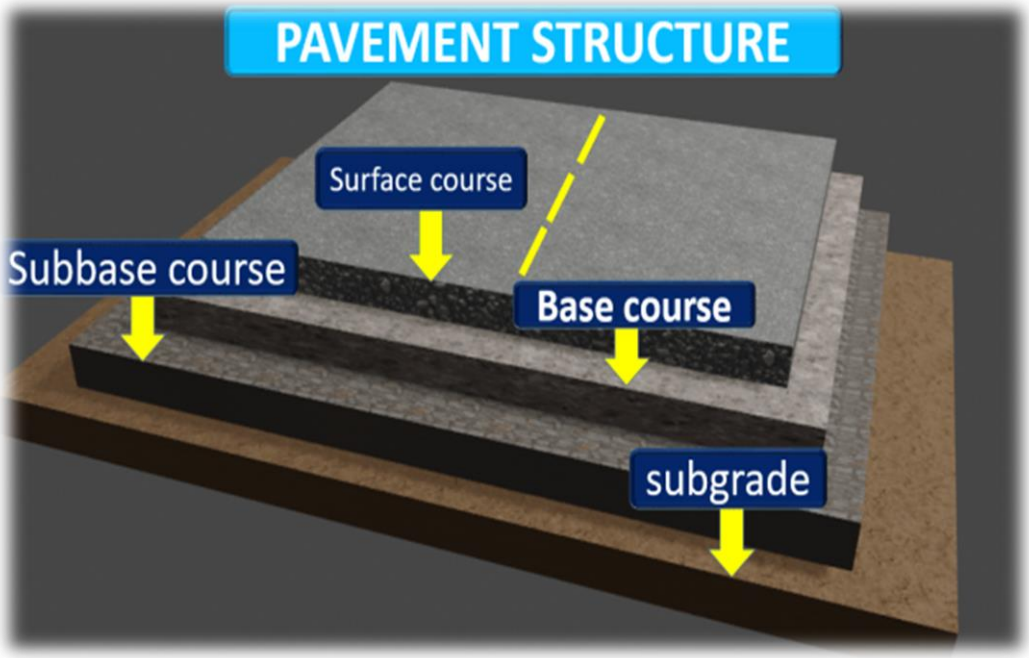


Figure I. 1: Multilayer Structure of a Pavement

A cross-section of the road shows that it is generally composed of the subgrade soil, the capping layer, the subfoundation layer, the base layer, and the surface layer. The latter, known as the wearing course, is of particular interest and is the focus of our study.

- **Natural terrain:** This is the soil as it appears after stripping the surface layer or performing the excavations.
- **Foundation soil or platform soil or support soil:** Prepared natural terrain, or a combination of natural terrain and backfill, located beneath the pavement or, if applicable, beneath the capping layer.
- **Capping layer:** A layer of high-quality materials placed at the top of backfills or excavated material. It may be composed of treated soils or imported materials.
- **Foundation layer:** This layer consists of materials laid over the capping layer (backfill, prepared natural terrain, or capping layer). It helps to reduce the stresses transmitted to the support soil or the capping layer and is designed to withstand the loads generated by traffic.
- **Base layer:** Composed of either treated or untreated materials, this layer is applied over the foundation layer. It is intended to further reduce the stresses transmitted to the support soil or the capping layer, with its performance ensuring resistance against traffic-induced loads.
- **Surface layer = bonding layer + wearing course:** This layer consists of the wearing course and, where applicable, a bonding layer. It serves to absorb shear forces and waterproof the layers underneath.
- **Wearing course:** This layer is made of bituminous materials or cement concrete, directly subjected to traffic and weather effects, and it functions as a waterproofing and protective cover for the underlying layers.

3. Road Classification in Algeria

3.1. Classification according to Algerian Technical Standard B40

The entire Algerian road network can be classified into five functional categories, reflecting the economic and administrative purposes set by the country's spatial planning policy [5]:

- Category 1: Links major economic centers and key heavy industry hubs. It also includes roads that connect industrial and processing centers to the primary network mentioned above.
- Category 2: Connects transformation industry poles to one another, and provides links between diversified light industry poles and the networks in the previous categories.
- Category 3: Connects district (daïra) capitals and provincial (wilaya) capitals not already served by the higher-category networks.
- Category 4: Connects all inhabited centers that are not linked to categories 1, 2, or 3 to their respective district (daïra) capital.
- Category 5: Includes all roads and tracks not covered by the above categories.

3.2. Administrative Classification

Roads in Algeria are also classified administratively [5] into the following types:

- National Roads: Major roads connecting the capital to main cities or linking major urban centers. They are built and maintained by the state under the authority of the Ministry of Public Works.
- Wilaya Roads: Formerly known as departmental roads, these connect towns either within a wilaya or between neighboring wilayas. Their construction and maintenance fall under the responsibility of the wilaya authorities.
- Municipal Roads:These are managed by the commune. They include:
- Rural roads, which connect rural dwellings and agricultural properties,
- Urban roads, which are located within urban agglomerations.
- Highways: These are national or international roads reserved for high-speed motorized traffic.

4. The Algerian Road network

The Algerian Road network is one of the densest in Africa, with a total length of 133,741 km. It is dense in the northern part of the country and becomes increasingly sparse toward the south [6].

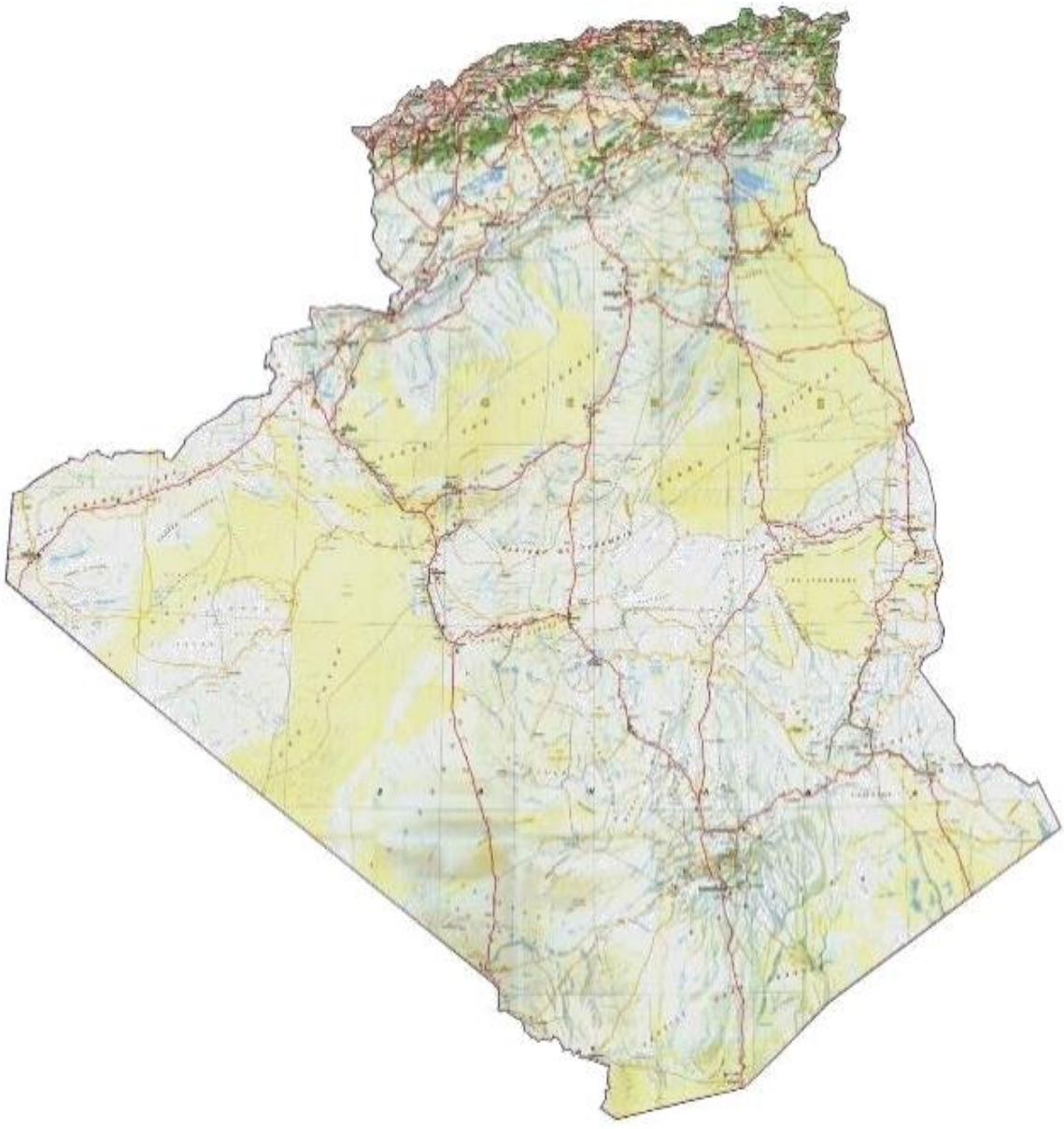


Figure I. 2: The Algerian Road network.

5. Road degradation

5.1. Degradation

Is a wear process through which the functional and structural capacity of a pavement decreases. It can also be defined as the progressive transition of a road from an acceptable condition to a poorer state under the effects of traffic, climate, and the surrounding environment [7].

5.2. Factors of degradation

- Climatic action:

Any soil that is not water-saturated generally has good bearing capacity, and even high plasticity does not hinder traffic. However, some highly plastic materials, such as clay when saturated, become slippery and collapse due to lack of bearing strength.

- Vehicle action ("traffic"):

A distinction must be made between surface effects and those affecting the lower layers of the pavement. On unpaved roads, surface defects are more pronounced when the cohesion of the wearing course is low, meaning it consists of less plastic and drier materials.

- Geographical actions:

Topography, through slopes and gradients, affects parameters such as the efficiency of drainage systems, the adhesion of materials and pavement layers, and braking performance.

- Material quality:

The quality of materials directly influences the quality of the road. Defects leading to degradation include:

- Incorrect grain size distribution
- Insufficient aggregate hardness
- Rapid polishing of poorly manufactured aggregates

- Incorrect percentage of fines

  - Implementation (construction quality):

Even with high-quality binder and aggregates and well-executed design, poor workmanship during implementation, handling, or compaction can result in a finished structure of poor quality. Various construction defects can thus lead to significant degradation.

  - Lack of maintenance:

Maintenance is essential for preserving the road, just like traffic. Whether periodic or routine, the absence of maintenance leads to various “diseases” that affect the “health” of the road and turn it into a hazard for road users.

5.3. Types of Degradations

Pavement distresses are depressions or undulations in the road that generally originate within the pavement structure or the subgrade soil and manifest on the wearing course. They are distinguished based on their shape and location. These distresses can be divided into four major groups (or categories), as defined by [8]:

- Deformations
- Cracking
- Surface disintegration
- Upheavals and upward intrusions

In this study, we will focus on four types of pavement distresses — longitudinal cracks, transverse cracks, alligator cracking, and rutting — which will be the subject of our application section.

5.3.1. Longitudinal Crack

Definition:

This is a category of surface distress characterized by a line of rupture that appears on the pavement surface, running approximately parallel to the roadway axis [9].



Figure I. 3: Example of a longitudinal crack

Probable Causes:

• Poor construction of the longitudinal joint between two asphalt lanes.

• Differential movement in cases of roadway widening.

• Pavement fatigue due to insufficient structural capacity to support traffic or inadequate subgrade bearing capacity.

• Soil characteristics: settlement or shrinkage of clay soil following a prolonged dry period (drying out).

5.3.2. Transverse Crack

Definition

These are cracks that are approximately perpendicular to the roadway axis. They can be isolated or regularly spaced, and may affect all or part of the pavement width [9].



Figure I. 4: Example of a transverse crack

Probable Causes:

• Poor construction or improper implementation of the wearing course

• Aging of the binder

• Advanced pavement fatigue due to repeated loading or under-design of one or more pavement layers

• Decrease in the bearing capacity of the subgrade soil

5.3.3. Alligator Cracking

Definition: Alligator cracking refers to a pattern of interconnected cracks forming more or less fine meshes, occurring on the surface layers [10].



Figure I. 5: Example of alligator cracking

Probable Causes:

- A rigid wearing course over a highly deformable base layer
- Poor bonding between the surface layer and the base layer
- Premature aging of the binder

5.3.4. Rutting

Definition:

Rutting is a permanent deformation that develops under repeated vehicle wheel paths. It appears as one, two, or sometimes three longitudinal depressions of variable width. In extreme cases, the road surface displays a W-shaped profile [11].



Figure I. 6: Example of rutting

Probable Causes:

- Insufficient bearing capacity under traffic loads
- Under-dimensioning of the pavement structure
- Contamination of the base layer
- Lack of compaction or creep of bituminous material

6. Methods Used for Studying Road Degradation

There are several methods for collecting data related to road degradation [12]. In Algeria, the most commonly used method remains visual and manual inspection, carried out by technical agents who travel along the roads on foot or by vehicle to identify and record visible defects (cracks, rutting, alligator cracking, etc.). Although this approach is simple and low-cost, it remains subjective, ime-consuming, and sometimes dangerous on high-traffic roads. In contrast, in developed countries, pavement surface condition surveys rely on advanced and automated technologies, such as survey vehicles equipped with laser sensors, high-resolution cameras, 3D scanners, ground-penetrating radar (GPR), and high-precision GNSS positioning systems. These methods allow for objective, rapid, large-scale, and repeatable diagnostics, while ensuring the safety of operators. The current trend in these countries is to combine these professional surveys with embedded intelligent systems (vehicle-mounted sensors, smartphones, etc.) to enable continuous monitoring and optimize preventive maintenance strategies.

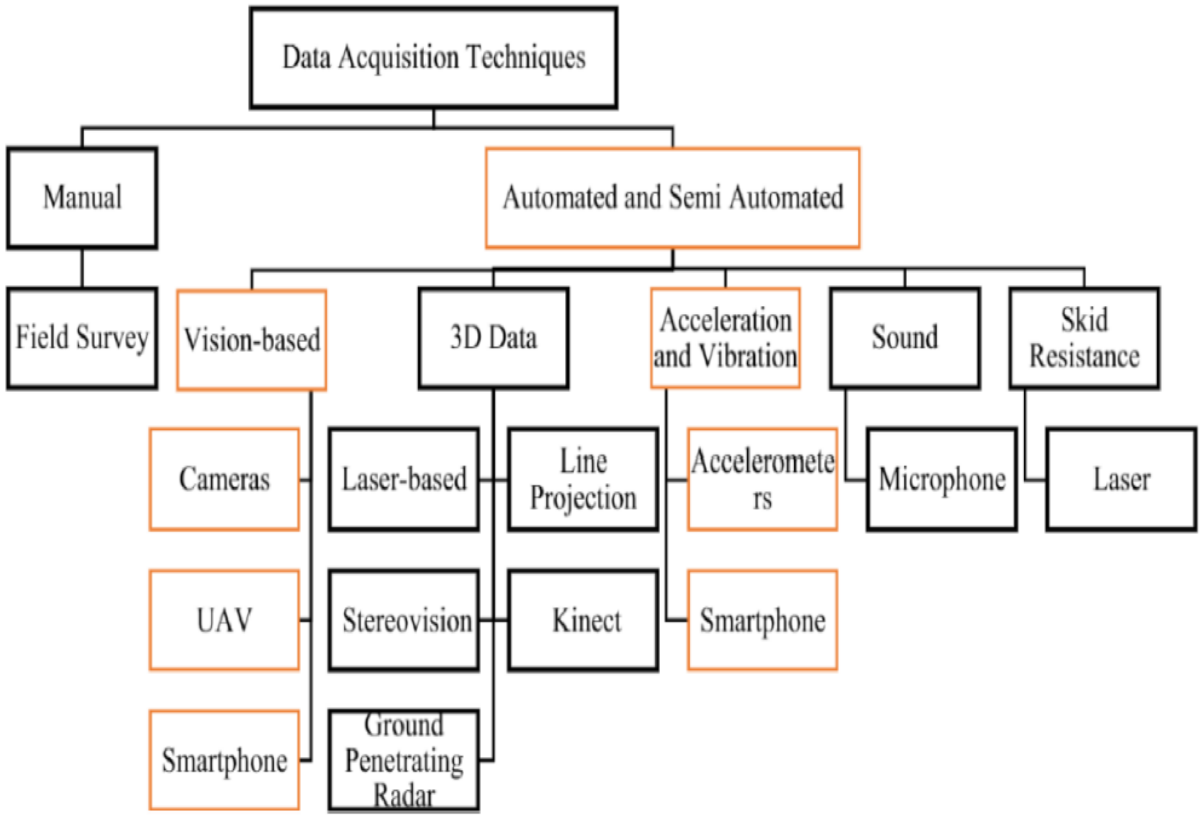


Figure I. 7: Methods Used for Studying Road Degradation

In Europe and North America, the methods commonly employed are semi-autonomous systems, which combine automated data collection with human intervention for result analysis. These approaches typically involve vehicles equipped with high-precision sensors that collect detailed information on pavement conditions while in motion. However, the interpretation and classification of the data—such as identifying types of cracks or assessing severity levels—still rely on the expertise of engineers or trained technicians. This hybrid model allows for a balance between efficiency, accuracy, and human judgment, making it a reliable solution for large-scale road monitoring programs.

7. Conclusion

This chapter has established the necessary foundation for analyzing road surface deterioration. Through the description of pavement layers, the classification of roads in Algeria, and the major types of surface defects, it becomes clear that pavement performance depends on a combination of technical, climatic, and geographic factors. The comparison between conventional methods and instrumented approaches also emphasizes the growing interest in faster, more objective, and automated inspection techniques, paving the way for innovative solutions such as smartphone-based, low-cost data collection.

Chapter II

Use of Smartphone Sensors for Road Degradation Localization

1. Introduction

This chapter explores the use of smartphone sensors as an innovative tool for detecting and locating road surface degradation. It begins by presenting the types of sensors embedded in modern smartphones and their respective roles in capturing physical and positional data [13]. The chapter then describes the different coordinate systems required to interpret this data correctly. Finally, it introduces the *Road Recorder* Android application, developed to collect synchronized video and sensor information for the purpose of mapping road defects with geospatial accuracy.

2. Sensors in Smartphones

Until now, the identification of road surface degradation has mostly relied on visual inspections conducted by field agents. While simple, this method remains imprecise and heavily dependent on the observer's experience.
In this context, our application proposes an innovative approach: combining human observation with precise geolocation of degradation using a smartphone.

Modern smartphones are equipped with numerous sensors such as accelerometers, gyroscopes, magnetometers, and more. These sensors collect valuable data that can be leveraged in a wide range of applications [14], including for road diagnostics.

Since our primary goal is location-based, we begin by introducing the coordinate systems associated with these sensors, followed by the transformation methods between different reference frames.

Smartphone sensors can be divided into two main categories:

- **Hardware sensors** (hard sensors): physical components built into the device that directly measure physical phenomena.
- **Software sensors** (soft sensors): virtual sensors not physically present but simulated through algorithms that combine data from multiple hardware sensors to provide new information.

Based on their functions, sensors can also be classified as follows [13]: Motion sensors: measure acceleration and rotation along the three axes. Examples:

accelerometer, gyroscope, gravity sensor, rotation vector sensor. Position and attitude sensors: determine the position and orientation of the device. Examples: gyroscope, GPS, magnetometer, orientation sensor. Environmental sensors: measure ambient conditions. Examples: barometer, thermometer, light sensor.

Sensor	*System Value*	*Type*	*Description*	*Primary Role*
Accelerometer	TYPE_ACC ELEROMETER	Hardware	Measures acceleration along X, Y, and Z axes, including gravity (m/s^2).	Detects movement and orientation.
Gyroscope	TYPE_GYROSCOPE	Hardware	Measures angular rotation rate along the three axes (rad/s).	Detects rotation of the device.
Light Sensor (Photometer)	TYPE_LIGHT	Hardware	Measures ambient light level in lux (lx).	Adjusts screen brightness based on ambient light.
Magnetometer	TYPE_MAGNETIC _FIELD	Hardware	Measures the geomagnetic field along three axes (μT).	Measures magnetic field; functions as a compass.
Orientation Sensor	TYPE_ORIENTATION	Software	Measures the rotation angles of the device along the three axes.	Determines spatial orientation of the device.
Barometer	TYPE_PRESSURE	Hardware	Measures atmospheric pressure in hPa or mbar.	Tracks pressure variations; estimates altitude.
Proximity Sensor	TYPE_PROXIMITY	Hardware	Detects the proximity of an object in centimeters (cm).	Detects if the phone is held near the ear during a call.
Thermometer	TYPE_TEMP ERATURE	Hardware	Measures internal device temperature in Celsius (°C).	Monitors the device's thermal condition.

Table II. 1: Main Smartphone Sensors

3. Sensor Definitions

3.1. Accelerometer

The accelerometer measures the device's acceleration along the X, Y, and Z axes. These data can be used to calculate speed and estimate changes in the device's position. Combined with orientation data, it plays a key role in movement tracking.

3.2. Gyroscope

The gyroscope operates on the principle of angular momentum conservation. It measures the angular position or rate of rotation around one, two, or three axes, providing precise orientation information.

3.3. Camera

The camera is an optical device used to capture still or moving images (video). It helps document visual signs of road degradation or complement geolocation data.

3.4. Magnetometer

This device measures the intensity and direction of a magnetic field. It helps determine orientation relative to the Earth's magnetic north.

3.5. GPS (Global Positioning System)

The GPS is a satellite-based positioning system managed by the United States government. It provides accurate geographical coordinates (latitude, longitude, and altitude) of the device.

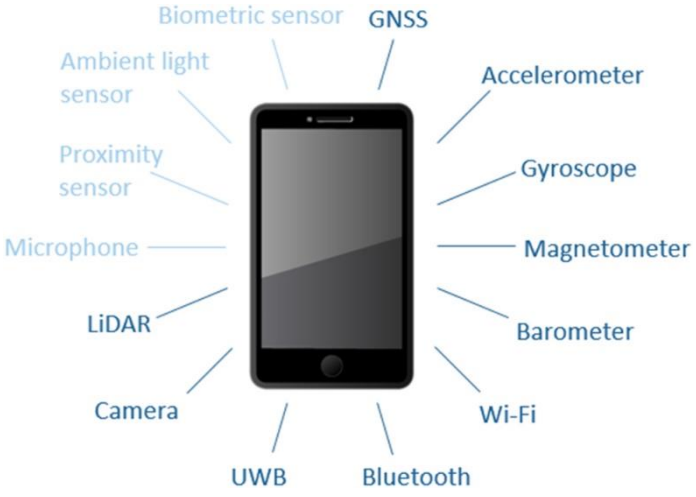


Figure II. 1: Main Smartphone Sensors

4. Possibility of Geolocation via GPS

The GPS sensor (or GNSS – Global Navigation Satellite System) enables precise geolocation of each detected road degradation.

- **Accuracy**: Under optimal conditions, accuracy can reach 3 to 10 meters with modern smartphones [3].
- **Possible improvement:** Filtering algorithms (such as Kalman filters or trajectory smoothing) can be used to compensate for signal errors.
- **Spatio-temporal association**: Each detected degradation can be linked to a specific location and timestamp, facilitating mapping and temporal monitoring.

5. Comparison Between Smartphone-Based Surveys and Traditional Methods

The traditional methods used for diagnosing pavement conditions include:

Method	*Description*
Manual visual inspection	Performed by field agents who record defects (cracks, potholes, etc.) using paper forms or tablets.
Survey vehicles	Vehicles equipped with high-end sensors (LiDAR, laser profilometers, high-precision GPS, 3D cameras) that drive along roads to produce detailed models.
Mobile 3D scanner	Generates a high-density point cloud of the road profile; used for precision inspections.
Ground Penetrating Radar (GPR)	Used to probe internal pavement layers and identify moisture zones or structural weaknesses.
Topographic levels / total stations	Tools used occasionally to measure vertical settlements or deformations.

Table II. 2: Conventional Means of Road Degradation Survey

6. Coordinate Systems Used

6.1. Smartphone Systems

6.1.1 Motion Sensor System

This reference system is used by accelerometers, gyroscopes, and magnetometers.

- Oz: Perpendicular (screen facing upward)
- Oy: Parallel to the screen and pointing upward
- Ox: Perpendicular to both Ox and Oy axes

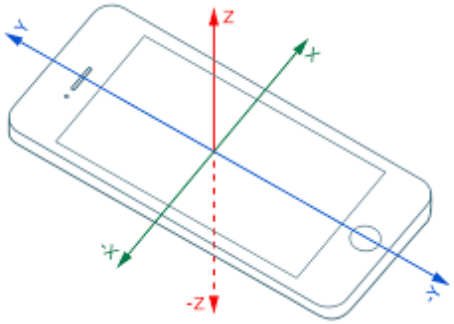


Figure II. 2: Motion Sensor Coordinate System.

6.1.2 Orientation Sensor System

- OX: Defined as the cross product OY × OZ. It is tangent to the ground at the device's current location and approximately points eastward.
- OY: Tangent to the ground and pointing toward the geomagnetic north pole.
- OZ: Points toward the zenith and is perpendicular to the ground plane.

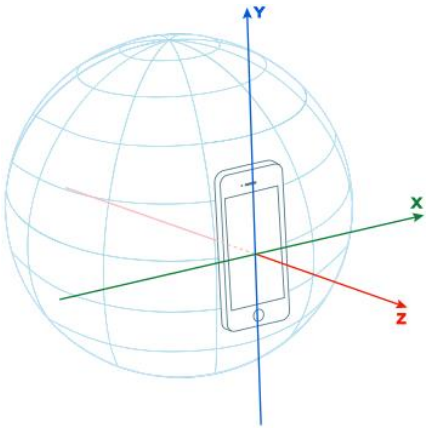


Figure II. 3: Orientation Sensor Coordinate System.

6.2. Image File Coordinate System

This is a two-dimensional (pixel-based) system with its origin at one of the image corners. Each pixel is identified by its row and column numbers (i, j).

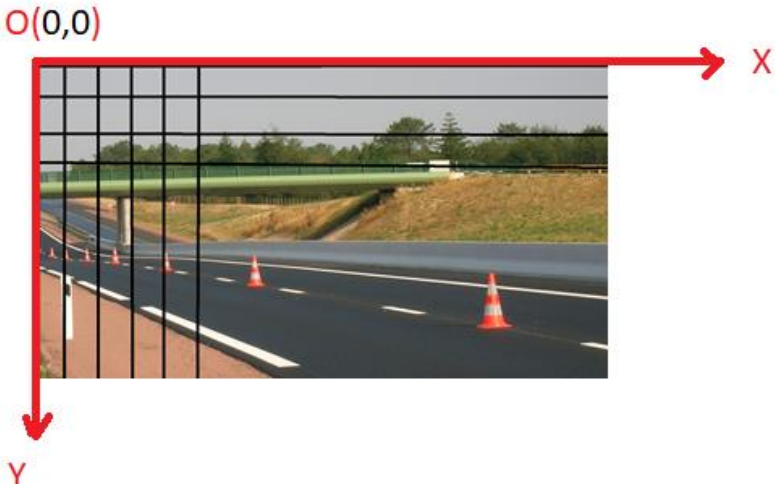


Figure II. 4: Image File Coordinate System. [13]

6.3. Image Coordinate System

Also, a two-dimensional system, where the center is the principal point. An image point is identified by its coordinates (x, y).

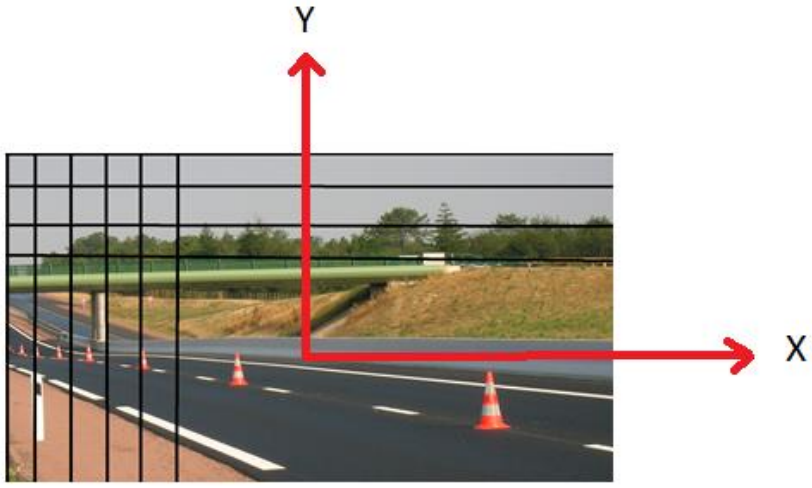


Figure II. 5: Image Coordinate System. [13]

6.4. Camera Coordinate System

This is a three-dimensional system obtained after internal orientation using image and calibration data. The origin is the camera's optical center (camera center). Each point is defined by its three coordinates (x, y, -c) [13].

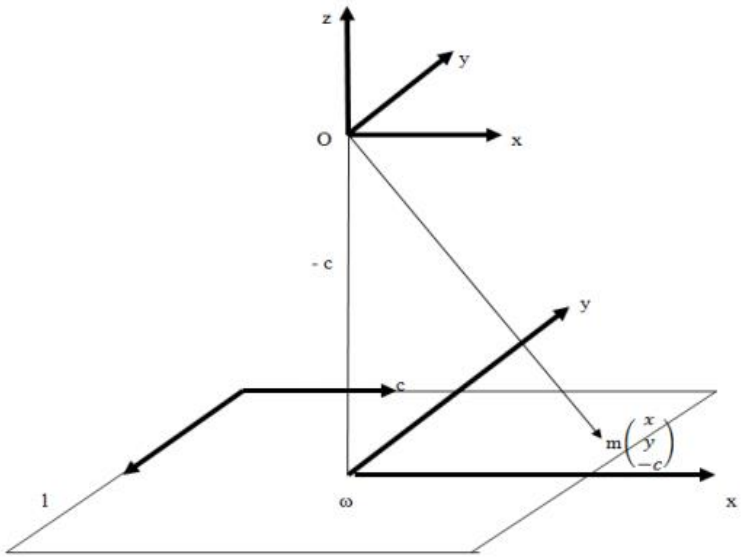


Figure II. 6: Camera Coordinate System. [cts2019]

6.5. Vehicle Coordinate System

The vehicle coordinates system follows the ISO convention for rotation. Each axis is positive in the clockwise direction when looking in the positive direction of that axis.

Typically, the origin is placed on the ground directly under the central point of the rear axle. Locations in this coordinate system are expressed in metric units.

Values returned by individual sensors are converted into the vehicle coordinate system to ensure a unified reference frame.

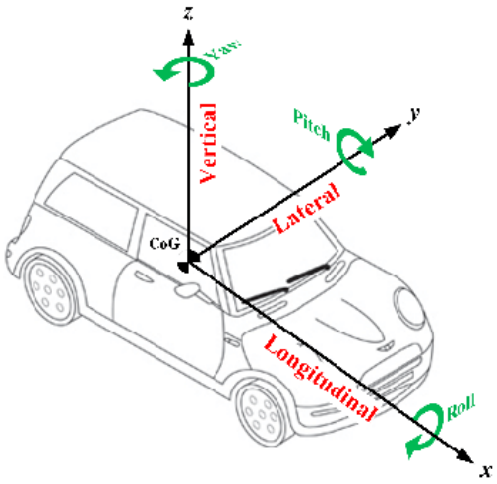


Figure II. 7: Vehicle Coordinate System.

6.6. North-East-Up (ENU) System

Also called the Local Tangent Plane (LTP), this geospatial coordinate system is commonly used in aviation to represent state vectors. It consists of three axes:

- The first points northward (NORTH)
- The second points eastward (EAST)
- The third is perpendicular to the plane formed by the first two, following the right-hand rule (UP)

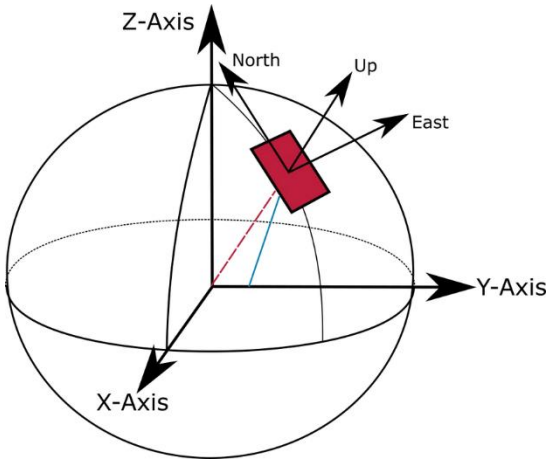


Figure II. 8: North-East-Up System.

6.7. Geographic Coordinate System

This is a three-dimensional system, where each point is defined by:

- Latitude,

- Longitude,
- and Altitude (or Elevation).

These geographic coordinates are based on a geodetic system that models the shape of the Earth.

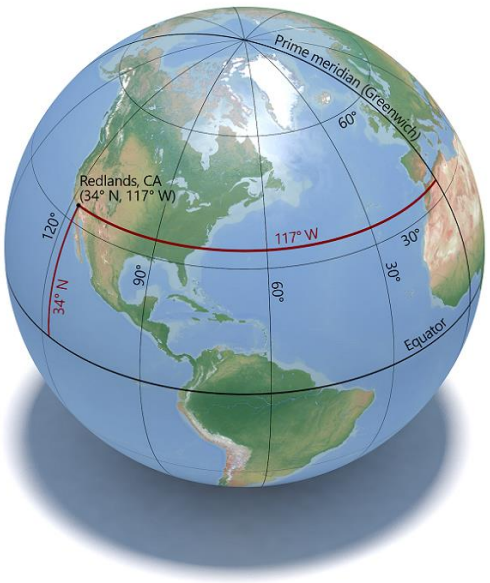


Figure II. 9: Geographic Coordinate System

In this section, we present the "Road Recorder" program, an Android application for data acquisition via smartphone, developed at the Centre of Space Techniques (CST Arzew) in 2019.

7. Description of Road Recorder

It is an Android application designed to capture data in the form of video images, which are essential for the research and detection of pavement surface deteriorations [13].

7.1. Permissions Required by Road Recorder

Every Android application requires permissions to access various internal components and apps on the phone.

- *Storage: Allows access to the smartphone's internal storage.*
- *Phone: Allows access to the phone's information status.*
- *Location: Allows access to GPS location information.*

- *Camera: Allows access to the camera sensor to take photos or record videos.*
- *Microphone: Allows access to the microphone.*

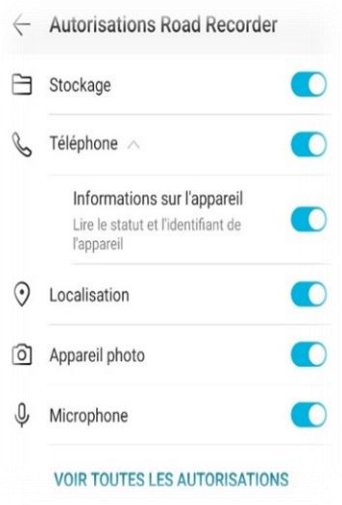


Figure II. 10: Les autorisations [13].

7.2. Using Road Recorder

The Road Recorder application is easy to use, but before starting, the smartphone's location services must be activated. Once location is enabled, the app is launched and a project name is assigned (Figure 44.a). The record button (Figure 44.a) starts video recording, smartphone geolocation, and sensor data collection. The button label changes from "RECORD" to "STOP" (Figure 44.b). When the data collection mission is completed, press "STOP". A message appears in the center of the screen (Figure 44.c): "file saved".

7.3. Recorded Data

The data is saved in two **.txt** files, one for positioning data and the other containing sensor recordings, along with a video file in ***.mp4*** format. All recorded projects are saved in the same folder named "Road Recorder", and each project is stored under its specific name (Figure II.11).

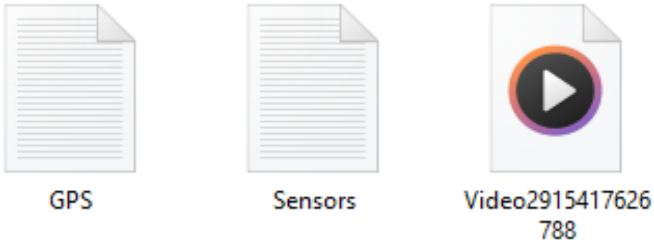


Figure II. 11: Data captured in a "Road Recorder" project.

The GPS location file is named “GPS.txt”, and its structure is as follows:

ID , ***Longitude*** , ***Latitude*** , ***Altitude*** , ***Accuracy*** , ***Speed***(m/s) , ***Time***.

The recording frequency is once per second (Figure 46).

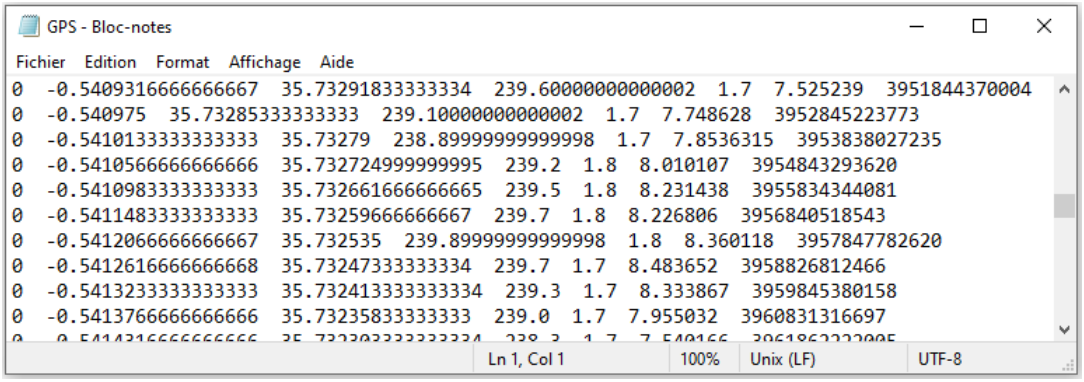


Figure II. 12: Data Recorded in the Position File

8. Conclusion

In summary, this chapter highlighted how smartphone technology—particularly built-in sensors and GPS capabilities—can support efficient and low-cost road condition monitoring. The classification and functionality of hardware and software sensors were detailed, alongside the coordinate systems essential for interpreting their output. The *Road Recorder* application serves as a practical implementation of this approach, offering a simple yet effective way to geolocate pavement deterioration and support future maintenance strategies.

Chapter III

Study Area

1. Introduction

This chapter presents the study area selected for the implementation of our road degradation detection approach. The focus is on a section of the East-West Highway, one of Algeria's largest infrastructure projects, passing through the provinces of Constantine and Mila. The chapter provides an overview of the geographical location, demographic context, and strategic importance of this corridor. It also includes an analysis of the topographic, climatic, and geological characteristics of the area, which are essential for understanding the environmental and structural constraints that influence road behavior and degradation.

2. Algerian Highway East-West

This map illustrates the East-West Highway, considered one of the most important infrastructure projects in Algeria [7]. It stretches from the Moroccan border in the west to the Tunisian border in the east, covering a distance of more than 1,200 kilometers. The East-West Highway connects major cities in northern Algeria and passes through around 24 provinces (wilayas), including Tlemcen, Oran, Mostaganem, Chlef, Aïn Defla, Algiers, Boumerdes, Bouira, Bordj Bou Arreridj, Sétif, Mila, Constantine, Annaba, and El Tarf.

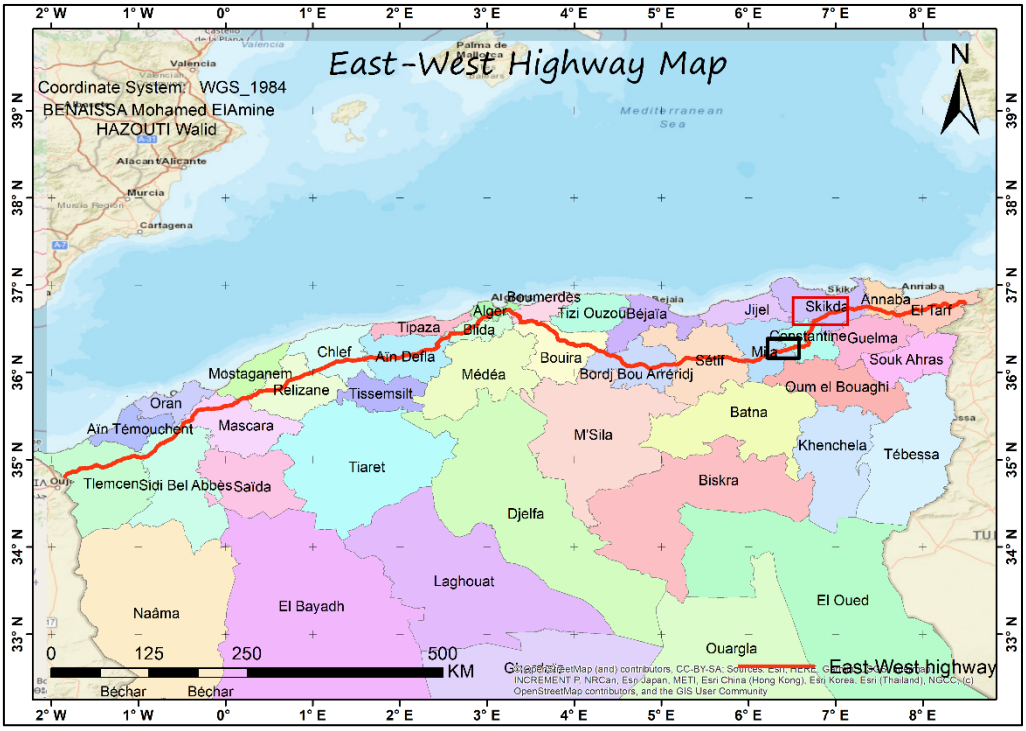


Figure III. 1: Map of highway East- west

It serves as a vital corridor for the movement of goods and people, facilitating links between coastal plains and inland highlands, and thus contributing to economic and social development along its road.

3. Study area location

The East-West Highway passes through the provinces of Constantine and Mila, both situated in eastern Algeria. The provinces surrounding Constantine and Mila are:

- To the North: Jijel and Skikda, two coastal provinces bordering the mediterranean Sea.
- To the East: Guelma, located near the country's eastern border.
- To the South: Oum El Bouaghi and Batna, situated in the mountainous Aurès region.
- To the West: Sétif, a major province in the High Plateaus region.

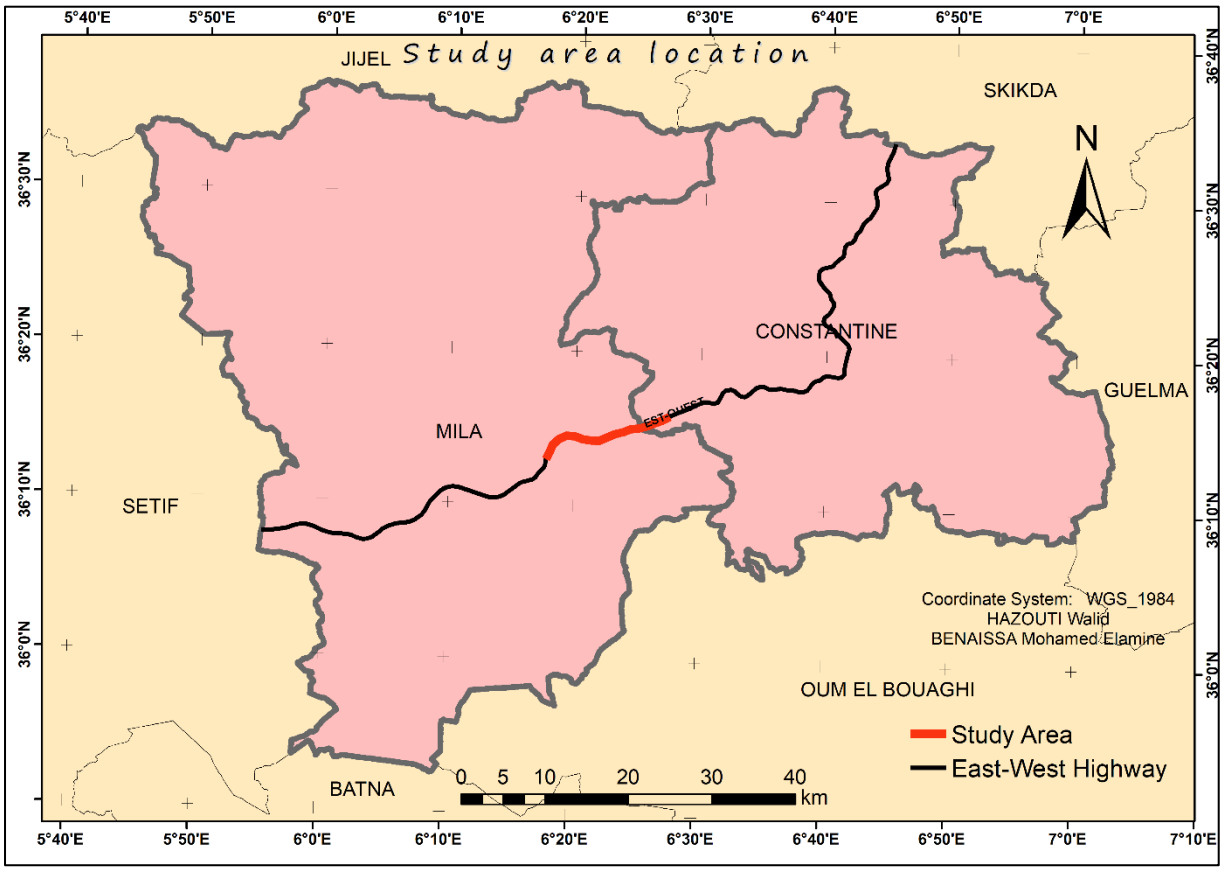


Figure III. 2: Study area location

This map shows the boundaries of Constantine (in red) and Mila (in green) in eastern Algeria, highlighting the road of the East-West Highway in black as it passes through them. This highway is considered a strategic corridor connecting various regions of the country from the Moroccan border in the west to the Tunisian border in the east.

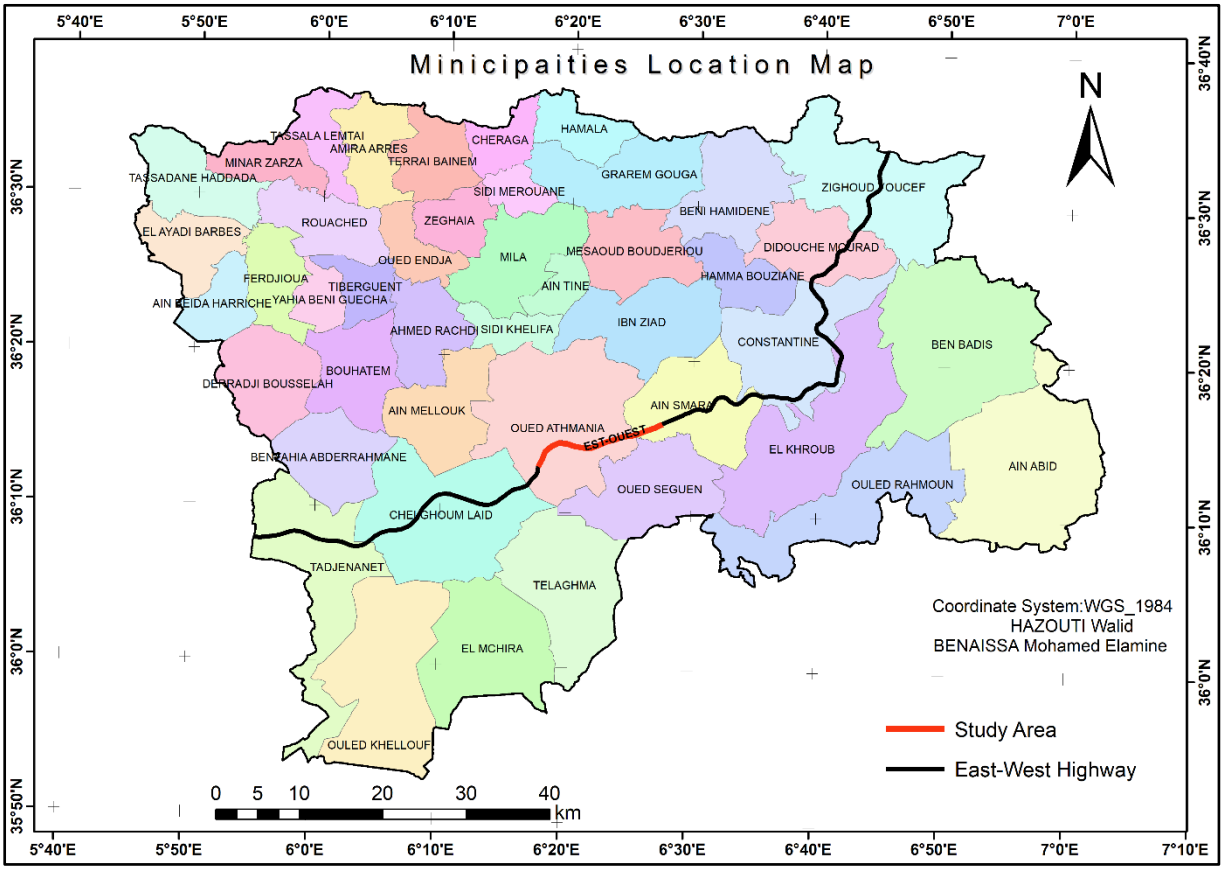


Figure III. 3: study area municipalities location

In the Wilaya (province) of Mila, the black line can be seen passing mainly through the communes of Chelghoum Laïd, Téléghema, Oued Athmania, and Zeghaia, before heading eastward toward the Wilaya of Constantine.

In the Wilaya of Constantine, the highway enters from the western side of the province, passing through El Khroub and Aïn Smara, then continues toward the eastern outskirts of the province, linking with other areas such as Didouche Mourad, before moving on toward neighboring eastern provinces.

4. Study area population (1998)

A presentation of the main municipalities through which the East-West Highway passes in the wilayas of Constantine and Mila, referring to approximate population estimates from 1998 based on the statistical data available at that time:

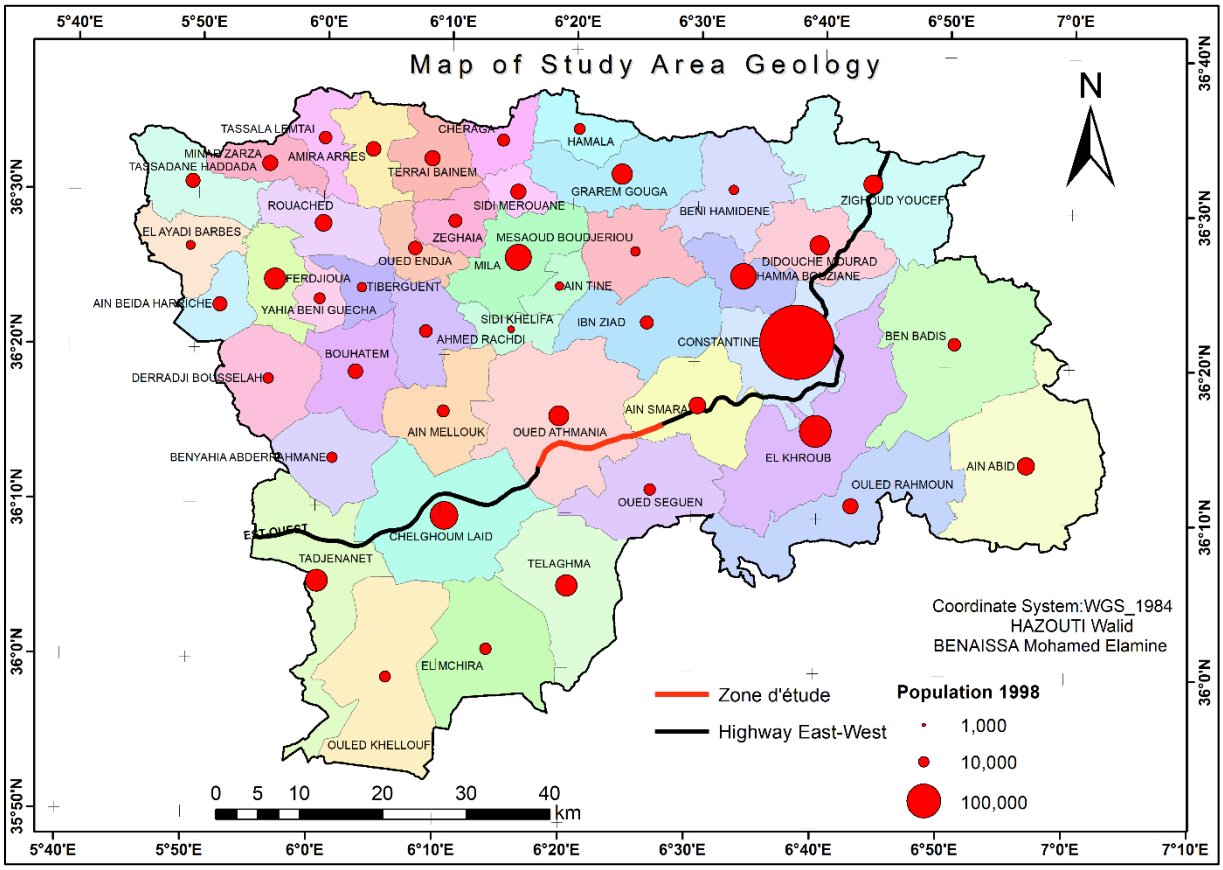


Figure III. 4: Study area population

A presentation of the main municipalities through which the East-West Highway passes in the wilayas of Constantine and Mila, referring to approximate population estimates from 1998 based on the statistical data available at that time:

4.1. First: Municipalities in Mila

- Chelghoum Laïd: Considered one of the largest population centers in Mila, it enjoys a strategic location on the East-West Highway, making it an important transit point.
- Oued Athmania: Its population was estimated at around 20,000 inhabitants (1998). Passage through this municipality is crucial for connecting southern areas of Mila to the highway's main road.

4.2. Second: Municipalities in Constantine

- Constantine: Its population was estimated at about 100,000 inhabitants (1998).
- Aïn Smara: Considered one of the most important districts in the wilaya, it serves as the western gateway to Constantine on the East-West Highway. Aïn Smara has been experiencing urban expansion due to its proximity to Constantine's city center.
- Didouche Mourad: Located in the northern part of the wilaya, it is crossed by the East-West Highway heading toward the eastern wilayas.

4.3. Importance of the East-West Highway for These Municipalities

- Economic Development: The highway's presence attracts investment, improves the movement of goods and merchandise, and fosters the development of industrial and service sectors.
- Enhanced Connectivity: It facilitates access to neighboring wilayas, ports, and airports, positively influencing job opportunities and local development.
- Reduced Travel Time: It shortens distances and travel times between the eastern and western parts of the country, enhancing overall connectivity among various regions.

5. Study area DTM

The East-West Highway passes through diverse terrain, with elevations ranging from about 64 meters to more than 1,500 meters above sea level. Overall, the following points can be noted regarding the section on which the highway was built:

Low to medium elevations (green and yellow colors): The highway begins in areas with relatively low elevations. These areas are generally less rugged, which simplifies construction and reduces the need for complex engineering works such as long bridges and tunnels.

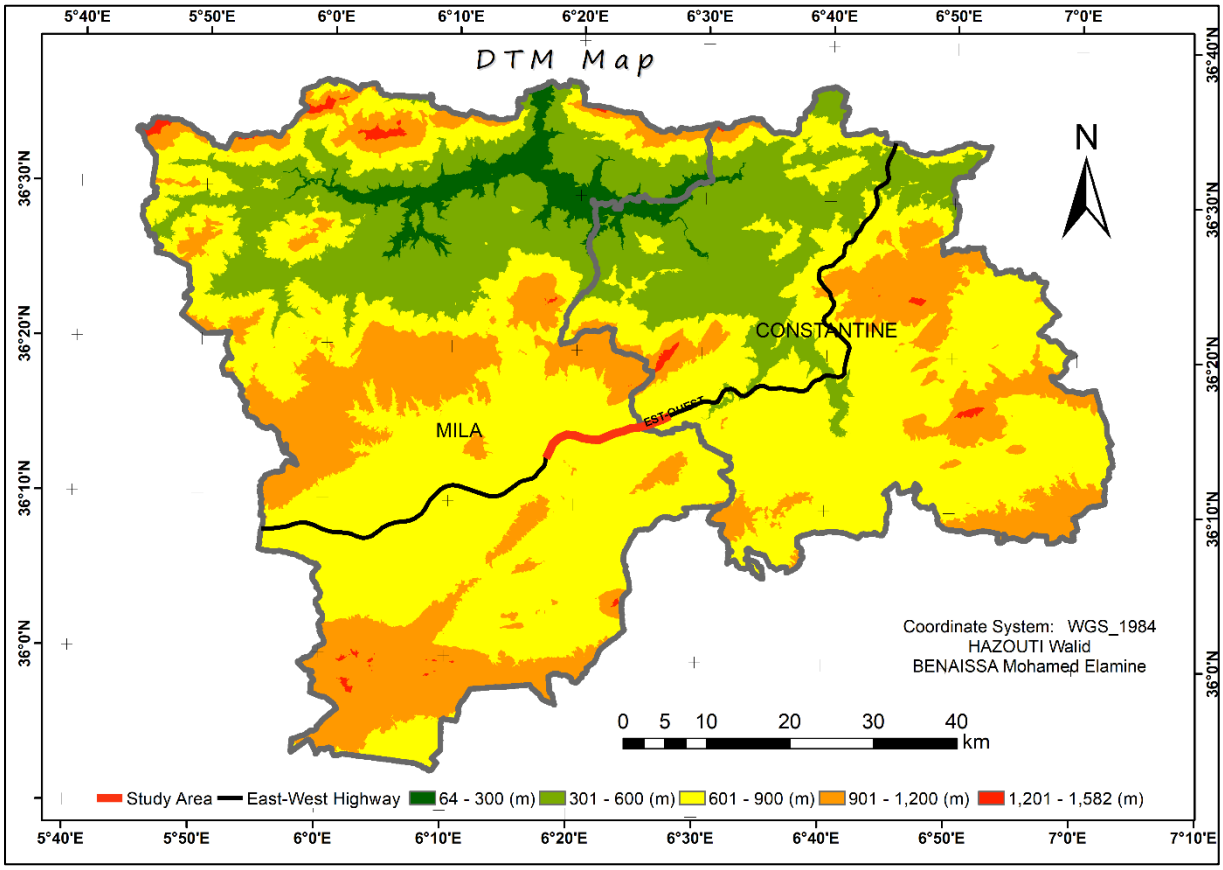


Figure III. 5: Study area DTM

Transition toward higher elevations (orange and red colors): As one moves eastward or into the higher-elevation sections, the terrain rises. In these areas, building the highway requires more extensive engineering studies and may involve the construction of bridges, tunnels, or soil leveling to make the road suitable for traffic.

Road selection and avoidance of extreme elevations: Overall, the highway was designed to steer clear of the steepest elevations (indicated by red) as much as possible, in order to lower construction costs and reduce geological risks (such as landslides or rockfalls). Consequently, most of the highway traverses moderately elevated terrain, ensuring smoother traffic flow and easier maintenance in the future.

The Digital Elevation Model (DEM) shows that the section of the East-West Highway benefits from a road selection that takes into account the varying

topography. This approach minimizes the need for complex engineering in high mountainous regions and capitalizes on moderate elevations to create a highway that facilitates travel and reduces overall costs.

6. Study area slope

The East-West Highway traverses areas with varying slopes. Several key points regarding its road and its relationship with the terrain can be noted:

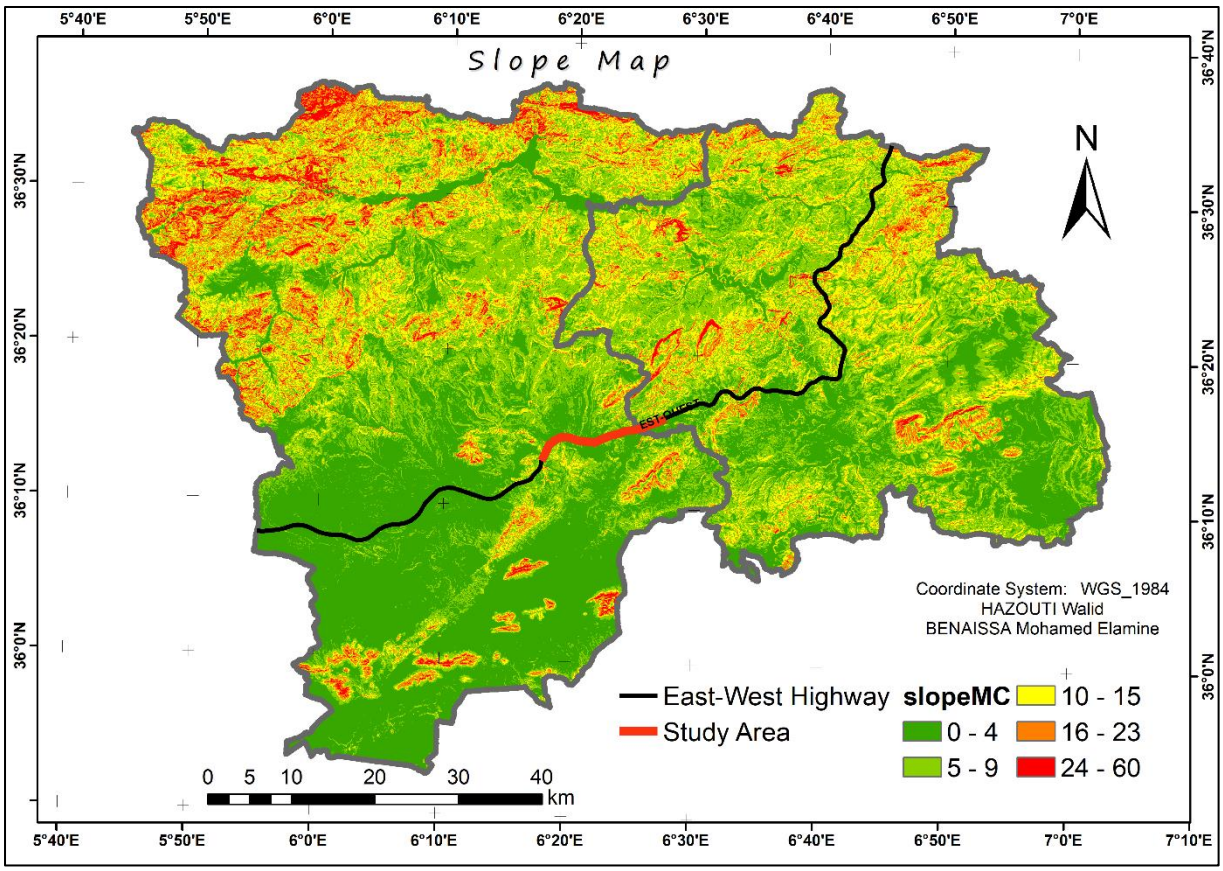


Figure III. 6: study area slope

6.1. Avoiding Steep Slopes

The highway mostly passes through areas shaded in green, which represent flat or gently sloping lands (0 to 4.25 degrees). This choice is an engineered strategy to reduce construction costs, such as excavation and backfilling, and to facilitate easier maintenance later on.

6.2. Roading Through Moderate Slopes

There are sections where the highway passes through areas shaded in yellow and orange (4.25 to 14.90 degrees), indicating more rugged terrain.
In these areas, it is likely that engineering structures such as bridges are required, especially if the highway passes over hills or plateaus.

6.3. Avoiding Very Steep Areas (Red Zones)

It is evident that the highway largely avoids areas with very steep slopes (represented in red), where slopes exceed 23°.
In such regions, it is generally preferable to look for safer alternatives or to use special techniques, such as stabilizing the slopes with barriers or retaining walls.

6.4. The Importance of the Road in Enhancing Connectivity

The highway facilitates travel between urban and rural areas, especially in the wilayas of Constantine and Mila, linking several key municipalities such as El Khroub, Chelghoum Laïd, Oued Athmania, and Aïn Smara. It also promotes economic development by connecting areas with agricultural and industrial activities to national and international markets.

The slope distribution on the map highlights the significant impact of topography on the planning of the East-West Highway. Its road has been carefully selected to avoid rugged terrain, minimize costs, and ensure the highway's long-term sustainability across areas with diverse topographical features.

7. Study area aspect

This map illustrates the distribution of slope aspects (Aspect) in the study area (the wilayas of Constantine and Mila), based on eight main directions (North, Northeast, East, Southeast, South, Southwest, West, and Northwest). Each direction is shown in a different color on the map, indicating how the terrain slopes and the direction it faces.

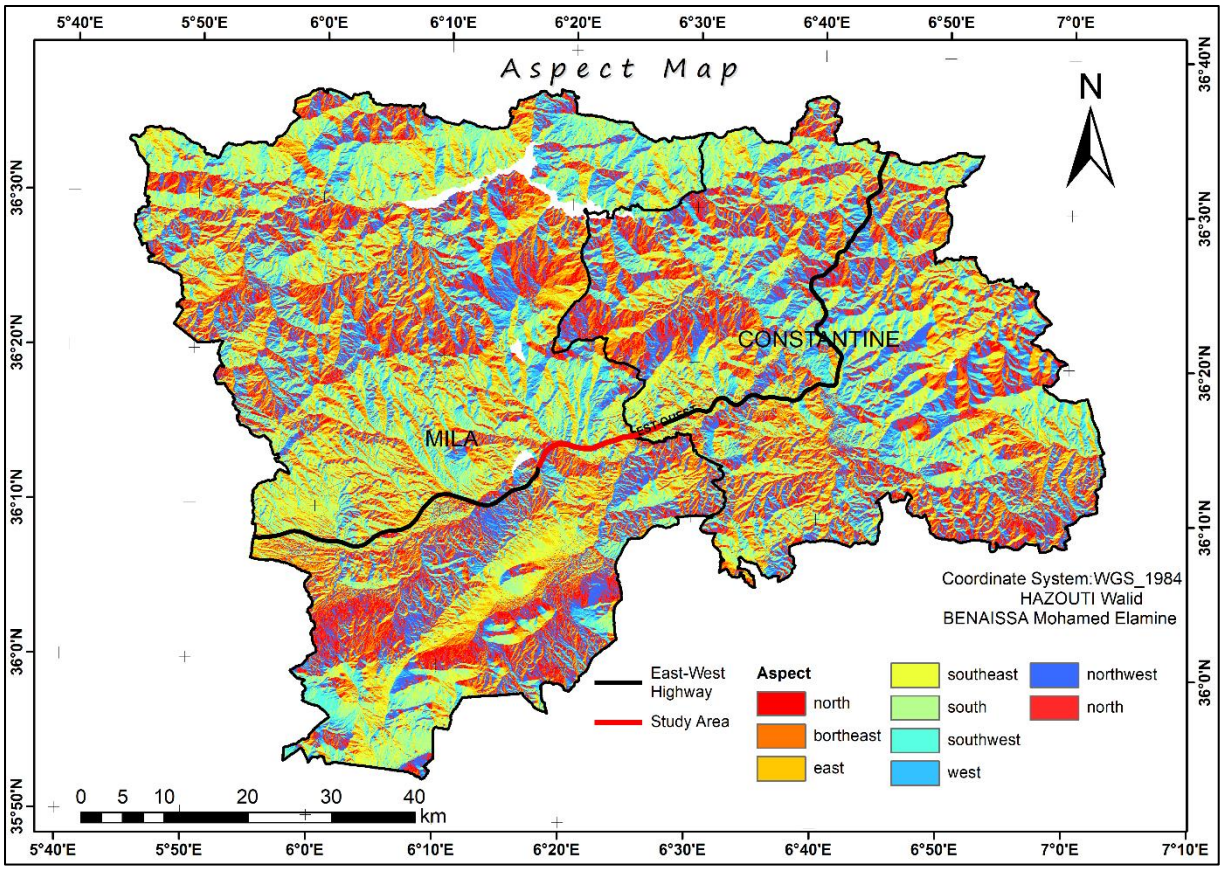


Figure III. 7: Study area aspect

The highway crosses areas with various slope aspects (different colors), which affects the nature of the construction work needed. When a slope faces a particular direction, specific engineering measures may be required for soil stabilization or rainwater drainage. In areas with slopes facing north or east, there is typically less direct sunlight, which impacts soil dryness and moisture levels. Conversely, in areas facing south and west, the soil is more susceptible to heat and dryness, necessitating special measures to maintain surface stability.

The East-West Highway road tries to avoid directions that could increase the risk of landslides or erosion (such as steep slopes facing the prevailing erosion factors in the region), aiming to minimize construction costs and ensure the road's long-term safety.

8. Importance of Understanding Slope Aspect in Road Planning

- **Stormwater Drainage:** Slopes facing certain directions may require additional drainage channels or flood control structures to prevent water from accumulating on the road or causing landslides.
- **Sunlight Exposure:** Helps in assessing the potential for snow and ice accumulation in cold areas, as well as estimating evaporation rates on the road surface.
- **Wind Protection:** Slopes oriented toward prevailing wind directions may need measures to protect the road from dust or sand carried by the wind.

The slope aspect model (Aspect) shows how the terrain is distributed in the study area and demonstrates how the East-West Highway traverses various topographical orientations. This diversity in slope aspects presents different engineering and environmental challenges, emphasizing the careful selection of the road to avoid risks, reduce costs, and ensure the highway's sustainability in the long run.

9. Study area precipitation

The map illustrates the distribution of rainfall in the provinces of Constantine and Mila, Algeria, based on a gradient of blue colors, where each shade represents a specific range of precipitation levels.

Analysis of the map based on geographical distribution of precipitation:

- Areas with the lowest precipitation (567 - 603 mm/year):

Represented by light blue color and mainly located in the southern parts of Mila province, near Batna and Oum El Bouaghi. This indicates that these areas receive lower amounts of rainfall compared to the northern regions.

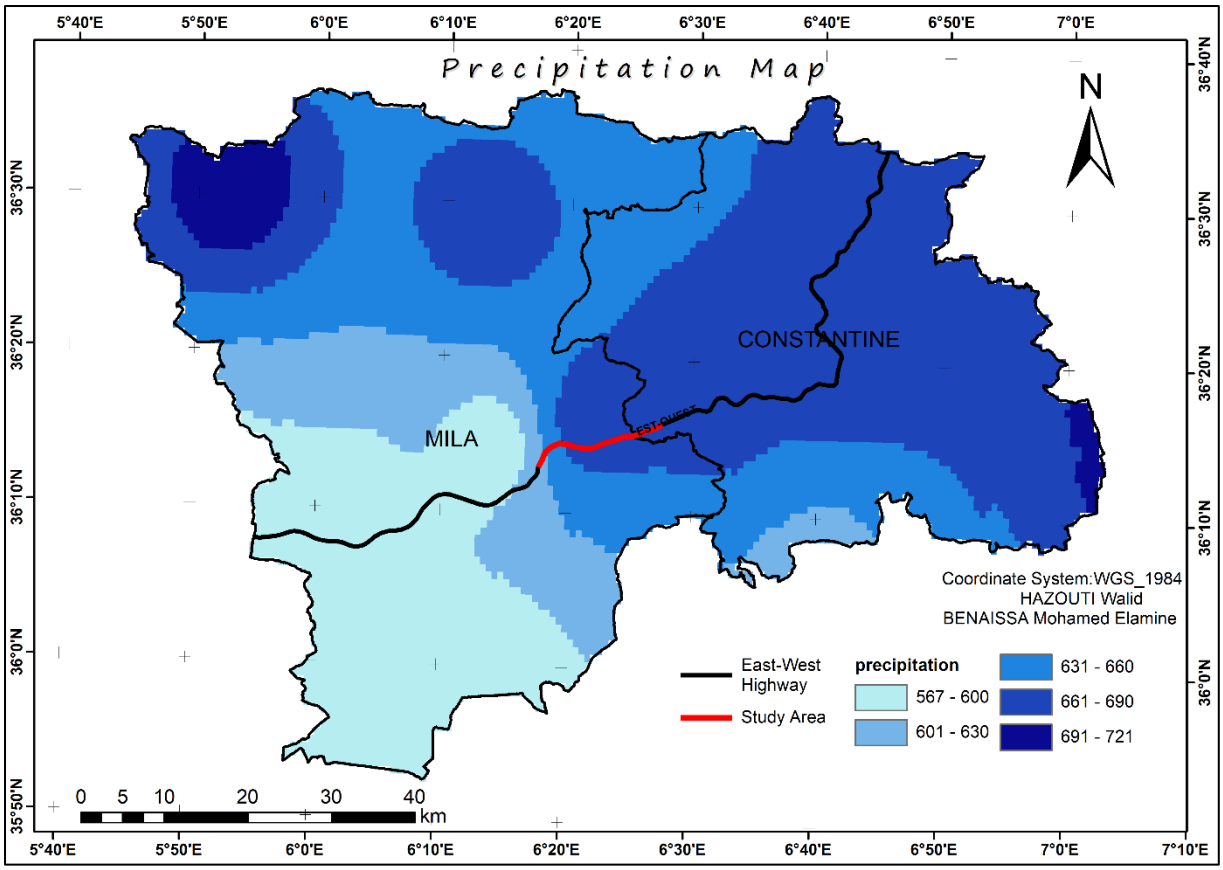


Figure III. 8: study area precipitation (https://power.larc.nasa.gov)

- Areas with moderate precipitation (603 - 662 mm/year):

Found in the central part of Mila province and parts of southern Constantine province. The blue color intensifies slightly, reflecting a moderate increase in precipitation levels.

- Areas with high precipitation (662 - 720 mm/year):

Located in northern Constantine and parts of Mila, especially in areas near Jijel and Skikda.

The dark blue color signifies the highest rainfall rates, which is expected due to the proximity to the sea and the influence of a humid climate.

The northern regions of Constantine and Mila receive more rainfall compared to the southern areas. The topographical influence is evident, as the higher northern regions (closer to the coast) receive more rain than the lower inland areas. The information provided in this map can be useful for agricultural planning and water resource management in the region.

10. Map of Study Area Geology

This map illustrates the geological distribution of the study area, covering Constantine and Mila provinces. Different rock formations are represented by various colors, with the East-West Highway marked in black.

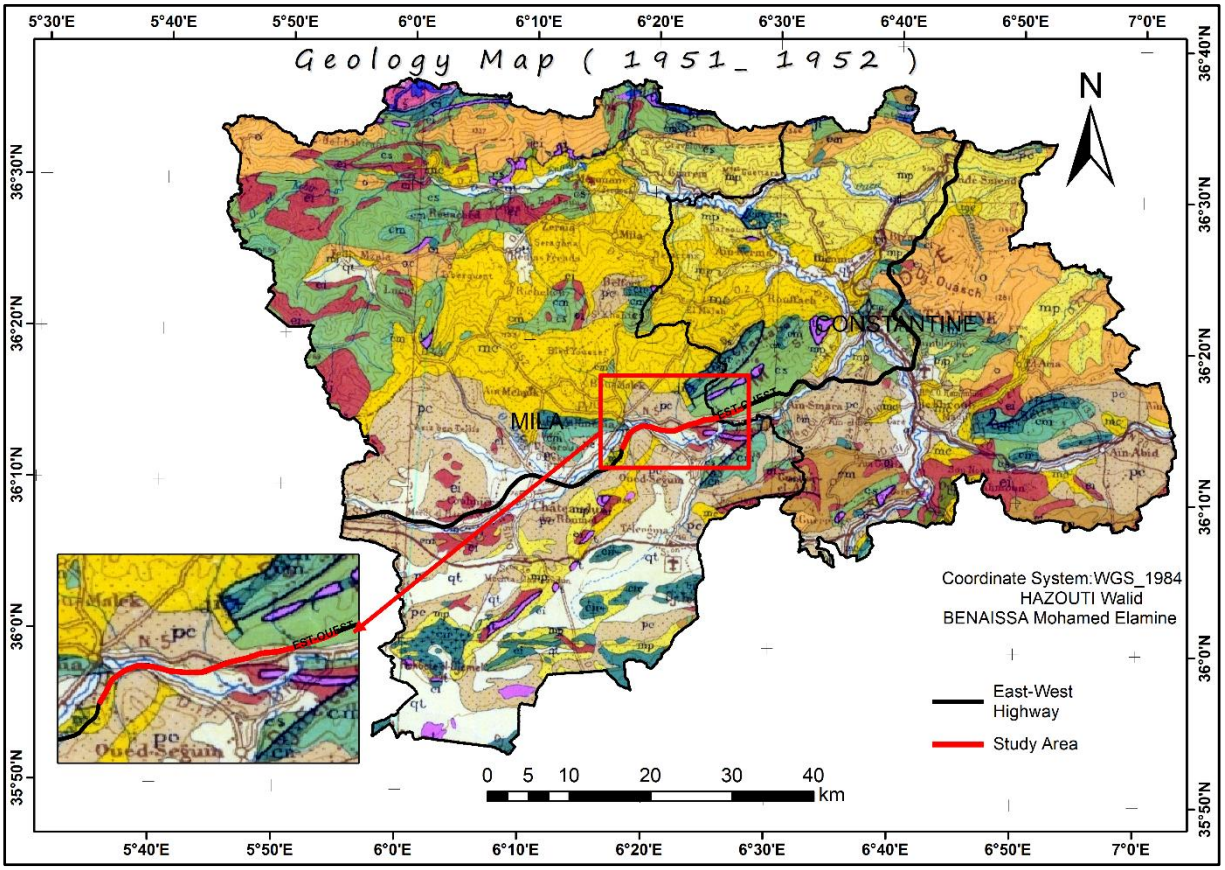


Figure III. 9: study area geology

10.1. Geological Features Analysis

- Cretaceous Formations:

Cover a large part of the region, especially in the central and eastern areas. Consist mainly of sedimentary rocks such as limestone and shale, which are suitable for infrastructure but may require additional stabilization in certain areas.

- Lower Cretaceous Formations:

Found in limited areas in the southern part of the region. Generally more stable compared to other formations but may contain soft layers that require reinforcement during road construction.

- Mesozoic Era Formations:

Located in the southwestern part of the region. Include sedimentary and metamorphic rocks, which may pose challenges during construction due to their hardness or tendency to fracture.

- Quaternary Formations:

Scattered throughout the region. Often consist of clayey or gravelly deposits, which may require additional stabilization for infrastructure development.

- Tertiary Formations:

Present in some scattered areas. Mainly composed of soft sedimentary deposits, which may pose challenges in steeply sloped areas.

- Tertiary and Cretaceous Formations:

Spread across several areas, especially in the north and central parts. Represent a transitional zone between geological periods, containing rocks of varying hardness and stability.

- Triassic Formations:

Mainly found in the eastern part of the region. Consist of hard, metamorphic rocks, making them difficult to excavate for road construction without advanced engineering techniques.

10.2. Relationship Between the Highway and Geological Conditions

The East-West Highway crosses a diverse geological landscape, impacting the required infrastructure. In Cretaceous and Triassic areas, rock blasting or deep excavation may be necessary to level the road. In Quaternary and Tertiary areas, soil stability issues may arise, requiring additional engineering reinforcements. The highway avoids highly resistant rock zones wherever possible, except in areas where no alternative route was feasible.

This map highlights the significant geological diversity of the study area, which played a key role in determining the East-West Highway's route. The selection of the highway's path was not random but based on rock type analysis, soil stability,

and construction feasibility, ensuring long-term infrastructure safety and sustainability.

11. Conclusion

In conclusion, the chapter has detailed the main physical and human features of the study area.

The selected section of the East-West Highway crosses a region with significant topographical diversity, variable precipitation, and complex geological formations. These factors directly impact road construction, maintenance, and degradation patterns.

Understanding these local characteristics provides a crucial basis for assessing the reliability and applicability of smartphone-based road monitoring techniques in this context.

Chapter IV

Experimental Approach and results

1. Introduction

As part of the preparation for conducting the field study aimed at monitoring pavement distresses along the East-West Highway (specifically between kilometer markers 152 and 170) a preliminary experimental phase was carried out within the university campus. This choice was made based on considerations of safety, logistics, and proximity, allowing for easy access and movement. Conducting data collection directly on the highway, which is characterized by heavy traffic and high-speed vehicles, could have posed a significant risk to the team.

In contrast, the university campus provided a controlled and safe environment, with minimal traffic flow, enabling the work to be carried out freely and securely.

Weekends and holidays were purposefully utilized to conduct this initial phase under optimal conditions, away from vehicular congestion and campus activity. This facilitated the efficient execution of tasks, including familiarization with the equipment, standardization of data collection protocols, and the development of consistent analysis procedure ensuring high-quality and accurate results.

It is important to note that the campus work was not a substitute for the actual study site, but rather a (crucial preparatory step) intended to test tools and methods, and to minimize potential errors prior to entering the project's main phase. The same procedures and methodologies were later applied in the targeted highway section.

In conclusion, the choice of the university campus was a (strategic and methodological decision), allowing the team to be well-prepared and ensuring readiness, while upholding safety standards and data quality. This integrated approach contributed to the effective and efficient achievement of the study’s objectives.

As part of the graduation project, a research study was conducted to assess road surface damages using a methodology based on three main approaches:

a. **Data collection using a total station equipped with GPS**, providing high-precision spatial measurements.

b. **Manual data collection through mobile phone photography**, combined with a ***Garmin GPS* device** to record geolocation coordinates.

c. **Automated data collection using mobile phone photography mounted on a moving vehicle**, allowing for efficient and continuous surveying of the road network.

2. Means used

2.1. Data used

HP EliteBook 840 G4 Base Model Notebook PC



Dell Latitude 5400



Samsung Rv520



Realme C25 Y and Redmi9



Leica TCRP 1203



Garmin GPSmap 62s



Vehicle Tucson (2014)



Field setup



2.2. Software used

ArcGIS (Map 10.8): Is a Geographic Information System (GIS) tool used to manipulate (store, process, analyze, manage, and present) all types of spatial and geographic data.

Google Earth Pro: is a software developed by Google that allows users to explore the Earth using satellite and aerial imagery. It enables visualization of images from various parts of the world, including 3D views, geographical data, maps, and other geospatial information.

Spyder (v6): is typically known as an integrated development environment (IDE) primarily used for scientific programming in Python.

Global Mapper: is a GIS software known for its simplicity and efficiency in managing spatial imagery. It was selected for its ability to directly display images based on embedded GPS data from EXIF[1] metadata, eliminating the need for complex georeferencing procedures.

[1] **EXIF** stands for **Exchangeable Image File Format**.
It is a standard format used to store **metadata** within image and video files captured by digital devices such as cameras and smartphones. Among the types of information that EXIF data can contain (The **date and time** the photo was taken; **Geographic coordinates** (GPS Latitude/Longitude); **Camera settings** such as shutter speed, aperture, ISO; The **model of the device** used for capturing the image).

ContextCapture: is a photogrammetry software developed by Bentley Systems, primarily used for generating 3D models from sets of photographs. In our case, it was utilized to extract individual frames from the recorded video at fixed time intervals, allowing for more precise spatial and temporal analysis of road surface conditions.

AutoCAD: is a computer-aided design (CAD) software developed by Autodesk. It is widely used in engineering, architecture, and construction for creating precise 2D and 3D drawings. In the context of this study, AutoCAD was used to visualize and edit spatial data, particularly the detailed mapping outputs generated from the total station survey.

Covadis (v17.0): is a civil engineering and surveying software that operates as an add-on to AutoCAD. It is commonly used for topographic surveys, road design, and infrastructure projects. In this study, Covadis was used in conjunction with AutoCAD to process and represent the topographic data collected by the total station, enabling the creation of detailed and accurate maps of the selected area.

At the beginning of the fieldwork, an exploratory tour was conducted across the university campus to gain a general understanding of the environment and to identify areas showing visible signs of pavement distress. This initial reconnaissance allowed us to plan our approach and to select the locations that best represented the overall condition of the infrastructure.

3. Surveying with a Total Station

As part of the preliminary stage of the project, total station surveying was carried out using a **Leica TCRP 1203** device to obtain high-precision spatial data. This method was implemented on a selected portion of the university campus, and allowed for the acquisition of highly accurate **(X, Y, Z)** coordinates for each surveyed point, with millimeter-level positional accuracy.

The survey focused on a sample of road surface distresses similar to those targeted in later methods. Each point was meticulously mapped, resulting in detailed topographic data that included elevation profiles and precise horizontal positions. These outputs were used to generate technical site plans and were particularly valuable for establishing a baseline understanding of the study area.



Figure IV. 1: survey using Leica TCRP1203



Figure IV. 2: Longitudinal crack releved

At the time, no smartphone-based data was yet available, so the total station data was not directly used for comparison. However, this high-accuracy dataset later served as a spatial reference for understanding the limitations and expected deviations of alternative, lower-cost methods.

Although extremely accurate, the method is resource-intensive and limited in scalability, making it less practical for large-scale or rapid surveys.

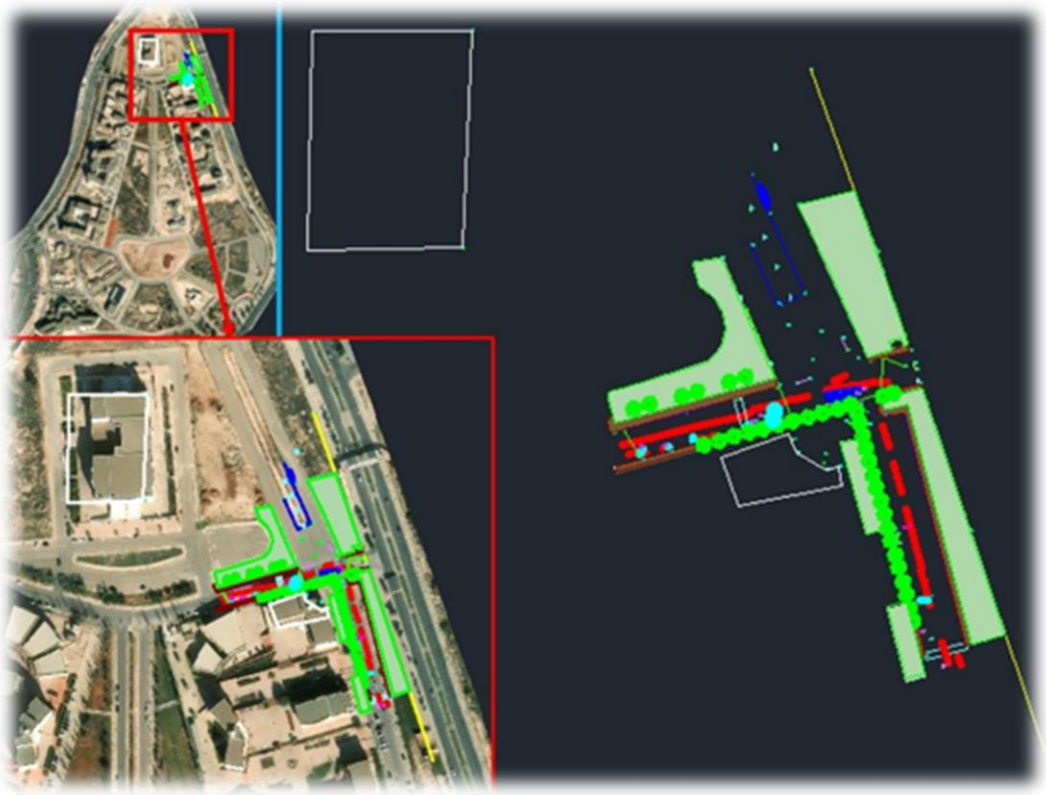


Figure IV. 3 conventionnel topographic survey

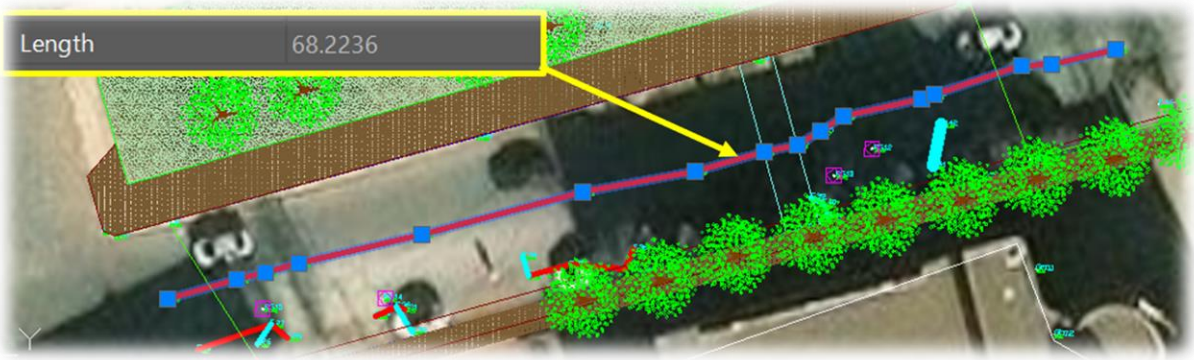


Figure IV. 4: Dimensions of longitudinal Crack

We proceeded with the first data collection method: **manual smartphone photography.**

4. Manual smartphone method

A ***Realme C25Y*** device was used, and before beginning the documentation, we ensured that all settings were properly configured. In particular, we **activated the GPS function** and made sure that **location data was embedded in the**

EXIF metadata of each image. This was essential for enabling later spatial analysis and accurately mapping the photos to their real-world positions.

The creation of **sketches (croquis)** and **signaletic forms (fiche signalétique)** was limited to **a selected subset of distress points**, chosen to represent the diversity of observed defects. This selective approach was due to the time-consuming nature of this step, which required detailed on-site measurements and descriptions.

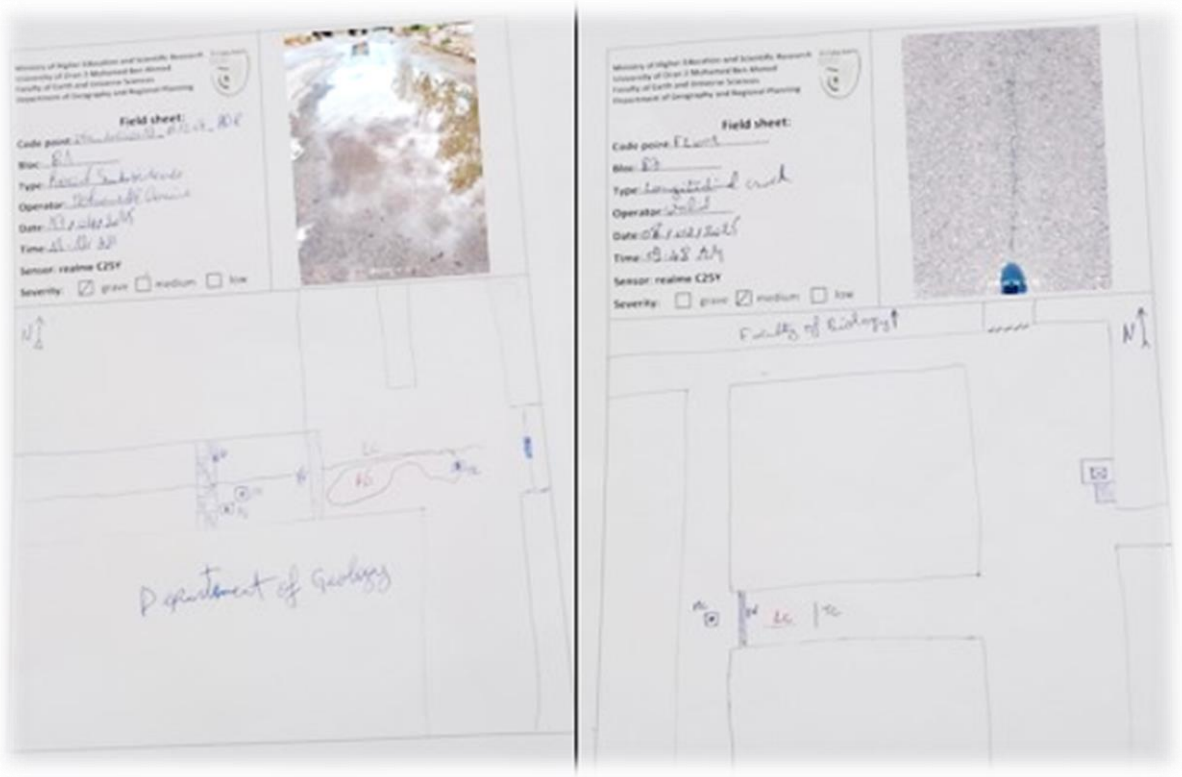


Figure IV. 5: Field sheets

Despite the simplicity of the method, it was physically demanding, requiring continuous field movement and direct engagement with each point of interest. Nevertheless, this approach enabled us to document eight major types of road surface distress (figure IV.5)

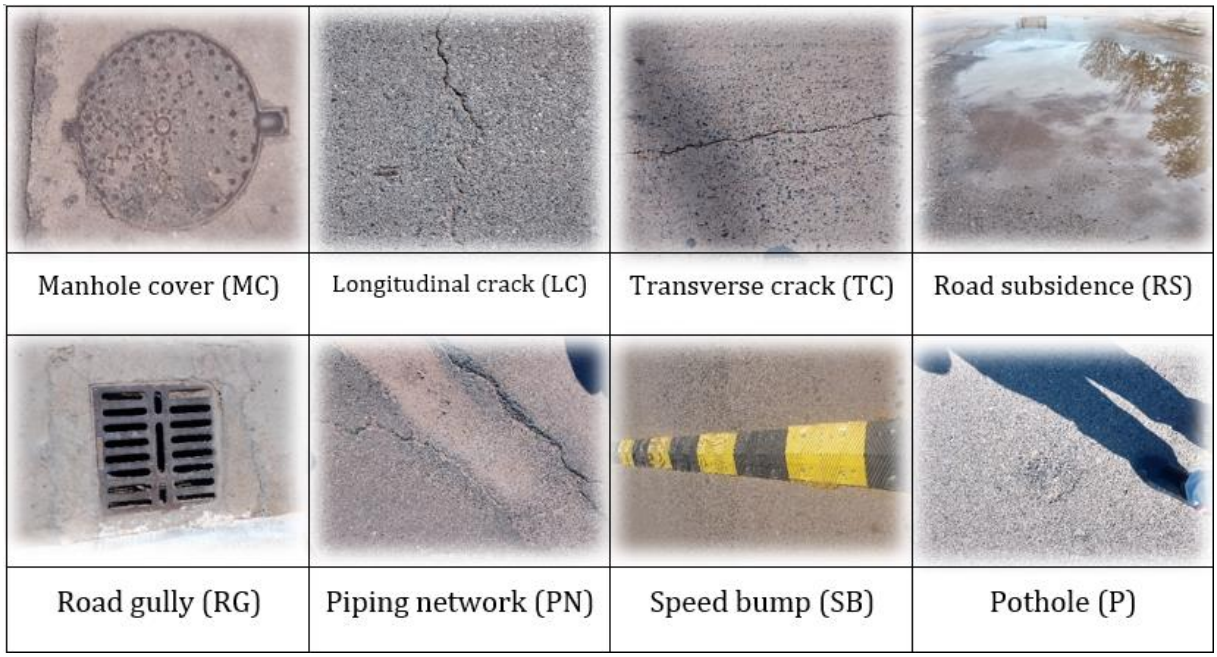


Figure IV. 6: All degradations releved

These categories provided a solid foundation for understanding the types of degradation present on campus roads and served as a primary dataset for comparison with subsequent methods.

After completing the classification of the road degradations, the next step was to visualize these points on a map in order to study their spatial distribution and analyze their patterns.

Initially, the geo-tagged images were imported into Global Mapper, a software chosen for its ease of use in handling images with embedded GPS coordinates. The program allowed us to display the photos at their exact geographic locations based on EXIF metadata, without the need for complex georeferencing procedures.

Subsequently, the data were exported and further processed using ArcMap 10.8. Within this GIS environment, we created feature layers representing the various types of recorded road distresses. This allowed us to generate thematic maps illustrating the distribution of surface defects across the university campus, which facilitated further analysis and comparison with other surveying methods.

validation campaign using a *Garmin GPSmap 62s*, which served as a more precise reference tool.

In this phase, a significant number of degradation points were surveyed using the Garmin device. These points were deliberately selected to match the locations previously documented by smartphone photography, ensuring that comparisons were made on the same spatial basis.

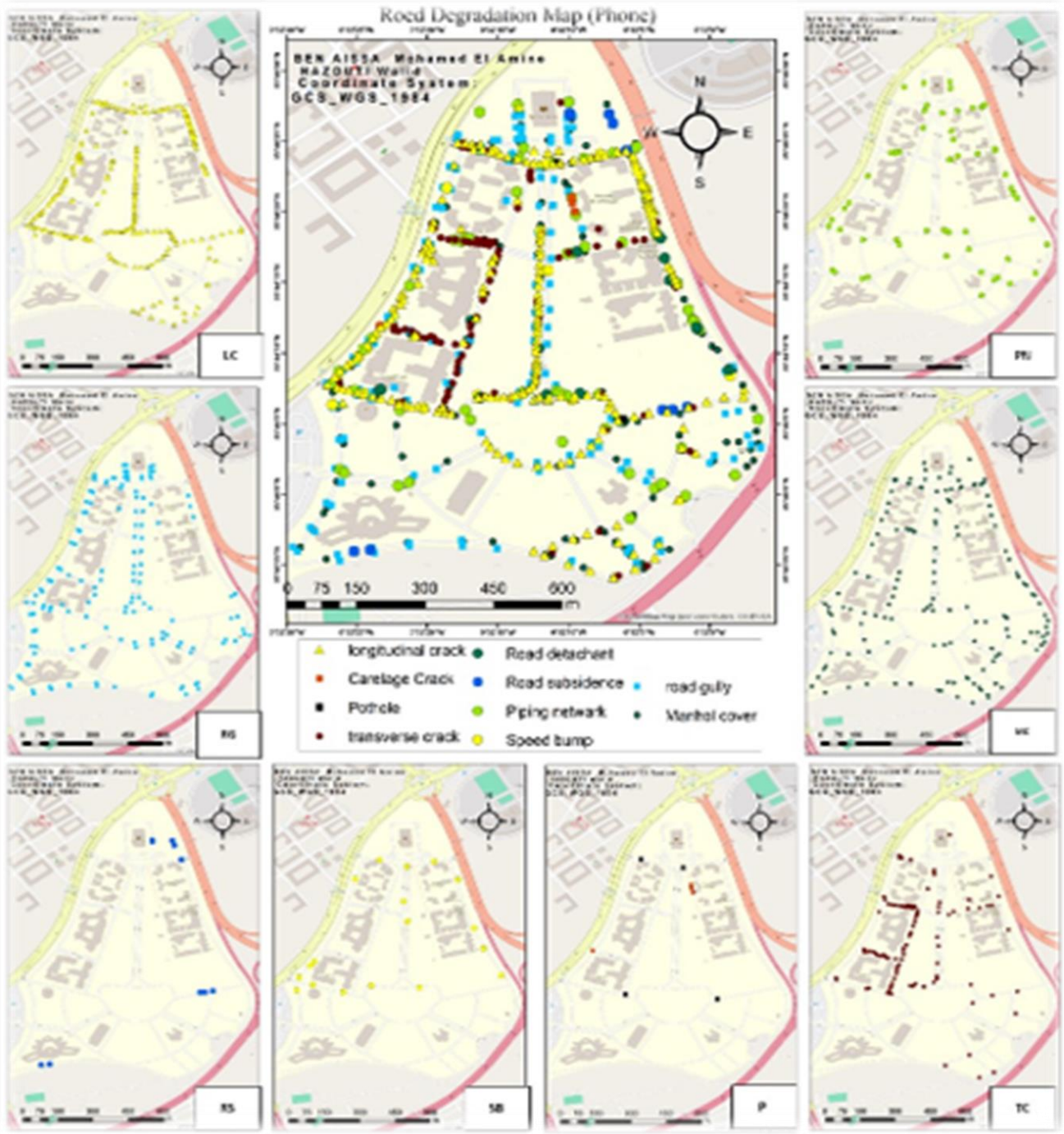


Figure IV. 7: mapping all degradations

The validation was performed on two levels:

4.1. Visual Comparison

Both the Garmin and smartphone-derived points were overlaid in a GIS environment (such as ArcMap). This allowed for a visual inspection of positional deviations. It was generally observed that the displacement between the two datasets ranged from *5 to 10 meters*, which is reasonably acceptable for mobile-based data collection.

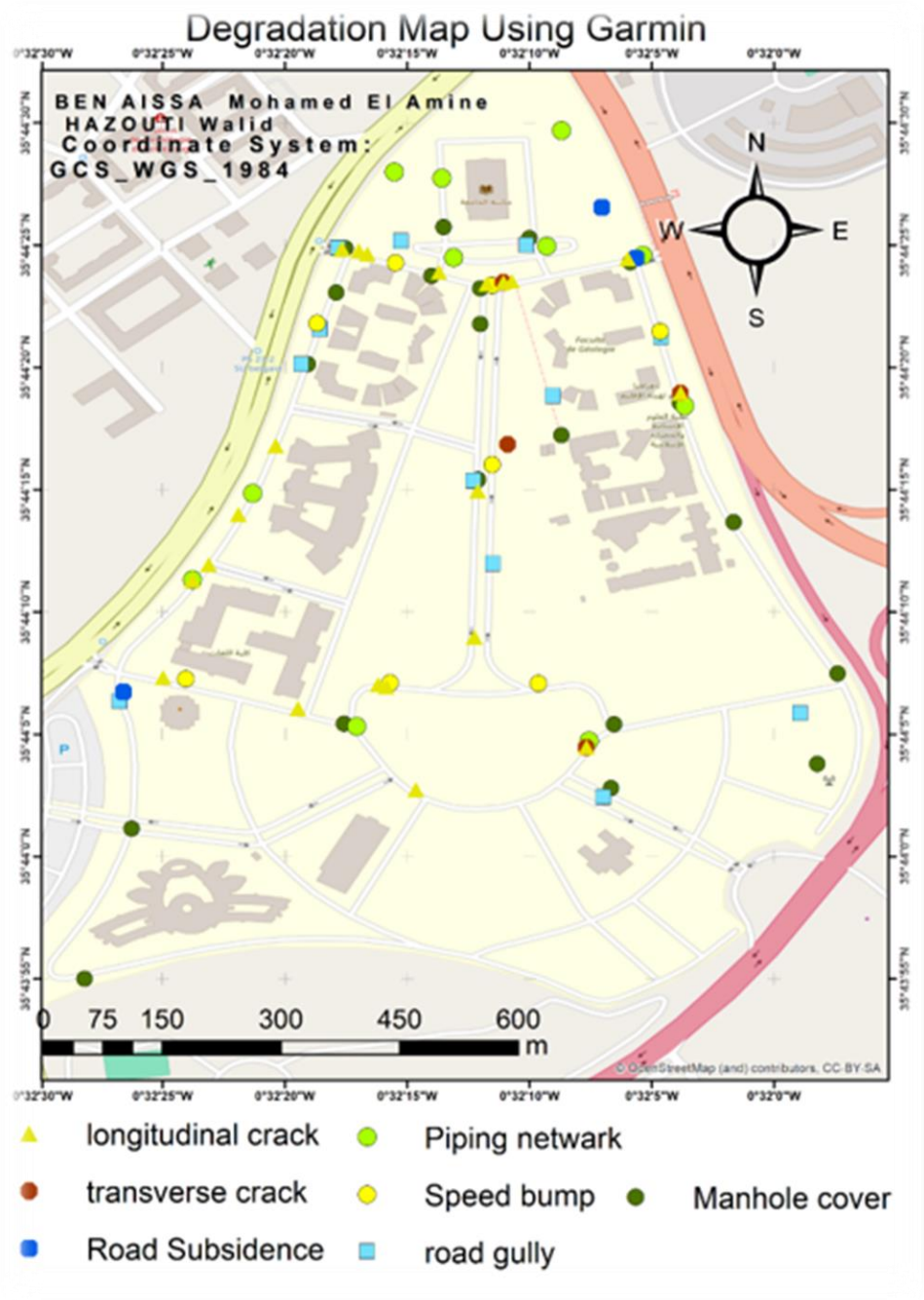


Figure IV. 8: Degradation map using garmin

4.2. Quantitative Assessment

Beyond visual analysis, we constructed a **confusion matrix** to assess how well the smartphone data matched the Garmin reference in terms of **correctly identifying the type of degradation at each point**. Based on this matrix, several **performance metrics** were calculated, including:

- **Evaluation metrics**

Accuracy	$\frac{TP}{\text{total points}}$
Recall	$\frac{TP}{TP+FN}$
Precision	$\frac{TP}{TP+FP}$
F1-score	$\frac{\text{Precision}\times\text{Recall}}{\text{Precision}+\text{Recall}} \times 2$

Table IV. 1: Evaluation metrics

Evaluation and confusion matrix Algorithm:

```
BEGIN
Read Garmin data from file "Degradation position (gamine).txt": Extract points as (X, Y, type).
Read Smartphone data from file "Degradation position (smartphone).txt": Extract points as (X, Y, type).
END READ DATA
        Compute Euclidean distance D = sqrt((X_g - X_s)^2 + (Y_g - Y_s)^2).
    END FOR
END FOR
FOR EACH Garmin point G(X_g, Y_g, type_g) DO:
    IF type_g == 0 (Not degraded) THEN:
        Search within a radius of 5 meters.
        IF no other class is found within the area:
            Match to itself.
        ELSE:
            Take the nearest Smartphone point (even if different type).
    ELSE:
        Search for a point of the same type within 10 meters.
        IF none is found:
            Select the closest Smartphone point regardless of type.
        END IF
    END IF
  END FOR
Initialize confusion matrix cm[n_classes][n_classes] to zero.
FOR EACH matched pair (G(type_g), S(type_s)) DO:
    Increment cm[type_g][type_s].
END FOR
FOR EACH class i DO:
    Precision(i), Recall(i), F1-Score(i), Support(i)
Calculate overall metrics (Macro Precision, Macro Recall, Macro F1-Score, Micro Precision, Micro Recall, Micro
F1-Score, Accuracy)
END
```

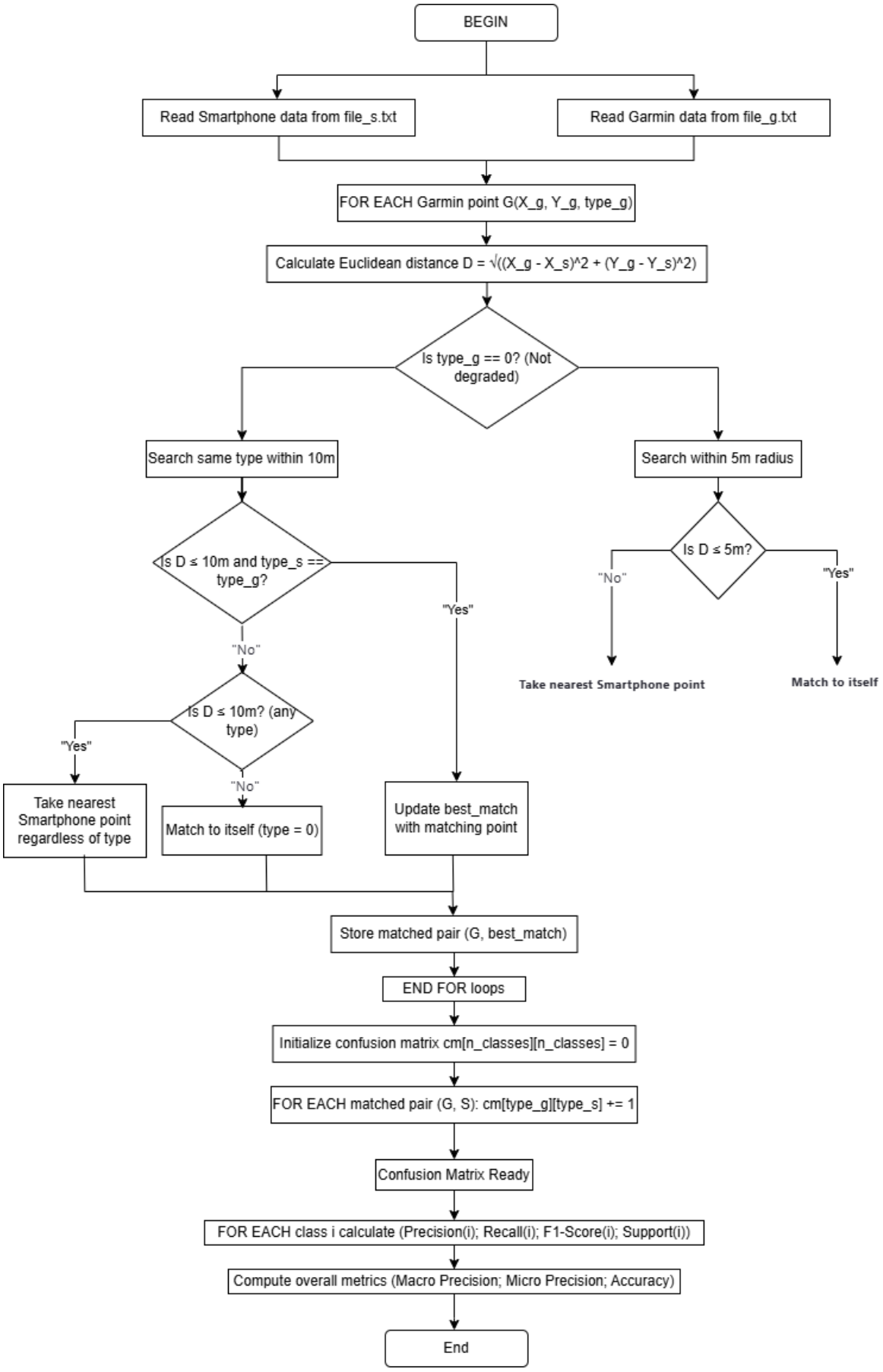


Figure IV. 9: Organigram of validation

Diagram confusion matrix & performance:

These metrics provided a **quantitative evaluation** of the smartphone's reliability, particularly in relation to its ability to localize road defects with sufficient precision for analytical mapping purposes.

Class	Precision	Recall	F1-score	Support
Not degraded	1	1	1	7
Manhole cover	0,842	0,8	0,821	20
Longitudinal crack	0,893	1	0,943	25
Transverse crack	1	0,714	0,833	7
Piping network	0,846	0,917	0,88	12
Road subsidence	1	0,667	0,8	3
Speed bump	1	0,625	0,769	8
Road gully	0,667	0,833	0,741	12
Accuracy	0,862	0,862	0,862	94

Table IV. 2: Evaluation metrics

The overall performance is very good, with an overall accuracy of **86.2%**. The **ND**, **LC**, and **PN** classes showed the best performance. Some classes exhibited noticeable confusion:

- **SB** with **LC** or **RG**
- **TC** with **PN**
- **MC** with **RG**

Additionally, classes such as **RS** and **SB** have a relatively small number of samples, which may result in statistically unstable performance.

	ND	MC	LC	TC	PN	RS	SB	RG
ND	7	0	0	0	0	0	0	0
MC	0	16	0	0	0	0	0	4
LC	0	0	25	0	0	0	0	0
TC	0	0	0	5	2	0	0	0
PN	0	1	0	0	11	0	0	0
RS	0	1	0	0	0	2	0	0
SB	0	0	2	0	0	0	5	1
RG	0	1	1	0	0	0	0	10

Table IV. 3: Confusion matrix

The model performs excellently in classifying **ND** and **LC**, achieving perfect accuracy.
There is a noticeable confusion between **MC** and **RG**, which may be due to visual similarities in the manhole covers or their shapes.
SB (Speed Bumps) were sometimes misclassified as **LC** or **RG**, possibly due to similarities in shape or the angle of capture.
The confusion between **TC** and **PN** remains one of the recurring weaknesses.
Some classes, such as **RS** and **SB**, have relatively few samples, which may negatively affect the model's performance.

The results showed that, although the smartphone's GPS is inherently less precise than that of the Garmin device, it can still serve as a **practical and cost-effective alternative**, especially in contexts where high precision is not mandatory or when resources are limited. Furthermore, the observed spatial error was generally consistent, which makes it **predictable and potentially correctable** during post-processing.

4.3. Dynamic Smartphone Recording Mounted on a Vehicle

As the third approach in our data collection methodology, we implemented dynamic video recording using a smartphone mounted on a vehicle. The process began with carefully configuring the smartphone settings and securely mounting the device on the vehicle to ensure stability during motion.

A custom-developed application, designed by **Dr. X**, was used to simultaneously record:

- ✓ A **720p video**, and two data files:
- ✓ **GPS.txt**, which logs geographic coordinates at a frequency of **one second (1 Hz)** — this file formed the primary source for spatial analysis.
- ✓ **Sensors.txt**, which records sensor data every **10 nanoseconds** (though not directly used in this project).

This method proved to be particularly effective and practical, as it required minimal physical effort and enabled full coverage of the campus road network in a relatively short period of time. In addition to being significantly less costly, it also allowed for longer operational sessions without interruption, and was conducted in a safer and more controlled manner compared to traditional manual methods. These advantages make it a superior alternative for data collection in similar environments.

Data Processing Steps:

Following data acquisition, a series of technical steps were undertaken to associate geographic coordinates with each image frame extracted from the video:

4.3.1 Video Frame Extraction

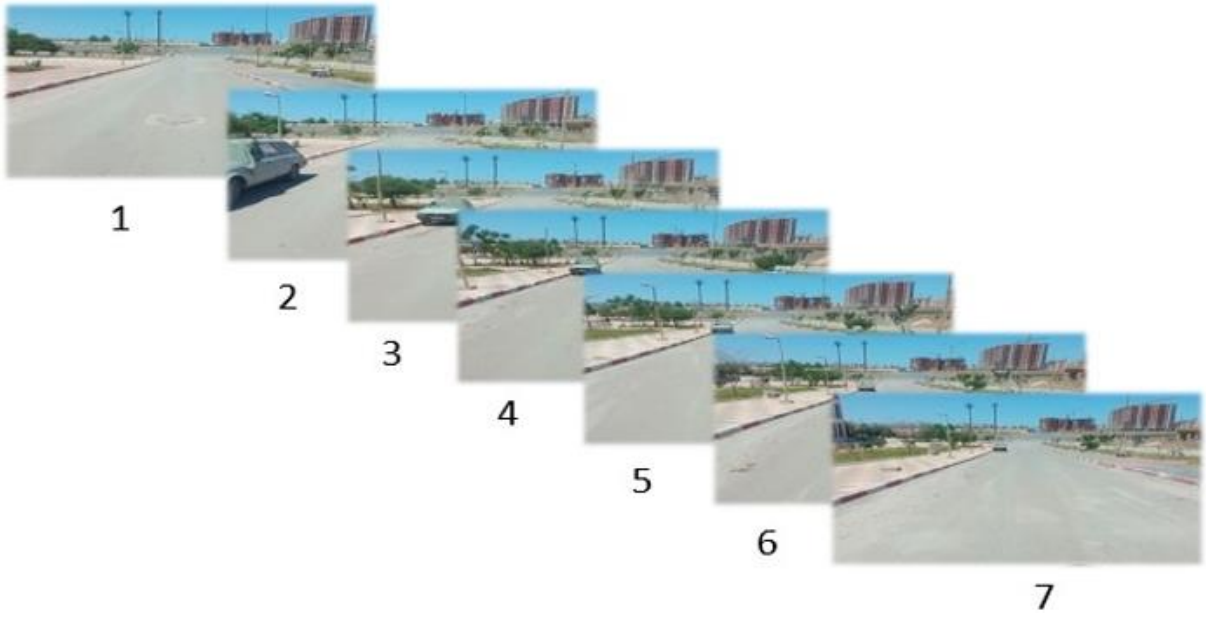


Figure IV. 10: Video to frams

Using Context capure, frames were extracted at half-second intervals, chosen due to the vehicle's slow speed, ensuring a dense spatial representation.

4.3.2 Timestamp Conversion in GPS.txt

The GPS timestamps, originally recorded in nanoseconds, were converted into a readable time format (hh:mm:ss) to enable temporal matching with the video frames.

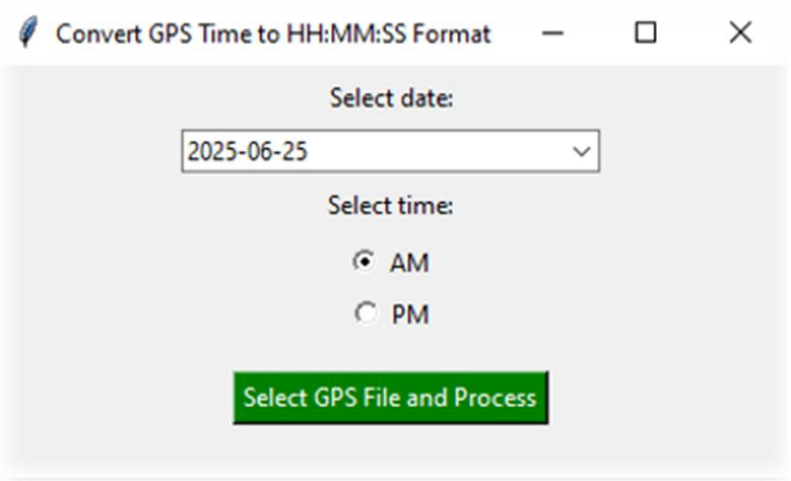


Figure IV. 11: GPS time conversion

4.3.3 Frame–GPS Time Synchronization

Each frame's timestamp was derived from its filename, allowing for direct matching with the corresponding GPS data, thus assigning a precise location to each frame.

4.3.4 d Embedding Coordinates into EXIF Metadata

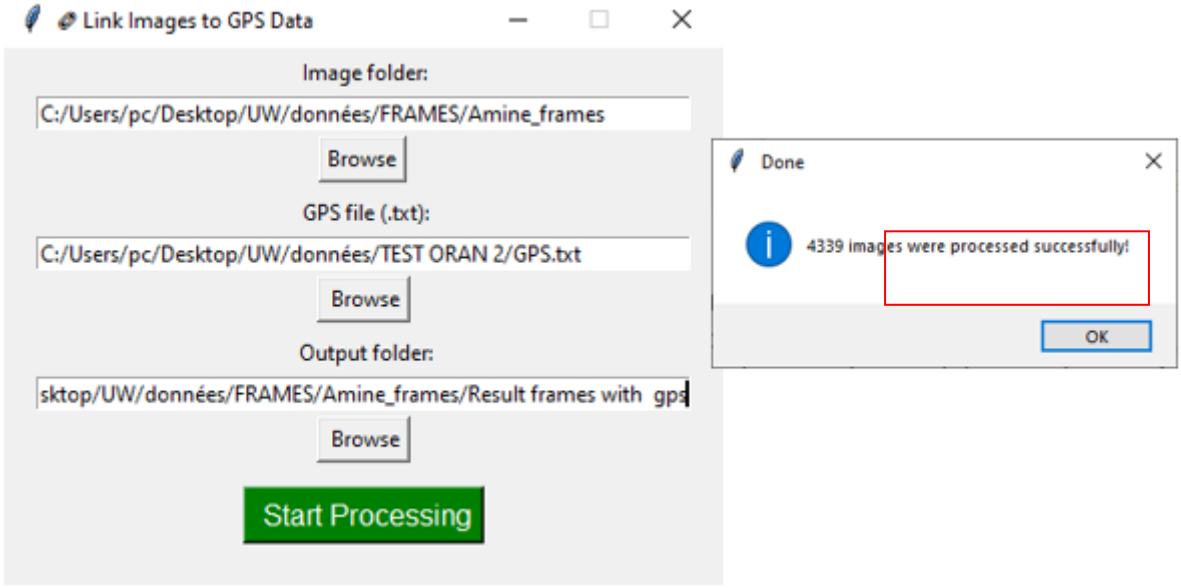


Figure IV. 12: matching frams to GPS position

The final step involved injecting the geographic coordinates into the **EXIF** metadata of each image, effectively converting each frame into a geolocated photograph.

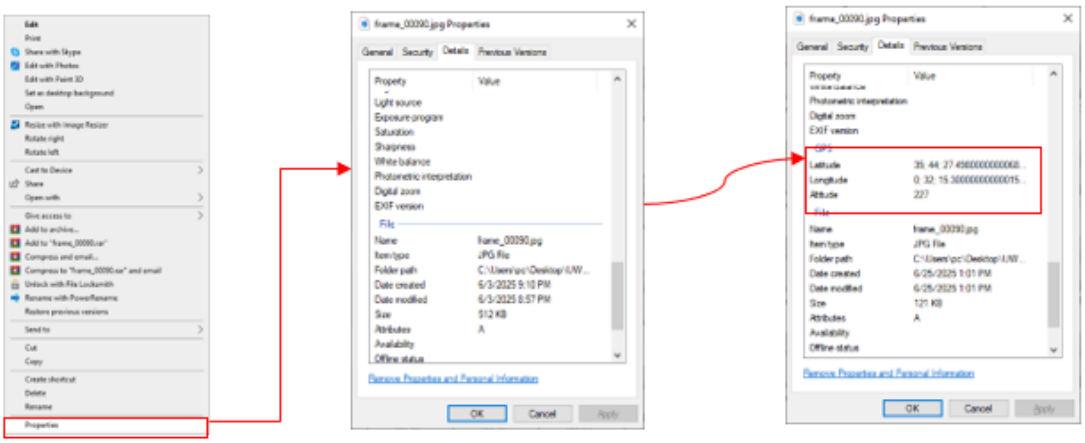


Figure IV. 13: GPS position integrated in frames proprieties

4.3.5 Outcome:

This process resulted in the creation of a rich dataset of **geolocated frames**, which can be directly imported into **GIS platforms** for visualization, spatial analysis, or the development of interactive degradation maps.

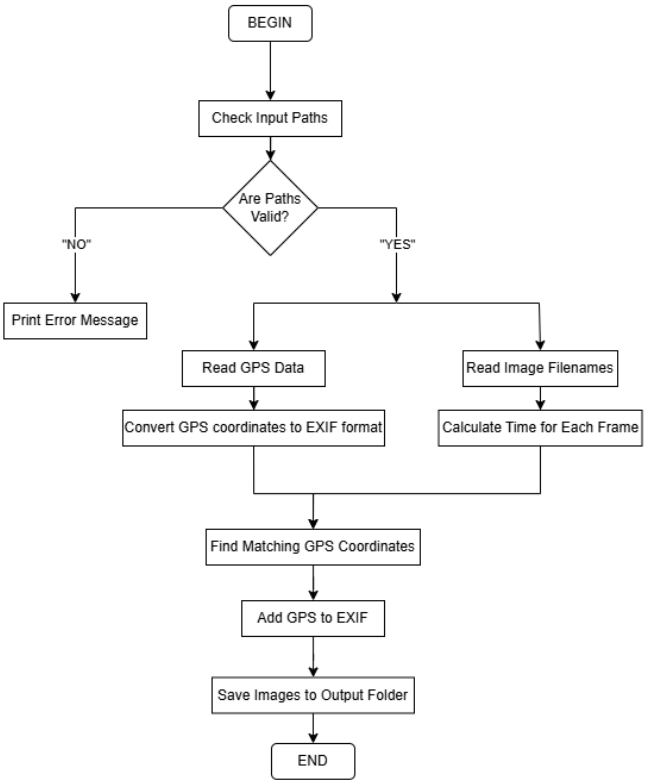


Figure IV. 14: Organigram video to geolocated frames

Algorithm Matching Frames with GPS Data:

```
FOR EACH file IN image_folder DO:
  IF file extension == ".jpg" THEN
    EXTRACT digits from filename ← frame_number
    ADD file to list of images
SORT the list by frame_number in ascending order
FUNCTION load_gps_data(gps_file):
  OPEN file for reading
  FOR EACH line IN file DO:
    TRY:
      READ date and time ← gps_time
      READ longitude ← longitude
      READ latitude ← latitude
      READ altitude ← altitude
      APPEND (gps_time, latitude, longitude, altitude) to gps_data
    EXCEPT read error:
      SKIP line
  RETURN gps_data
FUNCTION interpolate_gps(gps_data, target_time):
  IF target_time < first GPS time THEN
    RETURN first GPS point
  ELSE IF target_time > last GPS time THEN
    RETURN last GPS point
  ELSE
    FIND two consecutive GPS points where t1 ≤ target_time ≤ t2
    COMPUTE interpolation ratio = (target_time - t1) / (t2 - t1)
    lat = lat1 + (lat2 - lat1) * ratio
    lon = lon1 + (lon2 - lon1) * ratio
    alt = alt1 + (alt2 - alt1) * ratio
    RETURN (lat, lon, alt)
BEGIN matching process:
  GET sorted image list
  LOAD GPS data
  IF no GPS data loaded THEN
    SHOW error message and stop
  END IF
  CALCULATE start time of frames:
    frame_time = gps_start_time + (frame_number / CAMERA_FPS)
  UPDATE UI with:
    "First Frame Time"
    "Last Frame Time"
  OPEN output_file as CSV
  WRITE header: frame, timestamp, latitude, longitude, altitude
  FOR EACH image IN sorted list DO:
    EXTRACT frame_number from filename
    COMPUTE frame_time = gps_start_time + (frame_number / CAMERA_FPS)
    INTERPOLATE to get coordinates at this time
    WRITE [filename, timestamp, lat, lon, alt] to CSV
    UPDATE console output with progress
  CLOSE CSV file

  SHOW success message with output file path
```

Class	Precision	Recall	F1-score	Support
Not degraded	1	1	1	7
Longitudinal crack	0,917	1	0,957	22
Transverse crack	1	0,667	0,8	6
Piping network	0,8	0,8	0,8	10
Road subsidence	1	1	1	3
Speed bump	1	1	1	8
Accuracy	0,929	0,929	0,929	56

Table IV. 4: Evaluation metrics 2

The overall performance of the model is very good.

The only notable errors occurred between **TC** ↔ **PN** and **PN** ↔ **LC**, which may indicate visual similarities between these classes or a lack of sufficient training data.

ND, **RS**, and **SB** were classified with perfect accuracy, suggesting that these classes are visually distinct or well-represented in the dataset.

	ND	LC	TC	PN	RS	SB
ND	7	0	0	0	0	0
LC	0	22	0	0	0	0
TC	0	0	4	2	0	0
PN	0	2	0	8	0	0
RS	0	0	0	0	3	0
SB	0	0	0	0	0	8

Table IV. 5: Confusion matrix 2

The model demonstrated excellent performance, achieving an overall accuracy of **92.9%**.

Transverse crack was the weakest class in terms of recall (**0.667**), indicating that some instances of this category were not correctly identified.

The model showed high confidence in classifying categories such as **SB**, **RS**, and **ND**.

The performance of the **PN** (Piping Network) class was acceptable but could be further improved, possibly due to visual similarities with other classes such as **TC**.

5. Mapping

A comparative technical analysis was carried out between the two traffic directions, namely the Mila–Constantine section and the Constantine–Mila section. The objective is to highlight the differences in surface degradation, identify the causes of deterioration, characterize the nature of the soil and structures, and integrate all geographical and structural data into a coherent analytical approach.

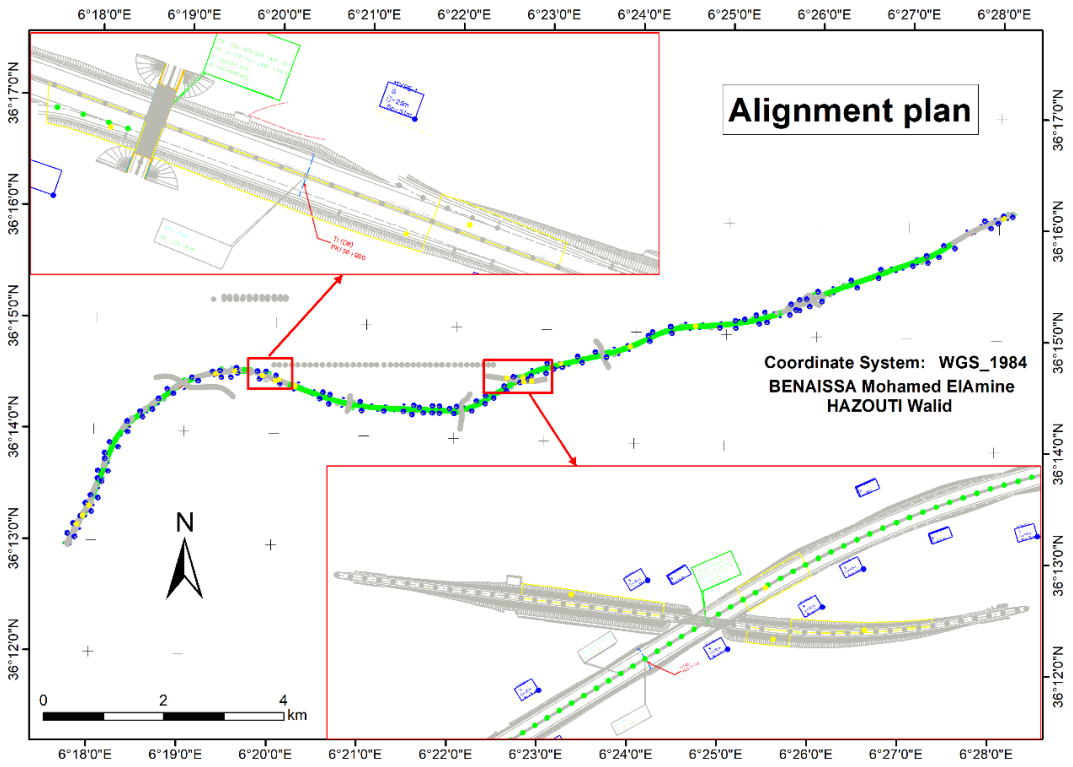


Figure IV. 15: Technical study of Coojal

5.1. Degradation map analysis

The analysis of the degradation map reveals contrasting levels of deterioration between the two traffic directions. The right side, corresponding to the Mila–Constantine direction, is characterized by severe and widespread degradation, particularly between PK 159 and PK 162, as well as between PK 165 and PK 168.

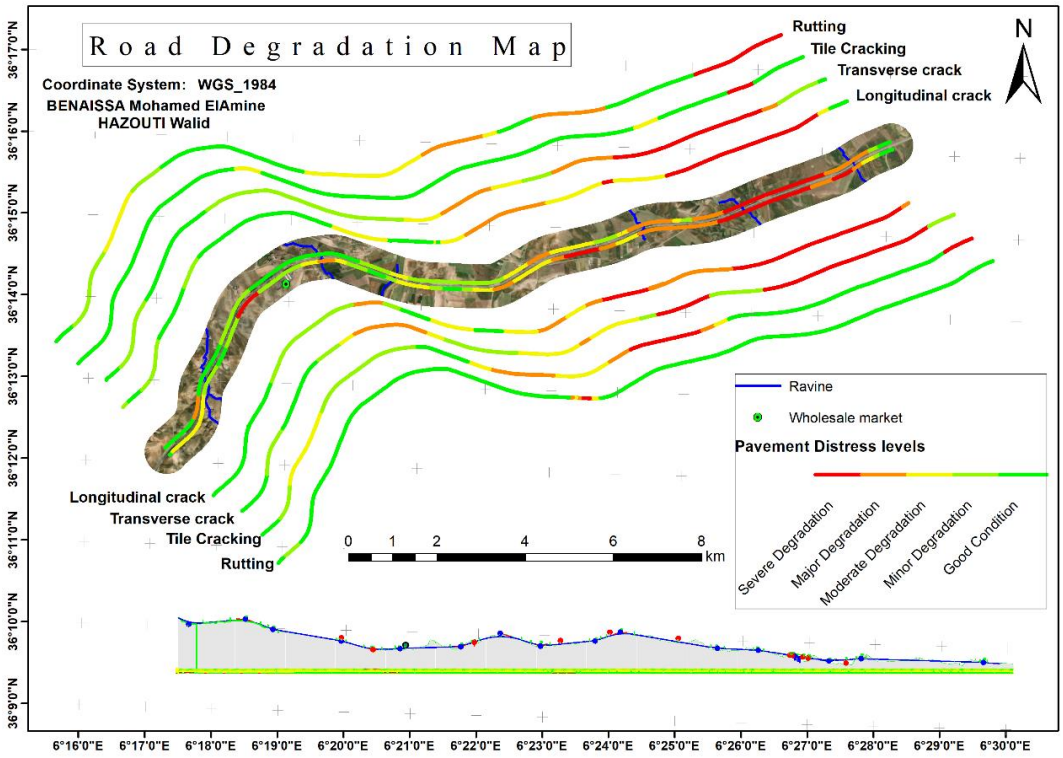


Figure IV. 16: Degradation map

In contrast, the left side, in the Constantine–Mila direction, shows less pronounced and more localized degradation, except in a few specific areas.

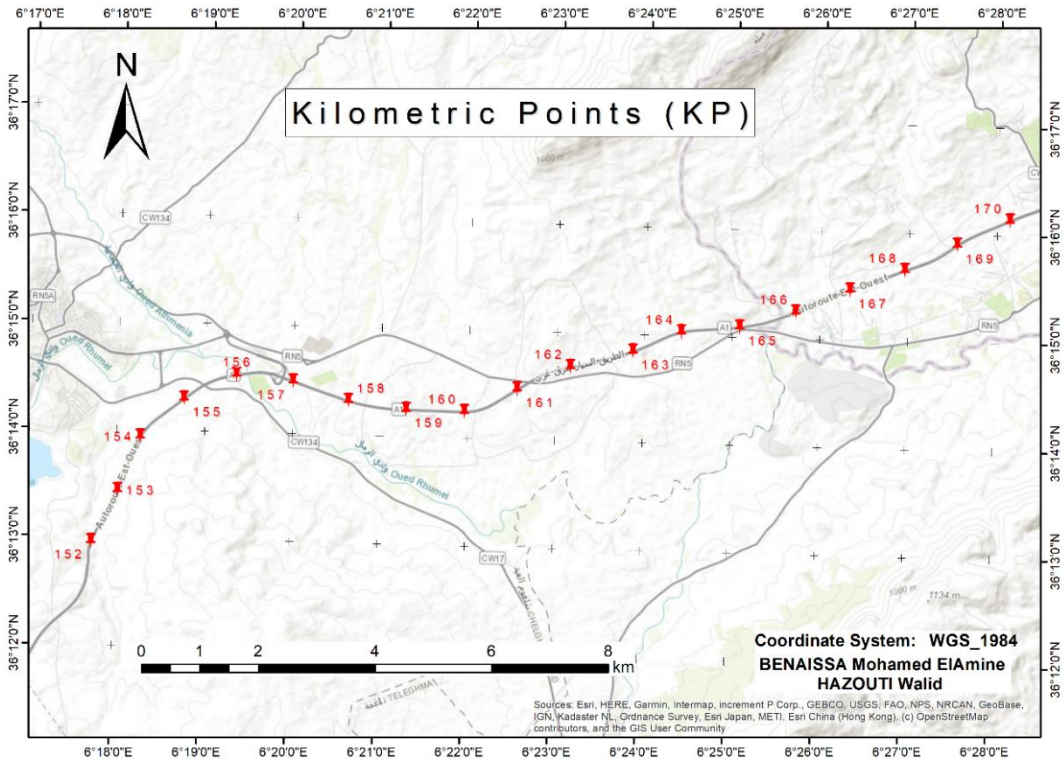


Figure IV. 17: Kilometric points

5.1.1. Longitudinal profile of the road

Based on the digital elevation model of cut-and-fill volumes, it appears that the right side of the road includes several deep embankment zones, where the road is elevated by more than 10 meters above the natural ground level at certain points.

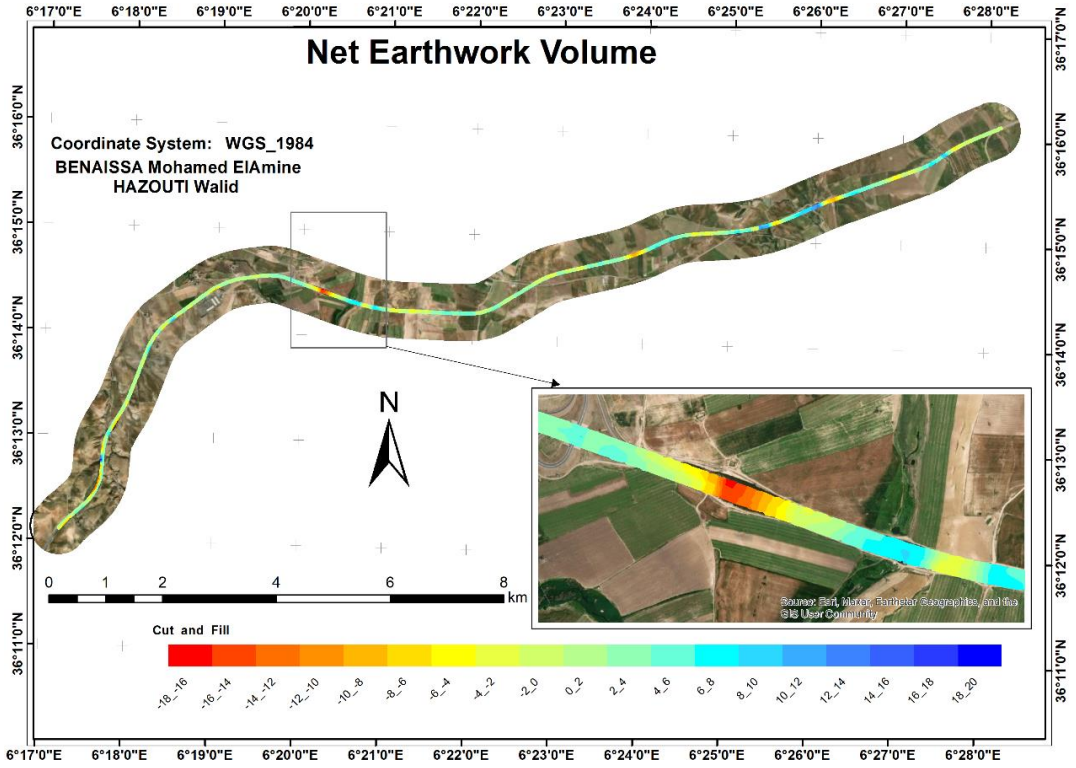


Figure IV. 18: Embarkments model

This configuration makes the infrastructure more susceptible to settlement, especially in cases of insufficient compaction or the use of inappropriate materials. Moreover, the longitudinal profile of the road axis highlights a rugged terrain with abrupt slope changes, generating additional dynamic stresses due to the acceleration and deceleration of vehicles as they navigate inclines and declines. These stresses increase the load on the pavement surface and accelerate its deterioration, particularly under frequent heavy truck traffic.

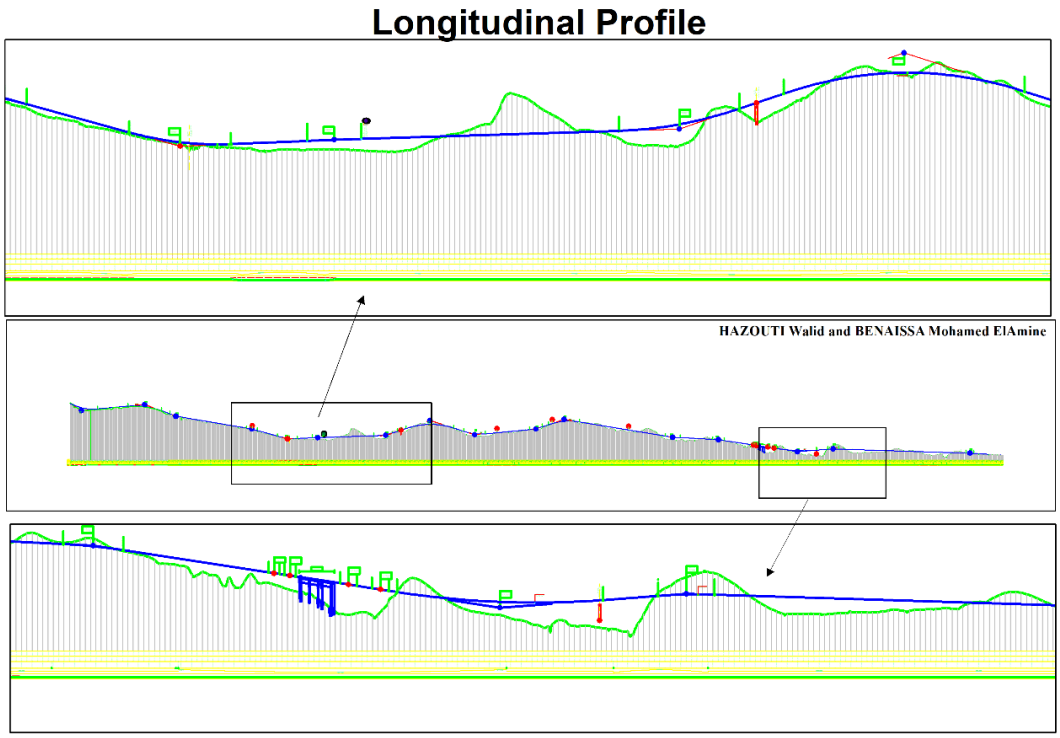


Figure IV. 19: Analysis of the longitudinal profile

In contrast, the left side contains more cut sections than fills meaning the road was constructed below the natural ground level in many places. This design generally enhances stability, provided that retaining walls and protective measures against lateral collapse are implemented. Additionally, the slope profiles on the left side are more regular, which reduces dynamic stresses and improves load distribution.

5.1.2. Drainage System Analysis

Analysis of the drainage systems shows a clear disparity between the two sides. On the right side, many areas lack effective drainage channels, especially in low-lying regions or terrain depressions where water accumulates and infiltrates the sublayers. The presence of embankments in these areas increases the risk of water penetration into the road base.

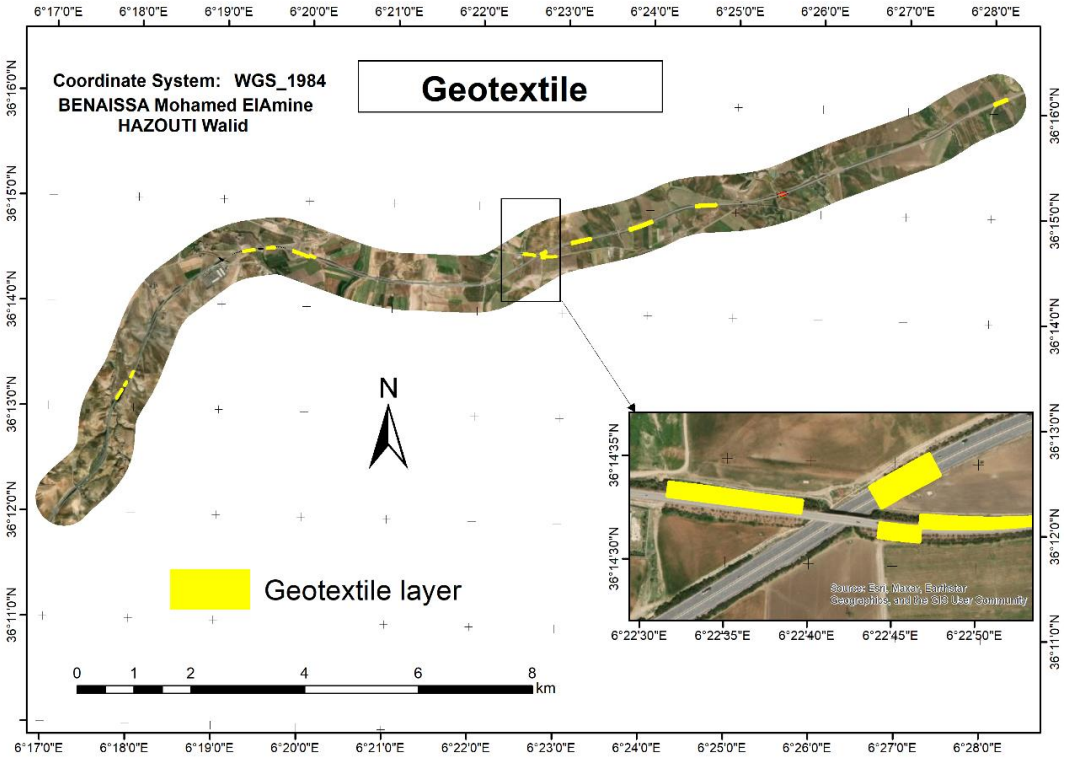


Figure IV. 20: Drainage system map

This lack of drainage is one of the main contributors to surface degradation and the appearance of longitudinal and transverse cracks.

On the other hand, the left side contains a greater number of drainage elements, such as side channels and culverts, which have helped maintain structural stability.

5.1.3. Geotextile Layer (Geotechnical Fabric)

The geotextile layer is absent in many of the severely deteriorated areas on both sides. It was only applied in high-risk zones, which may explain the appearance of surface cracks and delamination due to the lack of interlayer stability.

Highway sections incorporating a geotextile layer within their structure generally exhibit enhanced stability and increased bearing capacity. The geotextile functions as a **reinforcement element**, helping to distribute traffic loads more evenly across the subgrade

5.2. Longitudinal Cracks

5.2.1. Mila to Constantine: (2119 cracks)

Cracks appear more frequently on the eastern side of the road between 162+000m and 162+780m, and between 165+600m and 169+200m, extending over long distances. These areas coincide with embankments.

5.2.2. Constantine to Mila: (1211 cracks)

Cracks are concentrated on the northern side of the road between 163+300m and 164+440m, and more moderately between 156+100m and 156+600m. A wholesale market is located near this area.

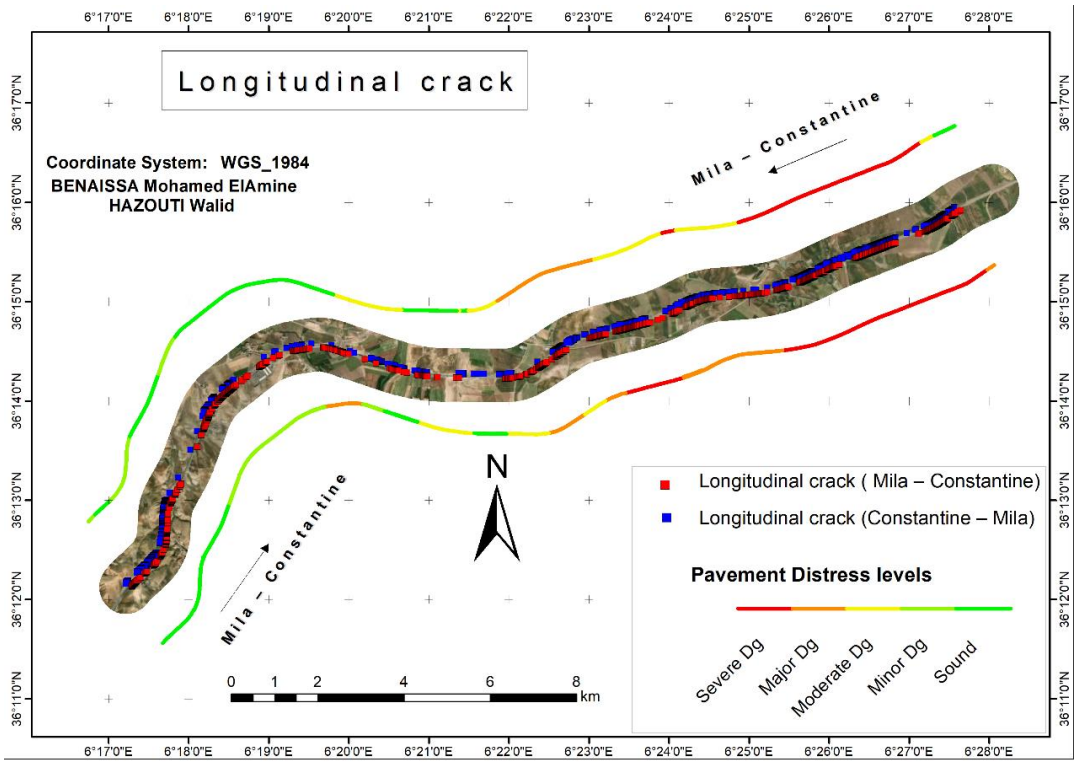


Figure IV. 21: Longitudinal cracks

5.2.3. Possible Causes:

- Failure to follow proper procedures during the laying of the top layer, especially regarding time intervals between layers, which leads to longitudinal cracks.
- Poor compaction of lower layers.
- Absence of geotextile fabric in embankment zones on both sides.

- Heavy vehicle traffic, particularly trucks, especially in uphill areas which exert additional pressure on the top layer.

5.3. Transverse Cracks

5.3.1. Mila to Constantine: (106 cracks)

Severe wear appears at 166+000m and 169+400m, and between 163+000m and 164+900m, especially on the eastern side. Moderate cracking is noted between 155+200m and 157+200m, near the vegetable and fruit market.

5.3.2. Constantine to Mila: (203 cracks)

Cracks are more prevalent between 163+500m and 183+500m on the eastern side. Moderate occurrences between 163+200m and 163+800m, and in the vicinity of the fruit and vegetable market between 160+500m and 161+800m.

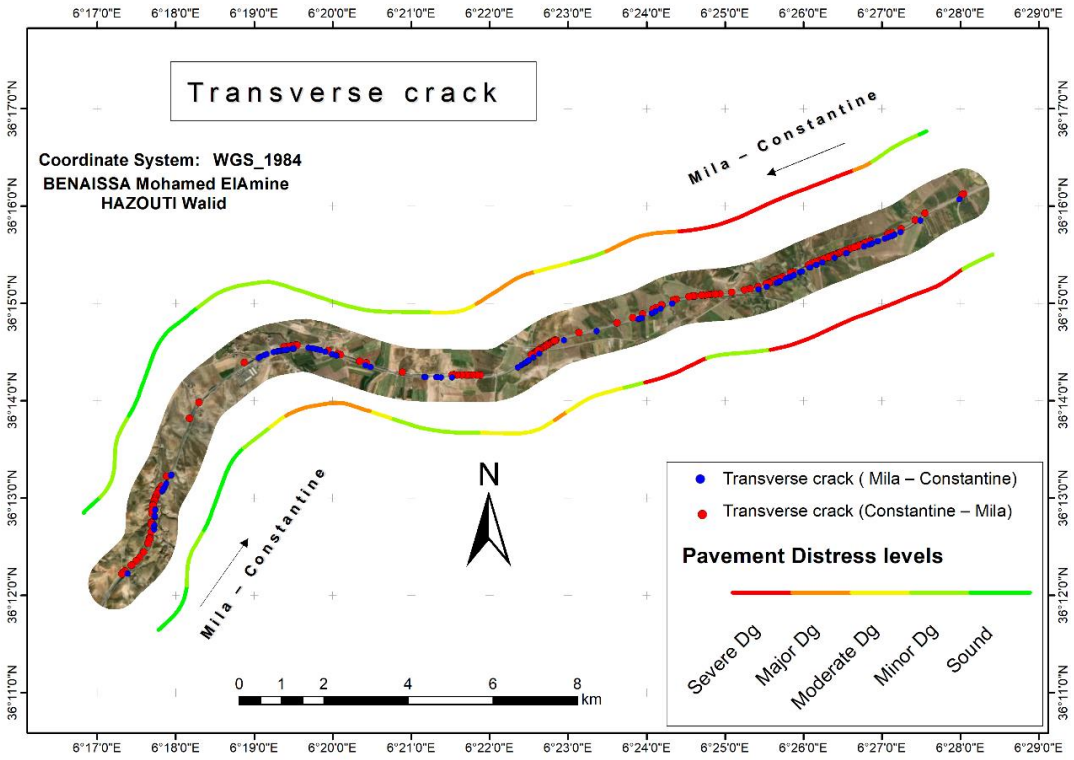


Figure IV. 22: Transverse cracks

5.3.3. Possible Causes:

- Resulting from joints between layers during top layer construction.
- Absence of geotextile fabric, especially on the eastern side.

- Poor compaction, particularly in embankment zones.

5.4. Tile Cracking (Alligator)

5.4.1. Mila to Constantine: (76 cracks)

Common between 169+300m and 170+000m, and between 161+800m and 163+700m. Also present to varying degrees between 159+100m and 161+800m. These cracks result from the accumulation of longitudinal and transverse cracks, along with sublayer issues due to water infiltration caused by inadequate drainage and lack of geotextile in degraded areas.

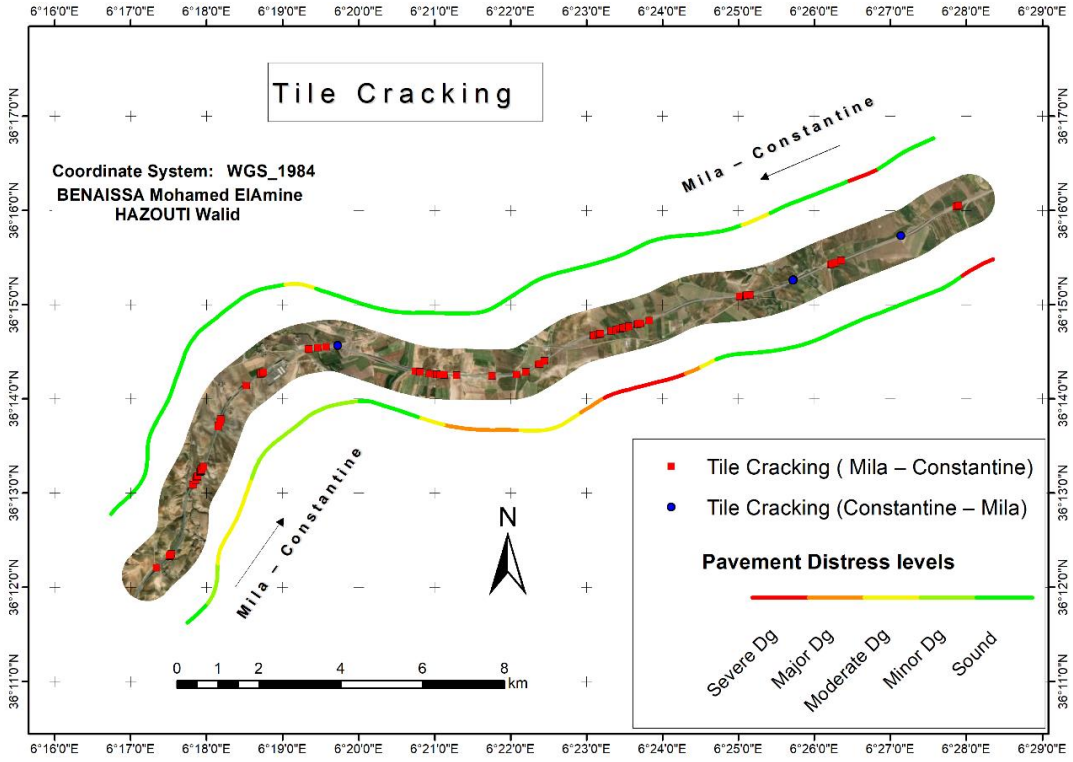


Figure IV. 23: Alligator

5.4.2. Constantine to Mila: (4 cracks)

Cracks appear at 166+000m and 165+920m, both in areas with embankments up to -6 meters deep. Others at 156+540m and 168+280m, also in filled sections. Caused by the absence of geotextile in these areas, structural failure due to water seepage into lower layers, accumulation of cracks, and lack of regular maintenance.

5.5. Rutting:

5.5.1. Mila to Constantine: (67 instances)

Concentrated between 160+100m and 159+700m. Likely due to heavy truck wheel pressure on the same track, inadequate compaction during construction, and repeated braking in the same path.

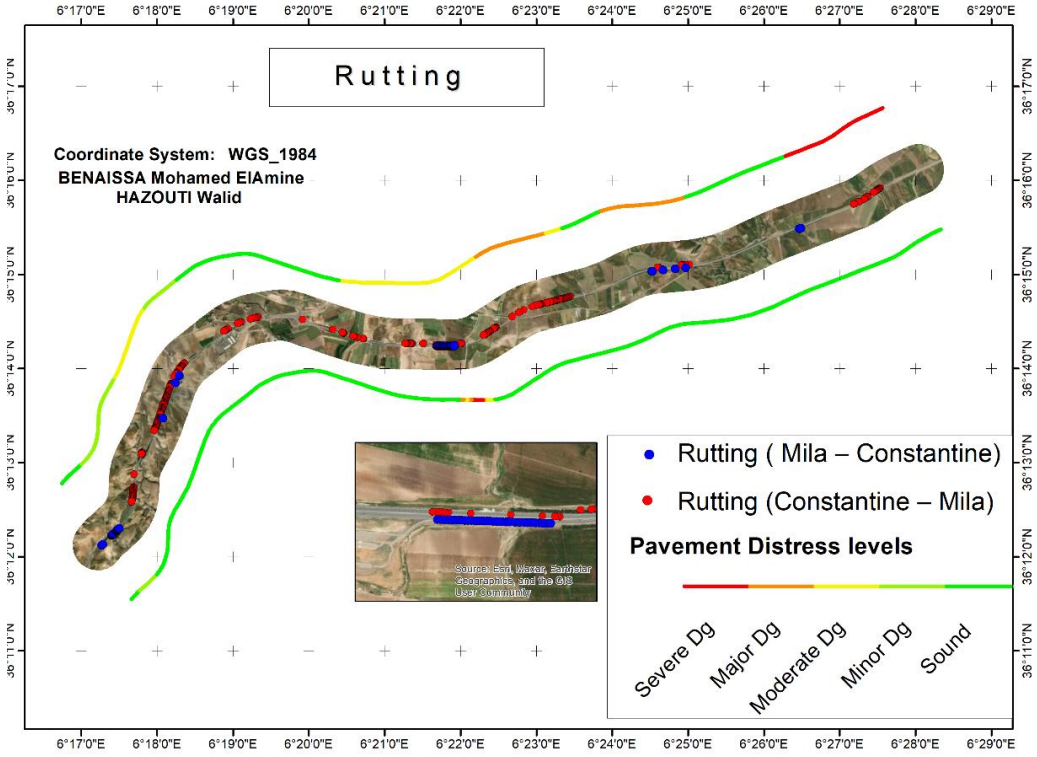


Figure IV. 24: Rutting

5.5.2. Constantine to Mila: (341 instances)

Significant deterioration between 170+000m and 167+800m, moderate between 165+500m and 163+800m, and again between 161+400m and 157+700m, and between PK 153+900 and PK 152+700.

5.5.3. Possible causes:

- Frequent truck traffic on this path.
- Uphill climbs increase wheel dynamic pressure.
- Poor compaction in embankment areas.

6. Conclusion

The results from the three survey methods demonstrate the potential of smartphone-based techniques as practical and scalable alternatives for road inspection, particularly in resource-constrained settings. The comparative analysis showed that while traditional surveying offers high precision, mobile approaches are effective for rapid, wide-area data acquisition. Furthermore, spatial variations in pavement deterioration between the Mila–Constantine and Constantine–Mila directions highlighted the impact of terrain, drainage infrastructure, compaction quality, and the presence or absence of geotextile layers. The findings confirm the relevance of integrating geomatic tools and low-cost technologies into road infrastructure monitoring strategies, supporting informed decision-making and optimized maintenance planning.

General Conclusion

This study has explored and validated an innovative, integrated, and low-cost approach for surveying and analyzing pavement deterioration using geomatics tools. By combining modern technologies such as Global Positioning Systems (GPS), Geographic Information Systems (GIS), and field data acquired via smartphone-based mobile sensing, it was possible to build an accurate spatial database. This integration contributed to a deeper understanding of road surface deterioration along the highway section between El Othmania and Aïn Smara, from PK152+000 to PK170+000.

The adopted methodology involved synchronizing video frames—recorded at a cruising speed of 80 km/h—with GPS data in order to accurately geolocate each detected defect. The degradations were classified into four main categories: longitudinal cracks, transverse cracks, alligator cracking, and rutting, along the East–West highway corridor. This classification enabled a multifactor spatial analysis, incorporating both technical and geographic variables such as embankment height, material quality, drainage efficiency, traffic volume, topography (slope and grade), and construction quality.

The analysis showed that deterioration is not random but rather influenced by distinct spatial factors. Integrating these parameters into a geospatial database provides a robust scientific foundation for guiding maintenance strategies and prioritizing interventions. This capability for retrospective analysis and predictive modeling—enabled by GIS tools—makes it possible to map high-priority maintenance areas and anticipate risk zones.

Additionally, the study demonstrated that smartphones can serve as mobile sensing devices, offering a practical, accessible, and cost-effective alternative to traditional monitoring methods, which are often expensive and complex to deploy. By enabling in-situ observations under real-world conditions, this approach supports continuous monitoring of road infrastructure, particularly in contexts with limited resources.

Although the initial objective of producing a prioritization map for maintenance interventions could not be achieved within the available timeframe, the study represents a decisive preliminary step toward a proactive, data-driven approach to road performance management. It also opens the door to future research incorporating artificial intelligence, predictive algorithms, and participatory citizen-based systems.

In this regard, geomatics should not be viewed merely as a technical tool, but rather as a strategic lever for enhancing infrastructure sustainability, reducing maintenance costs, and improving the efficiency and equity of spatial governance—particularly in the Algerian context.

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