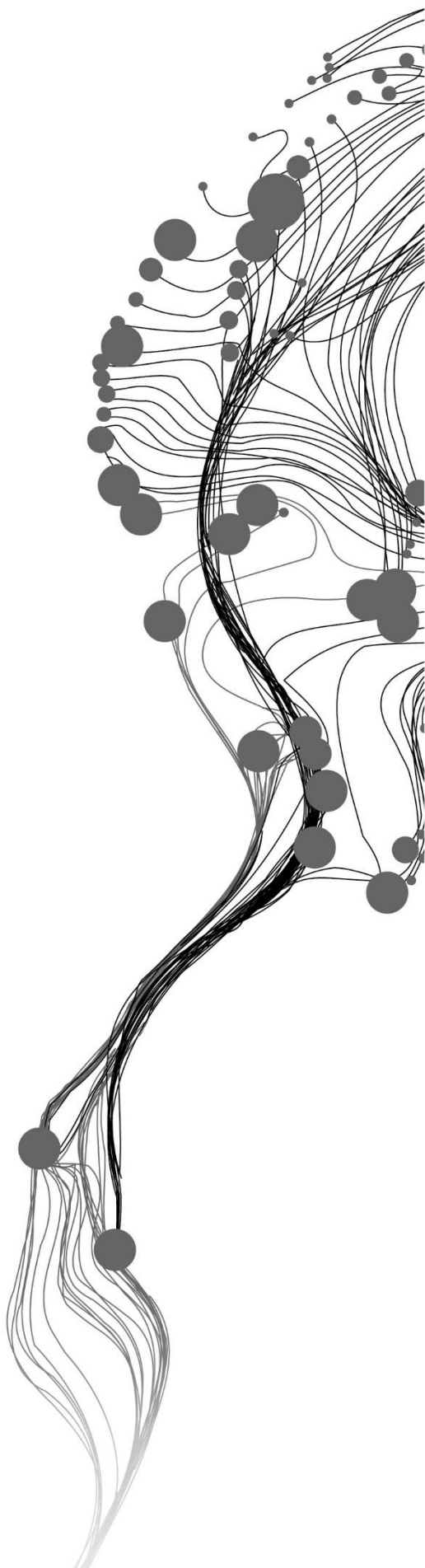


FIELD GIS: TOWARDS MOBILE COMPUTING TO SUPPORT PRE- DISASTER SPATIAL ANALYSIS IN THE FIELD

MUTLURU VENKATASRINIVASAMURTHY
RAGHAVENDRA SHARMA
March, 2017

SUPERVISORS:
Dr. Ir. R.L.G Lemmens
Dr. F.O. Ostermann



FIELD GIS: TOWARDS MOBILE COMPUTING TO SUPPORT PRE- DISASTER SPATIAL ANALYSIS IN THE FIELD

MUTLURU VENKATASRINIVASAMURTHY
RAGHAVENDRA SHARMA

Enschede, The Netherlands, March, 2017

Thesis submitted to the Faculty of Geo-Information Science and
Earth Observation of the University of Twente in partial fulfilment of
the requirements for the degree of Master of Science in Geo-
information Science and Earth Observation.

Specialization: Geoinformatics

SUPERVISORS:

Dr. Ir. R.L.G Lemmens

Dr. F.O. Ostermann

THESIS ASSESSMENT BOARD:

Prof. Dr. M.J. Kraak (Chair)

Dr. C. Stasch (External Examiner, 52°North Initiative for Geospatial
Open Source Software GmbH)

DISCLAIMER

This document describes work undertaken as part of a programme of study at the Faculty of Geo-Information Science and Earth Observation of the University of Twente. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the Faculty.

ABSTRACT

Mobile GIS is an integrated software/hardware framework for accessing geospatial data and services through mobile devices such as smartphones or tablets via wireless networks. Most of the mobile GIS applications are used for data acquisition and/or data validation in the field. However, field operators often require information derived from data to take instant decisions in the field. Therefore, this research introduced a concept called “Field GIS”. Field GIS is a type of mobile GIS that can be viewed as an up-scaled version of a mobile data collector system or a downscaled version of a desktop GIS software. Field GIS is developed on a mobile device for georeferenced spatial data acquisition and spatial data analysis that empowers field operators to take informed decisions in the field. This research defined the concept of Field GIS by developing a reproducible procedure for determining and implementing sufficient geoprocessing capabilities for field operators pertaining to the mitigation of landslides and floods. The procedure for constructing a Field GIS was influenced by two factors. The first factor defined the need of Field GIS in a disaster management setting and the second factor defined the extent of GIS functionalities that can be implemented on a mobile device. The need of Field GIS was defined by situational awareness, integration of local knowledge and the urgency of the situation. Whereas the extent of GIS functionalities on a mobile was influenced by the expertise of the user, type of data collected/used in the field, processing options, access to additional geo-data layers and the need of network connectivity. These factors aided in the classification of Fields GIS along the functionality spectrum of mobile GIS which ranges from data collector system to a full-fledged GIS. In the case of a novice user, the Field GIS was configured with minimum GIS functionalities such as data collection and visualization tools. In the case of intermittent user, the Field GIS was configured with data editing tools, navigation tools and also access to additional geo-data layers. In the case of an expert user, the Field GIS was configured with sophisticated GIS analysis tools such as interpolation, cross operation, flow direction and flow accumulation. Three potential usage scenarios of Field GIS pertaining to the mitigation of landslides and floods were gathered from potential users and translated into workflows diagrams for better identification of the inputs required, processes executed and the output generated. One of the use cases was implemented as a proof of concept. The developed prototype was evaluated with potential users which proved that expertise of the user indeed influences the extent of GIS functionalities on a mobile device.

Keywords

Mobile GIS, Mobile Computing, Field GIS, Spatial analysis, Geoprocessing tools

ACKNOWLEDGEMENTS

First and foremost, I thank the omnipresent ‘Sai Ram’ and my parents for their blessings and unconditional love throughout my life. This MSc would not have been possible without my friend Ms. Kaaviya Velumani whose passion for Geo-Information science motivated and inspired me to pursue for an MSc.

I am deeply indebted to my supervisors Dr Rob Lemmens and Dr Frank Ostermann who have supported and guided me throughout the thesis phase. I acknowledge my sincere gratitude to Dr Rob Lemmens for his patience and kind support throughout my research period. I thank Dr Frank Ostermann for his suggestions and constructive criticisms that helped me a lot in structuring my research.

I thank Dr C.J. Van Western for giving me a stunning idea ‘Landslide Reach app’, which is my first official mobile GIS application. I am deeply grateful to Dr Olga Mavrouli for her patience and innovative suggestions which helped me to build a useful mobile application.

This thesis wouldn’t have been possible without the potential users. I must thank Prof Dr Victor Jetten (ESA, ITC), Dr. Norman Kerle (ESA, ITC), Dr Melanie Kappes Simone (Disaster risk specialist, World Bank), Dr Rashmin Gunasekera (Disaster risk consultant, World Bank), Dr Carolina Rogelis Prada (Consultant, World Bank), Mr. Vivien Deparday (Disaster risk specialist, world Bank) for sharing their experience in the field of disaster management.

I thank ITC for introducing me many amazing friends Anand Vetrivel, Kanmani Imaya, Mony Zehra, Karma, Soheil, Freeman Ali, Rosa, Yumeng Zhu and many more. I must thank my two special friends Margret and Roy who have provided me with delicious food throughout these eighteen months.

Last but not the least, I thank my friend and brother Mr. Vikas Shantaram Pingle for all the wonderful moments throughout these eighteen months of ITC.

TABLE OF CONTENTS

1.	Introduction.....	1
1.1.	Background and significance.....	1
1.2.	Motivation and problem statement.....	2
1.3.	Research Identification.....	3
1.4.	Research Plan and Thesis structure.....	4
2.	Mobile GIS	7
2.1.	Introduction	7
2.2.	What is “mobile GIS”.....	7
2.3.	Mobile GIS in the context of disaster management	8
2.4.	Data collection vs Data processing.....	9
3.	Field GIS Requirements	11
3.1.	Introduction	11
3.2.	Identification of potential users	11
3.3.	Gathering user requirements	11
3.4.	Refinement of usage scenarios.....	12
3.5.	Creation of workflow diagrams	12
3.6.	Discussions	16
4.	Procedure for the construction of Field GIS.....	17
4.1.	Introduction	17
4.2.	Factors – construction of Field GIS pertaining to disaster management	17
4.3.	Tools for constructing a Field GIS	19
4.4.	Derivation of additional factors influencing Field GIS construction	25
4.5.	Discussions	26
5.	Prototype implementation.....	27
5.1.	Introduction	27
5.2.	Workflows to Prototypes	27
5.3.	Prototype requirements and background.....	27
5.4.	Data Preparation.....	28
5.5.	Development environment and implementation.....	30
5.6.	Pilot tests of the prototype	31
5.7.	Implementation of website	31
5.8.	Discussions	35
6.	Prototype evaluation	37
6.1.	Introduction	37
6.2.	Method for prototype evaluation	37
6.2.	Test participants and resources used	37
6.3.	Evaluation process	37
6.4.	Evaluation results	39
6.5.	Insights gained from evaluation.....	40
7.	Conclusions And Recommendations	41
7.1.	Conclusions	41
7.2.	Recommendations.....	43
	Appendix A: Usage scenarios of Field GIS.....	45
	Appendix B: Empirical runout model.....	47
	Appendix C: Screenshots of the prototype	51

LIST OF FIGURES

Figure 1: Research Plan	5
Figure 2: Visualization elements used for the construction of workflows of Field GIS.....	13
Figure 3: Exposure Assessment	14
Figure 4: Workflow diagram of flood depth app.....	15
Figure 5: Workflow diagram of landslide reach app.....	16
Figure 6: Functionality spectrum of mobile GIS	18
Figure 7: Factors influencing the classification of Field GIS	18
Figure 8: Procedure for constructing Field GIS apps	20
Figure 9: Aronoff's classification of GIS analysis tools (Aronoff, 1989).....	21
Figure 10: User-interface design of the prototype	28
Figure 11: System Architecture.....	29
Figure 12: Architecture of Apache Cordova (Apache Cordova, 2016a)	30
Figure 13: WordPress dashboard	33
Figure 14: Layout design of the landing page.....	33
Figure 15: Edit Page Window of WordPress dashboard	34
Figure 16: Code added using 'SyntaxHighlighter Evolved' plugin.....	35
Figure 17: Overview of a landslide prone site in Santa Coloma, Andorra.....	38
Figure 18: Reach Angle definition	47
Figure 19: Derivation of tangent of the reach angle	47
Figure 20: Slope scenarios.....	50
Figure 21: Landing Page of the landslide reach app	51
Figure 22: Unsafe scenario of landslide reach app.....	52
Figure 23: Safe Scenario of landslide reach.....	53

LIST OF TABLES

Table 1	Added value of mobile GIS app capable of spatial data processing.....	9
Table 2	Potential users	11
Table 3	Structure of the usage scenarios.....	12
Table 4	Difference between the open-source data collection tools.....	22
Table 5	Usage limits and Data source of Elevation service provided by various APIs.....	23
Table 6	Software libraries	23
Table 7	Regression equations incorporated in the prototype	27
Table 8	Development environment.....	30
Table 9:	Regression equations for all landslide type (Corominas, 1996).....	49

1. INTRODUCTION

1.1. Background and significance

In our daily lives, we come across questions such as these ‘What is the shortest route to reach school?’, ‘Is the neighbourhood safe to live in?’, ‘How many shopping malls are located in the neighbourhood?’, ‘Which hospital is close to my location?’, ‘Where am I?’ Questions such as these have made us realize that geography is a part of our everyday life; almost all decisions that we make is influenced or restricted by geography. Most of us, find the answer for such questions using our smartphone. To be more precise, we use Google Maps or any other web mapping service app in our smartphone. Google Maps is a rudimentary form of a geographic information system (GIS) that aids in answering such questions by integrating data from various sources and producing information in the form of maps that are easy to understand and enables us to take informed decisions on-the-spot. More advanced forms of GIS function as decision support system that are used for collection, management, analysis and visualization of geospatially referenced information (esri, 2016).

Over the decades, GIS has evolved through four stages in-line with computer technology (GISGeography, 2016). The first stage (1960-1982) was the pioneering stage of GIS, in which individual organisations such as Canadian government, United States Census Bureau and United Kingdom Ordnance Survey helped to shape the future development of GIS. During this period, few national mapping agencies around the world started to adopt GIS in their organisation as they realised the significance of digital mapping. The second stage (1982-1990) was the commercialization stage of GIS, in which private enterprise such as Environmental Systems Research Institute (ESRI) entered the commercial market. The first version of ArcInfo for desktop computers was launched by ESRI. The third stage (1990-2010) witnessed the increase of GIS users, which was mainly attributed to the introduction of powerful computers, internet access and integration of remote sensing technology. The fourth and the final stage (2010-present) is the open source era, in which the idea of sharing the software’s source code with the user community is highly valued. Over these years, GIS has gradually moved from mainframe computers to standalone desktop GIS, to local networking GIS, to web GIS and now mobile GIS (Mensah-Okantey, 2007).

Recent advancements in the Information and communication technology (ICT) sector are producing smart devices that are smaller, yet equipped with more powerful features such as the Global Positioning Systems (GPS), Wireless Fidelity (Wi-Fi), Bluetooth, quad-core processors, and other sensor systems (Oneil Williams, 2016). Smartphones, tablets, smart wristbands, smart lightbulbs and smart keys are some of the popular examples of smart devices that exhibit the capabilities of ubiquitous computing and artificial intelligence. Integration of these powerful capabilities on a small, handy device has empowered people as well as the devices themselves to take smarter and instant informed decisions. For instance, a smart lightbulb functions by sensing the motion of a living being. Smart wristbands continuously monitor the heart rate and provides various information possible for having a healthy life (Zuriñe Dopacio González, 2015). Smartphone apps such as ‘ActivPoint’ leverages the built-in GPS of smartphones and the data from central server to provide immediate situational awareness information to professionals living or working in a global threat environment about the safe zones and the no-go zones (NC4, 2017). The convergence of these smart devices with built-in GPS and wireless communication technology coupled with GIS technology has enabled the concept of “Mobile GIS”.

Mobile GIS is an extension of desktop GIS which makes use of spatial data on smart devices such as smartphones and tablets in the field (Abdalla, 2016). The basic idea of mobile GIS is to take GIS out of the office into the field on mobile devices such as smartphones and tablets. There are many examples of mobile GIS apps developed by private enterprises: ArcGIS app from esri (2015); Map3D from Moritz Gaupp Â (2013); GIS Pro from Garafa (2016); Wolf-GIS from Wolf-GIS APEX(2016). These mobile GIS apps are used in the field for performing tasks such as: field mapping, reporting or uploading incidents, querying the database, measurement tool, navigating using GPS, updating or editing attributes in related tables. For example, the Los Angeles Unified School District used the ArcGIS mobile app to report graffiti, broken window and other repair issues to the district's central database (Jim Baumann, 2012). Crisis360 (2017) is a mobile application used in disaster management that aids people to collect data regarding different entities such as buildings, roads, streetlights during the pre-disaster phase; update the status of the entities in real-time and thereby, enables the government organizations to assess the total damages sustained by different entities during the post disaster phase. Thus, mobile GIS enables field operators to manage spatial as well as non-spatial data efficiently.

1.2. Motivation and problem statement

Most of the mobile GIS applications are used for field data acquisition and/or data validation. However, field operators often require information derived from data to take instant decisions in the field (Ali Mansourian, Farnaghi, & Taleai, 2008). For acquiring this valuable information, operators need a mobile GIS application which has sufficient geospatial analysis tools in the field. To utilize these tools in the field, this research introduces a concept called "Field GIS". Field GIS is a mobile GIS that can be viewed as an up-scaled version of a mobile data collector system or a downscaled version of a desktop GIS software. Field GIS is developed on a mobile device for georeferenced spatial data acquisition and spatial data analysis based on the combination of desktop Geographic Information Systems (GIS), positioning (e.g., by the Global Positioning System (GPS)) and intermittent server connections for data or functionality download. Recent advancements in mobile technology such as quad-core processors, expandable memory storage in smartphones and tablets have strengthened the basis to realise Field GIS. However, the use of these devices is hampered by constraints such as touchscreen-only, small displays and limited battery power. This raises the question, to what extent GIS functions can be incorporated in a Field GIS. This study examines this question using disaster management as a test case.

Geographic Information System (GIS), Remote Sensing (RS) and Global Positioning systems (GPS) have become important decision-making tools in disaster management (Thomas, Ertugay, & Kemec, 2007). Portability enables Field GIS as an excellent addition to desktop GIS especially in disaster management which demands rapid decision making to protect life and property (Mobaraki, Mansourian, & Malek, 2009). Even though there are mobile GIS applications available on the market that are used in the context of disaster management Rapid disaster reporting android application (ICIMOD, 2016), AEGIS (2015), AGTERRA(2016), these applications are predominantly used to report an incident, to find an optimal path to the disaster location or to map the damaged area. Field GIS, on the other hand, will be equipped with tools that are capable of performing geospatial analysis such as interpolation, filtering, finding the flow direction & flow accumulation and is targeted for field operators to assist them with on-the-spot analysis enriching field and office information. However, Field GIS needs to be configured with relevant GIS functions suitable for the particular phase of a disaster management.

Disaster management consists of four different phases: mitigation, preparedness, response and recovery. For each phase, GIS can play an important role. For example, it can be used for collecting large amounts of data to prioritize areas and evaluate current mitigation alternatives during the mitigation phase; for laying out the evacuation plans and risk assessment during the preparedness phase; for damage assessment,

response and relief coordination, aid allocation during the response phase; and for resource allocation during the recovery phase (Thomas et al., 2007). Thus, it is important to define the various steps that are involved in each phase of the disaster management to define the corresponding set of GIS functions.

Disaster Management is defined as the systematic process of using administrative directives, organisations, and operational skills to implement strategies, policies and improved coping capacities in order to mitigate the adverse impacts of hazards (UNISDR, 2007). Different hazards have their own spatial and temporal extent (Liu, Yang, & Li, 2012). Natural hazards such as floods and landslides are the most common and frequent disasters in hilly-mountainous areas. Landslides are triggered by rainfall and earthquakes (Pellicani, Van Westen, & Spilotro, 2014). Floods are caused by a steep mountain, rainfall, failure of artificial dams created as a result of landslides (Stoffel, Wyzga, & Marston, 2016). With 700 million people around the world living in mountainous areas, there is a need to assess and mitigate the landslides and flooding disasters (Bob Mckerrow, 2016). Hence, this study restricts to the disaster management of landslides and floods.

Thus, developing a Field GIS for disaster management aims to: support field operators with their on-the-spot analysis in the field; improve the risk perception of the people living in the disaster zone by communicating immediately about the current circumstances persisting in their environment; with less time involved, help to check the validity of the data collected in the field; consider community perspective and day-to-day experiences in the analysis (Mukherji, Ganapati, & Rahill, 2014). In addition, it can also provide useful preparatory information to the community and carry out rapid assessments in areas vulnerable to disasters.

1.3. Research Identification

The research proposes to define the concept of Field GIS by developing a procedure for identifying the geoprocessing tools required from an existing GIS software that are feasible to implement on a mobile device under the chosen scenarios to support on-the-spot analysis for field operators. There are four stages to this research, the first stage is concerned about the user requirement analysis. Secondly, developing a reproducible procedure for the construction of Field GIS. Thirdly, designing and implementing the prototype based on the developed framework. Finally, testing the prototype with the potential users.

1.3.1. Research Objectives

Main Objective:

To develop the concept of Field GIS: To establish a procedure for determining and implementing sufficient geoprocessing capabilities for field operators in a disaster management setting to support on-the-spot analysis to enrich field and office information.

There are four sub-objectives to this research,

1. To perform a user requirement analysis pertaining to the mitigation of landslides and floods.
2. To develop a reproducible procedure for the construction of Field GIS under different scenarios in the management of landslides and floods.
3. To design and implement a Field GIS prototype supporting the mitigation of landslides and floods.
4. To test the developed prototype with potential users.

1.3.2. Research Questions

- Questions related to first objective:
 - a) Who are the potential users of this research?
 - b) What are their requirements?
 - c) What are the potential use case scenarios in landslides and floods?
- Questions related to second objective:
 - a) What are the various factors to be considered for the construction of Field GIS?
 - b) What is the influence of the different factors considered?
- Questions related to third objective:
 - a) How to implement a combination of geoprocessing tools which run sufficiently on a mobile device under different scenarios of landslides and floods?
 - b) What functionalities can be implemented through client/server interaction and in such case, geoprocessing tool should reside on client versus server?
 - c) Which software (libraries) can be re-used?
 - d) What existing hardware is needed in different scenarios?
- Questions related to fourth objective:
 - a) Which type of usability method will be used to evaluate the performance of the Field GIS?
 - b) What can be done to improve the prototype?

1.4. Research Plan and Thesis structure

The research consists of four objectives: user requirement analysis (objective 1), development of a procedure for the construction of Field GIS (objective 2), implementation of the prototype (objective 3) and prototype evaluation with the potential users (objective 4).

Figure 1 shows the various steps followed in this research to accomplish the proposed objectives and to answer corresponding research questions. The first step of this research is to review the literature on how mobile GIS is being used in the field and discuss with potential users regarding potential usage scenarios of Field GIS. Thus, the identification of the added value of having the geo-processing tools in the field and the results of user requirements are discussed in **Chapter 2** and **Chapter 3** respectively.

Chapter 4 describes the procedure for the construction of Field GIS pertaining to disaster applications. **Chapter 5** explains the implementation of the prototype. **Chapter 6** presents the results of the prototype evaluation and the insights gained from the evaluation. Finally, **Chapter 7** describes the conclusion and recommendations as regards to the overview of research questions.

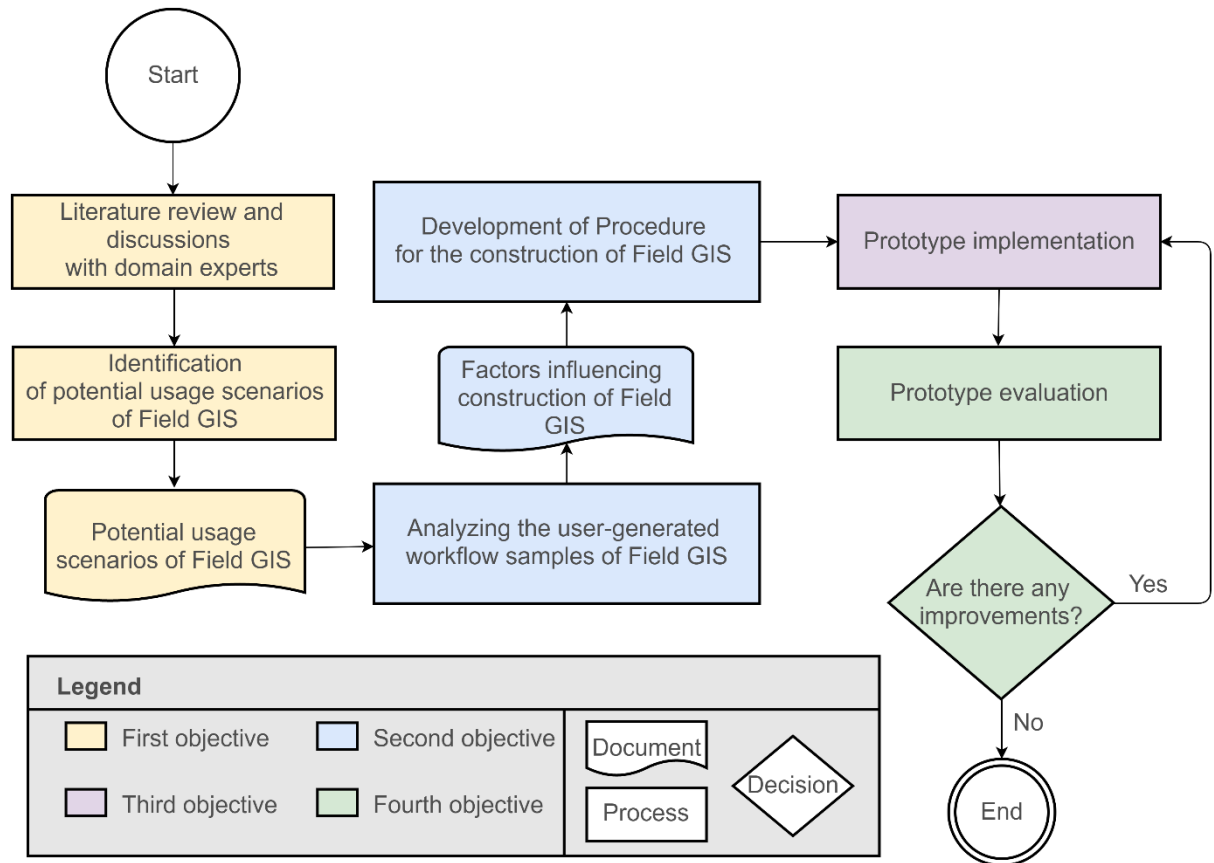


Figure 1: Research Plan

2. MOBILE GIS

2.1. Introduction

This chapter defines the concept of mobile GIS, the components of mobile GIS, lists mobile GIS applications from various fields and a review of scientific studies with respect to mobile GIS applications pertaining to the field of disaster management. By reviewing these information the chapter aims to unveil the capabilities of mobile GIS that ranges from a data collection system to a full-fledged GIS system. Thus, the chapter helps to understand the added value of a Field GIS i.e. a mobile GIS capable of processing spatial data when compared to a data collection system and also aids to construct potential use case scenarios of Field GIS pertaining to disaster management applications.

2.2. What is “mobile GIS”

Mobile GIS is defined as an “integrated software/hardware framework for accessing geospatial data and services through mobile devices such as Smartphones or tablets via wireless networks” (Tsou, 2004). There are two major application areas of mobile GIS: Location-based services (LBS) and Field-based GIS. Location-based services (LBS) focus on the location management functions such as navigation, finding a specific address or tracking a vehicle, whereas field-based GIS focus on spatial data collection, validation and updating in the field (EL-Gamily, Selim, & Hermas, 2010). However, mobile GIS functions by integrating components such as: mobile devices, mobile GIS software, positioning systems and wireless communications and server.

2.2.1. Components of mobile GIS

- **Mobile devices**

Mobile GIS extends the reach of a desktop GIS software to a broad range of mobile devices that includes: iPhones, iPads, Android smartphones and tablets, Windows tablet PC and Windows phone devices (esri, 2017).

- **Positioning systems**

Over the decades, positioning systems such as Global Positioning Systems (GPS) has been used to locate objects on the earth surface with great accuracy. Mobile devices with built-in GPS provide the opportunity to use these devices for carrying out GIS tasks in the field. The accuracy of the built-in GPS of the mobile devices such as smartphones and tablets mainly depend on factors such as: availability of GPS signals, Wi-Fi, cellular towers, area density and operating system used. Generally, the positional accuracy of the GPS in smartphones range from 10 meters – 30 meters (Aleks Buczkowski, 2016).

- **Mobile GIS software**

It is the software loaded with GIS basic functionalities such as navigation, feature identification and attribute edition as the mobile devices are limited in processing power and screen size. Mobile GIS software are usually based on these paradigms: GPS-centric to enable collection of field data, offline digitising (points, lines and polygon), measuring, displaying, data synchronisation and less but larger buttons (Marco, 2015).

- **Wireless communication**

Wireless communication is mainly responsible for the linkage between the mobile device and the server. The wireless communications are enabled either using Wi-Fi network or a mobile data network. Wireless communications are used for tasks such as: to synchronize data collected and/or updated in the field with the server, to access the large-sized GIS layers and services stored on the server.

- **Geospatial Server**

The geospatial server is the storehouse of large-sized spatial data and powerful geo-services such as Web Map Services, Web Feature Services, Web Processing Service and Web Coverage Service. GeoServer, MapServer, OpenLayers, MapFish and OpenStreetMaps are some of the examples of open source geospatial servers (Caitlin Dempsey, 2016).

2.2.2. Applications of mobile GIS

Recent scientific studies indicate a rise in usage of mobile GIS due to the proliferation of smartphone technology. This section gives a review of mobile GIS applications over the past decade to understand how the proliferation of smartphone technology has impacted the field of mobile GIS. Rizzini, Gardiner, Bertolotto, & Carswell (2006) developed a mobile GIS prototype “Mobile Environmental Management System (MEMS)” for managing the spatial and the attribute data of the fish species at risk. Li & Jiang (2011) developed a mobile GIS for field mapping and storing attribute data of forest resources. Zhao, Deng, Zhang, & Zeng (2012) developed a mobile GIS application for the inspection of power-line distribution. It was used for navigating to particular power-line for inspection and transmission of collected attribute data regarding the power-line through wireless networks. Khan et al., (2016) developed a mobile GIS app that provided an efficient way to collect, edit and update transportation related assets such as road signs, roads and parking lots in the field. Pierdicca et al., (2016) developed a mobile GIS application integrated with augmented reality (AR) engine to enrich riverbank inspections by overlaying the information on the mobile screen with the same point of view of the camera, providing an intuitive visualization of buffer zone location around the riverbank. The application aided in enhancing the user’s cognition about the surroundings by integrating multiple datasets in one view. Thus, the journey of mobile GIS that started as a mobile data collector for efficient management of spatial data in the field has reached the point where mobile GIS is also capable of processing the data in the field (Geospago, 2016).

2.3. Mobile GIS in the context of disaster management

Mobile GIS facilitates the access to up-to-date, reliable and accurate spatial data that is very crucial for collaborative decision-making in the context of disaster management (A. Mansourian, Rajabifard, Valadan Zoej, & Williamson, 2006). Tsou & Sun (2006) discussed the applications of mobile GIS in the three phases of disaster management: preparedness, response and recovery. They distinguished between long-term planning tasks and the tasks in the response phase of the disaster management. The distinction was based on the response time, number of users and map types used. For example, the response phase of the disaster management involves little response time to save human lives, more number of users involving the locals, rescue teams who lend their hand for saving other human lives and a simple map-interface so that the operations are simple and straightforward for the response teams carrying out the rescue operations. In the case of landslides and floods, during the pre-disaster field investigations, operators use mobile GIS to collect data regarding landslide type, subtype, relative age and depth (Abella & Van Westen, 2007). In order to identify the added value of a mobile GIS with processing capabilities, the Sections 2.3.1 and 2.3.2 present scientific studies in which mobile GIS was used as a mapping tool and as a computing platform in the context of disaster management.

2.3.1. Mobile GIS as a mapping tool for disaster management

To stay in roads with current smart technologies, only scientific studies that used smartphones and tablets as mobile GIS over the past decade are listed in this Section and in Section 2.3.2. De Donatis & Bruciatelli (2006) developed Map IT a GIS software on a tablet PC for digital data capture and digital mapping. It used built-in GPS of the tablet PC for capturing data points, lines & polygons. It was used for geologic applications such as mapping stratigraphic boundaries, marker beds and fault traces. Later Map IT was also used for landslide mapping in Italy using a Tablet PC (G Gallerini, Bruciatelli Lorenzo, Mauro De Donatis, 2007). Map IT was one of the few mobile GIS applications built with geoprocessing tools. However, it was only used as a mapping tool for field data acquisition and is brought by Geopaparazzi a mobile GIS used for qualitative geological surveys (Geopaparazzi, 2016).

2.3.2. Mobile GIS as a computing platform for disaster management

EL-Gamily, Selim, & Hermas (2010) developed a wireless mobile field-based GIS for crisis management. The field-based GIS was designed to manage the fire event with some basic GIS analysis tools relevant only to the response phase of the disaster. The basic GIS analysis tools were path selection for finding the shortest paths between fire stations and the location of the fire event and buffer analysis tool for finding the initial spatial extents of the fire event at the server-side. Athanasis et al. (2015) developed a mobile application named “AEGIS” for windows phones. The application was built to support wildfire management in Greece and also for some parts of Europe. The mobile application supports basic GIS functions such as routing, spatial search for closest facilities, firefighting support infrastructures. In addition to this, it provides access to the remote automatic weather stations (RAWS) for displaying real-time weather data. It also utilizes the services of “Cortana” (artificial intelligence developed by Microsoft for Windows phones) for issuing voice commands. Disaster Reporting Application: An android application for reporting disaster was developed by a joint collaboration of International Centre for Integrated Mountain Development (ICIMOD) and Kathmandu University, Nepal. This application was not only used as a reporting tool, it also included a specific functionality named “geo-fencing” which creates a virtual boundary around the user’s current location (ICIMOD, 2016). A Disease Incidence Reporting Application (DIRA) was used to analyse the cholera outbreaks in Uganda for providing timely response and service to the people (Martin Klopfer, 2013). Kim, Kerle, & Gerke (2016) developed mobile GIS integrated with AR technology to carry out rapid and accurate assessments of building damages by overlaying pre-disaster images of buildings (virtual data) on actual post-disaster scenario (real world data).

2.4. Data collection vs Data processing

Table 1 compares all the scientific studies of mobile GIS applications stated in Sections 2.2.2, 2.3.1 and 2.3.2 in order to identify the added value of a Field GIS application. The table starts with general applications of mobile GIS presented in Section 2.2.2. and then moves on to compare mobile GIS applications restricted to disaster management.

Table 1 Added value of mobile GIS app capable of spatial data processing

Scientific Literature	Purpose of mobile GIS	Data processing	Added value
Rizzini, Gardiner, Bertolotto, & Carswell (2006)	Mobile GIS was used to collect spatial and attribute data regarding endangered fish species	-	Effective management of spatial data
Li & Jiang (2011)	Mobile GIS was used for field mapping and storing attribute	-	Effective management of spatial data

	information of forest resources		
Zhao, Deng, Zhang, & Zeng (2012)	Mobile GIS was used for managing information regarding powerlines in the field	Navigation tool	With navigation capability enables field workers to inspect the damaged powerline as quickly as possible
Khan et al., (2016)	Mobile GIS was used for managing data regarding transportation related assets in the field	-	Effective management of spatial data
Pierdicca et al., (2016)	Mobile GIS was used to carry out riverbank inspections	Mobile GIS integrated with AR technology	With the help of AR, the mobile GIS enhances the user's cognition by integrating multiple datasets in a single view
G Gallerini, Bruciatelli Lorenzo, Mauro De Donatis (2007)	Mobile GIS was used for landslide mapping in the field	-	Effective management of spatial data
EL-Gamily, Selim, & Hermas (2010)	Mobile GIS was used by firefighters to reach the spot as soon as possible	Navigation tool and Buffer tool	With navigation capability enables firefighters to reach the destination as quickly as possible and buffer tool enables the firefighters to define the spread of the fire event
Martin Klopfer (2013)	Mobile GIS was used by field doctors to register data about new cholera cases	Time Slider functionality	With the time slider, the application identifies the patterns of cholera outbreaks which enables the field operator to take rapid action to prevent the spread of the disease
Kim, Kerle, & Gerke (2016)	Mobile GIS was used to carry out rapid building damage assessments in the field	AR technology	By integrating multiple datasets in a single view, enables field workers to make rapid and accurate assessment of building damages

3. FIELD GIS REQUIREMENTS

3.1. Introduction

The purpose of this chapter is to describe the various steps that was followed to obtain the information about the geo-processing options that can support field workers pertaining to disaster management. The chapter starts with the identification of the potential users, followed by the methods that were used for gathering and refining the requirements acquired from potential users. The refined user requirements are presented as workflow diagrams in Sections 3.5.1, 3.5.2 and 3.5.3. Finally, the chapter concludes with Section 3.6 which discusses the shortcomings and breakthroughs of the requirements stage.

3.2. Identification of potential users

As this research is focused on disaster management, the potential users of Field GIS are United Nations Development Programme (UNDP), World Bank, International Federation of Red Cross and Red Crescent Society (IFRC), MapAction, Doctors without Borders and other organizations involved in disaster management or disaster research. These organizations deploy field workers or volunteers in disaster prone areas for risk reduction and management. I got the opportunity to discuss with four disaster risk specialists from World Bank and some faculty members of ITC in the department of Earth System Analyst (ESA). Table 2 lists the users consulted for gathering the user requirements.

Table 2 Potential users

Name	Designation	Organization
Prof Dr Victor Jetten	Professor	ESA, ITC
Dr C.J Van Western	Associate Professor	ESA, ITC
Dr Olga Mavrouli	Assistant Professor	ESA, ITC
Dr Norman Kerle	Associate Professor	ESA, ITC
Dr Melanie Kappes Simone	Disaster Risk Specialist	World Bank
Dr Rashmin Gunasekera	Disaster Risk Consultant	World Bank
Dr Carolina Rogelis Prada	Consultant	World Bank
Vivien Deparday	Disaster Risk Specialist	World Bank

3.3. Gathering user requirements

The user requirements were gathered by presenting a user with the possible usage scenarios of Field GIS. Usage scenarios provides the setting (context or environment), tasks or activities to be performed and the goal that a user achieves by the end of the tasks. It helped to structure meetings with domain experts and served as a quicker way of gathering both the functional and non-functional requirements (Herman & Heidmann, 2002). Four preliminary usage scenarios of Field GIS pertaining to landslides and floods were constructed based on literature review and the discussions with potential users from the World Bank and faculty members of ITC. The four preliminary usage scenarios were: generating DEM in the field, exposure assessment, proximity analysis and the assessment of landslides using reach angles. The usage scenarios were written using the structure shown in Table 3.

Table 3 Structure of the usage scenarios

Fields	Significance
Title	The title of the use case scenario
Brief Description	Description of the use case scenario
Functionality Needed	List the GIS functions needed for the scenario
Importance of performing the operation in the field	Explains about the need for performing a particular functionality in the field
Basic Flow	Sequence of tasks that the user needs to perform in the scenario
Scope	Lists the added value that a particular scenario brings to the application
Limitations	Lists the limitations of the scenario

The structure of Table 3 was chosen in order to eliminate the perception of mobile GIS as a data collector and emphasize more on the added value of a mobile GIS that is capable of processing the data in the field. The complete details of the usage scenarios are presented in Appendix A.

3.4. Refinement of usage scenarios

The four usage scenarios were refined from time-to-time based on the feedback given by the domain experts: Dr Cees Van Western and Prof Dr Victor Jetten, Department of Earth Analyst Systems, ITC. The refinement process resulted in three concrete usage scenarios of Field GIS. These refined usage scenarios were translated into workflow diagrams for better understanding of the inputs required, GIS processes that are executed either locally on the mobile device or on the server and the outputs generated for each potential application of Field GIS. Workflow diagrams are business processes that represent a specified flow of activities or tasks from an initial point to an end point of a project (PNMSOFT, 2017). There are various techniques for modelling a business process: Gantt charts, flow charts, Activity Diagram, Data Flow Diagram (DFD), Functional Flow Block Diagram (FFBD), Program Evaluation and Review Technique (PERT), Control Flow Diagram (CFD), Unified Modelling Language (UML) and Business Process Model Notation v2.0 (BPMN). Workflow diagrams provides a bird's eye view of a project that would help in assessing the feasibility and validity of a project (Edraw, 2017). The three workflows depicting potential usage scenarios of Field GIS are presented in Sections (3.5.1, 3.5.2 and 3.5.3) of this thesis.

3.5. Creation of workflow diagrams

Draw.io, an online workflow marker was used to create the workflow diagrams. There are seven rules for creating the workflow diagram: defining the purpose of the workflow, identifying the process, naming the process, identifying a clear start point and terminal point, drawing the series of steps that happen between the start point and the terminal point, considering alternate processes for each step and finally, limiting the number of notations/symbols to avoid confusions (Edraw, 2017). Figure 2 shows the visualisation elements that were used for the construction of workflow diagrams. For the straightforward construction of workflow diagrams, only a limited number of shapes and colours were used. The shapes and colours were limited to an extent that there were enough to differentiate between different components of interest. The workflow diagrams differentiate the components such as the type of inputs required (raster/vector/non-spatial or tabular data), storage area of these inputs/outputs (locally stored on the mobile device/stored on the server), type of manual inputs in the field (input from locals/input from experts/input from both) and the type of processing of geospatial and/or attribute data (locally processed on the mobile device/processed on the server). The workflows for the following applications were constructed: exposure assessment, landslide

reach and the flood depth. Sections 3.5.1, 3.5.2 and 3.5.3 describe the details regarding the inputs required, GIS processes executed and the outputs generated for each application of Field GIS.

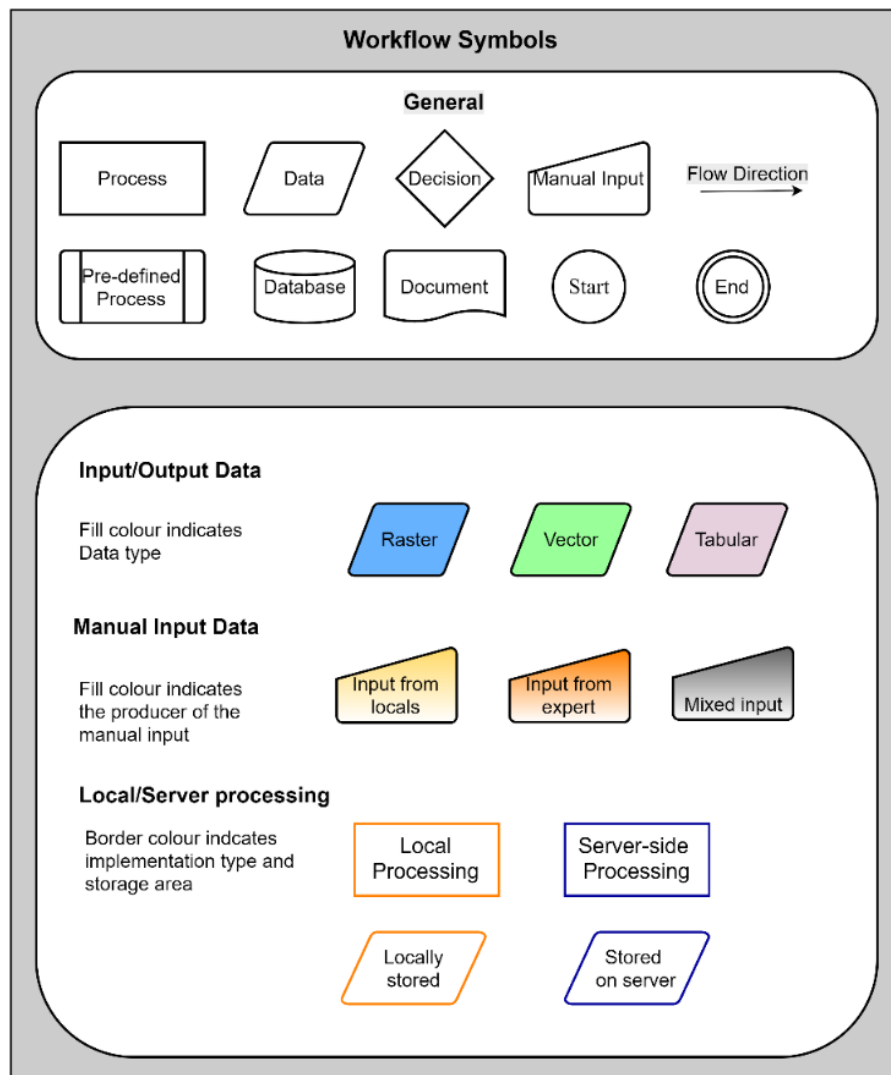


Figure 2: Visualization elements used for the construction of workflows of Field GIS

3.5.1. Exposure assessment

The exposure assessment workflow provides the opportunity for the field workers (Section 3.2) to perform the cross operation and table calculations on-the-spot in the field (as shown in Figure 3). Field workers can use the results of these operations to provide concrete evidence to a stakeholder e.g. government official if he/she is present with the field worker. These would enhance the government official to take rapid action in the field.

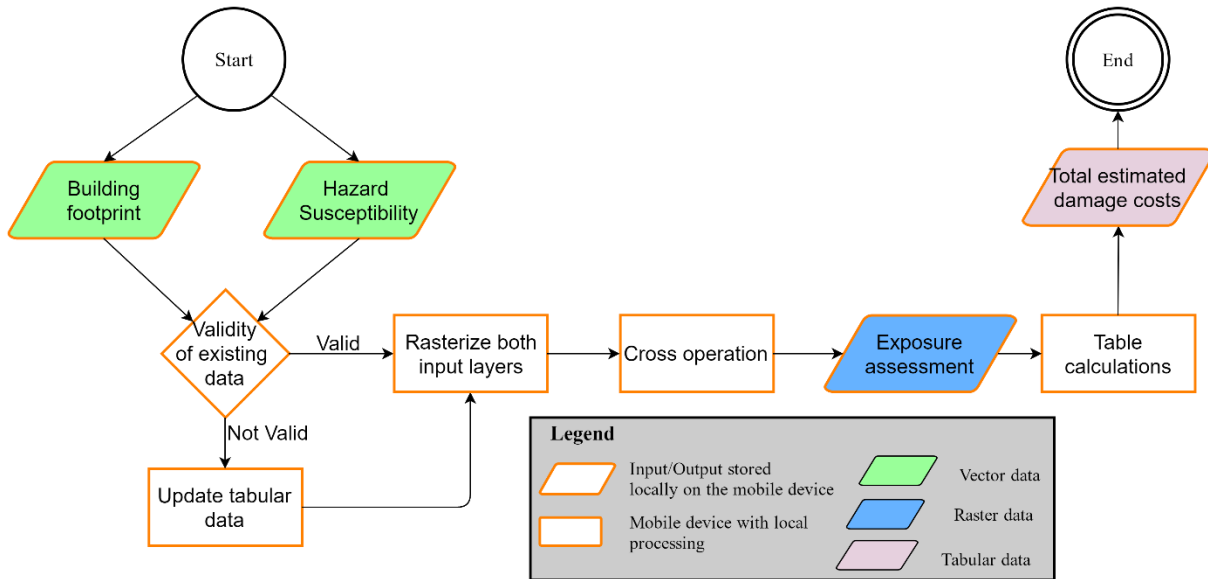


Figure 3: Exposure Assessment

Inputs required

- Hazard susceptibility map depicts the level of vulnerability of each zone (eg. Low, medium, high) and building footprints map depicts the two-dimensional representation of buildings present in the area.
- Google maps with the current location of the user is used as background.

Processes executed

- Updating the attributes in the building footprints table and the hazard susceptibility table if they do not reflect the ground situation.
- Rasterize both input layers, so that they can be used for the cross operation as an input for the next step.
- Cross operation of rasterized hazard susceptibility map and the rasterized building footprint map.
- Table operations such as update, aggregate functions to find the damage cost associated with each building unit.

Outputs generated

- Updated attribute table of building footprint and hazard vulnerability maps.
- Exposure map depicting the number of building exposed to the hazard for the current location of the user and his surroundings.
- Table showing the total damage cost for an area.

3.5.2. Flood depth

The flood depth workflow enables the field worker (Section 3.2) to create a continuous raster map depicting the flood susceptibility instantly in the field. The resultant raster layer is created based on the flood water-level information given by the locals and/or by the field worker through visual markings on the doors or walls of the house. As the resultant layer is based on a voluntary-based information, it can be cross-checked with the digital elevation model of the area before using the layer for further analysis. The flood depth workflow also provides the field worker to perform the cross operation of the flood susceptibility map and the building footprint for visualising the total area exposed to floods (as shown in Figure 4).

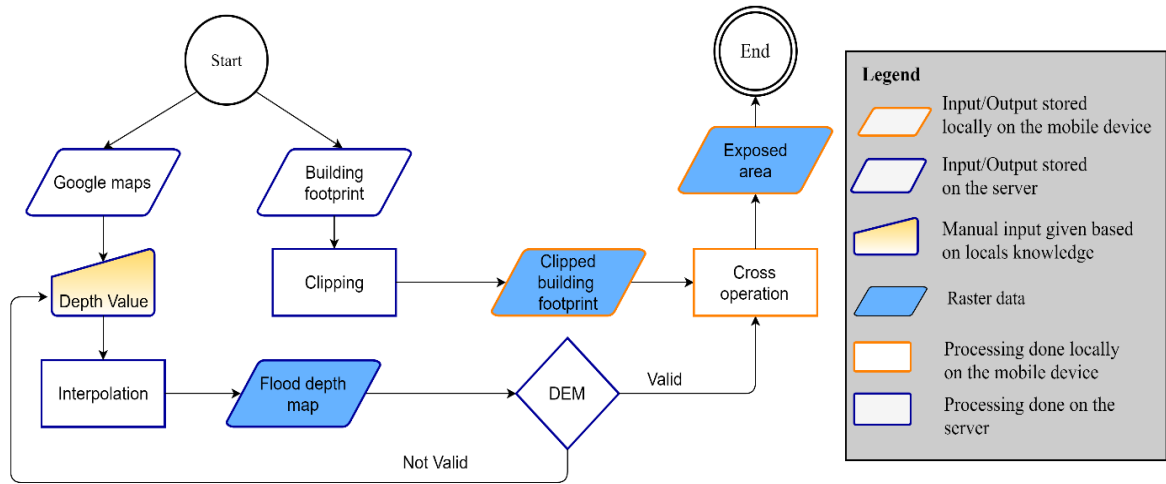


Figure 4: Workflow diagram of flood depth app

Inputs required

- Google maps with the current location of the user is as background.
- Building footprints map depicts the two-dimensional representation of buildings present in the area.
- Manual input of flood-depth based on the information given by the locals.

Processes executed

- Interpolation of the flood depth values to generate a continuous surface.
- Clipping of the building footprints data based on the location of the user.
- Cross operation of clipped building footprint data and the resultant flood depth raster layer.

Output generated

- A raster layer depicting continuous flood-depth after interpolation.
- Clipped building footprints data based on the extent given by the user.
- Exposure map depicting the number of building exposed to flood for the current location of the user and his surroundings.

3.5.3. Landslide reach

The landslide reach workflow enables the field worker (Section 3.2) to assess the safety of the present and future settlements by evaluating the reach of a landslide. The landslide reach is based on the empirical runoff model created by Jordi Corominas. Corominas (1996) analysed log-log plot between the tangent of the reach angle and the landslide volume of 204 landslides and established the empirical relationship between the tangent of the reach angle and the volume of the landslide. Figure 5 shows the workflow diagram of landslide reach.

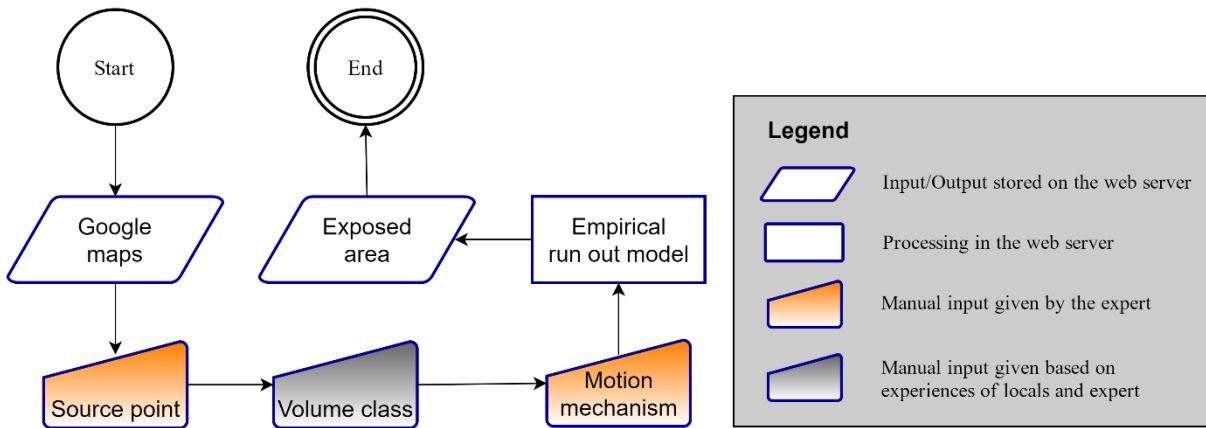


Figure 5: Workflow diagram of landslide reach app

Inputs required

- Google maps with the current location of the user is used as background.
- Selecting the source point/starting point of the landslide, estimated volume and the type of movement.

Processes Executed

- Execution of the empirical runout model. The explanation of the empirical runout model is provided in Appendix B

Output generated

- The exposure of the field worker's location to a landslide type (rockfall, translational slides, debris flow, earth flows) initiating from a particular source point and volume.

3.6. Discussions

The potential usage scenarios were gathered through discussions with potential users. Three potential usage scenarios were formulated based on the discussions with disaster risk specialists from the World Bank and the faculty member of Earth System Analyst (ESA), ITC. Insights gained from these discussions aided in defining the need for geospatial analysis tools in the field and the opportunities it provides: improves risk perception of the people living in the disaster zone, as a validation of collected data with less time involved, integration of local knowledge in the analysis and rapid assessments in the field. The three potential usage scenarios were translated into workflow diagrams for better identification of inputs, processes executed and outputs generated. In order to gather more usage scenarios of Field GIS pertaining to disaster management, the workflow diagrams (Sections 3.5.1, 3.5.2 and 3.5.3) were sent to disaster organizations such as MapAction, Federal Emergency Management Agency (FEMA) and also shared with an online forum "Open forum on Participatory Geographic Information System and Technologies". However, there were no proper response from both the forum and the organizations. Therefore, the research proceeded with the three workflows representing the usage scenarios of Field GIS.

4. PROCEDURE FOR THE CONSTRUCTION OF FIELD GIS

4.1. Introduction

The purpose of this chapter is to describe the procedure that was developed for the construction of a Field GIS pertaining to the field of disaster management. The chapter starts with the identification of the factors that influence the construction of a Field GIS pertaining to the field of disaster management. Section 4.3 provides the list of software libraries that are available for implementing the GIS analysis tools on a Field GIS. Section 4.4 describes the existing ways for gathering more user-generated workflows of Field GIS from various application fields. Finally, the chapter concludes with Section 4.5 which discusses the overall process of this chapter.

4.2. Factors – construction of Field GIS pertaining to disaster management

4.2.1. Identification of Factors

There are two basic factors influencing the construction of a Field GIS: first, the need for the Field GIS i.e. defining the need for performing geospatial analysis in the field. The second factor is the extent of geospatial analysis tools that can be incorporated on a smart device such as tablet or smartphone. These two factors, in turn depend on multiple factors that were identified from workflow diagrams (see Sections 3.5.1, 3.5.2 and 3.5.3) obtained from the user requirement analysis stage of this research.

4.2.2. Why do we need Field GIS?

A detailed examination of the three workflow diagrams: landslide reach, flood depth and exposure assessment led to the identification of three factors that mainly influence the need of a Field GIS. The three factors are urgency of the situation, integration of local knowledge and the awareness of the current situation or situational awareness.

The urgency of the situation

Application fields such as disaster management are very dynamic in nature always involve confusion and urgency. Given the urgency of the situation, field workers (see Section 3.2.) need to produce rapid and informed decisions instantly in the field. The outcomes of these decisions made during disasters are very important as they involve human life and property (Withanaarachchi & Setunge, 2014). For example, during a fire event, the firefighters deploy location-based mobile GIS apps such as Google Maps, customizable ArcGIS mobile apps to obtain the shortest path to the destination (Matteo Luccio, 2010). With less time involved to save human lives, the situation demands firefighters to make a rapid and an informed decision for reaching the destination as quickly as possible.

Integration of local knowledge

Integration of local knowledge facilitates the field workers (see Section 3.2) to engage with the local communities. It allows field workers (see Section 3.2.) to recognise the values of the community. Disaster management is one of the application fields that considers the integration of local knowledge as an integral part of the disaster risk management (Graciela Peters Guarin, 2008). Some data acquired from the people are time sensitive, people tend to forget or give a misleading perception of the environment. So, there is a need to validate the data acquired from the local people to avoid frequent re-visits to the site. Mobile GIS with processing tools and access to reference data empowers field workers to cover all basis that validates the reliability of the acquired data from the local communities and increases the confidence of the field workers to utilize the data for further analysis.

Situational awareness

The ultimate main purpose of Field GIS is to entrust the field workers with a concrete information about the current status prevailing in a location. For example, FreeStyle Libre system is a wearable sensor system developed to monitor the blood sugar levels for people with diabetic condition. A small wearable sensor is worn on the upper arm of the users which measures the blood levels beneath the skin of the user. The user can visualize the recorded sensor information by using a smartphone. The smartphone scans the FreeStyle sensor system and displays the patterns of the past, present and the future blood sugar levels. These wearable devices are based on lightweight optical sensors that detect the blood flow through the human body (James Stables, 2016). Thus, when a diabetic patient is on the move, the information provided by these devices enables the patient to take informed decisions about his/her diet, activities, insulin dosing and other healthcare conditions that are crucial for survival (Abbott, 2016).

4.2.3. Extent of geospatial analysis tools on a Field GIS app

The functionality spectrum of a mobile GIS ranges from a data collector system to a full-fledged GIS (as shown in Figure 6). Field GIS is located along the functionality spectrum of mobile GIS between the simple data collection system and the full-fledged GIS system.



Figure 6: Functionality spectrum of mobile GIS

The extent of geospatial analysis tools that can be incorporated on a Field GIS, classifies it along the functionality spectrum of the mobile GIS. The extent of geospatial analysis tools on a Field GIS is influenced by factors such as expertise of the user, type of data inputs/collected in the field, processing options, the need for accessing additional geo-data source and the need for network connectivity. These five factors determine the type of Field GIS that can be deployed in the field. Figure 7 shows the interaction between the various factors influencing the classification of Field GIS.

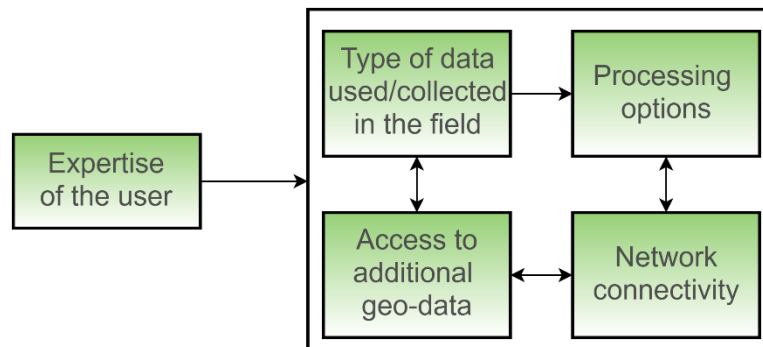


Figure 7: Factors influencing the classification of Field GIS

The expertise of the user is based on the knowledge of geo-information technology as well as the corresponding application field. The expertise level can be classified as novice, intermittent and expert. The expertise level of the user directly influences the type of data used/collected in the field which has a direct influence on the processing options, access to additional geodata and network connectivity.

A novice user has a basic knowledge of geo-information technology and corresponding application field. A novice user is capable of collecting spatial data using the built-in GPS of the smartphone, a simple map interface such as Google Maps, OpenStreetMap (OSM) with basic measurement tools to calculate the

length, area and location-based services such as points of interest, route selection, etc. However, the novice user is not provided with access to additional geodata layers as the user does not possess sufficient knowledge in the geo-information technology. Thus, the Field GIS used by the novice user closely oriented towards the left-most part of the functionality spectrum of mobile GIS i.e. the data collection functionality.

An intermittent user has a sufficient knowledge of geo-information technology and the corresponding application field. An intermittent user is capable of collecting spatial data using the built-in GPS of the smartphone, a simple map interface such as Google Maps, OpenStreetMaps (OSM) with basic measurement tools, location-based services and also access to additional geodata layers through the available networks or local storage. Thus, the Field GIS used by the intermittent user is placed in the middle part of the functionality spectrum of mobile GIS as it enables the user to collect spatial data as well as to edit existing spatial data in the geodata layers.

An expert user has vast knowledge of geo-information technology and the corresponding application field. An expert user is capable of collecting spatial data using the built-in GPS of the smartphone, a simple map interface with basic measurement tools, access to both additional geodata layers and geoprocessing functions such as interpolation, cross operation, rasterization, flow direction that can be implemented using GIS open-source libraries such as Integrated Land and Water Information System (ILWIS) python API, Python Quantum GIS (Pyqgis) and Geospatial Data Abstraction Library (GDAL)/OpenGIS Simple Features Reference Implementation (OGR). These scripts can be either accessed locally on a mobile device or on a server through available networks (e.g. portable server or the internet). Thus, the Field GIS used by the expert user is oriented towards right-most part of the functionality spectrum of mobile GIS as it empowers the user to collect spatial data as well as to leverage required spatial analytical tools through the network.

4.3. Tools for constructing a Field GIS

The functionalities of a Field GIS can range from a simple map display with atomic tools to complex GIS analysis tools (as shown in Figure 8). There are many software libraries such as Google Maps API, OpenLayers API, Pyqgis, GDAL/OGR and ILWIS python that can be used for implementing these analysis tools on a Field GIS. However, a simple and clear-cut classification of GIS analysis tools would enable efficient identification of the software libraries that are feasible for implementing a particular set of GIS analysis tools. Section 4.3.1. provides the information of the adopted classification of GIS analysis tools followed by Section 4.3.2. which provides the overview of existing software libraries that can be used for building a Field GIS.

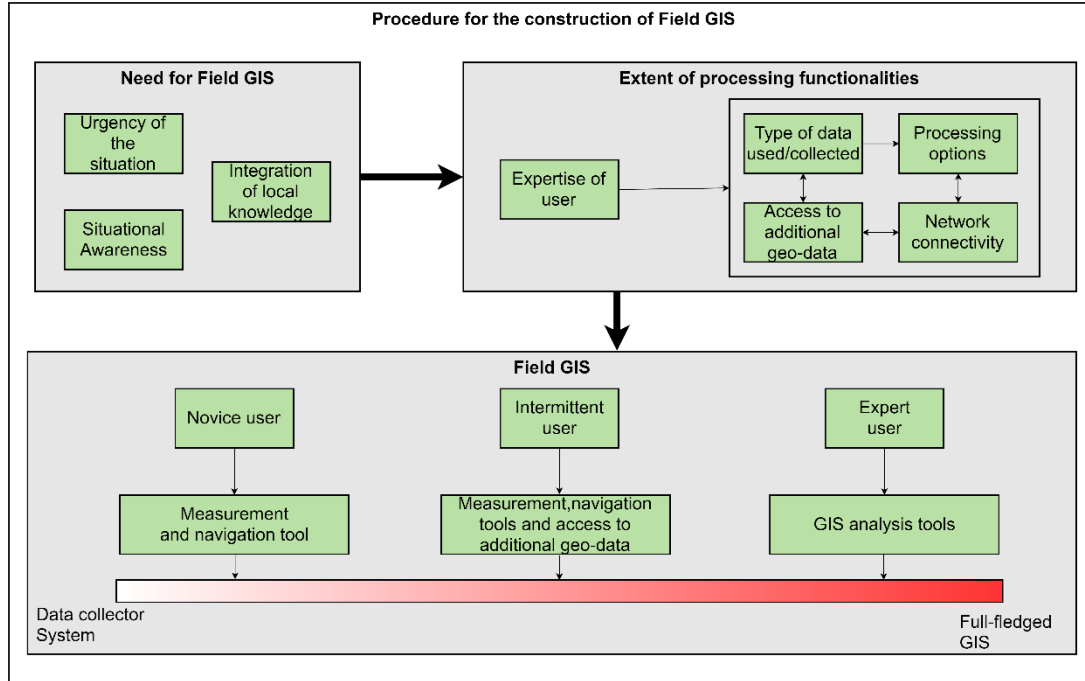


Figure 8: Procedure for constructing Field GIS apps

4.3.1. Classification of GIS analysis tools

A simple and straightforward classification of GIS analysis tools would enable efficient identification of the GIS functionalities provided by different software libraries. Johannes Brauner, (2015) provides a detailed description of the classifications of GIS analysis tools from prominent scientific literatures such as Tomlin's Map Algebra (Tomlin, 1990), the Egenhofer operators (Egenhofer & Franzosa, 1991), Albrecht's 20 universal GIS operations (Albrecht, 1996), Kuhn's core concepts of spatial information (Kuhn, 2012), (Goodchild, 1987) and further classifications from GIS text books such as (Aronoff, 1989), (Burrough & Mcdonnell, 1998) and many others. After reviewing all these classifications, Johannes Brauner (2015) concluded that classification of Stan Aronoff (1989) provides a user friendly view of the GIS analysis tools. Stan Aronoff (1989) classification of GIS analysis tools provides four straightforward classes: maintenance and analysis of the spatial data, maintenance and analysis of attribute data, integrated analysis of spatial and attribute data and output formatting (Johannes Brauner, 2015) (as shown in figure 9). For this research such a classification which groups the functionalities based on the type of data would clearly qualify as a winner. Because the type of data collected or used in the field plays an important role in deciding the extent of functionalities that can be incorporated on a Field GIS (see Section 4.2.3). Therefore, this research would adopt the Aronoff's classification of GIS analysis tools for efficient identification of the GIS functionalities provided by different software libraries.

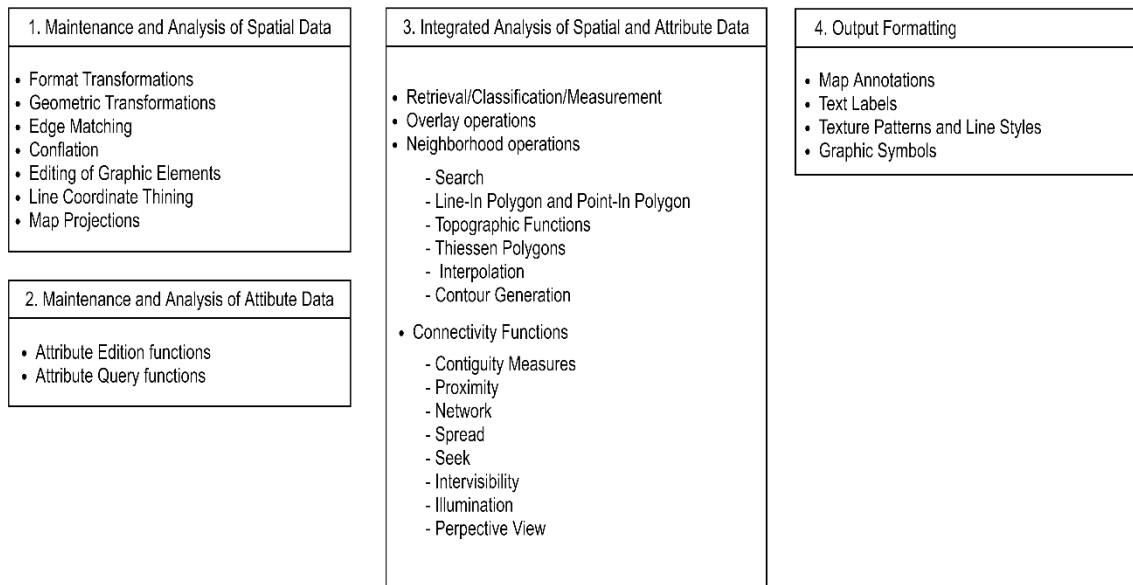


Figure 9: Aronoff's classification of GIS analysis tools (Aronoff, 1989)

Maintenance and Analysis of Spatial Data

Spatial data refers to the data that is stored as coordinates and topology. The GIS functions used for the analysis and maintenance of spatial data: format transformations, geometric transformations, map projections, conflation, editing of graphic elements, line coordinate thinning and edge matching. These operations are used for pre-processing the data such as validating for data completeness, removal of sliver polygons, etc. In the case of Field GIS, these geo-processing tools would be useful in GPS tracking applications to snap the GPS points to accurate positions similar to the functionality provided by Google roads API service (Google, 2017b).

Maintenance and Analysis of Attribute Data

Attribute data refers to the tabular data appended to the spatial features. There are four types of attribute data: character data, numerical data, date/time data, binary large object (BLOB). Attribute data linked to a spatial feature can be manipulated and queried within a GIS environment (Caitlin Dempsey, 2013). The current scenario of mobile GIS applications are leveraging these functions for effective data collection in the field.

Integrated Analysis and Maintenance of Spatial and Attribute Data

This class contains the more powerful tools of GIS. They enhance the concept of Field GIS as they have the ability to manipulate both spatial and non-spatial data for deriving valuable information except measurement and the retrieval tool does not change the original data. The other operations such as classification, overlay operations, neighbourhood operations and connectivity operations manipulate the contents of the GIS database to produce valuable information. Overlay operations refers to the manipulation of two input data sets using either mathematical functions or logical operators. Neighbourhood operators manipulate the characteristic of the area surrounding a specific location. Lastly, connectivity tools operate over an interconnected network of lines for resource allocation, route planning and network loading (Albert, Gesler, & Levergood, 2000). The main objective of this research is to bring these GIS functionalities to the field.

Output formatting

The output formatting refers to a set of tools that are used to present the map with additional information using annotations, text labels, texture patterns, line styles and graphic symbols. In the case of Field GIS, these operations would be useful only if a government official or a stakeholder is present during the field work.

4.3.2. Software libraries for Field GIS

This section introduces the software libraries that can be used for building the Field GIS with functionality ranging from a simple map display to sophisticated GIS analysis tools. The software libraries start from data collection and visualization tools, followed by the web mapping APIs and finally, the open source python libraries for implementing sophisticated GIS analysis tools.

Data Collection and Visualization tools

Data collection and visualization tools such as Open Data Kit (ODK, 2017), KoBoToolbox (2017), Formhub (2017) and Geographical Open Data Kit (2017) are effective tools for collecting data in the field both in online and offline mode and it consists of three common steps:

- Design data collection form using an online form builder provided by the web interface of the data collection tools or upload the survey form in XLSform format created using Excel sheet.
- Collect data using mobile devices and upload to server based on the availability of network connectivity.
- Extract the collected data in the form of comma separated values (CSV) problems, Keyhole Markup language (KML), JavaScript Object Notation (JSON) and other useful formats.

Table 4 shows the difference between the open-source data collection tools in terms of form creation, export formats, Google play store applications and mapping capabilities.

Table 4 Difference between the open-source data collection tools

Process	ODK	KoboToolbox	Formhub	GeoODK
Form Creation	ODK build or upload XLSForm	KoboForm interface	Formhub form interface	Upload XLSForm
Export formats	CSV, KML, JSON	ZIP, CSV, KML, XLS, CSV	CSV, KML, JSON	Shapefile, CSV, KML
Google Play store application for offline data collection	ODK Collect	KoBoCollect	It is based on ODK Collect	GeoODK Collect
Mapping Capabilities	The collected data points are visualized on a web interface	The collected data points are visualized on a web interface	The collected data points are visualized on a web interface	Provides a map interface within the mobile application for collecting points, lines and polygons. It also provides tools for uploading custom map layers

Web Mapping APIs

A web mapping API includes classes and methods for maps which enables users to create an interactive and dynamic map without writing any lower-levels of code. There are many web mapping API such as Google Maps API, Microsoft Bing Maps API, Mapbox API, MapQuest API, OpenLayers API (Janet Wagner, 2015). Most of the services offered by these APIs are similar such as Map service, elevation service, geolocation service. However, they differ in two aspects: data source and usage limits of the services. For instance, Table 5 shows the different usage limits up to which the elevation service is free and elevation data sources offered by different APIs: Google (2017a), Microsoft (2017), MapQuest (2017). But, OpenLayers is an open-source web mapping API is not restricted to these usage limits, user can also cache map tiles on the device and user can also upload custom map layers to his/her own web application using OpenLayers (OpenLayers, 2017). There are many other examples of open-source web mapping APIs: GeoServer, GeoMajas, MapServer, MapFish and OpenWebGIS, MapGuide open source (Caitlin Dempsey, 2016). The prominent open source web mapping APIs over the past five years are OpenLayers and Geoserver (Google Trends, 2017b).

Table 5 Usage limits and Data source of Elevation service provided by various APIs

Elevation Service	Google Maps API	Microsoft API	MapQuest API
Usage limit per day	2500 requests	2700 requests	500 requests
Data source	Information not revealed	Information not revealed	Shuttle Radar Topography Mission (SRTM)

Open-source software libraries for Sophisticated GIS analysis tools

Integrated Land and Water Information System (ILWIS), Quantum GIS, Flow Map, Geographic Resource Analysis Support System (GRASS), Open Jump GIS, GDAL/OGR, etc are some of the common open source modules that provides comprehensive GIS analysis tools ranging from measurement tool to network analysis. Table 6: provides an overview of some prominent software libraries that can be used to implement the GIS analysis tools on a Field GIS.

Table 6 Software libraries

Software libraries	Description	Functionalities From Aronoff's Classification
Data collection and Visualization tools		
OpenDataKit (ODK), KoboToolbox, Formhub, GeoODK	These tools are used to collect, store and visualize data in the field.	Maintenance and analysis of attribute data
Web Mapping APIs		
Google Maps API	Google Maps API is the most prominent web mapping API over past five years (Google Trends, 2017a) and it provides services such as Map service, distance matrix service, roads service, direction service, geolocation service, elevation	Maintenance and analysis of attribute data
		Maintenance and analysis of spatial data: editing graphic elements

	service, places service and geometry library (Google, 2016b).	Integrated analysis and maintenance of spatial and attribute data: measurement, search, proximity and network
		Output formatting
Microsoft Bing Maps API	Microsoft Bing Maps API provides service such as Map service, route service, geocoding service, elevation service (Microsoft, 2017).	Maintenance and analysis of attribute data
		Integrated analysis and maintenance of spatial and attribute data: measurement, proximity
MapQuest API	MapQuest API provides service such as mapping, geocoding, data manager, search, directions, traffic, static map and elevation service (MapQuest, 2017).	Maintenance and analysis of attribute data
		Integrated analysis and maintenance of spatial and attribute data: measurement, proximity
Mapbox API	Mapbox API provides service such as Map matching, geocoding, distance, optimized trips, directions. These APIs are free and have certain usage limits. Some APIs such as analytics are available only under the premium package (Mapbox, 2017).	Maintenance and analysis of attribute data
		Integrated analysis and maintenance of spatial and attribute data: measurement, proximity
OpenLayers API	OpenLayers is used for dynamic and interactive map displays. It can display the map tiles, vector data from any other data source such as OpenStreetMap, ArcGIS server, Mapbox, etc. It also provides the geolocation service (OpenLayers, 2017).	Maintenance and analysis of attribute data
		Maintenance and analysis of spatial data: format transformations, geometric transformations
		Integrated analysis and maintenance of spatial and attribute data: measurement, proximity
GeoServer	GeoServer is an open source tool written in Java programming language. It supports standard raster/vector formats, It provides services such as Web Map Service, Web Feature Service, Web Coverage Service and Virtual OWS service (GeoServer, 2013a). It provides Web Processing Service as an extension that contains processes which are built using two libraries: Java Topology Suite (JTS) and GeoServer specific processes (GeoServer, 2013b).	Maintenance and analysis of attribute data
		Maintenance and analysis of spatial data
		Integrated analysis and maintenance of spatial and attribute data: measurement, line-in polygon, point-in polygon, overlay operations, proximity and buffer

		Output formatting
Libraries for GIS analysis tools		
Integrated Land And Water Information System (ILWIS Python API)	ILWIS python API allows users to write high level scripts for multi-source geo-processing tools in a standard scripting environment, possibly running on multiple platforms (ILWIS, 2016).	Maintenance and analysis of attribute data
		Maintenance and analysis of spatial data
		Integrated analysis and maintenance of spatial and attribute data: except network analysis
Pyqgis (Python Quantum GIS)	Pyqgis, a geospatial python library enables the user to create standalone python scripts or custom applications using processing resources of qgis and other libraries such as Geographic Resources Analysis Support System (GRASSGIS), SAGA GIS and GDAL/OGR (QGIS, 2017).	Maintenance and analysis of attribute data
		Maintenance and analysis of spatial data
		Integrated analysis and maintenance of spatial and attribute data
Python Spatial Analysis Library (PySAL)	PySAL is an open source geospatial library for spatial analysis. It consists of the sub-packages: computational geometry, core data structure and IO, exploratory spatial data analysis, spatial inequality analysis, spatial constrained clustering, spatial dynamics, regression and diagnostics, spatial weights, network constrained analysis and contributed modules refers to user contributed libraries such as matplotlib, shapely (PySAL, 2017).	Integrated analysis and maintenance of spatial and attribute data

4.4. Derivation of additional factors influencing Field GIS construction

The procedure described in Section 4.3 considers the factors that were derived from workflow diagrams (see Sections 3.5.1, 3.5.2 and 3.5.3) obtained from the user requirement analysis stage of this research. These workflow diagrams are restricted to the field of disaster management. However, to derive a comprehensive list of factors that influence the construction of Field GIS more user-generated workflows of Field GIS are required from various application fields such as environmental monitoring, land register, infrastructure, etc.

4.4.1. Existing ways for gathering the workflows

Workflows are business processes that are modelled using various techniques such as Gantt chart, flow chart, Activity diagram, Functional Flow Block Diagram (FFBD), Data Flow Diagram (DFD), Program Evaluation and Review Technique (PERT), control flow diagram, Unified Modelling Language (UML) and Business Process Model Notation v2.0 (BPMN). Among these BPMN is the latest technique for modelling a business process (Creately, 2014). Chrysanthis et al., (2016) compared four commonly used techniques for business process modelling based on two criteria: notation and a case study. Chrysanthis et al., (2016) compared the Activity Diagram, Data Flow Diagram (DFD), Business Process Modelling Notation (BPMN) and Integration Definition for Function Modelling (IDEF) and concluded BPMN has a well-defined syntax

and understood by most business analysts. BPMN acts as a communication bridge between the process design stage and the implementation stage (Heflo, 2016).

Owing to its popularity and significance among business analysts the BPMNv2.0 standard is used by some websites for creating Business Process Automation (BPA) workflows and also documenting the created workflow in an online repository. Heflo (2016), a website enables users to create a workflow of process model based BPMNv2.0 standards and publish it on a collaborative portal to receive feedback from top business analysts. Orbus Software (2017) provides iServer an online central repository that captures and documents the process model created using BPMNv2.0 standards. It also involves stakeholders in the process design for effective process improvements. Modelworld (2017) an online business process modelling tool and repository. It enables users to create process models using standards such as BPMN, IDEF and Archimate. However, these online websites are not complete with the visualization elements that were used for creating the workflows of Field GIS (see section 3.5). But these solutions project the value of a website that can be used as a repository for gathering user-generated workflows. Therefore, a website was created to gather more user-generated workflows of Field GIS. The prototype implementation of the website is explained in Section 5.7 of chapter 5.

4.5. Discussions

The procedure for the construction of Field GIS initiated by identifying the factors influencing the need of Field GIS and the extent of GIS functionalities on a mobile device. The factors were derived by examining the three workflows diagrams (see Sections 3.5.1, 3.5.1 and 3.5.3) obtained from the user requirements stage of this research. Eight factors were derived (see Section 4.2.2 and 4.2.3), out of which the three represent the factors that influence the need for Field GIS in the field of disaster management and the last five represent the factors that influence the extent of GIS functionalities on a mobile device. The factors influencing the need for Field GIS are pertained to disaster management, whereas the extent of functionalities on a mobile device were generalized to overall applications of Field GIS. The “expertise of the user” factor is a prominent factor that plays an important role in deciding the extent of GIS functionalities on a mobile device. The next step was to identify the software libraries that were feasible to implement the GIS analysis tools. For efficient identification of the GIS functionalities provided by different software libraries, a straightforward Aronoff’s classification of GIS analysis tools was used. The software libraries were listed with respect to three categories: data collection and visualization, Web Mapping APIs and open source software libraries for sophisticated GIS analysis. The list of software libraries provided in this research (see Section 4.3.2) covered some of the recent and prominent GIS software libraries available on the market. Thus, the procedure for constructing a Field GIS pertaining to disaster management was formulated with the influential factors such as need of Field GIS and the extent of GIS functionalities. However, this thesis realizes the wider scope of Field GIS and aimed for gathering more user-generated workflows in order to identify more factors influencing the need of Field GIS in various application fields. Therefore, existing tools for gathering user-generated were reviewed. However, the existing tools were based on BPMNv2.0 standards which were not complete with the visualization elements used in the workflow diagrams. Thus, this research proceeded with implementation of its own website www.fieldgis.nl, enabling the users to create and upload their own workflows of Field GIS.

5. PROTOTYPE IMPLEMENTATION

5.1. Introduction

The purpose of this chapter is to describe the implementation process of a Field GIS prototype and a website for gathering more user-generated workflows. A prototype was developed to demonstrate the added value of Field GIS. The chapter begins with the list of options that were available for prototyping, followed by requirements and background functions of the selected prototype. Section 5.4 of the chapter describes the data required for the prototype and the corresponding services that provide the required data. Sections 5.5 and 5.6 explain the implementation process and pilot tests of the prototype. Lastly, the development of the website for gathering more user-generated workflows and the discussions are explained in Sections 5.7 and 5.8 of this chapter.

5.2. Workflows to Prototypes

There were three workflows derived from the user requirement analysis stage of this research: landslide reach, exposure assessment and the flood depth (see Section 3.5.1, 3.5.2 and 3.5.3). The landslide reach workflow was chosen as a prototype as it required less time to implement when compared to the other workflows.

5.3. Prototype requirements and background

This section lists the inputs required and processing tool of the prototype used from landslide reach workflow (see Section 3.5.3).

5.3.1. Inputs required

- Location and the elevation of user in the field
- Location and elevation of the source point of the landslide.
- Estimated volume in cubic metre
- The type of landslide (Rockfall, Translational slides, Earth flows, Debris flows)

5.3.2. Processing tool

Empirical runout model

It is based on the empirical relationship between the reach angle and the volume of the landslide that was formulated with help of simplified plots and regression equations (Corominas, 1996). The regression equations shown in Table 7 were used for calculating the reach of each type of landslide as they had higher correlation coefficients when compared to other equations.

Table 7 Regression equations incorporated in the prototype

Landslide Type	Regression equations formulated by Corominas (1996)
Rockfall	$\text{Log} \left(\frac{H}{L} \right) = 0.167 - 0.119 \text{ Log } V$
Translational Slides	$\text{Log} \left(\frac{H}{L} \right) = -0.143 - 0.080 \text{ Log } V$
Earth Flows	$\text{Log} \left(\frac{H}{L} \right) = -0.220 - 0.138 \text{ Log } V$

Debris Flows	$\text{Log} \left(\frac{H}{L} \right) = -0.031 - 0.102 \text{ Log } V$
--------------	---

5.3.3. Background function

There are three basic processes in the functioning of the landslide reach prototype,

- Calculation of H/L ratio, Where H is the height difference between source point of the landslide and the user's location on the ground and L is the distance between the source point and the user's location.
- Prediction of H/L ratio, based on volume of the landslide and the landslide type calculated from the regression equations incorporated in the prototype (Table 4: regressions equations).
- Comparison of the calculated H/L ratio and the predicted H/L ratio. For a continuously decreasing slope, if the predicted H/L is less than the calculated H/L, then the location of the user in the field is probably not safe. Whereas, if the predicted H/L is more than the calculated H/L, then the location of the user is safe.

5.3.4. User-interface design of the prototype

Based on the three basic processes, a simple user-interface was designed for the prototype (as shown in Figure 10).

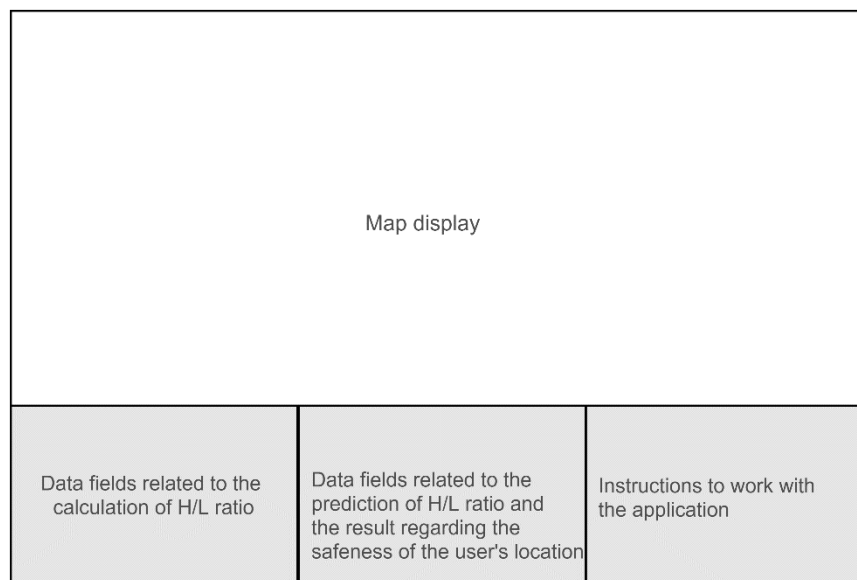


Figure 10: User-interface design of the prototype

- Map display: Displays a map retrieved using an external map API service
- Data fields related to calculation of H/L ratio: Displays the fields such as: Location and elevation of the user and the source point of the landslide from which the H/L ratio is calculated.
- Data fields related to prediction of H/L ratio: Displays fields in which the user can select the type of movement and the estimated volume. This section also contains fields that inform the user whether his/her current location is safe or unsafe.
- Instructions: Displays the instruction to work with the application.

5.4. Data Preparation

The main inputs for the prototype are location and elevation of both the user's location and the source point of the landslide. Whereas the estimated volume and the type of the landslide are entered manually by the user based on his/her experience in the field. To retrieve the location of the user and the source point

Google Maps API was used as it was the best web mapping service. For retrieving elevation data the following options were considered: Google Maps Elevation API, Microsoft Elevation API, MapQuest Elevation API and GeoNames Elevation API. Out of the four GeoNames elevation API provided the most accurate elevation as it used Shuttle Radar Topography Mission one Arc-second (SRTM1) data that provided an elevation data of 30 metres accuracy. Figure 11 shows the system architecture based on the required data.

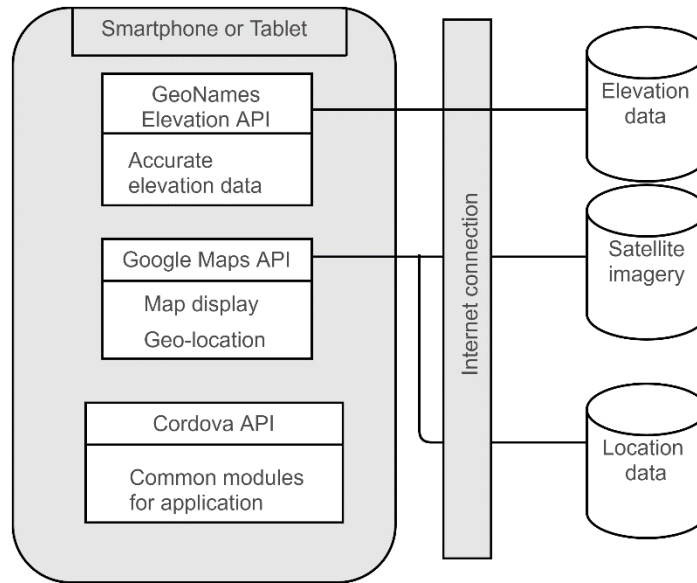


Figure 11: System Architecture

5.4.1. Google Maps API

Google Maps API was used to display the satellite imagery as a background image for the visualization of the landslide's source point location and the user's current location in the field. The Google Geolocation API was used to retrieve the current location of the user only if, the user provides permission to access his/her location information (Google, 2016a).

5.4.2. GeoNames API

GeoNames API service provides four web services for elevation data: Global 30 Arc-Second data, SRTM One-Arc Second, SRTM three-Arc Second and Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTERGDEM). SRTM One-Arc second was chosen as it provided 30 metre accuracy and ASTERGDEM was not used as it contained several issues such as artefacts that affect the accuracy of the data (Forkuor & Maathuis, 2012).

5.4.3. Cordova API

Apache Cordova, free and open source mobile application framework was used to implement the prototype. Cordova aids in building mobile applications by leveraging standard web technologies such as HTML5, CSS and JavaScript. This enables the developer to build the application once and target multiple mobile platforms such as: Android, IOS, Windows, Blackberry 10, Ubuntu etc. . Figure 12 shows the architecture of Cordova framework. Cordova architecture contains three main components: Web app, Cordova plugins and WebView. Web App component contains the code for the web application that Cordova wraps to the corresponding native mobile platform (El-Kassas, Abdullah, Yousef, & Wahba, 2015). Web App component also contains config.xml file that specifies the parameters that affects the working of the application behaviour such as response to orientation shifts of the device. The Cordova plugins component provides the link between Cordova and the native components of the mobile device with help of JavaScript

APIs. The WebView component provides the user-interface of the application that is implemented through standard HTML5, CSS and JavaScript. Cordova provides two development paths for creating mobile application. The first one is cross-platform method that focuses on developing mobile applications for more than one mobile platform using high-level tools. The second method is platform-centric that focuses on one single mobile platform by accessing lower-shell scripts that enables to control particular features of the mobile device (Apache Cordova, 2016a).

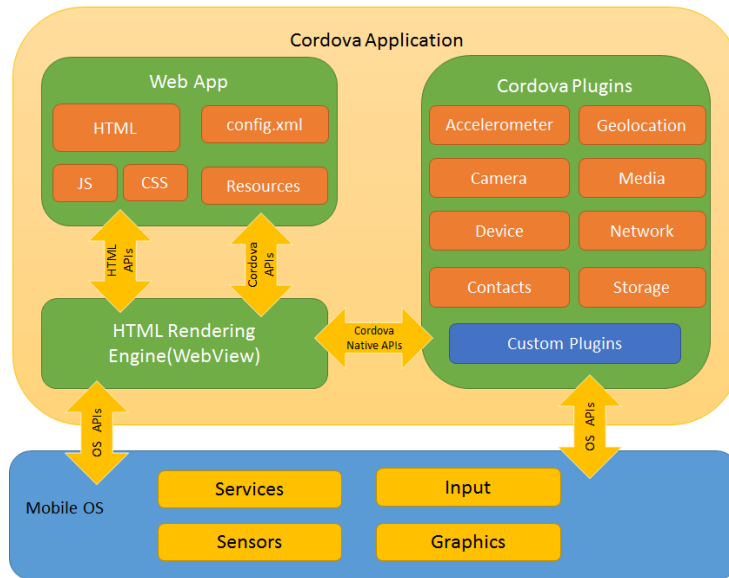


Figure 12: Architecture of Apache Cordova (Apache Cordova, 2016a)

5.5. Development environment and implementation

This section describes the development environment and the procedure used for the prototype implementation. Table 8 shows the hardware and software used for developing the prototype.

Table 8 Development environment

PC (development environment)		
OS	Windows 10	RAM: 8GB
Programming Languages	JavaScript, HTML5, CSS, Python	
Integrated development environment	Notepad++ and PyCharm	
External Map API	Google Maps API v3	
External Elevation API	GeoNames API	
Mobile Device		
Asus K013	Android 5.0: Lollipop	RAM: 1GB

5.5.1. Implementation

The implementation of the prototype was done in two-steps. The first step is the development of web application and second is wrapping the web application into mobile application using Cordova cross-platform method.

- Development of web application

The prototype was developed using the standard web technologies such as HTML5, CSS and JavaScript. The web application was hosted in my student's account of the win371 server of ITC. As mentioned earlier, Google Maps API was used to display the satellite imagery as the background image and also to retrieve location of the user and the source point of the landslide. Google Maps Geolocation API was used to indicate the user's current location on the satellite imagery. GeoNames API was used to retrieve the accurate SRTM1 elevation data. The web application can be accessed using <http://gip.itc.nl/experimental/mutluru/Simple-Map>. The screenshots of the prototype are presented in Appendix C.

- Wrapping Web to mobile application using Cordova Cross-platform method

The steps followed to wrap the web application to a mobile application (Apache Cordova, 2016b),

- Cordova project was created in the preferred directory using the command prompt of node.js
- Android mobile platform was added using Cordova commands for deploying the mobile application in the Asus K013 tablet.
- Cordova creates a set of files under the project the name that was specified in the first step.
- The index.html file inside the WWW folder of the Cordova project was replaced with the index.html file of the web application and also corresponding files such as JavaScript, CSS and images were added under the respective folders of Js, css and img inside the created Cordova project.
- Asus tablet was tethered to PC via USB cable and the Cordova project was built and run.
- Thus, the web application was wrapped into an android application.

5.6. Pilot tests of the prototype

Pilot tests of the prototype was carried out using the data of historical landslides events provided by Dr Olga Mavrouli, Assistant Professor, Department of Earth System Analyst (ESA), ITC. The prototype was evaluated with the rockfall events of Sola d'Andorra, next to the urban area of Santa Coloma, Andorra (Corominas et al., 2005), Spain (Ruiz-Carulla, Corominas, & Mavrouli, 2015), debris flow and translational slide events of Rasuwa district in Nepal. The tests results for the translational slides and the debris flows were conforming to the historical events but the rockfall events of Andorra, Spain did not yield realistic results. So the regression equation of rockfall event was replaced with the regression equation (1) that considers all types of landslides. After the change of the regression equation, the prototype yielded realistic results for the rockfall events.

$$\text{All types of landslides} \quad \log \left(\frac{H}{L} \right) = -0.047 - 0.085 \log V \quad (1)$$

The pilot tests proved to be an effective checkpoint to find out the flaws before carrying out the actual prototype evaluation with potential users.

5.7. Implementation of website

5.7.1. Objectives and functions of the website

A website was built to achieve the following objectives:

- To illustrate the concept of Field GIS to potential users.
- To gather more workflows of Field GIS for identifying the factors influencing the construction of Field GIS.

Based on these objectives, the website incorporated the following functions in its structure:

- Display existing workflow content of Field GIS (related to the first objective):

The website should enable the user to view existing workflow samples of Field GIS and also provide access to the underlying GIS processing libraries deployed in the particular workflow sample.

- Create and upload workflow content of Field GIS (related to the second objective):

The website should enable the user to create their own workflow based on specific workflow rules. These workflow rules should be displayed on the website. The website should also enable the user to upload their workflow diagram along with the information pertaining to the underlying GIS libraries used in their workflow.

5.7.2. Development of website

Development of a website involved three steps: Selecting a platform for building the website, selecting a domain name and web-host for the website and finally, setting up, designing and tweaking the website (Robert Mening, 2016).

Website building platform

The website was built using 'WordPress' as it is a well-known platform for building websites. WordPress is an online, open source tool written in PHP. Over the years it has evolved into a versatile content management system (CMS). It provides two ways to install a web server. First, the web server can be part of the local network with the help of software package 'WordPress.org'. Second, it can be a part of the internet hosting service known as 'WordPress.com'. WordPress.org provides more tools for creating customizable websites by installing several plugins. While WordPress.com enables the user to create simple blogging websites without an official domain name with limited tools (WordPress.org, 2017a). For this research, the website required sophisticated plugins for building functions such as file upload, workflow creation etc. These powerful plugins were available only on WordPress.org. As a result, WordPress.org was selected as the tool for building the website for field GIS.

Domain name and Web hosting service providers

Domain name and the web hosting service provider are the two major requirements for building a website. HostGator, BlueHost, SiteGround, iPage, DreamHost are some of the popular web hosting service providers (wpbeginner.com, 2016). After the comparison, SiteGround was selected as it was affordable for a student thesis and the domain name was purchased using SiteGround. SiteGround provides cPanel as an admin panel to manage the installation of software like Drupal, Joomla and WordPress on your account. For this research, www.fieldgis.nl was used as the domain name as it indicates the concept Field GIS and the country where it was created.

Setting up, designing and tweaking of the website

After the installation of WordPress.org, the steps executed for setting up and designing the website: WordPress theme selection, Customization of the selected WordPress theme, creation of web pages and addition of Plugins.

WordPress theme selection

WordPress provides access to more than 1500 freely accessible themes. 'Bizlight' theme was selected as it was a responsive theme i.e. the theme that makes the website adaptable to any kind of device such as smartphones, tablets and desktops (Cyberchimps, 2017).

Customization of the selected WordPress theme

The selected WordPress theme 'Bizlight' comes with default layout design. The default layout design of the Bizlight theme was simplified as the layout design plays a prominent role in engaging the users with a website. The theme was customized from the dashboard of my WordPress account (as shown in Figure 13).

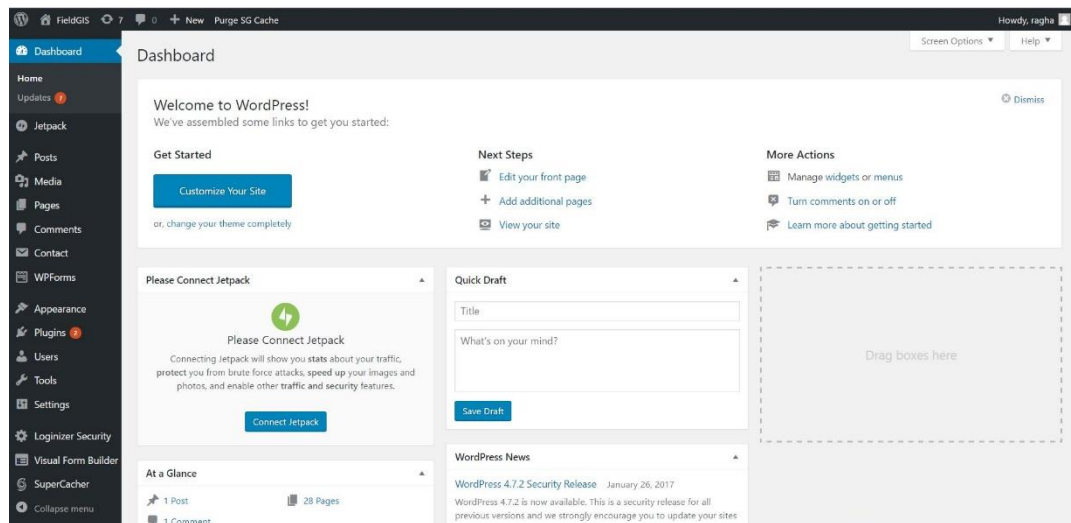


Figure 13: WordPress dashboard

For this research, a very basic website layout design was sketched. Figure 14 shows the customized layout design of the landing page of the website.

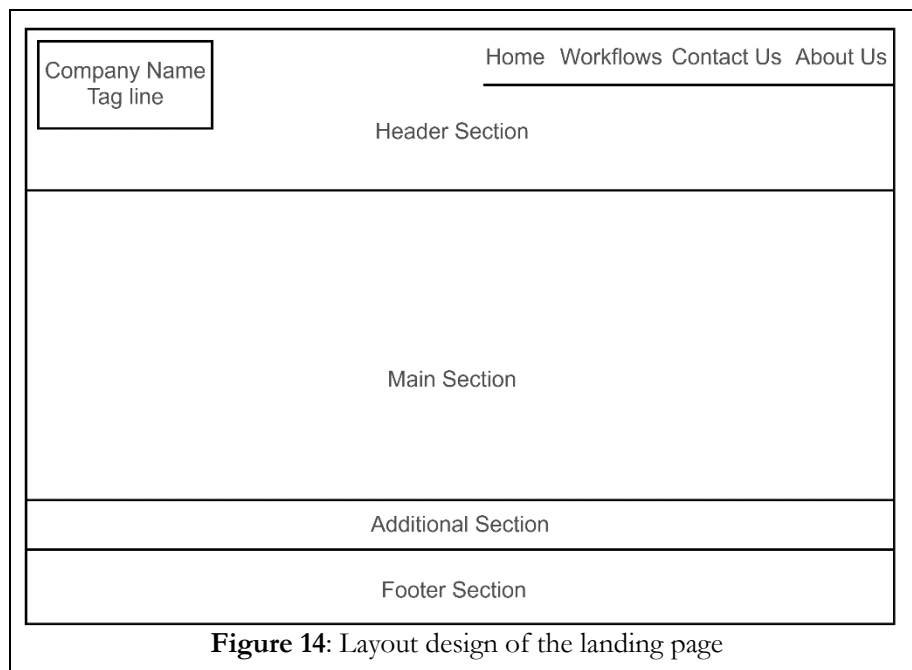


Figure 14: Layout design of the landing page

The sections included in the landing page:

- a. Header section: The header section is placed at the top part of the website and it contains two components company name and the navigation bar.
 1. Company name and tagline: The company name and tagline on the top left corner is made visible in all pages of the website. "FieldGIS" is the company name and the tagline is "Bringing GIS to the field".

2. The navigation bar: The navigation bar on the top right corner is made visible in all pages of the website for easy navigation throughout the website. The navigation bar provides path to the home page, workflows page, contact us page and the about us page.
- b. Main section: The section displays the main content part of the landing page. In this case, it contains the welcome message.
- c. Additional section: The section is placed below the main section and it displays the inspirational quotes of prominent men in GIS.
- d. Footer section: The section at the bottom part of the website, displays the copyrights information.

Creation of web pages and addition of plugins

The following pages were added to achieve the first objective (To illustrate the concept of Field GIS):

- Workflow Samples
- Landslide Reach App
- Exposure Assessment App
- Flood Depth App

The pages were created from the WordPress dashboard of my account by clicking Pages → Add New option. The Workflow samples page displays the three workflow diagrams of Field GIS derived from the user requirement analysis stage of this research (see Sections 3.5.1, 3.5.2 and 3.5.3). The workflow diagrams were added to the page using the Add Media option in the Edit Page window of the WordPress dashboard (shown in Figure 15).

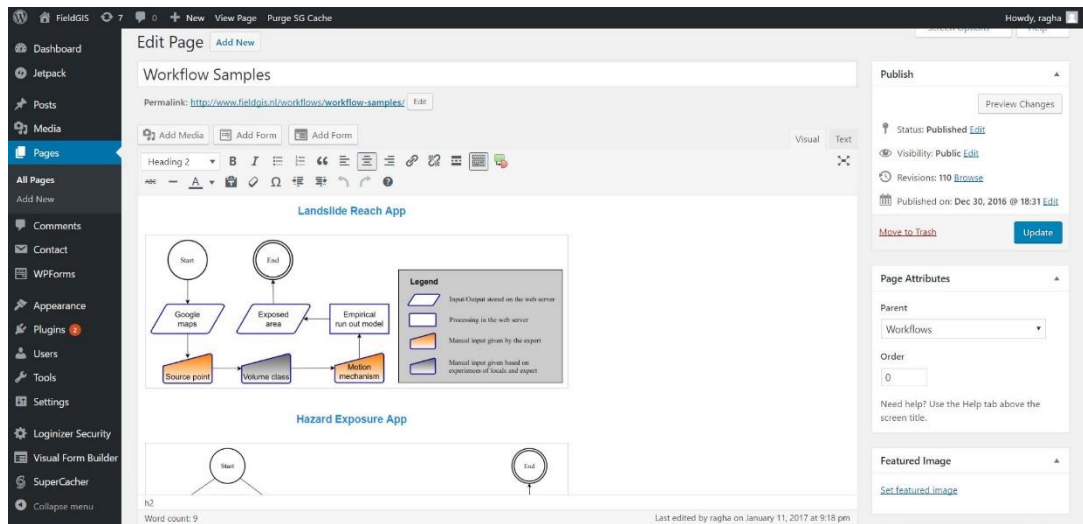


Figure 15: Edit Page Window of WordPress dashboard

The other pages such as: landslide reach app, exposure assessment app and the flood depth page were created to display the detailed information about the inputs required, GIS functions used in the application and the outputs generated in that particular application. The information were added as a text in the Edit Page window of the WordPress dashboard. The code that were used to implement the GIS functions were also included in the page. For instance, in the case of the exposure assessment, Integrated Land and Water Information System (ILWIS) Cross operation was used, the python code for implementing the Cross operation was added to the page using the 'SyntaxHighlighter Evolved' plugin. The 'SyntaxHighlighter Evolved' plugins' displays the code in a readable format based on the type of programming language (WordPress.org, 2017b) (as shown in Figure 16). WordPress plugins are installed from the dashboard window by clicking Plugins → Add New. After installation of the plugin, the code for implementing the cross operation was added in the Edit Page Window enclosed between the [code] and [/code] tags.

PYTHON CODE ILWIS CROSS OPERATION

```

1  import ilwis
2
3  #Get the inputs
4
5  raster1 = ilwis.RasterCoverage("file:///C:/my director/first raster.mpr")
6
7  raster2 = ilwis.RasterCoverage("file:///C:/my director/second raster.mpr")
8
9  #Cross Operation
10
11  #cross_raster=ilwis.Engine.do("operation name", input raster1, input raster2, undef han
12
13  cross_raster = ilwis.Engine.do("cross", raster1 , raster2, "ignoreundef", True)
14
15  #Store the output
16
17  #cross_raster[0] - output table
18
19  #cross_raster[0].store("out") #Table saved in Ilwis format
20
21  #cross_raster[1] - output Map
22
23  #cross_raster[1].store("out") #Map saved in Ilwis format
24
25  cross_raster[1].store("ou34","GTiff","gdal") #Map saved in GeoTiff format

```

Figure 16: Code added using ‘SyntaxHighlighter Evolved’ plugin

Thus, by displaying the Workflow Samples of Field GIS and the underlying information regarding the GIS functionality enables the website to illustrate the concept of Field GIS.

The following pages were created to achieve the second objective (To gather more workflows of Field GIS for identifying the factors influencing the construction of Field GIS):

- Workflow Rules
- Workflow Creation
- Upload Your Workflow

Workflow Rules page was created from the WordPress dashboard of my account using Pages → Add New option same as the creation of the previous pages. Workflow Rules page displays the visualization elements that can be used by potential users to construct their own workflow diagram of Field GIS. Workflow Creation page was created with a link to Draw.io, an online tool for creating workflows that allows the user to create their own workflows. Finally, the ‘Upload Your Workflow’ page was created to gather the workflow diagrams of Field GIS from the users. The WordPress File Upload plugin was installed to add the upload functionality to the page. After the installation of the plugin, the upload functionality was incorporated in the ‘Upload Your Workflow’ page using the shortcode “[wordpress_file_upload]”. The page was also incorporated with a form to collect the background information of the workflows uploaded by potential users of Field GIS. The form was created using Visual Form Builder plugin and it was incorporated in the ‘Upload Your Workflow’ page using the shortcode “[vfb]”. The form was designed with the following fields: Name of the user, application name, GIS functions used in the application and the GIS libraries used for implementing the GIS functions. Thus, by viewing the workflow rules will enable the user to create their own workflow which they can upload in the www.fieldgis.nl website.

5.8. Discussions

The Field GIS prototype was developed based on the landslide reach workflow (see section 3.5.3). The prototype was implemented using standard web technologies such as HTML5, CSS and JavaScript. Most of the functionalities were implemented using Google Maps API. The services used from Google Maps API were geolocation service, geometry service and the elevation service. However, the initial prototype produced inconsistent results due to the inaccurate elevation data provided by Google Elevation service. Elevation data was one of the main inputs of the landslide reach prototype therefore, a more accurate elevation service was required for the prototype. GeoNames API provided the most accurate elevation data derived from SRTM (~ 30 accuracy) when compared to other options: Microsoft elevation service,

MapQuest elevation service. After the inclusion of the GeoNames API, results of the prototype had consistently improved however, the performance of the prototype was degraded with synchronous XMLHttpRequests as the values could not be returned from an Asynchronous JavaScript Extensible Markup Language (AJAX) call request. A workaround for this problem was the creation of a callback function inside the AJAX call block (Stackoverflow, 2013). But the solution, failed to provide the required results in the case of the prototype. Therefore, the elevation data was retrieved using the synchronous XMLHttpRequests. The developed web version of the prototype was wrapped into a mobile application using Cordova open source tool.

The main objective of the Field GIS website was to gather more-user generated workflows from various application fields. The website was built using 'WordPress.org', a well-known platform for building websites. Realizing the wider scope of Field GIS a domain name was purchased from a web host. Currently the website has a 'Click to start' button which can be only eliminated in the pro version of the website. The workaround for this problem is to purchase the current theme for having more customizable options. The website's main plugin is the WordPress File Upload plugin. It is a free plugin from WordPress.org that allows to build an upload file button on the website. However, there are many other commercial file upload plugins that provide sophisticated graphical user interface. Moreover, the website was not tested with potential users due to time constraints. But it has the potential to become a web repository that can store a collection of workflow examples of Field GIS from other application fields of mobile GIS covering a broader spectrum of users.

6. PROTOTYPE EVALUATION

6.1. Introduction

The purpose of this chapter is to presents the results of the prototype evaluation that was performed with potential users of Field GIS. The chapter starts with the description of the method used for the evaluation, followed by the evaluation process that describes the selection questionnaires and tasks performed by the user and finally evaluation results are presented in section 6.4 of this chapter.

6.2. Method for prototype evaluation

The prototype evaluation was focused on driving the concept of Field GIS among potential users i.e. the added value of processing the data or access to additional information in the field. Therefore, the prototype evaluation was narrowed down to qualitative methods rather quantitative usability studies. For qualitative testing methods, minimum five participants are enough to find out the major usability problems (Jakob Nielsen, 2012). The qualitative testing of the prototype consisted of tasks and questionnaires coupled with think aloud protocol, which were used to obtain the information regarding the added value of Field GIS. Think aloud protocol enables to understand mind-set of the participant when he/she is performing a task (Elekes Katalin, 2016). The participants are allowed to speak their thoughts, frustrations and reactions. There are three types of think aloud protocols: traditional protocol (only the participant keeps talking), speech-communication protocol (the test facilitator can ask the participant to explain more about a problem or process) and the coaching protocol (the test facilitator helps the participant if he/she is struggling) (Usability.gov, 2013). Out of the three protocols, the coaching think aloud protocol was used as some participants tend to drift from the idea of Field GIS to a data collector system. Thus, coaching think aloud protocol was used to obtain the information about the additional processing functionalities or access to additional information in the field.

6.2. Test participants and resources used

Six participants were selected from the Department of Earth System Analyst (ESA) with varying experience in landslide studies in order to test validity of the user expertise factor, one of the main factors influencing the construction of Field GIS (see Section 4.2.3).

6.2.1. Resources used for the test

- Asus tablet k013
- Dell laptop
- Motorola G2 voice recorder application

6.3. Evaluation process

The evaluation process started by providing the participants a brief explanation of my thesis and objective of the evaluation. The evaluation process of the prototype consisted of:

Pre-test questions: To know whether the user has used any mobile GIS apps with processing capabilities.

Pre-task: To make the user acquainted with the prototype.

Main task: To allow the user to explore the full capabilities of the prototype.

Post-test questions: To obtain the information about additional processing options and the corresponding added value of having those options in the field.

Sections 6.3.1, 6.3.2, 6.3.3 and 6.3.4 lists the pre-test questions, pre-task for users, main task description and the post-test questions respectively.

6.3.1. Pre-test questions

- Have you used any mobile GIS apps? If any name them.
- What was the purpose of using the app in the field?

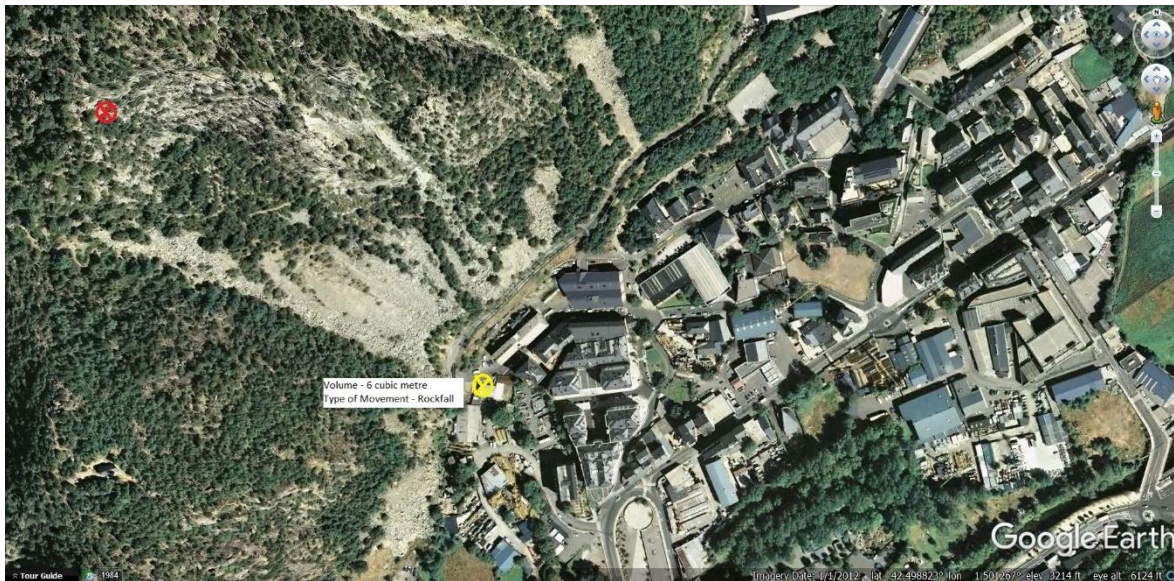


Figure 17: Overview of a landslide prone site in Santa Coloma, Andorra

6.3.2. Pre-task: Steps for the user to get acquainted with the app

- The yellow marker indicates the user's location in the field. Drag and drop it in the area marked by the yellow circle as shown in the figure 17.
- The blue marker indicates the source point of the landslide. Drag and drop it in the area marked by the red circle as shown in the figure 17.
- The lat/long and elevation information of the user's current location and the source point will be retrieved after the execution of the first two steps.
- Enter the volume mentioned in the estimated volume field (10-100 cubic metre).
- Select the type of movement (rockfall, translational slides, earth flows, debris flows) from the movement type drop-down list.
- The application will provide information regarding the exposure of the user's location in the field.

6.3.3. Main Task description

This Section describes an imaginary scenario that was presented to the users:

Roy, the landslide expert is in Andorra, Spain. He has an Asus tablet loaded with the landslide reach app. The current location of Roy in the field is indicated by the yellow marker while, Roy can use the blue marker to mark the potential landslide source point. The estimated volume is entered by Roy based on his experience and/or by consulting the people who are living in the locality.

Imagine you are Roy, the landslide expert carry out your landslide assessment with the help of the landslide reach app to find the exposure of your current location for different landslide source points and different amounts of volume.

6.3.4. Post-test questions

These post-test questions are targeted towards the added value that the users get in the field and also towards the other processing options they can have in the field.

- a. How would you use the information regarding your location's exposure to landslides instantly in the field?
- b. Suppose you have the option to define the extent of damage caused by a landslide from a particular source point. Will that be useful?
- c. Suppose you have the option to create a map showing the exposure of the locations for different source points. Will that be useful?
- d. Suppose you have the option to assess the reach of the landslide based on the probabilistic way rather than a deterministic approach. Will that be useful?
- e. Suppose you have the option to visualise the trajectory of the landslide using the analysis functions such as flow direction and flow accumulation. Will that be useful?
- f. Suppose you have the option to calculate the velocity of the landslide from a particular source point. Will that be useful?
- g. What other options would you prefer in the app that would add more value to the information retrieved from the landslide reach app?
- h. Would you prefer to have access to additional (geo)-data layers through e.g. the internet?

6.4. Evaluation results

From the pre-test questions, it was found that half of the participants have been acquainted with ArcGIS apps for landslide mapping, collecting data and validations for hazards inventory in the field. The other half have not used any mobile GIS applications. The pre-test questions were followed by the pre-tasks that introduced the steps the participants had to follow for operating the prototype. All the participants were vocalizing their thoughts and opinions as expected. In Sections (6.4.1, 6.4.2, 6.4.3, 6.4.4), the shortcomings of the prototype, advantages of the prototype, additional functionalities and additional geo-data mentioned by all participants are described in detail respectively.

6.4.1. Shortcomings of the prototype

- As the prototype is based on the empirical model, the results of the prototype cannot be used to communicate with the local authorities and local people.
- A comprehensive physical based model is required in the field to be absolutely sure for communicating with the people living in the disaster zone.
- The prototype does not take into the direction, only the distance to assess the safety of the location.
- The prototype is providing information only for a point.
- The prototype does not indicate the unit for the landslide volume.
- The prototype cannot be used to predict small or medium-size landslides because the prototype is using SRTM data which has the accuracy of 30 metres.
- The prototype does not give the option for more landslides types.
- The prototype does not show the scale of the image, which is useful for estimating the volume.
- The "move!" message is overlapping the marker.
- The misconception of the size of the green circle.
- The prototype displays an annoying message of "Enter valid number between 0 and 1".

6.4.2. Advantages of the prototype

- It can be used as a tool to check the landslide expert's knowledge in the field.
- It can be used for assessing the safeness of a region for engineering projects in disastrous locations.
- It can be used by urban planners who have about knowledge about landslides.

- It can be used for validating the risk assessment map for each and every building.
- It can be used as an additional source of information next to one's own observations.

6.4.3. Additional functionalities

- It would be useful to have exposure to an aerial extent rather for a single point.
- Defining the boundary for collecting the samples in the field.
- Time slider functionality to visualize the recent landslide triggered zones in the area.
- Volume should be calculated not guessed. It should be calculated using empirical volume formulas.
- Functionalities to calculate the depth of the deposition.
- Functionalities to validate whether the placement of the source point of the landslide is valid or not and to incorporate a DEM to calculate the flow direction of the landslide.

6.4.4. Access to additional geo-data

Lithological maps, landuse and land cover map, ground water level, soil moisture, digital elevation model, hill shade map, slope map, precipitation map, geological map and pre-calculated flow paths.

6.5. Insights gained from evaluation

From the results of the prototype evaluation, it was evident that the concept of Field GIS was well understood by all the participants. The participants agreed that having functionality in the field would prove as an additional source of information that can be used to validate one's own observations in the field. But the main question that popped-up from this prototype evaluation is about the expertise of the user or what the expertise level of the user is. This was highlighted with reference to the estimated volume and the type of movement parameters which are some of the required inputs of the prototype. A basic user couldn't estimate the volume and also the type of movement (rockfall, debris flow, earth flow, translational slides). So, for a basic user there must be an alternative way for using the prototype in which the volume and type of movement can be incorporated through some other input sources. For example, type of movement can be incorporated by sending an image of the area to a server that compares the input image with the reference images and gives the user about what the movement type is. In this way, more landslide movement types can be incorporated in the application.

Contrasting observations were made from an expert's point of view. An expert user criticized the prototype for its reliability and simplicity. The expert user suggested the incorporation of more comprehensive tools in the application so that it enables him/her to be absolutely sure before communicating with the local authorities in the field. Thus, the expertise of the user plays an important role in defining the type of data collected/used in the field which in turn decides the processing options, access to additional geo-data sources and the need for network connectivity as mentioned in Section 4.2.3. Some users suggested some alternative ways for calculating the volume instead of the expert entering it approximately.

Some questions in the post-test questionnaire were not understood by some users. In those cases, the facilitator explained the questions. Some of the potential add-ons suggested by the users are exposure for an aerial extent instead for a single point, time slider for visualizing the historical images of landslides, volume calculated using empirical formula and functionalities to validate the position of the source point of the landslide. Among these, top priority for the next version of the prototype would be the aerial extent of exposure rather a single point exposure of safety as it would be more useful to visualize the exposed areas and their corresponding property values, in order to estimate the total damage in the field.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

This thesis introduced a concept Field GIS, a type of mobile GIS capable of spatial data acquisition and spatial data analysis on a mobile device. Field GIS emphasizes the concept of spatial analysis in the field. But there are two underlying questions for Field GIS. The First is “do we need it?”, the need for Field GIS pertaining to the field of disaster management is mainly influenced by situational awareness, being aware of the situation enables a person to take informed decisions in the field. Urgency of the situation, situation that demands a person to take rapid action and finally the integration of local knowledge in the analysis. The second underlying question is “how much GIS functionality should we have in the field?” This is mainly influenced by the expertise of the user in both GIS and the corresponding application field. This factor decides the classification of Field GIS along the functionality spectrum of mobile GIS that ranges from a simple data collector system to a full-fledged GIS. For instance, in case of a novice user, the Field GIS should be configured with low-end GIS functionalities in an intuitive manner such as point data collection through geotagged images and visualizing the collected data on a map. These functionalities are provided by existing solutions such Open data Kit (ODK), KoboToolbox, Formhub and GeoODK. In case of an intermittent user, the Field GIS system should be configured with medium GIS functionalities such as data editing tools, navigation tools, points of interests and also access to additional geo-data data sources such as elevation layer, soil layer. These functionalities are provided by web mapping APIs such as Google Maps API, Microsoft Bing Maps API, MapQuest API, Mapbox API, OpenLayers, GeoServer etc. There are three differences between these solutions: usage limits of the service, the data source and the need to be online. In the case of an expert user, the Field GIS can be configured with sophisticated GIS analysis tools such as interpolation, overlay operations, proximity, network analysis, etc. These functionalities are provided by open-source libraries such as ILWIS Python API, Pyqgis, PySAL and many more. ILWIS python API allows the user to create high-level scripts for multi-source geo-processing tools in a standard scripting environment. Pyqgis is a complete geospatial python library that contains packages such as: GDAL/OGR, GRASS and SAGA GIS. With the proper identification of the tool that is required in the field, the discovery of the corresponding software libraries providing the functionality can be efficient. So, with open-source solutions such as these in hand there is a third straightforward question that Field GIS posts to others, “Why do we go for commercial solutions such as Fulcrum apps, ArcGIS apps?”. The commercial apps such as ArcGIS apps are tightly integrated with one particular platform that makes workflow of a project effective and efficient. ArcGIS nemeses Quantum GIS has launched QField its mobile solution for navigation, feature identification and attribute editing (OPENGIS.ch, 2015). However, QField is built for only Android smartphones but it is not far from being ported into Windows and IOS platforms.

This section describes the main research objective that was achieved by answering the research questions that were formulated by sub-objectives,

- *Questions related to first sub-objective (user requirements):*

a) Who are the potential users of this research?

The potential users of this research are organizations such as MapAction, UNDP, IFRC, World Bank, Doctors without borders and other organizations involved in disaster risk management. These organizations function in pre, during and post disaster conditions to help people meet their basic needs and improve the lives of the vulnerable people.

b) What are their requirements?

The organizations involved in disaster risk management deploy field worker in disaster prone areas to collect data regarding vulnerable population, hazardous zones etc. The users required geoprocessing tools such as interpolation, overlay operation, proximity and also tools for table operations. Interpolation for cross-checking the flood depth values collected from locals with a DEM. Overlay Operation to find the exposure of buildings to various hazards. Proximity to assess the reach of a landslide. Table operations for calculating the total damage cost of exposed buildings.

c) What are the potential use cases in the mitigation of landslides and floods?

Three potential use cases pertaining to the mitigation of landslides and floods were gathered from potential users. First, an application to predict the reach of a landslide from a particular source point, secondly, an application to assess the exposure of buildings to any type of hazard and calculate the total damage costs and finally, an application to generate an instant hazard map based on flood depth values collected from local people. In addition to these three potential use cases the other general use cases for Field GIS are network analysis for finding the shortest route between point origin and destination. In the application of land management, the line-in polygon and point-in polygon would be useful to determine the coincidence of jurisdiction and protected area extents.

- *Questions related to the second sub-objective (Construction of Field GIS):*

d) What are the various factors to be considered for the construction of Field GIS?

The factors influencing the construction of Field GIS were derived from the workflow diagrams of potential use case scenarios pertaining to landslides and floods (see Sections 3.5.1, 3.5.2 and 3.5.3). The influential factors are situational awareness, integration of local knowledge, urgency of the situation, expertise of the user, type of data used/collected in the field, processing options, access to additional geo-data and the need of network connectivity.

e) What is the influence of the different factors considered?

The factors such as situational awareness, integration of local knowledge and urgency of the situation influence the need of Field GIS. Whereas, the factors such as expertise of the user, type of data used/collected in the field, processing options, access to additional geo-data layers and the need of network connectivity influences the extent of functionalities on a Field GIS. The landslide reach (see Section 3.5.3.) demonstrated the situational awareness and integration of local knowledge by empowering a field worker (see Section 3.2.) to assess the safety of the location. The current prototype was built for expert users as the locals cannot estimate the volume of the landslide. Therefore, the expertise of the user decides the type of input collected/used in the field which in directly influences the processing options, access to additional geo-data layers and need of network connectivity.

- *Questions related to the third sub-objective (Prototype implementation):*

f) How to implement a combination of geoprocessing tools which run sufficiently on a mobile device under different scenarios of landslides and floods?

Standard web technologies such as HTML5, CSS and JavaScript can be used to build the client interface of the web application. Sophisticated geoprocessing tools can built using python programs on the server-side. Finally, Cordova an open source cross platform tool can be used to wrap the web application into a mobile application. Using Aronoff's classification of GIS analysis tools (see Section 4.3.1), the different geoprocessing tools can be easily identified and combined based on the type of data

collected or used in the field. The type of data collected/used in the field is one of the important parameter in deciding the extent of GIS functionalities on a mobile device (see Section 4.2.3).

g) What functionalities can be implemented through client/server interaction and in such case, geoprocessing tool should reside on client versus server?

Sophisticated geoprocessing tools such as connectivity and neighbourhood operations mentioned in Aronoff's classification (Section 4.3.1) should reside on the server for better performance. Whereas the atomic geoprocessing such as measurement can reside on the client-side. This scenario was demonstrated with the implementation of the prototype (See Section 5.3.3.) in which the calculations regarding the H/L ratio resided on the client-side. However, the data regarding the location and the elevation of the point were retrieved using Google Maps API.

h) Which software (libraries) can be re-used?

There are many software libraries that can be re-used (See Section 4.3.2). Open source tools such as Open Data Kit (ODK), KoboToolbox, Formhub and GeoODK can be for data collection and visualizations. Web-Mapping APIs such as Google Maps API, Microsoft Bing Maps API, MapQuest API, Mapbox API can be used for map display, measurement, proximity and navigation. Open source libraries such as ILWIS python API, Pyqgis and PySAL can be used for deploying sophisticated GIS analysis tools such as interpolation, cross operation, flow direction and flow accumulation etc.

i) What existing hardware is needed in different scenarios?

There is no clear cut classification of smartphones in today's scenario. Today's smartphone can be tomorrow's feature phone due to the proliferation of technology. However, based on the potential use case scenarios (See Section 3.4), the landslide reach (See Section 3.5.3) case would suffice a low-end smartphone as it is based on basic map display and simple distance calculations. However, for the exposure assessment (See Section 3.5.1) and the flood depth (See Section 3.5.2.) would require a high-end smartphone as it incorporates more sophisticated GIS analysis tools.

- *Questions related to the fourth objective (Prototype evaluation):*

j) Which type of usability method will be used to evaluate the performance of the Field GIS?

Think aloud protocol was used to evaluate the performance of the prototype. As the prototype evaluation was focused on driving the concept of Field GIS among potential users i.e. the added value of processing the data or access to additional information in the field.

k) What can be done to improve the prototype?

The current version of the prototype can be improved by incorporating a time slider, landslide exposure for an aerial extent rather than single point. The current prototype can be extended with OpenLayers API which provides a time slider plugin. An accurate digital elevation model as an input to find out the flow direction and the flow accumulation of the landslides.

7.2. Recommendations

This section provides the recommendations for future work (7.2.1.) and recommendations for the current prototype (7.2.2.)

7.2.1. Recommendations for future work

The following points indicate the recommendations for future work,

- The remaining two workflows diagrams: Flood depth (see Section 3.5.2) and exposure assessment (see Section 3.5.1) could be implemented with the help of the codes presented in the www.fieldgis.nl website to demonstrate the concept of Field GIS as a locally running application on a smartphone application.
- The website www.fieldgis.nl was built for gathering user-generated workflows. However, the website has not been tested. The usability testing of the website could be done with potential users which would transform the website into a web repository of Field GIS workflows. With more user-generated workflows from various application fields, it would provide the opportunity to identify more factors that influence the construction of a Field GIS application
- Classification of GIS analysis tools based on a smartphone processor's performance would enable software developers to define the minimum metrics required for having GIS functionalities in the field.
- A system that suggests all the open source libraries based on a GIS task. Such a system can be built using a repository of GIS tasks in which, when a user inputs his/her GIS task, the system would map the GIS task given as input with all the GIS tasks on the repository and produce results that are related. The produced results would contain all the possible open source libraries that provide the tools for completing that particular GIS task.

7.2.2. Recommendations for the current prototype

The following points indicate the recommendations for the current prototype,

- The current prototype version of the landslide reach app predicts whether a location is inside the path of a soil/rock mass or outside the potentially affected area, along a profile which is defined by the location of the user and the source point. But the next version could assess the exposure for an aerial extent rather than single point.
- The prototype could also consider parameters such as: velocity of the movement, direction of the movement and also the position of the obstacles on the path of the movement for creating a comprehensive landslide reach application.
- The current prototype is leveraging SRTM for elevation data (~30m accuracy). Availability of a more accurate DEM would certainly enhance the reliability of the application.
- The prototype could also incorporate a time slider which would enable a field worker to visualize the recent landslide activities and aid in selecting the source point of the landslide in the field.

APPENDIX A: USAGE SCENARIOS OF FIELD GIS

Use case 01

Title: Generating Digital Elevation Model (DEM) for assessing the hazardous conditions of an area.

Brief Description: DEM is an important dataset for many disaster applications. With current satellites like SRTM, more accurate DEM of an area can be obtained. However, there are still areas in the globe which lack proper DEM. For those areas, Field GIS which leverages GPS technology can be used to capture sufficient points over an area and with interpolation functionality present in Field GIS can be used to generate a DEM of the area.

Functionality Needed: Interpolation methods: Inverse distance weightage, Kriging, Natural Neighbour, Spline, Topo to Raster, Trend.

Importance of performing the operation in the field: Assessment of a building unit in a dynamically changing environment.

Basic Flow:

1. Select sufficient points over the area using the map interface of Field GIS.
2. Collect the coordinates of the selected points using GPS technology embedded in the Field GIS.
3. Perform the preferred interpolation method.
4. Finally, obtain the continuous surface

Scope:

1. Generation of DEM for a large scale area.
2. Very useful when there is no proper or up-to-date DEM for an area.
3. Other products such as slope, aspect, flow accumulation, flow direction can be derived from DEM. These products are very important inputs for assessing the hazardous conditions in an area.

Limitations:

1. The accuracy of the embedded GPS technology plays an important role in the generation of DEM.
2. GPS horizontal Accuracy on mobile devices usually vary between 5-8 metres.
3. Major concern will be the vertical accuracy of the embedded GPS technology.
4. The accuracy needs usually depends on the use case.

Use case 02

Title: Assessing the closeness of a unit to a hazard zone.

Brief Description: Distance to road has a strong relation with landslide occurrence (Abella & Van Westen, 2007). The stability of the slope may change from stable to unstable during road constructions and vehicle movements. So, buffer around the road network can be used to find out the units which are vulnerable to the landslide.

Functionality Needed: Proximity analysis: distance to roads, polygon on roads and polygon on building to find the relationship between hazard zone and the assets within that zone.

Importance of performing the operation in the field: To incorporate local knowledge for defining the boundary of the buffer zone, to make people aware of the danger persistent in the zone they are living.

Basic Flow:

1. Digitize the road based on GPS technology.
2. Perform buffer analysis for the road network.
3. Inspect the slope characteristics within the buffer zone.

Scope:

1. Ability to digitize features which are not visible in the satellite image.
2. Incorporation of local knowledge in the analysis step.
3. To facilitate rapid communication with the people living in the area.

Limitations:

1. GPS accuracy plays a major role.
2. Availability of government official during the assessment can facilitate in rapid communication with the people living in a particular area.

Use case 03

Title: To estimate the threat caused by mass movements in a particular zone by calculating the reach angle.

Brief Description: The hazard caused by mass movements can be estimated using the Height/Length relationship (empirical runout model). The travel distance is mainly affected by the type of landslide, obstructions, reach angle and volume of the mass.

Functionality Needed: Distance measurement, basic trigonometric functions and interpolation methods (if the DEM which is available is not up-to-date).

Importance of performing the operation in the field: Dynamically changing environment which demands rapid calculations in the field. The clear overview of the type of material and volume present in an area will help in accurate assessment of speed and depth of the flow.

Basic Flow:

1. Identify the two points in the ground, one point near the vulnerable population and another point near the source of the mass movements.
2. Find the height difference between the two points (H) and the distance between these points (L).
3. From the (H/L) relation, the angle of reach can be obtained.

Scope:

1. Angle of reach is an index of landslide efficiency (Corominas, 1996).
2. The in-field computation of reach angle gives an advantage of getting a clear picture of the obstacles present in the path, topographic constraints and the material composition.

Use case 04

Title: Exposure assessment

Brief Description: The correct quantification of building units at risk will help insurance agencies and the government to take precautionary actions. The information of different risk levels in which building units are situated can help the government in allocating funds (Abella & Van Westen, 2007).

Functionality Needed: ILWIS cross operation (simple overlay operation of two vector layers).

Importance of performing the operation in the field: Sometimes a building might be situated in a relative less susceptibility zone, but due its age and structure faults it is still more vulnerable to destruction.

Basic Flow:

1. Compare the hazard data in the tablet with current ground situation.
2. Perform the cross operation of the hazard data and the building units present in an area.

Scope:

1. This use case helps in updating the data about the structures.

2. Table operations such as aggregation can be performed on the cross tables to get an accurate estimate of the exposure units.

APPENDIX B: EMPIRICAL RUNOUT MODEL

The landslide reach is based on the empirical runout model developed by Corominas (1996). The empirical runout model establishes the angle of reach as a proper index of the relative mobility of the landslides. The reach angle (α) is the “angle connecting the source point of the landslide and the farthest point of the displaced mass” (Corominas, 1996). The tangent of the reach angle (α) is expressed as the coefficient of friction of contact between the moving mass and the ground (as shown in Figure 18).

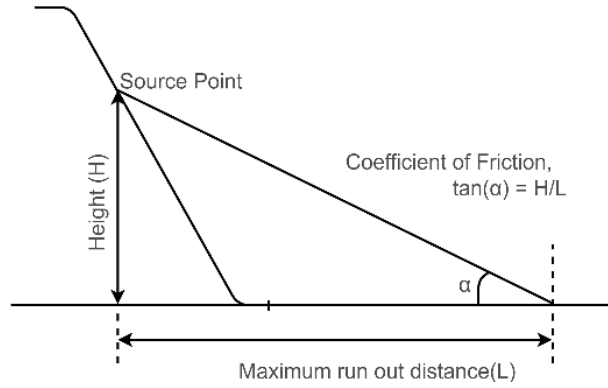


Figure 18: Reach Angle definition

The coefficient of friction or the tangent of the reach angle is derived using the energy balance equation (1), in which the potential energy of the block at the source point is equal to the summation of the kinetic energy of the block and the energy loss due to friction (as shown in Figure 19).

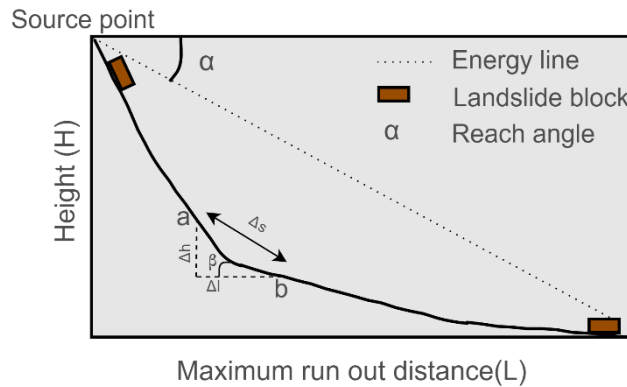


Figure 19: Derivation of tangent of the reach angle

$$mg \sin \beta \cdot \Delta s = \frac{1}{2} m \Delta v^2 + \mu mg \cos \beta \cdot \Delta s \quad (1)$$

Where,

m is the moving mass, g is the acceleration due to gravity, v is the velocity of the moving mass, Δs is the slope of the moving mass between points a and b , β is the slope angle. From Figure 19, we know that,

$$\Delta s . \sin \beta = \Delta h \quad (2)$$

$$\Delta s . \cos \beta = \Delta l \quad (3)$$

Where,

Δh , Δl are the height difference and the distance between a and b respectively

Using equation (2) & (3) in (1), then equation (1) becomes,

$$mg\Delta h = \frac{1}{2} m\Delta v^2 + \mu mg\Delta l \quad (4)$$

Simplifying (4) as,

$$\Delta h - \mu\Delta l = \frac{1}{2} \Delta v^2 \quad (5)$$

Integrating from $s=0$ to $s=$ total distance (L),

Equation (5) becomes,

$$H - \mu L = 0 \quad (6)$$

Where μ = coefficient of friction = tangent of the reach angle,

Equation (6) is written as,

$$\tan \alpha = H/L \quad (7)$$

Corominas (1996) analyzed log-log plots between the tangent of the reach angle and the landslide volume of 204 landslides and established the empirical relationship between the tangent of the reach angle and the volume of the landslide shown in equation (8).

$$\text{Log } \tan \alpha = A + B \text{ Log } V \quad (8)$$

Where, $\tan \alpha$ is the tangent of the reach angle (radians), A, B are coefficients indicating the type of movement and topographic constraints on the path, V is the volume of the landslide (m^3).

Using equation (8) in (9),

$$\text{Log } (H/L) = A + B \text{ Log } V \quad (9)$$

Corominas (1996) formed the regression equations for the following categories:

- All the landslide types
- Landslides considering all topographic constraints
- Obstructed landslides
- Unobstructed landslides

Table 9 shows the equations along with their correlation coefficients for all the categories. The regression equations of the unobstructed landslides group was incorporated in the landslide reach prototype as they had higher correlation coefficients when compared to other equations and were used to assess the safety of a point by evaluating the reach of the landslide.

Table 9: Regression equations for all landslide type (Corominas, 1996)

Category	Regression equation	Correlation Coefficient
All types of landslides	$\text{Log} \left(\frac{H}{L} \right) = -0.047 - 0.085 \text{ Log } V$	0.625
Landslides considering all topographic constraints		
Rockfall	$\text{Log} \left(\frac{H}{L} \right) = -0.210 - 0.109 \text{ Log } V$	0.759
Translational Slides	$\text{Log} \left(\frac{H}{L} \right) = -0.159 - 0.068 \text{ Log } V$	0.670
Earth Flows	$\text{Log} \left(\frac{H}{L} \right) = -0.214 - 0.070 \text{ Log } V$	0.648
Debris Flows	$\text{Log} \left(\frac{H}{L} \right) = -0.012 - 0.105 \text{ Log } V$	0.763
Obstructed landslides		
Rockfall	$\text{Log} \left(\frac{H}{L} \right) = 0.231 - 0.091 \text{ Log } V$	0.834
Translational Slides	$\text{Log} \left(\frac{H}{L} \right) = -0.133 - 0.057 \text{ Log } V$	0.756
Debris Flows	$\text{Log} \left(\frac{H}{L} \right) = -0.049 - 0.108 \text{ Log } V$	0.849
Unobstructed landslides		
Rockfall	$\text{Log} \left(\frac{H}{L} \right) = 0.167 - 0.119 \text{ Log } V$	0.924
Translational Slides	$\text{Log} \left(\frac{H}{L} \right) = -0.143 - 0.080 \text{ Log } V$	0.796
Earth Flows	$\text{Log} \left(\frac{H}{L} \right) = -0.220 - 0.138 \text{ Log } V$	0.908
Debris Flows	$\text{Log} \left(\frac{H}{L} \right) = -0.031 - 0.102 \text{ Log } V$	0.868

Basic assumptions of empirical runout model

- The empirical runout model is valid for conditions in which the slope is continuously downwards and it's not valid for an upward slope (as shown in Figure 20).

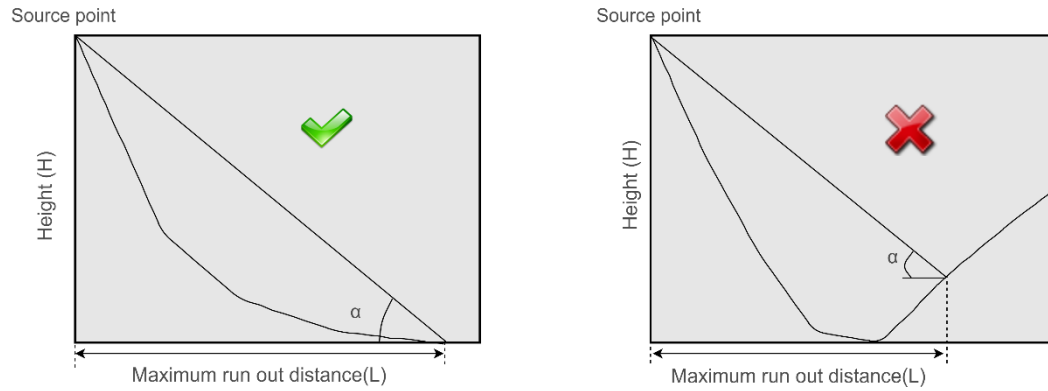


Figure 20: Slope scenarios

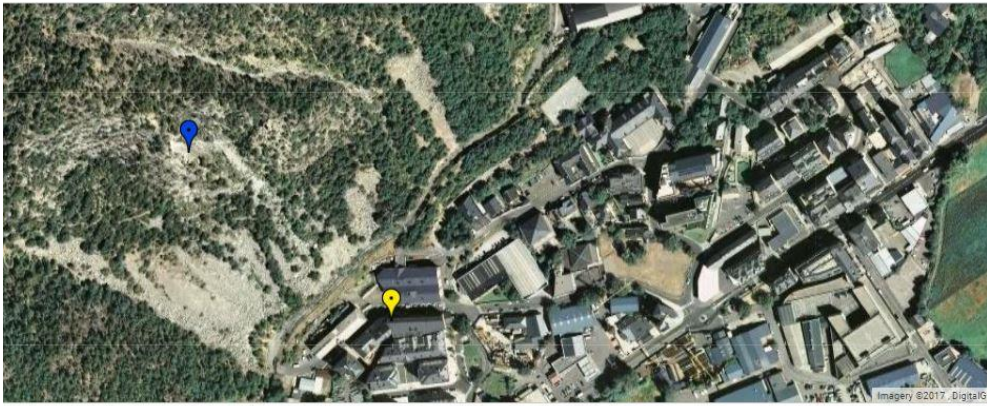
- The empirical runout model does not consider the direction of movement. Instead it can be used to predict whether a location is inside the path of a soil/rock mass or outside the potentially affected area, along a profile which is defined by the location of the user and the source point.

APPENDIX C: SCREENSHOTS OF THE PROTOTYPE

Landslide Reach App

Powered by Google Maps API

Select your Source Point



Choose the Source Point

Current Location

Lat/Long:

Elevation:

Source Location

Lat/Long:

Elevation:

Calculation of H/L ratio

Elev_diff: Elevation Difference

Distance: Distance b/w two locations

Cal(H/L): Elev_diff/Distance ratio

Set the Parameters

Estimated Volume: Cubic Metres

Type of Movement:

Predicted (H/L):

Status of Current Location:

● Your location is unsafe

● Your location is safe

Follow the Steps

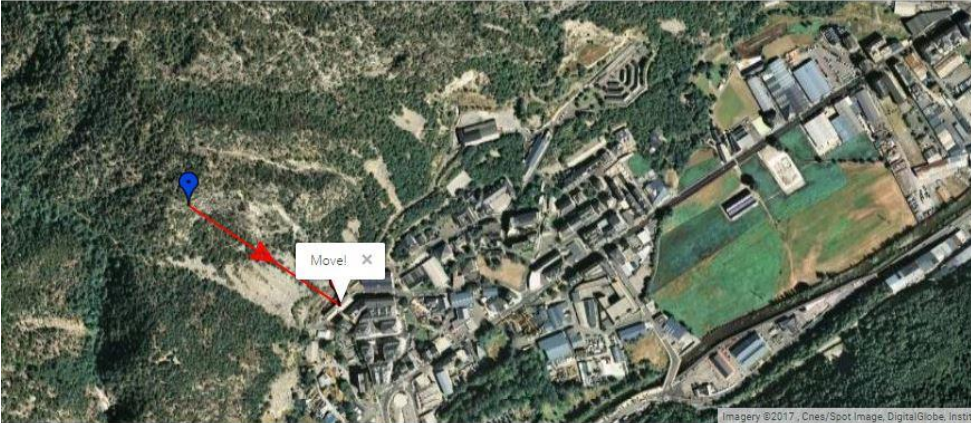
1. Yellow marker indicates the current location of the device
2. The blue marker is used to mark the source point of the landslide
3. Enter the volume manually in the Estimated Volume box
4. Select the type of movement
5. The status of current location of the user is displayed
6. Hit the ReCalc button to calculate the extent of same landslide type with different volume
7. Reload to refresh the entire application

Figure 21: Landing Page of the landslide reach app

Landslide Reach App

Powered by Google Maps API

Select your Source Point



Choose the Source Point

Current Location
Lat/Long: 42.496518, 1.497232
Elevation: 990

Source Location
Lat/Long: 42.498013, 1.494132
Elevation: 1258
Calculation of H/L ratio
Elev. diff: 268
Distance: 304.0022
Calc(H/L): 0.8816

Set the Parameters

Estimated Volume: Cubic Metres
Type of Movement:
Predicted (H/L):

Status of Current Location:
Your location is unsafe

● Your location is unsafe
● Your location is safe

ReCalc Erase

Follow the Steps

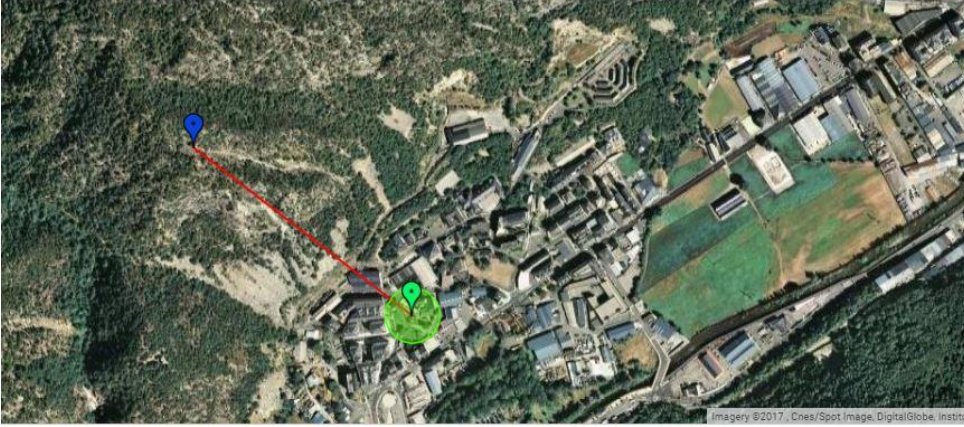
1. Yellow marker indicates the current location of the device
2. The blue marker is used to mark the source point of the landslide
3. Enter the volume manually in the Estimated Volume box
4. Select the type of movement
5. The status of current location of the user is displayed
6. Hit the ReCalc button to calculate the extent of same landslide type with different volume
7. Reload to refresh the entire application

Figure 22: Unsafe scenario of landslide reach app

Landslide Reach App

Powered by Google Maps API

Select your Source Point



Choose the Source Point

Current Location
Lat/Long :42.49636,1.498948
Elevation:984

Source Location
Lat/Long :42.498883,1.494476
Elevation:1328
Calculation of H/L ratio
Elev_diff:844
Distance:462.2569
Cal(H/L):0.7442

Set the Parameters

Estimated Volume: Cubic Metres
Type of Movement:
Predicted (H/L):

Status of Current Location:
Your location is Safe

● Your location is unsafe
● Your location is safe

Follow the Steps

1. Yellow marker indicates the current location of the device
2. The blue marker is used to mark the source point of the landslide
3. Enter the volume manually in the Estimated Volume box
4. Select the type of movement
5. The status of current location of the user is displayed
6. Hit the ReCalc button to calculate the extent of same landslide type with different volume
7. Reload to refresh the entire application

Figure 23: Safe Scenario of landslide reach

LIST OF REFERENCES

- Abbott. (2016). Using wearable electronic devices for health monitoring | FreeStyle Blood Glucose Meters. Retrieved January 23, 2017, from <https://freestylediabetes.co.uk/freestyle-thinking/post/wearable-electronic-devices>
- Abdalla, R. (2016). Mobile GIS and Location-Based Services (LBS). In *Introduction to Geospatial Information and Communication Technology (GeoICT)* (pp. 83–103). Cham: Springer International Publishing. http://doi.org/10.1007/978-3-319-33603-9_5
- Abella, E. A. C., & Van Westen, C. J. (2007). Qualitative landslide susceptibility assessment by multicriteria analysis: A case study from San Antonio del Sur, Guantánamo, Cuba. <http://doi.org/10.1016/j.geomorph.2006.10.038>
- AGTERRA. (2016). MapItFast: Mobile Cloud Data Logging for GIS Systems. Retrieved August 16, 2016, from <http://www.agterra.com/mapitfast-mobile-cloud-data-logging-for-gis-systems/>
- Albert, D. P., Gesler, W. M., & Levergood, B. (2000). *Spatial analysis, GIS, and remote sensing applications in the health sciences*. Ann Arbor Press. Retrieved from <http://docshare01.docshare.tips/files/23083/230838774.pdf>
- Albrecht, J. (1996). Universal analytical GIS operations — a task-oriented systematization of data structure-independent GIS functionality. *ISPA*, 577–591. Retrieved from <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.452.8262&rep=rep1&type=pdf>
- Aleks Buczkowski. (2016). How accurate is your smartphone's GPS in an urban jungle? - Geoawesomeness. Retrieved January 30, 2017, from <http://geoawesomeness.com/how-accurate-is-your-smartphones-gps-in-an-urban-jungle/>
- Apache Cordova. (2016a). Architectural overview of Cordova platform. Retrieved February 2, 2017, from <https://cordova.apache.org/docs/en/latest/guide/overview/index.html>
- Apache Cordova. (2016b). Creating your first Cordova app. Retrieved February 6, 2017, from <https://cordova.apache.org/docs/en/latest/guide/cli/index.html>
- Aronoff, S. (1989). Geographic information systems: A management perspective. *Geocarto International*, 4(4), 58–58. <http://doi.org/10.1080/10106048909354237>
- Athanasis, N., Karagiannis, F., Palaiologou, P., Vasilakos, C., & Kalabokidis, K. (2015). AEGIS App: Wildfire Information Management for Windows Phone Devices. *Procedia Computer Science*, 56, 544–549. <http://doi.org/10.1016/j.procs.2015.07.249>
- Bob Mckerrow. (2016). 700 million people live in mountain regions. Retrieved February 10, 2017, from <http://sustainable-summits.com/700-million-people-live-in-mountain-regions/>
- Burrough, P. A., & McDonnell, R. A. (1998). Principles of Geographical Information Systems. Retrieved from [http://dds.cepal.org/infancia/guide-to-estimating-child-poverty/bibliografia/capitulo-IV/Burrough Peter A y McDonnell Rachael A \(1998\) Principles of geographical information systems.pdf](http://dds.cepal.org/infancia/guide-to-estimating-child-poverty/bibliografia/capitulo-IV/Burrough%20Peter%20A%20y%20McDonnell%20Rachael%20A%20(1998)%20Principles%20of%20geographical%20information%20systems.pdf)
- Caitlin Dempsey. (2013). Attribute Data Types for GIS. Retrieved February 9, 2017, from <https://www.gislounge.com/attribute-data-types-gis/>
- Caitlin Dempsey. (2016). Open Source GIS and Freeware GIS Applications. Retrieved February 5, 2017, from <https://www.gislounge.com/open-source-gis-applications/>
- Chrysanthis, P. K., Nasution, J., Kamath, M., Ramamritham, K., Dalling, I., H T Tangkawarow, I. R., & Waworuntu, J. (2016). A Comparative of business process modelling techniques Correctness issues in workflow management Understanding and assessing safety culture A Comparative of business process modelling techniques. *Mater. Sci. Eng*, 128. Retrieved from <http://iopscience.iop.org/1757-899X/128/1/012010>
- Corominas, J. (1996). The angle of reach as a mobility index for small and large landslides. *Canadian Geotechnical Journal*, 33(2), 260–271. <http://doi.org/10.1139/t96-005>
- Corominas, J., Copons, R., Moya, J., Vilaplana, J. M., Altimir, J., & Amigó, J. (2005). Quantitative assessment of the residual risk in a rockfall protected area. *Landslides*, 2, 343–357. <http://doi.org/10.1007/s10346-005-0022-z>
- Creately. (2014). Business Process Modeling Techniques. Retrieved February 11, 2017, from <http://creately.com/blog/diagrams/business-process-modeling-techniques/#workflow>
- Crisis360. (2017). How Crisis360 Works. Retrieved February 10, 2017, from <https://www.crisis360.com/how-crisis360-works>
- Cyberchimps. (2017). Free Responsive WordPress Theme. Retrieved February 2, 2017, from

- <https://cyberchimps.com/responsive-theme/>
- De Donatis, M., & Bruciatelli, L. (2006). MAP IT: The GIS software for field mapping with tablet pc. *Computers & Geosciences*, 32(5), 673–680. <http://doi.org/10.1016/j.cageo.2005.09.003>
- Edraw. (2017). Benefits of Using Workflow Diagrams. Retrieved February 9, 2017, from <https://www.edrawsoft.com/using-workflow-diagram.php>
- Egenhofer, M. J., & Franzosa, R. D. (1991). Point-set topological spatial relations. *International Journal of Geographical Information Systems*, 5(2), 161–174. <http://doi.org/10.1080/02693799108927841>
- EL-Gamily, I. H., Selim, G., & Hermas, E. A. (2010). Wireless mobile field-based GIS science and technology for crisis management process: A case study of a fire event, Cairo, Egypt. *The Egyptian Journal of Remote Sensing and Space Science*, 13(1), 21–29. <http://doi.org/10.1016/j.ejrs.2010.07.003>
- El-Kassas, W. S., Abdullah, B. A., Yousef, A. H., & Wahba, A. M. (2015). Taxonomy of Cross-Platform Mobile Applications Development Approaches. *Ain Shams Engineering Journal*. <http://doi.org/10.1016/j.asej.2015.08.004>
- esri. (2015). Esri Software. Retrieved February 13, 2017, from <http://www.esri.com/software/arcgis/arcgis-app-for-smartphones-and-tablets>
- esri. (2016). What is GIS. Retrieved February 13, 2017, from <http://www.esri.com/what-is-gis>
- esri. (2017). Mobile GIS. Retrieved February 13, 2017, from <http://resources.arcgis.com/content/mobilegis/about>
- Forkuor, G., & Maathuis, B. (2012). Comparison of SRTM and ASTER Derived Digital Elevation Models over Two Regions in Ghana – Implications for Hydrological and Environmental Modeling. Retrieved from <http://cdn.intechopen.com/pdfs/32991.pdf>
- Formhub. (2017). Formhub. Retrieved February 11, 2017, from <https://formhub.org/>
- G Gallerini, Bruciatelli Lorenzo, Mauro De Donatis, S. S. (2007). Geomatics applied to landslide digital field mapping. In *European Geosciences Union 2007*. Retrieved from <file:///C:/Users/ragha/Downloads/EGU2007-J-08225.pdf>
- Garafa. (2016). GIS Pro & GIS KitGarafa | Garafa. Retrieved August 16, 2016, from <http://garafa.com/wordpress/all-apps/gis-pro>
- Geographical Open Data Kit. (2017). GeoODK. Retrieved February 11, 2017, from <http://geoodk.com/>
- Geopaparazzi. (2016). Geopaparazzi - Geopaparazzi 4.4.0 documentation. Retrieved August 22, 2016, from <http://geopaparazzi.github.io/geopaparazzi/>
- GeoServer. (2013a). GeoServer User Manual. Retrieved February 11, 2017, from <http://docs.geoserver.org/2.3.5/user/index.html>
- GeoServer. (2013b). WPS Processes. Retrieved February 11, 2017, from <http://docs.geoserver.org/2.3.5/user/extensions/wps/processes.html>
- Geospago. (2016). Data Collection vs. Mobile GIS - Geospago. Retrieved January 18, 2017, from <https://geospago.co/2016/02/07/data-collection-vs-mobile-gis/>
- GISGeography. (2016). The Remarkable History of GIS. Retrieved November 6, 2016, from <http://gisgeography.com/history-of-gis/>
- Goodchild, M. F. (1987). A spatial analytical perspective on geographical information systems. *International Journal of Geographical Information Systems*, 1(4), 327–334. <http://doi.org/10.1080/02693798708927820>
- Google. (2016a). Get Started with Google Maps APIs. Retrieved February 6, 2017, from <https://developers.google.com/maps/get-started/>
- Google. (2016b). Google Maps Web Service APIs. Retrieved February 9, 2017, from <https://developers.google.com/maps/web-services/>
- Google. (2017a). Google Maps Elevation API Usage Limits. Retrieved February 10, 2017, from <https://developers.google.com/maps/documentation/elevation/usage-limits>
- Google. (2017b). Introduction to the Google Maps Roads API. Retrieved February 11, 2017, from <https://developers.google.com/maps/documentation/roads/intro>
- Google Trends. (2017a). Google Maps API, OpenLayers, Mapbox, Microsoft API, Mapquest API - Explore - Google Trends. Retrieved February 10, 2017, from [https://www.google.com/trends/explore?q=Google Maps API,OpenLayers,Mapbox,Microsoft API,Mapquest API](https://www.google.com/trends/explore?q=Google%20Maps%20API,OpenLayers,Mapbox,Microsoft%20API,Mapquest%20API)
- Google Trends. (2017b). Openlayers, GeoServer, MapServer, MapFish - Explore - Google Trends. Retrieved February 11, 2017, from <https://www.google.com/trends/explore?q=Openlayers,GeoServer,MapServer,MapFish>
- Graciela Peters Guarin. (2008). *Integrating Local Knowledge into GIS-Based Flood Risk Assessment, The case of Triangulo and Mabolo communities in Naga City - The Philippines*. University of Twente. Retrieved from

- https://www.itc.nl/library/papers_2008/phd/peters.pdf
- Heflo. (2016). BPMN notation 2.0: Why and how to use it? Retrieved February 11, 2017, from <https://www.heflo.com/blog/bpm/bpmn-notation/>
- Herman, F., & Heidmann, F. (2002). User Requirement Analysis and Interface Conception for a Mobile, Location-Based Fair Guide (pp. 388–392). Springer Berlin Heidelberg. http://doi.org/10.1007/3-540-45756-9_45
- ICIMOD. (2016). Mobile application for reporting disaster events. Retrieved July 27, 2016, from <http://www.icimod.org/?q=18659>
- ILWIS. (2016). Getting started: Using Python with ILWIS. Retrieved February 9, 2017, from http://ilwis.itc.utwente.nl/wiki/index.php/Getting_started:_Using_Python_with_ILWIS
- Jakob Nielsen. (2012). How Many Test Users in a Usability Study? Retrieved February 6, 2017, from <https://www.nngroup.com/articles/how-many-test-users/>
- James Stables. (2016). Best heart rate monitors and HRM watches. Retrieved January 23, 2017, from <https://www.wareable.com/fitness-trackers/best-heart-rate-monitor-and-watches>
- Janet Wagner. (2015). Top 10 Mapping APIs. Retrieved February 10, 2017, from <https://www.programmableweb.com/news/top-10-mapping-apis-google-maps-microsoft-bing-maps-and-mapquest/analysis/2015/02/23>
- Jim Baumann. (2012). Smartphone App Aids District's Facilities Maintenance. Retrieved February 5, 2017, from <http://www.esri.com/news/arcuser/0312/smartphone-map-aids-districts-facilities-maintenance.html>
- Johannes Brauner. (2015). *Formalizations for geoperators -geoprocessing in Spatial Data Infrastructures*. Technische Universität Dresden. Retrieved from http://www.qucosa.de/fileadmin/data/qucosa/documents/18250/dissertation_brauner-Neu.pdf
- Khan, G., Bueff, A., Mihov, I., Tessema, N., Garrido, J., Russel, C., & Parnia, A. (2016). Development of Transportation Asset Management and Data Collection System (TAMS) Using Mobile Applications. *Procedia Engineering*, 161, 1180–1186. <http://doi.org/10.1016/j.proeng.2016.08.536>
- Kim, W., Kerle, N., & Gerke, M. (2016). Mobile augmented reality in support of building damage and safety assessment. *Nat. Hazards Earth Syst. Sci*, 16, 287–298. <http://doi.org/10.5194/nhess-16-287-2016>
- KoBoToolbox. (2017). KoBoToolbox | Data Collection Tools for Challenging Environments. Retrieved February 11, 2017, from <http://www.kobotoolbox.org/>
- Kuhn, W. (2012). Core concepts of spatial information for transdisciplinary research. *International Journal of Geographical Information Science*, 26(12), 2267–2276. <http://doi.org/10.1080/13658816.2012.722637>
- Li, C., & Jiang, Y. (2011). Development of mobile GIS system for forest resources second-class inventory. *Journal of Forestry Research*, 22(2), 263–268. <http://doi.org/10.1007/s11676-011-0160-1>
- Liu, Y., Yang, Y., & Li, L. (2012). Major natural disasters and their spatio-temporal variation in the history of China. *Journal of Geographical Sciences*, 22(6), 963–976. <http://doi.org/10.1007/s11442-012-0976-4>
- Mansourian, A., Farnaghi, M., & Taleai, M. (2008). Development of New Generations of Mobile GIS Systems Using Web Services Technologies: A Case Study for Emergency Management. *Journal of Applied Sciences*, 8(15), 2669–2677. Retrieved from <http://docsdrive.com/pdfs/ansinet/jas/2008/2669-2677.pdf>
- Mansourian, A., Rajabifard, A., Valadan Zoej, M. J., & Williamson, I. (2006). Using SDI and web-based system to facilitate disaster management. *Computers & Geosciences*, 32(3), 303–315. <http://doi.org/10.1016/j.cageo.2005.06.017>
- Mapbox. (2017). Mapbox API Documentation. Retrieved February 10, 2017, from <https://www.mapbox.com/api-documentation/#introduction>
- MapQuest. (2017a). MapQuest Developer Network. Retrieved February 10, 2017, from <https://www.developer.mapquest.com/plans>
- MapQuest. (2017b). MapQuest Developer Network. Retrieved February 10, 2017, from <https://developer.mapquest.com/>
- Marco. (2015). QGIS Mobile 0.2 Demo. Retrieved January 30, 2017, from <http://www.opengis.ch/2015/01/11/qgis-mobile-0-2-demo/>
- Martin Klopfer. (2013). *EO2HEAVEN mitigating environmental health risks*. (Martin Klopfer, Ed.) (First). Retrieved from <http://www.eo2heaven.org/sites/default/files/content-files/documents/eo2heavenbook.pdf>
- Matteo Luccio. (2010). Esri ArcWatch June 2010 - Mobile GIS Helps Firefighters Respond More Effectively. Retrieved January 23, 2017, from <http://www.esri.com/news/arcwatch/0610/marietta->

fire-dept.html

- Mensah-Okantey, E. (2007). *Designing A Prototype Mobile GIS to Support Cadastral Data Collection in Ghana*. University of Twente, ITC. Retrieved from http://www.itc.nl/library/papers_2007/msc/gfm/mensah.pdf
- Microsoft. (2017a). Bing Maps API Best Practices. Retrieved February 10, 2017, from <https://msdn.microsoft.com/en-us/library/dn894107.aspx>
- Microsoft. (2017b). Understanding Bing Maps Transactions. Retrieved February 10, 2017, from <https://msdn.microsoft.com/en-us/library/ff859477.aspx>
- MIDLAND GIS Solutions. (2016). Integrity Mobile GIS Now for iPhone and iPad | Midland GIS Solutions. Retrieved August 16, 2016, from <http://www.midlandgis.com/2012/10/08/integrity-mobile-gis-iphone-ipad/>
- Mobaraki, A., Mansourian, A., & Malek, M. (2009). Mobile GIS for Emergency Management in SDI Framework. *Journal of RS & GIS*, 1(3), 65–80.
- Modelworld. (2017). Modelworld. Retrieved February 11, 2017, from <http://www.modelworld.nl/>
- Moritz Gaupp A. (2013). Maps 3D. Retrieved August 16, 2016, from <http://www.movingworld.de/index.html>
- Mukherji, A., Ganapati, N. E., & Rahill, G. (2014). Expecting the unexpected: field research in post-disaster settings. *Natural Hazards*, 73(2), 805–828. <http://doi.org/10.1007/s11069-014-1105-8>
- NC4. (2017). NC4 Risk Center. Retrieved February 1, 2017, from <http://nc4.com/Pages/nc4-risk-center.aspx>
- ODK. (2017). Open Data Kit. Retrieved February 9, 2017, from <https://opendatakit.org/>
- Oneil Williams. (2016). New Trends in Information and Communication Technology. Retrieved November 9, 2016, from <http://techin.oureverydaylife.com/new-trends-information-communication-technology-1380.html>
- OPENGIS.ch. (2015). QGIS Mobile 0.2 Demo | ANDROID · GIS · WEB. Retrieved January 22, 2017, from <http://www.opengis.ch/2015/01/11/qgis-mobile-0-2-demo/>
- OpenLayers. (2017). OpenLayers. Retrieved February 9, 2017, from <https://openlayers.org/>
- Orbus Software. (2017). BPMN Software. Retrieved February 11, 2017, from <http://www.orbussoftware.com/business-process-analysis/bpmn/benefits/>
- Pellicani, R., Van Westen, C. J., & Spilotro, G. (2014). Assessing landslide exposure in areas with limited landslide information. *Landslides*, 11(3), 463–480. <http://doi.org/10.1007/s10346-013-0386-4>
- Pierdicca, R., Frontoni, E., Zingaretti, P., Mancini, A., Malinverni, E. S., Tasseti, A. N., ... Galli, A. (2016). Smart maintenance of riverbanks using a standard data layer and Augmented Reality. *Computers & Geosciences*, 95, 67–74. <http://doi.org/10.1016/j.cageo.2016.06.018>
- PNMSOFT. (2017). What is a Workflow? Retrieved February 11, 2017, from <http://www.pnmsoft.com/resources/bpm-tutorial/workflow-tutorial/>
- PySAL. (2017). Library Reference — Python Spatial Analysis Library. Retrieved February 10, 2017, from <http://pysal.readthedocs.io/en/latest/library/index.html>
- QGIS. (2017). Pyqgis Developer Cookbook. Retrieved February 9, 2017, from http://docs.qgis.org/testing/en/docs/pyqgis_developer_cookbook/intro.html
- Rizzini, A., Gardiner, K., Bertolotto, M., & Carswell, J. (2006). MEMS Mobile GIS: A Spatially Enabled Fish Habitat Management System (pp. 113–122). Springer, Berlin, Heidelberg. http://doi.org/10.1007/11935148_11
- Robert Mening. (2016). How to Make a Website. Retrieved February 2, 2017, from <https://websitesetup.org/>
- Ruiz-Carulla, R., Corominas, J., & Mavrouli, O. (2015). A methodology to obtain the block size distribution of fragmental rockfall deposits. *Landslides*, 12, 815–825. <http://doi.org/10.1007/s10346-015-0600-7>
- Stackoverflow. (2013). javascript - How do I return the response from an asynchronous call? - Stack Overflow. Retrieved February 12, 2017, from <http://stackoverflow.com/questions/14220321/how-do-i-return-the-response-from-an-asynchronous-call>
- Stoffel, M., Wyzga, B., & Marston, A. R. (2016). Floods in mountain environments: A synthesis. *Geomorphology*, 272, 1–9. <http://doi.org/10.1016/j.geomorph.2016.07.008>
- Thomas, D. S. K., Ertuğay, K., & Kemec, S. (2007). The Role of Geographic Information Systems/Remote Sensing in Disaster Management. In H. Rodriguez, E. L. Quarantelli, & R. Dynes (Eds.), *Handbook of Disaster Research* (First, pp. 83–96). New York, NY: Springer New York. http://doi.org/10.1007/978-0-387-32353-4_5

- Tomlin. (1990). *Geographic information systems and cartographic modeling*. Englewood Cliffs, New Jersey. Retrieved from http://www.wiley.com/legacy/wileychi/gis/Volume1/BB1v1_ch23.pdf
- Tsou, M.-H. (2004). Integrated Mobile GIS and Wireless Internet Map Servers for Environmental Monitoring and Management. *Cartography and Geographic Information Science*, 31(3), 153–165. Retrieved from <http://map.sdsu.edu/publications/Tsou2-CaGIS-final-short.pdf>
- Tsou, M.-H., & Sun, C.-H. (2006). Mobile GIServices Applied to Disaster Management. In J. Drummond (Ed.), *Dynamic and mobile GIS : investigating changes in space and time* (pp. 213–233). CRC Press. <http://doi.org/10.1201/9781420008609.ch12>
- UNISDR. (2007). Terminology - UNISDR. Retrieved August 23, 2016, from <https://www.unisdr.org/we/inform/terminology>
- Usability.gov. (2013). Think-Aloud Protocols for Website Usability Testing. Retrieved February 7, 2017, from <https://www.usability.gov/how-to-and-tools/resources/multimedia-and-trainings/think-aloud-protocols-website-usability-testing.html>
- Withanaarachchi, J., & Setunge, S. (2014). Influence of Decision Making During Disasters and How It Impacts a Community. *10th International Conference of the International INstitute for Infrastructure Resilience and Reconstruction*, 176–188. Retrieved from <http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1005&context=i3r2>
- Wolf-GIS APEX. (2016). Wolf-GIS APEX - The Pinnacle of Mobile Mapping Data Tools and Storage. Retrieved August 16, 2016, from <http://www.wolfgisapex.com/>
- WordPress.org. (2017a). About — WordPress. Retrieved January 24, 2017, from <https://wordpress.org/about/>
- WordPress.org. (2017b). SyntaxHighlighter Evolved. Retrieved February 2, 2017, from <https://wordpress.org/plugins/syntaxhighlighter/>
- wpbeginner.com. (2016). The Truth About Shared WordPress Web Hosting. Retrieved January 25, 2017, from <http://www.wpbeginner.com/the-truth-about-shared-wordpress-web-hosting/>
- Zhao, Q., Deng, F., Zhang, W., & Zeng, X. (2012). The Research of Mobile GIS Power Distribution Line Inspection Based on Mobile SVG/J2ME. *Physics Procedia*, 24, 1038–1043. <http://doi.org/10.1016/j.phpro.2012.02.155>
- Zuriñe Dopacio González. (2015). The New Smart Wristbands for 2015. Retrieved January 30, 2017, from <https://www.wearable-technologies.com/2015/02/the-news-smart-wristbands-for-2015/>