THE TECHNICAL UNIVERSITY OF KENYA

SCHOOL OF SURVEYING AND SPATIAL SCIENCES

DEVELOPMENT OF A MOBILE BASED CROWDSOURCING GIS FOR REPORTING EMERGENT WASTE DISPOSAL SITES

BY

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DECLARATION

Declaration by the student

This project and project report is my original work and has not been presented for a degree in any other university.

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SIGNATURE…………………………………………………………………………

Declaration by the Supervisors

This project report has been submitted for examination with our approval as university supervisors

NAME OF SUPERVISOR………………………………………………………………...

DATE……………………………………………………………………………………...

SIGNATURE……………………………………………………………………………...

DEDICATION

I dedicate this work to my parents Maina Thuha and the late Mary Wambui, my dear sisters Naomi and Juliet, and my brother Geoffrey. Knowing you were there kept me going.

I also dedicate this work to everyone, family and friends who guided and willingly provided support throughout my undergraduate degree. I can't thank you enough.

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I would like to express my deepest appreciation to my supervisor Mr David Kanyari for offering me great advice on the project and this project report.

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Abstract

Illegal dumping has been one of the most prevalent environmental crimes. The National Solid Waste Management strategy describes illegal dumping as dumping of solid and liquid waste in places not designated by the National Environment Management Authority. Illegal dumping is detrimental to the health and general quality of life of people who live in close proximity to these illegal dumpsites.

In addition, illegal dumping is persistent due to lack of a proper and streamlined reporting system to connect people who are affected by these illegal dumpsites, and people who are responsible for waste management. This reporting system would be Mobile and GIS based owing to the fact that GIS is essential for the locations of these dumpsites is as essential, and the fact that the mobile phone has a widespread use all over the country.

The system was tested on real dumpsite data collected and the results displayed both on the mobile application and the web application. The data was also made available through a REST API that supplies the data in GeoJSON format.

Chapter 1

1.1 Introduction

Illegal dumping is the discarding of any waste, upon a piece of land that the dumping person does not own. Illegal dumping is a big cause of health and poor quality of life for the people who live in close proximity to these kinds of dumpsites, in addition to contributing to the current environmental crisis.

In most of the developing world and in Kenya specifically, there are no mechanisms put in place to actively report existing illegal dumpsites that appear near settlements. Reporting is usually done through such means as calling the authorities. This reporting is not usually always done. Sometimes, the dumpsites are neither reported nor collected. This leads to them accumulating and therefore adding to the effects.

It is for this reason that I am developing a crowdsourcing system based on GIS to report the dumpsites. This system will ensure that the people directly affected by the dumpsites close to their houses and places of business are involved in solving this problem as it affects them most after all.

1.2 Background Information

Crowdsourcing is a term coined by Jeff Howe, and while the technical definitions vary, the basic idea of crowdsourcing is to involve the public to complete business-related tasks, that the business would normally perform itself, or hire third parties to perform them. In my case here, crowdsourcing is used to collect geospatial data on the illegal dumping. Typically, crowdsourcing happens online due to the efficiency, cost, ease and size of the data points collected. Involvement of the public is crucial in the fact that the public has access to the many locations where these illegal waste disposals points exist. Hiring personnel to collect this data would turn out to be an expensive, and non-thorough way of collecting the required data.

The crowdsourced geospatial data can also be referred to as Volunteered Geographic Information (VGI), user generated geographic content (Fast and Rinner, 2014) among other terms. These terms will be used interchangeably throughout this paper. VGI blurs the line between data collectors and the data users. Crowdsourcing geospatial data requires that the users be at the location where the phenomenon needed to be captured by the mobile sensors is. This method has proven to be a successful data collection method before, considering the sheer number of data points that are collected over a short period of time. A major example of VGI is OpenStreetMap. Its main advantage is the free labour (in the data collection step) that is provided, and that data doesn't have to be paid for so that it is accurate. Companies have used this method of data collection to collect feedback on products, staff etc.

Crowdsourcing geospatial data however has its limitations. One of the main limitations is the data quality. The general public do not have a grasp of how important the locations of these dumpsites are because it is assumed that they do not have the necessary skills in Geoinformation. There are several ways of assessing VGI accuracy. These are: (a) Comparing data against "Authoritative" spatial data (Koukoletsos *et al.* 2012, Dorn *et al.* 2015), (b) user's and/or machine learnt rules and patterns for checking the entries (Neis et al. 2012, Jilani et al. 2013; Ali and Schmid 2014, Basiri et al. 2016a, 2016b, Leibovici et al. 2017) (c) gatekeeping and weighting users' entries (e.g. with respect to the their experiences, expertise, proximity, number of their entries, history and changesets) (McGreavy et al. 2017, Ciampaglia et al. 2018). Having a better understanding of VGI may aid in the adoption of such a system that mostly relies on data from the public.

At this point, I feel that it is imperative to mention that data quality, especially location accuracy of this system will depend on the device that the user is collecting this data on, whether or not the data is being collected on a clear day – for the system is purely dependent on the GPS. It is therefore very crucial that I limit the types of devices that can install the client application to only the higher end and latest devices thereby sacrificing the number of data points for more quality data.

1.3 Problem Statement

Illegal dumping means refuse that has been left at a place with the intention of abandoning it, such refuse as sand, paper, plastic bottles, builder's rubble and any other material that may create a nuisance or that is unsightly and detrimental to the environment. Illegal dumpsites are places where hazardous substance is intentionally and illegally dumped.

Illegal Dumping has plagued Nairobi to unimaginable proportions. In places where there are informal settlements, this illegal dumping while being defacto legal, because nobody is prosecuted. These dumpsites are never collected and growing in terms of size. Part of the reason for the pile up has been lack of a reporting system that the public can use to report these dumpsites, once they emerge, to prevent them from growing any longer.

Waste disposal is not considered a land use. This has made many governments not include it in their planning purposes. This has made governments not to consider waste disposal points for planning purposes. This is another issue that could be looked at to reduce illegal dumping. However, there still remains the indifferent attitude in the general public as far as proper waste management is considered. This makes it necessary for such a system to be developed to facilitate reporting of these waste dumps.

1.4 General Objectives

- To develop a GIS that can be used to collect data on emergent waste disposal sites and visualize it.

1.5 Specific Objectives

- To develop a mobile application for spatial data collection on illegal waste disposal.
- To test the mobile application with real users
- To build an API for data access and integration with GIS software
- To demonstrate how the spatial data described above can be accessed.
- To visualize the collected data on a Web based environment

1.6 About This Document

This document describes the steps taken to develop the system, the knowledge scope, the technical aspects, and the system itself, including hardware, software, data, methods and people.

The document can be used as reference by project managers and developers to develop similar and/or to improve on this system that I have developed. It is necessary to note that the end result should not be just the system, but a cleaner and more liveable planet for a start, as this system can be applied anywhere, based solely on the worldwide internet reach. The system is created with the intention to reach this goal and should only be used to achieve it.

Any subsequent improvements in the system should be done.

1.7 Project Scope

The primary data collection responsibility lies in the general public. I therefore intended to make it as easy as it can be for the general public, even the most tech unaware to use it, without having any technical expertise in GIS. As mentioned, the end goal of this project is to have the illegal dumpsites recorded in a database and this database can therefore be accessed by the relevant stakeholders and the public. The access to the database is demonstrated through the mobile application, the web application and a REST API that returns data in GeoJSON format.

This project was developed by me, from scratch following the **Android Standards** and **documentation.**

Chapter 2

2.1 Literature Review

2.1.0 Crowdsourcing as a means of Data collection

Crowdsourcing of Geographic has been done before successfully. An example of a publicly available repository of data from crowdsourcing is OpenStreetMap (OSM). Crowdsourcing of geographic data is based on the assumption that there are no limitations to the people who record this data. Ideally, there is not limitations to the demographics, in terms of skills or any other factor, and that the data is collected by the public without bias. There is however an unconsidered bias in the collection of data as it ends up being the people with a vested interest in the system and the specific phenomenon being recorded, in our case the illegal dumpsites. The data is therefore collected by volunteers. This may not directly affect the data quality, but considering that there is no readily available data of the people who are involved in the data collection makes a bias to appear.

By considering the fact that it is not always the people with technical skills in GIS and Geographic Information are used in the collection, this will usually affect the perception of data quality and subsequently the adoption of crowdsourcing as a method of data collection for geographic data. However, there are features that can be added to a system to validate the data and make sure that the added data is near accurate especially in terms of location. Considering the system described in this paper, the most crucial accuracy that I needed this system to have been the location accuracy. If the locations of the dumpsites as recorded in the system is/was wrong, this would mean that the whole reporting system is flawed.

Another major point to note on crowdsourcing is that the tasks that are being caried out here are really not dependent on the system, and can be done offline and manually. The system only facilitates easier carrying out of these tasks and therefore saving resources which can be redirected to other tasks.

2.1.1 The National Solid Waste Management Strategy (NSWMS)

The NSWMS is a strategy that was developed by the National Environment Management Authority for the purpose of providing guidance on the management of solid waste to ensure a healthy environment for all. It is important to note at this point that I based all my development principles and literature on this strategy. The strategy was developed with the context of various laws that are currently in force in the Kenyan constitution. The legal framework for this strategy is based on the following laws and principles:

- The constitution of Kenya
- Vision 2030
- Environment Management and Coordination Act of 1999
- Environmental Management and Coordination regulations of 2006
- Occupational Safety and Health Act
- Public Health Act
- County Governments Act, among others

The NSWMS served a key influence in the conception of the idea of such a system for collection of illegal dumpsites

2.1.2 Spatial Crowdsourcing Applications

Mobile technology has become prevalent to unimaginable proportions in the world today. In Kenya, and specifically in Nairobi, majority of the young population own smart phones and have access to wireless internet. This system described in this document is dependent on a client application that will be installed in the user's smart phones. It is therefore necessary that I consider the availability of an ecosystem that will make the system be useful. This ecosystem involves a large number of people who own smart phones, are willing to install the client application (Android Application) and are either actively or passively seeking out illegal dumpsites. The current smart phone technology is equipped with features and sensors such as a camera, GPS sensors for geolocation which offer new and efficient ways to collect data.

Many mobile crowdsourcing applications have therefore been developed and are making data collection easier than ever. However, spatial crowdsourcing is still a relatively new approach to spatial data collection.

The following software architecture formed part of spatial crowdsourcing application that I built:

The system should:

- Allow management of workers
- Allow management of spatial tasks
- Provide incentive mechanisms
- Provide quality control mechanisms
- Allow workers to upload spatial data
- Provide web and mobile and web interface

Chapter 3: Methodology

3.1 Conceptualization

From reading the National Solid Waste Management Strategy, and from personal observations, it became apparent to me that Kenya has a long way to go in terms of efficient waste management and illegal dumping. It is known that Nairobi does not have a centralized method of data collection for illegal dumping. The most Nairobi Metropolitan Services have done is to enforce laws that do little to prevent illegal dumping in the outskirts of the city centre. I have lived in the Makadara constituency for the last 4 years up to 2021. Most places, I have observed that the illegal dumping is prevalent and the illegal dumpsites are not collected. This leads to these dumpsites being bigger in terms of both size and the effect to the surrounding areas.

Fig 1: An illegal dumpsite among a settlement in Bahati, Kenya

The idea that an android application was needed to collect the data on the unreported illegal dumpsites came naturally due to the understanding of how deep the mobile phone has penetrated the population. People use these devices which have all the required functionality inbuilt in to collect spatial data and yet there is no way to collect data on illegal dumpsites. I therefore deemed it appropriate to develop a mobile application as it was to give the expected penetration of the market and any subsequent data requirements could be met this way.

It is important that I note that spatial data collection using mobile applications has been done before, an example of such is **Uber**, where people who need a taxi use the application to request a taxi and the application allows them to either set the location for both the pickup and drop-off, or the application records their location automatically once the requester requests an uber taxi.

3.2 System Requirements Specification

This application is comprised of several main parts

3.2.1 The Android Application

The client application will have the following specific features:

- Access to an android phones camera to capture an image for the dumpsite

- Capability to read the user's location for the purpose of reading where the data was filled.
- Input fields to receive the user's input for the waste details, for instance size of the dump, materials that make up the dump, accessibility of the dump, location of the dump- This will be automatically collected to

reduce human errors in location detection, reporter name and reporter email.

- A map – provided by Google Maps API, and overlaid to display all the already reported dumpsites.
- Details for a specific added dumpsite, once a marker on the map is clicked.
- Options to update the database on the accuracy of the dump and if the dump is still there or not.

3.2.2 Database - Cloud Firestore database to store specific instances of these dumpsites. Reading and writing to this database

- Ability to read and write to this database will be written directly to the client-side application.
- Different clients will have different rules that will restrict or allow access and ability to read and/or write to the database. These rules are intended to be tied to the authentication statuses of the clients.
- The deletion of some specific entries in the database will be subject to review by the database administrators. For instance, if an entry is reported as spam or incorrect, the report will be received and the review be pending. If the database administrators ascertain that the report was correctly placed, the entry will be deleted.

3.2.3 An image storage unit hosted in the Google Cloud to store all the captured images.

- The image storage will generate a link to the uploaded image so that it can be referenced for download later.

3.2.4 A web application

This will be used to display the data for users in a browser environment

3.2.5 **A REST API** that will give data access to the general public. Any user sensitive information is not intended to be released or shared with anyone.

3.3 Operating Environment

The android side application is expected to run on all android devices starting from Android 8.0 all the way to Android 11. While it would have been better to cover all types of devices in a multiplatform client application, Kenya demographic data shows that most Kenyans use android devices and that the fact that it is an android application, will not give any significant drawbacks. However, older and low-end devices are going to result in location inaccuracies, poor quality images and so it is imperative that I restrict the type of devices that can run the application, thereby sacrificing the number of data points, for better quality data.

The Web Application can be accessed from a browser.

3.4 Android Prototype Design

From the concept of an android application for the collection of data. It was necessary to develop a prototype to graphically visualize the expected application, by prototype, I mean a wireframe that does nothing more than show the application user interface and how it would be used. The resulting prototype gave me a graphical representation of how the client application would be look and feel and was used to demonstrate the outlook of the graphical user interface design, layout and user flows. The application prototype was used as a reference in the development process when designing the user interface. When developing a prototype, it is always important to think as the user of the intended application, in this case, factors such as colours, the ease of using the application features.

The prototype acted as a great input to design process and the actual development of the user interface android studio using XML and the Java programming language. The following figures describe the prototype in more detail.

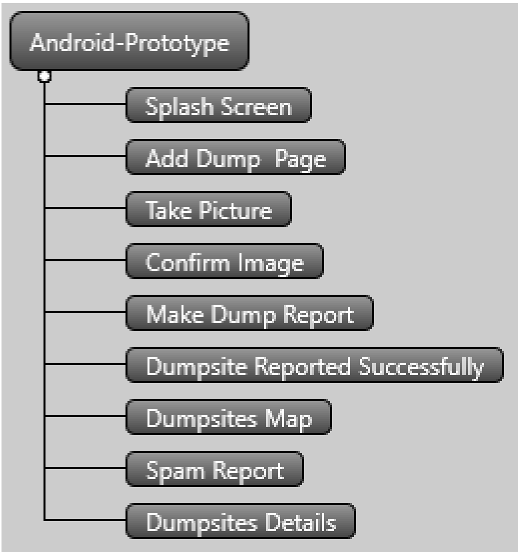


Fig 2: A tree diagram showing the various screens that the application was intended to have

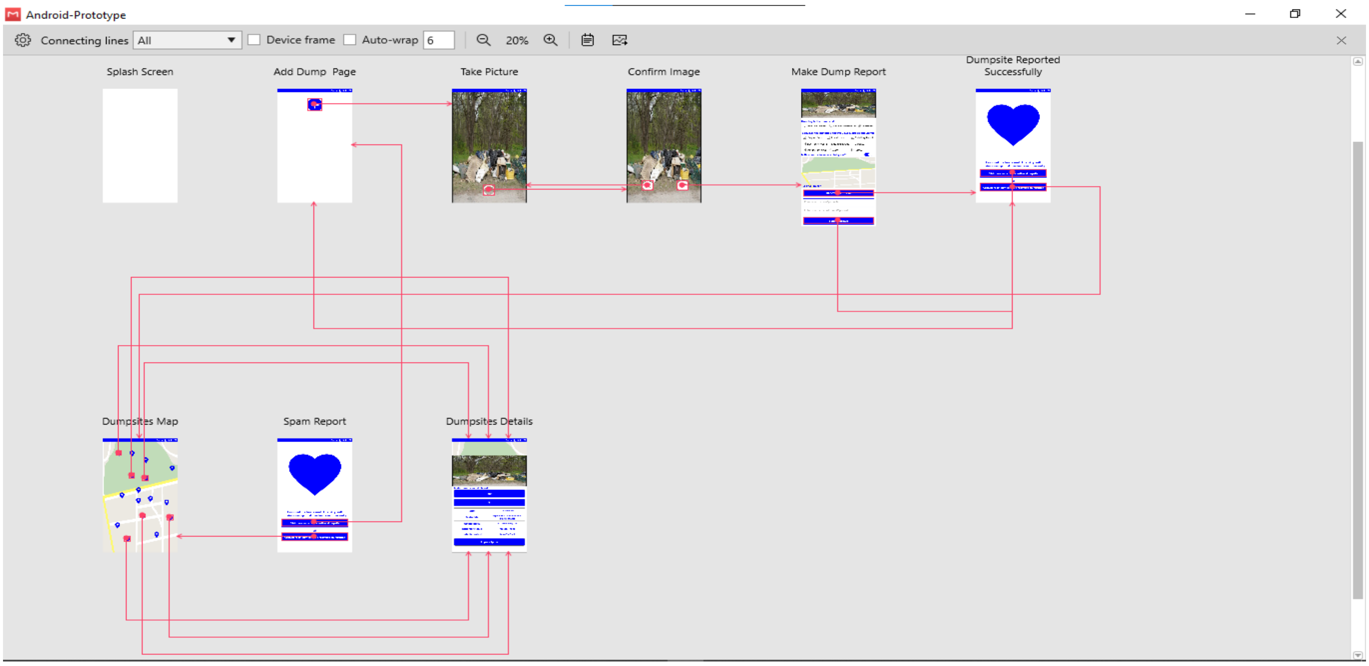
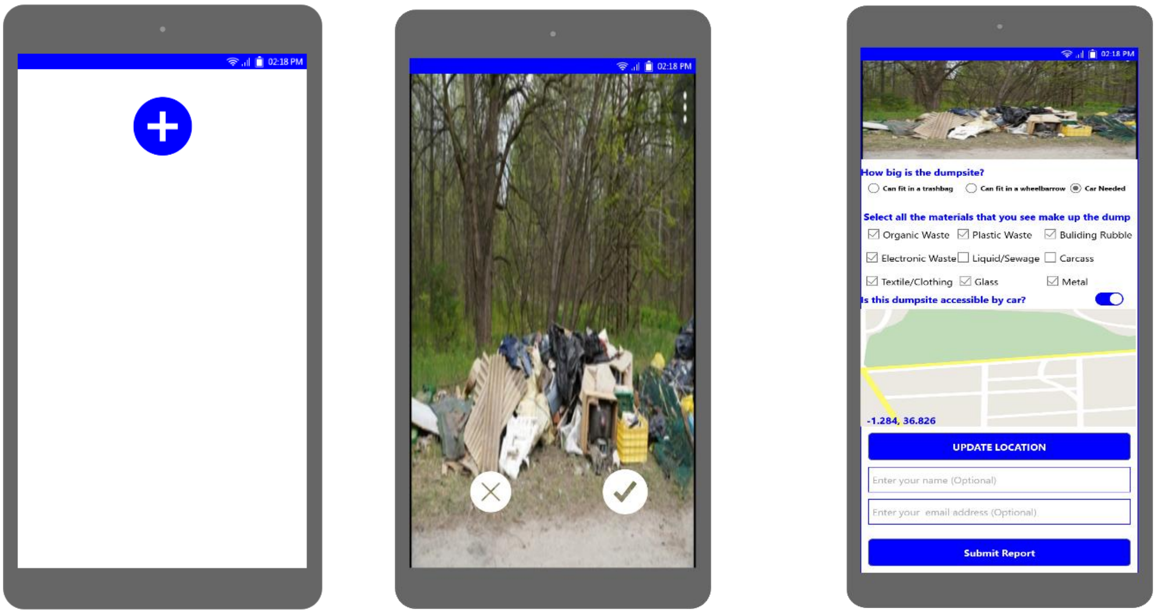


Fig 3: A diagram showing the UI flow of the intended client application.



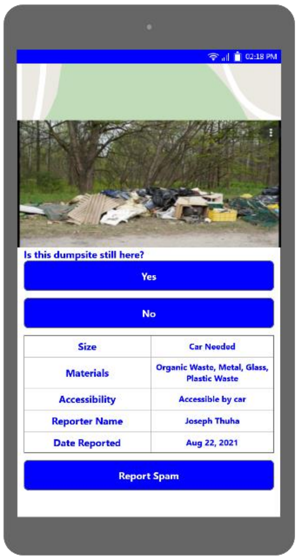
(a) User clicks the + button to open camera

(b) User takes an image of the dumpsite

(c) User fills the rest of the details concerning the dumpsite and submits

Fig 4. Data collection step (Reporting of the illegal dumpsites)

(d) Already reports of Dumpsites ss seen from the client application



(d) Dumpsites details and a prompt to report the entry as spam

Fig 5. Viewing of the existing dumpsite reports.

From the prototype figures above, it was clear the kind of application I needed to implement. The development of the exact features will be discussed later in this paper.

3.5 Decisions on the Technology Stack

Making a decision on the technology stack to use has not always been an easy process. This is mostly because the choice of technology depends on very specific factors that are not just the skillset a developer has in a certain technology. It is important to also note that the technology is only a tool that will assist one into developing whatever product one needs, and in some cases has no significant effect to the end product that the user needs. Choice of a technology stack to use for developing this system was a factor that I was faced with when I settled on this specific project, and even before a prototype was developed. I settled on native android development for the client application, Cloud Firestore, which is a backend as a service (BAAS) that provides a document-based NoSQL database that was used to store the entries collected. Python Firebase SDK for reading the spatial data from the database and Django – a python backend framework for developing web applications and RESTful APIs. The purpose of the web application was to give people an idea of how crowdsourcing data can be accessed by someone from using a web application and not just from the web application. The data could also be used in reports and subsequent research and projects.

3.6 System Architecture Overview

System Architecture Diagram

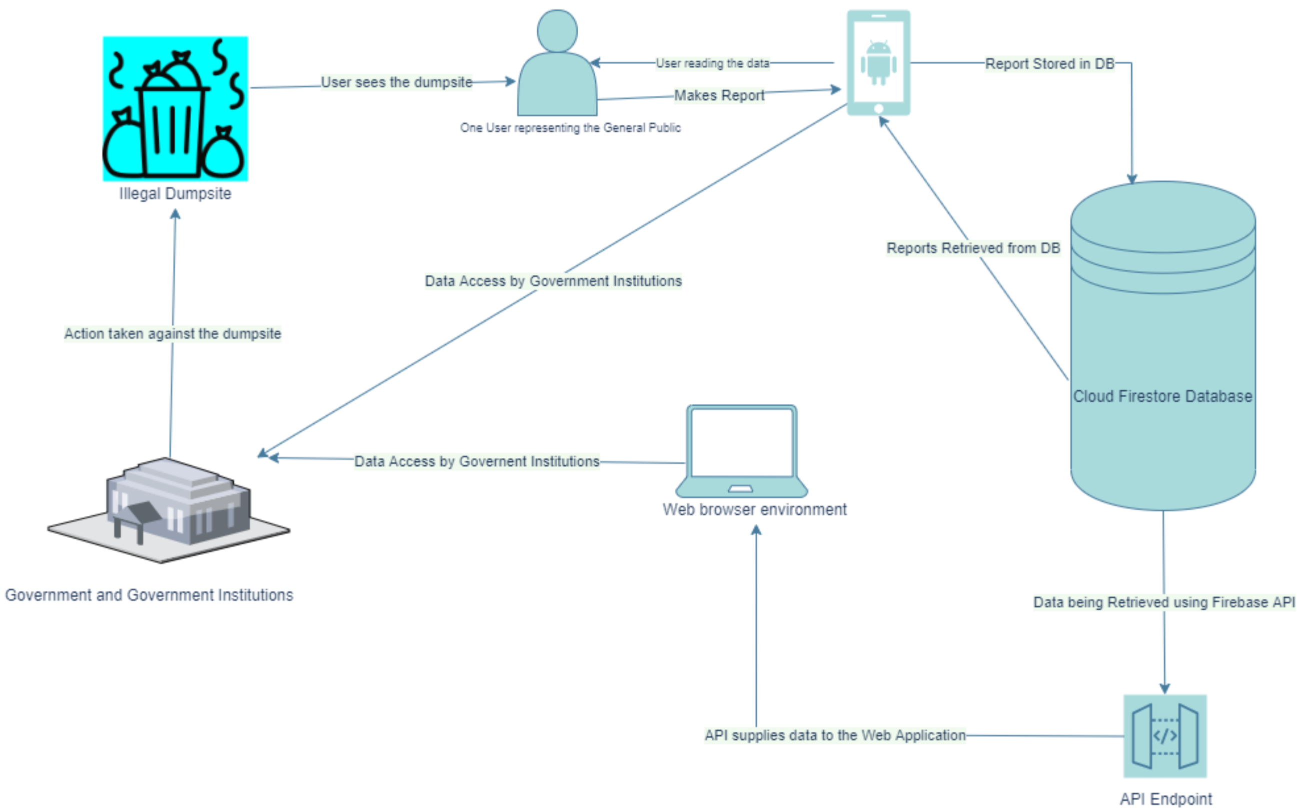


Fig 6. A simplified System Architecture Diagram

3.7 The development process overview

The development process explains the steps that were taken to develop the system. This development process involves: Database design, User Interface design, connecting to the database and the actual login to run the application.

In the progress of the development of the application, it was necessary for me to see myself as the user of the application, due to the fact that this would give me an idea of what the user wants and finds easy to use in the application. It was obvious that I couldn’t take into consideration all the user needs because I was looking at this from a developer’s perspective, taking into consideration the specific development issues that came into place. I therefore needed to conduct user research and interviewed several expected users who were the test group for the development of the application. I advised them to be methodical in the approach to criticism because their valuable feedback would translate to the final product and the specific decisions made during the development process.

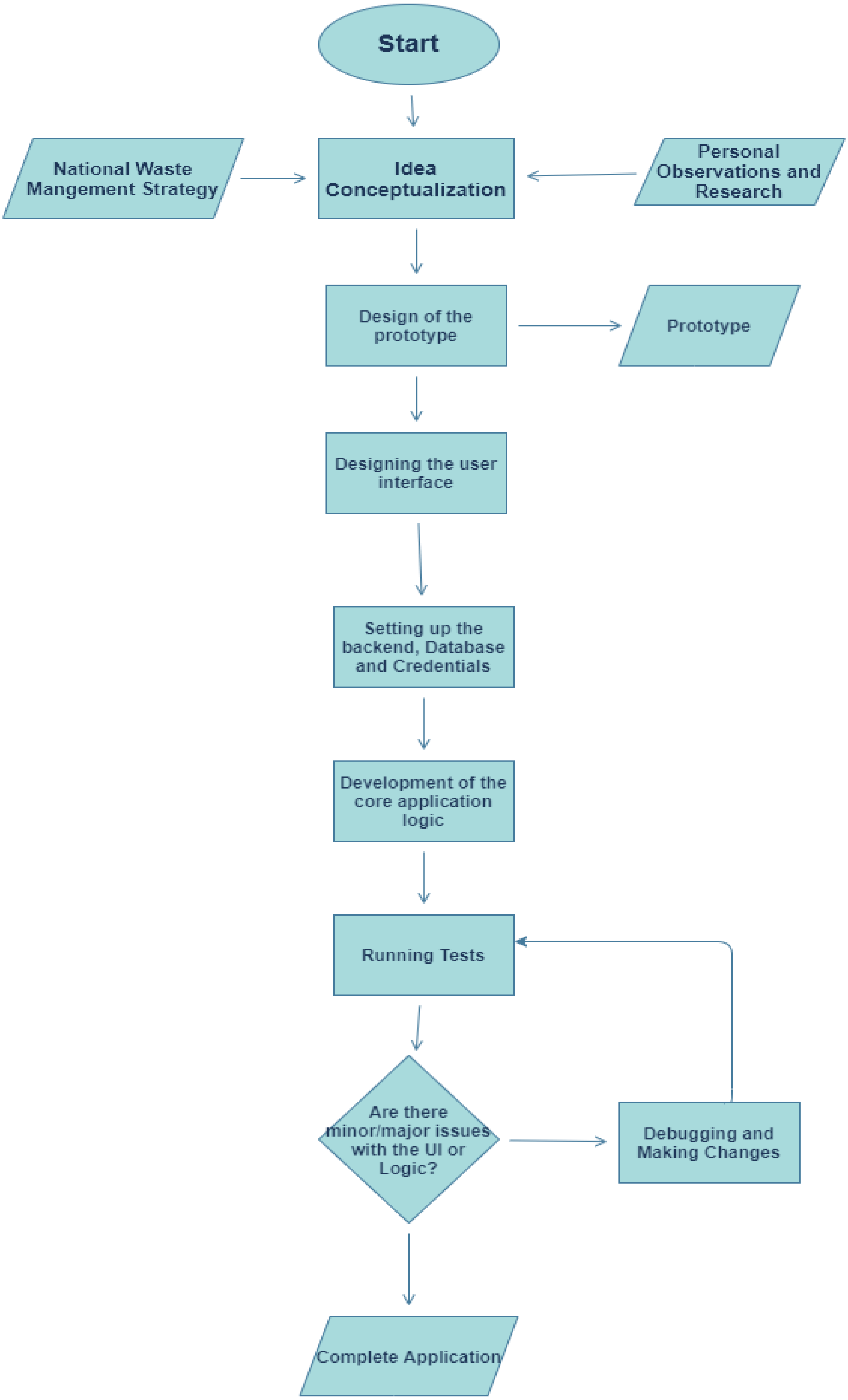


Fig 7: The development process of the android application

3.8 Database Design Process

Even before I picked a Database Management System that can handle the collected data about illegal dumpsites, the database structure had to be designed. There was a need to understand the kind of data that I needed to place in the database, which can therefore be accessed by both the relevant stakeholders and the general public – with varying access rights, given according to the level of need and rights of use.

The data I needed to have needed to have a location attribute. This was the crucial part. Now, the location was needed to be a point, and this point is specifically where a report was made, to represent the illegal dumpsite. There are other attributes that were required for the data model to be complete. They are for instance, size of the dumpsite, the materials that make up the dumpsite, an image of the dumpsite, accessibility/ease of access to the specific location where the dumpsite exists, The reporter's name and email address.

3.8.1 Data Structure and Data Attributes

3.8.1.1 Size of the Dumpsite

The size of the dumpsite is a required attribute that was to be filled with either of the three choices that I provided. These choices were:

- Can fit in a trash bag,
- Can fit in a wheelbarrow
- Car is needed.

From the three choices given above, it is clear that these do not actually represent the actual that the dumpsite could have, which could be represented as the area of the region that the dumpsite occupies, or the weight of the dumpsite. However, while this way of representing the dumpsite would have been more accurate, these methods would require actual measuring equipment which beats the whole point of making it as easy as it can for the public to report the dumpsites. The user will find it easier to estimate what the dumpsite in question can fit, but harder to estimate the actual area, mass of the specific dumpsite. I therefore provided user friendly way of saying small, large, huge without it having to be vague since such terms are relative, and it mostly depends on the user of the application. The size of the dumpsite is needed by the expected collectors of the reported waste so they can go to the site of the dumpsite prepared and with the right tools. The datatype for this was intended to be a String that could accept any of the three predefined options, but not more than one.

3.8.1.2 Materials that make up the Dumpsite

Waste can be household, industrial, organic, liquid waste, recyclable waste, hazardous waste and more. These are details that needed to be captured to determine the urgency of the collection. Some waste materials as stated above are hazardous and could result in fatalities which come when humans and animals come into contact with the specified waste materials. It is also important to note that the materials that make up a specific dumpsite vary depending on the waste produced by the individuals/groups/companies/industries that dump the waste here.

Research done before has concluded that the majority of waste thrown in illegal dumpsites is comprised of household and organic waste (Markus Skogsmo, A Scalable Approach for

Detecting Dumpsites using Automatic Target Recognition with Feature Selection and SVM through Satellite Imagery, University of Uppsala, Sweden)

The various materials that I considered including in the attributes are:

- organic waste
- plastic waste
- building rubble
- electronic waste
- liquid/sewage
- animal carcass
- textile/clothing
- glass
- metal.

From the list above, it is clear that this list is in no way exhaustive and that there are still some skipped materials that could make up a dumpsite. It is also quite general. Considering the first part, these are the major items that will be found in almost all dumpsites around Nairobi. Some materials such as radioactive materials might be hard to detect for the general public and there are also not easily found in places like Makadara. The user was intended to find it easy to report the dumpsites without having to struggle. The data type for this attribute was intended to be an array, which is basically a list of all the items that the user can see on the dumpsite.

3.8.1.3 Dumpsite Accessibility

The dumpsite accessibility was a necessary attribute that was intended to be used during the clean-up process that could determine how easily the cleaning team can access the dumpsite. Some dumpsites may be located in places where a car cannot approach and therefore, there is need for special moving equipment to move the trash up to where the car can access. This attribute was therefore needed to check if the location of the dumpsite is actually accessible by car. This attribute was therefore expected to be a Boolean value where True means a car can access the location of the dumpsite and False if the a cannot access the dumpsite.

3.8.1.4 Reporter Name and Email Address

This is an attribute that was needed for the purpose of getting the user details in case I decided to place incentives for the collection of the data. The incentives could be monetary and non-monetary. However, due to financial constraints, the monetary incentivisation could not be done. Incentivisation will be elaborated later in this paper. The reporter's name and email were also needed to create data models such as users for the sake of creating a trusted team. This team can thereafter be awarded with monetary and non-monetary incentives to continue actively or passively collecting data about illegal dumpsites.

From the perspective of the user, the name and email details were optional and the user didn't need to fill these details. However, the field was intended to be a non-null value from the database perspective so I therefore implemented logic that would check if the reporter's name and/or email is added and if not, it should fill the field with a String, either "Anonymous Reporter" or "No email" respectively.

3.8.2 The Data Model

Java Programming Language is an Object-Oriented Programming Language. This meant that I needed to have a data model that would have all the attributes described above that could be stored in the database. To define this, a Java data class which I named “Dump” was created, that had all of these attributes defined above, and a GeoPoint object as an attribute, that would have two attributes, a longitude and a latitude.

3.9 The Database Management System

Google provided a document-based NoSQL database for the storage of data called Firebase Database that provides 2 options: The Realtime Firebase Database and the Cloud Firestore Database. This database is a schema-less database that is compatible with many systems and can be accessed with just authentication and reference to the database. I settled on using the Cloud Firestore database considering its ease and efficiency in Android Applications as compared to other relational database management systems such as PostgreSQL. The ease of setting up was apparent because all I needed to do was define a data model and any new entry that was being added to the database would be added as a node to the database, and was to be read as such. The database also automatically assigned the ID which would be the equivalent of an identifier of primary key in a relational database system. The following image shows the structure of the data model and the database.

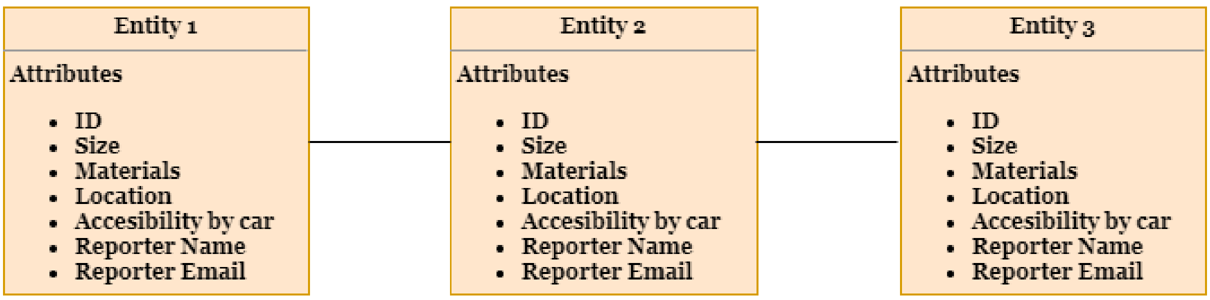


Fig 8: A data model diagram showing three entries connected through nodes.

3.10 The User Interface

The client application's user interface was designed using a test-based design process. I constantly looked out for feedback on the outlook of the application and factors such as colours, all while following some design best practises and personal preferences and the prototype that I developed before. I will however note that both the prototype and the actual user interface of the app were met by some design constraints which stemmed from various factors such as the resolution of the mobile phone which required me to build different UI designs for those outliers.

Android User interface is developed using a markup language know as Extensible Markup Language (XML).

3.11 Setting up the APIs and API Credentials

In this application, I was needed to use several APIs, SDKs and Libraries. For the display of the map and the mapping on the client application, I settled on using the Google Maps API for this. The Google Maps API provided a basemap provided by google. I could therefore overlay the data collected by the user's application on this map. Google's terms and conditions demand that one gets an API key to be allowed to have access to their APIs. The APIs needed in this case are the Location API, on top of the Google Maps API, to detect the location of the device every time a new entry is being made. All of these credentials can be set in the Google Developers and Google Cloud Platform. The technicalities of setting up APIs depend on the type of application a developer is building and the APIs the developer wants to use. This is therefore beyond the scope of this paper.

3.12 The Client Application Logic

The client application needed to have all the features described in the system requirements specification. These features needed to be written directly to the client application's logic. It is worth mentioning that the client application was developed using the Java programming language. The application was developed keeping in mind all of these features.

The logic to add new data to the database – In this case, the logic that facilitated the user to add dumpsites and their attributes as described above was done. Note that the user didn't need to enter the location and instead only needed to turn on the GPS sensor for the device. If the user hadn't turned on the device's GPS, the application will prompt the user to turn it on, and the location was added automatically to the new object. This was needed to improve on the accuracy of the location and only leave it to the device's location accuracy. When the user submitted the object, the database would then be updated with a new entry. The user could thereafter view the entry in the web application, the Nairobi Safi API or the client application. The details for the user flow are explained in more details in the following chapter.

3.13 The Web Application

I developed the web application as part of demonstration of how this data can be visualized and accessed on the web. This web application formed part of the data retrieval process and was tied together with a REST API that would make this data available to anyone who intended to develop their own applications. On the web application, a routing functionality was implemented whereby the waste collectors could click in a dump location and a line representing the route to that specific location would be drawn on the web map.

Routing was not implemented on the client application due to costs of using Google's Direction API and incompatibilities with some of the dependencies. Instead, it was implemented in the web visualization of the data.

Chapter 4: Results and Analysis

4.1 The Client Application User Flow

The client application user flow is the process that the user will undergo to use the application for: (a) Reporting new dumpsites and (b) Viewing the details for the already reported dumpsites.

4.1.1 Reporting the Rubbish Dumps

The above are the main components that are considered in this paper. The user will need to install the application first, which will be hosted in app marketplaces such as the Google Play Store. The user will therefore install the application with the intention of actively or passively reporting these dumpsites.

When the user comes across a dumpsite, he will open the application and click on the + button on the first screen to open the camera. Once the user captures the image and confirms, a screen to fill up the details of the specific dumpsite will appear and the user is requested to fill up these details as he can see. For instance, if the trash in the dump appears to fit in a car, he will be needed to indicate that from the user interface. As mentioned before, the data needed is size, accessibility, materials, location, reporter name and email. This screen is where all of this information will be filled. The application itself will detect the location of the device from its GPS and fill this location automatically. This is implemented to prevent the user entering the location and therefore reduce errors injected by the users. On this screen there is an **UPDATE LOCATION** button that the user might be needed to press to update the location because the FusedLocation API saves the last know location of the device. The user will however need to do this rarely because I have implemented a situation where the application requires the location at that specific time. The user will then hit submit and the entry will be added to the database. After this entry is added to the database, the user will be directed to a success screen showing that the entry has been successful. The user can therefore go and view his and other people's entries on the map page. The following figures show the User Interface of the working application collecting data step.

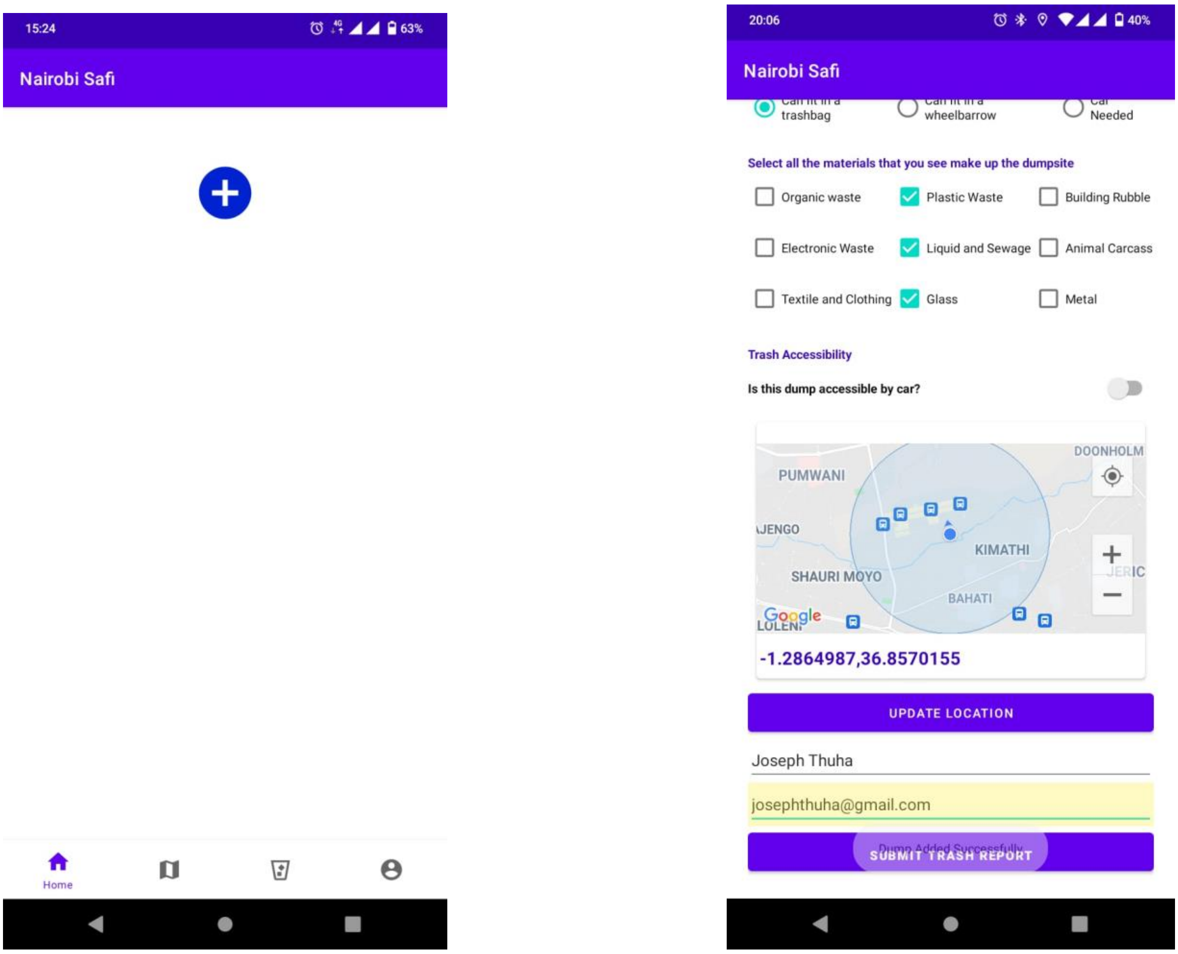


Fig 9: A user interface of the working application collection of data module

4.1.2 Reading the data

The client application offers a platform to view the collected data and its attributes. These data as explained is location based. Every dumpsite is tied to a location where it exists. Every site is displayed on the map as a marker. The marker is clickable and the user can click it to see the attributes of the specific rubbish dump at the location of the marker which has been clicked. The figure below shows screenshots of both the map showing markers that represent the location where illegal dumping has been done, and a screen showing the details of the illegal dump that has been clicked.

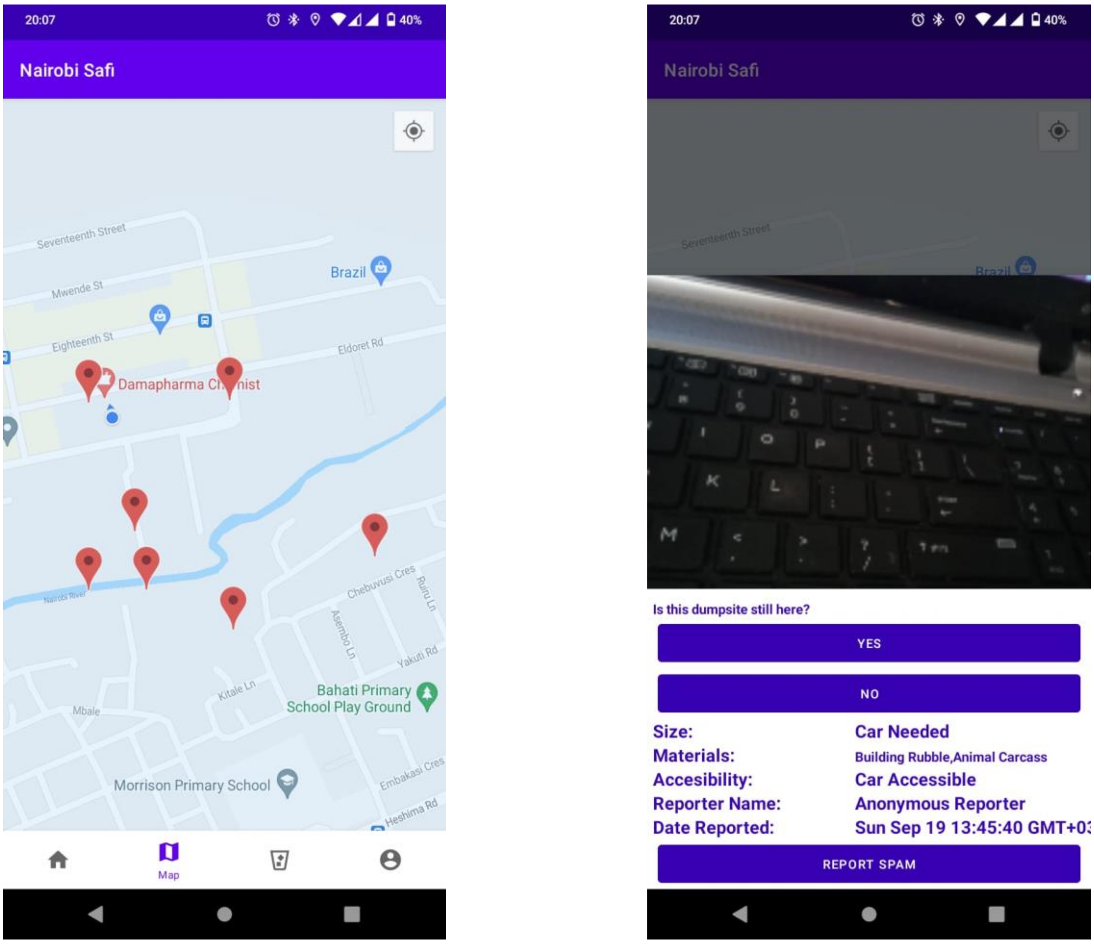


Fig 10: Screenshots showing the a how markers that represent the illegal waste locations are displayed on a map. Note that this were added by users. On the right, there is a details screen that shows the details of the dumpsite at the location where the marker is once the marker is clicked

This data is stored in a document-based NoSQL database management system that is based on the Google Cloud Platform known as the Cloud Firestore database, that can be accessed even outside the application once the access rights are granted. This is demonstrated by the web application and the API described in the previous chapter. The API gives access to the database to everyone who is accessing it outside the application. The web application shows similar information to the one displayed on the client application. The web application has the following features that are not in the android application.

4.2 Web Application Features

4.2.1 Reading the data

The data as described above exists in a Cloud Firestore database. This database can be accessed with once the right credentials are established. The web application was able to demonstrate that the data can be read visualized on the web, making it easy for people who need to do more spatial analysis. The following figures show the data as has been accessed by the web application.

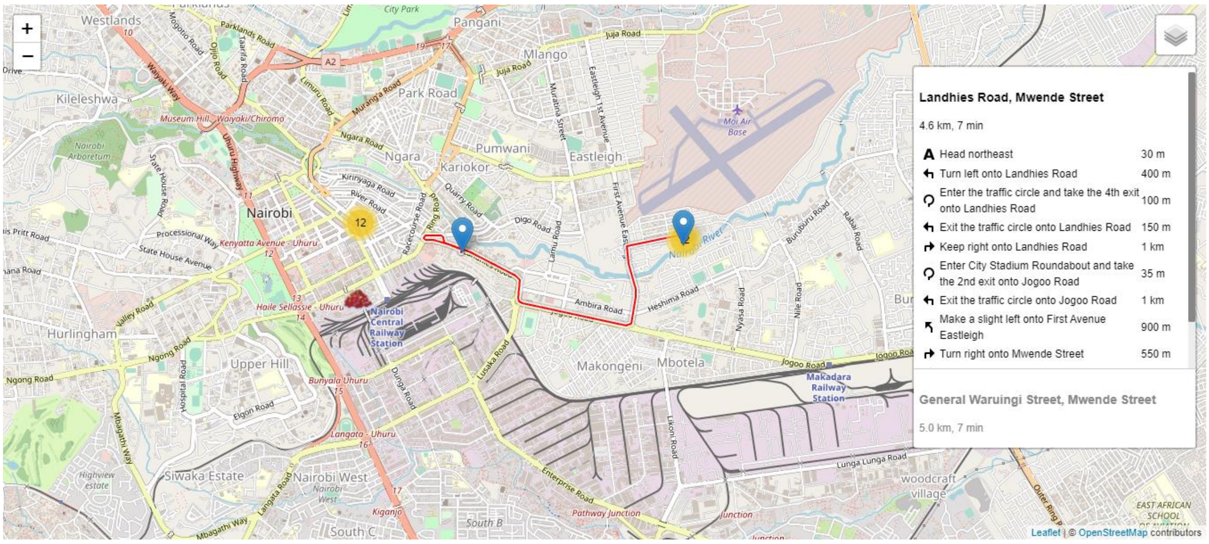


Fig 11: The illegal dumps as visualized from the web application.

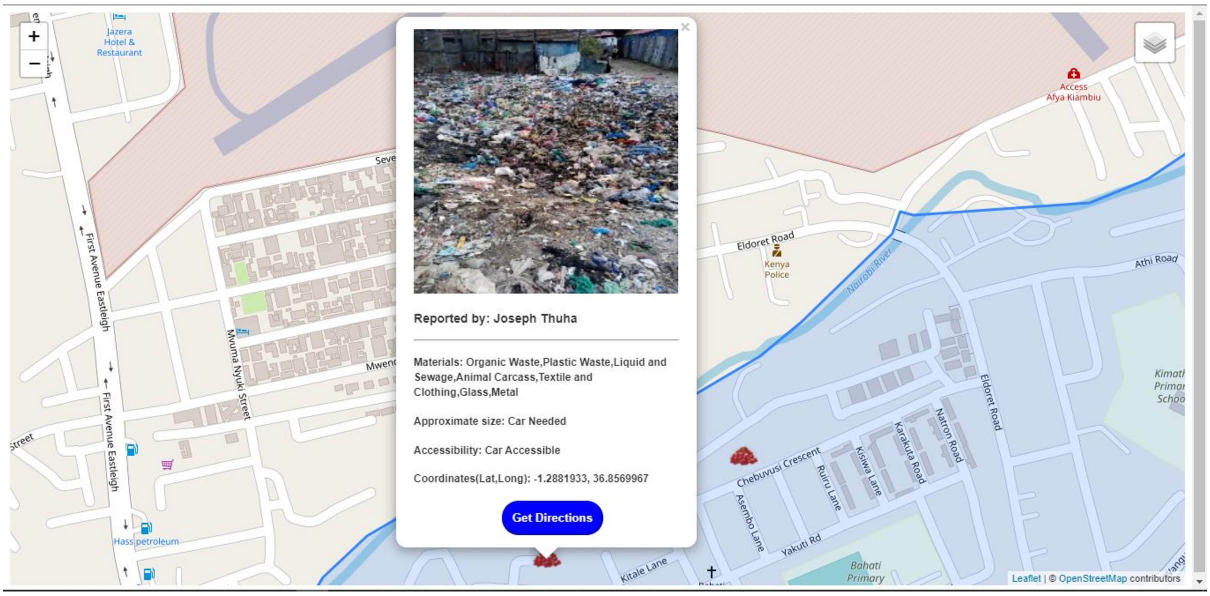


Fig 12: Attributes of a dumpsite as visualized from the web application.

4.2.2 Routing

Routing has been written directly into the web application. This routing gives the users of the web application the direction from their location to the location of the dumpsites. The markers representing the dumpsite can be clicked and and the route towards this location is drawn directly on the web application. The starting point for the route can also be dragged to a specific location and the route will be drawn. The following screenshot show a route drawn from a location to a dumpsite on the web map.

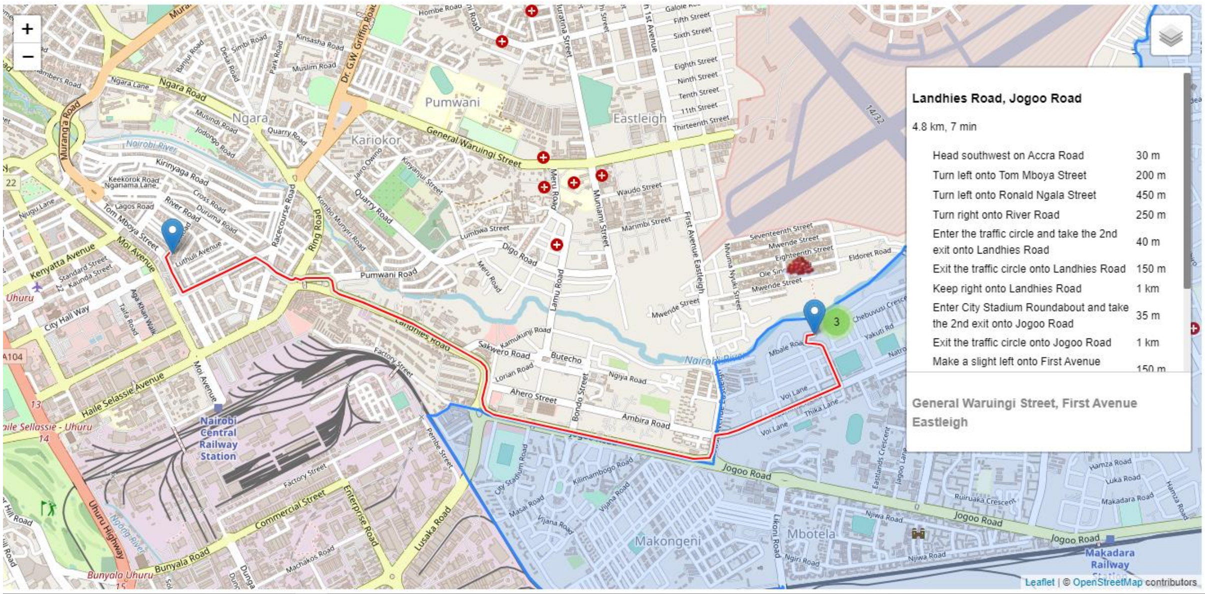


Fig 13: A screenshot showing the route a waste collector would follow a dumpsite reported by a user from the mobile application. Note that this is from the web application that the route is given.

On the right of the screenshot, directions to the specific rubbish dump are given by the Geocoder.

4.2.3 Marker Clusters

As the data is collected by the users, in places where there is a lot of these dumpsites, the subsequent markers are going to be too close together when the zoom level is high. To prevent this, I implemented marker clusters that prevent this from happening.

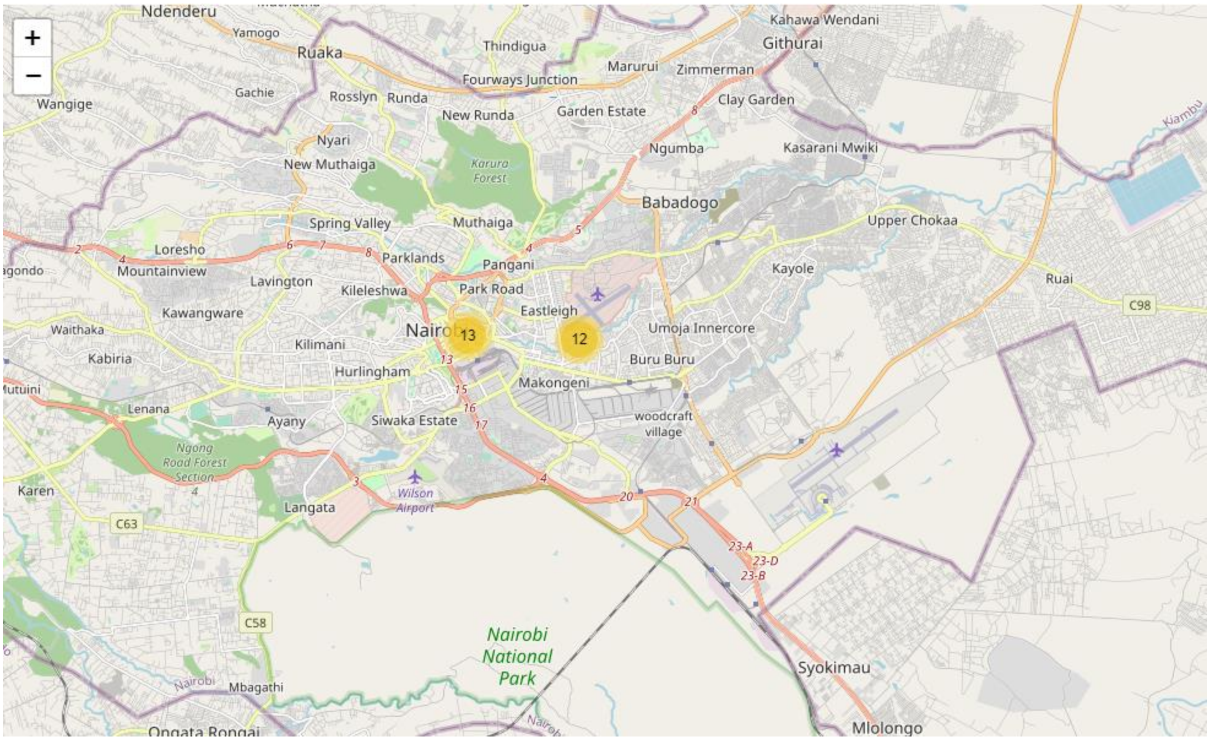


Fig 14: A map showing some marker clusters implemented on the web map. Note the marker clusters are implemented to reduce the clutter that might appear from markers being too close together.

4.3 RESTful API

I wrote the API to demonstrate how anyone who needed access to this data outside the application for his/her own spatial analysis tasks can, without having to authenticate or get the credentials directly. The API returns data in JSON that can be converted into any format the user needs it to be. The GeoJSON can also be loaded into traditional GIS software such as ArcGIS/QGIS as will be demonstrated in the following sections.

API documentation

The REST API expects a GET request. Any other request will return a HTTP/403 error.

The data can easily be accessed using the following python script:

```python
import urllib.request
import json



try:
    url = r"https://nairobi-safi.herokuapp.com/api/get-reported-dumpsites"
    response = urllib.request.urlopen(url, timeout=10)
    print(json.loads(response.read()))
except Exception as e:
    print(e)
```

Fig 15: A python code snippet to access the data in the Nairobi Safi API

The expected output will be a GeoJSON object as follows:


```
{'type': 'FeatureCollection', 'features': [{'type': 'Feature', 'geometry': {'type': 'Point',
'coordinates': [36.8612508, -1.2867953]}, 'properties': {'reporter_name': 'Joseph Thuha',
'materials': ['Organic Waste', 'Plastic Waste', 'Liquid and Sewage', 'Textile and Clothing',
'Glass', 'Metal'], 'car_accessible': 'Car Accessible', 'reporter_email':
'josephthuha@gmail.com', 'dump_size': 'Car Needed', 'image_url':
'https://firebasestorage.googleapis.com/v0/b/nairobi-safi.appspot.com/o/
46BoiTgPFY7HrwO84tGm?alt=media&token=aff0180f-6ecf-43a9-874f-53b304c0f8d0'}}, {'type':
'Feature', 'geometry': {'type': 'Point', 'coordinates': [36.8593129, -1.2866045]}, 'properties':
{'reporter_name': 'Joseph Thuha', 'materials': ['Building Rubble'], 'car_accessible': 'Car
Accessible', 'reporter_email': 'josephthuha@gmail.com', 'dump_size': 'Car Needed', 'image_url':
'https://firebasestorage.googleapis.com/v0/b/nairobi-safi.appspot.com/o/
9d4VgL1I93Sg834R18W3?alt=media&token=92356c72-21bd-4871-af05-574f2aabab47'}}, {'type':
'Feature', 'geometry': {'type': 'Point', 'coordinates': [36.857755, -1.28759]}, 'properties':
{'reporter_name': 'Joseph Thuha', 'materials': ['Organic Waste', 'Plastic Waste', 'Textile and
Clothing', 'Glass'], 'car_accessible': 'Not Car Accessible', 'reporter_email':
'josephthuha@gmail.com', 'dump_size': 'Car Needed', 'image_url':
'https://firebasestorage.googleapis.com/v0/b/nairobi-safi.appspot.com/o/
EKmYzXSkpiH1xVFU386A?alt=media&token=4f583c75-d9e1-42e2-ba41-69b8360ea35a'}}, {'type':
'Feature', 'geometry': {'type': 'Point', 'coordinates': [36.8601738, -1.2861891]}, 'properties':
```


Fig 16: A GEOJSON response object from the Nairobi Safi API.

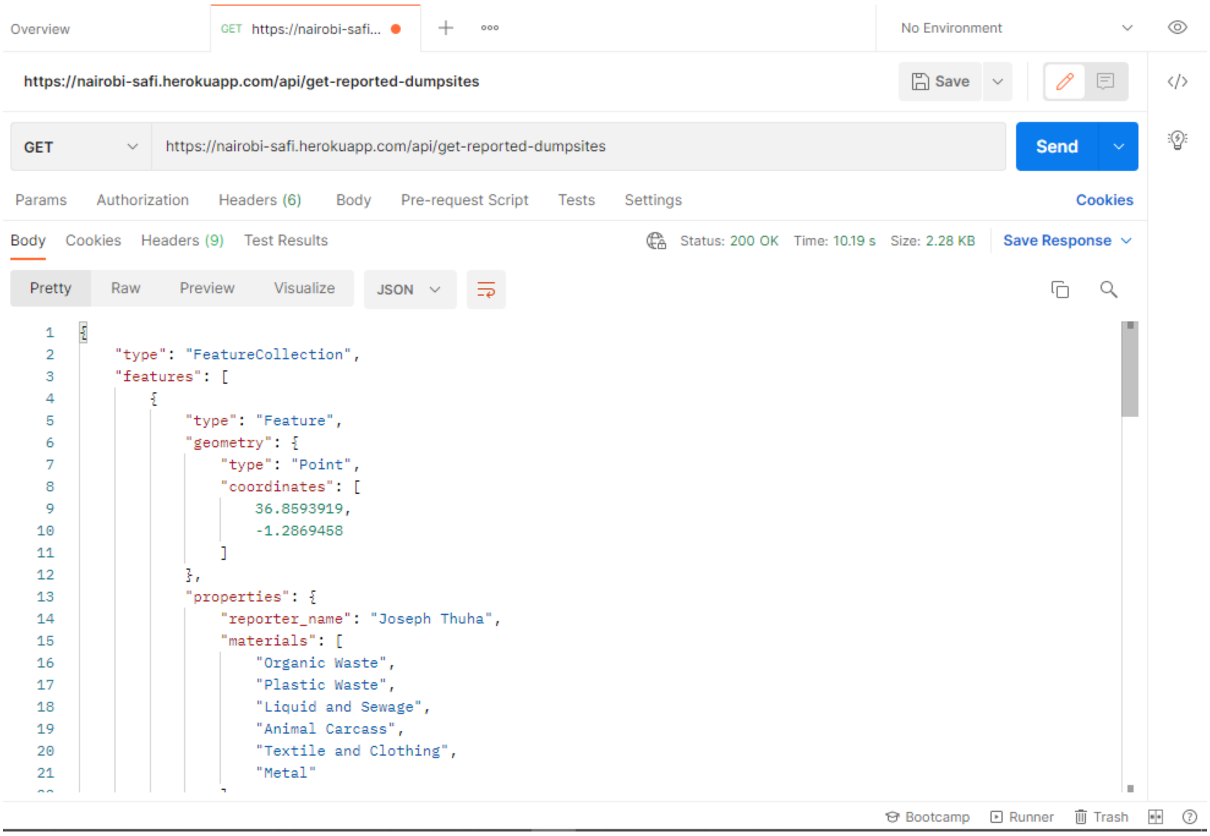


Fig 17: A GeoJSON OBJECT returned from the API request as accessed from postman.

The data collected can also be read using traditional GIS software. For instance, QGIS as demonstrated below

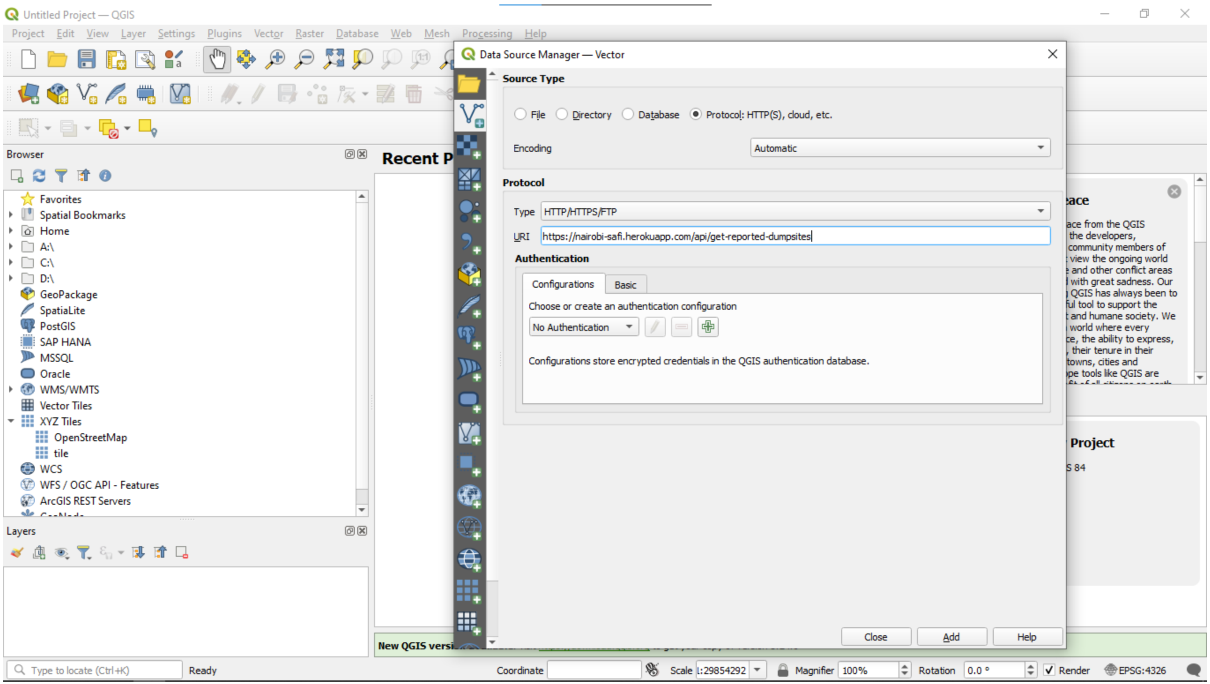


Fig 18: Loading dumpsites data from the Nairobi Safi API directly to QGIS

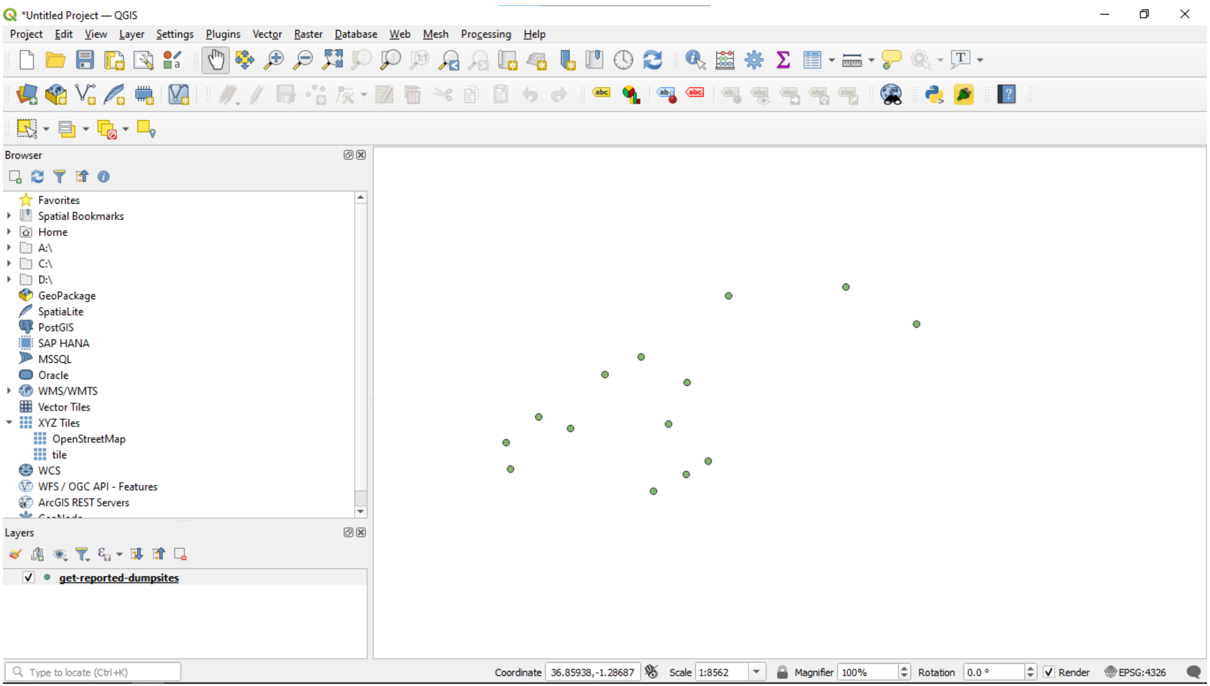


Fig 19: Dumpsites data as it appears from the QGIS interface

Chapter 5: Conclusion

5.1 Conclusion

As stated earlier the goal of this system is to provide the general public with a no-knowledge needed GIS platform to report dumpsites, in addition to democratizing the GIS data collected to be available to the general public and the authorities.

By developing this system from start to finish a subsequently testing it on with different users. It was clear that this is an effective method of GIS data collection owing to the amount of data collected, accuracy and costs – which in this case are almost none.

Costs associated with GIS data collection are traditionally known to be high. It is therefore important and advisable to adopt low costs methods which are necessary for data collection. The low costs methods make data more available to the public and this can be used to reduce the problem. In this case being the illegal dumping that is prevalent.

Action against this data collected will need to be taken. Otherwise, there is no effective use for this system. The system is put in place to take care of the difficult task of locating these dumpsites, and connecting the general public affected by the dumpsites to the bodies responsible for waste management.

More work will need to be done to actually remove the dumpsites from these locations.

5.2 Recommendations for the system

This system can be improved. Some of the improvements that could be done are for instance:

- Real time data collection to visualization can be done. To improve the general application experience, real time data collection can be implemented. From a purely technical perspective this can be done using WebSockets.
- Future improvement on the system may even use high resolution satellite imagery and machine learning models in conjunction with the data collected by the public for data validation and collection.
- Addition of monetary and other incentives to encourage data collection using our system
- Adoption of this system by government authorities.

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