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A tool for mapping and monitoring landslides emergency management and disaster response - case study Murang'a County

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A Tool for Mapping and Monitoring Landslides Emergency Management and Disaster Response: Case Study Murang’a County

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Declaration and Approval

I declare that this work has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

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Abstract

Murang’a County is considered the county which is more prone to landslides than any other part in Kenya. This is mainly due its mountainous terrain that has rugged a landscape composed of steep valleys punctuated by numerous hills. The terrain is dissected therefore creating the menace of landslides that come often during the rainy season. According to Kenya Red Cross, they have reported that Murang’a County has recorded the highest number of loss of life as well as property destruction as a result of landslides. The magnitude of the landslide often stretch to about three kilometres making it difficult to reach the affected villages. There has been a big challenge in identifying the impact of the landslides and infrastructures affected, hampering the coordination of emergency response efforts mainly because the data is not integrated spatially. Most of infrastructure damaged are people’s houses, roads, tea factories, tea buying centres, schools, hospitals, the tea farms not mention loss of human life and animals. To address this challenge, a tool that utilizes location intelligence as a spatial analytic technique to map and monitor landslide emergencies as well as respond to disasters in a more informed manner was developed. Spatial analysis lends new perspectives to a decision-maker as they study landslide occurrence, households destroyed, infrastructure affected and the relationships among them in an easily understandable manner. The tool was used to record & monitor landslide events, using an interactive operation dashboard that spatially showed where the landslides occurred, location of affected households and damaged infrastructure so as to coordinate the response services deployed. The tool was anchored on location intelligence, a spatial analysis technique, which provided various ways of analysing landslides events geographically and integrated infrastructure data to determine the likely impact. The findings of the research showed that users found the application informative and easy to use. The users were able to locate the areas where landslides often occur and were satisfied with the useful information that assisted them in identifying the infrastructure that was at risk.

Keywords: Landslides, Operation Dashboard, Spatial Analysis, GIS, Tool, Emergency, Disaster

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Finally I would like to acknowledge my classmates in the MSc. IT class, who constantly supported me through regular consultation and brainstorming on certain aspects of this study. I am also grateful to my family for supporting me throughout the course of undertaking my master's degree and this study.

Dedication

This research work is dedicated to my son John Njururi Ngugi who died of brain cancer in the course of this research. Although John is not here to see me cross the finish line, I know he is smiling in heaven knowing that I managed to fulfil this work despite the hardship & challenges experienced throughout. My sincere gratitude to my wife, Stella Kagendo and my son David Kimani.

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List of Abbreviations / Acronyms

AOI - Area of Interest

API - Application Programming Interface

CDRU - County Disaster Response Units

DEM - Digital Elevation Model

GIS - Geographical Information System

GPS - Global Positioning System

ICT - Information and Communication Technology

IT - Information Technology

KeNHA - Kenya National Highways Authority

KMD - Kenya Meteorological Department

KNBS - Kenya National Bureau of Statistics

KRC - Kenya Red Cross

KURA - Kenya Urban Roads Authority

KWS - Kenya Wildlife Services

NDMA - National Disaster Management Authority

NYS - National Youth Service

RAD - Rapid Application Development

REST - Representational State Transfer

WARMA - Water Resources Authority

WFS - Web Feature Service

WMS - Web Map Service

OGC - Open Geospatial Consortium

Definition of Terms

Disaster Disasters come about based on the scope and magnitude of an emergency. They quite often result in a lot of damage, sometimes loss and destruction of property and even human life. (Donald C, 2014).

GIS Geographic Information Systems can be defined as computer-based systems designed to function specifically on spatial information used to acquire, manipulate, store and display geographic data for purposes of planning (Reimold, 2019).

Emergency A deviation from planned or expected behaviour or a course of events that endangers or adversely affects people, property, or the environment (Rahman, 2014).

Landslide A landslide is a term commonly used to refer to movement of rocks, soil and organic material down a steep slope because of influence caused by gravity (Varnes, 1984).

Spatial Analysis Spatial analysis looks at how we understand our world, mapping where things are, how they relate and what actions to take. The most basic way in understanding how spatial analysis works is consciously recognizing where something is located and navigating towards it (Hover, 2018).

Remote Sensing Remote sensing is the science of obtaining information about objects or areas from a distance, typically from aircraft or satellite images (NOAA, 2018).

Chapter 1 : Introduction

1.1. Background Information

In the recent past, Kenya has experienced a series of landslides disasters that have severely brought serious issues and in many cases, overwhelmed the capacity of the leading responding agencies i.e. The Kenya Red Cross, National Disaster Management Authority (NDMA), National Youth Service (NYS), Kenya Meteorological Department (KMD) and County Disaster Response Units (CDRU). These landslide disasters have led loss of life, displaced families, property destruction, disease outbreak, environment degradation just to mention a few.

Murang'a County is considered the county which is more prone to landslides than any part in Kenya, mainly due its mountainous terrain that has rugged a landscape composed of steep valleys punctuated by numerous hills. The terrain is dissected creating the menace of landslides that come often during the rainy season (Bashir, 2018). According to the Kenya Red Cross, Murang'a County was reported to have recorded the highest number of deaths as well as property destruction as a result of landslides.

According to a report done by Mbuthia Bashir for Citizen Digital on 27 May 2018, about 4,000 people living in 1,193 houses in Murang'a County were affected severely by weak fault lines as a result of landslides that have also destroyed coffee farms, leaving many households without any source of income and learning institutions have not been spared either (Bashir, 2018). The Kenya Red Cross even launched a walk to raise Ksh. 4 million, to be used to collect food and other items for the victims.

In June 2018, it was reported by a local broadcaster, Nation Television (NTV), that Murang'a County was facing food shortage, as landslides had affected their farms. Farmers said that even though they had crops in the fields, harvesting was impossible because the earth kept moving every day, making it unsafe to go to their farms (Bashir, 2018).

Agatha Ngotho, a business reporter of the Star newspaper, wrote that Landslides had cut off tea farms particularly in Kiagotho location, Kanyenyaini ward. Jennifer Wangui, a tea farmer, said that every day there were new cracks on her one-acre farm and although the tea leaves were ready for plucking she was afraid to go to the farm in case more landslide corrosion occurred (Ngotho, 2018).

In May 2018, fifteen families in Murang'a County were displaced by mudslides caused by floods. In one of the incidents, property worth KSh 20 million was destroyed at Marumi coffee factory in Kigumo sub-county (Angela, 2018). With modern technologies such as satellite imaging and web map services such as Google Earth, it is possible for anyone with access to the Internet to see the magnitude of the disaster. This study is about Spatial Analysis Technology that is applied in Geographical Information System and the role it plays in emergency management and disaster response.

An evaluation done by the Kenya Red Cross Society Program on Strengthening Disaster Preparedness and Response, it was recommended that there was need to consider strengthening use of geo spatial technology to map the landslide incidents reported. This information was to help improve the risk and hazard maps in support of disaster preparedness and response. The evaluation however noted that the risk and hazard are not comprehensive and lacked or failed to utilize geospatial technology to analyse the risks mainly because data is not integrated spatially. This made it difficult to assess the damage when a landslide occurs (Kenya Red Cross, 2019).

Geospatial data describes the locations of things on the Earth's surface and geospatial tools manipulate such data to create useful products. Thus, this study will have outputs of maps that form an essential part of search-and-rescue operations; about the Global Positioning System (GPS) receivers that allow first responders to locate damaged buildings or injured residents, about images that are captured from satellite to provide a comprehensive picture of an event's impact, about road maps that form the basis of evacuation planning, and about all of the other information connected to a location that can be used in emergency management.

Most emergency management have programs that are designed, developed, implemented and rolled out through the analysis of information. The majority of this information is usually spatial and can easily be mapped. This information is carefully mapped, the data is linked to the map and thereafter emergency management planning can begin. The human population, property and environmental surroundings are combined with hazards, emergency management personnel so that they can quickly begin to formulate the necessary mitigation, preparedness, response, and recovery program activities as urgently required (Ahmed, 2000). It's against this backdrop, a tool that can assist how landslides are managed will be anchored.

1.2. Problem Statement

Whenever a landslide occurs in Murang'a County, the County Government often struggles to identify and measure the exact impact of a landslide disaster. There are some which stretch to about three kilometres, leaving a wave of property destruction, crops destroyed, deaths and displaced families (Mwangi, 2018). According to (O'Connor, 2017), there is a very big challenge in analysing and integrating data spatially so that critical information can be quickly communicated, understood and acted upon in a simple way that is clear and precise. Sharing of information across responding agencies is common universal problem that is often hampered by a lack of data interoperability because critical data is maintained in dissimilar systems and there are no common standards to enable the various organizations to efficiently organize and share their resources during response operations. In Murang'a County, the problem is further compounded since computerized GIS system does not exist other that manual records that are scantly recorded. Lack of a GIS based database makes it difficult to identify which assets are affected whenever landslides occur and hampers the coordination of response efforts. (Agatha, 2018). In addition, landslides can impair the functioning of critical infrastructure and destroy cultural heritage and ecological systems.

According to a research done by the Red Cross Society Program on Strengthening Disaster Preparedness and Response in Kenya, there was need to consider strengthening use of geo spatial technology to map the landslide incidents reported, so that this information can help improve the risk and hazard maps in support of disaster preparedness and response. The evaluation however noted that the risks are not comprehensive and lacks to utilize geospatial technology to analyse the risks mainly because data is not integrated spatially, making it difficult to assess the damage when a landslide occurs (Kenya Red Cross, 2019).

In this regard, a tool that utilizes GIS technology to effectively analyse data spatially for disaster response units to confidently use this information to tackle landslides emergency was the solution this research sought to provide. The tool leads to an improved situation awareness of land slide affected areas and integrating the results with other spatially distributed information such as schools, roads, health facilities etc. This is what existing solutions often lack, the ability of data to be integrated spatially with other datasets so that they can be easily be shared across various respond agencies as well as ensure the final output is easily understood. Therefore, this system provides a solution to one of the most pressing and important problems associated with the development of landslide systems that is characterised by incompatible platforms and database formats.

1.3. Aim

The aim of this study was to come up with an interactive operation dashboard tool for landslides emergency management and disaster response to analyse the impact of landslides as well as identify the affected infrastructure within a GIS data frame, useful for decision making.

1.4. Specific Objectives

i. To determine the different type of datasets that can be linked to landslide occurrences spatially.
ii. To review the various tools that utilize GIS technology uses to analyse & manage landslides impact on infrastructure
iii. To develop an interactive operation dashboard tool that can be used to map land slide occurrences as well as the affected infrastructure.
iv. To test and analyse the interactive operation dashboard tool.

1.5. Research Questions

i. What is the spatial data required for modelling this solution for landslide emergency management and disaster Response?
ii. Which are the existing tools that utilize GIS techniques to improve how landslides impact on infrastructure are analysed & managed?
iii. How will the operation dashboard tool be developed and be implemented?
iv. How will the interactive operation dashboard tool be tested and analysed?

1.6. Justification

This research was extremely important to address the landslide perennial problem that has affected the livelihood of so many villagers in Murang'a County. In fact, the County's Integrated Development Plan (2013 -2017) enlists landslides as the major source of disaster followed by drought and famine. Most of the people living in Murang'a County are tea and coffee farmers making them among the highest contributors of foreign exchange earners in Kenya. The fact that a large section of these farmers are affected by landslides makes it extremely important for a solution to be developed to assist the responding agencies in planning and managing the problem before and after it happens. Therefore, integrating the location of landslides and nearby infrastructures using GIS is very important in coordinating response activities and it is essential to the interpretation of the data. This can be done by displaying the location of available resources on a map such as village settlement, schools, health facilities, road network and the physical terrain is very useful for measuring and determining the impact of a landslide disaster.

Providing spatial analysis of these data whose output is a series of interactive maps, ensures the user can detect and identify data patterns that are key to saving lives and preventing property destruction. Spatially designed maps are essential tools to coordinate the efforts of disaster response teams in the following ways: They provide a guide for any possible action by the public especially during evacuation or search and rescue operation; they help in the flow of resources and services before, during and after a disaster; they serve as the quickest method of locating all the elements in a specific geographic area without having to read large volumes of information; they assist in determining the physical constrains of the incident location and make optimal decision for action and lastly but not the least, to serve as educational tools or public awareness campaigns on where landslide are likely to occur.

1.7. Scope and Limitation

The scope of this data was limited to only one county i.e. Murang’a County. To produce the spatial maps, the data sources for this study was acquired from The Kenya Red Cross, National Disaster Management Authority (NDMA), National Youth Service (NYS), Kenya Meteorological Department (KMD), County Disaster Response Units (CDRU) and Online data that is publicly available. The study made use of an online questionnaire to acquire non-spatial data that was vital for analysis. The interactive dashboard operation tool developed was made accessible online though a web browser. Information was geographically validated to ensure the location of the landslides was well captured with the highest accuracy as possible. A big challenge encountered was to get reliable data without gaps, although some of the data was available, only existed in bits and pieces and it needed thorough cleaning and integration to ensure the study draws the right conclusion. The research made use of the current land use data and population data to estimate the possible regions that were likely to encounter landslides due to population growth and expansion of the surrounding communities. Due to the vast size of Murang’a County the study focused on seven constituencies that have experienced landslides in the past 5 years.

Chapter 2 : Literature Review

2.1. Introduction

This chapter examines the key problems caused by landslides, the challenges of spatial analysis when dealing with landslides, causes of landslides, available GIS technologies for managing landslide and lastly the system architecture of existing applications that are useful in management of landslides. Many farmers in Murang'a County are affected by landslides because of the mountainous steep terrain that makes most places in that county very vulnerable, especially during the rainy season. GIS is an ideal tool for landslide modelling owing to its versatility in handling a large set of data, providing an efficient environment for analysis and display of results with its powerful set of tools for collecting, storing, retrieving, transforming and displaying spatial data from the real world. One of the main advantages of the use of this technology is the possibility of improving hazard occurrence models, by evaluating their results, adjusting the input variables thus better interpretation and understanding of how to respond to landslides emergencies. In particular, the ability of spatial analysis in GIS to present the data and analyse results in a map, plays a key role in identifying the critical areas (where more rigorous analysis and improved solution is required) by its interactive visualization in a spatially optimized mode (Gichaba, 2013).

2.2. Landslides in Murang'a County

In Murang'a County Integrated Development Plan (2013 -2017), launched by Governor Mwangi wa Iria, the document listed landslides as the major disaster in the County. In the whole country, Murang'a leads the other counties in having the highest number of landslides which has led to deaths and property destruction. Some of the most dangerous landslides have occurred on the eastern foot slopes of Aberdare ranges (Agatha, 2018), whereby houses collapsed, gullies run all over, and farms and houses were sliced into pieces. Springs appeared everywhere, even in areas that have never gotten water. Most of the tea farms in parts of Kangema Sub-County were completely cut off. Landslides are common occurrences in Murang'a County after heavy rains and this rendered many families homeless due to their homes being destroyed leading them to look for shelter elsewhere. Table 2.1 (UNDP & NDMA, 2011) shows the notable landslides reported in the last five years.

Table 2.1: Notable Landslides Reported in the last Five Years

#	Location of landslide	Impact
1	Kanyenyaini and Kiruri in Kagema Constituency	Loss of life, tea farm destroyed and Property destruction
2	Gaturi and Gathaithi in Kiharu Constituency	Property destruction
3	Gatura in Gatanga Constituency	Property destruction
4	Gitugi in Mathioya Constituency	Tea farm destroyed
5	Marumi in Kigumo Constituency	Tea farm destroyed and Property destruction
6	Mariira	Loss of life, tea farm destroyed and Property destruction
7	Lower Kambirwa, Mugoiri in Kigumo	Loss of life and Property destruction
8	Gitugi in Mathioya	Loss of life and Property destruction

2.3. Problems caused by landslides

There are some of the notable problems that are caused by landslides in Murang'a County such as loss of human life and livestock, uprooting tea bushes, coffee plants, trees and other planted crops which leads to heavy loss, property destruction such as farmers houses, tea factories, damaging infrastructure such as bridges, roads, power lines, schools, worship places and health facilities. Landslides cause panic among farmers and evacuating families is a big problem since most farmers don't want to leave their ancestral farms. (Agatha, 2018).

2.4. Examples of GIS Systems that manage Landslides, what to leverage and gaps

2.4.1. Monitoring and Information Management of Landslide at Guanling, China

This system presented an integrated approach for mapping and analysing spatial features of a landslide that are triggered by earthquake or rainstorm and often results in serious property damage and human casualties. Due to this, the town of Guanling felt it was necessary to establish an emergency management system to facilitate the processes of damage assessment and decision-making. Spatial Database was created to provide a platform for analysing the spatial distribution and characteristics of the landslide on different dimensions. In addition, the results of spatial data interpretation was hosted on an online cooperating platform, which was built to improve the coordination of all the key players involved in different phases of emergency response management, e.g., hazard experts, emergency managers and fast responders. A mobile-based application was developed to enhance the data exchange & on-site investigation. This application facilitates the phases of landslide monitoring and information management, e.g., emergency preparedness, hazard assessment, planning mitigation and response. (Hou, 2017)

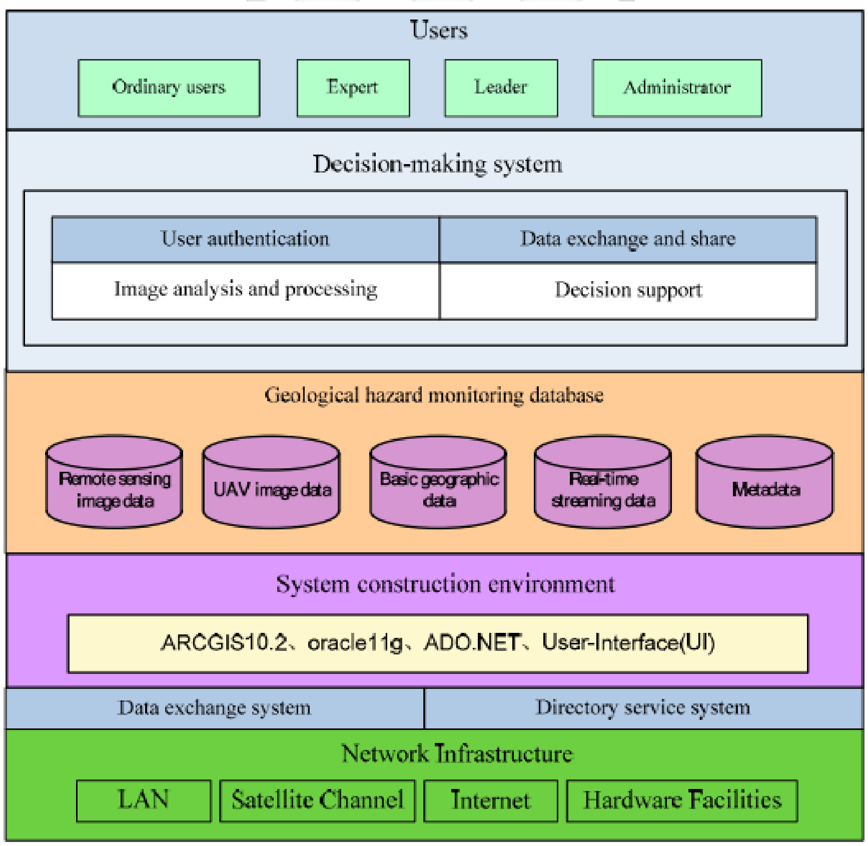


Figure 2.1 System Design and Components

2.4.2. Landslide Disaster Management System in Calgary, Canada

This system utilizes a GIS-based decision support to help emergency managers better prepare for and respond to landslide disasters. It is comprised of three key components: a geo-database, mapping portal and a communication system. This architecture provides valuable insights into landslide early warning, landslide risk and vulnerability analyses, and maps of critical infrastructure that are likely to be damaged. The developed system allows emergency management decision makers to acquire landslide hazard management information in real time, such as location of critical resources and assets (i.e., nearby operation centers, hospitals, schools area, settlements, and airports). The landslide system improves real-time communications and information sharing during a disaster and creates valuable landslide risk maps (Assilzadeh, 2015).

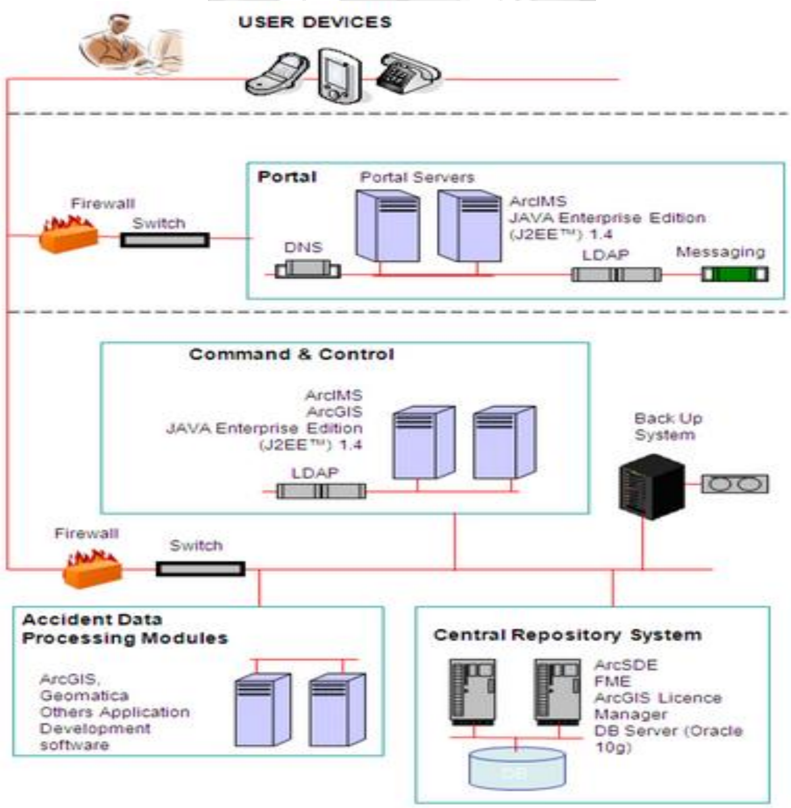


Figure 2.2 Landslide Monitoring and Management System Configuration

2.4.3. Things to leverage from the two systems

To effectively conceptualize the design of the tool for landslides emergency management and disaster response, the research leveraged on the following features that have were quite useful: Geo-mapping the infrastructure/ assets and spatially linking the data to the landslide occurrences; ensured the system was web based; the design of the system incorporated a central database for compiling and capturing all the data; utilized a mapping platform that was easily scalable and incorporated satellite imagery data to view the location of the landslide and nearby assets in real time. In combining all the above mentioned capabilities, it was possible to come up with a system that provides a solution to one of the most pressing problems associated with the development of landslide systems that is attributed to incompatible platforms and database formats.

2.4.4. Gaps identified

Table 2.2 Gaps Identified

Challenges Noted	What was implemented in the research
The system relied on web map services to share the data	Integrated web feature services to connect to the spatial data as they offer more capabilities for data analysis than web map services.
Incompatible mapping platforms and database formats when accessing external datasets	Utilized Open Geospatial Consortium (OGC) standards to provide access to the hosted data to and from the databases
Satellite images were not tilled and they were very big, this made the system quite slow in terms of its performance	Accessed the satellite images using an application programing interface (API) after tilling them instead of uploading & attaching the whole satellite image
The system's interface was very difficult to use and very difficult for someone to interpret the data at first glance	Came up with three interface for interacting with the system i.e. for decision makers, data managers and a high level executives who need precise reports
Demographic Data Profile not included	Developed an info-graphic that had demographic profile of the study area and linked it to the geospatial datasets through web feature service
Difficult to compare the situation before the landslide and after the landslide occurs	Incorporated a swipe tool, for comparing the situation before the landslide and after the landslide
Extracting selected data on the fly was not possible	Designed a feature for extracting the data and allowed the user to download it as a CSV

2.3. GIS Challenges when dealing with landslides at Murang'a County

2.3.1. Applicability of Spatial Analysis is not yet done adequately

There is challenge of showing a good road map of how Spatial Analysis in GIS can be used to enhancing emergency management and disaster response. Although GIS is being used it's not yet to a level which one can really rely on the data/ map and output to make instant decisions in real time.

2.3.2. Data interoperability and data sharing platform

There is still lack of accurate spatial data that is interoperable with other data sources. This makes it difficult to aggregate datasets because there is no common standard of exchanging data. Relevance refers to how recent and accuracy of the data being shared. The absence of an existing tool to share data in a way that it is easy to interpret by decision makers, this greatly impacts how people coordinate whenever a landslide disaster occurs.

2.3.3. Hardware, Software and Data

Spatial Analysis in GIS requires investments in hardware equipment such as computers, GPS, smart phones for mobile data collection. This provides a good reliable software that has all the necessary extension in place to design and implement the spatial models unavailable. Data is the biggest challenge in that most of the emergency/ disaster response agencies lack accurate, precise, and up-to-date data that can easily be used for planning. For instance not having a good satellite image for the whole County more so the areas experiencing the landslide will result to the emergency/ disaster response team not being able to analyse the terrain/ topography of the affected region/ community.

2.3.4. Knowledge, Expertise and Skills

Adequate skills are needed to be able to perform spatial analysis in GIS. Most of the emergency and disaster response teams lack systems in place that provide this kind of data as up to date as possible.

2.3.5. Financial Resource Support

Since spatial analysis is a function under planning in the Lands Ministry in Murang'a County, it does not get enough financial support like other Ministries. This has made the section to stagnate without having any investment of GIS.

2.5. Applicability of GIS Technologies in assessment of landslides

Attempts to implement GIS in Kenya to manage issues with landslides have been made during the past years (Kipchumba 2011). Commonly used factors in landslide spatial analysis are slope angle, aspect and curvature, bedrock and soil character, land use, precipitation, and proximity to rivers and to roads. For the analysis of these factors the application of geographic information systems (GIS) is an essential tool in the data analysis.

2.5.1. Sources of Data

Data is usually obtained from the following sources: Digital elevation model (DEM; Shuttle Radar Topography Mission (SRTM), 30 meters resolution). Google Earth (showing high resolution images from Digital Globe or Google Earth Engine), precipitation data, historical landslides data from scientific articles, field observations and photographs as well as interviews with farmers and the District Agriculture Extension Officer.

2.5.2. Assignment of weights and triggering criterion

The weights for slope, soil and land use is assigned and categorized as described in Table 2.3 (S.S. Ramakrishnan, 2002) and their rankings shown on Table 2.4 (S.S. Ramakrishnan, 2002).

Table 2.3: Categories of Landslide Triggers

#	Trigger	Category
1	Slope	54 degree - Very steeply sloping
		36 - 54 degree - Steeply sloping
		18 - 36 degree - Moderately sloping
		0 - 18 degree - Gently sloping
2	Soil	Very highly erodible
		Highly erodible
		Moderately erodible
		Poorly erodible
3	Land Use	Tea or Coffee
		Tree plantation or Grassland areas
		Mixed Agriculture or Forest zones
		Settlement area

Table 2.4: Sample of Landslides Ranking

THEME	RANK1	RANK2	RANK3	RANK4
	(4 * weight)	(3*weight)	(2*weight)	(1*weight)
Landuse	Grass land, Agriculture	Tea, Tree plantation	Forest	Settlement
Soil	KG4, KG5	KG3, KG6	KG2, KG7, KG8	KG1, KG9
Slope	36-54 deg	18-36 deg	> 54 deg	0-18 deg

2.5.3 GIS tools used in Spatial Analysis

The following tools have been used to come up with landslide management applications and their universal use make them ideal for this research as well. They include:

Table 2.5: Common GIS Tools used in Spatial Analysis

Tool	Function
ArcGIS and QGIS	For Mapping and editing task s as well as map based spatial analysis
Story Maps	To combine geospatial data with photos, video, audio, and text to visualize a theme or sequential events
Operation Dashboard	To gives real-time data visualization and analytics of people, services, assets, and events
Collector for ArcGIS	Mobile Tool for collecting Geospatial Data on the field
Survey 123/ survey Monkey	Tool for conduction surveys via questionnaire
ArcGIS Online	Cloud-based GIS mapping software that connects people, locations and data using interactive maps. It also assist in hosting datasets and application such as story maps
Python and R	For running models and algorithms

2.5.3. Spatial Analysis Key Steps

A successful spatial analysis requires a systematic approach that begins with asking the right questions and ends with making an informed decision. It is imperative to underscore that spatial analysis is not just running a model, but rather a workflow and an approach to problem solving.

Figure 2.3 (ESRI, 2013), outlines the steps followed when coming up with a successful spatial analysis.

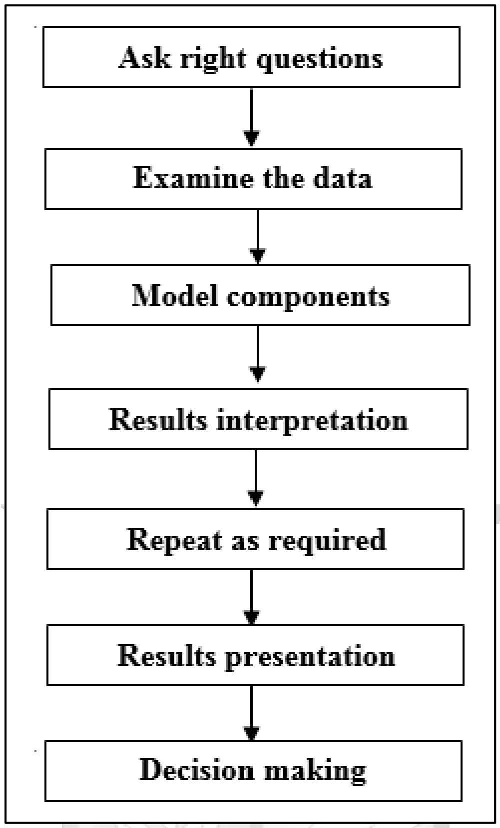


Figure 2.3: Spatial Analysis Key Steps

Step 1. Ask right questions: This involves formulating a probable hypotheses and the right spatial questions to ask.

Step 2. Examine the data: It entails exploring and critically examining the data quality, its completeness and limitations in terms of scale and resolution so as to determine the level of analysis and interpretation it can support.

Step 3. Model components: It will deal with dissecting the problem down into solvable components that can be easily be modelled. It will thereafter quantify and then evaluate the identified spatial questions.

Step 4. Results interpretation: it involves performing an evaluation and analysis of the results in respect to the question posed, data limitations, data accuracy and other relevant implications.

Step 5. Repeat as required: Since spatial analysis is meant to be a continuous and iterative process that often leads to further questions, it can positively lead to refinements of the results. In this regard there is a need to repeat this process to refine the results albeit not mandatory.

Step 6. Results presentation: So as to easily share the results of the spatial analysis done, it is valuable when this information is presented and shared with a larger audience in a manner that is easy for them to understand and comprehend quickly, even if they are not GIS users.

Step 7. Decision making: The ultimate goal for spatial analysis is to support the decision-making process while attempting to solve the existing problem which in this case is landslides and the decision makers are the emergency/ disaster response agencies.

2.5.4. How to Perform Spatial Analysis in GIS

Most data and measurements can be associated with locations and, therefore, can be placed on the map. Using spatial data, you know both what is present and where it is. The real world can be represented as discrete data, stored by its exact geographic location (called "feature data"), or continuous data represented by regular grids (called "raster data"). Of course, the nature of what you're analysing influences how it is best represented. The natural environment (elevation, temperature, precipitation) is often represented using raster grids, whereas the built environment (roads, buildings) and administrative data (countries, census areas) tends to be represented as vector data. Further information that describes what is at each location can be attached; this information is often referred to as "attributes" (Team E. P., 2018).

In GIS each dataset is managed as a layer and can be graphically combined using analytical operators (called overlay analysis). By combining layers using operators and displays, GIS enables you to work with these layers to explore critically important questions and find answers to those questions. Figure 2.4 (ESRI, 2015) shows how GIS datasets are managed as a single layer

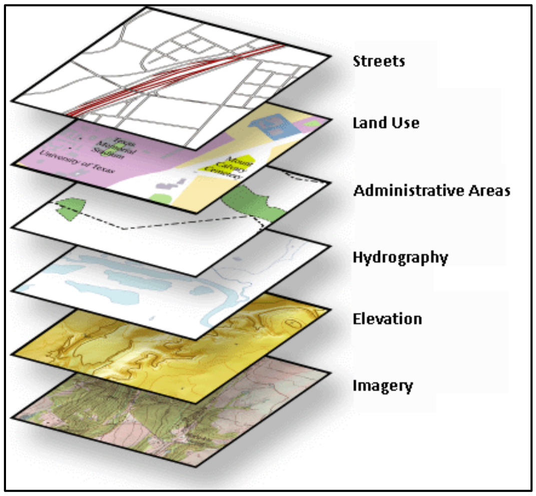


Figure 2.4: GIS dataset managed as a single layer

The idea of stacking layers containing different kinds of data and comparing them with each other on the basis of where things are located is the foundational concept of spatial analysis. The layers interlock in the sense that they are all geo-referenced to true geographic space (Team E. P., 2018).

2.7 Applied System Architecture Components

Using the ArcGIS platform, the following system architecture component are considered ideal when coming up with a tool that can be used to assist in landslide emergency management and disaster response

2.7.1. Infrastructure Component

It includes the hardware (Server Computer, Mobile Data Collection Gadgets), software (Desktop, Server, Server based Operating System and Database Platform), Web Map Services (to handle both vector and raster datasets), and data repositories (spatial and non-spatial) that are the core of the ArcGIS Solution platform. This will handle data management, analysis, visualization, and Data Storage.

2.7.2. Data Access Portal Component

This will use registered person's identity to deliver the right content to the right person at the right time. From a product perspective, the portal runs on ArcGIS Online. It provides access controls, content management capabilities and a sharing model that enables users to share information products across the organization. The products are shared under an open data site that includes web maps, web layers, tools, files, application. Data is grouped and tagged to easily assist in accessing it. (ESRI, 2013)

2.7.3. Internal and External Data Interface Component

It includes other systems that either provide services to the system or consume the hosted Web Map Services to geospatially enable their capabilities. The ability to easily geo-enable other enterprise business systems is a key capability of the solution.

2.7.4. Web and Mobile Apps Component

It illustrates the components of the platform that most users interact with, including end user applications such as Collector for ArcGIS, Story Maps, and Operations Dashboard for ArcGIS. Maps Centric Apps will be created to have widgets that show case things like Time series, Swipe Capability, Summarized data, Heat Maps, Spatially Analysed Maps, Querying Tools, Export data, Location Analysis, Compare Maps etc. Figure 2.5 (ESRI, 2013) shows a detailed solution architecture.

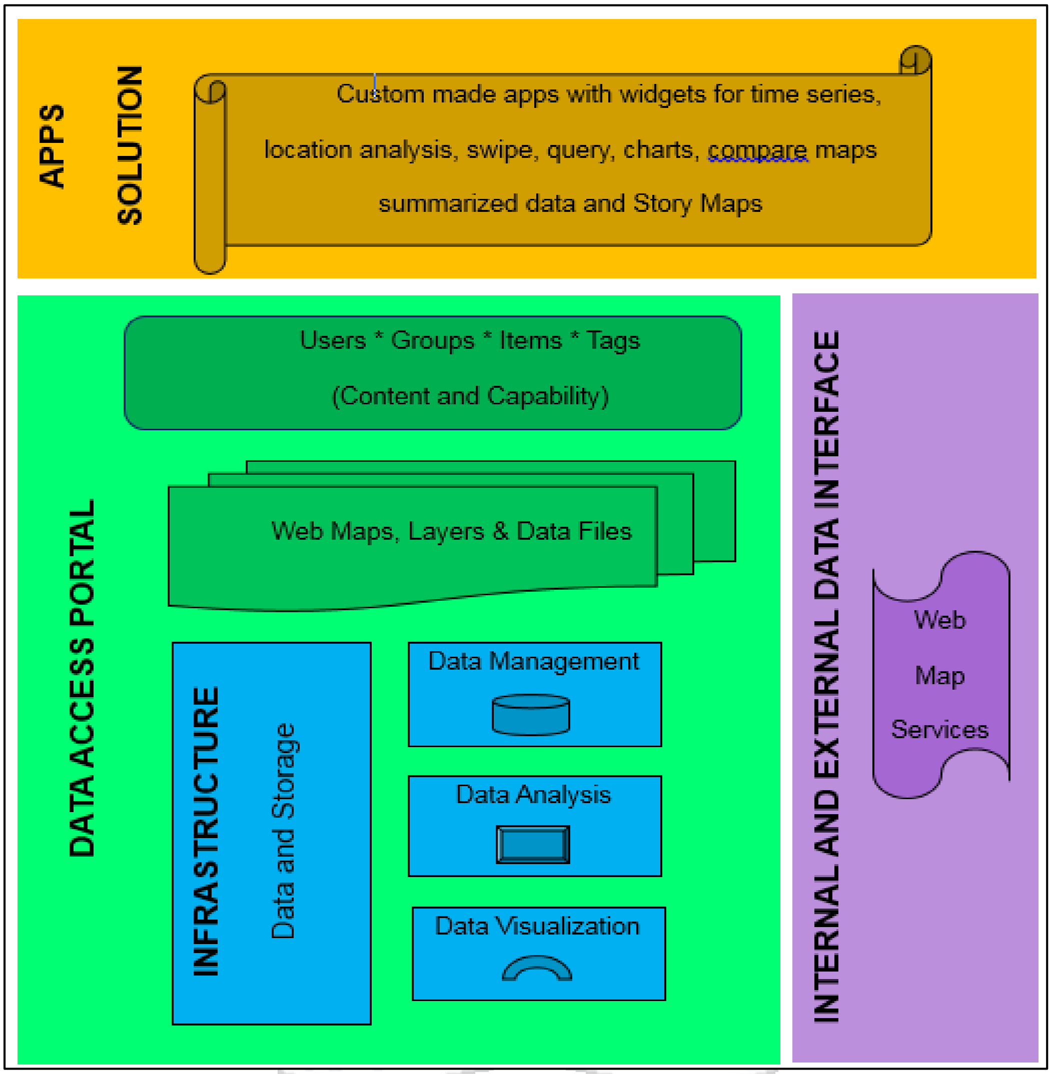


Figure 2.5: Detailed Solution Architecture

2.7.5. Conceptual Framework

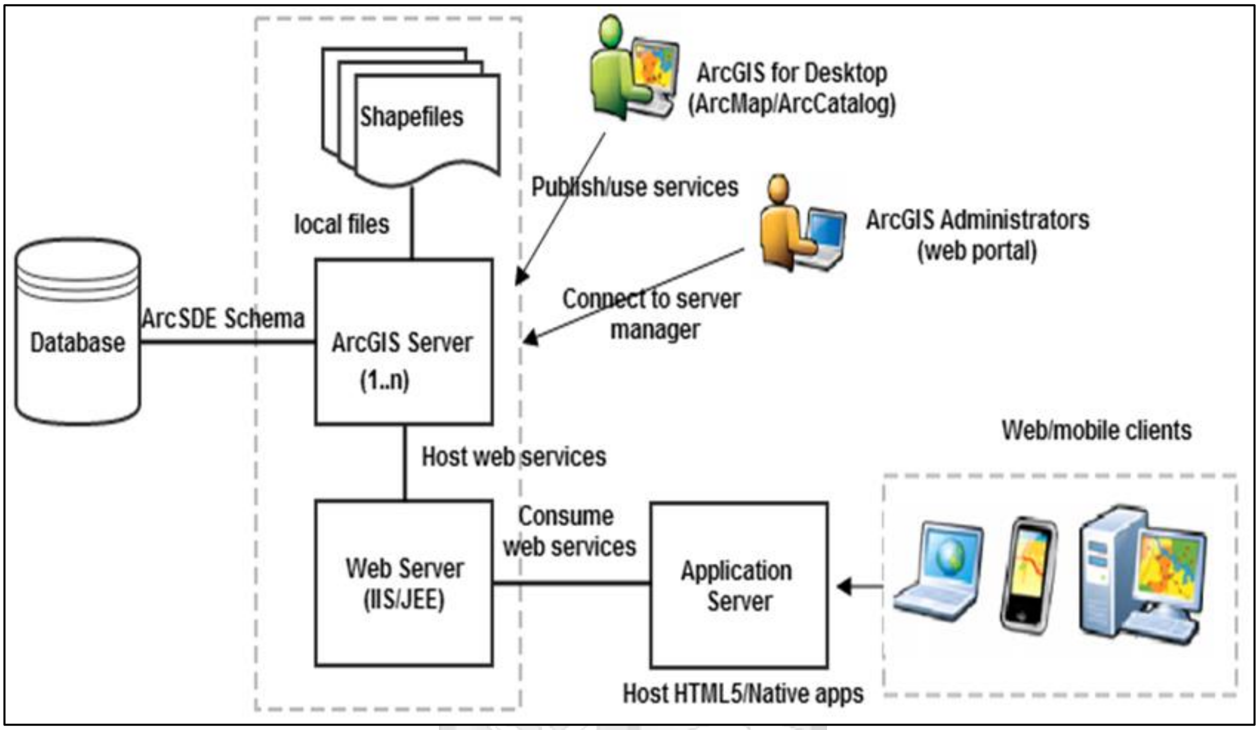


Figure 2.6: Conceptual Framework

The database contains both the spatial and non-spatial data that is accessed applications through web map services. The database schema will be handled by ArcGIS Spatial Database Engine that will ensure that spatial data is well consumed by ArcGIS Server. The acceptable data format for the vector datasets (points, lines or area data) will be shape files, which will be published by ArcGIS Desktop users to appear as web map services on ArcGIS Server. The published web map service will be made available to third party applications inform of either REST or SOAP services. ArcGIS administrator will responsible for managing the entire web portal and users. The front end applications, consuming the web map services, will be made consumed either on the web or using a mobile device.

Chapter 3 : Research Methodology

3.1. Introduction

This chapter looks at the research strategy that was used in terms of what steps and techniques were undertaken to achieve the intended objective. In this regard, the chapter defines the scope of the research design, highlights the location of the study, it describes the target population and sample that was used, examines the six phases of application development that was used, the research quality and lastly the ethical recommendations.

3.2. Research Design

The research design refers to the overall strategy that was used to integrate the different components of the study in a coherent and logical way, thereby, ensuring an effective way of addressing the research problem. It constitutes the blueprint for the collection, measurement and analysis of data (Johnson, 2000). This research is an applied research mainly because it provided information that can be used and applied in an effort to help other people understand and control their environment as far as landslides are concerned i.e. in terms of emergency management and disaster response.

3.3. Location of the Study

Murang'a County is one of the five counties in Central Region of the Republic of Kenya. It is bordered to the North by Nyeri, to the South by Kiambu, to the West by Nyandarua and to the East by Kirinyaga, Embu and Machakos counties. The county has a population of 942,581 (2009 census) and it occupies a total area of 2,558.8 km^2 (Master, n.d.). The county lies between 914m above sea level (ASL) in the East and 3,353m above sea level (ASL) along the slopes of the Aberdare Mountains in the West.

3.4. Target Population and Sampling Technique

The target population for this study was Murang'a County and clustered sampling was used because it is more efficient especially where a study takes place over a wide geographical region like it is the case in Murang'a County. A total of 14 sample clusters were used, two from each of the seven constituencies that have recorded landslides in the past five years. The members of each cluster were randomly selected based on the ones who were willing to answer the researcher's questions. The constituency's clusters and their respective wards related are shown in Table 3.1.

Table 3.1: Constituencies sampled in this research

No	Constituencies	Exact Wards	No of Sample Clusters	No of People in each cluster
1	Kangema	Kanyenya-Ini	2	7
2	Mathioya	Gitugi,	2	6
3	Kiharu	Gaturi	2	7
4	Kigumo	Marumi	2	5
5	Maragwa	Nginda	2	6
6	Kandara	Ithiru	2	5
7	Gatanga	Gatura	2	6

3.5 Data Collection Instruments

Three methods were used for data collection i.e. interviews, questionnaire and online sources.

3.5.1. Interviews

Interviews were used for two reasons; to gather more insight about the landslide occurrence and acquire important data that was useful in measuring and mapping the impact of landside to the village settlement areas and infrastructure affected. The interviews were done on the three key institutions that were very informative i.e. Kenya Meteorological Department (KMD), The Kenya Red Cross and National Disaster Management Authority (NDMA) Murang'a County Office. Various type of datasets were collected to ensure they provide a solid data platform for this research work, the most important dataset being the land slide occurrence data. In regard to the landslide data, acquired from Kenya Meteorological Department, it showed landslides that occurred in 2017, 2018 and 2019. Interestingly, all the landslides occurred during the long rain period that usually occurs in the months of March and April.

We noted that this period was the most severe in terms of the adverse effect the landslide had in the Murang'a County because of the high amount of rainfall. To ensure the data collected provided the right results, it was thoroughly cleaned and harmonized. The missing values especially wrong names for the sub county, locations and village as well coordinates were corrected. The geospatial dataset that would complement this work in terms of analysing what is affected by the landslide included the following datasets; Schools, Health Facilities, Towns, Roads, Rivers, Settlement Areas, Rainfall Data and a satellite imagery of Murang'a County.

3.5.2. Questionnaire Survey

The questionnaire survey was carried out to collect information about the factors that hinder proper response of landslide disaster and gather information about what the requirements should the interactive operation dashboard tool incorporate to ensure the challenges are addressed in an appropriate way. Questionnaires were adopted because data can be analysed more scientifically and objectively in quick and efficient manner. The information gathered through the questionnaire was based on the respondents' experiences regarding landslide disasters.

The questionnaire had a mix of Closed-Ended Questions whereby respondents were given a list of predetermined responses from which to choose their answer e.g. they required yes or no answer and Open-Ended Questions whereby respondents were asked to answer each question using their own words. The questions were sent online using survey monkey tool that was also used to perform the analysis.

3.5.3. Online Sources

This data source was meant to supplement the primary data collected and it included mainly collating GIS data from existing online sources. The infrastructure data covered the whole country and the research had to use ArcGIS software to clip the data for Murang'a County and clean the datasets that were not interoperable.

3.6. Problem Analysis

After the questionnaire data was collected, an automated analysis was done using survey monkey and ArcGIS software to correctly analyse the data. In validation of the research objectives, user and system requirements analysed was represented in form of graphs, chart and tables. The feedback got from the respondents allowed the researcher to properly structure the functionalities of the interactive operation dashboard tool and ensure the challenges of landslide disaster management and emergency response were addressed appropriately. This information really informed what components should be included in the design of the tool.

3.7 Software Development Methodology

This research adopted Rapid Application Development (RAD), a form of agile software development methodology that prioritizes rapid prototype releases and iterations. It focuses on gathering user requirements through focus groups, early testing of the prototypes by the user using iterative concept, reuse of the existing prototypes, continuous integration and rapid delivery. (Phil, 2018)

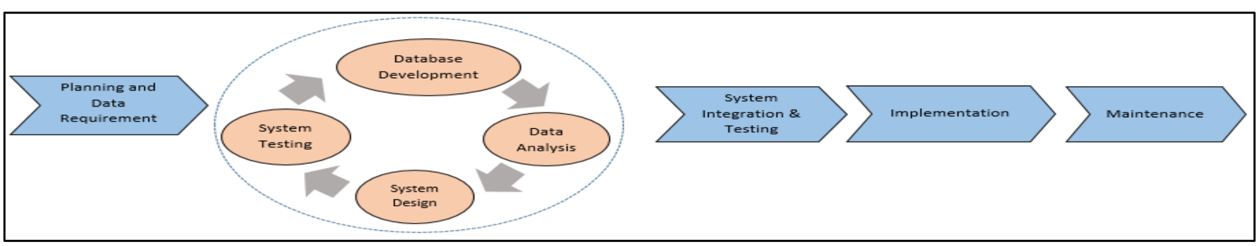


Figure 3.1: Rapid Application Development Methodology

3.7.1. Phase 1: Planning and Data Gathering

The purpose of this exercise was to determine the different type of datasets that would be linked to landslide occurrences geographically so that it was easy to map and identify the landslide impact. After collecting the datasets, the following operations were done; data collation, analysis of each data spatially, harmonized the data, cleaned the data to remove unreferenced & wrongly projected data as well as integrated all the datasets spatially so that they can be used visualized in the tool without any errors. The final datasets that were analysed and mapped geographically are shown in Table 3.2. The data layers were grouped thematically so that it's easy to manage them before being published.

Table 3.2 Data Layers analysed and integrated spatially

Thematic Area	Dataset
A. Landslide Disaster	▪ Landslide Occurrences Location
B. Infrastructure Dataset	▪ Health facilities (i.e. hospitals, dispensaries, and clinics)
	▪ Primary schools
	▪ Secondary schools
	▪ Main roads
	▪ Power Plants
	▪ Dams
C. Water Bodies	▪ Rivers
	▪ Wetlands
	▪ River Basins
D. Administrative Units	▪ County Boundary and sub county boundaries
	▪ Towns
	▪ Village settlement areas

3.7.2. Phase 2: Database Development

The reason for developing a database was to eliminate data redundancy, inconsistency, incorporate data files, share and publish data. The collected spatial data was integrated with the attribute data. To store both the spatial data and non-spatial data, the study used an Enterprise database platform called Microsoft SQL Server. The spatial database, developed using this platform, was linked to ArcMap (a Map authoring tool) to define and apply some Geodatabase capabilities that defined the data models useful for data storage, maintenance of data integrity, enabling multiuser editing capabilities and it's quite scalable. To ensure that critical data management workflows of data access was achieved appropriately, the study implemented special features such as versioning, replication, and historical archiving. Some of the activities that done on the database were to process collected and generated data and converting data files into database format. Cleaned and harmonized data that was not database friendly, uploaded data into the database, developed stored procedures and triggers. Created various queries for filtering data, sorting and searching for data. Lastly, designed data views for various purposes such as reporting, analysis, querying, exporting data etc.

3.7.3. Phase 3: System Analysis

This study used ArcMap software that is part of the ArcGIS 10.5 package to do the spatial analysis. Using the various geo-processing tools found in ArcMap, the following types of analysis were performed on the geographic data and incorporated into the application.

Table 3.3: Data Analysis and their Objectives

Type Spatial Analysis	Objective/ Purpose of doing it
Location analysis	To identify and map where landslides have occurred and mapping the infrastructure nearby
Incident Analysis	To locate a landslide incident on the map and analyse nearby infrastructures as available in different layers
Buffer Analysis	To create a buffer area around where a landslide has occurred to determine its extent coverage from the epicentre.
Swipe Analysis	To easily compare the content of different layers such as the situation before and after the landslide has occurred

Statistical Analysis	To generate statistics of the affected house-holds dynamically

3.7.4. Phase 4: System Design

This entailed designing the Interactive Operation Dashboard Tool that was used to visualize data elements in an online web accessible interactive map. The design of the system included elements such as Data visualization, interactive querying, web editing, data extraction, geocoding, printing, filtering the data as required, customizing the pop up and feature attribute. Using the map viewer to compose and visualizing the data collected, activated the configurable web app templates to create great-looking and useful web maps for end users. Designed data visualizing widgets inform of charts and indicators, to effectively show case specific elements of this study e.g. where landslides have occurred, are likely to occur, the hot spots, the effect, evacuation paths etc.

3.7.5. Phase 5: Integration and Testing of all components

All the components of this tool were integrated and tested thoroughly. The types of testing were carried out i.e. unit/ module testing performed as the code is being written, on each module and integration testing. For instance the interactive dashboard, web maps, data layers, graphs, indicators were all tested separately and they after integration they were tested again to ensure they are working as expected.

3.7.6. Phase 6: Implementation

The whole solution was deployed and hosted on ArcGIS Online, all the web maps created were shared so that data can be accessible. ESRI Satellite images and open street maps were used as base maps. To make it faster for the data to load, all data layers were made accessible through web map services. Metadata was captured for all the available layers and maps to ensure data is described well for anyone who would like to utilize it. The operation dashboard was linked to the web map services and had several elements such as landslide events maps, base map, charts and indicators. Figure 3.4 shows the tools and programming languages that will be used in the implementation.

Table 3.4: Tools and Programming languages to be used in the implementation

Tool	**Function and Purpose of using it**
HTML, CSS, JavaScript & Mappetizer,	Used to make spatial data available on a browser and accessible online
Python and Dojo	For running models and algorithms
ArcGIS	For Mapping and editing task s as well as map based spatial analysis
Story Maps	To combine geospatial data with photos, video, audio, and text to visualize a theme or sequential events
Operations Dashboard	To give real-time data visualization and analytics of people, services, assets, and events
Survey 123/ collector for ArcGIS	Tool for conduction surveys via questionnaire and collecting data from the fields
ArcGIS Online	Cloud-based GIS mapping software that connects people, locations and data using interactive maps. It also assist in hosting datasets and application such as story maps
REST Service API	Data sets will be available as a REST service that acts as an Application Programming Interface (API) and programmer can connect to it as Web Feature Service (WFS) or Web Map Service (WMS). ArcGIS Server will be used to create the REST services.

3.8. Research Quality

Research quality most commonly refers to the scientific process encompassing all aspects of study design; in particular, it pertains to the judgment regarding the match between the methods and questions, selection of subjects, measurement of outcomes, and protection against systematic bias, non-systematic bias, and inferential error. (Baker, 2000).

The standards for assessing the quality of this research include the several elements that include: Posing a significant question that can be investigated empirically; contributes to the knowledge base, test questions that are linked to relevant theory, apply methods that best address the research questions of interest, provide the necessary information to reproduce or replicate the study, ensure the study design, methods and procedures are sufficiently transparent and ensure an independent, balanced, and objective approach to the research. Provide sufficient description of the sample, the intervention and any comparison groups; Use of appropriate and reliable conceptualization and measurement of variables, evaluate alternative explanations for any findings, assess the possible impact of systematic bias and adhere to quality standards for reporting (i.e., clear, cogent, complete).

3.9. Ethical Considerations

Ethical considerations in research are critical. Ethics are the norms or standards for conduct that distinguish between right and wrong. They help to determine the difference between acceptable and unacceptable behaviour (Kingsley, n.d.). Some of the ethical considerations that this study took into consideration was to have an **informed consent**, the participant who shared data and filled the questionnaire were very well informed about the purpose of the study. To seek **voluntary participation**, meant that people who participated in this study were free from coercion and could withdraw their participation at any time. **Data Integrity** was ensured so that data would not be distorted in a bias manner likely to influence the results. To **have confidentiality** such that any identifying information would not be made available to, or accessed by anyone without prior consent from the people who participated in this study. **Harmless intention**, which ensured that this study would not bring any harm whether intended or otherwise to the participants.

Chapter 4 : System Analysis and Design

4.1. Introduction

This chapter looks at the findings of the data that was collected in the field and consequently analysed. It further examines the various Unified Modelling Language (UML) diagrams that guided the design of the system in terms of establishing the system boundaries which defined scope, the coverage of the system and the system architecture. All the system stakeholders and their roles are mentioned and lastly the functional & non-functional requirements are provided. By undertaking this exercise it was possible to understand the functional boundaries of the system, the internal components of the system, the people/users involved in the system, identified the data inputs, how data flow systematically, data process or transformation, storage of data and ultimately how data output for the entire system was achieved and presented.

4.2. Data Analysis derived from results of the questionnaire

An online based questionnaire survey was administered to 84 people. 76 were filled correctly as required, 2 were incomplete and 6 were not returned. Below are the key responses from the questionnaire that helped shape the design the application. Figure 4.1 shows the datasets that were required to be available so that it's easy to determine the affected infrastructure

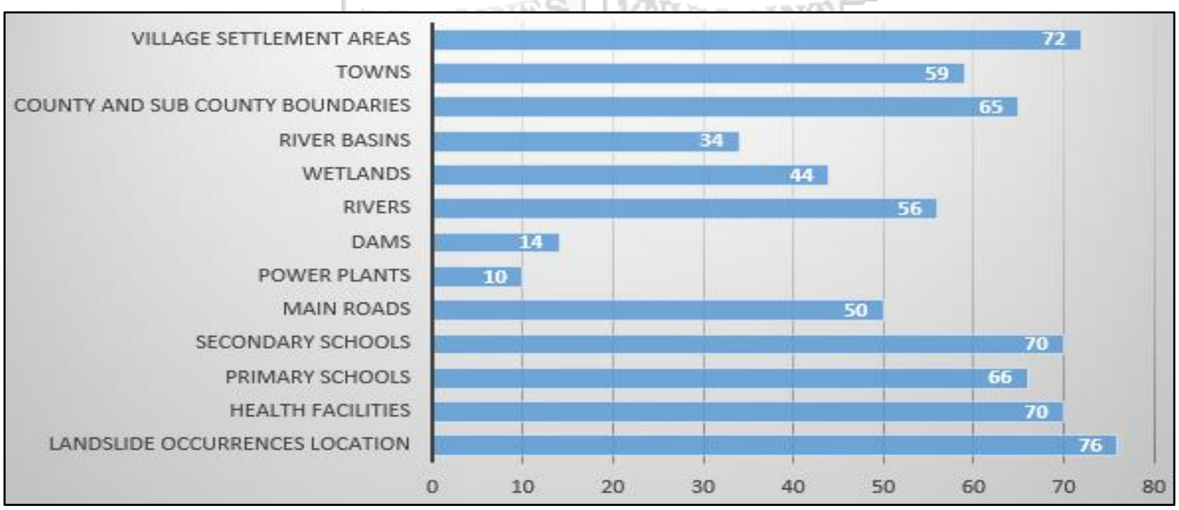


Figure 4.1 Data required in the application

Figure 4.2 shows the base maps that should be availed in the system. The base maps are satellite images that show the terrain of the study area. The respondents mostly preferred Open Street map because it is very light to load, free to use, easy to update, has a good coverage of Murang'a County compared to the others base maps and it is dedicated to humanitarian related action as well as community development through open source mapping.

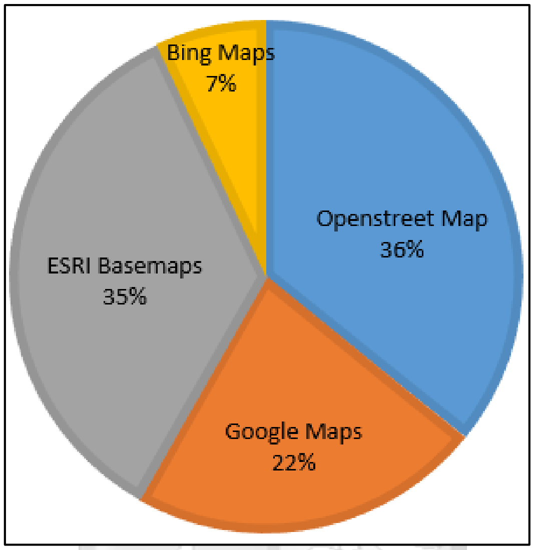


Figure 4.2 Base maps suggested for inclusion

The key users who are often the first to respond to landslide and should be given access to the tool are shown in figure 4.3.

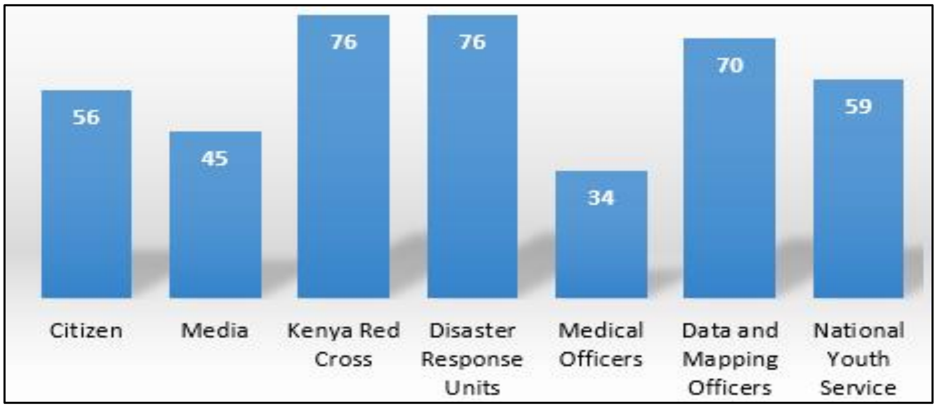


Figure 4.3 Key stakeholders of the system

To ensure no component is left out in the operation dashboard tool, the respondents indicated that the tool should show have a numerical snapshot of information as indicated in figure 4.4. This section of the tool is for the decision makers.

Component	Respondents
Houses Destroyed	68
Housed Needed	74
Map of Landslides	72
Human Death	76
Animal Death	66
Tea Farms Destroyed	53
House owner details	76
Year of occurance	47
Sub County Affected	71

Figure 4.4 Key components for Decision Makers

Figure 4.5 shows the detailed capabilities the tool should have. This section of the tool is for the data managers who interact with the data at a deeper level and use the distilled information to draw conclusions of the impact of the landslide occurrences and consequently advise what action should be undertaken.

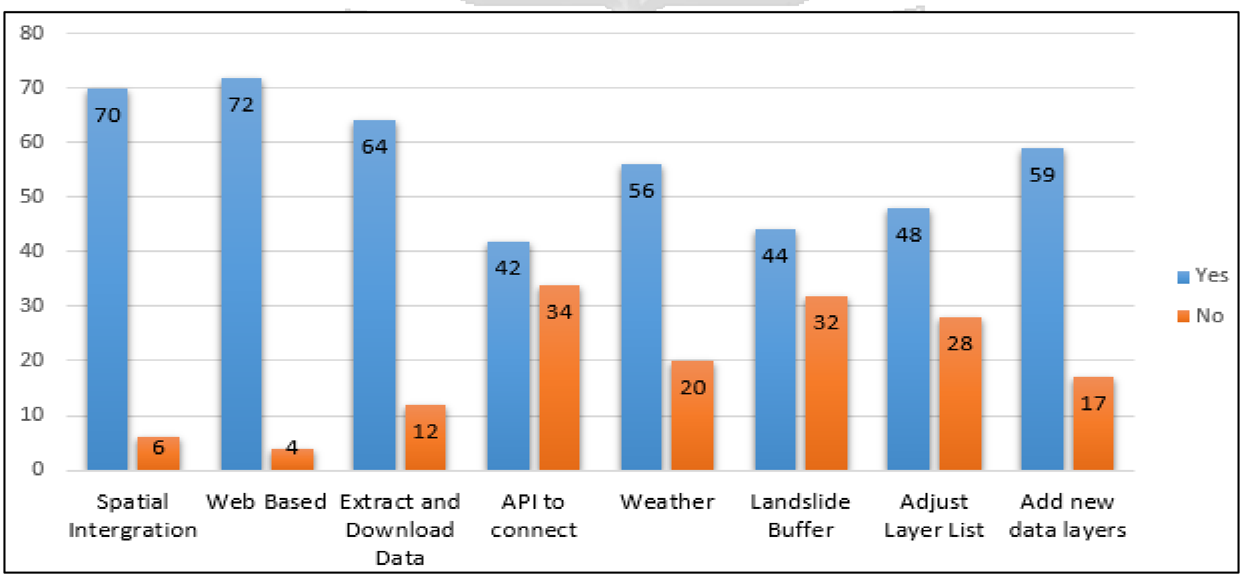


Figure 4.5 Detailed capabilities for data managers

Figure 4.6 shows the elements that should be included in the interactive info-graphics. This section of the tool targets the decision makers who just want to get a snapshot of what is the situation at the county inform of an interactive info-graphics.

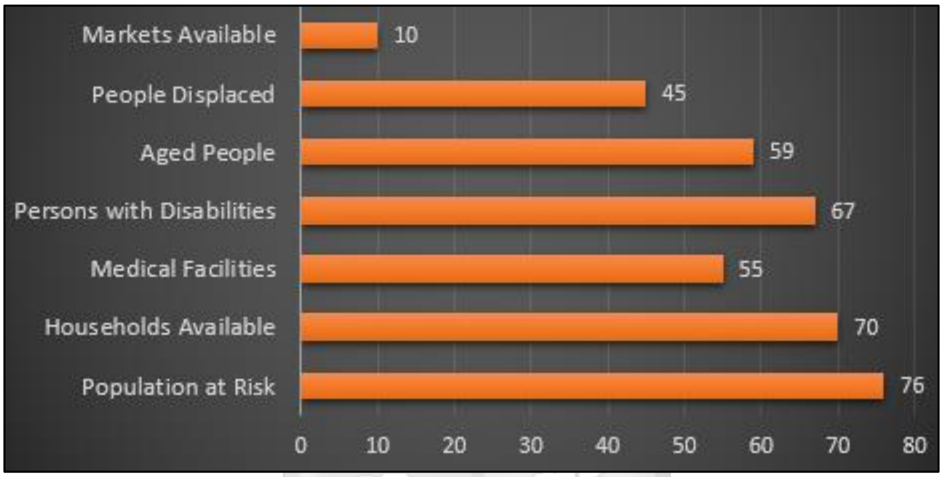


Figure 4.6 Info-graphics data elements

4.3. System Design

To effectively understand how the various components of the system work, this section looks at Unified Modelling Language (UML). The UMLs used have been grouped into two categories i.e. **structural** and **behavioural** diagrams. The **structural diagrams** represent the static aspect of the system which form the main structure and are therefore stable. The second category is **behavioural diagrams**, which basically capture the dynamic aspect of a system and show what should happen in the system. They describe how the objects interact with each other to create a functioning system.

4.3.1. Use Case Diagram

They were used to describe the various users and how they interact with the system. The primary actors identified were citizens, Kenya Red Cross, National Disaster Management Unit & County

Disaster Unit, Medical Officers, Security Officers, Field Data Officers and the National Youth Service. The Secondary actors identified were data & mapping officers and satellite imagery officers.

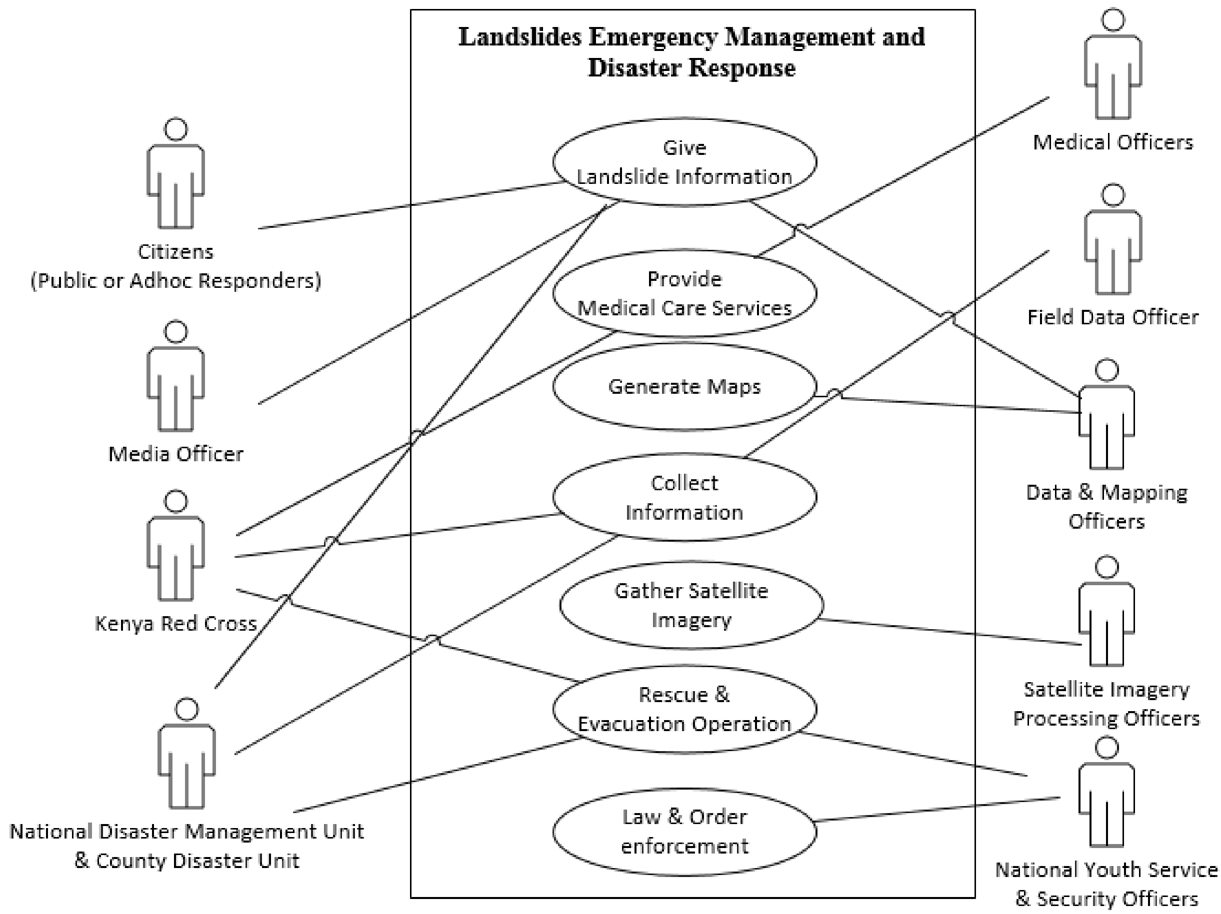


Figure 4.7 Use Case Diagram

Four examples of a use case description are shared below:

Table 4.1: Use Case Description – Give landslide information

Use Case Section	**Description**
Name	Give Landslide information
Actors	Citizens, Data Mapping Officers. Media, and National Disaster Management

	Unit & County Disaster Unit
Flow of Events	▪ Use case starts when a landslide has occurred ▪ Data is collected by field data officers ▪ Satellite imagery of the location of the landslide is available ▪ Landslide has occurred ▪ Information is being collected and validated
Pre-condition	Data is available for mapping to be done
Post-condition	Output Data can be downloaded and shared if necessary

Table 4.2 Use Case Description –Show affected infrastructure

Use Case Section	**Description**
Name	Show affected infrastructure
Primary Actors	Data Mapping Officers and National Disaster Management Unit & County Disaster Unit
Flow of Events	▪ Use case starts when a landslide spot has been selected ▪ Buffer distance radius is specified ▪ Infrastructure affected is detected within the buffer distance ▪ Output is viewed on a map
Pre-condition	▪ User must select a desired landslide spot ▪ Buffer radius distance must be specified ▪ Spatial Data is available for mapping to be done
Post-condition	Output Data can be downloaded and shared if necessary

Table 4.3 Use Case Description –Generate Maps

Use Case Section	**Description**
Name	Generate Maps

Primary Actors	Data Mapping Officers, Citizens and National Disaster Management Unit & County Disaster Unit
Flow of Events	▪ Use case starts when a landslide has occurred ▪ Mapping the housed affected by landslides ▪ Integrate the infrastructure ▪ Map is generated
Pre-condition	▪ User must select a desired landslide region/ area ▪ Map components added ▪ Spatial Data is available for mapping to be done
Post-condition	Output Data can be downloaded and shared if necessary

Table 4.4 Use Case Description –Update data info-graphic

Use Case Section	**Description**
Name	Update data info-graphics
Primary Actors	Data Mapping Officers
Flow of Events	▪ Users receive location details of where landslides has occurred ▪ The info-graphics elements are updated ▪ Demographic information is added ▪ Info-graphics is generated
Pre-condition	▪ User must select a desired landslide region/ area ▪ Demographic information to be availed
Post-condition	Info-graphics can be downloaded online if necessary

4.3.2. Activity Diagram

An activity diagram was used to visually present a series of actions of three key stakeholders i.e. flow of information from the Government or the media, to the Data Centre and eventually to the disaster response team who would ultimately be more informed as they make critical decisions.

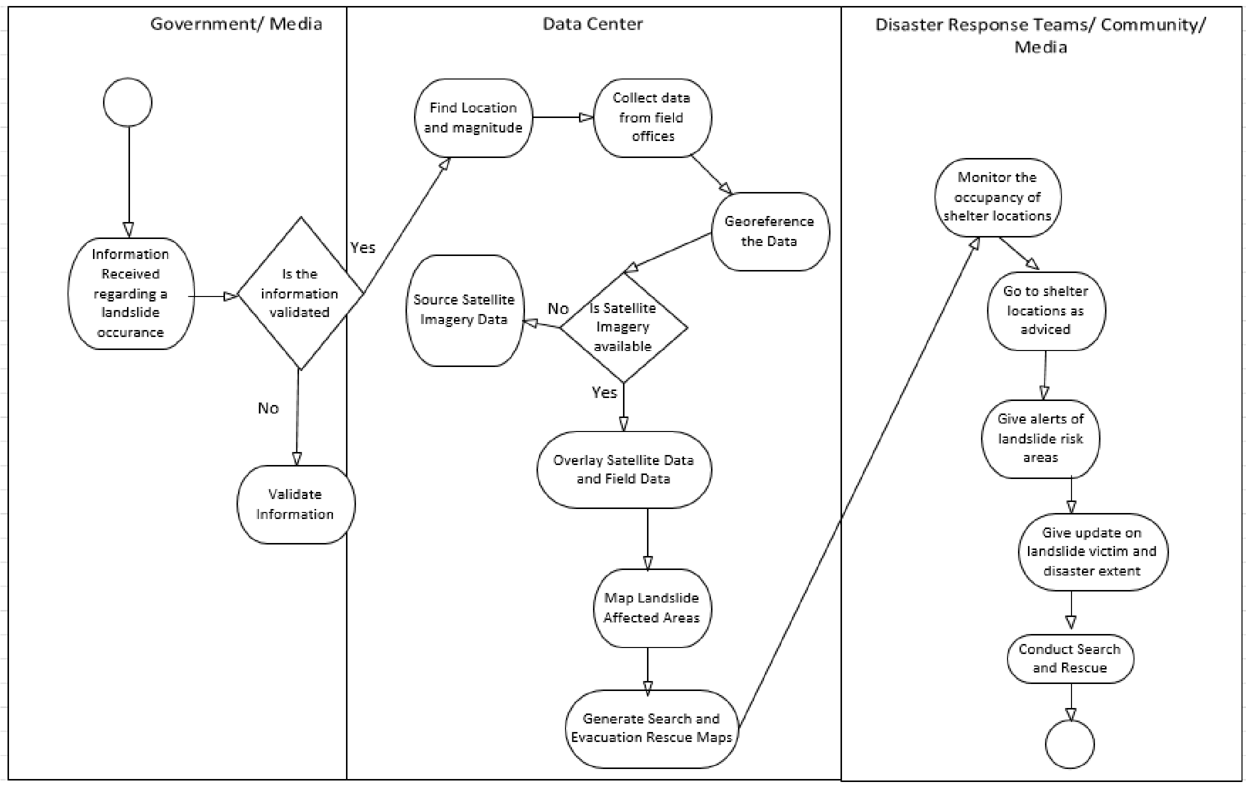


Figure 4.8 Activity Diagram

4.3.3. State Chart Diagram

State chart diagrams were used to provide an efficient way to model the behaviour or interactions that occurred in the system. Figure 4.9 shows a start chart diagram that highlights the process involved in the registration of a landslide victim.

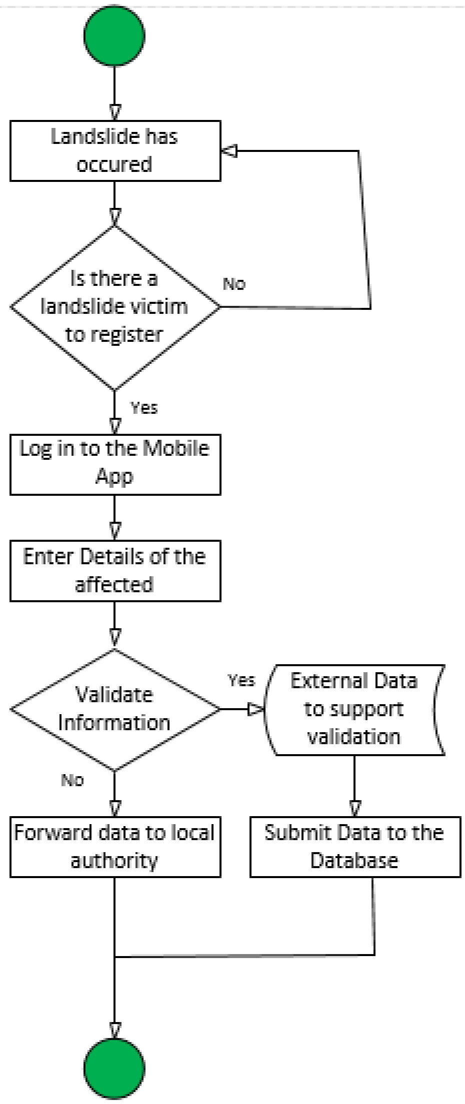


Figure 4.9 State Chart Diagram

4.3.4. Sequence Diagram

The sequence diagram was used primarily to show the interactions between objects in the sequential order that those interactions occur.

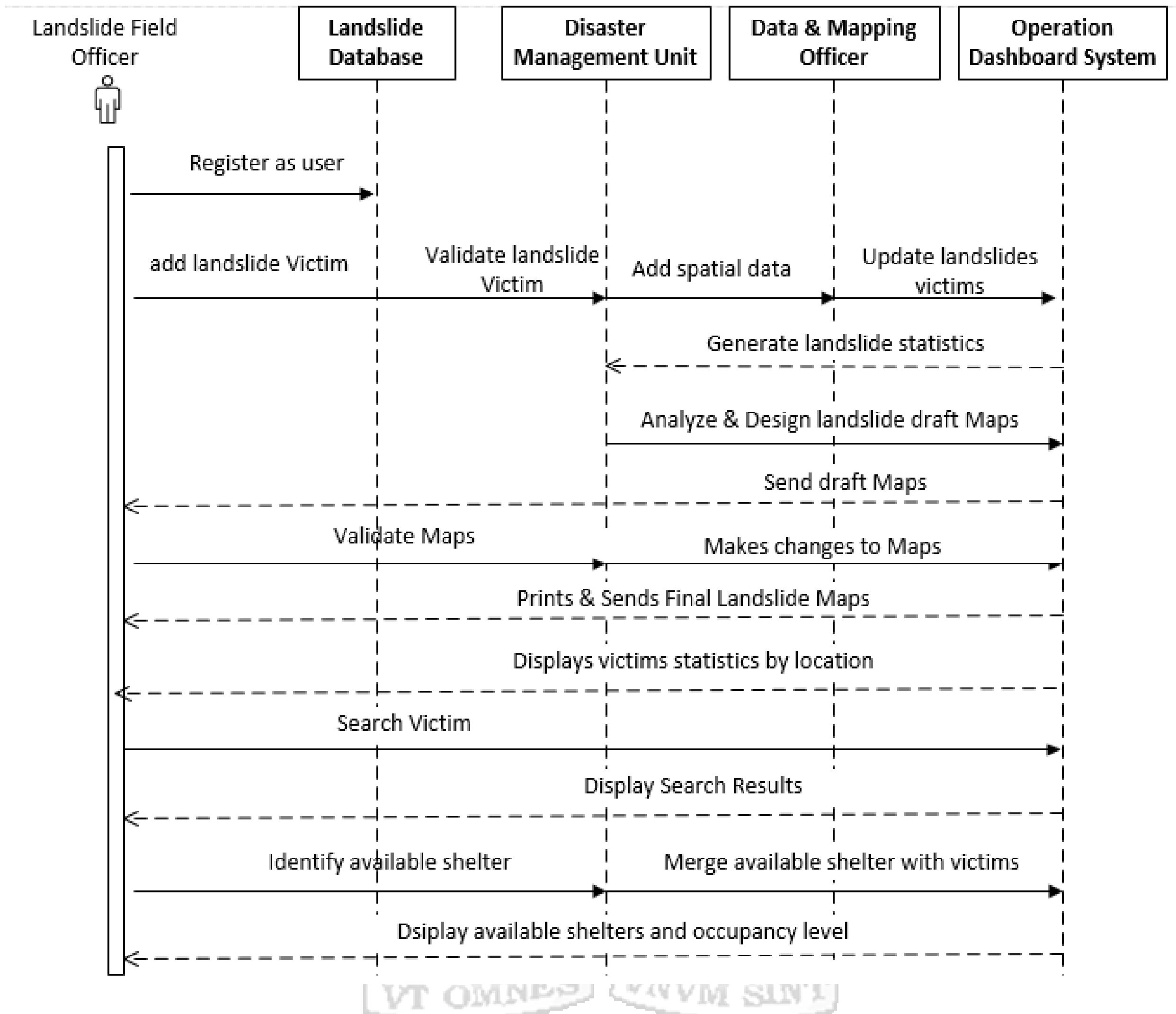


Figure 4.10 Sequence Diagram

4.3.5. Class Diagram

It is used to show the different objects in a system, their attributes, their operations and the relationships among them.

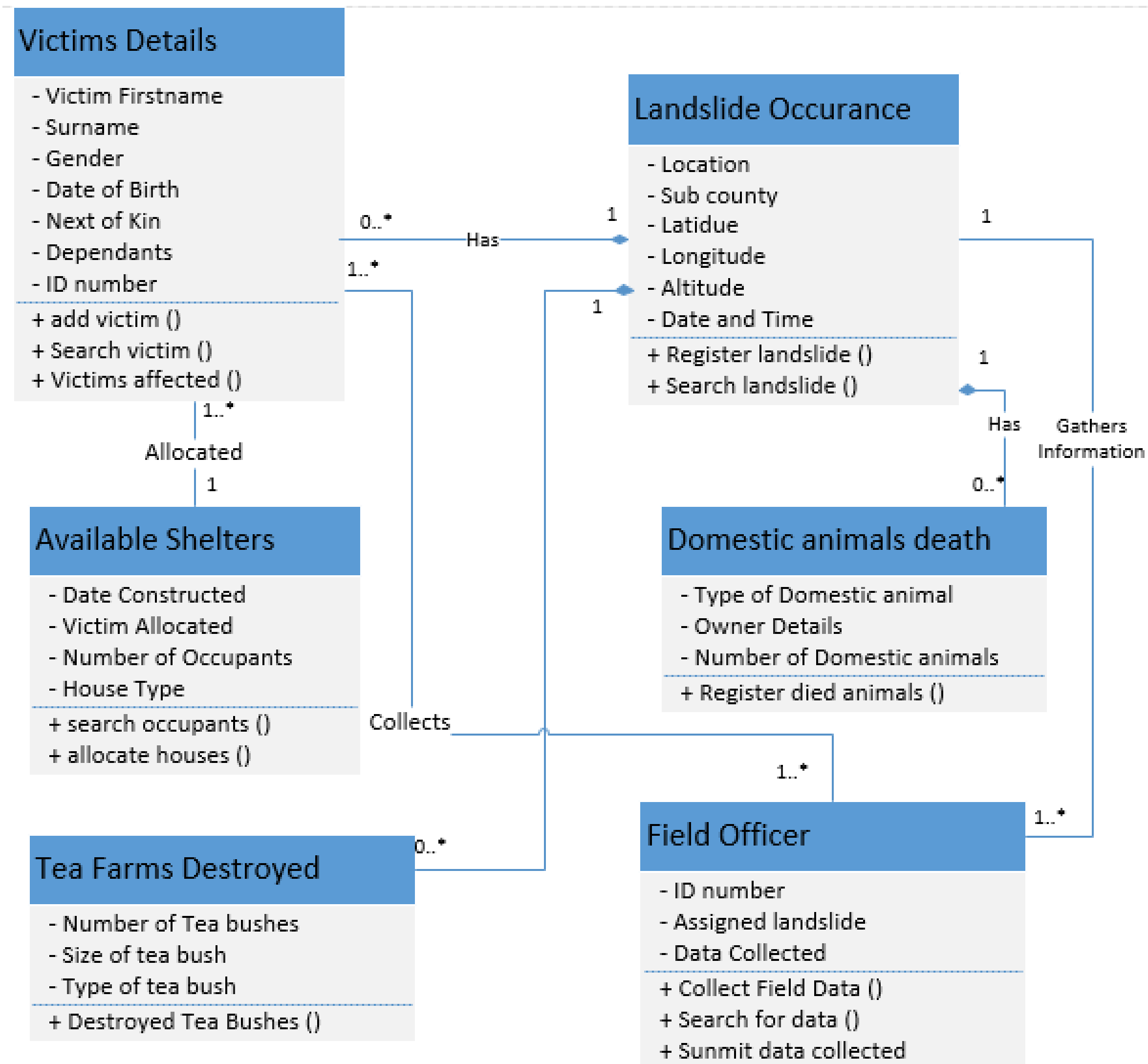


Figure 4.11: Class Diagram

4.4. System Architecture

The system architecture was made of three tiers i.e.:

Presentation Tier – It is the front end layer that consists of a graphical user interface (GUI). It will be accessible through a web browser because the application system is web based that will display content and information that is quite useful to an end user.

Business Logic Tier - This layer coordinates the application, processes, executes commands such as geo-processing, makes logical decision, evaluations and performs calculation. It also moves end processes data between the two surrounding tiers.

Database Tier - It comprises of the database/data storage system, field data and data from other sources such as satellite imagery access. Data is in the database tier is accessed by the application tier via Web Map Services or API calls.

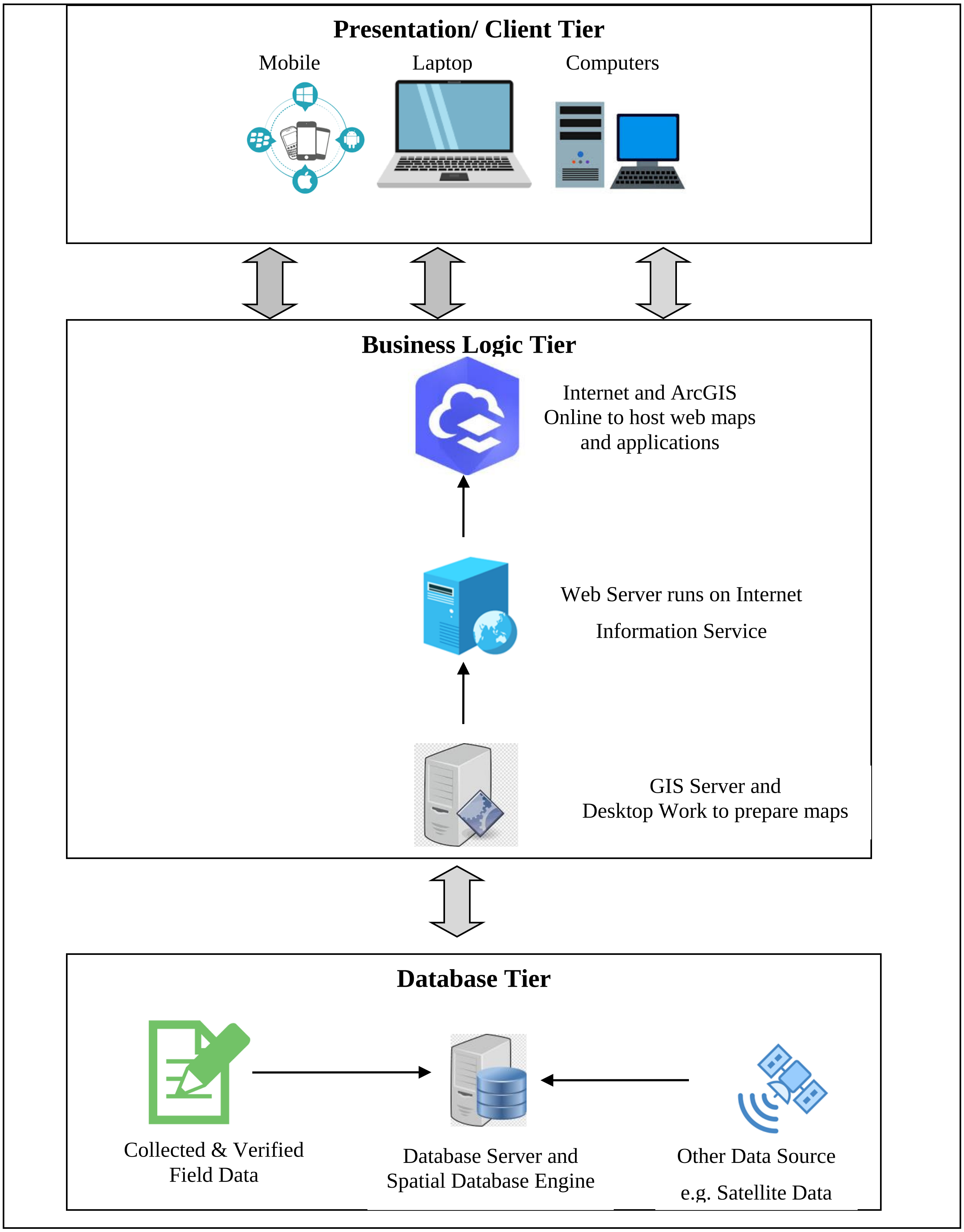


Figure 4.12 System Architecture

4.5. System Stakeholders

For any system to justify why it needs to be developed, it is very important to identify the stakeholders. To achieve this adequately, a stakeholder mapping exercise was developed so that it can assist in categorization of various users or stakeholders in the product delivery chain. The landslide tool being the product in question. The following are the various categories of users and examples of institutions that represent them.

Table 4.5: Stakeholder Categories

Category	Description	Example
Stakeholder Type:	Indicates the type of stakeholder based on its registration	Government, Faith Based, Community Based or NGO
Data Collectors	Responsible for collecting primary or secondary data, these institutions provide data in an information system, e.g., owners of satellites, meteorological agencies, census bureaus, etc.	Red Cross, County Government, National Government, Hospital, Security Officers & Disaster Management Units
Data processors & analysers	Involved in analysis of data for the preparation of products and tools.	Red Cross, Disaster Management Units, County Government & National Government
Intermediary	Responsible for the communication or dissemination of information between the data analysers, decision-makers, enablers and beneficiaries.	County Government, National Government, Red cross
Enablers	Stakeholders not directly involved in the information system, but who influence the policy environment.	Media, Public Citizens, Security Officers & Disaster Management Units
Decision	Those with authority to make decisions based	County Government,

Category	Description	Example
Makers	on data, products and tools produced by the information system.	National Government, & Red cross
Beneficiaries	Those who benefit from decisions informed by the application system.	County Government & National Government, Media, Public Citizens, Security Officers
System administrators	The task of the system administrators is to make sure the information provided to the users is up to date and accurate, adding more information and information sources when necessary. Making these adjustments should be facilitated, but only after authorization to prevent abuse.	Disaster Management Unit System Administrators

4.6. Functional Requirements

The functional requirements describe what the system should do.

4.6.1. Generating Data Statistics & interactivity

The system should handle all the calculations that have been programmed to show useful statistics dynamically and geographically. Once the criteria of statistics changes, the tools should change the results in the map without restoring or reloading the browser. Interactivity should be on the fly not just for the derived statistics indicators, but also the map being visualized.

4.6.2. Data and Integration

The system should accept vector data and satellite imagery data to be overlaid as base maps. An API will be used to load the open street map and ESRI based imagery. All datasets to be rendered inform of a Web Feature Services and they should all be in the same Geographical coordinate system (the recommended one is WGS 1984) so that integration can occur without errors.

4.6.3. Security Requirements

The system should be secure so that the datasets are not altered, distorted or deleted by malicious people, user groups will be used to manage the permission for all users. Data sent from the filed should go straight to the database but will become visible in the application after the relevant officers have validated and approved its usage.

4.6.4. Performance

The fact that most of the GIS datasets (Vector and Satellite Imagery) that are utilized by GIS tools are usually very heavy in terms of size, this should in no way interfere with the performance or speed of how data loads and visualized. This is because the tool will utilize web feature services that will improve the performance of the layers when being used.

4.6.5. Data Conversion, Rest Service, & Export

The system should allow data conversion of the various coordinates automatically. This is important because all the datasets should eventually be displayed in the same geographical projection to avoid mismatch when data layers are being overlaid. A feature for data exporting should be available so that users who wish to extract/ download the data can be able to do so. For programmers who wish to utilize the data without downloading it, the tool should have rest service link that will act as Application Programming Interface (API).

4.7. Non Functional Requirements

The non-functional requirements describe how the system works or behaves. They include the following capabilities:

4.7.1. Data Correctness and Accuracy

This attribute is very important in the sense that, for data to be trusted and acted upon, it must be correct and accurate. The information should be valid. The attribute data for the spatial data should be very accurate, the base map should overlay with layers without mismatch. The data from the field officers should be verified and validated before it is uploaded into the system so that the information remains consistent.

4.7.2. Timeliness, Relevance and Cost of data

Time is very much of the essence when dealing with landslide emergencies and disasters. One minute may make the difference between saving a life or in worst case scenario losing life. Data should come in a very timely manner when expected and when it is very much needed. If data comes weeks after the disaster, it will not help much. **Relevance** has to do with ensuring that important information that can aid decision making is obtained. Irrelevant data tends to distract people and one may lose a lot of time analysing the wrong thing. **Cost** covers several elements such as data cost, storage cost, data processing cost etc. It is important to have a good idea of how this cost should be managed to ensure maximum utilization of the available resources as far as management of landslides is concerned.

4.7.3. Data Usability and Accessibility

Usability has to do with ensuring that one data cannot only be accessed but also be used in a way in which it will derive the much needed information for decision makers to quickly act on. The data formats play a critical role in ensuring if that data can be used at all. For example for GIS vector files, the preferred format of data is shape files. **Accessibility** deals with how someone can quickly access the data when they need it for use. For example the speed at which one is able to access data stored in a network drive and several read and write functions are being done will determine if the data will be used in an quick and effective manner.

4.7.4. Reliability of Data

The Geodatabase should at all-time be accessible and highly efficient when staff want to work on it. The data should be accurate without any fault tolerance and should be certified for use. Imported data should have proper metadata so that one can easily verify the source with an intention of utilising the data in a confident manner. The data should have backup so that in case the primary data is not accessible, then the backup can be used as an interim measure reliably.

4.7.5. Data Heterogeneity

To avoid a situation where one has to deal with datasets that or various formats, standards are not know and the data structure is poorly done, it is better to have data guidelines that echo how data should be named, saved, arranged, structured, formatted, projected, stored, shared, published, accessed etc. It will be very difficult to analyse data that is not consistent. The very use of shapefile that is widely accessible and web map service would ensure the data is standardized appropriately. This includes a key element known as data projection. It is highly recommended that all datasets should be in the same projection so that it is easy to analyse and work on them when they are overlaid on each other.

4.7.6. Data and Tools Complexity

This is often addressed through the use of data mapping platforms that are good and easy to use map visualization components. Without a proper tool that can be used effectively to make the required data accessible, the target end users are disappointed by the complex graphical user interfaces or even the many steps required to accomplish a task. One should ensure the tool being used does not make the key users struggle when conducting basic features like to search for data or interoperability on the various technology platforms being utilized. This is where the operation dashboard tool becomes useful as it will show the map and statistical indicators inform of charts.

Chapter 5 : Implementation and Testing

5.1. Introduction

This chapter describes how the system was implemented in terms of development and the testing done to ensure the objective of the system was achieved. It looks at how the Geo-database was developed, how data was prepared, cleaned and harmonised before uploading into the Geodatabase. It examines how data was published online as web feature services and thereafter how web maps were created. It further delves into how the interactive dashboard was designed with its informative widgets and lastly how testing was done to achieve the required results. The various programming languages that were used in the development of this solution are mentioned as well.

5.2. Designing the visualization Interfaces

To ensure various users interact with the system at their appropriate level, the tool is designed to have four main interfaces. All the four interfaces are accessible under one web address and the user can choose the one they want to use.

Table 5.1 Visualisation Interfaces Designed

Available Interface	**Purpose**
Landslide Indicators Dashboard	To display multiple visualizations that use graphs, gauges, maps, and other visual elements to reflect the status and performance of landslide on a single screen.
Population at risk Info-graphic	To present a new way to visualize key indicators and information in the form of beautiful info-graphics that are easy to read and understand
Landslides Detailed Data Analysis	To show detailed information about the landslides and affected infrastructure. Users can zoom-in to a specific area, filter data, overlay data, extract data, add new data, change the base map etc.
API interface	To allow developers to access the hosted data services published so that more applications can be developed.

Figure 5.1 Web access to four visualizations

5.3. Geo-Database Development and web map data publishing

As part of the Geo-database development, data is grouped into three major categories, The first set of data is landslide occurrence data, the second dataset is the field data that was used to validate the landslides occurrences data as accurately as possible, the third type of dataset are infrastructures and services datasets that shows what would be affected when landslides have occurred in terms of service provision. The Geodatabase is designed on SQL Server database platform and its key role is not only to host all the spatial data (Vector) but also the non-spatial data (textual). Instead of downloading the satellite images, the application makes use of API to load satellite imagery data from Open Street Map & ESRI satellite maps as base maps for the application.

So that the database can have spatial capability the database was converted to a geo-database using a database management tool called enable enterprise Geodatabase. The software that was used to achieve this task is ArcMap. The data from the database is linked to the map software using an open database connectivity feature. Data that has the wrong projections is automatically re-projected so that it appears in Murang'a County and linking of the infrastructure data to the landslide data is done using a spatial location attribute feature.

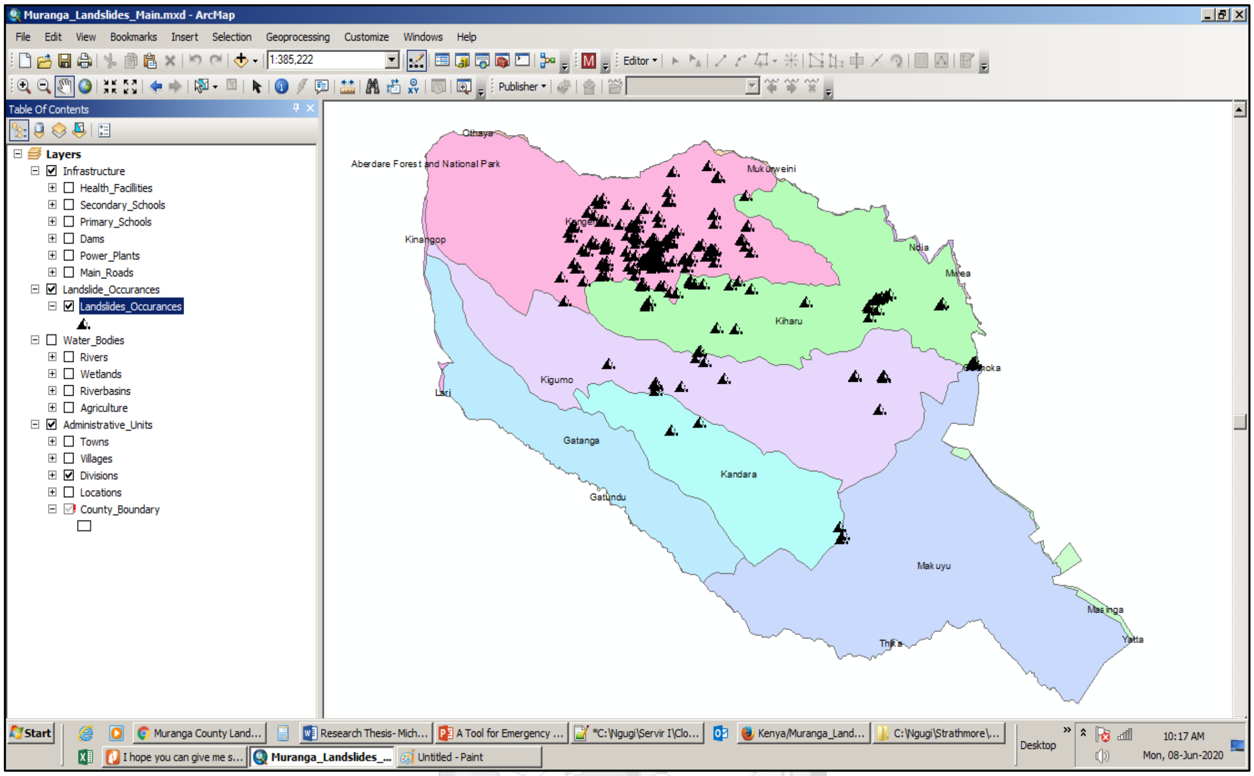


Figure 5.2 Data preparation done on ArcGIS software

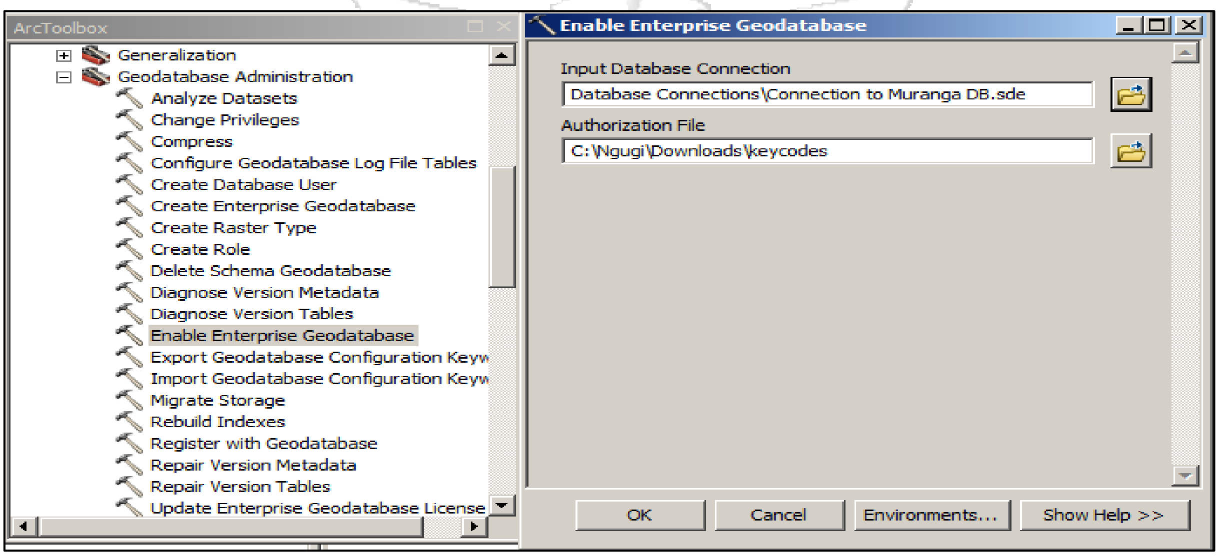


Figure 5.3: Enabling a Geo-database

After the Geodatabase was enabled, the next thing was to design the feature datasets meant to store the data tables (feature classes) and populate the data. After this exercise, the final database looks like the one shown on figure 5.4.

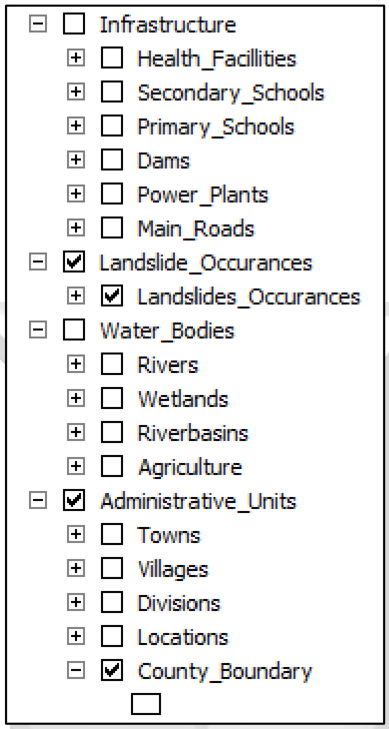


Figure 5.4: Database Layers

5.3.1. Data Cleaning, Harmonization and Integration

This was done mostly on the landslides occurrence data to ensure that it is free from any errors or anomalies. Gaps for the datasets which did not have the right coordinates or wrong location were identified and fixed appropriately. For the external datasets that was visible at a national extent, the data was clipped so that it eventually applied for Murang'a County only. Proper naming was done to all the datasets and associated data columns as well. Harmonizing of all the datasets so that they are in the same coordinate system was done and re-confirmed. Data without coordinates was left out because it would be difficult to plot this information on a map. The tool that was used to perform the data cleaning and harmonization is ArcMap. The datasets were grouped in four thematic groups so that it is easy to locate and understand which category they represent.

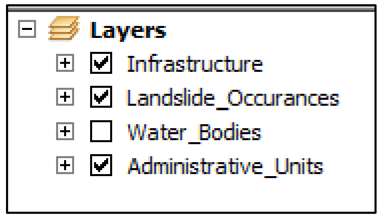


Figure 5.5 Thematic areas

5.3.2. Publish data layers on the web

Web feature services (WFS) allow all the data elements to serve features over the internet and provides the symbology to use when displaying the features online. WFS is an approved data sharing protocol as recommended by the Open Geospatial Consortium. This makes the data available for use in web clients, desktop apps, and field apps. The clients can execute queries to get features and perform edits that can be applied to the server. For the landslides application to show data, it was connected to the database using feature services. The link of where all the datasets is available, as feature service and its link, can be used by programmers as an API to access the data from any platform that accepts spatial data using WFS data sharing protocol, is here http://maps.rcmrd.org/arcgis/rest/services/Kenya/Muranga_Landslides/FeatureServer

For publishing maps, one should have a valid ArcGIS server license that is well setup and integrated to work with SQL Server Spatial Database Engine. This means that, all the data was migrated from a local folder accessible via standalone computer to the SQL server instance that is accessible to multiple users so that the vector data can be exported to the one central secure location before publishing the data. Once this was done the publishing of the layers was done thereafter. Figure 5.7 shows how the API for the published data looks like.

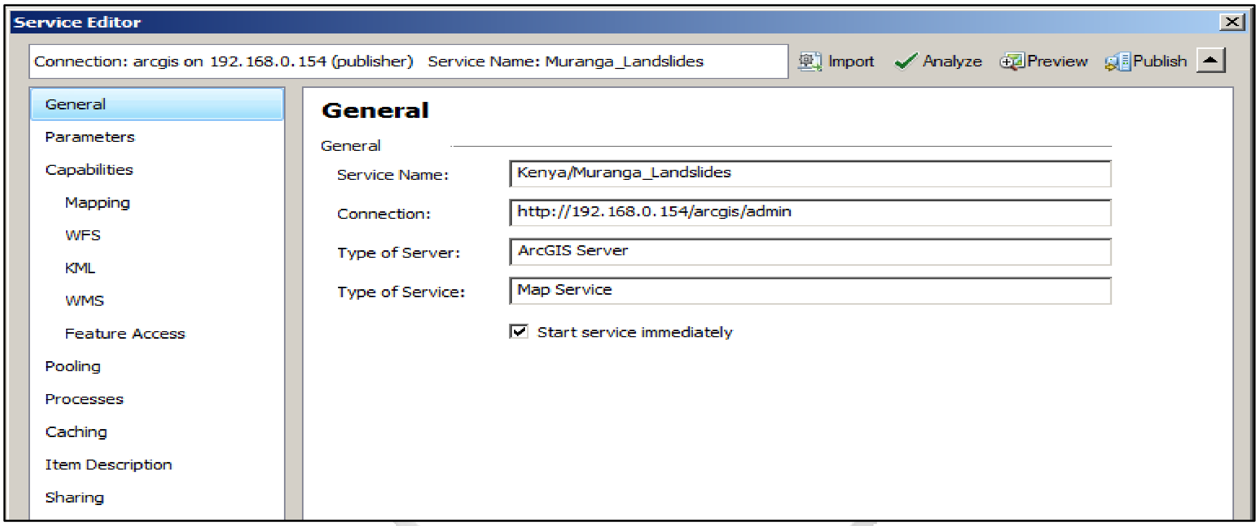


Figure 5.6 Publishing Web Feature Services

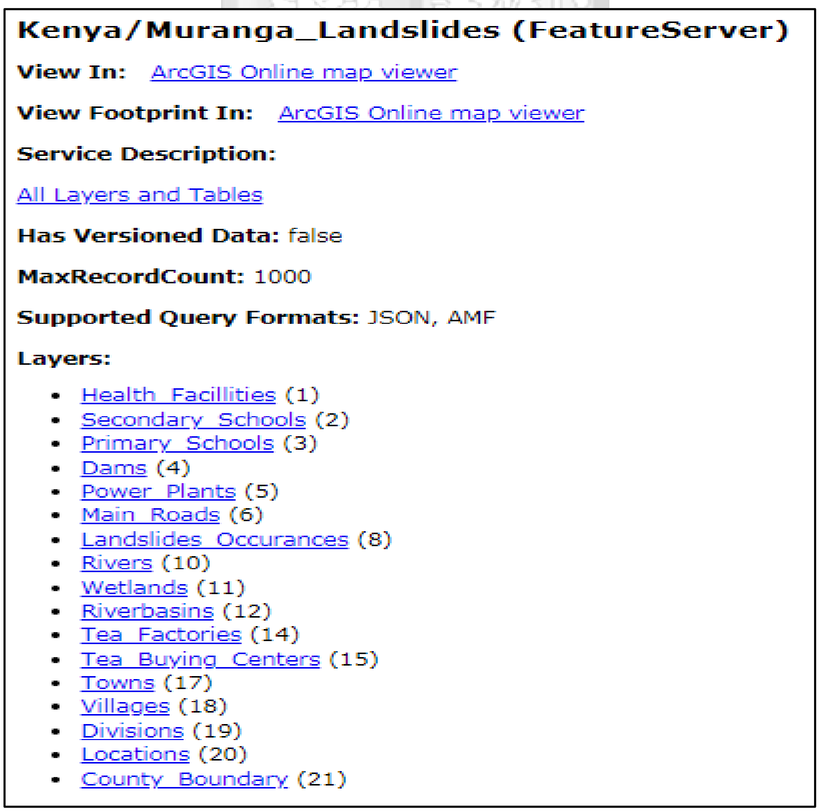


Figure 5.7 API to access the published data online

5.3.3. Developing the web maps

A web map is an interactive display of geographic information that is accessible over the internet. In this regard, this process involved developing all the maps that were integrated and utilized directly by the application. ArcGIS Online tool was used to undertake this task. The data source for all the web maps developed came from the web feature service that was already published. Each map published was incorporated with the following features, a legend, map title, base map, a set of data layers (many of which include interactive pop-up windows with information about the data), a map extent and navigation tools to pan and zoom, proper layering order of the data layers and eventually to have the map shared to the public. Without sharing the maps to everyone the web mapping application would not be able to access the web maps.

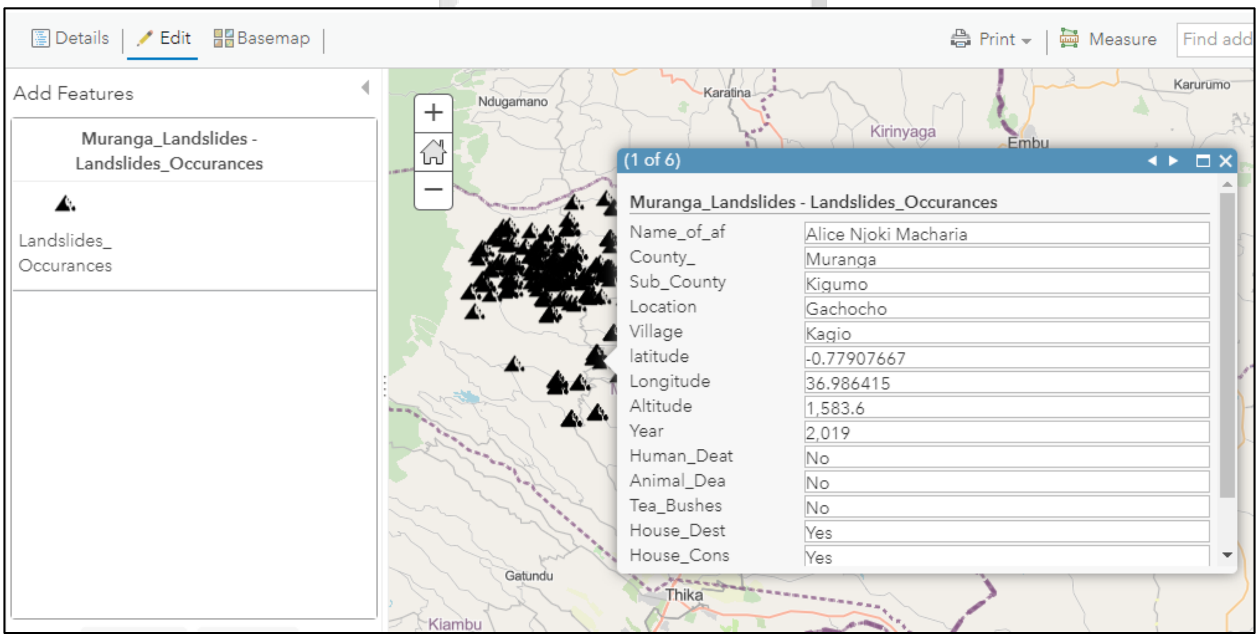


Figure 5.8 Web Map design and editing

5.3.4. Swipe Tool to compare satellite imageries

This widget was designed to compare the satellite image before the landslide and see how the ground looks after the landslide.

Figure 5.9 Swipe Tool to compare a map before and after the landslide

Murang'a County Secondary Schools	Web Map
Murang'a County Primary Schools	Web Map
Murang'a County Schools	Web Map
Murang'a County Health Facilities	Web Map
Murang'a County Tea Factories	Web Map
Murang'a County Tea Buying Centres	Web Map
Murang'a County Landslides in 2017, 2018 and 2019	Web Map

Figure 5.10 List of Web Maps Developed

5.4. Designing info-graphics for the population at risk

The purpose of the info-graphic is for the decision makers to quickly get a snapshot of what is happening on the ground. It presents a new way to visualize key indicators and information in the form of beautiful info-graphics. The dynamic info-graphic was developed using ArcGIS community analyst and the data show cased in the info-graphic is directly linked to the spatial date suing web feature services. The info-graphic showed in figure 5.11 can either be viewed as an image or the user can interact with it dynamically since it opens exported as like a web based html file that is accessible via a browser.

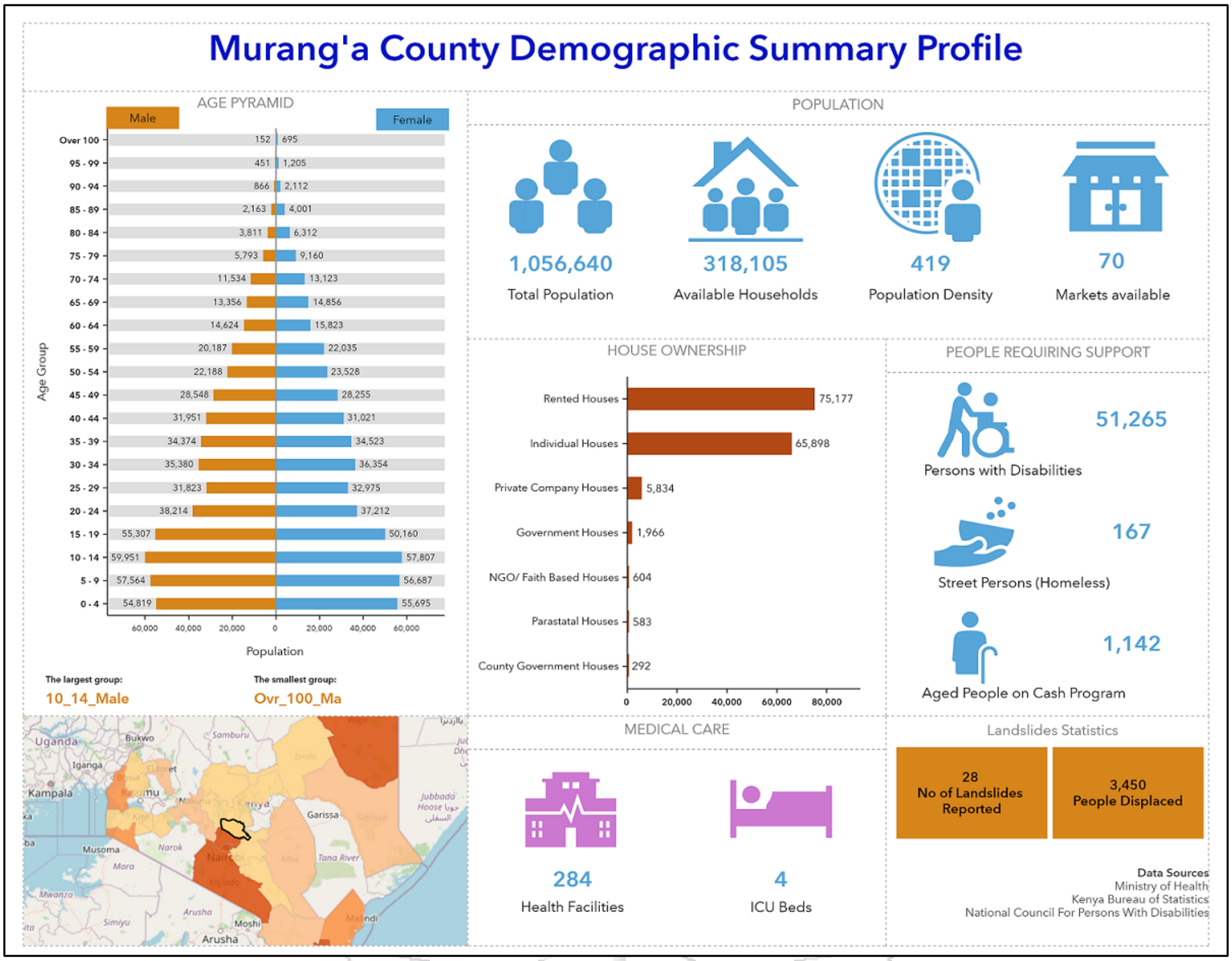


Figure 5.11 Info-graphic for decision makers

5.5. Developing the Interactive Dashboard and Landslides Detailed Data Analysis

The whole application was developed using ArcGIS API for JavaScript and the main framework was done using Dojo. The two programming languages are open-source modular JavaScript library designed to ease the rapid development of cross-platform that are JavaScript based applications. In order to separate the landslide statistics of the operation dashboard and the actual dataset, two products were developed to access the two end points. The application can be accessed on this link: http://muranga-county-landslides-rcmrd.opendata.arcgis.com.

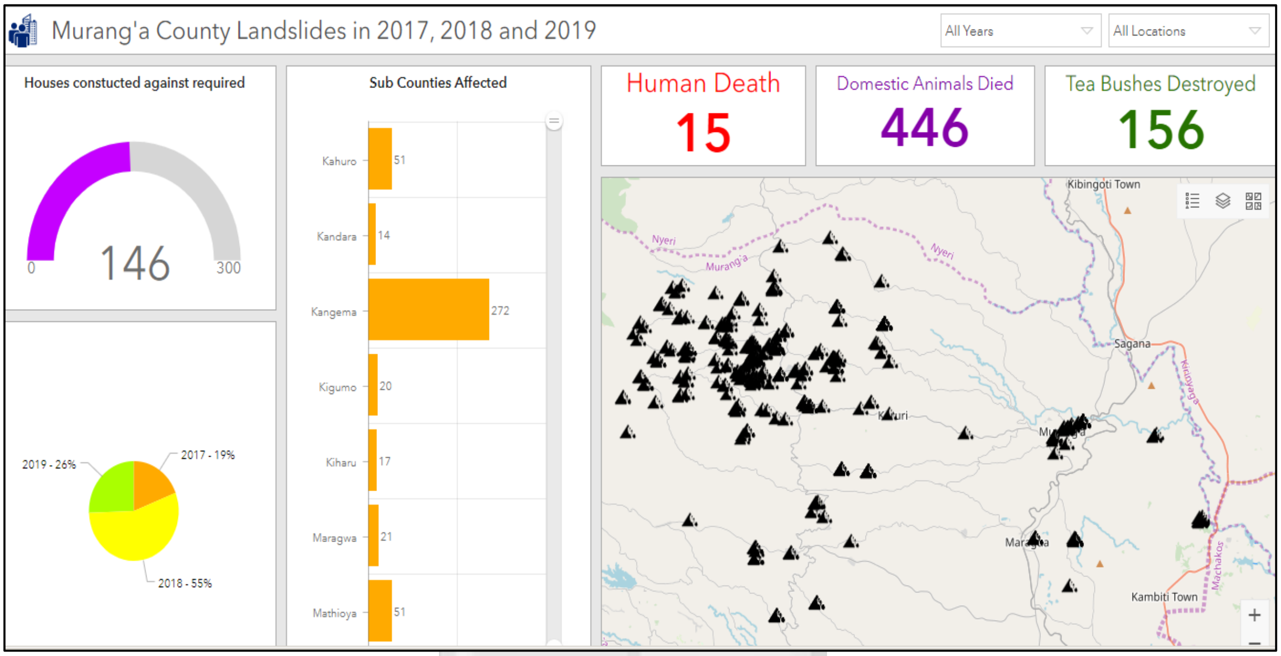


Figure 5.12 Landslides Interactive Operation Dashboard

Some of the useful widgets that are incorporated into the application include; charts, graphs, query, base maps, layers list, legend, info graphics, data filter, data selection, popups information window, incident analysis, map extent, zoom in, zoom out, map panning etc. The development of an incident analysis widget was done to allow someone to locate a landslide incident on the map and analyse information from different feature layers within a specified distance of the incident. . By clicking anywhere on the map, the application correctly shows the information of schools, health facilities, tea factories, tea buying centres & roads on the map dynamically. (Mertz, 2014)

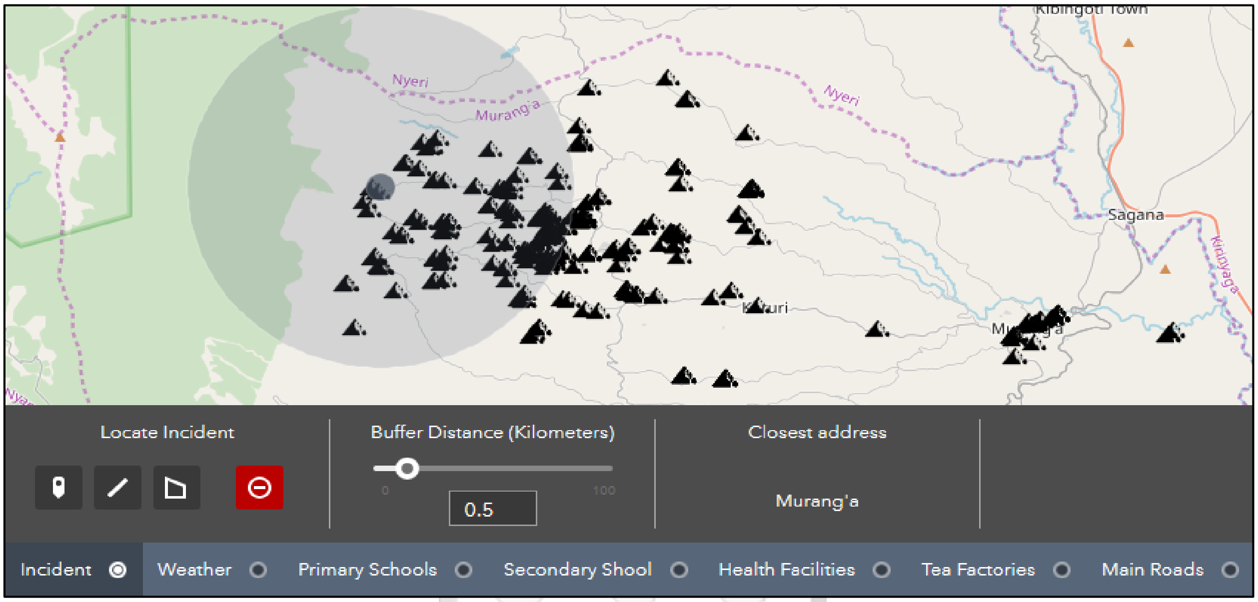
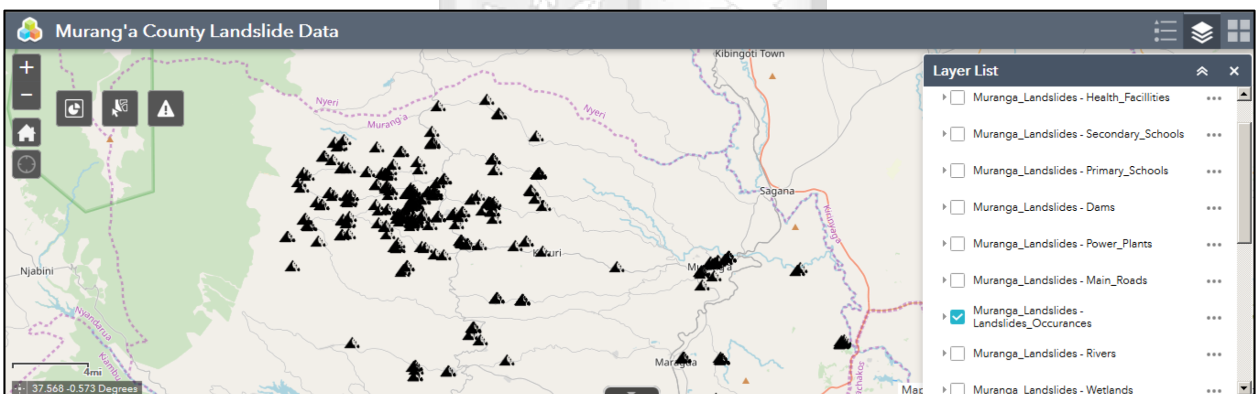


Figure 5.13 Incidence analysis tool that show close features based on buffer



Name_of_af	County_	Sub_County	Location	Village	latitude	Longitude	Altitude	Year	Human_Deat	Animal_Dea	Tea_Bushes	House_Dest	Hou
Dorglus kigondu mwangi	Muranga	Mathioya	Kamacharia	Mukui	-0.60861833	36.99976	1694.1	2018	No	No	Yes	Yes	No
Kennedy Thuo	Muranga	Mathioya	Kamacharia	Gatuhi	-0.59863667	36.99064833	1738	2018	No	No	No	Yes	No
Joseph migwi	Muranga	Kangema	Kiruri	Ichichi	-0.70175167	36.84152833	2209.3	2018	No	No	No	Yes	No

Figure 5.14 Landslides Detailed Data Analysis

5.6. Test Done and their Results

5.6.1. Testing Data integration via web features service

To test if the landslides data and infrastructure data has been integrated and the web feature service (WFS) is working, it is highly recommended to open the below WFS link to not only confirm that it opens but also to view all the published datasets using ArcGIS online map viewer option, http://maps.rcmrd.org/arcgis/rest/services/Kenya/Muranga_Landslides/FeatureServer

The map opens and shows all the layers published, confirming that the data has been integrated successfully as required and using the API, the data can be ported to any application.

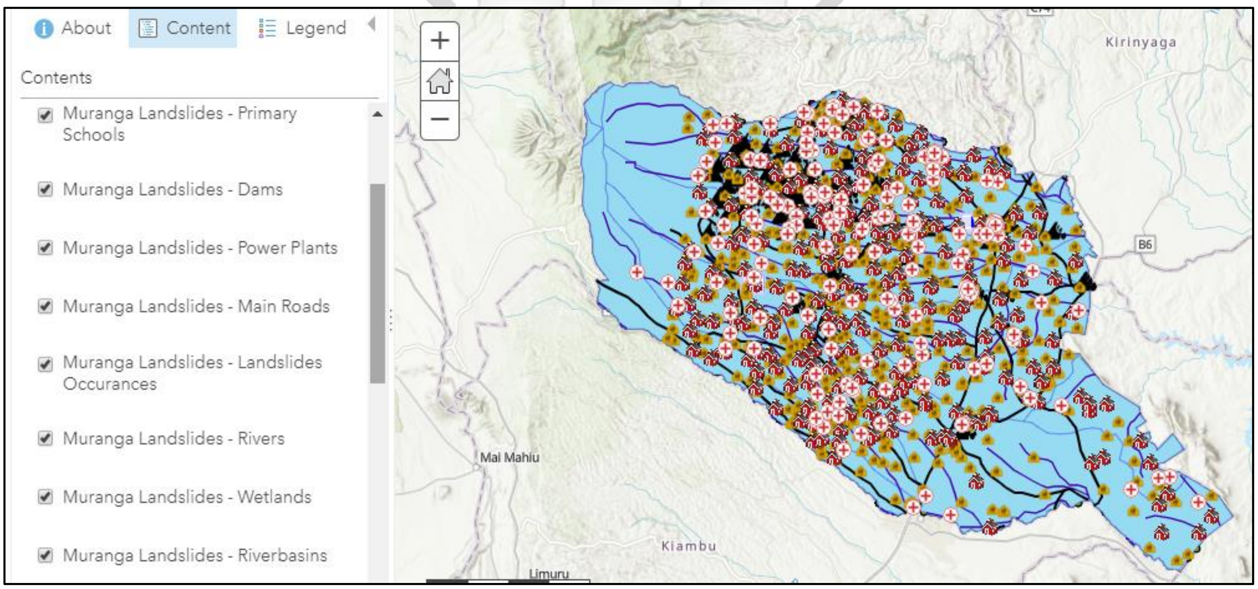


Figure 5.15 Checking if WFS is loading as expected

5.6.2. Testing the identification of affected infrastructure on a specific landslide

The incident analysis widget allows one to locate a landslide disaster on the map and analyse information from different feature layers within a specified distance of the landslide incident. It is able to do this because it supports feature layers from feature services and map services. By clicking on where a landslide has occurred, the application correctly shows the information of nearby schools, health facilities, tea factories, roads etc. on the map. Using a buffer distance of

0.5 kilometre on where a landslide has occurred, the application is able to get the nearby infrastructures automatically. In this case it shows the name of the nearest health facility (Wanjerere Dispensary) and the distance (1.81 kilometre) it is from the clicked incident spot as shown on figure 5.16.

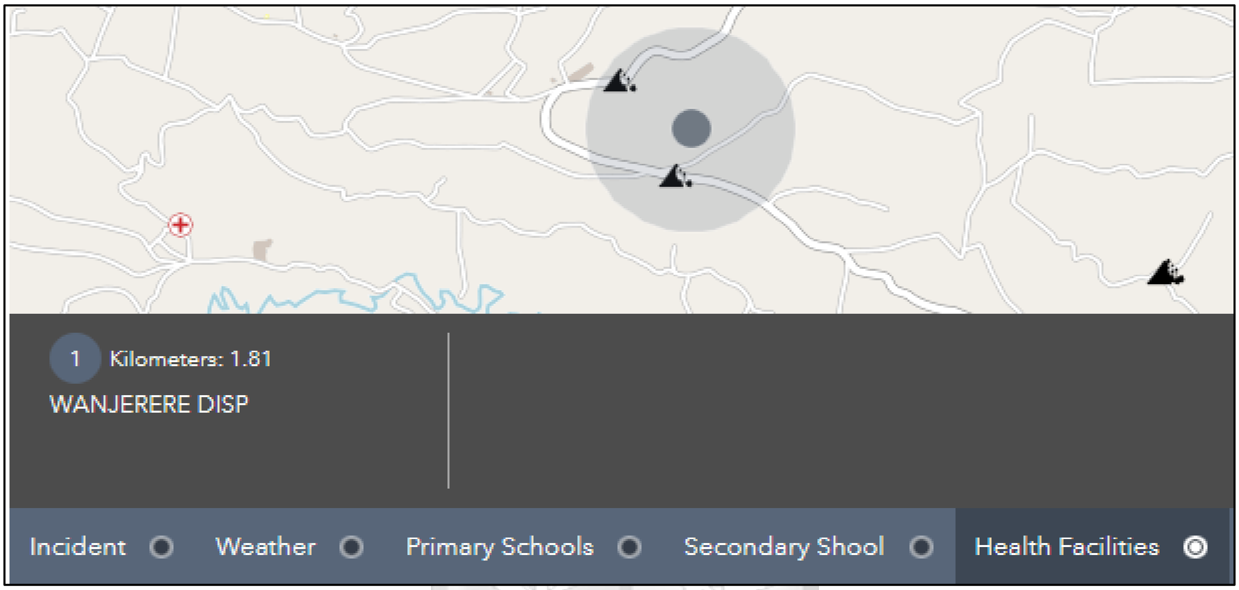


Figure 5.16 Incident Analysis Feature

5.6.3. Testing the available of base maps

Open street base map and ESRI base maps were found to be loading and working as expected i.e. in harmony with the overlaying Web Maps. It was also confirmed that the datasets were indeed loading as expected and displayed in their actual coordinate location.

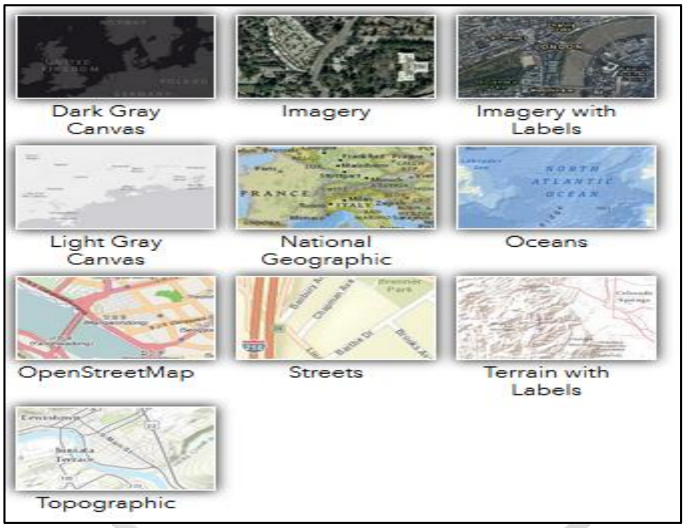


Figure 5.17 Available Base map Gallery

5.6.4. Testing the data statistics generated dynamically

The power of the operation dashboard is to generate the statistics dynamically and one can perform on the fly queries without reloading the web page. All this is working as expected and the screenshot on figure 5.18 shows a dynamic query that shows selection of a sub-county (i.e. Kangema) and all the indicators widgets update their respective sections automatically.

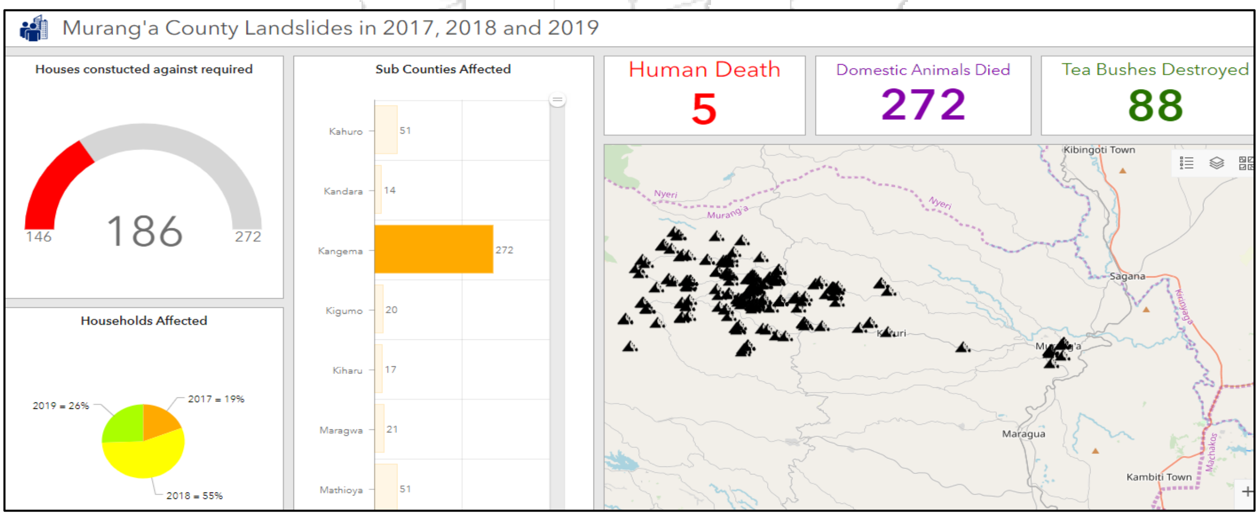


Figure 5.18 Dynamic Statistics

5.6.5. Testing the weather information

This test shows the weather information of any point that is clicked on the map. Data for the current weather is got through an API from Dark Sky. It has advanced weather information that is quickly available as an API for web application to use. Weather information is important so as to plan events accordingly especially after a landslide occurs.

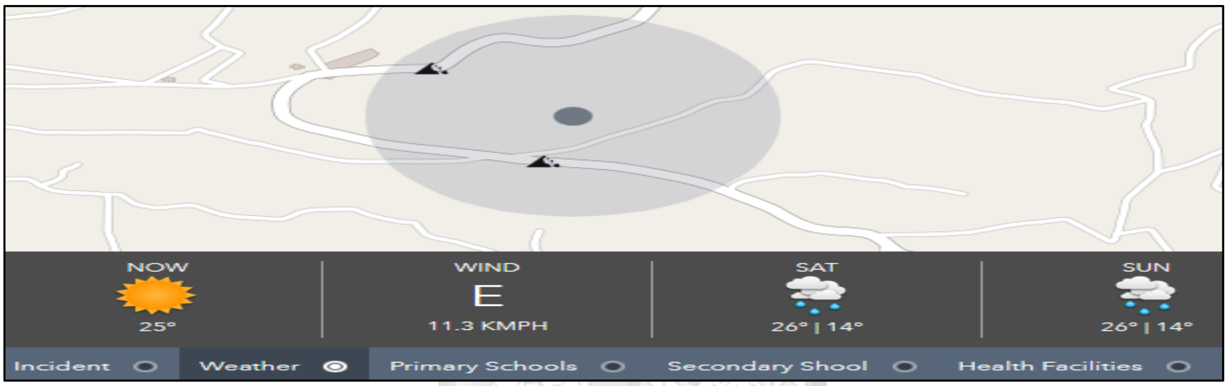


Figure 5.19 Useful Weather Information from Dark Sky

5.6.6. Checking errors on the web features service

To ensure there was no error as far as the web feature service is concerned, before publishing the WFS using ArcGIS software, there is a tool called service analyser that is run so that it can identify any errors before finalizing the actual publishing. The results of the service analyser produced no errors, as shown on figure 5.20.

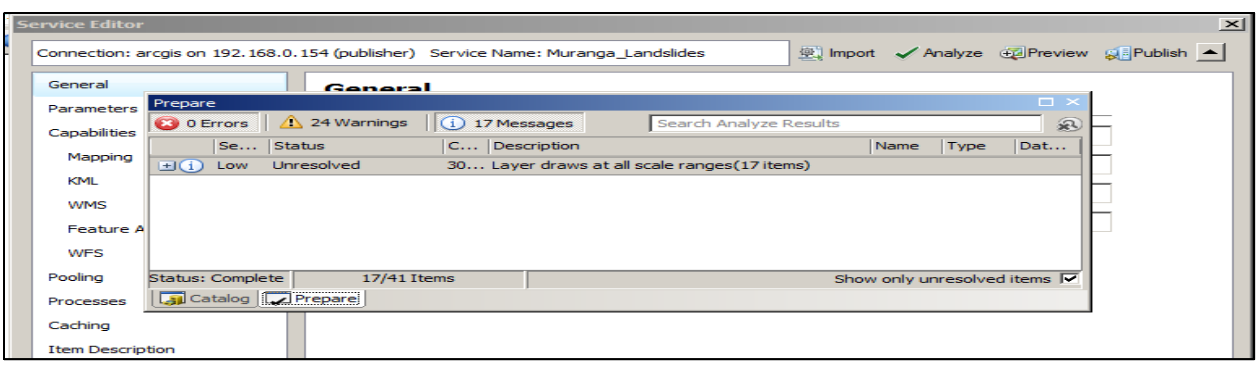


Figure 5.20 Checking errors in Web Feature Service

5.7. User Feedback Test Results

Testing of the application was done by 12 people i.e. 6 staff from Kenya Meteorological Department, 4 from the Kenya Red Cross and 2 people from the Murang'a County Disaster Management and figure 5.2 show the test results.

Table 5.2 User Feedback Test Results

Test Criteria	Not Satisfied	Satisfied	Very Satisfied
Functionality	0 %	25%	75 %
Adequate Datasets	0 %	0%	100 %
User Friendly	0 %	17%	83%
Informative & Reliable	0 %	0%	100%
Overall Feeling of the tool	0 %	8%	92%

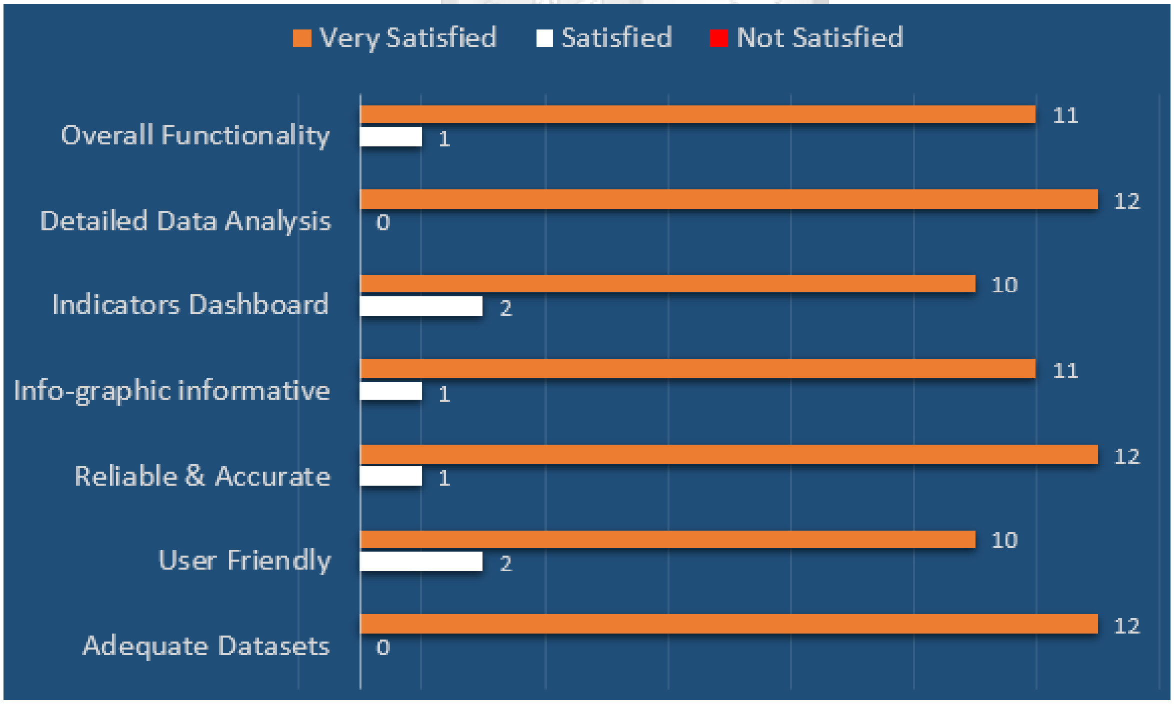


Figure 5.21 Test results voting

Chapter 6 Discussion

6.1. Introduction

This chapter looks at whether the application system met the intended objective of this study as outlined in the first chapter. It provides answers to the research question in detail and shares interpretation of the findings, some of which had not been anticipated as well as and which route the future research of this nature should probably take. The chapter will thus look at the key features of the application to be discussed such as how data was integrated as web feature services, usability of the operation dashboard tool, purpose of the incidents analysis feature and how the base maps and weather data was incorporated into the system.

6.2. Data integration through WFS

One of the biggest challenges when it comes to dealing with spatial data more so when the datasets come from various sources is the issue of how to integrate the datasets so that they are visible and accessible from the same coordinate projection. This research work addresses this issue by introducing the concept of web feature services and ensures that data access by the web maps, data entry by the collector for ArcGIS mobile app and data visualized on the operation dashboard tool comes from feature services. The Web Feature Service uses an interface that allows the exchange of geographic data across the Web. It defines the rules for requesting and retrieving geographic information using the Hyper Text Transmission Protocol (HTTP) by utilizing ArcGIS own REST APIs which implement the functionality of the WFS. The ESRI rest service is an acceptable data sharing standard protocol supported by the open source geospatial consortium. The interface describes the data manipulation operations on geographic feature and its uses. However it is important to note that WFS supports the vector data model that comprises of points, polygons or polylines. (Szukalski, 2012)

6.3. Usability of the operation dashboard tool

The target user for this tool is someone who does not know what GIS is but wants to know what the situation on the ground is whenever landslides occur. The interesting thing with this tool is not just the simplicity of how it is able to show case the data, but also perform on the fly data analytics that are so useful in understanding the elements of various datasets being showed at relative ease. The dashboard has seven main widgets that are playing a very critical role. The widgets are; The first widget is **a map for visualizing the landslides occurrences** and all the other map based datasets such health facilities, primary schools, secondary schools, tea factories, roads etc. Second widget, **a progress bar in the shape of a semi-circle** meant to show the new houses that have been constructed as shelter for displaced people due to landslides against the required houses. (Mertz, 2014)

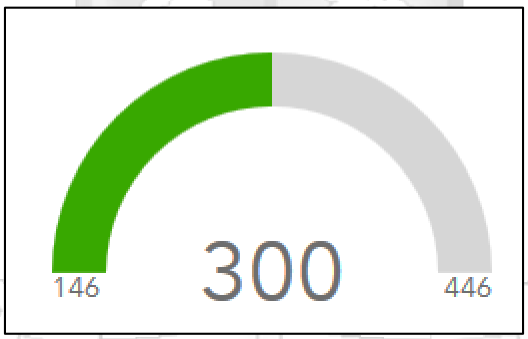


Figure 6.1 Houses required against required

The third widget is **a pie chart** that compares the landslides in the three years (2017, 2018 & 2019).The pie chart illustrates the actual number of landslides in each year and the percentage under each. The pie chart is dynamic in the sense that one can filter any year one wants.

The fourth widget is **a bar chart** that shows the sub counties affected and it is also dynamic in the sense that one can select a sub county and the entire dashboard will update itself on the fly without the need to reload the page. The fifth, sixth and seventh widget show three important indicators which are; **number of human deaths**, **domestic animals that have died** and the **number of tea bushes destroyed** bearing in mind tea is the major agricultural in Murang'a

County. The three indicators change dynamically if a sub county changes or the year changes in which the landslide occurred.

Figure 6.2 Numerical indicators

6.4. Incident Analysis Feature

One of the key objective of this research was to identify what infrastructure resources are affected whenever landslides occur. This requirement has been met adequately using an incident analysis feature that only requires one to click on a point, draw a line or select the area where the landslide occurred and specify the size of the buffer needed in kilometres. The application will trigger a geo-processing script that will provide useful information on what is surrounding. This information is nearby health facilities, affected primary and secondary schools, nearby roads, affected tea farms as well the tea buying centres. In this case, two secondary schools are within a half kilometre buffer radius of where the landslide occurred i.e. Rwathia Girls Secondary school which is 0.13 kilometre and Rwathia Mixed Day School which is 0.17 kilometre. Both schools are within 0.5 kilometre buffer radius (Donald, July).

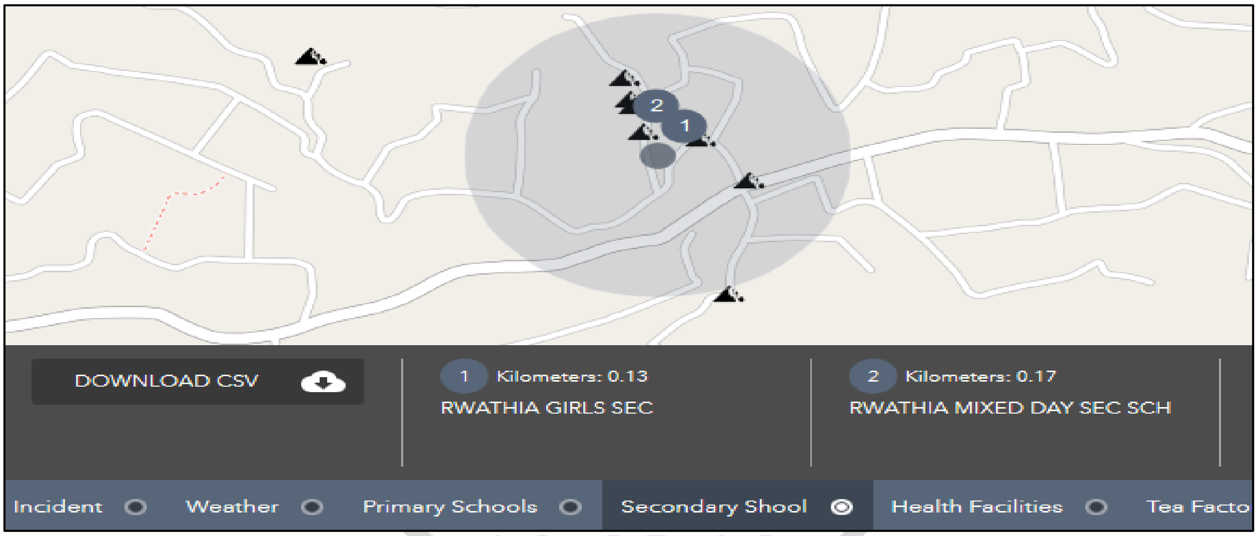


Figure 6.3 Secondary Schools near the landslide as captured by incident analysis tool

6.5. Incorporating Base maps and Weather Datasets

6.5.1. Base Maps API

A base map's job is to be an effective background for the landslides data. It provides critical reference information to enhance the map and lets the overlaid layers play the lead role in telling the story and they add an artistic appeal to a map. Using the base map one may be able to understand a specific location very well without physically being there. It is easy to identify features like the terrain, the streets, rivers, roads, infrastructure etc. This application provides the user with 10 different types of base maps that are very useful. They include nine base maps from Esri and one Open Street Map (ESRI Press Team, 2018).

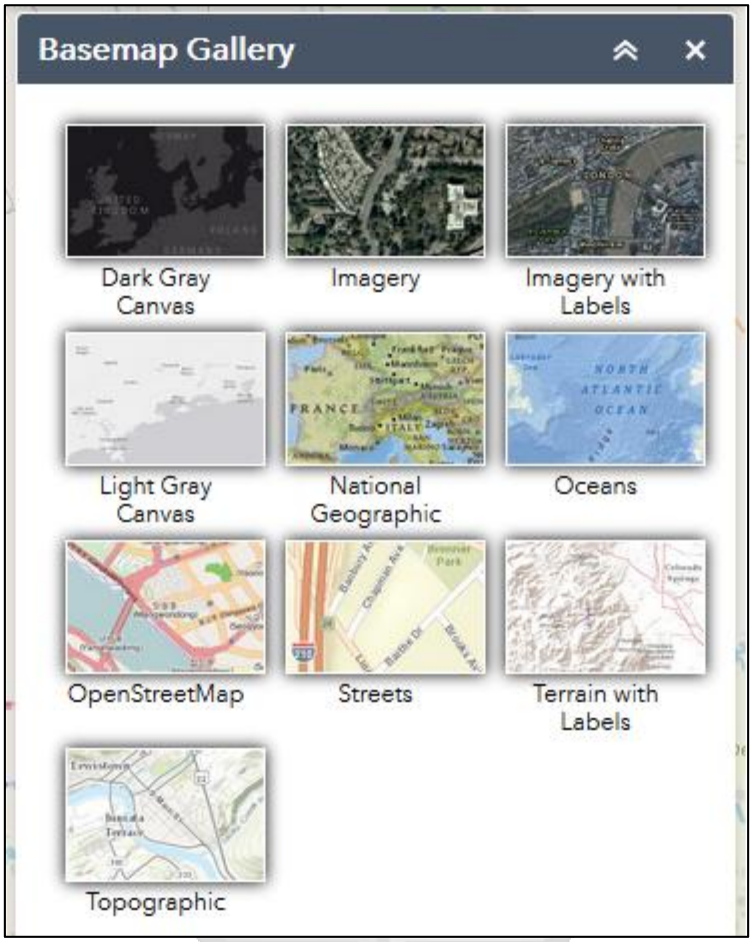


Figure 6.4: Ten available base maps

6.5.2. Weather datasets API

To ensure the application has up-to-date weather information that is dynamic, a weather widget was incorporated inform and it utilises an API from Dark Sky to get important weather information of any point that is clicked on the map. The information include, the current temperature, the wind speed and direction, humidity, cloud cover, nearest storm distance and direction among other features. This is useful in identifying likelihood of landslides happening. (Driver, 2019)

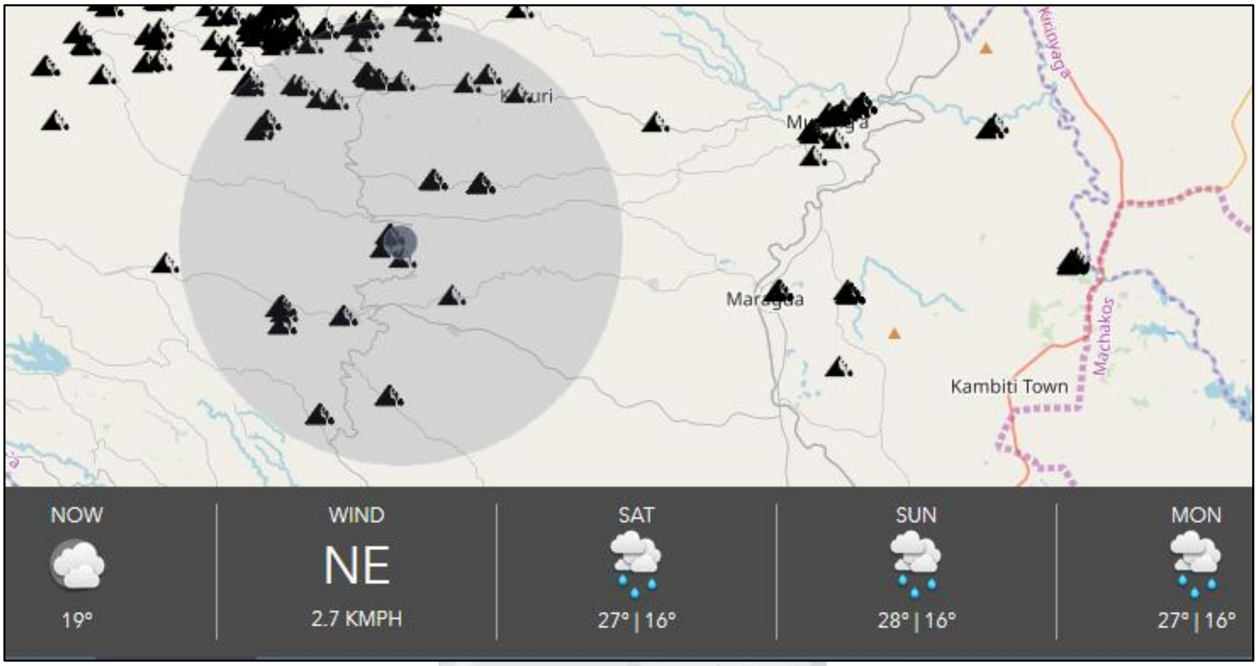


Figure 6.5 Up-to-to-date weather information

Chapter 7 : Conclusion and Recommendation

7.1. Conclusions

It is often said that in as much as you would want to put enough measures to prevent a natural calamity, you cannot fully prevent it from occurring and when it occurs, sometimes its magnitude can be overwhelming. This tool is meant to assist the disaster management units in having a centralized location of information in getting the right data as they deal with the issue at hand. The ability of this tool to merge spatial and non-spatial data using GIS technology ensures that different layers can be analysed together one dashboard hence revealing insightful patterns. If the strategy proposed in this research work is applied, it would greatly support emergency and disaster related cases as far as landslides is concerned. Although the solution was targeting Murang’a County, it can be applied by any other county that would be interested in it.

The ability of how this information about landslides is quickly analysed, processed and shared can result in managing the situation on the ground exceptionally well, more so on coordinating the response required promptly and decision makers can make informed decision based on the data that is backed up scientifically without hesitating. This can help save not just lives but also assist in planning on how to allocate and prioritize resources that would be required for such a system to be put in place in an effective and efficient manner.

7.2. Recommendations

Based on the outcome of this study, the following are the key recommendations:

a) To curb the notion that many people believe that setting up a GIS environment to manage the proposed solution may be an expensive undertaking it is recommended that the county should purchase the software license under the emergency response program that would ensure they get huge discount. This boosts the returns for such a solution in terms of hardware and software is quite immense and would give a good return on their investment within no time.

b) Proper training should be undertaken for the data analysts to process the data with the required software and field work officers skilled properly to collect & collate the data as accurate as possible. The training should also include how staff can update open street map satellite image that is free and open source.
c) Data should continuously be updated especially on the infrastructure such as schools, health facilities, roads, etc. The more up-to-date the data is, the more accurate and reliable it becomes when used.
d) It is good to have one coherent disaster management unit made up of the National Government, County government and the Red Cross. This will ensure that all the entities are reading from the same page unlike now where each institution works on their own.

7.2.1. Suggestion for future work

The following are suggestions for future work:

a) The system to include a functionality to assist the landslide victims to quantifying the loss that farmers experience when their tea bushes are destroyed due to landslides. This would entail identifying the extent of the tea farms for each farmer and computing the total worth of the tea bushes based on the recorded delivery of tea leaves to the Kenya Tea Development Agency's Buying Centre This information would be useful in undertaking crop insurance and hence assist farmers get compensation if landslides occur.
b) The database of managing the landslide victims should be expanded further and linked to the registrar of person's database so as to include things like next of kin. This information would create an easy mechanism of tracking their loved ones in case on any emergency and also getting full information about who is missing in the event of a land slide.
c) The system to have alerts and notification for sending important information to the affected persons after a landslide has occurred.

References

Abdalla, R. (2016, December 7). *Evaluation of spatial analysis application for urban emergency management*. Retrieved from NSBI Resources: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5142189/

Abdalla, R. (2016, December). *Evaluation of spatial analysis application for urban emergency management*. Retrieved from Springer: https://link.springer.com/article/10.1186/s40064-016-3723-y

Agatha, N. (2018, June 13). *Landslides in Murang'a cut off tea farms*. Retrieved from The Star Newspaper: https://www.the-star.co.ke/news/big-read/2018-06-13-landslides-in-muranga-cut-off-tea-farms/

Ahmed, J. (2000). *GIS Technology for Disasters and Emergency Management.* Los Angeles.

Angela, W. (2018, May 15). *15 families displaced by mudslides, tens by floods in Murang'a.* Retrieved from The Star Newspaper: https://www.the-star.co.ke/news/2018-05-15-15-families-displaced-by-mudslides-tens-by-floods-in-muranga/

Assilzadeh, H. (2015). *Landslide Catastrophes and Disaster Risk Reduction: A GIS Framework for Landslide Prevention and Management* . Calgary: Remote Sensing Journal.

Baker, G. (2000). What Are the Standards for Quality Research. *National Center for the Dissemination of Disability Research,* 9. Retrieved from Focus: https://ktdrr.org/ktlibrary/articles_pubs/ncddrwork/focus/focus9/Focus9.pdf

Bashir, M. (2018, May 27). *Red Cross launches walk to help Murang'a landslide victims*. Retrieved from Citizen Digital: https://citizentv.co.ke/news/red-cross-launches-walk-help-muranga-landslide-victims-201894/

Challenges for GIS in Emergency Preparedness and Response . (2000, May). Retrieved from ESRI Website: https://www.esri.com/library/whitepapers/pdfs/challenges.pdf

Conners, D. (2019, April 10). *Human World.* Retrieved from Earth Sky: https://earthsky.org/human-world/what-causes-landslides

Disaster. (n.d.). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Disaster

Donald, M. (July, 9 2015). *What's New in ArcGIS Online*. Retrieved from Open Data: http://opendata-aha.net/whats-new-in-arcgis-online-july-2015/

Driver, C. (2019, February 5). *A Change In The Weather*. Retrieved from The Dark Sky API: https://blog.temboo.com/the-dark-sky-api/

Emergency management. (n.d.). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Emergency

ESRI. (2013). The language of Spatial Analysis. California: Esri Press.

ESRI. (2015). *What are map projections*. Retrieved from ArcMap: http://desktop.arcgis.com/en/arcmap/10.3/guide-books/map-projections/what-are-map-projections.htm

ESRI Press Team. (2018, February 6). *Basemaps: The Setting for Your Story*. Retrieved from ArcGIS Blog: https://www.esri.com/arcgis-blog/products/product/uncategorized/basemaps-the-setting-for-your-story/

Gichaba, C. (2013). Overview of Landslide Occurrences in Kenya: Causes, Mitigation, and Challenges. *Developments in Earth Surface Processes,* 293-314.

Hou, W. (2017). *An Integrated Approach for Monitoring and Information Management of the Guanling Landslide (China).* Beijing: Intenational Journal of Geo-Information.

Hover, R. (2018). The Power of Where | The ArcGIS Book - Learn ArcGIS. *5*, 45.

Ichang'i, D. (2015). *Occurrence of landslides within Murang'a County.* Retrieved from http://geology.uonbi.ac.ke/sites/default/files/cbps/sps/geology/OCCURENCE%20OF%20LANDSLIDES%20WITHIN%20MURANG'A%20COUNTY.pdf

John Radke, T. J. (1999). *Application Challenges for Geographic Information Science: Implications for Research, Education, and Policy for Emergency Preparedness and Response*. Retrieved from Semantic Scholar: https://www.semanticscholar.org/paper/Application-Challenges-for-Geographic-Information-Radke-Cova/c0b58f0f0db0ca04fe1f3b27c5ffedff974278d8/

Johnson, R. (2000, May). Retrieved from https://www.esri.com/library/whitepapers/pdfs/disastermgmt.pdf

Kenya Red Cross. (2019). *Strengthening Disaster Preparedness and Response in Kenya Red Cross Society Program.* Nairobi: Acacia Consultants.

Kingsley, M. (n.d.). *Ethical Considerations*. Retrieved from https://cirt.gcu.edu/research/developmentresources/tutorials/ethics

Madaan, S. (2017). *What is a Landslide*. Retrieved from Earth Eclipse: https://www.eartheclipse.com/natural-disaster/causes-effects-and-types-of-landslides.html

Mariam, A. (n.d.). *What makes a quality*. Retrieved from Research Gate: https://www.researchgate.net/post/What_makes_a_quality_research

Marie, A. (2017, May 5). *Landslides*. Retrieved from Natural Disasters: http://eschooltoday.com/natural-disasters/landslides/types-of-landslides.html

Master, W. (n.d.). *Murang'a County Profile*. Retrieved from Murang'a County Website: https://muranga.go.ke

Meaden, G. J. (1996). Geographical information systems Applications to marine fisheries . Oxford Press Publishers.

Mertz, J. (2014, December 3). *SSP innovations*. Retrieved from ArcGIS Operations Dashboard: https://sspinnovations.com/blog/aboutarcgis-operations-dashboard-part-2/

Mwangi, D. (2018, June 11). *Murang'a county facing food shortage as landslides affect farms*. Retrieved from NTV News: https://ntv.nation.co.ke/news/2720124-4607294-xud5kn/index.html

Ngotho, A. (2018, June 13). *Landslides in Murang'a cut off tea farms*. Retrieved from The Star: https://www.the-star.co.ke/news/big-read/2018-06-13-landslides-in-muranga-cut-off-tea-farms/

NOAA. (2018, 25 6). *Remote Sensing*. Retrieved from Natioanal Ocean Service: https://oceanservice.noaa.gov/facts/remotesensing.html

O'Connor, S. (2017, May 30). *What Is Interoperability, and Why Is it Important?* Retrieved from Advanced Data Systems: https://www.adsc.com/blog/what-is-interoperability-and-why-is-it-important

Phil, F. (2018, July 23). *SDLC - RAD Model*. Retrieved from Tutorial Point: https://www.tutorialspoint.com/sdlc/sdlc_rad_model.htm

Pushpendra Kumar, D. K. (2006). GIS Based Landslide Susceptibility Mapping — A Case Study in Indian Himalaya. In *Disaster Mitigation of Debris Flows, Slope Failures and Landslides* (pp. 617 - 624). Tokyo: Universal Academy Press.

Rahman, A. (2014). Geoinformation for Informed Decisions. 164.

Reimold, D. (2019, Jan 5). *What is Geographic Information Systems (GIS)?* Retrieved from GIS Geography: https://gisgeography.com/what-gis-geographic-information-systems/

S.S. Ramakrishnan, V. K. (2002). Landslide Disaster Management and Planning. Tamilnadu, India.

Sai Nudurupati, N. M. (2017, June). *A hydro-climatological approach to predicting regional landslide probability using Landlab*. Retrieved from Research Gate Publications: https://www.researchgate.net/publication/317818956_A_hydro-climatological_approach_to_predicting_regional_landslide_probability_using_Landlab

Sarkar, S. (2016). GIS Based Landslide Susceptibility Mapping. *Disaster Mitigation*, 617.

Singh, H. A. (2018, March 6). *GIS and Remote Sensing tools to analyze landslides*. Retrieved from Geospatial World: https://www.geospatialworld.net/blogs/gis-and-remote-sensing-tools-to-analyze-landslides/

Strauch, R. (2017). *A hydro-climatological approach to predicting regional landslide probability using Landlab.* Washington. Retrieved from Research Gate: https://www.researchgate.net/figure/Workflow-for-landslide-modeling-using-the-Landlab-LandslideProbability-component-The_fig1_317818956

Szukalski, B. (2012, September 24). *Mapping*. Retrieved from ArcgGIS Blog: https://www.esri.com/arcgis-blog/products/arcgis-online/mapping/all-about-arcgis-online-layers/

Team, E. P. (2018, February 28). *How to Perform Spatial Analysis.* Retrieved from ESRI Website: https://www.esri.com/arcgis-blog/products/product/analytics/how-to-perform-spatial-analysis/

Team, E. P. (2018, February 28). *How to Perform Spatial Analysis.* Retrieved from ArcGIS Blog: https://www.esri.com/arcgis-blog/products/product/analytics/how-to-perform-spatial-analysis/

Thor, P. (2018). *GIS Architecture.* Redlands: ESRI.

UNDP & NDMA. (2011). *District Environmental Action Plan.* Nairobi: Poverty Environment Initiative project.

Wirkus, C. (2015). A Review Journal of Homeland Security and Emergency Management. *Geographic Information Systems for Disaster Response*, 571-602.

Appendices

(a). Murang'a County Inset Map

(b). Murang'a County Map

(c). Research Questionnaire

The purpose of this study is to come up with a tool for landslides emergency management and disaster response that utilizes GIS technology to analyse and monitor events spatially, within a GIS frame that will have an interactive operation dashboard useful for decision making. Therefore this questionnaire will assist in getting important information regarding the areas that have recorded landslides in the past five years and getting the required features of the system.

A. Respondent Personal Details

1. **Name (Optional)** ☐
2. **Gender** ☐
3. **Constituency** ☐
4. **Ward** ☐
5. **Contacts** ☐

B. Landslide Occurrence

1. **When was the last time this area experience landslide (Select one answer only)**

   1 to 2 years ☐

   3 to 4 years ☐

   5 to 6 years ☐

   Other Specify ☐

2. **How many time have landslides occurred in the time indicated above (Select one answer only)**

   Once ☐ *Twice* ☐ *Thrice* ☐ *Four Times* ☐ *Other Specify* ☐

3. **What was affected (One can select multiple values) and to be included in application snapshot**

   Tea Farms ☐ *Loss of Human life* ☐ *Houses destroyed & needed* ☐

   Households ☐ *Loss of animals* ☐ *Map of landslide area* ☐

   Trees ☐ *Sub county affected* ☐ *House owner details* ☐

   Roads ☐ *Year of occurrence* ☐ *Other, please specify* ☐

4. **Approximate value of what was lost in shillings (Numeric Value Entry)** ☐

5. **Approximately how many house hold/ families were affected (Numeric Value Entry)** ☐

6. **Did any disaster response officers come to help** *Yes* ☐ *No* ☐

7. **From which institution did the disaster response officers come from & are the main stakeholder**

National Government ☐ *Red Cross* ☐ *County Government* ☐ *Other Specify*

8. **Which base maps should be include in the map** ☐

   Google ☐ *Bing Maps* ☐ *Open Street* ☐ *Esri Base maps* ☐

9. **What dataset hinders the response and which should be included in the application** ☐

10. **Select the detailed features the application requires to have**

    Population at risk ☐ *Aged people* ☐
    People displaced ☐ *House-holds & Markets available* ☐
    Person with disabilities ☐ *Weather* ☐
    Landslide Buffer ☐ *Medical Facilities* ☐

11. **What information should be include in the info-graphic for decision makers**

    Add new data layers ☐ *Spatial Integration* ☐
    Web Based ☐ *Extract and Download Data* ☐
    API to connect ☐ *Weather* ☐

12. **What time of the day do landslide occur most**

    Raining during the night ☐ *Raining during the day* ☐

13. **How far was the evacuation location site**

    Less than 2 km ☐ *More than 2 km* ☐

14. **Interview Date:** ☐

15. **Any other comment/ feedback** ☐

(d). Turn It In Report