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Thesis submitted to the

UNIVERSITY OF MOHAMED BOUDIAF – MSILA

FACULTY OF MATHEMATICS AND COMPUTER SCIENCE

DEPARTMENT OF COMPUTER SCIENCE

In partial fulfillment of the requirements for the degree of

Master in **artificial intelligence**

By

Azri, Oumaima

Title of the thesis

Geographic Information System for Forest Fire Management with Prediction

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Under the supervision of

Amel Meliouh

Composition of the jury

M. Brahimi	**University of Msila**	**President**
Amel Meliouh	**University of Msila**	**Reporter**
H. Khelil	**University of Msila**	**Examiner**

june,2026

Abstract:

As part of this academic work, we designed and developed a geographic information system for managing and predicting forest fires. The system's implementation involved several key steps, including collecting and preparing geographic data represented in layers in Shapefile format obtained from the Forestry Department of Bouira Province. These layers were then integrated into a geographic database, processed and analyzed, and finally, a prediction model was developed, trained, and tested according to user needs.

Key words: GIS ; prediction ; Forest fires; Climate data; Machine Learning.

الملخص :

في إطار هذا العمل الأكاديمي، قمنا بتصميم وتطوير نظام معلومات جغرافي لتسيير والتنبؤ بظاهرة حرائق الغابات. شمل انجاز النظام عدة خطوات رئيسية من بينها جمع وتحضير البيانات الجغرافية الممثلة في طبقات بصيغة Shapefile تم الحصول عليها من محافظة الغابات لولاية البويرة، ثم دمج هذه الطبقات في قاعدة بيانات جغرافية و معالجة وتحليل هذه البيانات و أخيرا تطوير نموذج التنبؤ مع تدريبه و اختباره حسب احتياجات المستخدم.

الكلمات المفتاحية: نظام المعلومات الجغرافية ؛ تنبؤ؛ حرائق الغابات؛ بيانات المناخ.

Résumé

Dans le cadre de ce travail académique, nous avons conçu et développé un système d’information géographique pour la gestion et la prévision des feux de forêt. La mise en œuvre du système a impliqué plusieurs étapes clés, notamment la collecte et la préparation de données géographiques représentées dans des couches au format Shapefile obtenues auprès du conservation des forêts de la wilaya de Bouira. Ces couches ont ensuite été intégrées dans une base de données géographique, traitées et analysées, et enfin, un modèle de prédiction a été développé, entraîné et testé selon les besoins des utilisateurs.

Mots clés: SIG ; prédiction; Feux de forêt; Données climatiques ; Apprentissage automatique.

Dedications

“Praise be to Allah who made the beginnings easy for me, completed the endings for me, and conveyed the goals for me

No path has ended, no effort has been sealed, and no endeavor has been pursued except by the grace of Allah

From the bottom of my heart I dedicate this humble work

To my dear soul

The road was not easy, but you were strong, patient and persistent

And now you are reaping the rewards of your hard work

So proud

To whom her prayers were the secret of my success and her tenderness was the balm for my wounds

To my dear mother

To my support in this life and the source of security

To my dear father

To those whose faces make my eyes happy and whose laughter makes my heart happy

To my sisters Sarah, Salma and Donia, and my brothers Zakaria and Yahya

To my dear friends Kawthar, Basmala and Oum Al Khair

The road was difficult and long without you by my side

May Allah perpetuate our love and bring us together in goodness

I dedicate this work to everyone who was the reason for my success

Thank you from the bottom of my heart.”

Omaima Azri

Acknowledgments

I thank Allah, the Most Gracious, and the Most Merciful, who has provided me with all the circumstances, granted me the blessing of knowledge, and guided me in my academic journey until I complete this humble work.

At the conclusion of this scientific journey, I can only extend words of thanks and gratitude to everyone who had an impact on this work, and everyone who contributed directly or indirectly to supporting and guiding us.

We would like to mention in particular Ms. Meliouh Amel for her leadership, assistance in completing the work, and encouragement in completing this project.

We express our deep gratitude to my professors in the Department of Computer Science, who planted the seeds of knowledge within me and accompanied me throughout this academic year with giving and guidance. We especially acknowledge the members of the discussion committee for graciously accepting to discuss my graduation project and for their interest in evaluating this academic effort.

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Abbreviations

Shortcut	Meaning
GIS	Geographic information system
GPS	Global Positioning System
ArcGIS	Architecture Center GIS
QGIS	Quantum GIS
MODIS	ModerateResolutionImaging Spectroradiometer
VIIRS	Visible Infrared Imaging Radiometer Suite
NDVI	Normalized Difference Vegetation Index
GWIS	Global Wildfire Information System
NASA	NationalAeronautics and Space Administration
FIRMS	Fire Information for Resource Management System
SARL	limited liability company
IOT	Internet of Things

General Introduction

Forest fires are among the most destructive natural disasters affecting ecosystems, human lives, biodiversity, and economic resources worldwide. In recent decades, the frequency and intensity of forest fires have increased significantly due to climate change, prolonged droughts, rising temperatures, and human activities. These fires not only destroy vast forested areas but also contribute to environmental degradation, air pollution, loss of wildlife habitats, and serious socio-economic consequences. As a result, effective forest fire management has become a critical challenge for governments, environmental agencies, and researchers.

Traditional methods of forest fire monitoring and management often rely on manual observation and delayed reporting systems, which may not provide rapid and accurate responses during emergency situations. With the advancement of modern technologies, Geographic Information Systems (GIS) have emerged as powerful tools for environmental monitoring, spatial analysis, and disaster management. GIS enables the collection, storage, analysis, and visualization of geographic and environmental data, allowing decision-makers to better understand fire-prone areas and optimize prevention and response strategies.

In the field of forest fire management, GIS can integrate multiple sources of spatial information such as vegetation type, temperature, humidity, topography, wind speed, and historical fire data. By analyzing these factors, GIS-based systems can identify high-risk zones, support early warning mechanisms, and improve firefighting resource allocation. Furthermore, the integration of predictive models with GIS technologies enhances the capability to forecast potential fire occurrences and fire spread patterns before disasters happen.

Prediction plays a crucial role in reducing the impact of forest fires. Recent developments in data science, remote sensing, machine learning, and artificial intelligence have enabled the creation of predictive systems capable of estimating fire risk with higher accuracy. Combining predictive techniques with GIS provides a comprehensive framework for intelligent forest fire management. Such systems help authorities take preventive measures, plan evacuation strategies, and minimize environmental and economic damages.

Vegetation cover in Algeria loses thousands of hectares annually due to forest fires. On the other hand, conservation of forests faces great difficulties in managing data related to fires. This is due to the absence of a central and predictive system that provides a comprehensive view and helps identify areas of risk according to environmental conditions. Hence the idea of this project, which aims to design and implement a geographic information system (SIG) on the web to manage and predict the phenomenon of forest fires in Algeria, relying on modern tools and technologies that allow the collection, storage and analysis of geographic data related to fires, while building a predictive model, as well as providing an interactive interface for users to easily display statistical information and interactive maps.

This thesis focuses on the design and development of a GIS-based framework aimed at improving forest fire management through prediction and spatial analysis. The study explores how geographic data and predictive techniques can be integrated to monitor forest conditions, identify vulnerable areas, and support decision-making processes for fire prevention and emergency response.

The objective of this research is to contribute to the development of efficient and intelligent solutions for forest fire risk assessment and management that concern the wilaya of Bouira. By leveraging GIS technologies and predictive approaches, the proposed system seeks to enhance the accuracy, speed, and reliability of forest fire detection and prevention strategies, ultimately contributing to environmental protection and sustainable forest management.

This thesis is organized into six main chapters:

A general introduction to the topic;

Chapter Two: deals with the basic concepts of geographic information systems;

Chapter Three: Explains the methodology for analyzing and designing the system;

Chapter Four: Presents the process of implementing and applying the system;

Chapter Five: present the forecasting Model used in prediction;

A general Conclusion that summarize the results obtained and future perspectives.

Chapter 1 Literature Review and Theoretical Background

1. Introduction

Geographic information systems improve forest fire management by allowing the collection and analysis of various data about forests, including vegetation cover, topography, soil, climate, and human activities. By taking this information into account, a fire prevention plan can be developed and the likelihood of fires and the areas where they are likely to occur can be predicted.

GIS can also help rehabilitate forests, by taking data from previous fires, forest managers and determine what types of trees to plant in Devastating fire aftermath that could survive potential future wildfires.

2. Geographic Information System

Since its emergence in the early 1960s, the geographic information system has not been clearly and jointly defined by the scientific community, so there are many related definitions, but most of them fall into one meaning, which is a technological information system that stores, analyzes and displays geographic information with the aim of helping experts and specialists make decisions [1][2].

2.1. The functions of a geographic information system

The term A5 is a concept that refers to the basic functions performed by a geographic information system [3]:

- Abstract: Transforming complex reality into a simple, representable model;
- Acquisition: Collection of spatial and descriptive data;
- Archiving: Storing data in a geographic database such as Post GIS;
- Analyze: Using spatial analysis tools to process and analyze data;
- Displaying: Displaying data on digital maps.

2.2. Basic components of a geographic information system

A geographic information system consists of five main elements:

- Devices: These include devices used to collect, store, and analyze data, such as computers, sensors, GPS devices, and monitors,
- Data: Data is essential to the functioning of a geographic information system. It can be metadata or spatial data,
- Users: Geographic information systems cannot function without the intervention of the user, who, in his role, designs, manages, develops, and uses the system to solve problems and make decisions,
- Software: Software connects devices, data and users. There are many GIS programs such as: ArcGIS, QGIS...etc.
- Methods: The success of implementing a geographic information system depends on adherence to methods and procedures in order to achieve the goals previously set in any project [4].

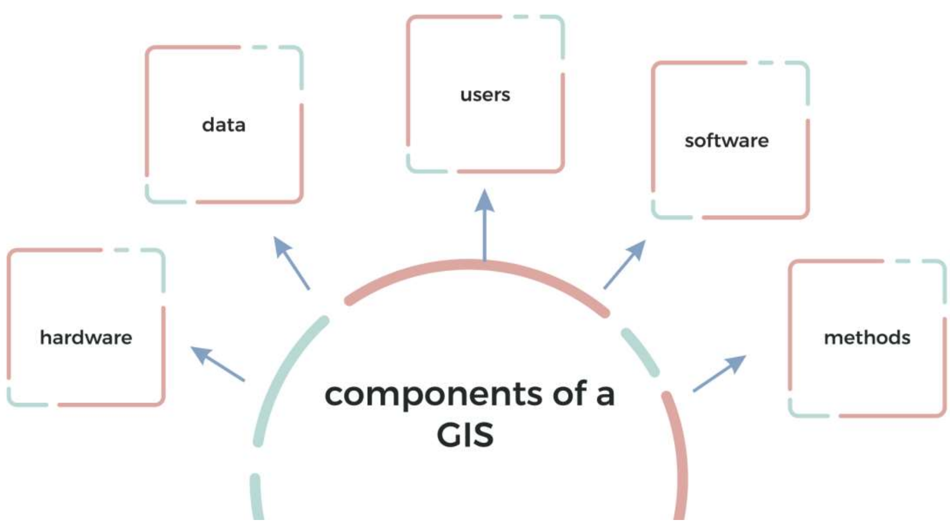

Fig 1: GIS components.

2.3. Examples of geographic information systems programs

There are a large number of GIS programs. Figure shows the most popular programs and their characteristics [5], [6].

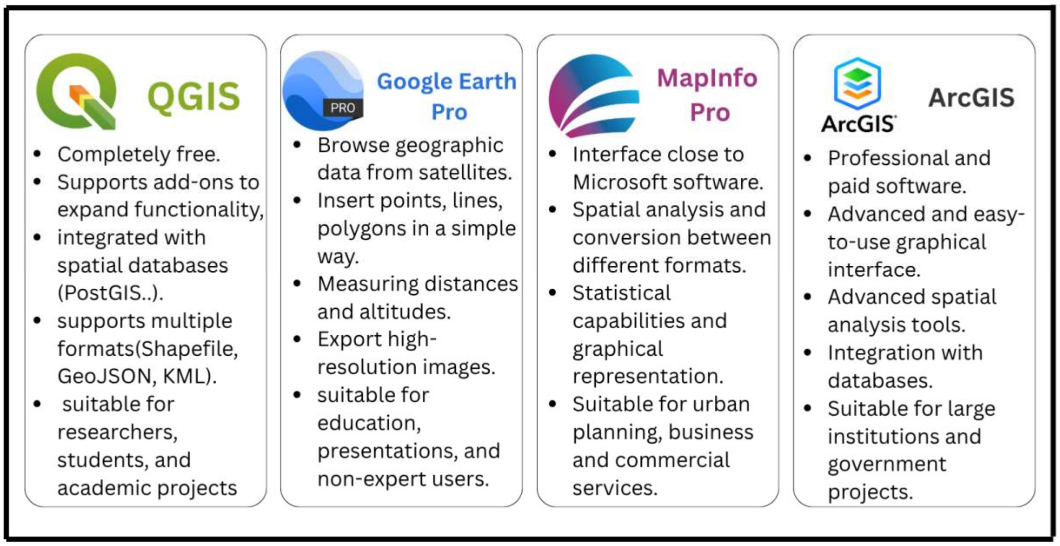

Fig 2: GIS programs.

3. Geographic information system in environmental management

A geographic information system collects, stores, analyzes, and visualizes geographic data, which helps provide an accurate picture of reality for making scientifically based decisions.

By integrating it with decision support systems, GIS becomes more capable of providing accurate and immediate solutions, especially in the following areas [7]:

- Urban planning: identifying and showcasing the best locations to create new infrastructure or resources;
- Natural resource management: monitoring and analyzing environmental changes;
- Disaster response: identifying affected areas and planning relief operations;
- Public Health: Tracking Disease Spread and Distribution of Health Services.

4. Forest fire management methods

Geographic information and remote sensing systems provide comprehensive solutions for managing environmental disasters, including forest fires. They are used in [8]:

- Detection and Monitoring: Satellite-based remote sensing systems (MODIS, VIIRS…) can identify fires by abnormal temperature rise (thermal anomaly) that indicates the possibility of a fire. Meteorological monitoring also provides real-time data and detailed analysis of fire intensity that is more accurate than satellites in some cases In addition, drones (Drones) equipped with thermal sensors provide accurate, high-quality images of fire behavior. These techniques help firefighters understand the nature of a fire and make quick and effective decisions in disaster management;
- Risk Assessment: Monitoring vegetation and identifying potential ignition zones are essential in forest fire risk assessment. Remote sensing is used to analyze vegetation status via vegetation indices (such as the NDVI). GIS, on the other hand, provides the ability to model vegetation type and distribution, which is crucial in predicting and identifying areas most vulnerable to forest fires;
- Response and Recovery: GIS integrates fire activity data from remote sensing systems with live fire propagation modeling (software that predicts how a fire will spread according to several factors: vegetation type, wind speed and direction, climate, and terrain). This allows for dynamic mapping that helps in controlling and managing evacuation routes.

After a fire ends, a geographic information system helps assess the extent of damage and plan recovery efforts by analyzing aerial or satellite images taken before and after the disaster. It can identify and measure the extent of damage caused by the fire. This information is essential for prioritizing recovery efforts, estimating financial losses, and allocating resources effectively. It also contributes to identifying reforestation areas and implementing strategies to restore the affected ecosystem.

4.1. Examples of geographic information systems in forest fire management

- Global Fire Information System GWIS: A joint initiative of the Earth Observation Group (GEO) and the European Copernicus Program, it aims to bring together existing information sources at regional and national levels to provide a comprehensive view and assessment of fire systems and fire impacts at the global level [9];
- Fire Information System for Resource Management FIRMS: An advanced platform developed by NASA to provide near-real-time wildfire data, used for wildfire monitoring and assessment [10];
- Wildfire project to combat forest fires in Algeria: It is an intelligent system developed by SARL Basseer Technology Innovation that aims to detect forest fires early and predict their spread using artificial intelligence (AI) and the Internet of Things (IoT). The system relies on installing environmental sensors in forests to measure climate indicators in real time, allowing risks to be assessed and rapid preventive action taken. The project has been field tested in collaboration with the General Directorate of Forests (DGF) in Tizi Ouzou province since summer 2023 and the results have shown the effectiveness of the system in supporting monitoring and early warning points[11], [12].

5. Fire prediction models

Predicting models are analytical tools that operate with artificial intelligence in order to predict or reveal future results

Predict models are used to estimate the probability of fires occurring and their areas of spread depending on several factors, including: climate, topography, vegetation cover, human activity...etc.

We summarize the types of prediction models in the following image [13]:

Regression	Regression techniques are used to analyze relationships between variables and predict future outcomes. They mainly include two types: linear regression and logistic regression.

	Linear Regression: Used for predicting continuous values by modeling a linear relationship between independent and dependent variables. It helps understand how changes in one variable affect another and improve prediction accuracy. Logistic Regression: Used for binary classification problems where outcomes belong to two categories. It estimates the probability of an event occurring using a logistic function and is widely applied in predictive modeling for categorical data.
Data Mining	Data mining uses statistics and machine learning to identify patterns, trends, and relationships within large datasets, helping organizations make informed decisions. An important step in this process is Exploratory Data Analysis (EDA), which explores and visualizes data to understand its main characteristics without relying on predefined assumptions. Clustering Clustering groups similar data points into subsets based on shared characteristics. It helps discover hidden patterns and predict future behaviors or trends, such as analyzing social media users to improve personalized recommendations.
Classification Models	Classification techniques use labeled historical data to categorize new data into predefined classes. Common methods include decision trees, random forests, and text analytics. Decision Trees: Predict outcomes by analyzing historical patterns and representing decisions in a tree-like structure. Random Forests: Combine multiple decision trees to improve prediction accuracy and handle both classification and regression tasks. Text Analytics: Uses machine learning to analyze text data and classify it into categories, such as spam detection or predicting customer behavior from reviews and feedback.
Neural Networks	Neural networks are advanced predictive analytics techniques used to identify complex and nonlinear patterns in data. They are inspired by the human brain and consist of three main layers: Input Layer: receives the data Hidden Layer: processes data and learns patterns Output Layer: produces predictions The hidden layer improves the model's intelligence by learning from previous data connections. Neural networks are often used to validate or enhance results from models such as decision trees and regression models.
Time Series Analysis	Time series analysis studies data collected over time to identify trends, patterns, and seasonal changes. It predicts future outcomes based on historical data, assuming future behavior will follow similar past patterns.

Table 1: the types of prediction models.

6. Conclusion

This chapter sheds light on the phenomenon of forest fires, in addition to highlighting the role of geographic information systems in combating this type of phenomenon.

In the next chapter, we will detail the design of a GIS-based system to analyze the phenomenon of forest fires in Algeria, explaining all the steps and tools used.

Chapter 2 System Analysis and Design

1. Introduction

After devoting the previous chapter to presenting the Geographic Information System (SIG), in this chapter we will design a geographic information system to manage the phenomenon of forest fires in Algeria, starting by defining the requirements to explaining how the system works and its internal structure. This chapter aims to provide a comprehensive and clear vision of the system before starting the development and implementation process.

2. Requirements Analysis

2.1. Functional requirements

- Dashboard display which provides an interactive map showing fire locations as well as forest infrastructure;
- View statistics showing the number of fires, types of plants burned and financial losses by months and years at the national and state levels.;
- Display points for fire locations expected to occur during the day;
- An editable and expandable database that enables the user to add new data and delete or modify existing data;
- Model for predicting forest fires.

2.2. Non-functional requirements

- Ease of use (easy and simple interface);
- Updateability and scalability;
- Work on the browser without installation;
- Performance (fast response);
- Security (user authentication) and data protection;
- Validity of the prediction.

3. System Architecture

In order to better achieve the functionality of the system, it is necessary to identify the users of this system:

Forest conservation in the study area and its tasks include:

- Protection of forest and animal wealth;
- Expanding vegetation and afforestation;
- Rural development;
- Managing natural disasters such as landslides, desertification and forest fires.

The system is a web-based geographic information system for managing and predicting forest fires in Algeria (Bouira). It allows users to track fires via an interactive map, view accurate statistics, add new fire data, and predict fires to support decision-making.

3.1. Main units of the system

The system is based on three main units:

3.1.1. Display interface

It represents the interface through which the user interacts with the system via a web browser and consists of:

- Home Page which enables the user to go to the rest pages;
- Dashboard: Contains an interactive map displaying fire locations across the study area, along with associated statistics;
- Statistics page for displaying graphs;
- Add Fire Page: To enter new fire data.

3.1.2. Processing unit

It is responsible for processing data in the system and performs the following tasks:

- Process requests from the display interface: such as logging in, adding new data, displaying statistics, displaying data on a map;

- Applying verification and processing rules: such as verifying the validity of the entered data;
- Coordinate communication with the database: by executing input, update and retrieval requests;
- Preparing data for display: by converting it into appropriate formats to represent it on a map or in graphs;
- Preparing the prediction model: by entering the data necessary for its operation and displaying the locations of the fires expected to occur on the map.

3.1.3. Database

It is the element responsible for storing and managing geographic and descriptive data and includes:

- Fire data;
- Geographic data;
- User data;
- Predict model database.

4. System modeling using UML

4.1. UML Definition

Unified Modeling Language is a unified visual modeling language that represents a versatile, flexible and easy-to-use approach to visualizing system design. Provides a set of charts (Use case, class…) to represent different aspects of the system [14].

Tools used in the design are drawio, which is an open source modeling software that supports the Unified Modeling Language UML [15].

4.2. Uses case diagram

This type of diagram illustrates the relationship between actors and the system.

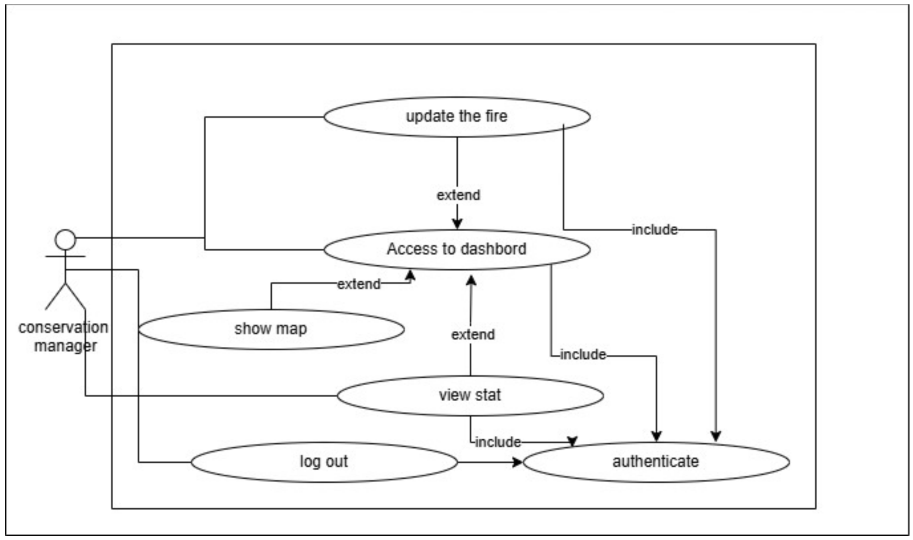

Fig 3: Comprehensive use case diagram.

4.3. Sequence diagram

A sequence diagram is used to display interactions between actors and a system according to the chronology of their occurrence.

4.3.1. Sequence diagram (dashboard view):

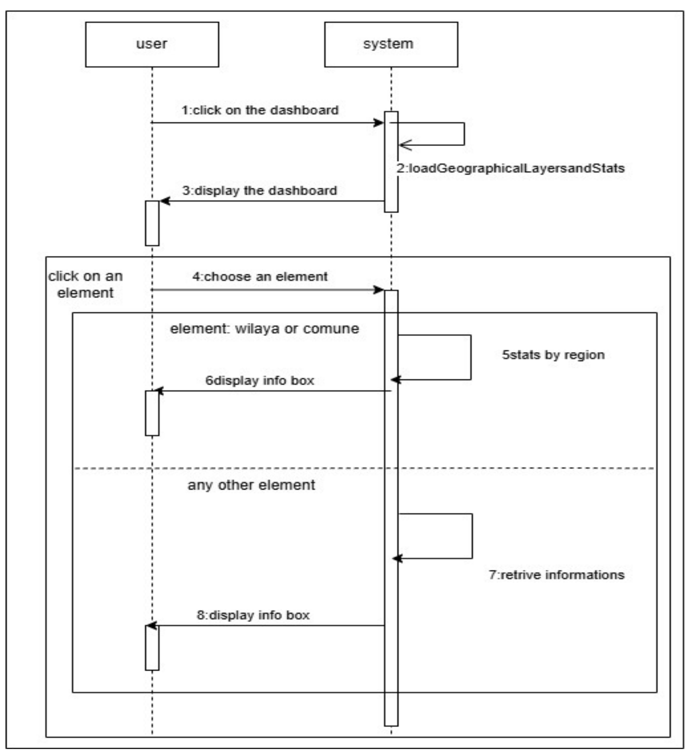

Fig 4: Sequence diagram (dashboard view).

4.3.2. Sequence diagram (login):

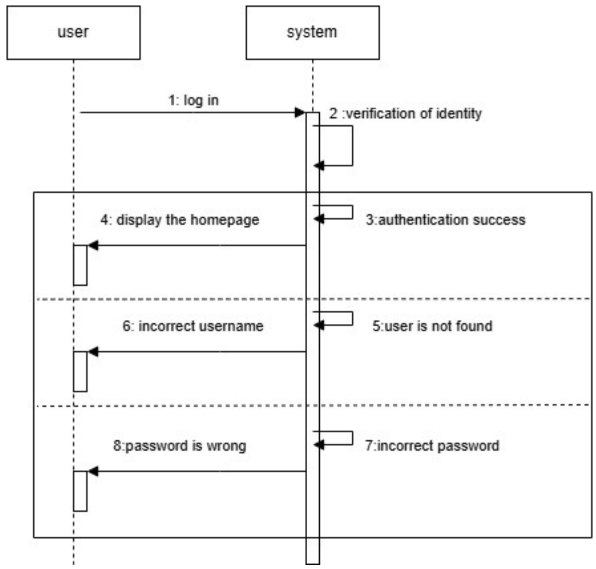

Fig 5: Sequence diagram (login).

4.3.3. Sequence diagram (add fire):

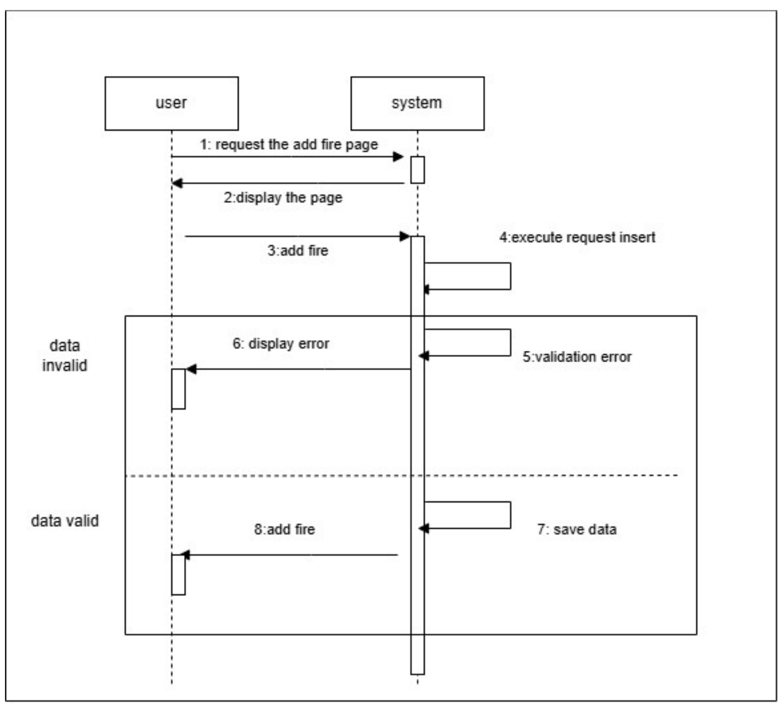

Fig 6: Sequence diagram (add fire).

4.3.4. Sequence diagram (fire prediction):

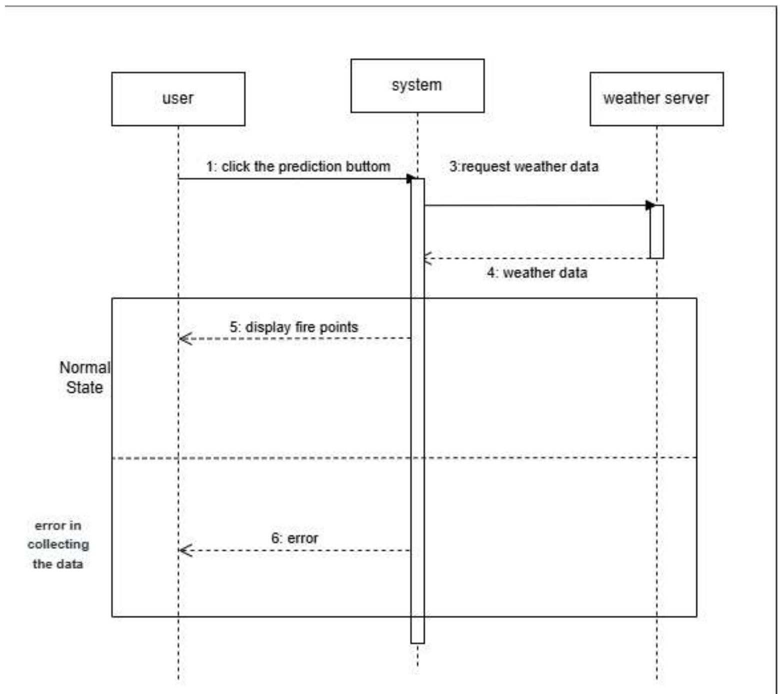

Fig 7: Sequence diagram (fire prediction).

4.3.5. Sequence diagram (display statistics):

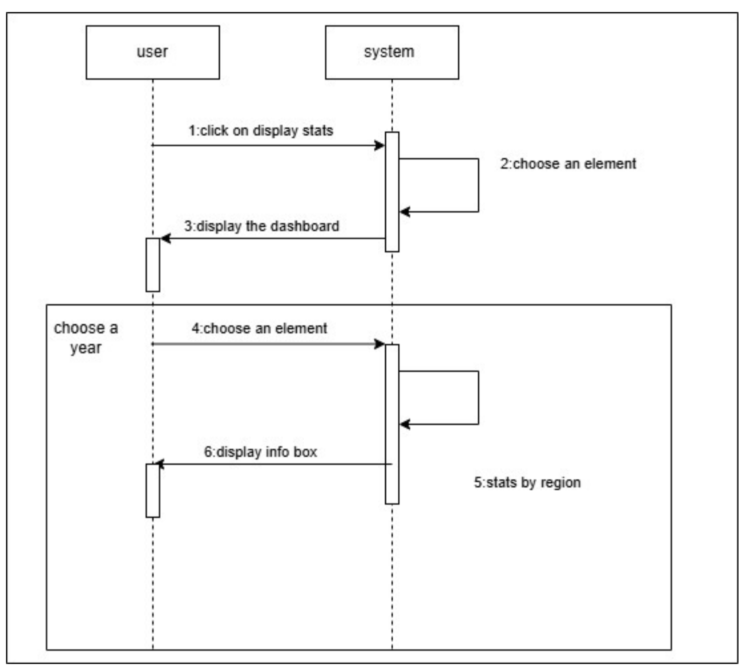

Fig 8: Sequence diagram (display statistics).

5. Database design

Database design is an essential step in developing any information system.

A category diagram designed based on actual state data for the study area illustrates the conceptual structure of the system's database.

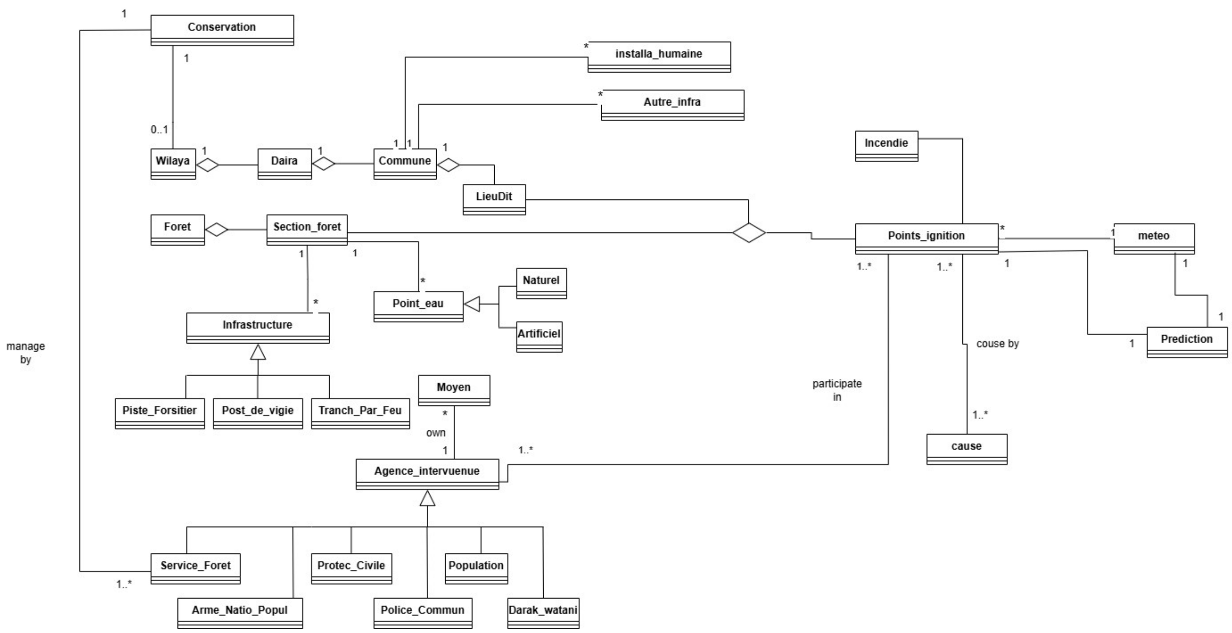

Fig 9: class diagram.

5.1. Describe the categories represented in the category diagram

The following table shows the basic classes that make up the system and their characteristics:

Wilaya	ID_wilaya Nom_wilaya Superficie(km²)	Numerical value String Numerical value
Daïra	ID_daira Nom_daira Superficie(km²)	Numerical value String Numerical value
Commune	ID_commune Nom_commune Superficie(km²)	Numerical value String Numerical value

Forêt	ID_foret Nom_foret Superficie(Ha) Degre_de_vulnerabilite	String String Numerical value Boolean
Section_foret	ID_section Nom_section	String String
Lieu_Dit	ID_lieudit Nom_lieudit	Numerical value String
Conservation	ID_Conserv Nom_Conserv	Numerical value String
Infrastructure	_	
Post_de_vigie	ID_pv Zone_pv Etat_pv Obs	Numerical value String Boolean String
Tranch_Par_Feu	ID_tpf Nom_foret Longueur (M) Largeur (M) Volume (HA) Etat Obs	Numerical value String Numerical value Numerical value Numerical value String String
Piste_Forestier	ID_pf Nom_foret Nom_commune Longueur (KM) Largeur (M) Longueur_praticable	Valeur numérique Chaîne de caractères Chaîne de caractères Valeur numérique Valeur numérique Valeur numérique

	(KM) Longueur_non_praticable(KM) Obs	Valeur numérique Chaîne de caractères Numerical value String
Moyen	ID_moyen Type Nombre Etat Location	Numerical value String Numerical value String String
Point_d'eau		
Naturel	ID Location Débit Capacité Mode de remplissage Sub_type Etat	String String Numerical value Numerical value String String Boolean
Artificiel	ID_ar Location Débit Capacité Mode de remplissage Sub_type Etat	String String Numerical value Numerical value String String Boolean
Autre_infra	ID_DGC Type Volume Etat	Numerical value String Numerical value String

	Location Obs	String String
Agence_intervenue	ID_AI Téléphone Nom	Numerical value String String
Protec_Civile	ID_PC Latitude Longitude Zones_interventions	Numerical value String String String
Darak_Watani	ID_DW Latitude Longitude	Numerical value String String
Population	ID_Pop Commune Adresse	Numerical value String String
Police_Commun	ID_POC Commune Adresse	Numerical value String String
Arme_Natio_Popul	ID_ANP Commune Adresse	Numerical value String String
Service_Foret	ID Indicatif de la brigade Circonscription Forêt	Numerical value String String String
Cause	ID_cause Type Sub_type	Numerical value String String

	Source	String
Prediction	ID_pre Date Longitude Latitude Validity	Numerical value Date String String Boolean
Météo	ID_meteo Description	Numerical value String
Point_d'ignition	ID_PI Longitude Latitude	Numerical value String String
Incendie	NI Date_declaration Date_intervention Date_extinction Sup_foret Sup_maquis Sup_brouss Sup_Halfa Sup_autre Essence_principale Enquête Signale Evaluation_financière	Numerical value Date Date Date Numerical value Numerical value Numerical value Numerical value Numerical value String String String String
Installa_humaine		

Table 2: Describe the categories represented in the category diagram.

5.2. Designing a relational model for a database

Using the class diagram we designed earlier and relying on the rules of transition to the relational model, we created the relational model that allows the logical structure of the database to be represented in the form of a table. This model shows the names of the tables and the primary and foreign keys.

(Table)	(primary key)	(Foreign Keys)
Wilaya	ID_Wilaya	-
Daira	ID_daira	ID_wilaya
Commune	ID_Commune	ID_daira
Conservation	ID_Conserv	ID_wilaya
Foret	ID_foret	-
Section_Foret	ID_section	ID_foret
Lieu_dit	ID_lieudit	ID_commune
Point_d'ignition	ID_Pi	ID_section ID_lieudit ID_meteo, NI
Incendie	NI	-
Post_de_vigie	ID_pv	ID_section
Tranch_Par_Feu	ID_tpf	ID_section
Piste_Forestier	ID_pf	ID_section
Moyen	ID_moy	ID_Ai
Agence_intervenue	ID_Ai	-
Protec_Civile	ID_PC	ID_Ai
Darak_Watani	ID_DW	ID_Ai
Population	ID_Pop	ID_Ai
Police_Commun	ID_POC	ID_Ai

Arme_Natio_Popul	ID_ANP	ID_Ai
Cause	ID_Cause	-
Météo	ID_meteo	-
Prediction	ID_pre	ID_Pi , ID_meteo
Intervention	ID_Ai , ID_Pi	ID_Pi ID_Ai

Table 3: Database relational model.

6. Technology Stack

To develop the system using several different techniques and tools, where Python was used as the basic programming language used in developing the system and Django used a framework to develop the application and link the interface to the database, both PostgreSQL and PostGIS are used to store and add geographic data and exchange it using GeoJSON and GDAL after preparing and analyzing it using QGIS, Designing system pages in HTML and CSS with JavaScript to interact and display maps by Leaflet library, and finally using Machine Learning to build a prediction model and use one of the algorithms (Logistic Regression, Random forest ….. etc.) with the following design [16]:

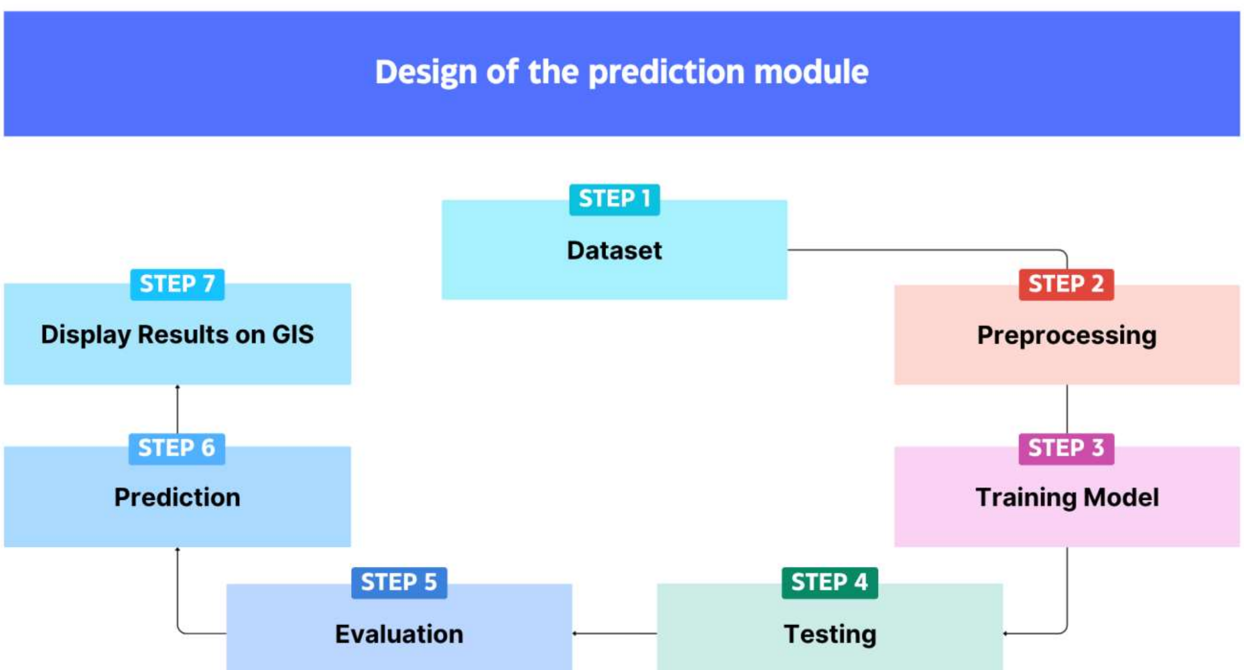

Fig 10: Design of the prediction module.

6.1. Database

Means all the operations that take place in the database with the data, i.e. obtaining sufficient data to represent the phenomenon studied and necessary to build the prediction model and then the process of storing the data using PostGIS and PostgreSQL.

6.2. Preprocessing

includes cleaning data (removing missing and incorrect values), converting data (converting text values to digital to make it easier to work with, for example) and selecting the features that are considered the data that have the most impact on the phenomenon of forest fires (temperature, humidity...) Finally, divide the data into 80% for training and 20% for testing in preparation for the next step.

6.3. Model Training

First, a machine learning model is tested (regression, random forests...) Depending on its adaptation to the phenomenon of forest fires, the existing data, and the required results as well, Model 80% uses training to understand the relationship between features with the phenomenon and extract a pattern or rule by which it works.

6.4. Testing

After training, we test the model using the remaining 20% from the dataset, which are new to the model, in order to evaluate the model's work and results.

6.5. Evaluation

In order to measure the validity of the model, we use one or several methods (accuracy, confusion matrix, recall... etc.) to know that the model is able to predict accurately before integrating it with the system.

6.6. Prediction

The actual work or predicting stage takes place after the success of training, testing and evaluation, where the model is ready to receive real data and give a good result.

6.7. Display results on GIS

After verifying the validity of the model, its operation, and its results, we integrate it with the geographic information system using Django, then display its results on the interface using Leaflet.

7. Conclusion

In this chapter, we have presented the steps of system design based on defining requirements and modeling the system using UML.

In the next chapter we will move to the implementation phase of the system.

Chapter 3 System implementation

1. Introduction

After completing the analysis and design phase, we move to the practical implementation phase of the system.

In this chapter, we will present the study area, as well as the source of the data, the steps for cleaning it, and the detail's implementation of the system.

2. Study area (Bouira State)

Bouira State was chosen as the study area due to the availability of data on forest fires over the past years for this state. Bouira Province is located in the north-central region of the country, with an area of 4,454 km2. It is bordered to the north by the provinces of Tizi Ouzou and Boumerdes, to the east by Bordj Bou Arreridj and Bejaia, to the west by Blida, and to the south by M'Sila and Medea.

The forest area in Bouira State is 112,250 hectares, equivalent to 25.2 percent of the total area of the province. It is divided into [17]:

- 49,795 hectares of natural forests;
- 17,087 hectares of reforested areas;
- 39,393 hectares are dense areas;
- 5975 hectares of scattered forests.

3. Data sources:

In this project, different data was relied upon from multiple sources with the aim of building an integrated database.

- Forest fire data, the data provided by DGF for the state of Bouira was used in the form of Excel tables between a period extending from 2011 to 2019. This data is the basis for analyzing the phenomenon of forest fires and also an important element in forecasting;

- Geographic information (Attribute and spatial) was obtained by DGF in the form of files (shapefile, tiff) and others downloaded from open sources or created manually;
- Climate data is basic data and is important in the prediction process. The data is downloaded through an API interface linked to Google Weather to provide weather information for a specific day.

Other data was brought in from the Civil Protection of M'Sila Province, but it was insufficient to analyze the phenomenon of forest fires or to make predictions.

3.1. Data types

In a geographic information system, files vary depending on the source and data type.

For this project, most of the data was collected from the forest governorate of the studied area. The following table shows the file types in a GIS and their extension depending on the type of data they represent [18]:

Category	file type	Form
Linear spatial data	Shape file	.shp , .dbf , .shx , .prj
	GeoJSon	.geojson
	KML	.kml
	MID/MIF , TAB	.mid , .mif , .tab
Network spatial data	GeoTIFF / TIFF	.tif
	GRID	There is no specific extension
Attribute data	data tables	.csv , .xls
	DBF	.dbf
	XML	.xml
Maps	project files Qgis	.qgs , .qgz
Images	Picture	.gif , .png , .jpg , .img , .jp2

geographic databases	File Geodatabase	.gdb
	Personal Geodatabase	.mdb

Table 4: File types in GIS.

3.2. Tools

In developing the proposed system, a set of software tools and techniques were relied upon to ensure effective performance and an easy user interface. The following are the most important techniques used according to the nature of the tasks:

3.2.1. Front-end

- HTML5: To create, structure, and define web pages;
- CSS3: To format web pages and specify their appearance on the browser, such as: colors and font;
- JavaScript: A web programming language used to change the content and behavior of web pages and create dynamic content for user interfaces;
- ChartJs: An open source JavaScript library used to create charts based on Canvas technology;
- Leaflet: is an open source JavaScript library used to create interactive maps;
- JQuery: It is a free and open source library used to facilitate writing code and dealing with web page elements quickly and easily;
- JSON: A format used to exchange data between a server and a client;
- Geojson: A format used to encode a variety of geographic graph structures such as points, lines, and polygons in a simplified manner [19].

3.2.2. Back-end background

- Python: A high-level programming language used for developing web applications and analyzing and processing data [20];
- Django: It is a high-level, open source framework used to develop web applications using Python [21];
- Geodjango: An extension of Django that supports the development of web applications containing geographic data;
- Django-cors-headers: A library that allows front-ends to interact with Django servers across different servers;

- Psycopg2: A library for linking Python with Postgresql databases in Django projects [22].

3.2.3. Database

- PostgreSQL: An open source relational database management system, supporting object-oriented Orient Objet [23];
- PostGIS: An extension of the PostgreSQL data management system that adds support to geographic data by representing it in geometric shapes [25].

3.2.4. GIS and data processing tools

- QGIS: An open source program used to display and analyze data Geography [25];
- GDAL: An open source library used to process and transform data Geography [26].

3.2.5. Development environment

Anaconda: An open source platform used to facilitate work and organize tools in Python projects.

4. Data Cleaning and Integration

After collecting the data, the process of cleaning it comes, and this process takes place in stages, which are [27], [28]:

- Handling Missing Data: The data is checked to detect missing and incomplete values, unfortunately there is a lot of them in the data used in this project (absence of coordinates, information about the fire.....);
- Error correction Detect and correct errors in data (such as coordinates, incorrect date and time writing method......);
- Coordinate System Standardization unifying the coordinate system using a coordinate system according to Global Geodetic References WGS84 to ensure compatibility of all data within the system;
- Convert data to the appropriate format, after cleaning the data, we convert it to appropriate formats (for example shapefile, geojson .....) To facilitate its entry into the geographical database;
- Data Integration Collect various data (Attribute and spatial) into a unified database that appropriately serves the project objective.

5. Spatial Database Implementation

5.1. Spatial data

It is data that shows a location or place. It is linked to geographical coordinates and includes all natural and artificial elements present in an area, such as: trees, roads, city boundaries, terrain, etc. This data can be divided into two parts according to the methods of processing, storage and display [29].

5.1.1. Vector Data

These are ways of representing spatial data through simple components (points, lines and polygons) .These geometric elements are defined by their coordinates in the projection system [30].

- Surface data: represents elements that have length and width, meaning they cover a specific area, such as: forests, lakes, states..., represented by polygons (polygons);
- Linear data: represents elements extending in a certain direction such as roads, waterways..., represented by lines (lines);
- Point data: such as wells, points (Points)..., represent fire centers.

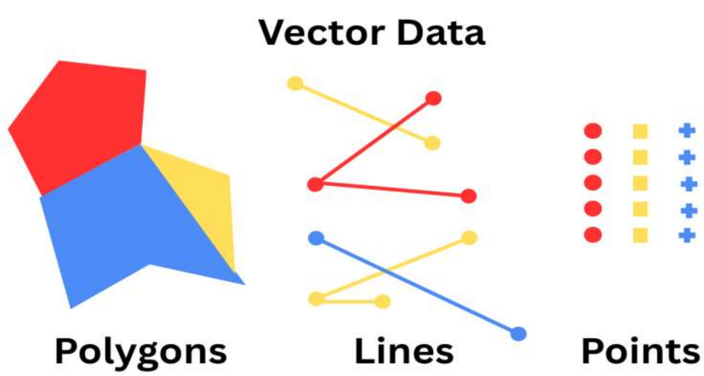

Fig 11: Vector representation of geographic data.

5.2. Raster Data

It is geographical data represented by a two-dimensional matrix, the basic element of which is the pixel (Pixel), each pixel is identified by the row and column number and expresses spatial information [31].

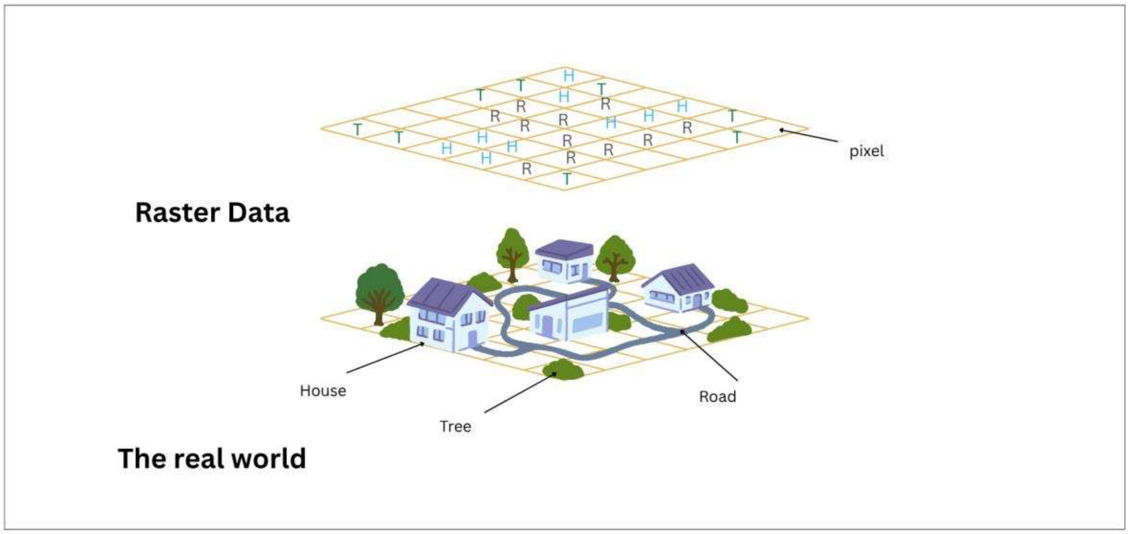

Fig 12 : Network representation of geographic data.

5.3. Geographic database

A geographic database is a special type of database that is an essential part of a geographic information system, because it combines spatial data (geographical locations, geometric dimensions, points, lines, polygons) and non-spatial data (characteristics and attributes) in an organized manner, which allows this data to be analyzed and managed in ways that facilitate decision-making related to it, such as determining the locations of geographical elements or analyzing the relationships between them[32].

A geographic information system stores information in layers that represent the real world within a geographic database. The data layer is a collection of spatial entities in addition to their locations, topology, and images [33].

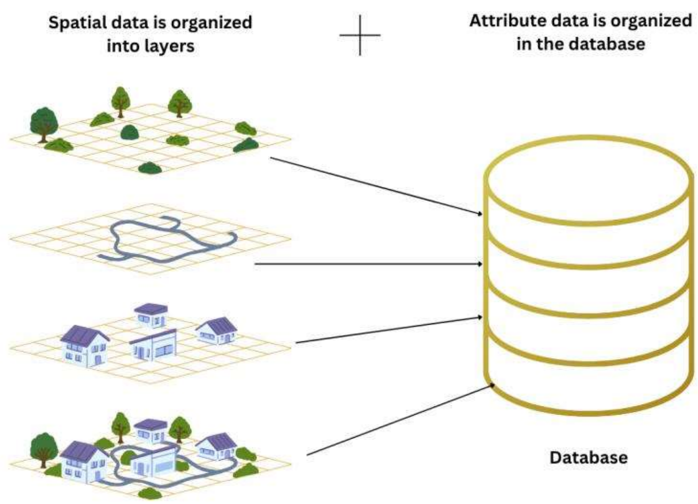

Fig 13: Geographic database and overlapping layers.

5.4. Database Implementation

- Create database: Download both postgresql and add postgis from the official website of each. Open pg admin, click Create, then give a name to the database;

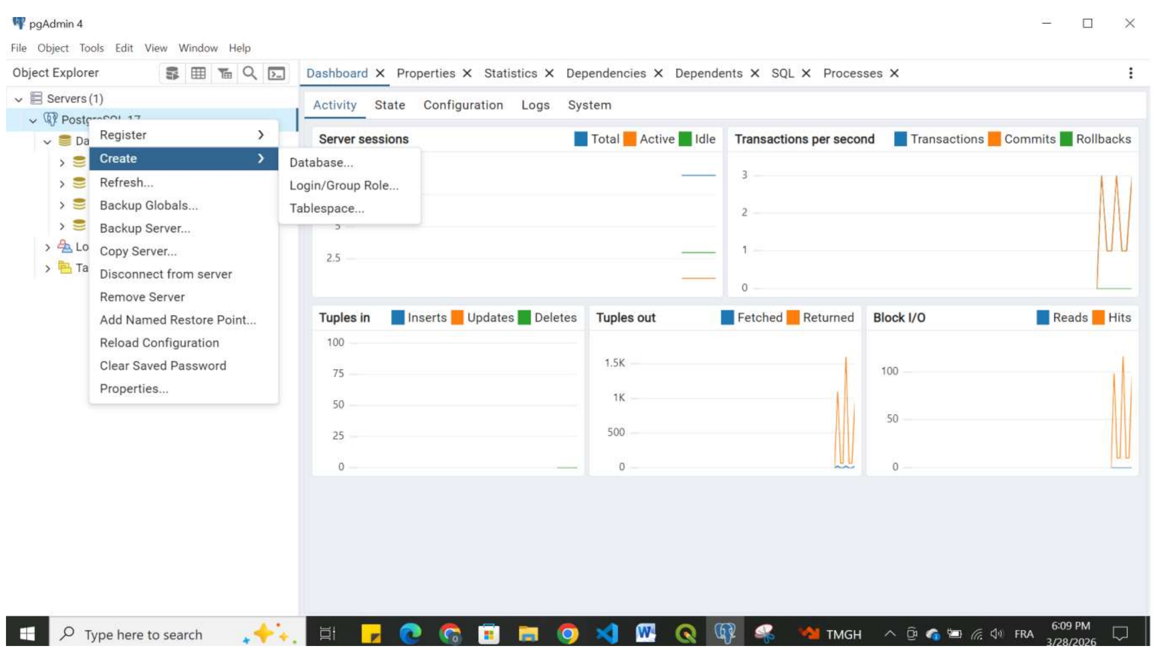

Fig 14: Create database.

- Activate postgis in pg admin and after creating the database we click on query tool and write a query in sql create extension postgis to support spatial data;

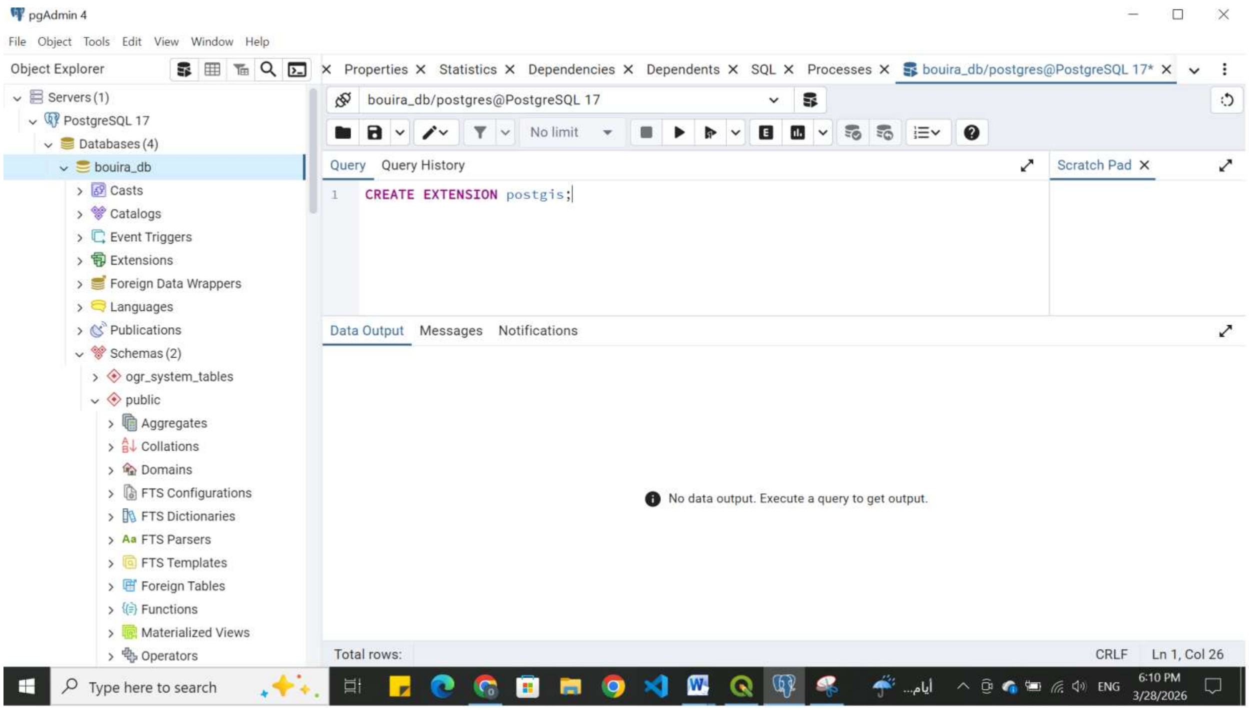

Fig 15: Activate postgis.

- Create a connection with QGIS Download QGIS from the official website on the Internet, then open the program and click on New Connection, writing the name of the database that we created and click on Connection, and then it appears the connection was successful;

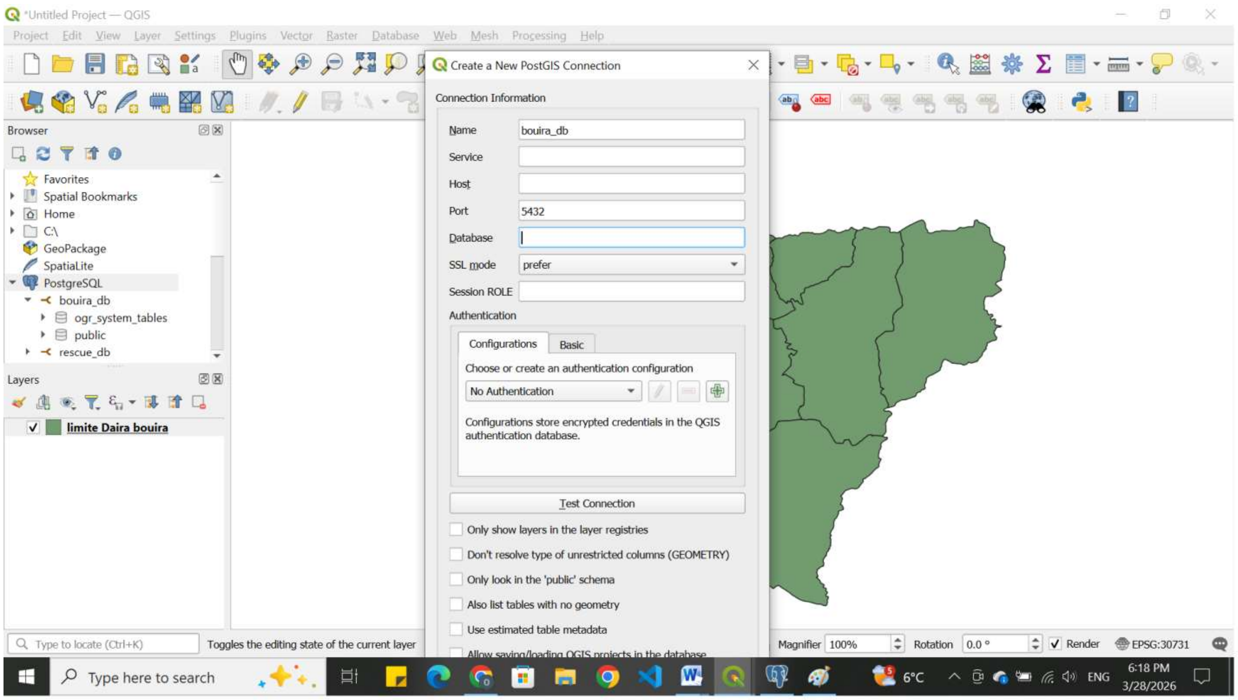

Fig 16: Create a connection with QGIS.

- Enter data into qgis: Click Add Layer and choose the type of data entered (linear, descriptive...) Then we enter the appropriate file;

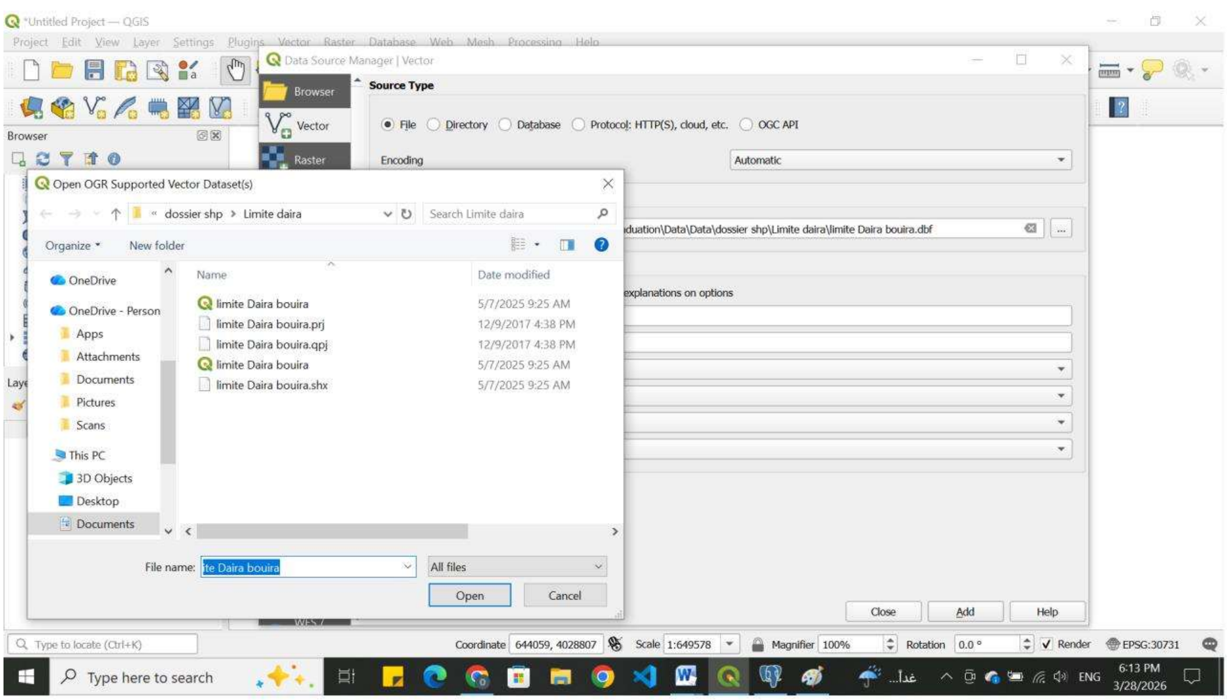

Fig 17: Enter data into qgis.

- The entered data appears in the qgis interface, which can be modified and also automatically added to the database to appear in the form of a table that can be verified and modified also in pg admin.

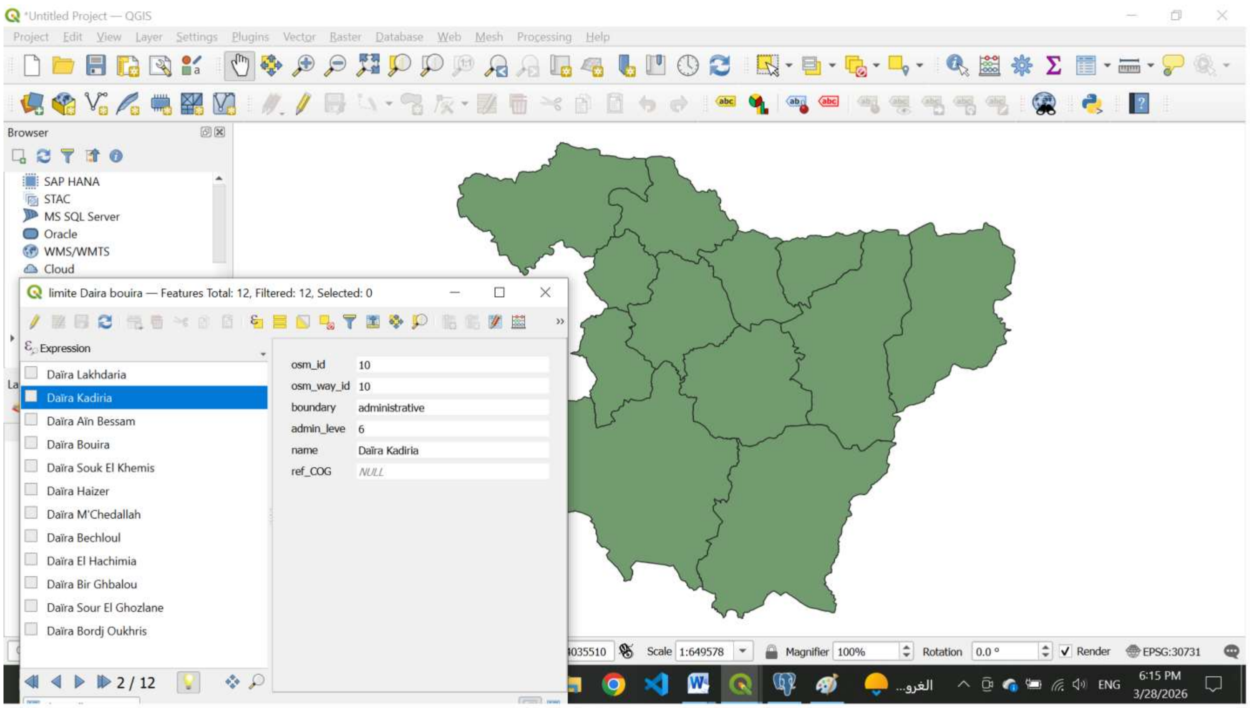

Fig 18: view data in QGIS.

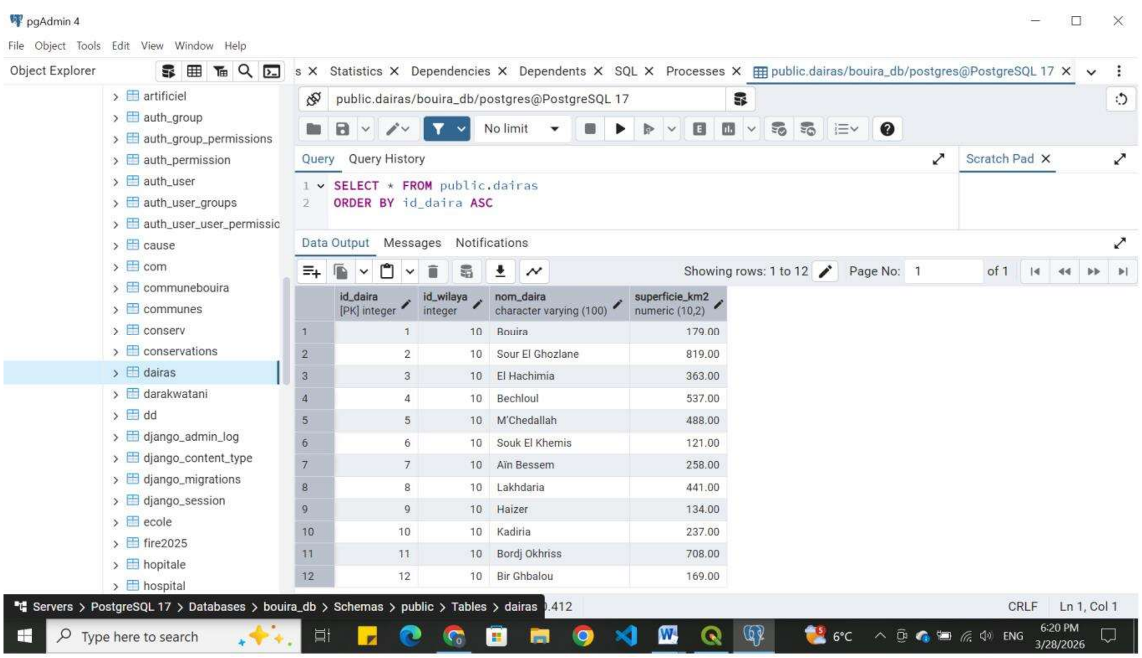

Fig 19: view data in POSTGIS.

6. Preliminary Map

After saving the points and all the spatial data in the database, we now create a preliminary map to display this data, which is a preliminary step to extend the entire system.

- Create a map using the Leaflet library and determine its center on the study area;

```
var map = L.map('map');

L.tileLayer('https://{s}.tile.openstreetmap.org/{z}/{x}/{y}.png', {
  attribution: '© OpenStreetMap contributors'
}).addTo(map);
```

- Add a basic base map from Open Street Map to display the geographic background;
- Adding layers: The layer (for example, the layer of Bouira state districts) is loaded in the form of a Geojson file and displayed on the map to represent the administrative division;

```
fetch('/static/daira.geojson')
    .then(res => res.json())
    .then(data => {
      dairaLayer = L.geoJSON(data, {
        onEachFeature: (feature, layer) => {
          const p = feature.properties;
          layer.bindPopup(`<b>${p.nom_daira}</b><br>id_wilaya:
${p.id_wilaya}<br>superficie_km2: ${p.superficie_km2}`);
        },
        style: {
          color: "black",
          weight: 2,
          fillColor: "#DEB887",
          opacity:1,
          fillOpacity: 1,
        }
      });
      map.fitBounds(dairaLayer.getBounds());

    });
```

- We add a feature to interact with the map, where when you click on an element from the layers, an information box appears:

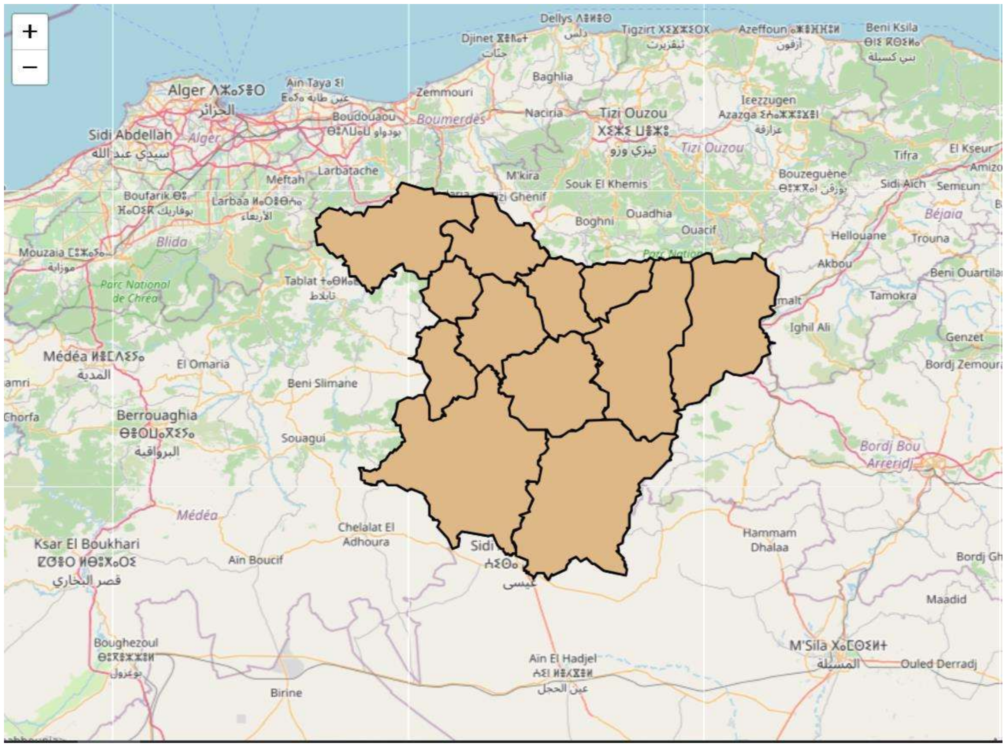

Fig 20: map visualization.

7. GIS Application Development

To develop a geographic web system that covers all functional and non-functional requirements, the following steps must be followed:

- Creating a Django Project, we used Anaconda to create the project because it is an open source platform used to facilitate work and organize tools in Python projects. We download Anaconda and then use the main interface to create a project and application where a folder appears automatically on a used computer with all the necessary Python files. You can use Anaconda Prompt and write codes for creating a project.

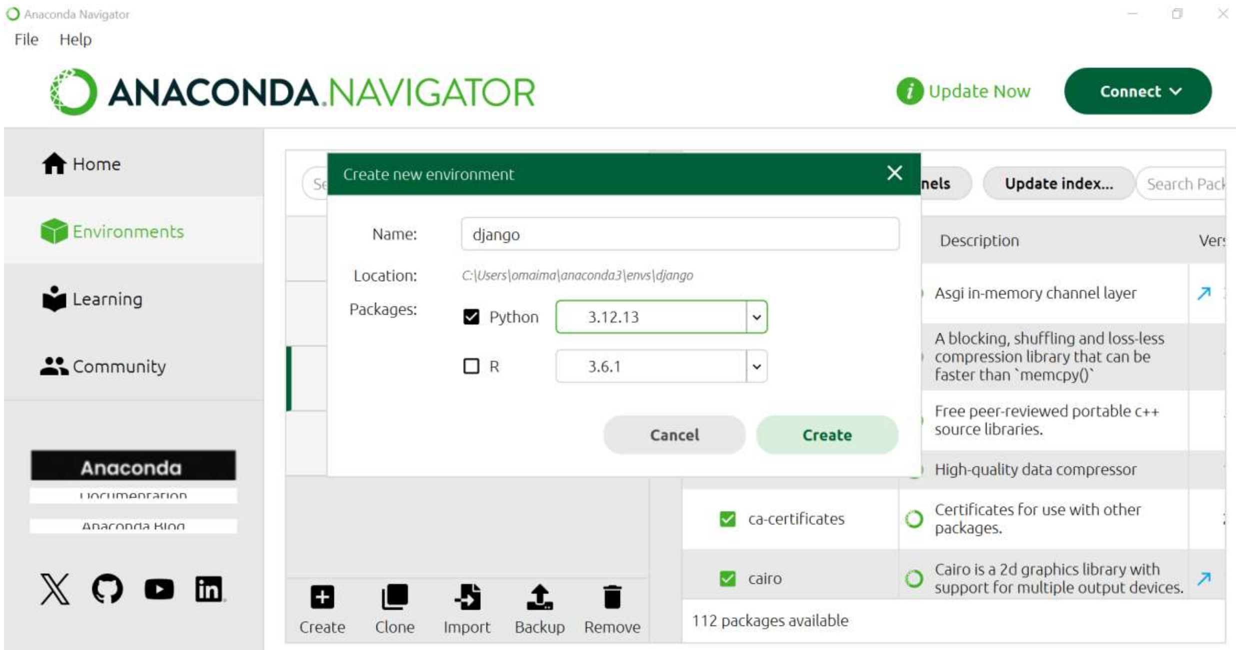

Fig 21: Anaconda interface.

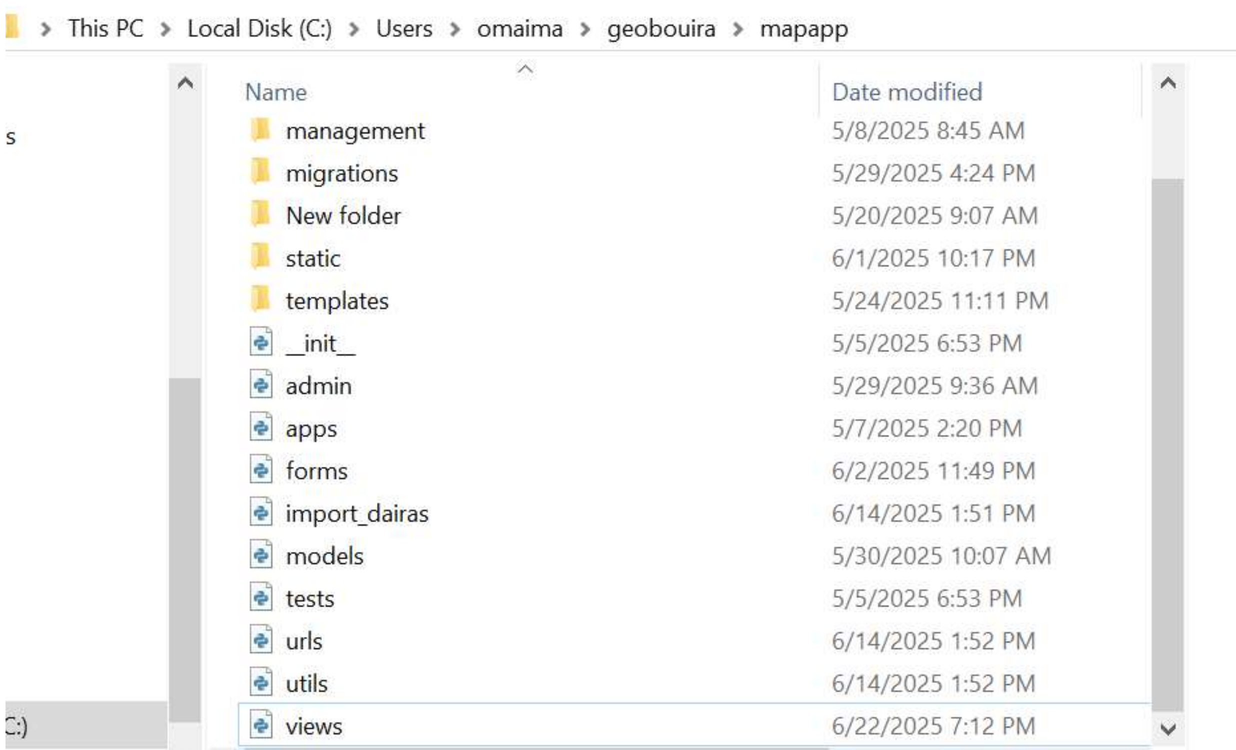

Fig 22: the Django project files.

- In the Python Models file we create the necessary models for the project, which are a representation of the tables in the database (states, districts.....etc.);

```
class communes(models.Model):
    id_daira = models.ForeignKey('dairas', models.DO_NOTHING,
db_column='id_daira', blank=True, null=True)
    id_commune = models.CharField(max_length=100, primary_key=True)
    nom_commune = models.CharField(max_length=100)
    #superficie_km2 = models.DecimalField(max_digits=10,
decimal_places=2)

    class Meta:
        db_table = "communes"
        managed = False

    def __str__(self):
        return self.nom_commune
```

- From the Python files that were created automatically with the project, we open the settings file to link the Django project to Postgis by entering database information;

```
# Database
# https://docs.djangoproject.com/en/5.2/ref/settings/#databases

DATABASES = {
      'default': {
        'ENGINE': 'django.contrib.gis.db.backends.postgis',
        'NAME': 'bouira_db',
        'USER': 'postgres',
        'PASSWORD': 'momo2003',
        'HOST': 'localhost',
        'PORT': '5432',
    }
}

```

To retrieve data from the database and display it on the front end in Json format, we develop a software interface in the view file;

```
def get_wilayas(request):
    data = list(wilayas.objects.filter(nom_wilaya="Bouira").values('id_wilaya',
'nom_wilaya'))
    return JsonResponse({'wilayas': data})
```

```
def get_dairas_by_wilaya(request, wilaya_id):
    data = list(dairas.objects.filter(id_wilaya=wilaya_id).values('id_daira',
'nom_daira'))
    return JsonResponse({'dairas': data})

def get_communes_by_daira(request, daira_id):
    data = list(communes.objects.filter(id_daira=daira_id).values('id_commune',
'nom_commune'))
    return JsonResponse({'communes': data})
```

- Linking Django with the interface We do this step by entering JavaScript and the Leaflet library, where layers can be displayed on the map and data displayed on it (fire points, information boxes, interactions with the map...) In addition to other functions (search button for a specific area, zoom map..).

8. Application interface

The system interfaces are designed to be simple, easy to use, and cover basic functionality. In this section, we will present the main interfaces of the system along with their basic functions.

- Login: To access the application, users must first authenticate using their username and password;

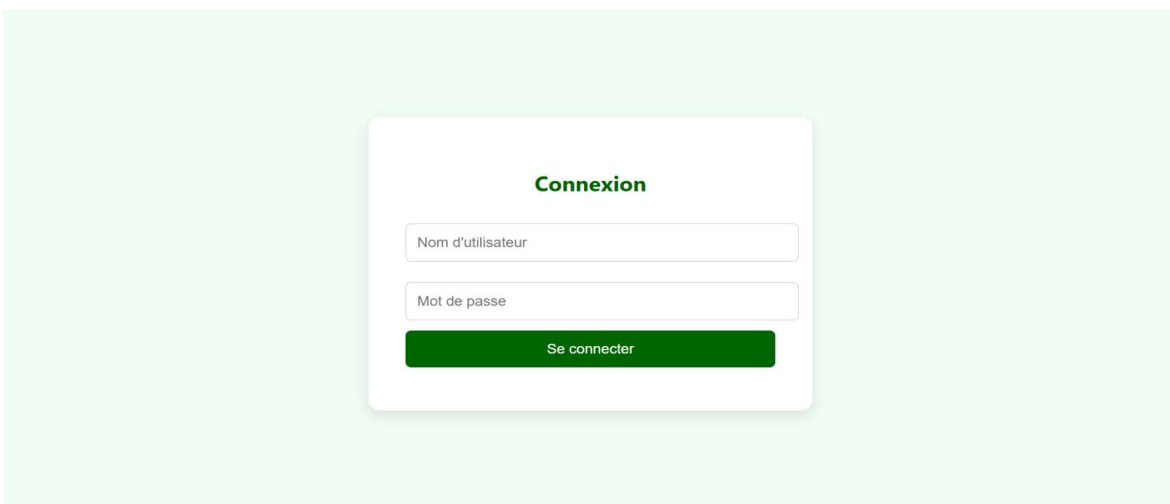

Fig 23: login interface.

- Homepage: After logging, the user will see a dedicated home page that matches his powers and role in the system. The interface have been designed for forest conservation users;

Fig 24: Home page for the forest conservation of Bouira.

- The following image shows the services that users can access from the home page;

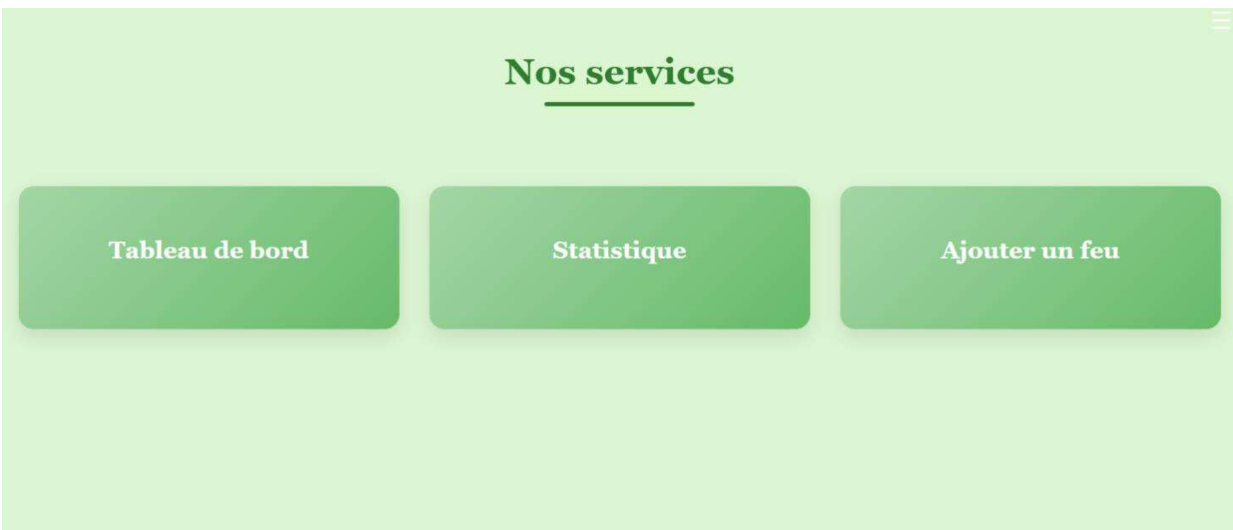

Fig 25: Home page services.

- Dashboard: This interface displays an interactive map of recorded fires accompanied by statistics. For the conservation user, only data related to his region appears. The user of the;

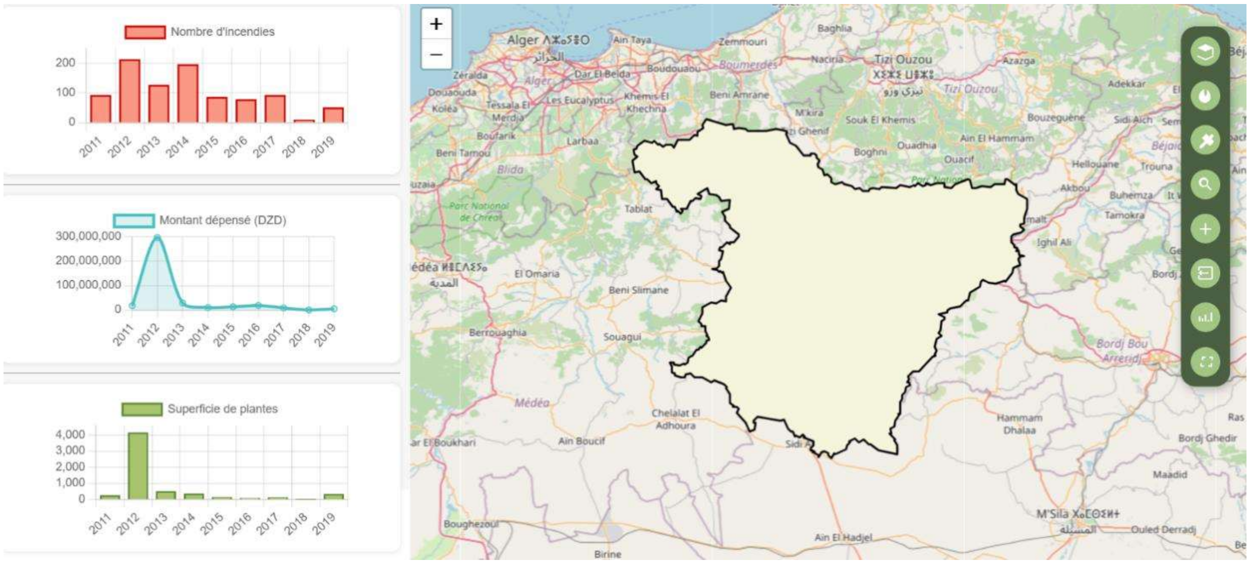

Fig 26: dashboard page.

- This interface also allows display of various elements of forest infrastructure, as well as various devices for fighting forest fires. This information is organized into layers that can be displayed upon request. All items that appear on the map also contain information that can be displayed in the information box with a simple click on the item in question. As shown in the image below;

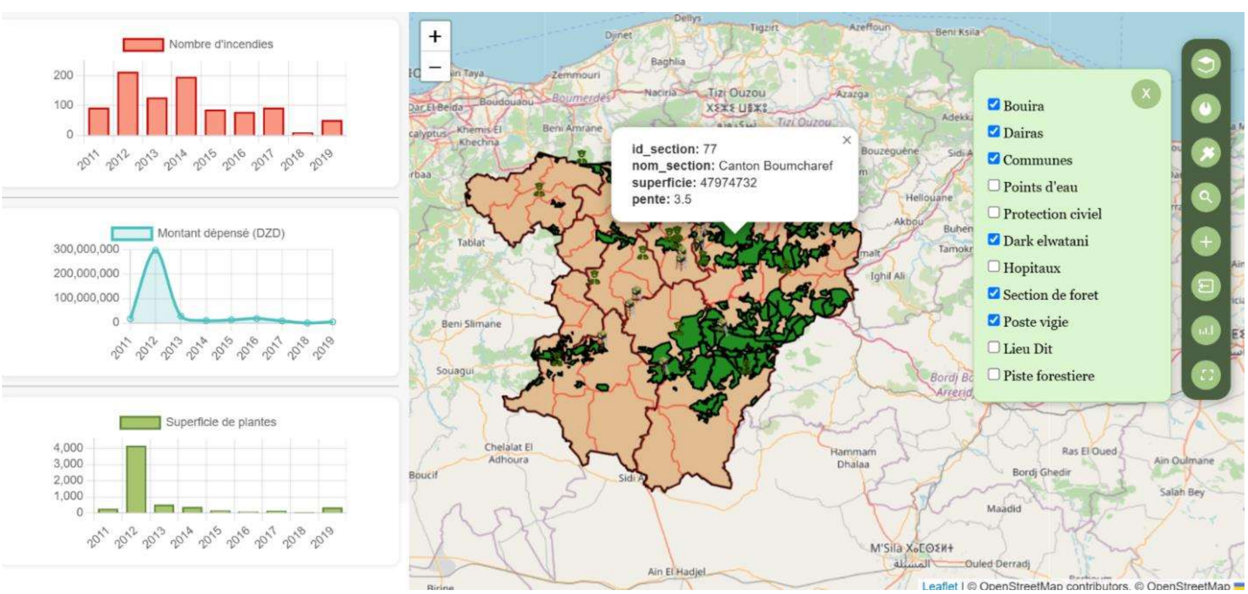

Fig 27: the display of information box.

- The user can view all fires on the map or specify a specific year as shown in the image;

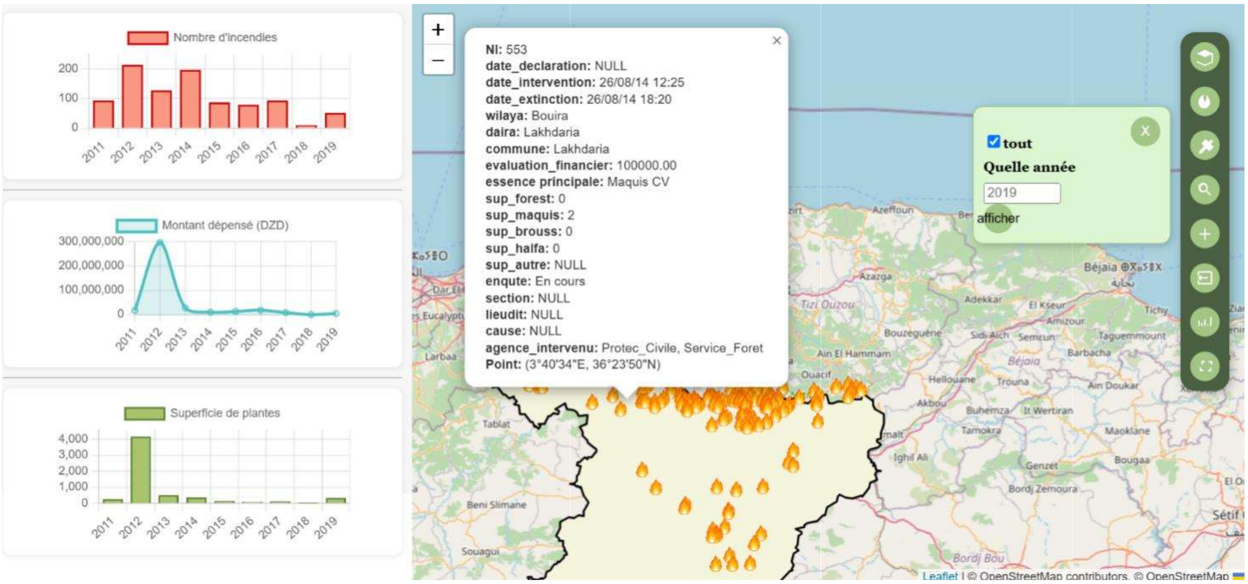

Fig 28: view fire on the map.

- Add fire: Starting from the home page or from the dashboard, the user can access the page for adding or modifying fires shown in the following image. Once the fire is added, it appears directly on the map in the dashboard;

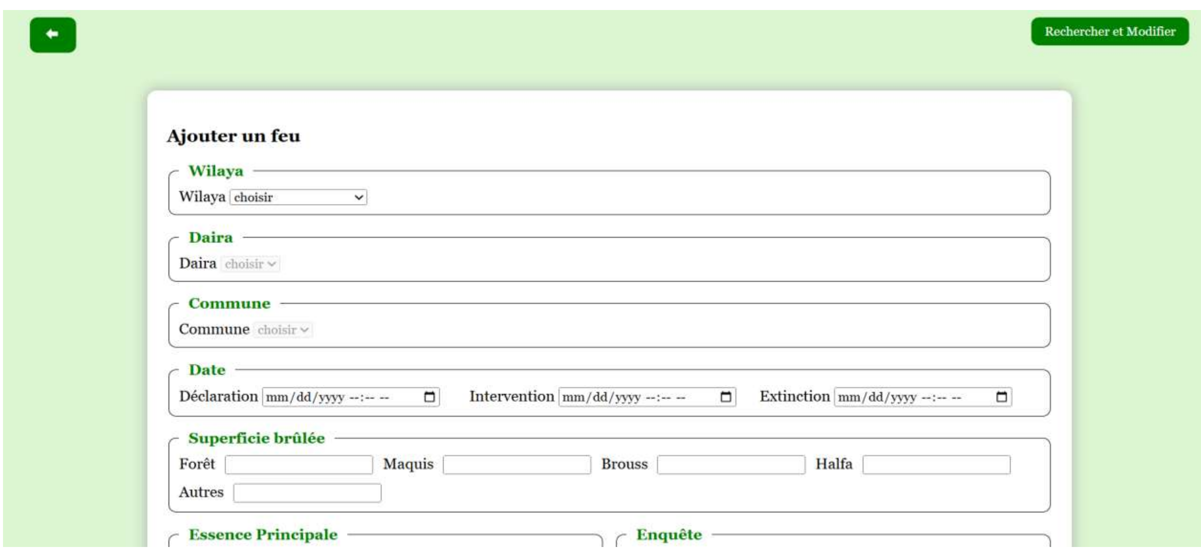

Fig 29: add fire part1.

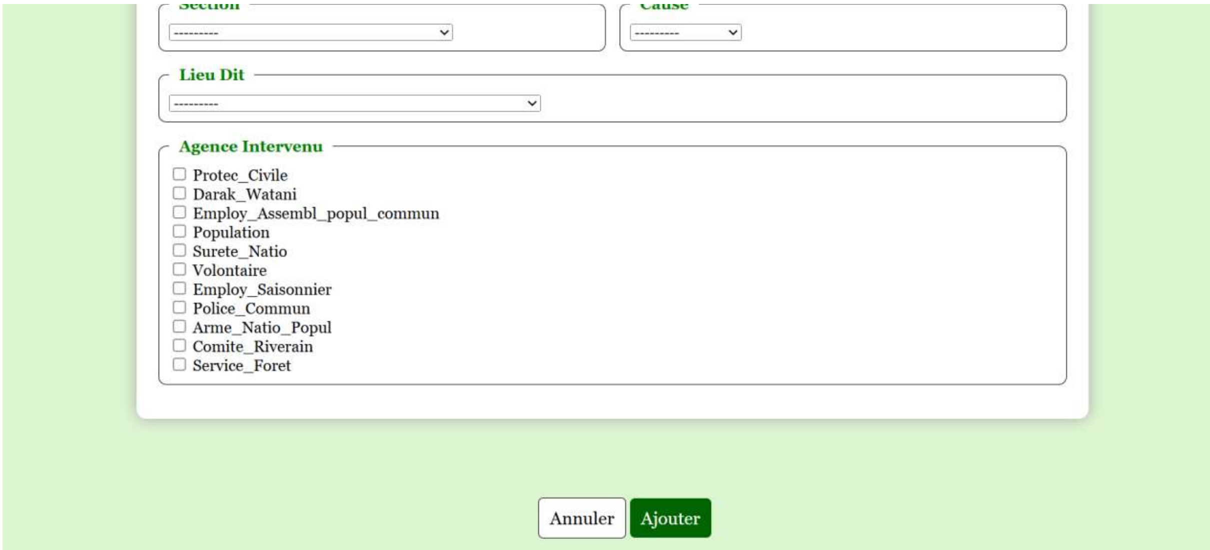

Fig 30: add fire part2.

- View statistics page: This page displays statistics related to fires: number of recorded fires, types of burned plants, and financial losses in terms of years and months, as the image shows;

Fig 31: view statistics.

- View prediction: Press the prediction button from the sidebar and the points where a fire is likely to occur for that day will appear on the map. You can press the displayed point to confirm whether a fire occurred or not.

Fig 32: view prediction.

9. Conclusion

In this chapter, we touched on the various technical aspects of implementing the system, starting with presenting the study area and system architecture, then we presented the interactive interfaces of the application that enable the user to deal with the system.

In the next chapter we will discuss the predicting model and all its aspects.

Chapter 4 Prediction Module

1. Introduction:

This chapter covers a comprehensive theoretical framework for predictive modeling. We will cover feature selection, model implementation, and ultimately testing and results.

2. Feature selection

2.1. Causes of forest fires

Fire is essentially a chemical reaction that depends on the presence of three main elements (Fire Triangle) is: Fuel, Oxygen, The heat [34].

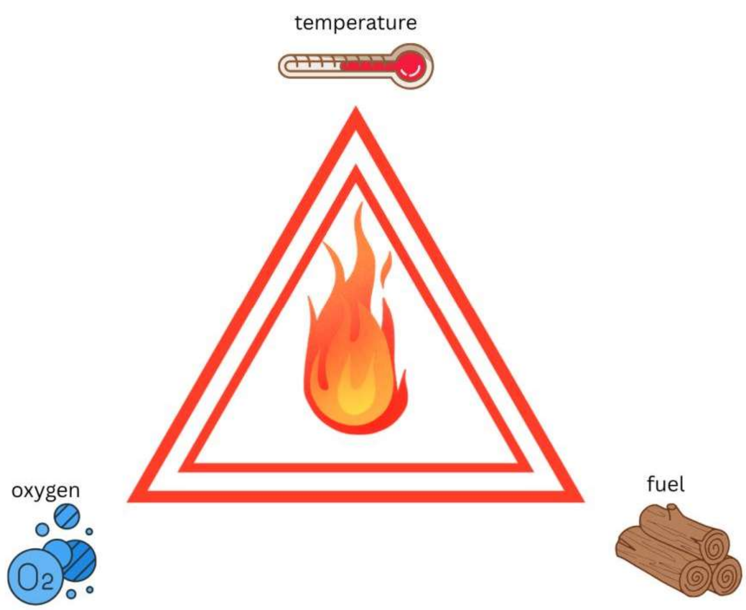

Fig 33: Fire Triangle.

- Natural causes:
- Climate: Climate greatly affects the occurrence and spread of fires, and we often talk about the 30-30-30 rule, which is a rule that indicates environmental conditions that are considered a strong indicator of the possibility of the outbreak of large and massive fires, and they are [35]:

- Temperature above 30°C (<30°);
- Wind speed exceeding 30 km/h (<30 km/h);
- Humidity less than 30% (>30%);
- It is noted that the closer conditions are to these numbers and the longer they take, the greater the risk of fires.

- Terrain: Terrain (slopes and slopes) also contributes to the outbreak of fires because the fire burns faster in sloping plain areas and facades and spreads from bottom to top due to heat transfer and wind gusts[36];
- Type and age of trees: Some species, such as needle trees like pine and cedar, contain flammable oils, making them highly flammable. Young trees or trees with dry branches close to the ground are more susceptible to fire than perennial trees[36];
- Human causes: The party causing the forest fires and the first accused before the Nature Court is humans. Most of the causes, and in many of the largest fires currently witnessed by the world, are due to irrational human interactions with the environment, such as deliberate burning or burning resulting from neglect and forgetfulness [36].

2.2. Features of the Study area

Due to the lack of data and the inability to know human actions, characteristics were limited to climatic factors according to the 30 30 30 rule and were modified according to the study area [37].

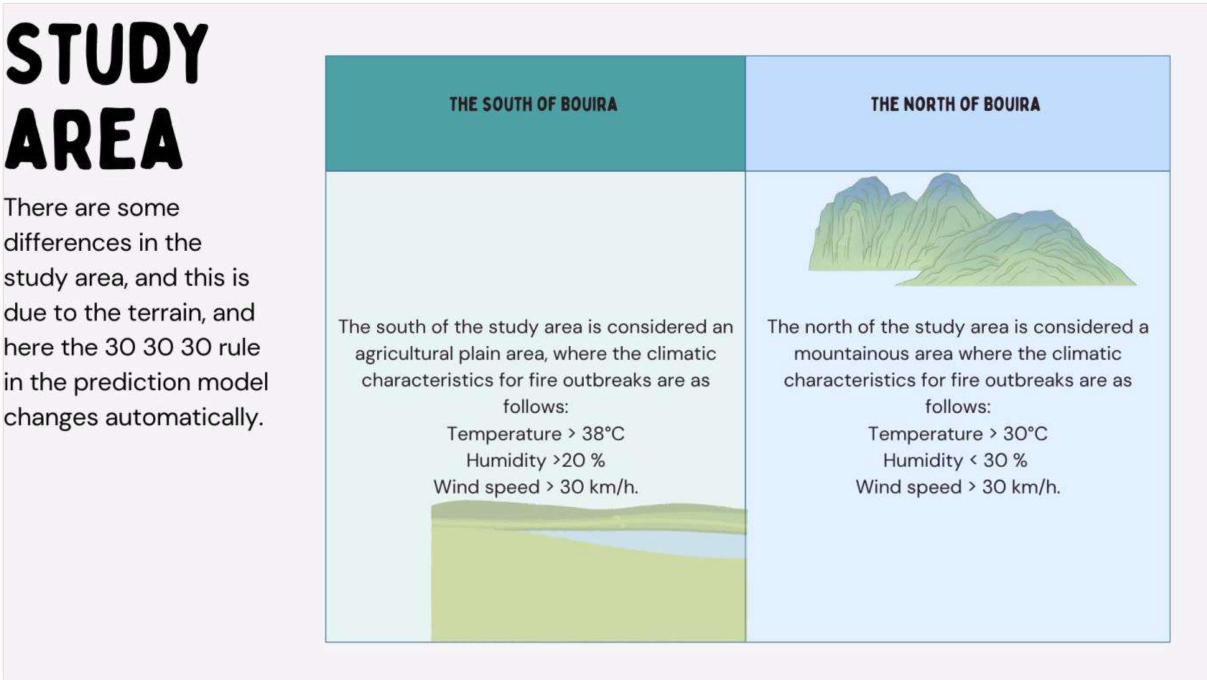

Fig 34: Features vary depending on the regions of the study area.

3. Model Development

The prediction methodology for the GIS project was organized using machine learning and a rule-based system, which were combined to give the system more accurate results.

Machine learning is the field of study that gives computers the ability to learn without being explicitly programmed [38].

A random forest is a supervised algorithm that uses an ensemble learning method consisting of a multitude of decision trees, the output of which is the consensus of the best answer to the problem. Random Forest can be used for classification or regression [39].

Rule-based predicting system is a form of expert artificial intelligence system, it is considered a rules-based predictive system that makes decisions or predictions using logical rules instead of automatic learning from data such as machine learning[40], [41].

3.1. Rule-based predicting system VS Random Forest

The disparity between the two predicting approaches is summarized in the figure bellow [40]:

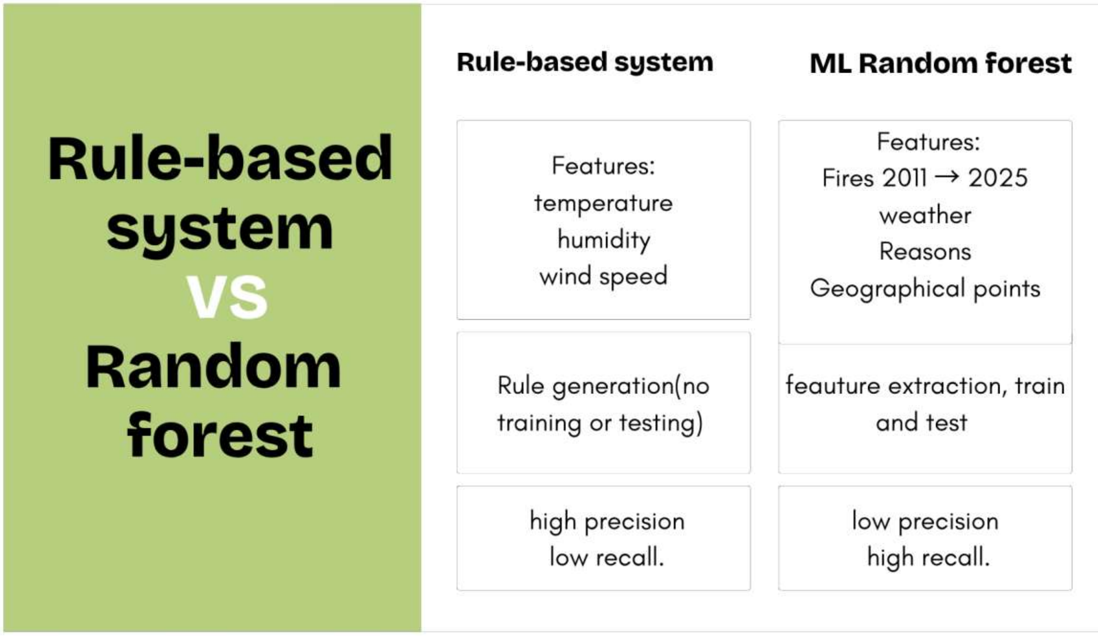

Fig 35: Rule based system VS Random forest.

At this stage, a wildfire prediction model was developed using random forest to analyze the relationship between wildfire occurrence and several climate variables.

The dataset was extracted from the PostgreSQL/PostGIS database and included the following attributes:

Feature	Description
Latitude	Geographic latitude
Longitude	Geographic longitude
Month	extracted from declaration date
Temperature	Air temperature
Wind Speed	Wind speed
Humidity	Relative humidity
Fire	Target variable (0 = No Fire, 1 = Fire)

Table 5: attributes of the train set.

The prediction model was implemented using the Random Forest algorithm due to its ability to:

- Handle nonlinear relationships;
- Reduce overfitting;
- Provide feature importance analysis;
- Achieve high predictive performance.

The dataset was divided into:

- 80% training data;
- 20% testing data.

4. Model Evaluation

Model evaluation involves the comparison between the expected outcomes and the actual outcomes produced by the mode [42], [43].

The following table summarizes the most important evaluation methods and arranges them based on their importance to our project [43]:

Evaluation Method	Definition	How It Works	Best Use in GIS Prediction
Recall	Evaluates the model's ability to detect real positive cases.	Calculates TP divided by actual positives	Most important metric for wildfire detection
F1-Score	The harmonic mean of precision and recall.	Balances false positives and false negative	Best overall metric for wildfire prediction.
Confusion Matrix	A table that displays classifications that are correct and incorrect	Sorts predictions by TP, TN, FP, and FN.	Excellent for understanding fire prediction errors.
Accuracy	The measure assesses the accuracy of predictions against all made.	Compares the labels that were predicted with those that were actually present and calculates the percentage of classifications that	Useful only as a general indicator.

		are correct.	

Table 6: Evaluation methods.

In this model, we used several methods to determine the accuracy of the results, and the results were positive:

```
Mean Accuracy:
0.900840991367307

Accuracy:
0.8789473684210526

Classification Report:
              precision    recall  f1-score   support

           0       0.91      0.90      0.91       126
           1       0.82      0.83      0.82        64

    accuracy                           0.88       190
   macro avg       0.86      0.87      0.87       190
weighted avg       0.88      0.88      0.88       190


Confusion Matrix:
[[114  12]
 [ 11  53]]

ROC AUC Score:
0.9327876984126984

Feature Importance:
       Feature  Importance
2   wind_speed    0.452513
1  temperature    0.412006
3     humidity    0.075329
0        month    0.060152

Random Forest model saved successfully!
```

Fig. 36: Evaluation results.

The Random Forest model showed an accuracy of 87.89% and an average cross-validation accuracy of 90.08%, which indicates good stability for the model. The ROC-AUC score was 0.933, which shows great ability in telling apart fire and non-fire events. The confusion matrix revealed 53 fire cases and 114 non-fire cases were identified correctly. Feature importance analysis found that wind speed at 45.25% and temperature at 41.20% were the main variables in predicting forest fire occurrence and humidity at 7.53% and month at 6.02% were also important. These results show the Random Forest algorithm works well for predicting forest fires.

5. Integration into GIS

The most important step is to link a prediction model with a geographic information system, and this is done through [44]:

- Connect to the database using PostgreSql;

```
conn = psycopg2.connect(
    dbname="bouira_db",
    user="postgres",
    password="momo2003",
    host="localhost",
    port="5432"
)

query = """
SELECT
    ST_Y(geom) AS latitude,
    ST_X(geom) AS longitude,
    temperature,
    wind_speed,
    humidity,
    "Date_Declaration",
    fire
FROM public.trainset;
"""
```

- Create a Python model, train it and test it;

```
X_train, X_test, y_train, y_test = train_test_split(
    X,
    y,
    test_size=0.2,
    random_state=42,
    stratify=y
)
```

```python

model = RandomForestClassifier(
    n_estimators=200,
    max_depth=10,
    random_state=42
)

model.fit(X_train, y_train)
```

- Save the model in the Django project in a View file and call the model again in the prediction function.

```python
joblib.dump(model, "mapapp/ml/fire_model_rf.pkl")
```

6. Performance Testing

Experimental results showed that the random forest model achieved strong predictive performance using climate variables [45] [46].

Analysis of the importance of the feature showed that:

- Wind speed was the most influential variable;
- Temperature was the second most important factor.

These results are scientifically consistent with the behavior of forest fires, as high temperatures and strong winds significantly increase the risk of forest fires, confirming the effectiveness of climate variables in predicting forest fires.

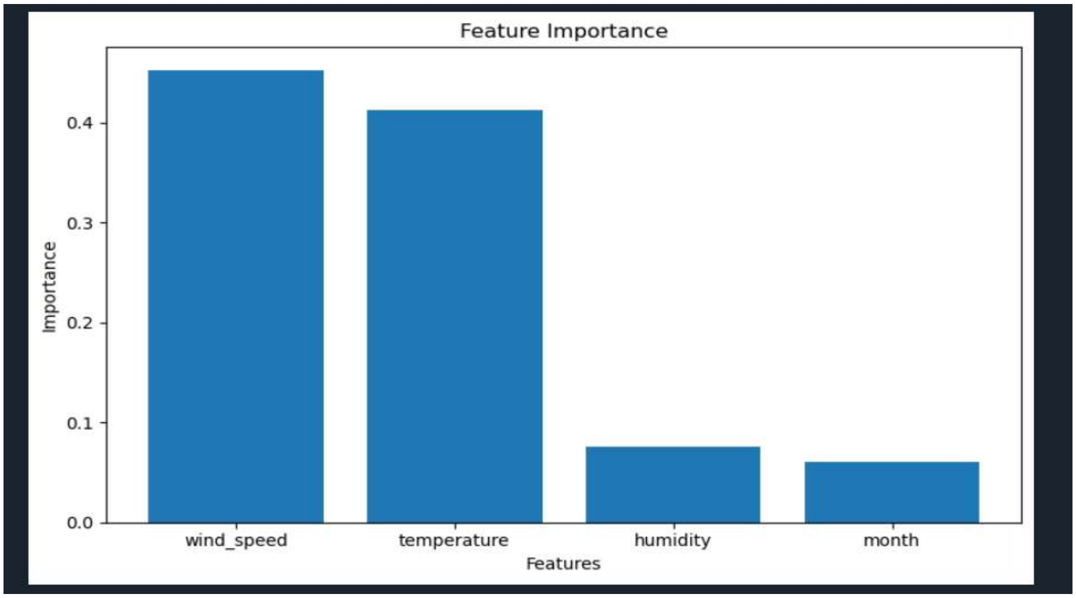

Fig 37: Feature importance.

The confusion matrix shows that the prediction model achieved strong classification performance.

The results confirm that the advanced random forest model is effective in predicting the occurrence of forest fires using climate variables.

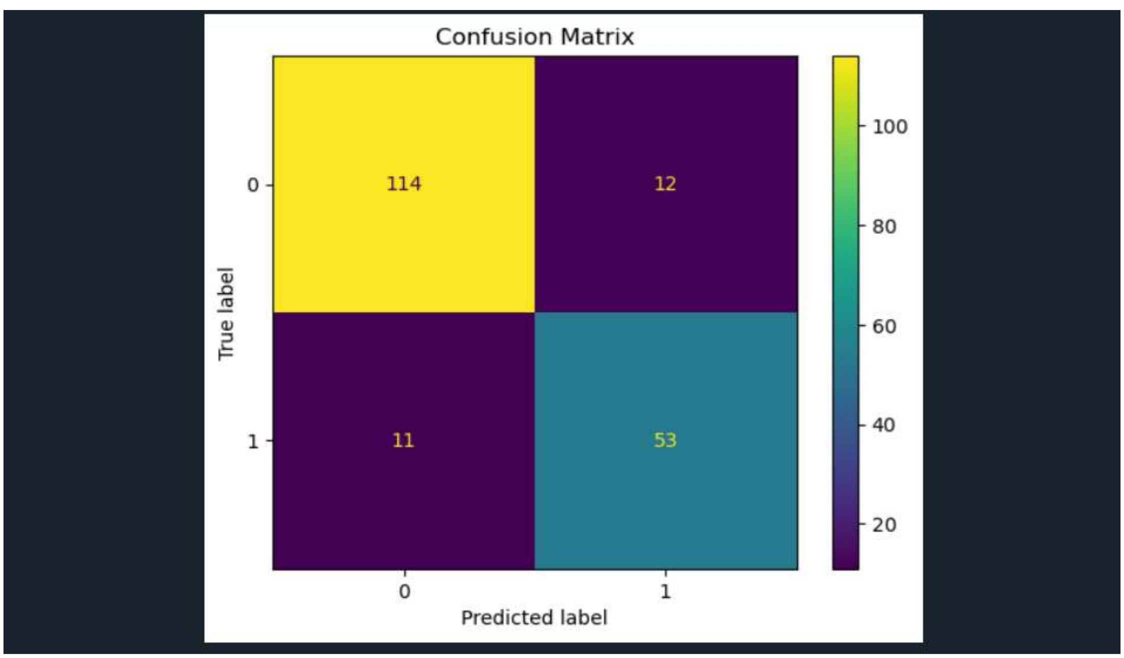

Fig 38: Confusion matrix results.

7. Results and Discussion

A performance test was conducted to evaluate the response of the forest fire management system under normal operating conditions, from which we ensure the operation of the geographic information system, data processing, forecast requests, and database operations during implementation times.

- Response time depending on internet speed;
- Data hall performance is fast and proportional to execution time;
- Speed up browsing map results;
- System stability during requests;
- Prediction accuracy through the model.

8. Conclusion

In this chapter, we have developed a model for predicting the use of machine learning and a rules-based system to suit the available forest fire data and for better results, after selecting the features that have the most impact on the phenomenon studied, then evaluating and testing the work and displaying the results on GIS.

General Conclusion

Within the framework of this project, we were asked to implement a web-based geographic information system to manage and predict forest fires in Algeria, specifically targeting the Bouira Forest Governorate, which expressed its urgent need for such a system, which aims to enable competent authorities to make informed decisions based on actual data.

First, we conducted a theoretical study that included GIS, forest fire phenomenon, and prediction model. We then designed and developed a web application based on a geodatabase that provides various interfaces, allowing for the display of interactive maps, statistical data, and predicted fire points through a model, in addition to updating fire-related data. This final word presents the achievements made in this project, and all the problems and challenges, and the future prospects for the work.

All functional and non-functional requirements of the system have been met, as the system provides an interactive interface in order to provide the most important information that contributes to facilitating work on forest conservation for the state of Bouira in managing the phenomenon of forest fires by:

- View state-specific layers (borders, districts, municipalities...etc.);
- Display statistics (general and also specific, either in years or by municipality);
- Flexible database that can delete changes or add ;
- A prediction model that works according to climatic conditions and displays the predicted fire points.

All of this helps decision makers read the situation faster and have a better view of areas vulnerable to forest fires in order to take appropriate preventive measures;

During the work on this project, we faced challenges and barriers, and the most important problems were:

- Data was invalid and unclean;
- Lack of data needed to display data (fire points, geographic points.....);
- Missing layers of Shapefile (mountain roads, forest areas.....);
- Wrong and incomplete dates;

Despite the positive results achieved, the project remains open to several future development prospects, including:

- Providing the system with real-time data (Real Time) through sensors and satellite images;
- Expanding the study to include other governorates outside the currently studied state;
- Developing a mobile version of the application in order to facilitate access to it by forest agents and citizens.

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