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Design and Evaluation of Geographic Information Systems for Environmental Protection Through Data-Driven Decision Making: A Case Study of Solid Waste Management in Ali Mendjeli, Algeria

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Abstract: Waste management poses a significant challenge in large urban areas, demanding meticulous logistical planning and scientific insight to balance environmental impact and cost-effectiveness. Ali Mendjeli, a newly established city in Constantine, Algeria, exemplifies this challenge without a mapped and documented inventory. This study employs a Geographic Information System (GIS) approach to develop a management application aimed at identifying key factors in solid waste management. Traditional waste management practices typically rely on manual methods prone to incomplete or inaccurate outcomes. In contrast, GIS tools facilitate the creation, organization, and modeling of comprehensive spatially referenced databases, integrating data on waste collection operators and disposal points hosted in cloud computing environments. This approach enhances precision and efficiency in waste management decision-making processes.

Keywords: Environmental protection, Database management, Geographic Information Systems (GIS), Waste management, Classification

1 Introduction

Information systems play a crucial role in managing environmental risks by acquiring, storing, processing, producing, and disseminating spatially referenced information [1]. The spatially referenced data (SRD) obtained and processed through these systems is essential in decision-making, planning, and problem-solving activities related to environmental management [2].

Urbanization is a remarkable phenomenon that has experienced an unprecedented surge in developing countries [3, 4], particularly in Africa. This incredible growth is driven by a natural proliferation of new cities and a massive rural exodus. However, despite the best efforts of public authorities, the infrastructure and equipment have not kept pace with the growth of these cities. As a result, numerous challenges need to be addressed urgently to ensure that rapid urbanization does not negatively impact the quality of life of those living in these areas. For this reason, we are seeing a deterioration in the environment and living conditions of the populations. Waste collects in newly built and undeveloped neighborhoods. And the poor management of this waste is one of the main causes of pollution in new towns, which generates massive consequences in terms of health risks (reproduction of mosquitoes and rats) [5], environmental impact (odors, pollution of water and air), clearance and social impact (for nearby people and for people working in waste collection), and infrastructure (waste blocks canals and access routes and gives a nasty landscape). Urbanization has impacted Algeria, particularly the city of Constantine. Over the years (from 1998 until now), the city has experienced rapid urbanization, resulting in the gradual absorption of small villages and phony towns into its districts [6]. This trend has been most noticeable in the town of Ali Mendjeli. This increase

in population exposes the city to major problems of health, environmental degradation, and waste management of different kinds: solid, liquid, and gaseous. Like other large cities in the country, "Ali Mendjeli suffers also from the constantly increased production of solid urban waste. According to the environmental inspection of the wilaya, the quantity of solid waste is an average of 263 tonnes/day compared to 508,837 inhabitants (1998 census), a quantity considered disproportionate and difficult to control. However, Constantine manages this waste predominantly through very limited and traditional landfill methods.

For a long time, solid waste management has not received particular attention in Algeria. The concerns lay elsewhere, and local authorities complained about the lack of resources, equipment, and suitable infrastructure, as well as the irresponsible behavior of the population. Solid waste management is not a recent activity. However, in Europe, particularly in France, it has taken on a new image recently with the use of GIS to facilitate and computerize the management of solid waste [7]. Solid waste, including data, is stored in databases (DB) in a way that helps decision-makers.

The primary focus of this study is to develop a spatial database that will be managed using a geographic GIS. The ultimate goal is to optimize solid waste collection circuits for the municipality of Ali Mendjeli. By organizing the available information, we plan to thoroughly monitor and evaluate the performance of waste collection actions. This will enable us to identify areas where improvements can be made and implement effective solutions. With a well-structured database, we are confident that we can achieve our objectives and make a positive impact. As we aim through this work, these objectives are:

- Identify waste management stakeholders;
- Define the usefulness of a GIS as well as spatial analysis indicators for waste management.
- Map the lots of the new city, Ali Mendjeli, and the collector circuits;
- Identify the types of waste collection points used by collection operators and determine the theoretical quantities of waste transferred there and the problems posed by collection and grouping points.
- Identify the weaknesses of the collection organization.

This paper is presented as follows: The prior knowledge is presented in Section 2, the proposed solution is explained in Section 3, the implementation and result is demonstrated in Section 4, the discussion in Section 5 and finally conclusion in Section 6.

2 Prior Knowledge

The management of waste, particularly industrial waste, which was previously considered purely environmental suffering taken care of by the state, has begun to be organized into profitable economic sectors [8].

Two action programs were implemented by the Ministry of Industry and the Environment of the Algerian State, which we cite in the following:

2.1 National Municipal Solid Waste Management Program (Progdem)

Progdem, initiated by the Ministry of Regional Planning and Industry, is an approach used for the management of this type of waste and is part of the implementation work of industrial policy. The Progdem aims to:

- Correct and change illegal dumping practices, organize the collection, transport, and disposal of solid waste under conditions guaranteeing the environmental protection and preservation of the natural and urban environment through the development and equipment of technical landfill centers (CET) in all cities.
- Development and implementation of commercial waste management plans;
- Promotion of recycling and waste recovery activities;
- Introduction of new forms of management;
- Gradual adaptation of the household waste removal tax and improvement of its recovery rate.

2.2 National Special Waste Management Plan (Pnagdes)

The Pnagdes is a management, planning, and decision-making tool that generates various and adapted solutions for the treatment of this type of waste. The Pnagdes is established for a period of ten years and is revised whenever circumstances necessitate it, either upon a proposal from the Minister responsible for the environment or at the request of the majority of the members of the commission responsible for its development. This plan aims to conserve natural capital, improve its productivity, reduce economic losses, and improve competitiveness through increased waste recycling.

In order to ensure the proper functioning of the waste service, several players are involved in the different segments of the waste service. However, the management method varies from one country to another, ranging from direct management to public procurement through delegation and concession.

2.3 Structures Responsible for Collecting and Transporting Waste

The waste management policy is part of the National Environmental Strategy (NES) as well as the National Environmental Action Plan and Sustainable Development, which resulted in the promulgation of Law 01-19 of December 12, 2001, relating to the management, control, and elimination of waste, dealing with aspects inherent to the management of waste. Constantine has a number of companies that handle this. The companies responsible for waste management at the city level of Constantine are summarized in Table 1 below:

Table 1. The different companies in the city of Constantine

Commune	EPIC de Collecte
Constantine	Propco-proprec
El khroub (+nouvelle ville)	EGUVAM-PROPREC
Ain Smara	EPAS
Ouled Rahmoune	ENOR
Ain Abid	EPCA
Ibn Badis	EPCI
Didouche Mourad	EGUCDM
Hamma Bouziane	Hamma verte
Zighoud Youcef	EPCNEVZY
Beni hmidéne	EPCEE
Ibn Ziad	EUUCIZ

The material and human resources relating to the collection and transport of waste in the city of Constantine are summarized in the following Table 2:

Table 2. Material and human resources

Municipalities	Human Collection Equipment	Material Collection Equipment	Quantity of Waste Collected (T/year)
Constantine	69 trucks	317 agents	78498
El Khroub	34 trucks	171 agents	96130
Ain Smara	/	/	24000
Ouled Rahmoune	3 trucks	34 agents	14000
Ain Abid	04 trucks	18 agents	14089
Ibn Badis	/	/	4760
Didouche Mourad	/	/	32400
Hamma Bouziane	/	/	43200
Zighoud Youcef	3 trucks	20 agents	13725
Beni Hmidéne	1 trucks	04 agents	2592
Ibn Ziad	/	/	9200
Messaoud boudjriou	/	/	10700

3 Proposed Solution

Urban solid waste management institutions suffer from poor management and a lack of organization in most of the tasks they carry out due to the lack of use of new information and communication technologies [9, 10].

Today, it appears that databases linked to their geographical information and their methods constitute an effective means of determining the paths and the quantities to be collected.

In this part, we are currently concentrating on the development of a GIS application [11] that aims to bring all the available statistics and data into one database. The techniques we have been working on will help us determine the most appropriate management methods while keeping time and cost in mind.

GIS is defined by Thériault [12] in 1996 as a set of principles, methods, instruments, and spatial reference data used to capture, store, transform, analyze, model, stimulate, and map the phenomena and processes distributed in geographical space [13]. It is therefore a tool in IT that stores and manages information with reference to the territory. The most important functions of GIS are as following [14]:

- Archiving, the storage of data by entering information in digital form.
- The analysis of spatial and thematic data makes GIS a powerful decision-support tool.

- The visualization of the analysis results is in the form of thematic maps. In the field of household waste management, there are many advantages provided by GIS [15]. First of all, GIS allows visualization of the situation. Using a thematic map can make it much easier to visualize and represent real-world data. With the help of GIS, we can easily locate where the collection operators are and even document their daily circuits or weekly collections. Additionally, we can also see the collection points for the waste that has been collected. This technology can be incredibly helpful in managing waste collection processes efficiently.

The rapid visualization of this information can allow the various management stakeholders to locate priority areas for improving services and sanitation. Actors and decision-makers can thus see where the problems lie and where it is preferable or urgent to act immediately. These measures not only enable quicker action but also ensure a coordinated approach that is better adapted to the specific needs of each sector.

3.1 Problems in Waste Management Institutions

The management of municipal waste in Algeria is considered a priority action of the Ministry of Industry in recent years. For this, a set of regulatory texts have been adopted. Human and technical resources have been committed since 2012 to better manage and improve this service. For that, the following problems can be mentioned:

1 - The absence of a spatial database that facilitates waste management;

2 - The tour planning problem;

3 - Lack of cards that represent the recoveries of the collection points.

Covering sectors through digitalization and locating black spots will facilitate the resolution of this situation.

3.2 Choice of Data Integrated

The types of data that were taken into account in the development of the GIS are as following:

• Geographic coordinates from geo-referencing work (inhabitants, points of reference Collection, Blackheads, Sweeping.);

• Attributes of geographical entities;

• Waste collection plans from responsible companies;

• The choice of attributes and geographical entities for the management of the new city of Ali Mendjeli;

• General data about the city;

• Data on waste collection points;

• Data on waste collection operators.

3.3 The Actors Involved

Waste collection and processing is carried out by public or private actors.

These activities are regulated by regulations. The municipalities are responsible for the management of household waste. The companies participating in the collection and transport of waste in the new city of Ali Mendjeli are as following:

a) **UMCAM: The Urban Management Company of the City of Ali Mendjeli**

Table 3 seems to provide a lot of useful details about the company, including its human resources, creation date, and sector of operation within the division of neighbourhood units (UVs).

Table 3. Presentation of the urban management company of the city of Constantine

Years of Creation of the Establishment	**March 2011**
Status of the Establishment	Public establishment of an industrial and commercial nature
Number of Workers:	373
- Administration	10
- Mastery	65
- Execution	298
Sector of Intervention: (New Town Ali Mendjeli)	- the VUs : 01 - 02 - 04 - 05 - 06 - 07 - 08 - 09 - 10- 13 - 14 - 15 - 16. - the extensions : 05 Ext – 20 Ext. - the Neighborhoods: 04 chemins - Ain elbey - GuettarElaich - Bir Dekich - Boulechfar - Brahmia - Belahrech - 140 logt rural - BELKHWENE

Concerning the material means of the establishment, these means are summarized in Table 4, which reflect the material means that the company has. This data was communicated to us by the company itself:

Table 4. Material resources

	Materials Nature	Number of Materials
01	packing dump truck	22
02	10 ton dump truck	01
03	roller amp truck	01
04	retro charger	03
05	charger	01
06	tractor	01
07	grader	01
08	light vehicle	06

b) **Public Establishment of Cleanliness and Public Health of the City of Constantine(PECPHC)**
Number of workers: 102
Sector of intervention: (new town Ali Mendjeli): VU17, VU18, VU19, VU20.
Table 5 shows the resources available to the second company, these data were communicated to us by the workers of the latter.

Table 5. Material means of PECPHC

	Nature of the Material	Number of Materials
01	B/T 07T trucks	06
02	05 ton truck	01
03	10 ton truck	01
04	retro charger	01

3.4 Methodology of Work: Data Structuring

After defining the data to be integrated into the system, it is now a matter of organizing and structuring it. Thus, the definition of management rules allowed us to align the order of appearance of the retained data. To move from complex reality to computer representation, we proceed to create a spatial database [16, 17]. Spatial databases are operational tools that make it possible to organize and manage geographic information in digital form. These are structured sets of files describing objects or phenomena located on the Earth (with their attributes and their relationships necessary for modeling geographic space [18–20]. The core of GIS-Waste Management is a geographic database integrating a set of thematic layers (division of neighborhood units (VUs), sectors, collection points (Figure 1), scanning, black spots, etc.) and data from analysis campaigns (Figure 2). A specific GIS application offers a set of tools, including data entry and control, statistical processing, spatial analysis, and cartographic representations.

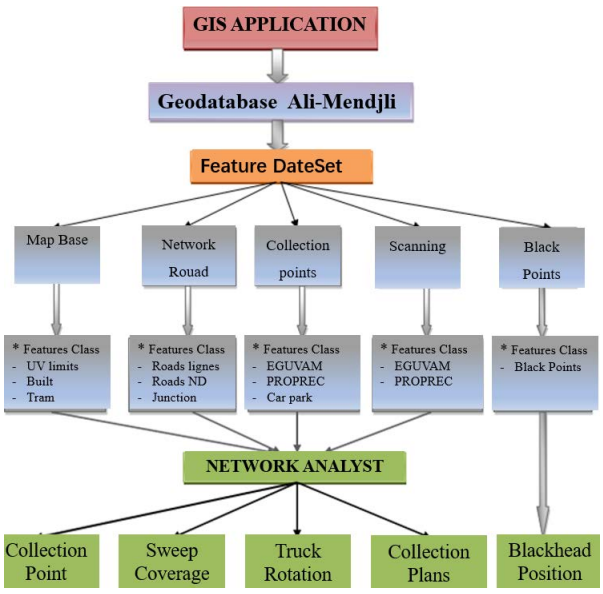

Figure 1. Methodology of work

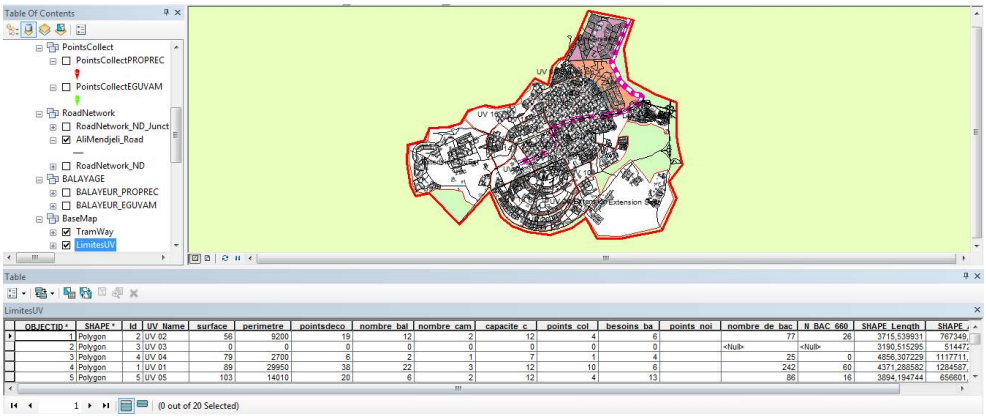

Figure 2. Structuring a spatial database

3.5 Integration of Geographic Data

After exporting the georeferenced maps of the new city Ali Mendjeli from Terra Incognita to the computer to then be integrated into the GIS, we started with the creation of the database (dBASE), then digitalization in parallel with the power supply associated attribute tables, as shown in Figure 3 and Figure 4.

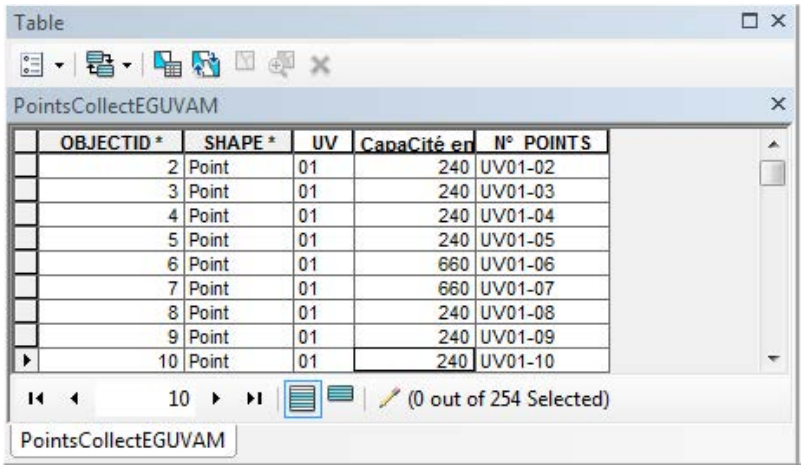

Figure 3. Data base of UMCAM

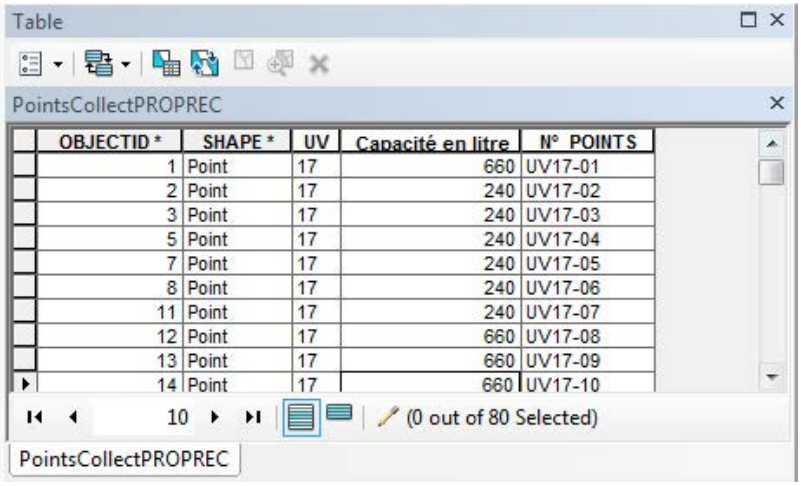

Figure 4. Data base of PECPHC

3.6 Positioning of Collection Points

Position collection points along the natural travel routes of local residents. And that they are easily accessible for users in pedestrian, road, vehicle, or collection agent traffic. And easily accessible to facilitate the work of collection teams, as shown in Figure 5 and Figure 6.

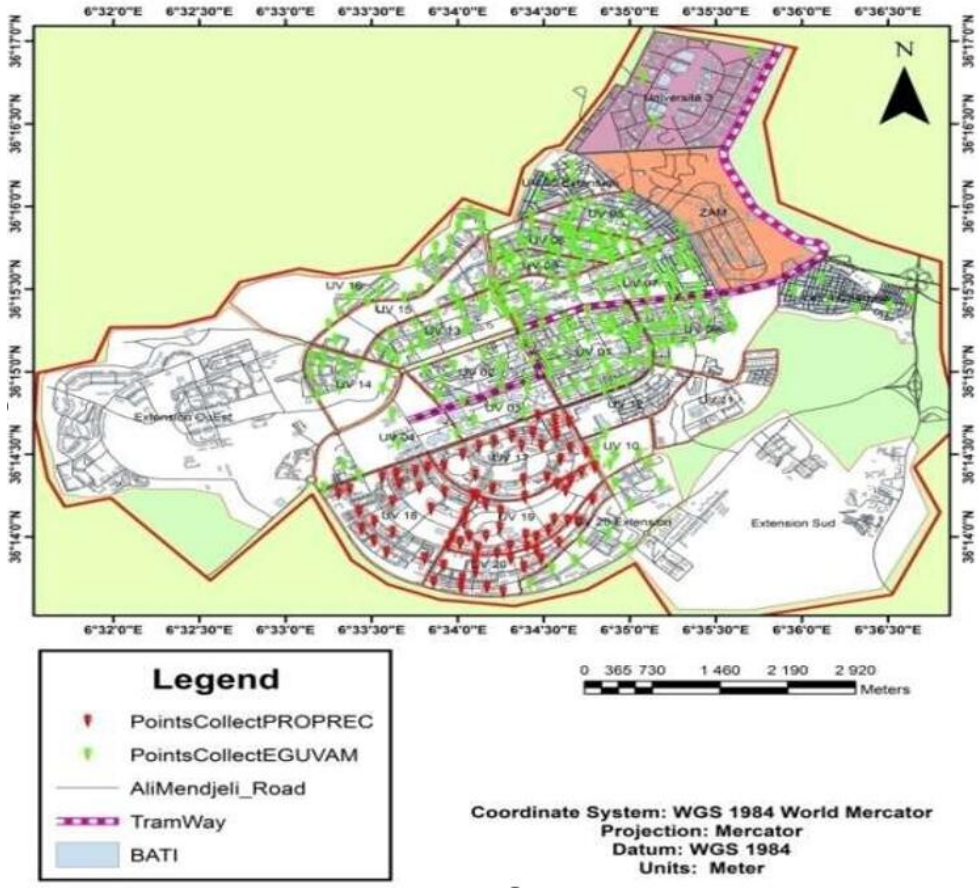

Figure 5. Collection points positioning map

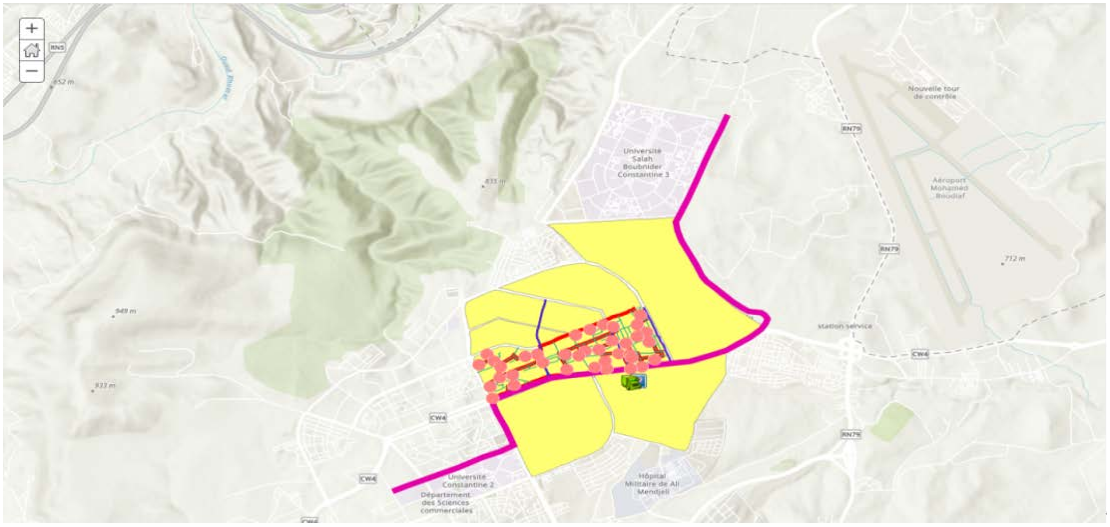

Figure 6. Rotation map

4 Implementation and Results

This part aims to demonstrate the feasibility and usefulness of our overall approach. It is divided into three parts: we describe the software and hardware environments on which we carried out our experiments on the side graphical interface, applications on ArcGIS online, and placement on the website. Also, we will demonstrate the implementation of the different processes for the graphical interface and the website. Let's go to his accommodation. The proposed approach simplifies waste management in the newly established city of "Ali Mendjeli." In fact, none of the studies on the complex market are to carry out the business.

A GUI (Graphical User Interface) is a window containing graphic elements called widgets. This widget can just as easily be a list of buttons, texts, frames, tables. . . .etc. The usefulness and objectives of the graphic interface are: digitization of the company's old system; integration of web mapping tools in waste management; consultability at any time; and quick editing.

Creating Program Code:

The Program Code Starts with:

* Importing the TKINTER library Figure 7.

Gesdech.py

```
* - import from TKINTER library
 1.      Import tkinter as tk
 2.      From tkinter import *
 3.      Import math
```

Figure 7. TKINTER library import

We create the main interface of the program Figure 8:

```
GdD = Tk()
GdD.title("Gestionnaire Des Déchets")
GdD.geometry("1600x900")
GdD.iconbitmap("icon.ico")
GdD.config(bg='black')


# Les fonctions "Coté logic de cet programme" :
def eguvam():
    egu = Toplevel()
    egu.geometry("1200x600+120+120")
    egu.title("EGUVAM")
    E1 = Label(egu, text=" L'entreprise de gestion urbaine de la ville d'Ali Mendjeli", font=("Castellar", 20, 'bold')
               fg="green")
    E1.pack()
    E2 = Label(egu, text=" Date de création de l'établissement:", bd=3, relief="groove", font=("arial", 20))
```

Figure 8. The main interface of the program

The methods and tools that are currently used are outdated; they generally take a lot of time to make unnecessary turns and do not cover the entire surface. By adding a touch based on GIS, we will bring much more efficiency to the management of this phenomenon, with a reduction of almost three times less time compared to the old system and coverage of all spaces, we show these differences in Figure 9 and Figure 10.

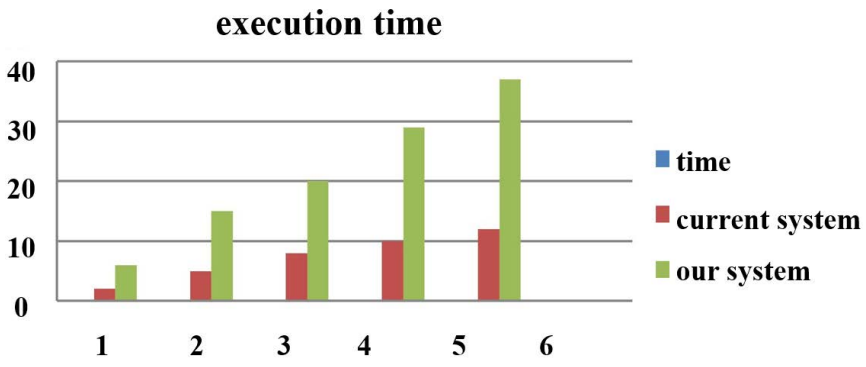

Figure 9. Methodology of work

Figure 10. Detection efficiency

The geographic information system (GIS) highlights a set of static and graphic data to better represent an operation in an organized, simulable and modifiable manner at any time.

For this reason, we found that the results obtained can be an effective tool that facilitates the various actors in this field (solid waste management) in a more practicable manner in accordance with modern standards. Figure 11 and Figure 12 are concrete examples of our work.

Figure 11. Collect points recouvrement

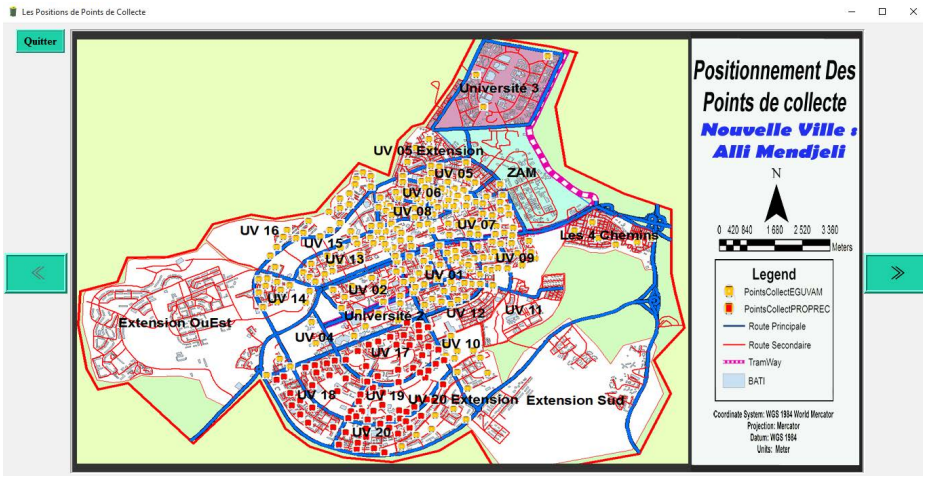

Figure 12. Collect points position's

5 Discussion

The creation of the GIS database in our approach showed very good results. Satisfactory in view of the objectives, and has even demonstrated excellent versatility in the data processing. The creation of the software opened up the possibility of moving forward and facilitating the updating data and their organization on the website to help better present the collection organization and its services, with a mention of the importance of recycling with the aim of raising awareness among citizens to respect and preserve the environment.

Obstacles and challenges related to waste management include the various processes, ranging from waste planning to waste collection and treatment to market development for recycled products. Furthermore, due to differences in the local conditions of each country, as well as the infrastructure on which each country's local capabilities rely, cities face various challenges. We chose the new city of Constantine as a study area in view of its rapid expansion and the explosion of its population in less than ten years. As we also know, a regression approach is necessary to solve such a complex problem. Our approach is adaptable to the means we have and the infrastructure currently available.

At the end of this study and to achieve our objectives of improving waste management solid in the new city of Ali Mendjeli, we propose the following points:

-Modernize the waste management cycle using IT tools, this will speed up the process and achieve more satisfactory results in a shorter time using GIS databases and thematic maps.

-Installation of necessary infrastructure, in order to guarantee the smooth running of the various operations linked to the management of household waste and their recycling.

-We offer qualified personnel who are specialists in the field.

-Raise awareness in the industrial sector in Algeria.

6 Conclusion

The city of "Ali-Mendjeli" within Constantine, like many cities in developing countries, faces significant challenges in household waste management, including economic, administrative, and organizational shortcomings. Our study has conducted a thorough diagnosis of the city's cleaning services, examining their collection methods, waste elimination processes, and ultimate treatment practices. These methods are found to be inadequate for effective waste collection throughout the city. This inadequacy is partly due to a severe lack of resources necessary to meet various requirements, exacerbated by a population explosion nearing 500,000 inhabitants. Additionally, there is non-compliance with hygiene collection and measurement standards, and a lack of suitable waste disposal sites. The city relies on a single, traditional treatment method: uncontrolled open-air dumping, which poses significant environmental pollution and health risks.

Data Available

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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