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DISSERTATION

ANALYSING THE PRACTICAL FEASIBILITY OF USING FREE AND OPEN SOURCE SOFTWARE FOR GEOGRAPHICAL INFORMATION SYSTEMS (FOSSGIS) IN MILITARY OPERATIONS

by

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DECLARATION

I, Susanna Jacoba Henrico, declare that the dissertation which I hereby submit for the degree Magister Artium at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

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SIGNATURE DATE

SUMMARY OF RESEARCH

Analysing the practical feasibility of using FOSSGIS in military operations

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SUMMARY

Remaining ahead of the enemy in all circumstances is crucial to any military power. Technology, especially GIS, has become a key factor in military operations. GIS can provide the military commander with geospatial information about the theatre of war that can assist him in the planning and execution of his mission. Unfortunately, technology usually comes at a price. GIS software is no exception. The cost of acquiring and maintaining GIS software and software training can be high. The cost of proprietary software limits the use of GIS in military operations. GIS software packages can be divided into proprietary and Free and Open Source Software for GIS (FOSSGIS) packages. GIS software packages consist of numerous tools and functionalities to assist military operations with geospatial queries, analysis and product creation. This study was done in order to evaluate FOSSGIS as a feasible alternative to available proprietary GIS software. FOSSGIS was evaluated in terms of prescribed GIS functionalities, user-friendliness and costs. Should the comparison be favourable, to what extent can FOSSGIS replace proprietary GIS software in military operations? QGIS was used as the FOSSGIS application to compare against ArcGIS. The GIS functionalities that were evaluated were identified by means of the literature study as well as the development of a use case. Results show that all GIS functions tested in this study could be successfully performed by both software products. These results are interesting, since it shows that units or directorates can successfully deploy FOSSGIS in certain use cases in order to expand the existing GIS capabilities for military operations.

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ACRONYMS AND MILITARY TERMS USED IN THIS STUDY

ACRONYMS	
3D	Three-dimensional
Bn	Battalion
COTS	Commercial off-the-shelf
CC	Creative Commons
EULA	End User License Agreement
FAR	Federal Acquisition Regulation
FIFA	Fédération Internationale de Football Association
FOSS	Free and Open Source Software
FOSSGIS	Free and Open Source Software for GIS
GIS	Geographic Information Systems
GEOINT	Geospatial Intelligence
GUI	Graphical User Interface
IMINT	Image Intelligence
ISO	International Organization for Standardization
KDE	Kernel Density Estimation
MOOTW	Military Operations Other Than War
MIMO	Map In - Map Out
OCOKA	Observation and field of fire, Cover and Concealment, Obstacles, Key terrain and Avenue of approach
OGC	Open Geospatial Consortium
OS	Open Source
OSI	Open Source Initiative
R(SA)	Republic of South Africa
SAAEF	South African Army Engineer Formation

SAMHS	South African Military Health Services
SANDF	South African National Defence Force
Sqn	Squadron
UAT	User Acceptance Test
US	United States
USL	Unlimited Site License
VPA	Volume Purchase Agreement
MILITARY TERMINOLOGY	
Battle	A battle consists of a set of related engagements and could affect the outcome of the campaign.
Battalion	A large body of troops ready for battle. Varies by nationality, but typically consists of 300 to 800 soldiers.
Campaign	A series of related military operations designed to achieve strategic objectives.
Campaign plan	Describes how operations are conducted.
Commander	A person in authority, especially over a squad of troops or a military operation.
Engagements	It is small conflicts or skirmishes usually between opposing manoeuvring forces. Their duration is usually short.
Manoeuvring	A planned and regulated movement or evolution of, among others, troops and warships. A series of tactical exercises usually carried out in the field by large bodies of troops in simulating the conditions of war.
Operational Level	The Operational level of War can be described as the level at which major operations (a series of tactical actions) and campaigns is carried out and supported in order to achieve goals set out by strategic commanders.
Operations	Consist of coordinated actions, for example battles, in a campaign and can decide the outcome of the campaign.

Scope of the battlefield	This concept establishes an area of geographical and operational responsibility for the commander.
Squadron	An operational unit in an air force consisting of two or more flights of aircraft and the personnel required to fly them.
Strategic Level	That level at which a national security objective is considered. Political goals are defined at this level.
Tactical Level	Battles and engagements are planned and executed at the tactical level to achieve campaign objectives as articulated by the operational commander in the campaign plan, using tactical missions.
Theatre of Operation	A subarea in a theatre of war defined by the geographic combatant commander required to conduct or support specific combat operations. A region in which active military operations are in progress.

CHAPTER 1: INTRODUCTION AND PROBLEM STATEMENT

1.1 INTRODUCTION

Bolstad (2005) defined Geographic Information Systems (GIS) as "a computer-based system to aid in the collection, maintenance, storage, analysis, output, and distribution of spatial data and information". Pickles (1995) stated that definitions are likely to change as technology develops. This statement proved to be true. According to Clarke (2011), GIS definitions evolved over the years as they were needed. Because of this evolution, a GIS can be defined in more than one manner. GIS answers our spatial questions about where features can be found, any patterns that exist, changes occurring over a specific period, conditions that apply and the spatial implications if certain actions are taken (Haywood et al., 1998).

The key components of any GIS are hardware, software, data, people and procedures. GIS is not merely a *software* package, but rather a *system* consisting of tools to organise and analyse geospatial data. The type of data that is used in a GIS is unique in size and it therefore requires a computer with enough storage space and processing power. It also requires other hardware sources that are often needed to input the data into the GIS, for example scanners, keyboards, printers and plotters to deliver an output product. Currently a wide variety of GIS software solutions are available. This software gives us the tools to manage, analyse and effectively display and disseminate spatial data (Bolstad, 2005; Clarke, 2011).

All software generally belongs to one of two broad categories: "proprietary" or "open source software" (see paragraph 2.4.2). The software's copyright holder usually licenses proprietary software, and various types of proprietary licenses can be distinguished (see Table 2.2). The source code of proprietary software is not shared (Ballardini, 2012). Many proprietary licenses are also commercial in nature. However, others are free. Conversely, with open source software, the source code is released and shared (Hall and Leahy, 2008). Since open source software is usually free, the term free and open source software (FOSS) came into existence. "*Commercial off-the-shelf (COTS) is a Federal Acquisition Regulation (FAR) term for commercial items, including services available in the* *commercial marketplace*"[1]. Commercial off-the-shelf (COTS) require configurations that are typically tailored for specific uses. These products can be leased, purchased and even licensed. Commercial software can be either proprietary or free and open source software. Commercialisation does not exclude the free sharing, reusing and duplication of the software (Open Source Initiative, 2016). GIS software packages can also be divided into proprietary and free and open source software (FOSS) for GIS (FOSSGIS) packages. In the GIS world, quite a few "commercially available" software products exist. Bolstad (2005) mentions that ArcGIS is the most popular GIS software. Other proprietary available GIS software packages include Autodesk, Bentley Systems, Inc., Cartographica, DeLorme, GeoMedia, Maptitude, MapInfo and MapMaker.

In comparison, FOSSGIS is becoming increasingly valuable in the international geospatial community. It consists of various tools to assist the GIS operator in performing both basic and advanced geospatial tasks. Some of the most widely used FOSSGIS applications are (Steiniger and Bocher, 2009) QGIS, gvSIG, GRASS, OpenJUMP, uDIG, PostGIS, MapWindow, SAGA, WhiteBox GAT, Kosmos and TerraView.

1.2 APPLICATION OF GIS IN THE MILITARY

The level of war (strategic, operational or tactical) defines the geographical extent for the commander. The operational level acts as a vital link between all levels of war (see paragraph 2.3.6) and is typically the level at which major operations are carried out. The range of operations that the military can support includes both war operations and military operations other than war (MOOTW), such as humanitarian operations.

In the military, terrain and the knowledge of the terrain (from maps or a GIS) are important factors for the commander to consider in the planning of any military operation. The terrain of an area affects the type of military vehicles and weapon systems that can be used in any given situation. The terrain layout also influences the execution time of certain manoeuvres or operations (Lodi et al., 2014). Even communications during operations are affected by terrain. Line of sight is crucial for certain communications as well as specific weapon systems. Terrain, knowledge thereof and its use can determine who wins a battle, as with those along the Modder River in South Africa between November 1899 and

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[1] Source: www.wikipedia.org/wiki/Comercial_off-the-shelf

February 1900 (Smit and Janse van Rensburg, 2014). Geomagnetic information also affects the equipment used in an operation. It is therefore critical for the commander to have the complete terrain picture in order to assess the terrain before making decisions. The role of a GIS in the military is to provide the military commander with geospatial information about the theatre of war. Consequently, GIS is a source of information that military commanders can use to plan and execute military operations (Saglam, 2005).

The military's use of GIS has become a requirement rather than an advantage. GIS is now an integral part of many of the directorates, formations and units at more than one level of war. The application of the GIS may differ for the various users of GIS in the military, and for that reason various products are created using GIS. The problem is not the military's use of GIS, but rather the costs involved in the initial purchasing of the software and all its needed extensions, as well as the maintenance and upgrading of this software. Extensive availability of GIS products in the military will lead to a more widespread application of GIS. This is not always possible due to the huge financial implication of proprietary software. Nonetheless, the use of FOSSGIS might be a feasible alternative during military operations when costs are the main factor for not expanding the use of GIS applications in the military domain.

One very important factor to consider would be to determine whether the use of FOSSGIS in military operations is feasible to such an extent that it can replace proprietary used software. Donnelly (2010) cites that in recent times, the development and implementation of FOSSGIS for the international geospatial community have increased. Deek and McHugh (2007) state that the open source movement is "a worldwide attempt to promote an open style of software development more aligned with the acceptable intellectual style of science rather than the proprietary modes of invention that have been characteristic of modern business". In the present day, numerous FOSSGIS applications exist to support different facets of GIS applications. The most widely used FOSSGIS software packages that can provide both basic and complex functionalities are mentioned in paragraph 1.1.

1.3 EXAMPLE OF A GIS BUSINESS PROCESS

It is important for a military organisation to realise the impact that a system could have on its business process. The business process shown in Figure 1.1 is an example of a military unit/directorate where geospatial products is created for a variety of military/or other clients. In general, the unit/directorate receives a task from a client; the task is completed, checked and sent back to the client. The client will provide feedback with regard to his/her satisfaction with the product.

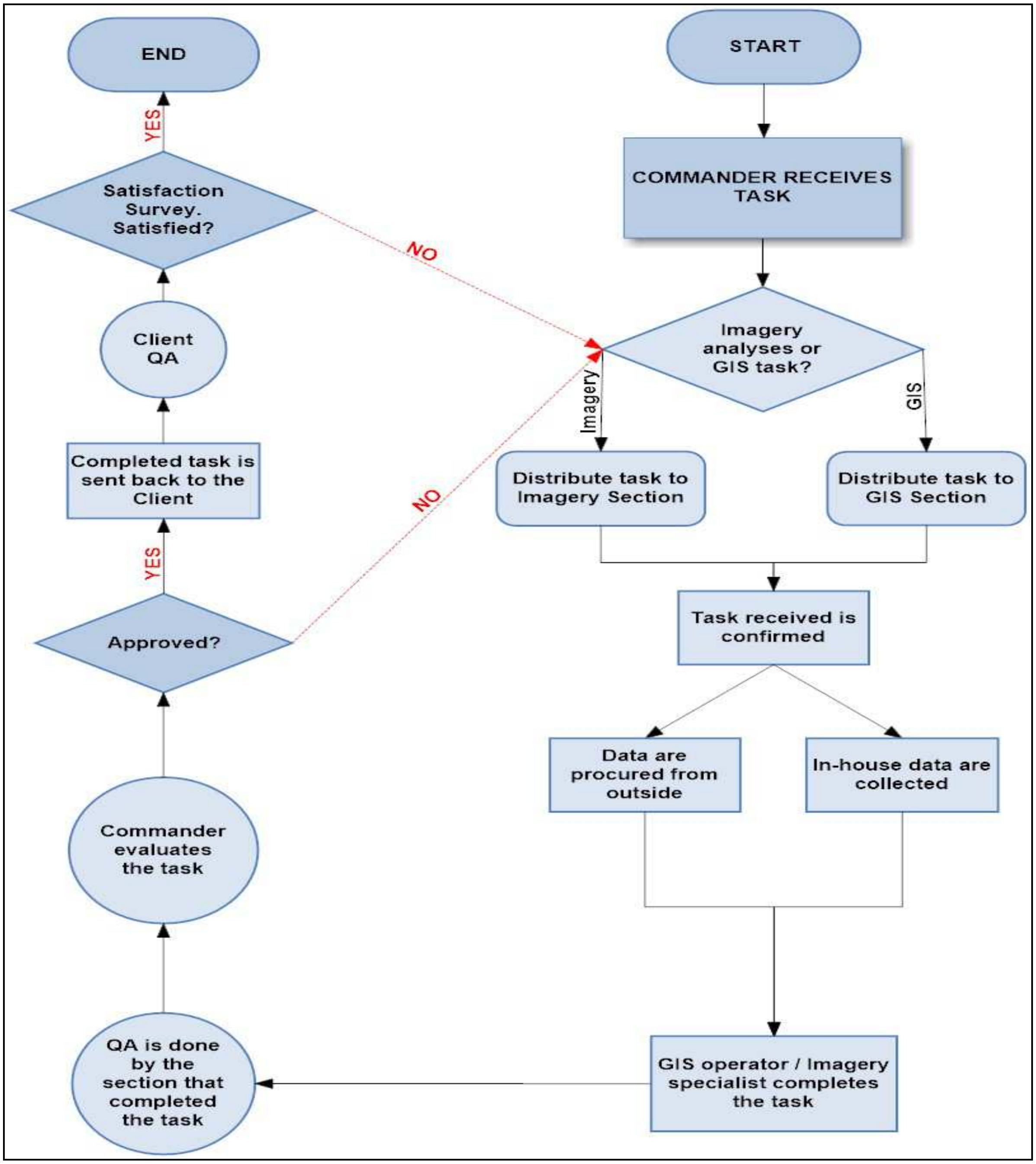

Figure 1.1: Example of a GIS business process

The process will usually commence with the commander receiving a request from the client. The client in this case can be his next higher commander or a client from another unit/directorate. The commander will then evaluate the task received and after evaluating it and liaising with subject matter experts, he/she will forward it to the appropriate section or GIS operator to complete the task. The GIS operator will then confirm the task and collect the data that will be used for the task. Data necessary to complete the task will be sourced from currently available data or procured from other suppliers. The GIS/Imagery section/operator then completes the task. The QA team in this section checks the task for correctness and completeness. The completed task is then sent back to the commander who evaluates the task. If the commander is satisfied with the task, the task is sent back to the client, together with a client satisfaction survey form that the client needs to complete. Otherwise the task will be sent back to the section/operator who performed the specific task to make corrections/improvements. Depending on the client's report, further steps might have to be taken to improve the task.

1.4 MOTIVATION AND PROBLEM STATEMENT

1.4.1 Motivation for the research study and problem statement

In this motivation, the SANDF will be used as an example of a possible defence force, since the researcher is currently working in this environment and is therefore familiar with it. The military delivers a great variety of GIS products that are mainly determined by the client's needs (see paragraph 1.3). For instance, some SANDF units might want to obtain GPS waypoints and might be able to view it with a GIS basemap, while other units might want to conduct advanced analysis (for example line of sight, terrain negotiability and flood modelling) and use cartography tools to build military maps. In the past, ArcGIS (a proprietary GIS software package) would automatically be prescribed to all new GIS users in the SANDF. The ArcGIS software provides all the required GIS functionalities and much more. This is the primary reason why the SANDF geospatial community currently uses this software. Another reason is that the SANDF geospatial community has, over the years, become "accustomed" to this software.

Trained personnel who understand the functionality of any given GIS software product are one of the key components of any GIS. Many of the SANDF units and directorates that are currently using ArcGIS have, over the years, undergone extensive training and gained a great deal of practical experience in operating the software. Esri provides excellent product support for the ArcGIS software and the "help files" encompassed in the software product are supportive. Even though ArcGIS is an all-inclusive GIS package, the financial implication of acquiring and maintaining the software and providing training is very high. GIS, with its vast array of benefits, should be made available to a greater number of military units and directorates. Some of these units' budgets are very limited. In addition, not all of these unit/directorates will be using GIS for the same reasons. The financial implications of operating and maintaining ArcGIS in the SANDF are limiting the expansion of GIS applications to the greater military geospatial community. It would therefore be beneficial to the SANDF to investigate the feasibility of using FOSSGIS in order to cut costs and to expand the GIS usage in the SANDF. The "cost" of GIS software (see Chapter 4, paragraph 4.5) does not only refer to the initial cost when acquiring the hardware and the software, but includes aspects such as the maintenance cost, technical support and the cost of acquiring new software upgrades. It includes other costs such as costs incurred in order to have access to the Internet. Costs related to training, among others, should also be considered. However, the problem is that the perception exists that open source GIS software is neither user-friendly nor mature enough to be used in an organisation such as the military for operations. This perception is based on personal experience, for example based on discussions with colleagues and experience in a defence force work environment where the use of FOSSGIS was proposed, but colleagues were hesitant to embrace the idea. In order to clarify the problem statement made above, the terms "user-friendliness" and "software maturity" will be defined and explained. Software products that are "difficult to figure out or poorly supported" are not user-friendly. Wallen (2010) identified 10 criteria that can be used to measure the user-friendliness of a software product. These criteria are listed below.

a. Simple to install: The software installation process should be "simple" and documented well.

b. Easy to update: Updates should also be easy to perform. When a user does not update his/her software, the user misses out on new features and the software can become less trustworthy and secure.

c. Intuitive: Wallen (2010) states that "software is only as good as its Graphical User Interface (GUI)." People will experience issues with using the software if the GUI poorly executed. A GUI with a good design will, in most cases, overrule a "less-than-friendly underlying structure (or poor coding)", but it still means that the software must be functioning as expected.

d. Efficient: Software should be able to perform as anticipated (be effective) and be "efficient". Efficiency is the ability of the product to perform in the best manner with the least waste of time and effort. It must be able to work "seamlessly with underlying structures and subsystems". The efficiency and effectiveness of the software are also tied to "intuitiveness".

e. Pleasant, easy-to-navigate GUI: The GUI of the software must be both effective and intuitive. The primary function of the GUI should be to make the job easier for the end user. It does not benefit the end user if the design is trendy, but creates an unpleasant experience.

f. Easy to remove: The software removal process should be simple, otherwise the software becomes "cumbersome". Wallen (2010) mentions that "cumbersome is not user-friendly."

g. Does not need third-party software: If third-party software is needed to keep it running, your computer can become exposed. This scenario can create a level of complication that the ordinary end user cannot handle.

h. Easy to troubleshoot: According to Wallen (2010), "no software is perfect." If a software problem exists, it is imperative that the software user can demand support and that the issue can be resolved.

i. Adheres to standards: Standards are important in order to make interoperability between applications and hardware stress-free. Complications surface when developers do not adhere to standards. When this happens, the end users will suffer because their tools will not be able to connect with tools that do comply with standards.

j. Effective error handling: The manner in which software handles a problem when it occurs is significant. The software must be able to warn users and let them know what they can do to solve the problem ("bug report"). The software should not only "time out" and close.

According to Etheredge (2009), software maturity can be defined as measuring how "solid" the software is (a measurement of its defects) and how well the "software has evolved to fit its role". Etheredge (2009) concludes that what we are actually measuring is the software's effectiveness – whether the software can perform the required functionality described by the user. For the SANDF to consider the use of FOSSGIS in the SANDF, FOSSGIS must be able to perform numerous GIS functionalities. It is imperative to determine the specific GIS products required for military purposes, as well as the level of war at which they are required. The creation of different GIS products requires the use of different GIS functions. In this study, a variety of GIS functions will be tested, as described in Chapter 3.

1.4.2 Research questions

Alternative methods and means need to be considered in order to provide military organisations with the equivalent GIS functionalities of ArcGIS, but at a much lower price. From the above discussions, the following research questions are formulated:

a. What different sets of capabilities should a GIS have to be suitable to support the many different applications in the military?
b. What are the GIS capabilities needed at the operational level of war?
c. Can open source GIS deliver these capabilities?

1.4.3 Research aim and objectives

The aim of this study is to establish whether FOSSGIS can provide the required functionality when considering its use for military purposes during operations. To achieve the aim of this study, the objectives below are identified.

a. <u>Objective 1</u>: Identify the GIS capabilities for use in military operations.
b. <u>Objective 2</u>: Describe the GIS capabilities at the operational level of war.
c. <u>Objective 3</u>: Investigate whether open source GIS can provide these capabilities.
    i. <u>Sub-objective 3.1</u>: Investigate and describe the differences between FOSSGIS and proprietary GIS software.
    ii. <u>Sub-objective 3.2</u>: Evaluate the functionality, user-friendliness and cost of FOSSGIS versus proprietary GIS for a test case in operations.

Because of the limitations identified in paragraphs 2.3.3 and 2.3.5, the researcher will focus on GIS tasks at the operational level of war. For the purpose of this study, QGIS is used as the FOSSGIS application to compare against ArcGIS, which is currently used by the SANDF. The newest available versions of both these software products were used to perform tests. The specific versions of the software products used were QGIS 2.8.5 (Wien) and ArcGIS 10.2. The QGIS software and all plugins used were downloaded from the Internet. The ArcGIS educational license used included all extensions needed to perform the test prescribed by the use case, and was issued by the GIS laboratory of the University of Pretoria. QGIS is chosen as the software package to be compared with ArcGIS due to a number of reasons. The main reason is that QGIS is already partially incorporated in the SANDF geospatial domain. The SANDF has already developed a two-week course that is presented at entry level to unit personnel. Other reasons are listed below.

a. When examining the graphical user interface (GUI), it looks similar to the GUI of ArcGIS.
b. It is easily available on and downloadable by means of the Internet, as well as easily installed.
c. Its operating costs are very low.
d. This software is supported in a number of ways.
   i. Firstly, online support is available by way of the international QGIS user community.
   ii. Secondly, the support in terms of training designed for the software in the RSA is quite extensive. A number of GIS institutions and other educational institutions offer courses on this software.
   iii. Thirdly, support documents are also available on the QGIS website, as well as “Help tips” that appear when using the software.
e. The software can run on a variety of computer operating systems.
f. Several easily assessable “plugins” are available that provide extra functionalities to QGIS.

1.5 OVERVIEW OF THE STUDY

1.5.1 Introduction

The research design and methodology will be discussed in detail in Chapter 3. Primary and secondary data were collected, investigated and analysed in order to address the problem of this study, which was discussed in paragraph 1.4.1. This study consists of two phases (see Figure 1.2), namely to conduct a literature study and to conduct empirical research. The literature study was conducted by investigating secondary sources such as books, journals, articles, discussions with software users and software specialists, and the Internet. All these sources were investigated to provide sound background information to

a. the use of GIS with specific reference to military applications,
b. differentiate between the use of GIS at the various levels of war, and
c. differentiate between FOSSGIS and proprietary GIS software.

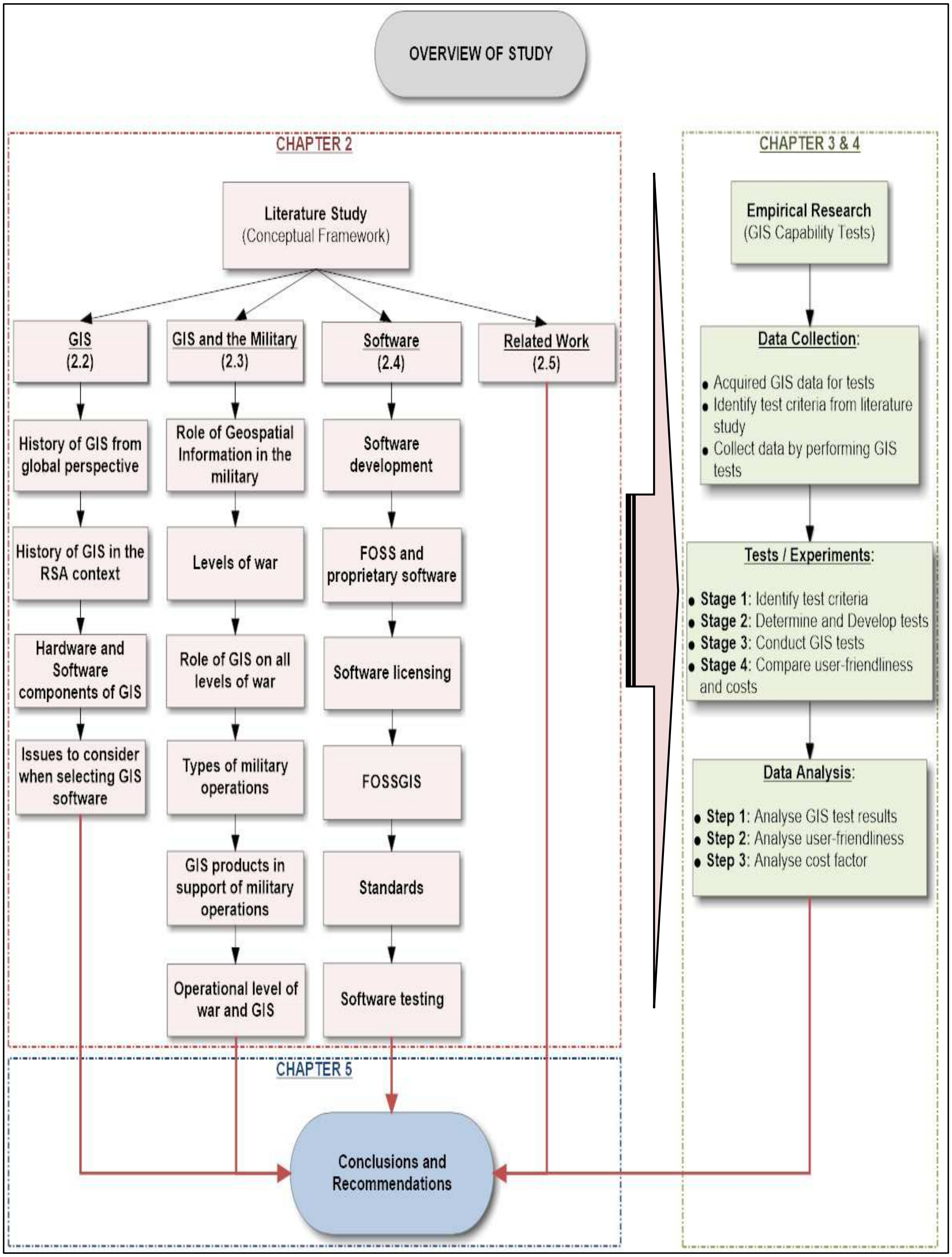

Figure 1.2: Overview of study

The empirical research phase was conducted by using a user acceptance test (UAT) based on a use case that was developed after consultation with commanders who previously assisted with similar operations. The use case is described in Chapter 3 and is based on an operational scenario with the purpose of producing GIS-related tasks required by the SANDF. As discussed in paragraph 1.4.3, these tasks were performed by using both ArcGIS and QGIS in order to test the performance of both GIS applications on delivering the required output products specified in the use case (Chapter 3). The UAT is attached to this study as Appendix A. It includes the illustrations and steps that were followed to perform the required tests as determined by the use case. The limitations are discussed in Chapter 3.

1.5.2 Data collection

Data were independently collected while performing all the required tasks. This was achieved by following a modified and adapted user acceptance test (UAT) that is described in detail in Chapter 3. Data collection was executed by following the evaluation of advanced GIS functions that are needed to satisfy the requirements as specified in the use case. Tasks were firstly performed by using ArcGIS and secondly by using the QGIS application.

Tasks were the same for both ArcGIS and QGIS, based on the execution use case describing the military operational scenario. To support the successful execution of use case tests, data covering the sample area were also acquired from various data vendors. (Refer to Chapter 3, paragraph 3.4.1 for the names of vendors and release dates of data.) This data were necessary to successfully execute the use case using both ArcGIS and QGIS and consisted of

a. vector data,
b. a satellite image,
c. a digital elevation source, and
d. 1:50 000 topographical raster maps.

1.5.3 Analysis of candidate systems

The data collected from the various tasks that were performed, as required by the use case, were descriptively analysed, contextualised and personally interpreted by the researcher. Data analysis was done by considering a set of predefined criteria for measuring the performance of both ArcGIS and QGIS software. The criteria are described in terms of the following questions:

a. Did the software have the GIS functionality needed to perform the specific test?
b. Could the software execute the functions necessary to perform all GIS tests successfully?
c. How user-friendly was the software when considering the use case scenario?
d. How did the costs of ArcGIS compare with those of QGIS in terms of the use case scenario?

After each test has been performed, a conclusion was arrived at about the availability, ease, correctness and accuracy of performing the specific GIS function using both ArcGIS and QGIS. An analysis of the user-friendliness and the cost of the software (in terms of the specified use case) was also done. According to the conclusions drawn for the study, recommendations were made on whether QGIS can provide functionality that is similar or better than ArcGIS when considering its use for military purposes in the SANDF.

1.6 CONTRIBUTION OF THE STUDY

The SANDF has always used maps for planning in different types of military operations at different levels. In today's digital era, GIS gives the commander so much more than simply a paper map. GIS has caused a revolution in the way that spatial data are used for military operations. Currently in the SANDF, GIS is used, among others, for the following purposes: intelligence analysis, cartography, battlefield analysis and management, terrain analysis, remote sensing and image analysis, facilities management, support for major weapon systems and border management.

Remaining ahead of the enemy in all circumstances is crucial to any military power. Technology, especially GIS, has become a key factor in any military operation. Unfortunately, technology usually comes at a price. GIS software is no exception. Although the SANDF would not like to deny any of its units access to GIS, currently the cost of commercially available software places a limitation on the use of GIS in the SANDF.

FOSSGIS can provide a feasible alternative to commercially available GIS software in terms of the functionalities that a GIS system in the SANDF needs. If this statement is true and software support and suitable training can be provided and developed, GIS can be made available to a more comprehensive military user group.

Consequently, the contribution of this study is three-fold. It provides

a. an in-depth description (based on the study of scientific literature) of the importance of GIS in support of military operations,
b. pros and cons to assist in deciding between FOSSGIS and proprietary GIS, and
c. detailed explanations of the steps followed to achieve test results that can possibly serve as a pre-deployment preparation document to assist GIS operators during military operations.

These contributions are useful to defence forces in other countries.

1.7 CHAPTER SUMMARY

In this chapter, an introduction to the topic was provided. The application of GIS in the military and an example of a GIS business process were briefly discussed. The motivation, problem statement, research questions, aim and objectives were also presented. In the next chapter, a literature study will follow during which the researcher reviews GIS and its uses for the military, software and related work.

CHAPTER 2: LITERATURE STUDY

2.1 INTRODUCTION

Chapter 1 clearly concluded that the use of GIS in the military is widespread and a definite requirement. In the literature review, the focus will be on geographical information systems (GIS), military operations and software. In the first part, the history and evolution of GIS are investigated, as well as issues to consider when selecting a GIS. Next, military operations are investigated, and special reference is made to the levels of war and GIS in support of military operations. Finally, software is discussed. In this discussion, a number of important issues must be addressed, for example software development models, FOSS and proprietary software, software testing, licensing and standards. The literature review will conclude with a discussion of related works.

2.2 BACKGROUND TO GEOGRAPHIC INFORMATION SYSTEMS (GIS)

2.2.1 The history of GIS from a global perspective

GIS comprises a variety of components. Software is only one of these components (Bolstad, 2005; Clarke, 2011; Longley, 2005). From literature studied, it is fair to conclude that most authors typically refer to the “GIS software” component when they refer to the history and development of GIS. According to Coppock and Rhind (1991), most of the early GIS developments took place in North America. The reasons for the development of GIS, or rather of components thereof, vary. Sometimes it was due to academic inquisitiveness or a need to figure out how to use new data sources, while at other times it was to increase the speed of processes. The enormous cost in manually analysing maps and the emergence of the digital computer in the 1960s acted as an incentive to develop a more automated process. Coppock and Rhind (1991) further state that by the 1980s, more than 1000 systems were in use in North America.

Morais (2012) states that four distinctive phases can be distinguished in the history of GIS. The first phase was evident between the early 1960s and the mid-1970s. During that period, a few main individuals, who shaped the discipline, dominated the new field. Clarke (2011) points out that in 1959, Waldo Tobler published a paper in the Geographical Review in which he outlined a “model for applying the computer to cartography”. This model had three elements (an input, a map and an output) and was referred to as MIMO (map in - map out). In 1960 the first scanner was developed, which led to more advances in the GIS world. During the second phase, from the mid-1970s to early 1980s, some national agencies adopted the technology. However, the commercial GIS market was first exploited during phase three, between 1982 and the late 1980s. When IBM introduced their first personal computer in 1982, some of the significant GIS programs shifted to the microcomputer. During the late 1980s (phase four) the emphasis was on ways to improve the GIS technology (Morais, 2012). Clarke (2011) states that the first GIS software packages had unsophisticated user interfaces where the user had to type in short scripts or commands on the computer. It is only when the second-generation GIS software products evolved that the graphical user interfaces to which we are now accustomed were included. He further states that operating systems also had a huge influence on the development of GIS software. The 1980s and 1990s saw the maturing of GIS as a subject and also the development of infrastructure for GIS that are both crucial when studying the subject (Clarke, 2011). The history of the evolution of GIS is short and very much still being written by all the role players involved.

2.2.2 The history of GIS in the South African context

In South Africa, the evolution of GIS seems to follow a very similar path to that in the rest of the world. From the various literature studies, as well as the interviews conducted, it is clear that different entities' viewpoints might vary concerning the history of GIS in South Africa. This is mainly because people's exposure to GIS had been different and some projects in state departments were classified and not open to everyone. Cilliers et al. (2013) note that South Africa fell behind in the fields of remote sensing and image processing. They state that these fields were dependent on the availability of multispectral images from sensors like Landsat and SPOT, to which South Africa had limited access due to South Africa's political circumstances and its isolation before 1994. According to Cilliers et al. (2013), these circumstances also had a direct impact on some state departments' lack of awareness of the use of GIS. Conversely, in the defence force, apart from the aerial photography being used, they also had access to analogue satellite images in the 1980s. However, it was only in the late 1980s that these images could be processed in digital format (DC Smith 2015, personal communication, 30 July). In the scientific and academic fields, many conferences were held relating to GIS and remote sensing.

Breetzke et al. (2011) agree municipalities, large metropolitan areas, other state departments and tertiary institutions only “recognised” GIS in the 1990s for the first time.

According to W. Herbst (personal communication, 12 August 2015) the use of GIS in South Africa was already widely adopted by specifically government institutions like municipalities, provincial and national departments, including Water Affairs, CSS (StatSA), Agriculture, Environmental Affairs etc. at that time. Sanctions forced software development companies in South Africa to become very innovative since they did not have access to overseas technologies. This resulted in the development of ReGIS by a company in South Africa called “Automated Methods”. According to Herbst, this GIS software was much more advanced than other GIS software at that stage in other parts of the world, and also had a CAD capability built into it. In the early 1990s data were not easily obtainable. GIS users had to capture their own data by either digitising on a digitiser tablet from mostly aerial photographs or by manually entering coordinates. Operating systems also had a huge influence on the development of GIS software, with most enterprise systems at this stage running on some form of UNIX. On the desktop computer side, OS2 and Windows were in great competition. Automated Methods decided to develop one set of source code with similar GUI, which could then only be compiled for UNIX, OS2 or Windows. OS2 eventually lost the race and disappeared from the scene. At this stage, all the GIS products only supported their own proprietary data formats, which made the exchange of spatial data very difficult. At that stage, the Chief Directorate Surveys and Mapping and the Chief Surveyor General both used ReGIS. It became important for other GIS software vendors to be able to import ReGIS data. ReGIS used their own exchange format, which was quickly adopted by most other vendors to enable them to import ReGIS data. The only alternative at that stage was the DXF format.

Herbst further states that in the mid-1990s, Autodesk decided to enter the GIS market and bought the ReGIS source code. They renamed it to Autodesk World. Unfortunately the product was changed to a single-user product and, in 1996, Autodesk discontinued it. At that stage about 3 000 licenses were deployed in South Africa, which made ReGIS the clear GIS market leader in South Africa. Clients were offered AutoCAD map, but they had to pay an additional amount (R20 000) for every package. Esri (in America) was then consulted in this regard and they offered a swop; for every Autodesk package, users were issued an Esri package. As a result of this, Esri instantly became the most widespread used GIS software package in the RSA. In 1995, after the 1994 elections, the IEC called a meeting to plan the 1998 elections. Among others, StatsSA, Surveys and Mapping, Mr Antony Cooper and Mr Wilhelm Herbst were invited. There was a crisis concerning the data capturing for the upcoming elections – voting districts had to be established and, to be able to do this, they needed a digital copy of the country's cadastral, topographical and Enumerator Area (Census) data. This data were only available in analogue format. To address this issue, Project MIRACLE was created. It was given this name because topographic, cadastral and census data all had to be digital in three years' time. Sixteen GIS companies in South Africa all worked together to achieve this goal. A complete data set was delivered on time, containing roads, rivers, contours and cadastral data.

The history of GIS in South Africa might have had a slow start, but since the 1990s it has boomed together with the GIS industry in the rest of the world. Today a magnitude of government institutions, private companies and educational institutions use GIS in some or other form. The GIS curriculum used in South African tertiary institutions has been in the past mostly influenced by those developed for North America and Europe (Zietsman, 2002). With the GIS experience and knowledge today, this state of affairs has changed and most universities and other training institutions are developing programs to suit their own needs. The availability of satellite images and other data sets is also becoming easier and more accessible with each passing day. The growing use of the Internet (for example Google Earth), GPS and certainly also the availability of FOSSGIS is contributing to the tempo of acceleration in the use of GIS. According to Du Plessis (2015), the number of GIS users in South Africa are expanding proportionally to the number of users "… having access to computers, smartphones and related technologies". The researcher agrees with Breetzke et al. (2011) that "… Geographical information systems (GIS) are an exciting and fast-growing tool that holds a lot of potential for South Africa".

2.2.3 Hardware and software components of GIS

The components of a GIS are specified as hardware, software, data, people and procedures. In this chapter, it is of importance to differentiate clearly between hardware and software in order to elaborate later on critical software issues and in particular software issues relating specifically to the "FOSS" environment. Computer hardware and software use each other extensively: software tells hardware which tasks it needs to perform. Hardware is the physical part of the computer system. Software is a collection of instructions that can be "run" on a computer (Copley, 2015).

Software is not a physical medium (it can be stored on a physical medium such as a CD-ROM), but is a bunch of codes. If the storage medium on which it runs breaks, the software is not broken, and if it is given to someone, the original copy still exists. Hardware cannot be copied in that sense and can be worn out or even stolen. According to Hall and Leahy (2008), there is much "more to software than just owning a copy that can be legally used". In economic terms, it makes sense to sell the idea that software is just another physical "good" that can be sold and even tied to a specific piece of hardware that can no longer be used when that piece of hardware breaks.

2.2.4 The issues to consider when selecting GIS software products

According to Clarke (2011), when one considers a software product, one must look at more aspects than simply the technical side of it. Amongst other aspects, one will have to look at your level of satisfaction when using the software product and whether it is flexible enough to easily install and run on your computer. For most people, cost plays an important role when selecting GIS software products. Software companies may not only charge fees for the software itself but also for its maintenance. The cost of always upgrading to the newer version of the software must also be considered. This is obviously the main advantage when it comes to FOSS (as was discussed previously). When considering software products, it is also very important to consider the available training. The software user might need training on a number of technical issues, and such training can also be rather expensive. Where formal GIS training ends, the help files usually start. Most users might also need technical support at some stage. Every one of the abovementioned issues is to be considered carefully before a choice can be made about which software product to select (Clarke, 2011).

2.3 GEOGRAPHIC INFORMATION SYSTEMS AND THE MILITARY

2.3.1 The role of geospatial information in the military

The role of geographic information in battle-decisions predates written history. With regard to the Gallic Wars from 60 to 55 BC, early writings can be found that show that the military considered a geographic perspective. In Europe, military geography evolved into a formal field of study during the nineteenth century. The role of military geography during peace as well as wartime cannot be overstated. As long as conflict, war and other disasters take place on the earth's surface or in its atmosphere, the military must consider geographical variables (Palka et al., 2000). As technology evolved, GIS became an important tool for analysing these geographical variables.

In order to understand the importance of geographical information, and ultimately GIS, in the military, it is important to first understand some crucial military concepts. Understanding these concepts will assist the reader in understanding various important concepts in the military, the importance of GIS in the military and the role that the military has played in the development of GIS software products worldwide.

2.3.2 Levels of war

Although no clear boundaries exist between them, the three levels of war (from highest to lowest) are the strategic, operational and tactical levels. Nevertheless, the levels of war assist commanders in comprehending the flow of an operation and in assigning their resources, responsibilities and tasks correctly and effectively. An understanding of the levels of war will clarify the link that exists between decisions made by strategic commanders and actions taken by operational and tactical commanders. The higher level of war sets the conditions for the lower level of war and is not determined by the size of the forces involved in a specific part of a conflict (see Figure 2.1 below).

According to a study done by Tuner (2003), information systems enhance warfare at all levels of war, and GIS is no exception. Information systems are integrated into traditional warfare disciplines like command and control, logistics, intelligence and various weapon systems, to name just a few. Terms such as information warfare, information operations and information superiority have become crucial concepts in the military and are especially viewed as force multipliers[2]. Information operations can therefore be seen as a giant leap in warfighting and one that will allow commanders at all levels of war to be more integrated and to therefore effectively and efficiently employ the principles of warfare. It is important to determine why GIS is critical for use in the military and at which level, as well as what the focus of this study will be based on (Tuner, 2003).

[2] Force Multiplier is defined as "a capability that, when added to and employed by a combat force, significantly increases the combat potential of that force and thus enhances the probability of successful mission accomplishment" (The Military Factory, 2016).

The strategic level of war. The strategic level is that level at which a national security objective is considered. It is at this level that a war's political goals are defined. The strategic commander will have to make decisions about when, where and how to employ the military resources. It is typically the level at which wars are won, and the effects can influence operations at other levels to succeed or to fail. In this regard, spatial information technology provides improved detection and reporting of these cues that the strategic commander needs to make crucial decisions quickly. Jacobs (2005) states that military strategic authority will regulate the location of the theatre[3] of war after a thorough appreciation of all "areas of air, land and water that are, or may become directly involved in the conduct of war" (Jacobs, 2005). The optimal use of GIS at the strategic level can reduce possible shattering political, societal and economic effects.

The operational level of war. The operational level of war can be described as the level at which major operations (a series of tactical actions) and campaigns are carried out and supported in order to achieve goals set out by strategic commanders. It involves the deployment of a military force and the arranging their goals. It is therefore crucial for an operational commander to maintain communication with strategic commanders at all times. When and where to carry out an operation are based on the objectives, the threat and the limitations of a mission. Among the limitations to consider are economic and military resources and the geography. It is important to note that all operations of a military nature take place in a clearly defined geographical area and that they can contribute to the strategic design. The manner in which the operation or campaign is implemented, inclusive of all forces, involves a series of battles to accomplish definite goals. The planning and execution of these "battles" represent "tactics". It can therefore be concluded that the operational level of war consists of all "those military activities that result in the desired end state at the military strategic level, that is, campaigns and major operations" (Jacobs, 2005). The focus of this study is on the operational level (see paragraph 2.3.6).

The tactical level of war. Jacobs (2005) argues that according to US doctrine, the battles and engagements planned and executed by tactical units or task forces to attain military objectives constitute the tactical level of war. According to Barclay, cited in Jacobs (2005), the manifestation of the tactical level starts when military forces reach the "battle area".

[3] Luttwak, cited in Jacobs (2005), defines a theatre as a "geographic area that is sufficiently separated from other theatres by important geographic barriers or sheer distance to be defensible or vulnerable on its own."

The focus is to accomplish combat objectives acknowledged by the operational level commander. Therefore tactics are defined as “the art and science of using available means to win battles and engagements”. It necessitates problem-solving on the battlefield, which can cover a small or a large geographical area. Jacobs (2005) further highlights the fact that commanders’ focus on the tactical level of war is to defeat the enemy by means of a series of tactical manoeuvres and battle techniques.

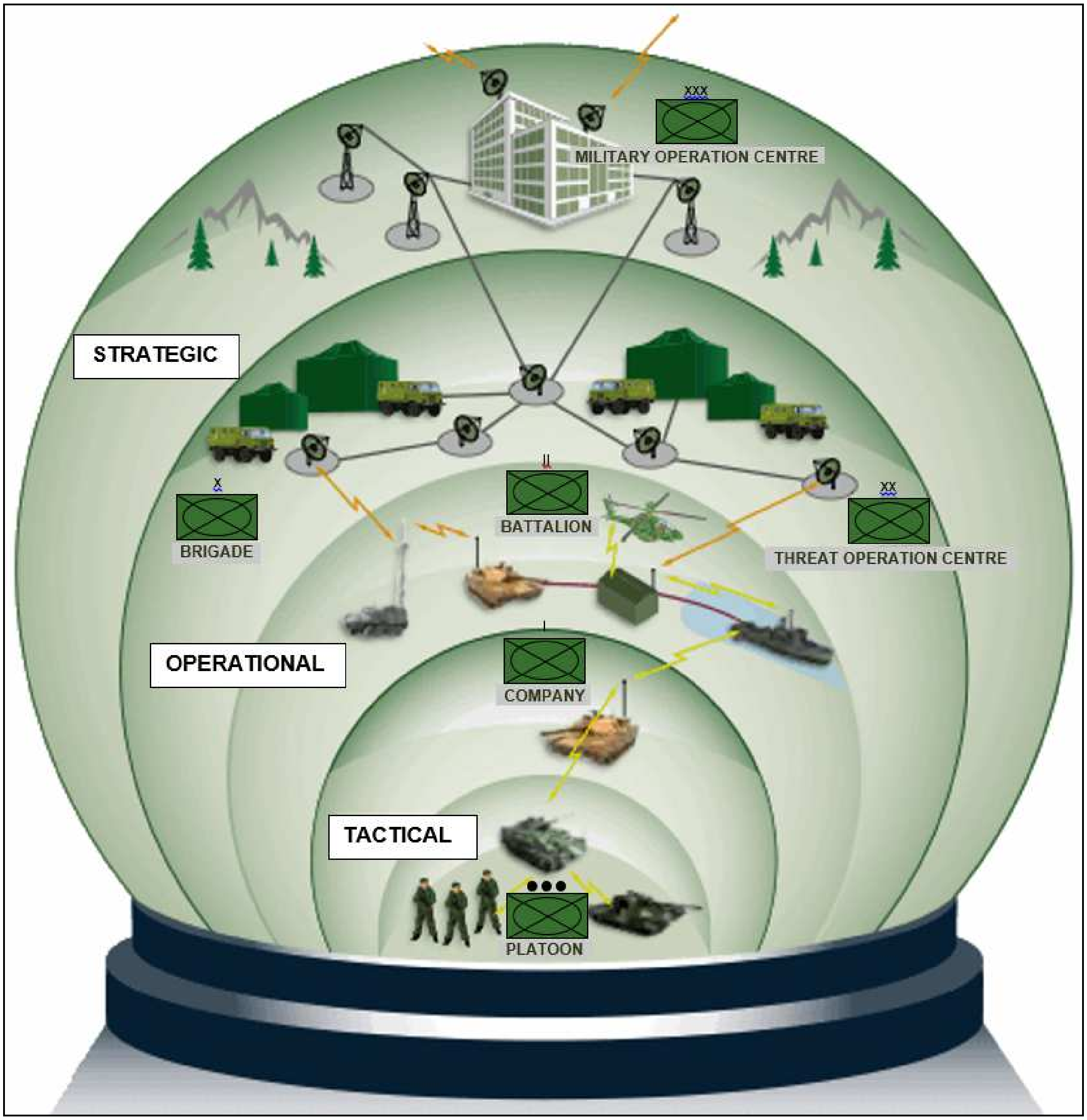

Figure 2.1: Illustrating the theater of the levels of war and communication interaction

Modified from Koch (2016)

2.3.3 The role of GIS in the military at all three levels of war

Swann (1999) states that commanders at all levels of war require a picture or a view of the battle space. They must be able to re-examine past information and anticipate future battles. It is imperative for them to integrate information received from a variety of sources. Continuous integration of information will provide a constant drive for improvement in decision-making with the purpose of winning the battle. This is especially true when facing an unpredictable enemy that is always improving its capabilities. There is also a growing need for supporting operations other than war, such as peace support and peacekeeping operations, disasters and other operations that the military supports such as the 2010 FIFA Soccer World Cup. The military is increasingly called on to keep peace and stability. In this role, even small actions can have strategic consequences. The commander therefore needs all required and available information to derive an accurate picture of the situation at hand. In such instances, GIS can and will play a pivotal role at all three levels of war to provide invaluable geospatial information (Swann, 1999). Some essential operations and tasks supported by a GIS in the military will now be discussed.

Air operations. Satyanarayana and Yogendran (2013) state that in a battle situation, air operations require comparable inputs in keeping with land operations, except that they also require very precise height information. This information includes, among others, information about the target, civilian and other “no-fire” areas (safety aspects), the terrain as well as up-to-date meteorological data. The virtual picture that a pilot (fighter, bomber and transport) can get from using a combination of raster and vector layers is very effective during air strikes and other air operations.

Land operations. In landward military operations, commanders are very concerned about the condition of the terrain, heights for manoeuvring armour vehicles and the use of several weapon systems. These army vehicles cannot manoeuvre in all terrain conditions. In an operation they will also need other layers that specify information relating to the vegetation cover, roads and lines of communication. Target assessment is a huge advantage that a GIS can offer the military commander, especially when the inputs are the same as those used by the system used for firing the weapon. Therefore a detailed and precise “land map” with data on the land use, terrain model and vicinity of civilians (a safety layer), as well as other features, is essential for military operations. Any inconsistencies in these factors will be disastrous for the operation and will result in the loss of life (Satyanarayana and Yogendran, 2013).

Naval operations. According to Dykes and Hancock (2002), GIS has proven to be an excellent tool for merging and analysing the increasing volume of geophysical data available from different sensors. GIS is also a subsequent requirement to quantify uncertainty in both the interpretation of the data and in forecasting the marine environment for Navy operations. Layers of importance to naval operations include oceanographic measurements like surface elevation, profiles of temperature and salinity, ocean currents, topography and bathymetry. GIS can even assist in naval sea-rescue operations and other operations like oil-spill detection and the clearing thereof (Dykes and Hancock, 2002). The production of naval charts is a specialised environment in the military, which is done by the Navy Hydrographic Office.

Weather information layer. The weather is a crucial element for the military commander to consider in the planning process on the battlefield. This information will be required for successful land, air and/or naval operations. Every commander must consider information regarding the weather such as "cloud coverage, wind conditions, visibility and temperature" (Satyanarayana and Yogendran, 2013).

Terrain analysis. Careful analysis of the terrain will influence the success of any military operation. The commander must analyse how the terrain, weather and light will affect own forces as well as enemy troops, weapons and tactics. Terrain analysis is therefore a key element of the reconnaissance step in any battle or operation. Lodi et al. (2014) mentions that military aspects of terrain are formulated as information on observation and field of fire, cover and concealment, obstacles, key terrain and avenue of approach (OCOKA). GIS forms a crucial part in this process.

Logistics management. GIS can be used very efficiently and effectively when planning for military logistics during wartime as well as during peacetime. During battle, the commander needs logistical support, as it will allow the movement of equipment, provisions and personnel to the correct location at the precise time. GIS can be used effectively for logistical management during battle when planning convoy routes or the quickest alternative route. Using a combination of the GPS and GIS effectively, sensitive equipment like nuclear warheads and other ammunition pieces can be tracked every step of the way (Satyanarayana and Yogendran, 2013). It is also important to realise that GIS plays an important role during peacetime to manage facilities that are owned by the Department of Defence.

Geospatial intelligence (GEOINT). The US National Geospatial Intelligence Agency (NGA) defines the term "geospatial intelligence" as the "exploitation and analysis of imagery and geospatial information to describe, assess and visually depict physical features and geographically referenced activities on the Earth, which are essential factors to consider during the planning and execution of military operations. GEOINT consists of imagery, imagery intelligence and geospatial information" (US National Geospatial Intelligence Agency, 2006).

Image Intelligence (IMINT). Image Intelligence is a source of intelligence derived from analysing images. These images can be obtained from a variety of different sensors such as satellites and aerial photography. It can provide information of a military force's equipment, infrastructure, movement, activities and possible intentions. The modern military image analyst uses GIS software to process and analyse images, and uses certain key elements in order to interpret and obtain useful information from such images. These interpretation keys are size, shape, height and shadow, tone or colour, texture, pattern, association, site and time. It is a specialised environment in the military that requires intensive training; both in terms of the software used and the applied processes.

Safety overlay/chart. A safety overlay or chart is an important part of any military commander's appreciation process. When making such a layer, the commander takes all the different weapon systems and their safety ranges into consideration. GIS can simplify this time-consuming process in a timely manner.

Military crime analysis. Crime (even military-related crimes) has an inherent geographical quality. Mapping military crime incidents by using GIS allows the user to identify military crime hot spots as well as other trends and patterns. Military crime analysts can overlay crime-related data with other layers, such as demographics, to obtain a better understanding of the causes of crime in specific military areas. It can assist the military police to formulate better strategies and make better decisions, and can assist in crime intelligence (Chainey and Ratcliffe, 2013).

Simulation systems. Simulation systems are extensively used by the military to simulate the battlefield environment. It is possible to simulate the activities of the enemy and to predict more than one outcome. The commander's decisions can be objectively judged without the obvious loss of lives. In this virtual environment, GIS is effectively used in conjunction with other multimedia resources. The firing range of weapons can be tested in a 2D or 3D environment based on their tactical parameters. Even pilots can assess possible dangerous terrain and situations and use the electronic GIS tools for orientation (Nagy, 2004).

Environmental protection. The military is also involved in protecting the environment, since some military institutions are located in environmentally protected areas. The GIS Commander should pay attention to all applicable policy requirements on environmental protection that could influence the GIS products (Bosetti et al., 2008).

Cartography. According to Swann (1999), military developments in cartography often led the business world. From the above descriptions of the uses of GIS in the military, it is evident that the military will need a variety of maps to cater for different operational functions. Consequently, a GIS can provide the means to create "custom-made maps" for a variety of military purposes.

Communications. Communications are an important element to any military operation or battle. Without good communication with higher and lower commanders, the battle will be lost. GIS can assist the commander in finding appropriate locations by creating radial line of sight maps for radio signal propagation.

Medical. Lang (2000) states that as part of force support during battle, the military commander must consider the deployment of medical support. Even during peacetime, the Medical Health Service plays a key role in keeping the military force healthy and deployable. A GIS can play an effective role in the Health Services to provide answers to questions such as the following (Lang, 2000): *Where is the origin of the disease? How will it spread? Where is the nearest military hospital or other health care facilities? What will be the fastest route for an ambulance to reach the patient/wounded soldier?* This study will investigate the outbreak of Cholera as a medical factor, presented as a case study. Humanitarian and disaster management will so be considered.

Humanitarian and disaster management. The military is increasingly involved in humanitarian relief efforts. Some of the application areas of GIS in humanitarian efforts comprise hazard, vulnerability and risk assessments, disease distribution and outbreak investigations and programme monitoring and evaluation (Kaiser et al., 2003).

It is very clear from the examples above that the military uses GIS extensively. In fact, it is so widely used by the military that it will be impossible to research all these military GIS functionalities in this study. Therefore this study will focus on the GIS functionalities needed to support the brigade commander at the operational level of war, due to the fact that the operational level of war links to both the strategic and tactical levels of war. Some examples of these functionalities include orientation maps, identification of geographic locations and boundaries, route maps, hyperlinking of photography to locations, radial line of sight maps for placement of observation posts, radio signal propagation, radar coverage, 3D visualisation maps, maps indicating no-flying zones and creation of threat domes. With regard to anti-air capabilities of targets, it includes geographic assistance in mission planning and emergency alternatives, plotting force deployments and movements on a map and flood simulation.

2.3.4 Types of military operations

Two broad distinctions can be made between the types of operations that the military supports. These are war operations and operations other than war (see Table 2.1 below).

War operations. According to the US Joint Chiefs of Staff (11 August 2011), these include major operations and campaigns. War operations involve combat, usually have an extended duration, and it mostly takes places on a large scale. Operational and strategic goals can be achieved by both campaigns and major operations. A major operation is defined as “a series of related tactical actions, such as battles, engagements, and strikes”. This type of operation is conducted autonomously or can serve as a central element of a campaign. A campaign, in comparison, “is a series of related major operations” (US Joint Chiefs of Staff, 11 August 2011).

Military operations other than war (MOOTW). According to the US Joint Chiefs of Staff (16 June 1995), military operations other than war (MOOTW) can be paired with any grouping of the other instruments of national authority. MOOTW is different from operations in war, although they might seem similar at times. The focus of MOOTW is to promote peace as far as possible and to deter war at all costs, whereas war involves large-scale, sustained combat operations to accomplish national objectives and/or to protect the country's shared "national interests". Political considerations play a big part in MOOTW, and often the military is not the principal component. The goal is usually to attain national objectives and therefore more restrictive rules of engagement are set. MOOTW are started by the National Command Authorities and are typically, not always, directed outside the borders of the country (US Joint Chiefs of Staff, 16 June 1995).

Table 2.1: The range of military operations

STATES OF THE ENVIRONMENT	GOAL	MILITARY OPERATIONS		EXAMPLES
War	Fight and win	War	Combat	• Large-scale combat operations • Attack • Defend
Conflict	Deter war & resolve conflict	Operations other than war	Combat / Non-combat	• Strikes & raids • Peace enforcement • Support to insurgencies • Anti-terrorism • Peacekeeping • Non-combat evacuation operations
Peacetime	Promote peace	Operations other than war	Non-combat	• Disaster relief • Civil support • Peace building • Nation assistance

**** Non-combat operations can occur during wartime; some MOOTW might require combat.***

Source: US Army Chief of Staff (31 May 1995)

Military force is used effectively during peacetime to keep any tensions that might exist between nations below the threshold of armed conflict or war. This type of operations can comprise "humanitarian assistance, disaster relief, counterdrug operations, arms control, support to civil authorities, evacuation of non-combatants and peacekeeping". Non-combat MOOTW can be a concurrent operation with combat MOOTW (Table 2.1). MOOTW principles can be considered to be an extension of doctrine that governs warfighting (Bonn and Baker, 2000). Examples of these operations are illustrated in Figure 2.2.

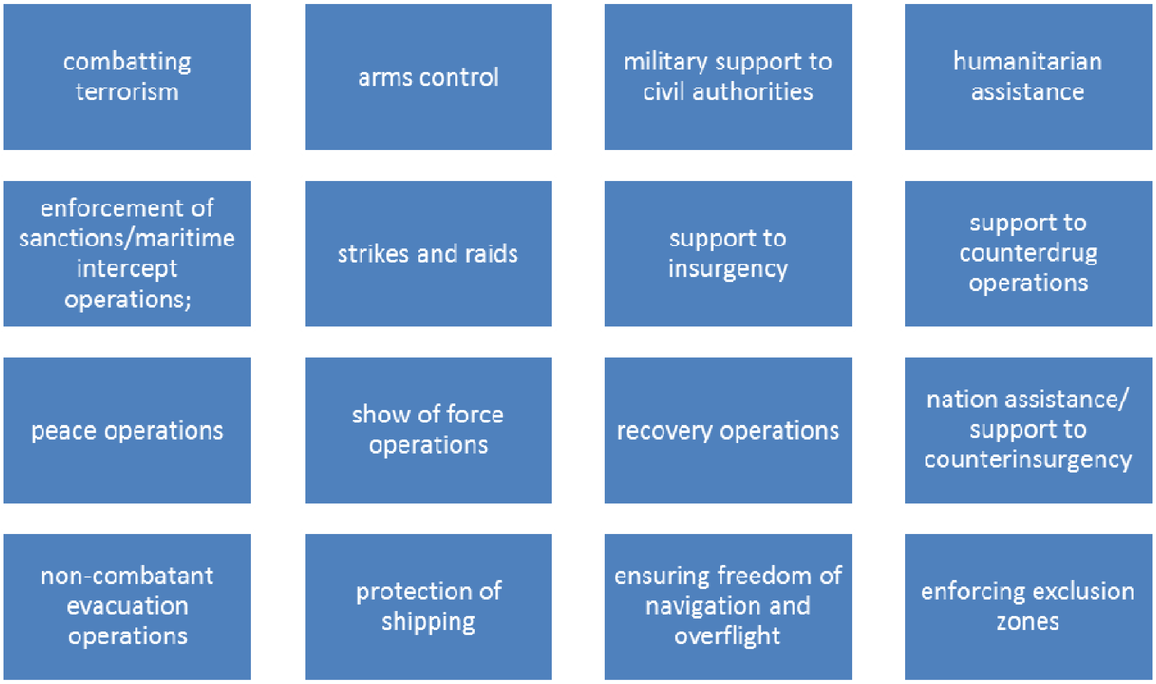

Figure 2.2: Examples of military operations other than war (MOOTW)

Source: Bonn and Baker (2000) and US Joint Chiefs of Staff (16 June 1995)

2.3.5 GIS products in support of military operations

Which questions can the GIS operator answer for the operational commander? These questions will be different to questions that concern the strategic and tactical commanders. The types of maps that the GIS team will produce in support of the operational commander will typically be custom-made maps. The operational commander will pose the questions to the GIS team. The test will be "what end-product (answer) is intended by the GIS analysis?" Following are examples of how GIS products were used at all three levels of war.

Maps indicating no-flying zones. A buffer area used to deter aircraft for either safety reasons or security (Gertler et al., 2011).

a. Strategic level: According to Gertler et al. (2011), a no-flying zone can be established over a certain country due to a security risk. During a combined operation that involved the US, France and the UK, Operation Northern Watch (ONW), a "no-fly zone", was established in Northern Iraq in order to prevent Iraqi suppression of the concentrated ethnic Kurdish residents living in that area. ONW took place from 1991 to 2003. Gertler et al further state that at the strategic level and in accordance with United Nations (UN) Security Council resolutions, ONW took place because of global pressure on the Iraqi government to conform to an "international weapons inspection regime" (Gertler et al., 2011).

b. Operational level: In 2011, during operation Odyssey Dawn, a coalition operation that took place in Libya, a no-flying zone was established in order to impose UN Security Council resolution 1973. This resolution was put into place to protect non-combatants in Libya. During 1992, in the UN Security Council resolution 781 (1992), the council decided to place a "ban on military flights in the airspace of Bosnia and Herzegovina". This was mainly attributable to humanitarian factors and to make sure that humanitarian support could safely reach the area (Gertler et al., 2011)

c. Tactical level: At the tactical level, it will be applied for the duration of the operation. According to J.M. Davids (personal communication, 12 May 2015), during the 2010 Soccer World Cup in the RSA, no-flying zones were created over the stadiums for the duration of the matches.

3D visualisation maps. 3D mapping is any method of mapping three-dimensional points to a two-dimensional plane. This includes visibility analysis and other 3D products such as hillshading and slope analysis.

a. Strategic level: J.M. Davids (personal communication, 12 May 2015) states that a 3D flythrough can be created to give the strategic commander an orientation of the terrain for land, sea and air operations. For example, a flythrough can be made to cover the operational area.

b. Operational level: According to J.M. Davids (personal communication, 12 May 2015), a radial line-of-sight map can be made to indicate all visible points in a radius of a given operational area. It can also be used to find places or to hide elements and to plan routes. More than two observer points will be used. More variables will normally be tested than at the tactical level.

c. Tactical level: Provides the operators on the ground with a picture of the terrain to determine what is possible in terms of terrain negotiability and the establishment of communications. An example of this is a linear line-of-sight map to display to path of possible communications between points A and B. Can radio communications be established between one area and a roving/mobile stadium at another location? When an operator deploys in an area where the terrain is highly dense, for example the Kruger National Park, a linear line-of-sight map can be created for the operator. This map could picture whether communications will be possible between two high points based on visibility between a specified observer and target points (J.M. Davids 2015, personal communication, 12 May).

Orientation maps. The commander uses these GIS products to orientate his forces and track the movement of forces (both his own forces and the enemy).

a. Strategic level: It will show all theatres of operations. An example of this is the deployment of military forces at all the stadiums during the 2010 Soccer World Cup in the RSA (J.M. Davids 2015, personal communication, 12 May).

b. Operational level: The operational level focuses on the theatre of operations where forces are deployed. For example; looking at the army deployments during the 2010 Soccer World Cup in the Pretoria area.

c. Tactical level: At the tactical level, the focus will be on the specific point of interest (target area) where an entity is deployed. For example the deployment of a Special Forces company at the Loftus stadium during the 2010 Soccer World Cup in the RSA (J.M. Davids 2015, personal communication, 12 May).

Threat domes. A 3D element can be used to build a zone around a potential threat.

a. Strategic level: According to J.D. Venter (personal communication, 26 May 2015), an example of this is National Radar Surveillance, with two strategic radars located within the borders of the country that show their extent (coverage area) by creating a threat dome.

b. Operational level: J.D. Venter (personal communication, 26 May 2015) explains that the radars deployed in the provinces of the RSA during the 2010 Soccer World Cup can be seen as such an example. Their extent was mapped in order to indicate the total area covered by the deployed radar. This was done in order to determine possible gaps with the intention of filling it with smaller radar deployments.

c. Tactical level: It can be used at the tactical level to evaluate the risk posed by anti-aircraft (AA) weapons. In such an example, the anti-aircraft gun position on the surface can be indicated as well as the three-dimensional (3D) line indicating the flight path. A DEM will be needed to perform such a task. If the GIS operator knows the model and the type of AA gun used, the other attributes can be calculated and indicated. The distances at and areas in which the weapon will be effective can therefore be shown on a map.

Simulation/flood simulation. Flood simulation is used for planning and design as well as for forecasting floods in order that measures can be taken in time. Simulation can also be used to simulate other disasters such as fires, volcanoes and stampedes (S.J. Wylie 2015, personal communication, 25 May).

a. Strategic level: At the strategic level, flood simulation can be used to simulate floods on a national scale. An example is if Cholera were to become a national epidemic. The Defence Force must assist the Department of Health and a flood simulation product is created to plan the operation/s. Data and maps collected can be used to inform the nation of the crises (S.J. Wylie 2015, personal communication, 25 May).

b. Operational level: At the operational level, an example would be if a river gets infected with cholera as a result of the breakage of a sewage dam. “Which towns will be affected”? In which towns should forces be deployed to assist with the crises? It can also assist with the evacuation of people in affected areas (S.J. Wylie 2015, personal communication, 25 May).

c. Tactical level: According to S.J. Wylie (personal communication, 25 May 2015), an example of using a flood simulation model at the tactical level is where a sewage dam wall breaks in a specific town. GIS can then be used in order to decide where to deploy forces with the aim of assisting with the disaster. It can also be used for the evacuation of people in affected areas.

Plotting force deployments and movements. Military symbols (NATO Standard 2525B) on a map are used to indicate which specific force, with its composition and strength, is deployed in a certain position (S.J. Wylie 2015, personal communication, 25 May).

a. Strategic level: S.J. Wylie (personal communication, 25 May 2015) states that an example of the use of military symbols at the strategic level will be to indicate force deployments in another country.

b. Operational level: At the operational level, tactical military symbols can be used, for example, to show the deployment of forces at hospitals countrywide (S.J. Wylie 2015, personal communication, 25 May).

c. Tactical level: At the tactical level, GIS can be used to show the deployment of own and/or enemy forces at a specific location (S.J. Wylie 2015, personal communication, 25 May).

Target profiling. A GIS profile can be created of a specific target by zooming in on the area and adding various vectors to a high resolution image (S.J. Wylie 2015, personal communication, 25 May).

a. Strategic level: J.D. Venter (personal communication, 26 May 2015) states that a geographic country profile can be compiled by means of analysing the available vector data of a country (contours, rivers and roads, among others).

b. Operational level: An area earmarked for deployment or movement of operational forces can be analysed before the start of an operation in order to determine operational movements and deployments (S.J. Wylie 2015, personal communication, 25 May).

c. Tactical level: An example of target profiling at the tactical level is to identify hostels that appear to be xenophobic hot spots. A hot spot analysis can subsequently be done (S.J. Wylie 2015, personal communication, 25 May).

These discussions prove the statement that the operational level of war links to the other two levels of war, but that it is more complex. If the GIS operator knows how to perform these GIS functionalities at the operational level of war, producing products for a commander at the strategic or tactical level will be less complex. The operational commander must remain certain of what his tasks are. In order to evaluate how the same GIS function can support commanders at the various levels of war, the following GIS functionalities were evaluated in terms of their role and purpose at each level. It will also show the reader how the geographical scope and extent of the data, as well as its scale and resolution, might differentiate according to the level on which it is focused.

The “scale effect” becomes most visible when viewed through the prism of the three levels of war. The timescale for delivering the product will be determined by a number of variables that include the urgency/priority of the task given by the commander, the availability of data, the knowledge of the GIS operator and the complexity of the specific GIS task. On average, all tasks are usually treated as “urgent” in an operational/deployment area (Caldwell et al., 2005). At the tactical level of war, GIS might be used in various weapon and other tactical command systems to which the researcher does not have access and, in terms of security purposes, would not like to expose these systems’ capabilities.

2.3.6 Operational level of war and GIS

The operational level as vital link. It is necessary to differentiate between the levels of war in order for the commander to clearly comprehend his responsibilities. In the previous section, it was concluded that the operational level would be used as focus for this study. The reason for choosing this level of war is to narrow down and focus the study and because of the fact that it provides the link between the strategic objective and all tactical objectives in the theatre of operations (see Figure 2.3 below). In a study done by Rowe (2000), he concluded that the "operational level is a vital link between national-and theatre-strategic objectives and the tactical employment of forces on the battlefield". The operational commander provides the coordination between the other two levels. According to Jablonsky (1987), the operational level is a pivotal location in the hierarchy of the levels of war. According to Rowe (2000), it is important to understand the operational level of war's place in the military domain. In order to understand this, a few critical terms should be evaluated.

The range of GIS products available to the operator supporting the operational level commander will therefore also be wider and will include more functionality to include aspects that overlap both with the strategic and tactical levels of war. The scale and the resolution of the data being examined for the operational level of war will be different from data used for the other levels of war. Therefore, while the GIS operation/function might be the same for the operator, the scale, resolution and extent of the data will be different. The scope of the battlefield will also be different. It is furthermore the operational commander's responsibility to train and develop skills, such as GIS, for use at the tactical level.

Responsibilities of the operational commander. According to the US Army Chief of Staff (31 May 1995), an operational commander designs, plans, sequences and sustains a campaign according to the authorised campaign plan within his area of operations. He leads operations in the campaign and makes sure of which tactical objectives he must attain in order to achieve campaign objectives.

When determining these objectives, he must always be certain that the action he performs is operational in nature and that it contributes directly to attaining the strategic goal. He also decides the sequence in which tactical objectives must be achieved and with which forces and resources. The commander must give direction to the forces under his command (US Army Chief of Staff, 31 May 1995). These forces also include the GIS team under his command. Since GIS is such a dynamic function and one that evolves with time, the operational commander should ensure that he stays abreast with the functions that the GIS team can provide him with.

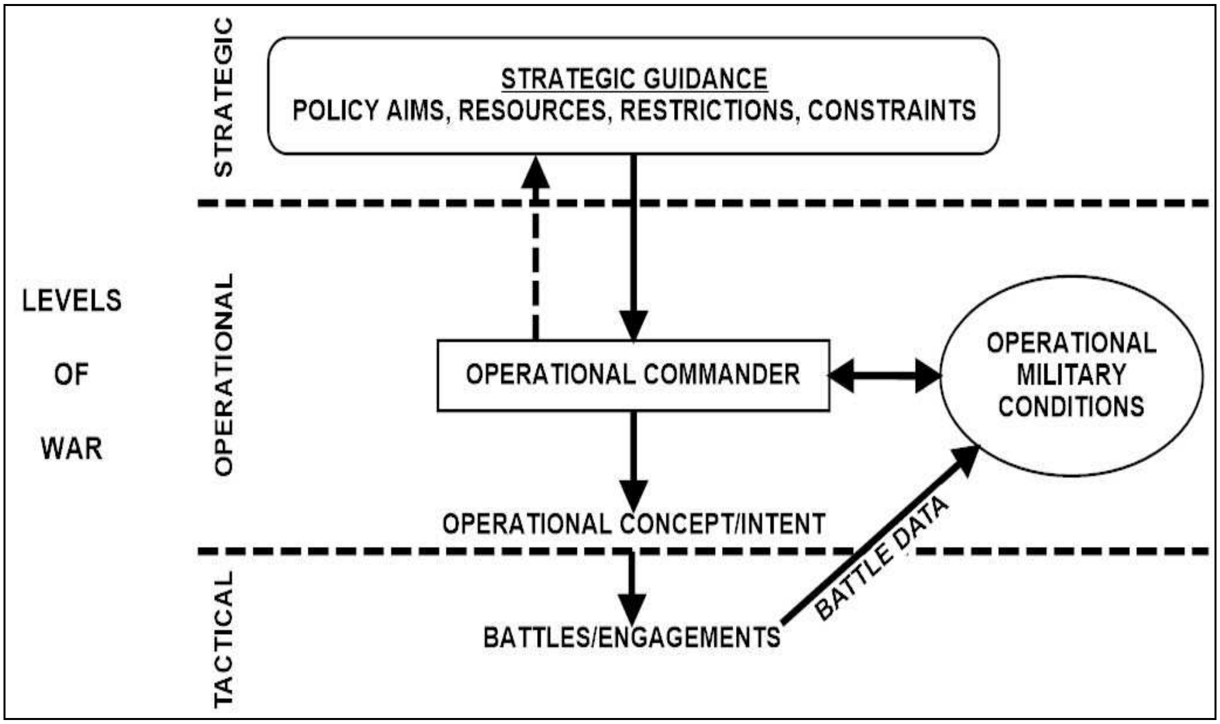

Figure 2.3: Interactions of the operational commander

Source: Jablonsky (1987)

Responsibilities of the GIS commander supporting the operational commander. The GIS commander is the leader of the GIS team that is placed under the command of the operational commander. He must possess excellent GIS skills and knowledge, be a good leader (the person's rank level can vary, but he will normally be a senior officer) and must also have good military knowledge in order to support the operation. The GIS commander must ensure that he is able to meet the requirements below.

a. Communicate with the operational commander on a regular basis to ensure that he is able to support him fully. He must also brief the operational commander with regard to the abilities of the GIS team and the functions they can perform, as well as and also concerning any needs that his GIS team might have. Not all commanders are aware of the magnitude of GIS functions that are available to solve their complex battle questions.

b. Ensure that his GIS team is well trained, especially on the pre-identified GIS tasks that are normally expected in operations. Ensure that he and his members attend regular GIS software courses in order to stay abreast with new developments in the software and in the GIS fields. Conduct regular in-post mentoring training with his team (Korte, 2001).

c. He must ensure that his team has all the necessary hardware and software needed to perform their tasks effectively. He must ensure that all licenses are booked out to deployment computers and that all the extensions are available. He must ensure that all printers are in a good condition and that his team has enough supplies (Longley, 2005).

d. Perform complex GIS data maintenance that will include “manipulation, analysis, extraction and generation assignments; performs data studies, investigation and verification; digitises maps and geographical feature data into various layers; prepares projects data” for the operational area and for future storage; perform record and inventory keeping in order to prepare for current and imminent projects; react to demands from the operational commander for maps and other products to comply with disasters, emergencies and other operational needs (Longley, 2005).

e. A variety of mapping techniques are used to prepare, plan and represent spatial data and to update different types of maps and layers, and to attribute data from a variety of own and other resources (Korte, 2001).

f. When problems are experienced with the software, communication has to take place with technicians and other resources to resolve these problems. Other GIS team members must also be given direction in order to solve the problems that were reported (Korte, 2001).

2.3.7 The physical environment in which GIS products is created

According to J.D. Venter (personal communication, 15 September, 2015), the physical environment of the GIS team will vary depending on the level of war at which it is operating. In general, at the strategic level, the location of the GIS office will be the Joint Operations Centre, and at an operational level it will be located at the Brigade HQ. The location of the Brigade HQ will vary from operation to operation. At the tactical level, it will be the Tactical HQ. The GIS team must be in a position to move their physical location at any given time. Therefore hardware must be of such a nature that it can be packed in a protective case and moved to another location at short notice. The physical structure will largely depend on the specific operation and where the operation is taking place. It can be anything from a nice, cosy building to a tent or a weather haven. Electricity might be readily available or generated. Deployment equipment for GIS teams must be kept serviceable and in a ready-for-use state to deploy at any given time. Resources such as printing consumables should be replenished once it reaches a certain stock level.

2.4 SOFTWARE

In the next section, different software development models, FOSS and proprietary software, software testing, software licensing and software standards are discussed. The goal of this study is not an attempt to discredit either proprietary or open source software in any sense, or to declare the one better than the other, but rather to provide an objective assessment of the differences.

2.4.1 Software development

The development cycles of proprietary and open source software vary greatly (Figure 2.4). The advantages and disadvantages of each of these software development models vary according to which software type/development model the author supports. Each of these development models fulfils an important role in both economical and academic circles and, in a way, might draw inspiration from one other.

GIS software development can also be done by way of either the proprietary or the free and open source route. According to Longley (2005), commercial GIS are built and released by GIS-vendor software development and product teams. These software products are subject to planned versioned release cycles that enhance the system's capabilities “incrementally”. Longley (2005) further states that as standards for GIS software become a reality, so too does the prospect of reusing software components. The developer can decide to buy some of the components or develop them from scratch.

In the present day, many FOSS GIS software developments are still taking place. OSGeo is a “not-for-profit organisation” whose mission is to support the collective development of open source geospatial software. Community members can contribute code to this legal entity (OSGeo, 2015).

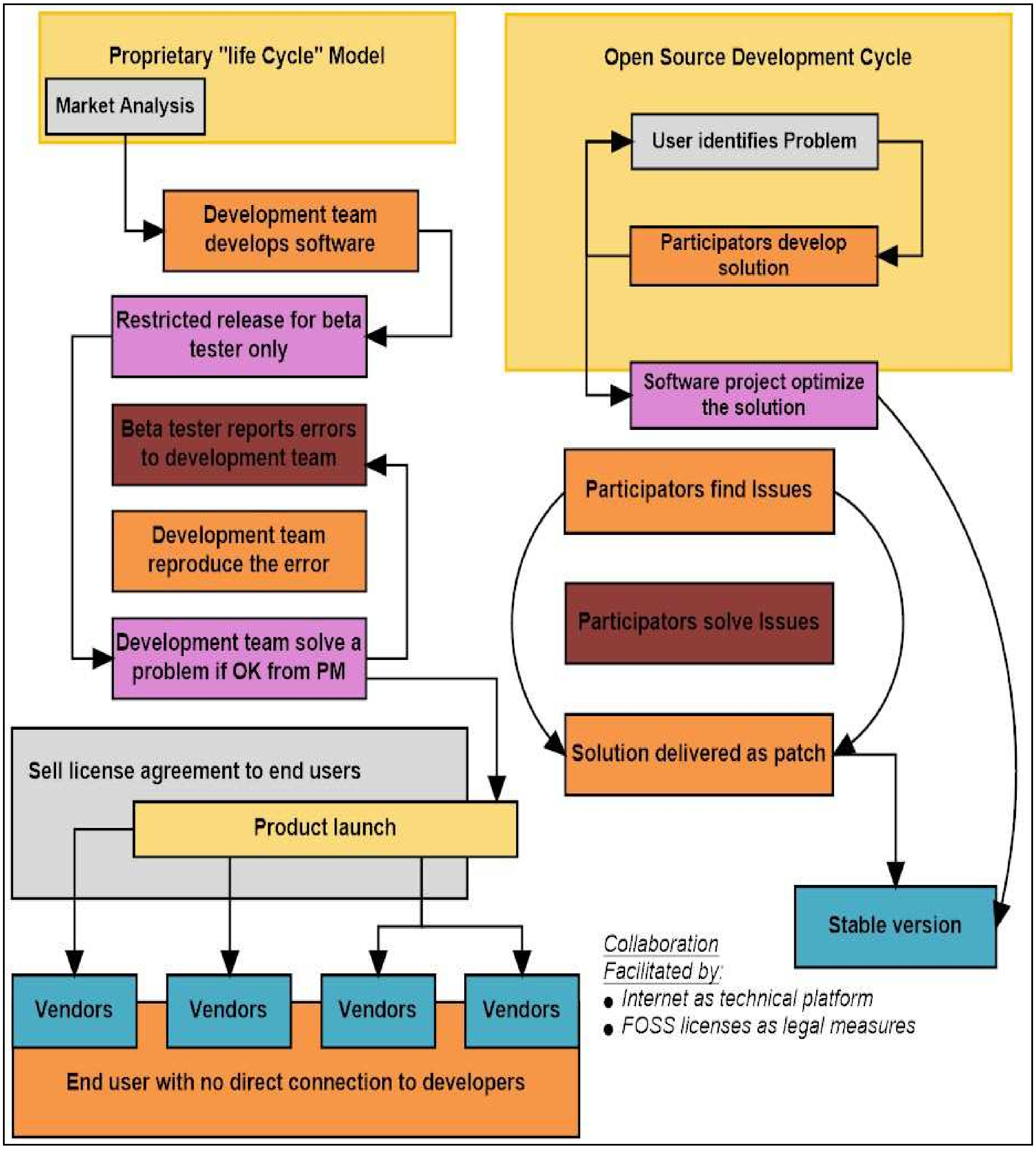

Figure 2.4: Software development cycles

Source: Hall and Leahy (2008)

Proprietary software development. As already mentioned, the development cycles of FOSS and proprietary software vary greatly (Figure 2.4). Hall and Leahy (2008) mention that in the proprietary software development cycle, the upgrading of software to newer versions may often require the end user to pay more money and to sign a maintenance contract. Without paying the maintenance fee, permission to use the software might expire after a certain period of time. In the proprietary model, the flow of development is mostly dependent on the software vendor who might decide to not implement enhancements at that time, but to wait for the next version. This might also make their next version more attractive to procure.

Open source software development. In the FOSS field, the development cycle can be much quicker and it is not profit-orientated since its main objective is to provide a stable software product that solves a specific problem. The developers of the software products are in most cases also users of the system. Users are very important when it comes to the testing of any software product. Raymond (2001) agrees that in the open source market, developers can "fail" without causing harm to the source code. This can result in fast responses to the demands in the market and a better capability to reinvent. In the proprietary model, one might argue that the developers/sellers of the software product know that they will lose money and/or customers if their product does not adhere to high standards. They therefore tend to address problems quickly and to ensure that their product is of a high standard.

2.4.2 FOSS and proprietary software

2.4.2.1 The difference between FOSS and proprietary software

The term FOSS is actually a combination of two terms that describes the uniqueness of non-proprietary software. According to May (2006), philosophical differences exist between the terms "free software" and "open source". The underlying issue in the term "free software" is the liberty to access the software's source code and to then be able to share and distribute this source code to others. Conversely, the "open source" group focuses on the developmental community. According to the free software approach, software is like a language that should not be owned since it is foundational to its users. Hall and Leahy (2008) explain that open source (OS) and its logo are trademarks of the Open Source Initiative (OSI). As such, any software that is claimed to belong to it must abide by the terms and conditions spelled out by the OSI. In order to avoid any confusion, the term "FOSS" is used throughout this study. However, as May (2006) states, the philosophical differences between the two terms are not denied.

According to Janssen (2016), free and open-source software (FOSS) allows users and programmers to edit, modify or reuse the software's source code and therefore affords the opportunity to keep improving the software product and its functionality continuously. The software is "free" since it does not place limits on copyright; the fact that the source code is open, encourages developers from various spheres to collaborate in its development. Stallman (2002) agrees that the term "free" can cause great confusion, seeing that it is meant as liberty and not price. It is called FLOSS (free/libre open-source software) or FOSS (free/open-source software).

Ballardini (2012) notes that the most important difference between FOSS and proprietary software is the way in which the software is developed. Proprietary software is developed in a centralised, closed type of environment where the developer has all the rights over it. Distribution to users is the other differentiating factor, and is where the licensing of the product features. The developers of proprietary software use a variety of licensing agreements in which restrictions are placed on the users that limit their rights. The source code is not made available, seeing that this is where the specific product's "trade secrets" lies. Thus, only the object code is distributed.

Janssen (2016) explains that before 1960, most software was free and accessible to all. As software grew in their complexity and development efforts, it became a market trend, and procedures such as Internet activation and product installation keys were put in place. These methods became a necessity for software developers to gain profit from their development efforts. According to May (2006), sub-Saharan African countries at the time "pay around US$24 billion each year to (mainly US-based) software companies" for the use of proprietary software products.

2.4.2.2 Advantages and weaknesses/risks of FOSS

It is imperative to note that the advantages and weaknesses/risks discussed below are general in nature and may not automatically be true for a particular FOSS project. The researcher will therefore revisit these aspects towards the end of this dissertation. Then the focus will shift to the particular FOSS software (QGIS) used for tests during this study and using the identified use case. (See Chapter 3, paragraph 3.5.) However, according to Still and Amant (2007), strong points of FOSS can be categorised into five categories, namely time, cost and effort, software evolution, freedom of use, quality of software and advantages to companies and programmers. These points are explained in the paragraphs that follow.

Time, cost and effort. The development costs are lower since it is usually being developed by global contributors. Ballardini (2012) agrees and states that this can allow the rapid implementation of features and security fixes and results in more ideas and greater creativity. Time and budget can be less of a constraint on the development of a system (Gacek et al., 2002). The cost of using the software is significantly reduced since it is not, as is proprietary software, affected by “limited licensing”. FOSS can save “non-profit organisations” money, since licensing costs are usually cheaper than proprietary software products. Maintenance costs are also reduced since it is a “shared cost” among all potential users of the specific software product.

Software evolution. The fact that many developers are included in the software development process means that FOSS contributes to the software evolution (Feller, 2005). The development of FOSS is a constant process compared to proprietary software where development usually takes places when a new release is made (Still and Amant, 2007).

Freedom of use. FOSS allows software source code to be used, modified and redistributed in its “original” or its “modified” form for further use and/or further modification (Hall and Leahy, 2008; Still and Amant, 2007). According to Wheeler (2007), as cited in Still and Amant (2007), an advantage that FOSS users have is that they can exercise control and flexibility when maintaining and modifying their software product to their own needs and likes. Users now also have the flexibility to change between software vendors; the user is therefore not left “at the mercy of the vendor”, even if the vendor goes out of business. The user also has access to free upgrades and newer versions at no cost. Wong and Sayo (2004), as cited in Still and Amant (2007), mention that a particular company does not control the industry (see paragraph 2.4.3).

Quality of software. FOSS is frequently under peer review of developers around the globe who can view and inspect source code and provide feedback. This fact enhances the quality of the software product. It can also reduce the number of bugs (Still and Amant, 2007; Raymond, 2001).

Advantages to companies and programmers. International knowledge obtained from programmers and other users is shared, and it provides a learning opportunity to everyone involved. Companies can now collaborate and everyone can gain from the software's rapid development (Still and Amant, 2007).

Still and Amant (2007) state that weaknesses/risks in FOSS are associated with "management, quality and security". The management of resources in an open source community can sometimes be a greater challenge than in a proprietary project. This means that coordination and collaboration might require a greater effort. Resources and funds can also be more difficult to obtain and sustain. Since FOSS programmers often do not earn the same income as proprietary software programmers (who often earn high market-related salaries), these programmers may often leave the project or be less motivated. Hissam et al. (2002), as cited in Still and Amant (2007), state the fact that the source code is open and available makes the software product more vulnerable to cyber terrorists. These cyber terrorists can learn more about FOSS and similarly also about proprietary software products, since they can share the same basic architecture.

2.4.3 Software licensing

This section starts with some background on software licenses in general as well as an overview of proprietary and FOSS licensing and Creative Commons (CC). Geospatial software licensing will also be discussed. According to the The University of North Carolina (2013), a software license is defined as "… a legally binding agreement that specifies the terms of use for an application and defines the rights of the software producer and of the end-user". The issues (terms of use) that the software license might specify is

a. the period of time for which it will be used and under which particular conditions,
b. technical and other assistance that will be provided to the user as part of the support,
c. warranty terms,
d. the rights to access the software's source code and ownership rights to the software, and
e. dispute resolution (Walker & Jocke Co., 2013).

Software licensing can be a challenging topic to discuss. It is challenging in view of the fact that not all authors agrees on which types of software licenses can be distinguished. What complicates the matter even more is that the definition of what "free" and "open source" software is might vary and that "free" might not necessarily mean "no cost". Another confusing term is "freeware". This does not imply that the software is free, since the license allows the redistribution but not the modification of the source code of the software. In addition, some other organisations also promulgate similar notions to that of open source licensing, but do not belong to the Open Source Initiative (OSI). Based on a review of literature, the conclusion was drawn that the two main types of software licenses are proprietary and open source licenses (Ballardini, 2012; Hall and Leahy, 2008; Open Source Initiative, 2016; Stallman, 2002).

Proprietary licensing. Proprietary licenses are widely used. A proprietary license is a "legal document" that requires the user to accept certain terms and conditions before the software product can be used. These terms and conditions stipulate the contract between the user and the developer. Users can be held liable for any "rules" that they might have broken. Different types of proprietary licenses and license contracts can be distinguished (Table 2.2). Software vendors use different terms to describe the license being used by them. These terms may be referred to as an End User License Agreement (EULA). These terms are also referred to as "clickwraps" or "shrinkwraps" (The University of North Carolina, 2013).

Table 2.2: Types of proprietary licenses

TYPE OF PROPRIETARY LICENSE	DESCRIPTION
Freeware/Shareware	There are no copyright restrictions on freeware. The developer creates and then puts it on the public domain. The source code cannot be changed, but it can be copied freely by users of the software. Shareware, however, is copyrighted, but can be copied and even redistributed to other users. A registration fee might be payable, after which the software and documentation will be sent to the user, as well as regular updates.
Limited License (LL)	This type of license specifies the number of copies that may be installed. Concurrent licenses are an example of this type, where the number of users is specified. This type of licensing is usually found in educational facilities and will only work while the student is connected to campus computer facilities.
Unlimited Site License (USL)	It is a license where no limit is placed on the number of copies that are installed. This type of license may be limited to a specific institution.
Volume Purchase Agreement (VPA)	When software is procured in large quantities, a better price can usually be negotiated. Since a specific number of copies is not specified with the initial purchase, the number might be increased in future using the same price (ROHAN Academic Computing, 2016).

Source: http://www.rohan.sdsu.edu/~cetc/softwarelicense.html

With regard to a proprietary license, the developer owns the right to the source code and is the only one that can modify it.

FOSS Licensing: Hall and Leahy (2008) state that the licensing model of FOSS is one of the key contributing factors to its success. Open source software is mostly licensed under the GNU General Public License. This model was developed in the 1980s by Stallman (2002), whose main goal was to legally protect the intellectual work by means of a license in order to confirm that it cannot be preserved as "individual property". A term frequently used to explain this phenomenon is *copyleft*[4] (Hall and Leahy, 2008). According to the Open Source Initiative (2016), a license is considered an open source license if it allows software to be freely used, modified and shared, as well as if it complies with the open source definition. Licenses labelled as "open source" will be subjected to a formal "license review process" in order to confirm that it conforms to existing community norms and expectations. This is a public review process. Adhering to the open source definition does not only mean access to the source code, but also that the distribution terms must adhere to the set of criteria set out by the Open Source Initiative (2016), namely

a. "Free redistribution: The license must not restrict any party from selling or giving away the software as a component of an aggregate software distribution that contains programs from several different sources. The license must not require a royalty or other fee for such a sale.
b. Source code: The program must include source code and must allow distribution in source code as well as in compiled form. Where some form of a product is not distributed with the source code, there must be a well-publicised means of obtaining the source code for no more than a reasonable reproduction cost, preferably, downloading by means of the Internet without charge. The source code must be the preferred form in which a programmer would modify the program. Deliberately obfuscated source code is not allowed. Intermediate forms, such as the output of a pre-processor or translator, are not allowed.
c. Derived works: The license must allow modifications and derived works, and must allow its distribution under the same terms as the license of the original software.
d. Integrity of the author's source code: The license may restrict source code from being distributed in a modified form only if the license allows the distribution of "patch files" with the source code for the purpose of modifying the program at build time. The license must explicitly permit the distribution of software built from modified source

[4] Its logo is a reversed "C" in a full circle such as the copyright symbol, but mirrored. It however does not have any legal meaning unlike the copyright symbol. Source: Hall and Leahy (2008).

code. The license may require derived works to carry a different name or version number than the original software.

e. No discrimination against persons or groups: The license must not discriminate against any person or group of persons.

f. No discrimination against fields of endeavour: The license must not restrict anyone from using the program in a specific field of endeavour. For example, it may not restrict the program from being used in a business or from being used for genetic research.

g. Distribution of license: The rights attached to the program must apply to all to whom the program is redistributed without those parties needing to execute an additional license.

h. The license must not be specific to a product: The rights attached to the program must not depend on the program being a part of a particular software distribution. If the program is extracted from that distribution and used or distributed within the terms of the program's license, all parties to whom the program is redistributed should have the same rights as those that are granted in conjunction with the original software distribution.

i. The license must not restrict other software: The license must not place restrictions on other software that is distributed along with the licensed software. For example, the license must not insist that all other programs distributed on the same medium must be open source software.

j. The license must be technology-neutral: No provision of the license may be predicated on any individual technology or style of interface."

The use of the OSI trademark and logo. The Open Source Initiative (OSI) has its own distinguishable logo, illustrated in Figure 2.5. This logo must be used on software licensed under an OSI-approved license. If the OSI logo is used, the standard trademark guidelines should be followed. These trademark guidelines can be reviewed on the OSI website (https://opensource.org/trademark-guidelines).

Figure 2.5: The official logo of the Open Source Initiative (OSI)

Source: Open Source Initiative (2016)

Creative Commons (CC) and CC BY-SA licenses. According to Creative Commons (2009), Creative Common (CC) licenses allow licensors (creators) to keep the copyright of their products and to get credit for the work they put in, while allowing others "to copy, distribute, and make some uses of their work". This takes place non-commercially. This license applies worldwide and it serves as a baseline on which licensors can add permissions. There are various types of CC licenses, but the one that is often compared to an open source license is the CC BY-SA license (see Figure 2.6 for the logo used for CC BY-SA). The CC BY-SA license allows other developers to expand on the work done by others, even if it is for commercial use. Credit must be given to the initial developer and the new work must be licensed under "identical terms". Not all CC licenses are free (Creative Commons, 2009). Creative Commons does not currently belong to the OSI. In February 2012, Creative Commons submitted their "CC0" license for approval to the OSI. The OSI, however, saw the request as a "waiver of rights" and disapproved their request (Open Source Initiative, 2016).

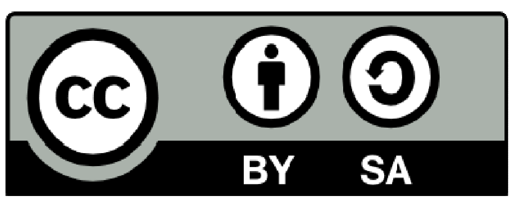

Figure 2.6: Logo used for CC BY-SA

Source: Creative Commons (2009)

2.4.4 FOSSGIS

The history of FOSSGIS. According to Donnelly (2010), the history of FOSSGIS goes back to the creation of the "Geographic Resources Analysis Support Systems (GRASS)". This software product was initially developed by the US Army Corps of Engineers

Resource Laboratory (CERL). The purpose of this software product was to provide a low-cost public domain alternative for resource management. This software product matured throughout the years, and in the 90s its management was transferred to a non-profit foundation. In 1999, GRASS was released under the GNU GPL license (see paragraph 2.4.3). Other FOSSGIS products were developed more recently, such as MapWindow in 1998 and QGIS in 2002. QGIS is now the “more user-friendly front-end” to GRASS.

Chand (2014) cites that the use of FOSS in the GIS field has risen in popularity and has become widespread. Chand (2014) states that this rise can be determined by using “four indicators”. The first is the vast number of FOSSGIS projects (330) that were started in the last 20 years. The second indicator is the financial support received from government institutions for these projects. The rate of FOSSGIS downloads experienced is the third indicator. Chand (2014) states that the fourth indicator is the number of use cases investigating open source GIS.

FOSSGIS products. FOSSGIS can generally be categorised into three “tribes” in terms of different programming languages (Dempsey, 2016; Ramsey, 2007). The first tribe uses the “C” programming language for its development. This group is generally considered the “most matured” group because of their extensive history in the field. These software products include, among others, GRASS, QGIS, PostGIS and GDAL/OGR. It also includes popular scripting languages such as Python that can bind into the “C libraries”. The next group of developers is called the “Java tribe”. Popular-used open source GIS in this group includes GeoTools, Geoserve and OpenMap. The last, very influential grouping is the .NET tribe. SharpMap and WorldWind are examples of this grouping that uses .NET as their implementation language. In addition to these three “tribes”, open source web mapping is also becoming increasingly popular. Examples of these are OpenLayers and MapBuilder.

OSGeo. The Open Source Geospatial Foundation (OSGeo) “is a not-for-profit organisation whose mission is to support and promote the collaborative development of open source geospatial software, data and education” (OSGeo, 2012). This foundation offers “financial, organisational and legal support” to the larger “open source geospatial community”. Members of this community can contribute in terms of code, funding and also other contributions. The contributions made are used to the advantage of the public. OSGeo is a common forum for the open source geospatial community and provides infrastructure for "cross-project" cooperation.

2.4.5 Standards

According to the International Organization for Standardization (2015), a standard can be defined as "a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose". Standards address a wide variety of fields, and more than 19 500 international standards are currently available from the International Organisation for Standardisation (ISO) or its members. ISO consists of national bodies worldwide and, among others, the South African Bureau of Standards (SABS), is one of them.

According to Cooper (1993), "standards are a necessary evil" since they influence our lives daily. It means that if we have good standards in place, they will facilitate integration, in turn reduce costs as well, and in some cases also promote safety. Standards can, however, be costly to develop and implement. The advantages of implementing standards, however, still outweigh the disadvantages. Some of the advantages mentioned by Egan (2002) include the following:

a. costs are reduced while production is increased;
b. it provides information regarding products;
c. it signals the product quality and compatibility with other products;
d. it can reduce liability; and
e. it can increase "competitive corporate strategy" and therefore creates management that is more efficient.

Thus the benefits of standards can be summarised as bringing forth technological advances. It can provide knowledge in fields where resources and/or experience are needed, as well as economic and societal benefits.

Open standard requirements for FOSS. The FOSS environment also has specified standards. As specified in the Open Source Initiative (2016), there is a requirement that an "open standard must not prohibit conforming implementations". In order for open software developers to not discriminate against other developers and in order for them to conform to the “Open Standards Requirement”, an "open standard" must adhere to the conditions below.

a. No intentional secrets: In order for “interoperable implementation” to take place, no detail must be withheld from the standard. The standard must also outline a procedure for fixing inevitable mistakes. The changes must then be incorporated in a revised or a superseding version.

b. Availability: It must be “freely and publicly available under royalty-free terms at reasonable and non-discriminatory cost”.

c. Patents: All the patents must “be licensed under royalty-free terms for unrestricted use, or be covered by a promise of non-assertion when practiced by open source software”.

d. No agreements: Under no circumstances should there be any prerequisite for the implementation of a “license agreement, NDA, grant, click-through, or any other form of paperwork” to deploy compatible applications of the standard.

e. No OSR-incompatible dependencies: Enactment of the standard should not necessitate any other technology that fails to meet the conditions of this requirement.

Standards in the Geospatial field. As was concluded from paragraph 2.4.5, standards are a beneficial and crucial part of our society; this is, of course, also true for the fields of industry and science and, very importantly, for this study and the geographic information (GI) science field. Standards in this field enable the interoperability of geographic information. ISO is also very involved in creating standards for the GI field. As stated by the Ordnance Survey (2015), ISO’s technical committee ISO/TC 211, Geographic information/Geomatics (ISO/TC 211), is looking at the production of standards with regard to a variety of aspects dealing with spatial data.

The International Hydrographic Organisation (IHO) is an intergovernmental consultative and technical organisation that aims to promote uniformity in the marine environment (Coetzee et al., July 2013). The expanding organisation, the Open Geospatial Consortium (OGC), is also very passionate about and dedicated to the creation of standards for geospatial systems. The OGC has “alliance partnerships” with numerous other standards development organisations and industry relations who work closely with the OGC on an extensive range of matters such as sensor fusion, urban modelling, aviation, meteorology and points of interest (POI), to name only a few. These OGC standards are technical documents that software developers use to build open interfaces and encodings into their products. The main products of the OGC are therefore standards, which are available to the public at no cost (OGC, 2015).

Interoperability and standardisation in geographic information are crucial aspects in the development of global geospatial information. Establishing global geospatial information can be increased when adhering to these principles. The United Nations initiative on Global Geospatial Information Management (UN-GGIM) plays a primary role in the advancement of global geospatial information and “to promote its use to address key global challenges” (Coetzee et al., July 2013).

2.4.6 Software testing

Software testing is regarded as an essential portion of the software development life cycle. Among others, it can be done in order to check the precision, comprehensiveness, security and excellence of developed computer software. It is therefore done to ensure that all aspects of quality standards are met and to measure software against specific occupational desires (Exforsys, 2014). This was also the case in this research, seeing that one of its objectives was to determine the feasibility of the software’s use at the operational level of war.

According to Tsui et al. (2013), software testing is a complex activity that encompasses many undertakings and which must be thoroughly planned. The steps involved in this process are as follows:

a. determine the objective of testing or the quality goal for the associated project;
b. determine the test methodology and procedures that must be used to achieve the objective that was set;
c. means and tools must be assigned and should be allocated;
d. a timetable must be set; and
e. a “test plan” that spells out all these particulars has to be developed (see Appendix A).

Various types of software tests are available. The circumstances will determine which software test must be performed. According to Tsui et al. (2013), programmers, testers or users can perform testing. When the test is being performed by programmers, it is usually referred to as “unit testing”. A tester is a person whose job it is to write test cases and then to execute them. They can be used to make “product release decisions”. It is a good idea to involve users in software testing, since they can provide “real-life scenarios” and can therefore identify problems easier. User testers are called “Alpha testers” if they belong to the specific developing organisation and “Beta testers” if they do not belong to the developing organisation. In this research, the researcher will therefore be a Beta tester. Before attempting to design the actual test for this research, the type of software testing that will be done had to be established. When performing software testing, it is wise to include more than one type of software test, given that each of the tests has their own goals and limitations. A wide variety of software tests is available to the tester. After a review of the literature, it was concluded that three types of software tests might be feasible for this study. The three tests considered are described as below (Exforsys, 2014; Tsui et al., 2013).

a. <u>Black-box testing</u>: Tsui et al. (2013) defines black-box testing as “testing based solely on specifications, without looking at the code ...” The tester does not have information about the interior mechanisms of the software to be tested. The tester will, however, know the inputs and also the probable output. Any person can perform a black-box test, since no programming skills are necessary to run the test and, in fact, the developer and the tester should work seperately from one another. In black-box testing the tester must indicate the test range. Black-box testing can be a successful testing method when used in conjunction with other tests. Different uncertainties and variances can be uncovered by using black-box testing. This can assist the tester to functionally design tests that can be used in an outside setting. Furthermore, this type of test can be performed at any stage of software testing including system testing and acceptance testing (Exforsys, 2014).

b. <u>User acceptance testing (UAT)</u>: According to Exforsys (2014), user acceptance testing is performed by end-users to determine whether developed software meets user-specific criteria. It is not a test performed in order to expose bugs in the system. It is rather a test with which to test the feasibility of the system for the particular business environment since it “simulates” the environment in which the user will use the software product. In general it is recommended that this type of testing be done by all software end users to determine whether the software product is really what they need for their business. The user can similarly test only certain parts of the software product when performing this type of test. Whereas all other types of software tests are mainly the responsibility of the software developer, the user acceptance test is the responsibility of the end-user. With a user acceptance test you can plan to find some errors that were not noticed with other software tests. A "test plan" is essential to determine the type of results that the client wants to see. In this study, a "use case" was developed based on a military operational scenario that tests functions used by the military operational commander.

c. Comparison testing: A comparison test "compares a software products' strengths and weaknesses with other software …" It will therefore test whether a particular software product will be competitive in the market. Your test must be able to determine whether it addresses the users' concerns. An important aspect to consider when performing a comparison test is the identification of relationships – each of the components and its related sub-systems might have to be defined. A comparison test serves as a "benchmark test" to establish what a person needs from the system.

Designing the software test using UAT. After a review of the literature it was determined that the UAT is the ideal type of software test for successfully conducting this research. Although, from the literature studied, it may seem as though various other types of software tests are suitable, they are all typically performed at the developmental stages of the software (see Figure 2.7 for the fitment of acceptance testing in the software development life cycle). The user acceptance test is performed at the final stage of the software development model (Tsui et al., 2013). The user acceptance test will therefore be suitable for use by the researcher since the software products to be tested have already been developed.

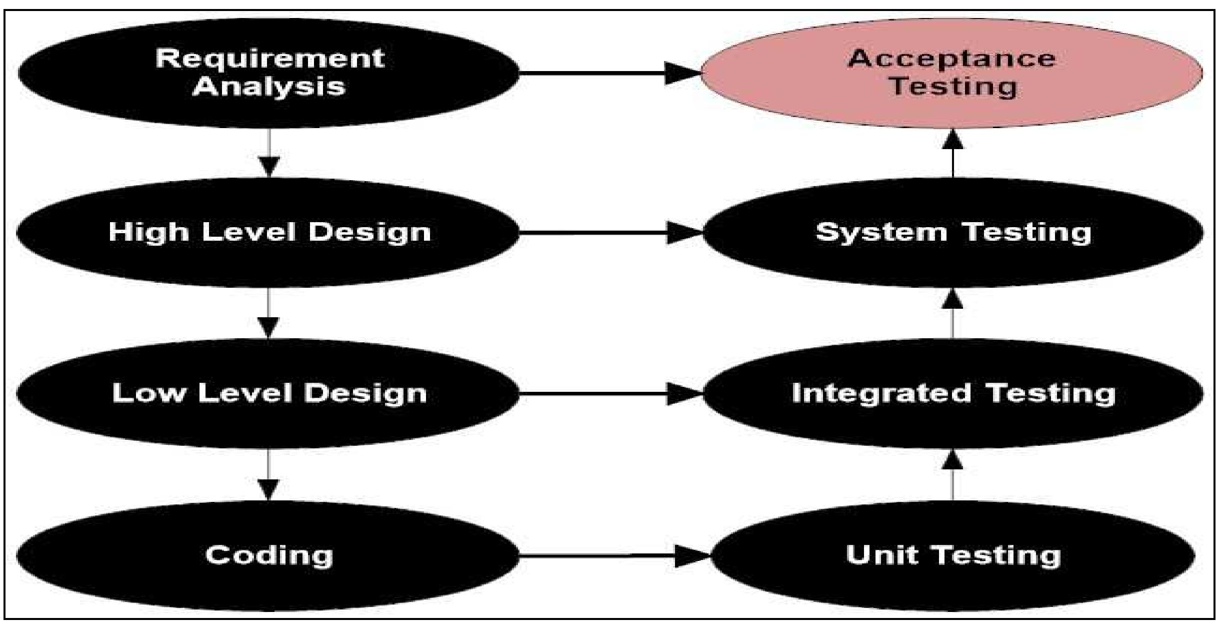

Figure 2.7: Fitment of acceptance testing in the software development life cycle

Source: Tutorial Point (2015)

This software testing method has numerous advantages. According to Exforsys (2014), it can be summarised as follows:

a. the user can run the test and consequently establish whether it has the necessary functionality;
b. the users perform the entire test themselves and will therefore gain confidence to operate the software; and
c. the acceptance test will disclose any errors that the user finds unsatisfactory, although it was accepted by the software developer.

When designing an acceptance test, it is important to keep the following criteria in mind:

a. a test plan with a precise list of the client's duties/responsibilities should be developed. This plan will clearly define the activities being tested when the test is performed;
b. acceptance criteria need to be developed. The level of errors that is allowed needs to be clearly stated in the test; and
c. a work plan for the acceptance test is important since it will inform the person/s performing the test what is expected of them and it will give them a "timeline" to specify the time they have to complete the specific test.

The user acceptance test plan. A user acceptance test plan was developed (see Appendix A). According to Tutorial Point (2015), the test activities that are being performed during acceptance testing must be carried out in phases. Therefore the data preparatory tasks must be done first. The evaluation of operational tasks can then be done as specified in the use case. The following attributes are contained in the acceptance test plan:

a. an introduction;
b. test items;
c. features to be tested/features not to be tested;
d. test approach;
e. suspension criteria and resumption requirements;
f. environmental needs;
g. test procedure. The test procedure for each test includes detail test case specifications;
h. responsibilities;
i. risks and contingencies; and

j. approval.

The user acceptance test activities are designed in such a way to reach at least one of the following end results:

a. accept the system as developed (for use by the operational level commander);
b. accept the system after the requested modifications have been made (for example after some features or functions have been added); and
c. do not accept the system as developed (for use by the operational level commander).

2.5 RELATED WORK

A number of studies were done to compare ArcGIS to QGIS[5]. However, this study is unique since it focuses on military operational requirements related to a specific use case. Secondly, it is not a competition to find a "victor", but rather an objective study to determine whether FOSSGIS can be used in a specific military operation considering certain operational GIS functionalities (specified in the use case), its user-friendliness as well as aspects related to costs. The GIS functionalities that were tested were therefore very specific in nature and specific goals were set. Concerning the user-friendliness and costs that were compared, specific criteria were also specified.

A number of examples of related work follow. These related works illustrate the importance of both proprietary GIS and FOSSGIS in the GIS industry, as well as the high quality of both ArcGIS and QGIS. The fact that the two software products were compared by so many authors in different studies also supports QGIS as a good choice for comparison against ArcGIS for this particular study.

According to GIS Geography (2016b), "Esri ArcGIS is the powerhouse in GIS. It is so influential that the term ArcGIS is sometimes (mistakenly) used interchangeably with GIS". GIS Geography agrees with Bolstad (2005), a widely used textbook, that Esri is the world's biggest GIS software company. On their list of GIS software products, QGIS was second, and they rated it "the most significant open source technology adoption in GIS today". The article also recognised QGIS' fast growth in the industry.

[5] see: *https://wiki.osgeo.org/wiki/Case_Studies*

In a study done by GIS Geography (2016a), ArcGIS and QGIS was compared with regard to 27 differences that the author found between these software products. The author concludes that both are good GIS software products.

Dempsey (2012) did a short comparison of the two software products by using 11 general categories to highlight some similarities and differences between the software, cost, licensing, development process, platform, loading time, extensibility, support, adoption, spatial analysis, geoprocessing and cartography. Dempsey (2012) further states that ArcGIS and QGIS are two of the most popular GIS desktop software products.

In an article published by Duggan (02 February 2015), the two software products were compared concerning "price, interface, load time, extras, development and speed". The author pointed out some "niggles" and "life savers" relating to both software products.

2.6 CHAPTER SUMMARY

In this chapter the researcher provided an overview of the literature study that was performed. In the first section she described the evolution of GIS, its components and some of the issues to consider when selecting GIS software products. In the next section she focused on military operations that relate to the different levels of war and the types of military operations. The role of GIS in these levels of war was also explained. Specific reference was made to the operational level of war and GIS. The focus then shifted to software. Software development models, FOSS and proprietary software, FOSSGIS, standards and software testing were discussed. Specific mention was also made of open standard requirements for FOSS and geospatial standards. The researcher concluded this chapter with an emphasis on related studies.

The methodological approach followed during this study is described in the next chapter.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 INTRODUCTION

In this study the researcher used an extended literature study and empirical research to solve a specific problem (paragraph 1.4.1). GIS has become a key factor in any military operation. The SANDF would not want to deny any of its units access to such a valuable planning tool. However, not all SANDF units have the funds to obtain GIS software due to the high cost of proprietary GIS software products. The perception that open source GIS software products do not have the needed functionality and that it is not mature enough to replace proprietary software products, is also apparent. This perception is not only true in the SANDF, but also in the broader GIS community. This perception motivated the researcher to analyse the practical feasibility of using FOSSGIS in military operations. The literature study was opened with a section on GIS. The literature study also provided good insight onto the precise role of geospatial information in the military, the levels of war and the use of GIS at each of these levels. It was then concluded that this study must be even further refined to focus solely on the operational level of war, since it would be impossible to conduct the study focusing on all the possible uses of GIS for the military. The study thus focused on the operational level of war and GIS, after which a number of GIS products often required by the operational commander were identified. The literature study was concluded with a section on software. Specific reference was made to software products of both a proprietary and a “free and open source” nature. The general advantages and risks associated with FOSS were also discussed, as well as related works. In this chapter, the researcher focuses on the research methodology and methods used. The research design and software testing are also discussed.

3.2 RESEARCH METHODOLOGY

According to Kothari (2004), research in common terms means “... a search for knowledge.” He further defines research as a “... scientific and systematic search for pertinent information on a specific topic.” Research methodology, however, means the study of how the researcher is going to conduct the research. The procedures that the researcher will use in order describe, predict and explain occurrences. The goal of research methodology is therefore to provide the plan for the research that will be conducted. There are two basic approaches to research, namely qualitative and quantitative (Rajasekar et al., 2006).

Qualitative research. Qualitative research concentrates on occurrences that encompass quality. The aim of this type of research is to acquire the meaning and sense and to define the situation. The features that describe qualitative research are

a. non-numerical,
b. descriptive and explanatory,
c. applies words,
d. uses reasoning, and
e. cannot be graphed.

Quantitative research. Quantitative research measures how much of an entity exists and is defined according to quantities. The outcome of this type of research is basically a "set of numbers". The features of this type of research are

a. it is numerical,
b. non-descriptive,
c. it applies statistics and uses numbers,
d. evidence is evaluated,
e. the results are frequently offered as tables or graphs,
f. it is conclusive, and
g. it often starts with data collection (Rajasekar et al., 2006).

The one approach can complement the other and they do not need to be mutually exclusive. Some researchers mix the two approaches, and this is known as the mixed method research (Bergman, 2008). For this particular research, qualitative research methods were used to collect data and analyse it.

3.3 RESEARCH DESIGN

A research design must be formulated in order to conduct scientific research. The research design will lay the foundation for the whole research study. The research design must specify the different approaches used to solve the research problem, the time needed to conduct the research as well as the cost implications. The research design will therefore link the research methodology of a research approach to research methods. It will help to solve the problem effortlessly and orderly (Rajasekar et al., 2006).

In this study, the researcher used methods that were explicitly applied to collect data and that coherently addressed the research problem. The use of a qualitative research approach assisted the researcher in analysing and interpreting the data collected in order to achieve the research aim. Pragmatism is applied to qualitative methods research. The data used for this study were collected in a specific manner (systematically and empirically) by doing set pre-selected computer software tests.

The research methodology used during this study allowed the researcher to indicate the selection of GIS functions to be tested according to operational GIS tasks as performed by the SANDF. These software functions were identified by the literature study. The "use case" assisted the researcher in testing these functions that are performed by both ArcGIS and QGIS software products. The design of the use case is presented below in paragraph 3.5. This study has four stages, as set out below.

a. <u>Stage 1 – Identifying test criteria and corresponding functionalities</u>: During Stage 1, the GIS functions to be tested by using both ArcGIS and QGIS software were identified. The literature study as well as the use case (see paragraph 3.5) allowed the researcher to identify the GIS functionalities that needed to be tested by using the specified proprietary and open source software. Two additional criteria were identified as a requirement for comparison purposes, namely user-friendliness and costs. These three test criteria and corresponding test components are specified in Table 3.1.
b. <u>Stage 2 – Determining and developing tests</u>: During Stage 2, the types of tests necessary to assess the functions identified at Stage 1 were determined and developed. Tests were developed to be performed using both ArcGIS and QGIS software for comparative purposes.
c. <u>Stage 3 – Conducting GIS functionality tests</u>: This stage consisted of conducting the tests developed during Stage 2. These tests served the purpose of qualitatively performing a comparative study between ArcGIS and QGIS software. This comparison was performed for the purpose of testing the GIS functionalities predetermined during Stage 2.

d. Stage 4 – Comparative study regarding user-friendliness and costs: During Stage 4, a comparative study was performed regarding the user-friendliness and costs criteria as indicated in Table 3.1.

Table 3.1: Three main criteria for comparing ArcGIS and QGIS software

CRITERIA	DESCRIPTION OF TEST COMPONENTS
GIS functions (according to specifications of the use case)	The use case (see paragraph 3.5) was used to identify functions to be performed on ArcGIS and QGIS. These functions are as follows: • buffering an area of operations; • hot spot analysis; • terrain analysis – hillshade; • creating a flood layer; • visibility layer (in order to indicate quality of radio communications); and • map showing locations/deployments, namely - determine helicopter landing zones (HLZs), - placement of hospitals/medical post/HQ, - nearest hospitals and police stations, - placement of roadblocks, - nearest airport (a search was done; there are no airports in the area of operations), and - placement of SAAEF water purification plants – this layer will also require a slope analysis.
User-friendliness (see paragraph 1.4.1)	The user-friendliness of both ArcGIS and QGIS was evaluated in terms of a list of criteria identified during the literature study (see paragraph 1.4.1). Test components for user-friendliness are • simple to install, • easy to update, • intuitive, • efficient, • pleasant, easy-to-navigate GUI, • easy to remove, • does not need third-party software, • easy to troubleshoot, • adheres to standards, and • effective error handling.
Costs	The costs of both ArcGIS and QGIS were evaluated in terms of the use case specifications (see paragraph 3.5). Test components for costs are • acquiring of license, • extensions, • training, and • software support.

3.3.1 Study area

For the successful completion of this study, numerous GIS tasks were performed, such as flood modelling and "hot spot analysis", among others. The Pilanesberg area, situated in the North West province of South Africa, was purposely and intentionally selected as the study area because of the following reasons:

a. the area consists of both mountainous as well as flat areas that were needed to conduct various GIS functions; and
b. sufficient digital elevation and image data covered this area.

3.4 DATA ACQUISITION AND COLLECTION

GIS data for this study were acquired from the National Geo-spatial Information (NGI), a component of the Department of Rural Development and Land Reform (DRDLR), as well as from TOMTOM South Africa. The primary data collected for this study (paragraph 3.4.1) include vector data, an image and a DEM covering the specified study area. A software user acceptance test (UAT) was performed during this study to collect data by performing specific software tests identified by the use case. These tests are described below in paragraph 3.6.

The UAT used (Appendix A) specifies all detail of the procedures followed during the software testing and the specifications applied to the tests performed. The UAT template was acquired from Softwaretestinghelp.com (2015) and was modified and adapted specifically for this study. The functions identified and tested included a variety of advanced GIS functions that were necessary to solve the use case. The primary data acquired for this study were used to perform the software tests on both the specified GIS, ArcGIS 10.2 and QGIS 2.8.5 Wien (see Figures 3.1 and 3.2 below). The GUIs of both software products are customisable and therefore it must be noted that the screenshots shown below were set according to the researcher's preferences.

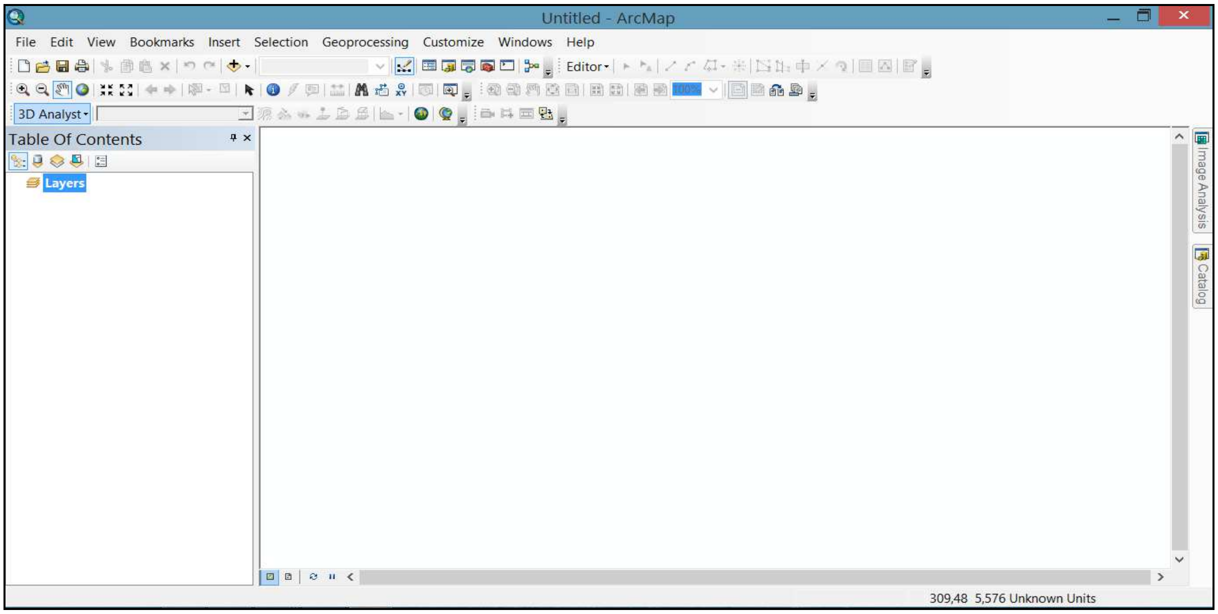

Figure 3.1: ArcMap GUI

The GUIs of the two software products have a comparable “look” and “feel”. They both have a smaller left-hand pane (where layers are listed) and a bigger right-hand pane (where data are displayed).

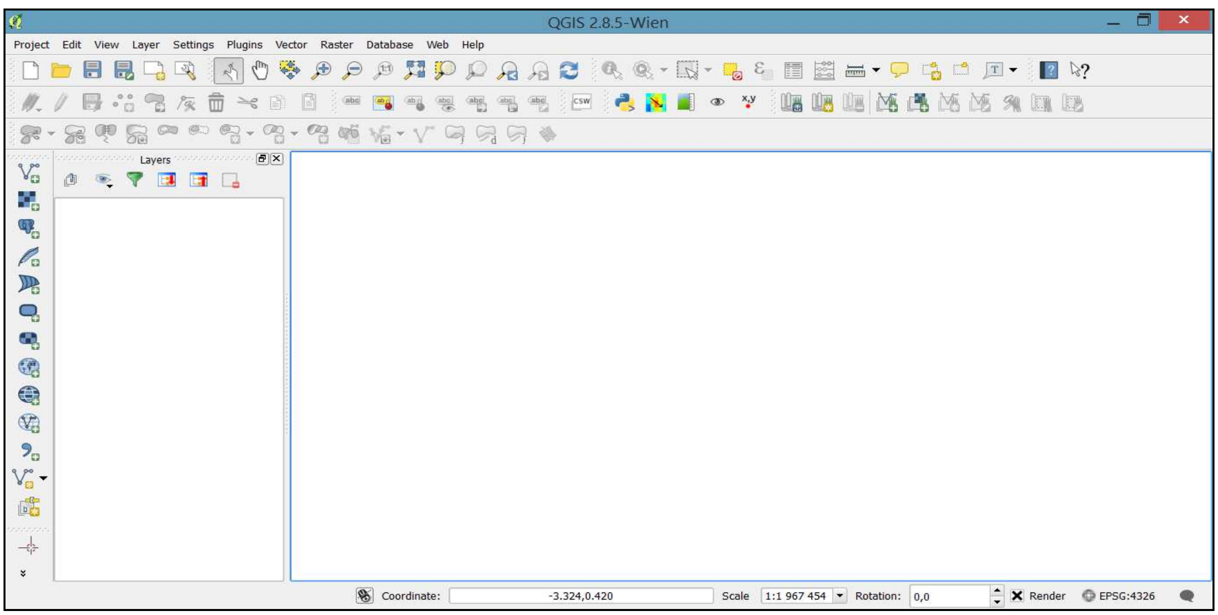

Figure 3.2: QGIS desktop GUI

All software tests were performed using the same hardware – an Acer Aspire V 11 Touch notebook with an Intel Pentium quad core processor, 4 GB memory. The operating system used was Windows 8.1 Single Language. The software tests produced the secondary data that were processed and analysed in a qualitative research approach. These results were descriptively analysed and evaluated.

3.4.1 Data types used during this study

The data sources necessary to complete all geospatial tasks are listed below. The file names presented in all map products and screenshots are indicated in brackets in italics.

a. Vector data: A clipped vector data set that includes roads (*roads_utm*), river lines (*rivers_utm*), railway lines (*railway_utm*), water areas (*water_areas_utm*), built-up area (*built-up_utm*) and points of interest (*poi_utm*).
b. Raster data: A subset of the SPOT6 image (*spot6_pilansberg_subset_proj.jp2*) as well as 1:50 000 topographical maps (*topo_2527_1996_mosaic_proj*).
c. Elevation data: The elevation source used was a 20 m DEM in GeoTIFF format (*pilansberg_20m_dem_subset_proj*).

TOMTOM supplied the vector data as well as the 20 m DEM covering the study area on 11 January 2016 (See Appendix B for the attached letter of request). The SPOT6 image and the topographical raster data were received from National Geo-spatial Information (NGI), a component of Department of Rural Development and Land Reform (DRDLR) on 06 November 2015. The researcher defined all the study data to WGS84/UTM grid zone 35S.

3.5 DESIGN OF THE USE CASE: CHOLERA OUTBREAK IN THE PILANESBERG AREA

Even though the scenario is an artificial example, it draws on potential military operations in response to disaster relief. It also does not expose any personal details about any real Cholera sufferers. After consultation with commanders involved at different levels and roles in operations (A.F. Van Niekerk 2015, personal communication, 04 September, A.C. Wylie 2015, personal communication, 05 October, J.D. Venter 2015, personal communication, 09 October), a use case was developed (Bittner, 2002; Bramble et al., 2002). This use case describes a military operational scenario in order to test both ArcGIS and QGIS' capabilities and functionalities to execute and produce SANDF-required geospatial tasks and products. This scenario describes a health risk disaster in the form of a Cholera outbreak (Zuckerman et al., 2007) in the Pilanesberg area of South Africa. Cholera is a highly infectious disease that still affects many parts of Africa, as well as other parts of the world, such as South Asia and Latin America. The disease is caused by drinking or eating contaminated water or food. It is often found in areas with "poor sanitation, crowding, war and famine". If left untreated, it can result in death (WebMD, 2016). The Minister of Health tasked the SANDF to assist in controlling this outbreak, since the SANDF is the only national entity with a medical deployment unit capability. The use case reads as follows:

The Ministry of Health requested the SANDF to assist in curbing the outbreak of Cholera in the rural population of the Pilanesberg area, North-West province, South Africa. The Chief of the SANDF tasked Chief Joint Operations (CJ Ops) to establish an operation room in the disaster management centre and to deploy the following forces to manage and control this health disaster:

a. the SAMHS were tasked to set up a medical post;
b. two Infantry Companies (Inf Coy's) responsible for barricading and securing the contaminated area;
c. one SA Army Engineer Squadron (SAAEF Sqn) consisting of a water purification unit. The SAAEF Sqn will be responsible for purifying the contaminated water.

In order for the SANDF to assist, the following geospatial tasks were required from the GIS commander:

a. The individual households reported as households with Cholera were digitised by using the Spot 6 image as backdrop in order to zoom in on the residential areas. The commander then wanted an area of 10 km around it to be demarcated, since this will be the "area of operations".
b. The high-risk Cholera areas in the Pilanesberg must be indicated. The key hot spot areas should be determined. It is required to produce a GIS Hot Spot analysis layer indicating these areas.
c. The commander of the operation must know the terrain in his area of operations. It is therefore required that a layer showing "hillshading" be made in order to show the mountainous areas in relation to the rest of the area.
d. One of the factors that influences the spread of Cholera is a very heavy rain season, which was the case in this region. It is required to produce a flood simulation layer in order to anticipate the influence on the spread of the Cholera should the water level increase.

e. *An important aspect during any military operation is communications. The GIS commander will be tasked to show areas of visibility from the identified HQ position in respect of the rest of the area of operations in order to determine line-of-sight visibility for radio communications.*

f. *A layer indicating locations of helicopter landing zones must also be created (HLZs). Firstly, existing helipads will be identified; secondly, additional suitable HLZs must be added to the layer.*

g. *An area where a possible medical treatment centre can be placed should be established in order to task the Medical Task Team. It is required to produce a layer indicating the most suitable location to deploy this medical post and to show other existing hospitals in the area of operations.*

h. *The commander also needs to know the locations of the closest police stations.*

i. *The infantry commander needs to show his members where to place their roadblocks.*

j. *A safe water supply for the rural population of the Pilanesberg has to be ensured. It is required to produce a layer indicating the most suitable place to deploy the SAAEF water purification plants. In order to indicate the suitable location of the water purification plants, a slope analysis must be done.*

3.6 DATA ANALYSIS

Data analysis was performed on the results acquired by executing Stage 3 of this study, as described in paragraph 3.3. Each criteria identified had corresponding components that were tested by using both the ArcGIS and QGIS software (see Table 3.1). Data were analysed in a descriptive and analytical manner. The questions posed in paragraph 1.5.3 were used as measuring components to analyse the success or failure of the test results. Data analysis was performed as set out below.

Step 1 – Analysing GIS functions. The Step 1 tests were performed to test the GIS functions as described in Table 3.1. Various test components were evaluated to produce military-specific GIS products produced by both the ArcGIS and QGIS software. The results achieved from these test components were each individually analysed and compared to the corresponding results achieved from using both the ArcGIS and QGIS software. The following GIS products had to be produced:

a. buffering an area of operations;

b. hotspot analysis;

c. creating flood layers;

d. visibility layer; and

e. location indicator layers.

Step 2 – Analysing user-friendliness. Step 2 consisted of analysing the user-friendliness of both software products. The user-friendliness of each software product was independently tested by performing various component tests that were identified in Table 3.1. The results achieved from performing these component tests were qualitatively analysed and described to determine the user-friendliness of each software product. The researcher personal evaluated the user-friendliness without involving a group of researchers.

Step 3 – Analysing costs. Step 3 entailed the analysis of the operating costs factor of each of the prescribed software products. Costs were independently tested and analysed in terms of the four components identified in Table 3.1.

3.7 LIMITATIONS OF THE STUDY

A limitation of this study is that it does not formally assess the general attitude towards FOSS, since it is beyond the scope of this study. In addition, not all GIS functionalities in the SANDF will be assessed – the reasons for this were discussed in Chapter 2. The GIS operational functionalities that were tested are therefore limited to those prescribed in the specific use case.

Another limitation is not testing the effectiveness of the GIS software to handle large volume data sets. The data sets used during this study were subset clips of the study area. The manner in which these GIS software products will respond to large volume data sets was thus not tested.

User-friendliness was based on the researcher’s subjective experience.

As explained in paragraph 1.4.1, only two software products were compared in this study. Therefore another identified limitation is the fact that only two software products were compared in this study.

This study was performed in the researcher's home environment using a single laptop with a Microsoft Windows 8.1 operating system. It is yet another limitation, since the study was not executed in a real operational environment where other operational challenges might exist, such as various workstations with different operating systems.

3.8 CHAPTER SUMMARY

In this chapter, the researcher discussed the research methodology used during the study. Qualitative research methods were used to collect data from performing various components tests and to analyse that data. These component tests were determined to be the essential elements of the identified criteria types, namely GIS functions, the user-friendliness and the costs of the software products. The researcher descriptively analysed, contextualised and personally interpreted all data collected. The next chapter comprises the various tests performed, the results obtained and the analysis of the data results.

CHAPTER 4: EMPIRICAL RESEARCH: ANALYSIS AND DISCUSSION OF RESULTS

4.1 INTRODUCTION

In this chapter, the researcher focuses on reporting the results of the software functions that were evaluated by using the QGIS and ArcGIS software, as well as the comparison of the user-friendliness and costs. First, each functional test result was separately evaluated and then analysed comparatively in relation to the two software products (ArcGIS and QGIS) in order to assess its suitability for use in the military during the operations specified in the use case. Thereafter, ArcGIS and QGIS were critically compared with regard to the specified criteria in order to analyse user-friendliness and costs.

4.2 TESTING GIS FUNCTIONALITIES

As stated earlier, a use case was developed to test certain operational GIS products' feasibility to be used at the operational level by the GIS commander (see Chapter 3, table 3.1 and paragraph 3.5). The tests described were independently performed by using both ArcGIS and QGIS software. The results obtained from using both these software products were discussed and descriptively analysed. The preconditions, input parameters used and steps followed for performing each test were included in the user acceptance test plan that is attached to this study as Appendix A. A comparative analysis was done after each test has been performed and the results obtained.

4.2.1 Test 1: Buffering an area of operations

Buffering is a very common and often used analysis tool. GIS commanders often employ it during operations, since it involves proximity analysis around points, lines or areas. The commander wanted an area of 10 km surrounding the reported Cholera cases to be demarcated as the "area of operations". Before building this buffer (*Buf_ops_area*), the individual Cholera cases were randomly selected and digitised as a point shapefile (*Cholera_households*). The Spot 6 image was used as a background in order to zoom in on the residential areas and to capture households that were identified as suffering from Cholera. See Appendix A, paragraph 10.1.1 for details of this test procedure.

4.2.1.1 ArcGIS test 1 results: buffering

Buffering is one of the standard geoprocessing tools in ArcMap. The process is relatively simple as long as the user specifies the correct unit of measurement. The fact that one can choose the unit of measurement by way of a drop-down list in ArcGIS is one of its "advantages", since known and familiar units of measurement (for example metres, kilometres and nautical miles, among others) can be selected to create the desired product, as opposed to working with unknown units. In ArcGIS, even the unexperienced GIS user can create a buffer, seeing that ArcGIS will correctly generate the buffer, even if the data used is not in a projected coordinate system. The buffering result obtained by ArcGIS is illustrated in Figure 4.1.

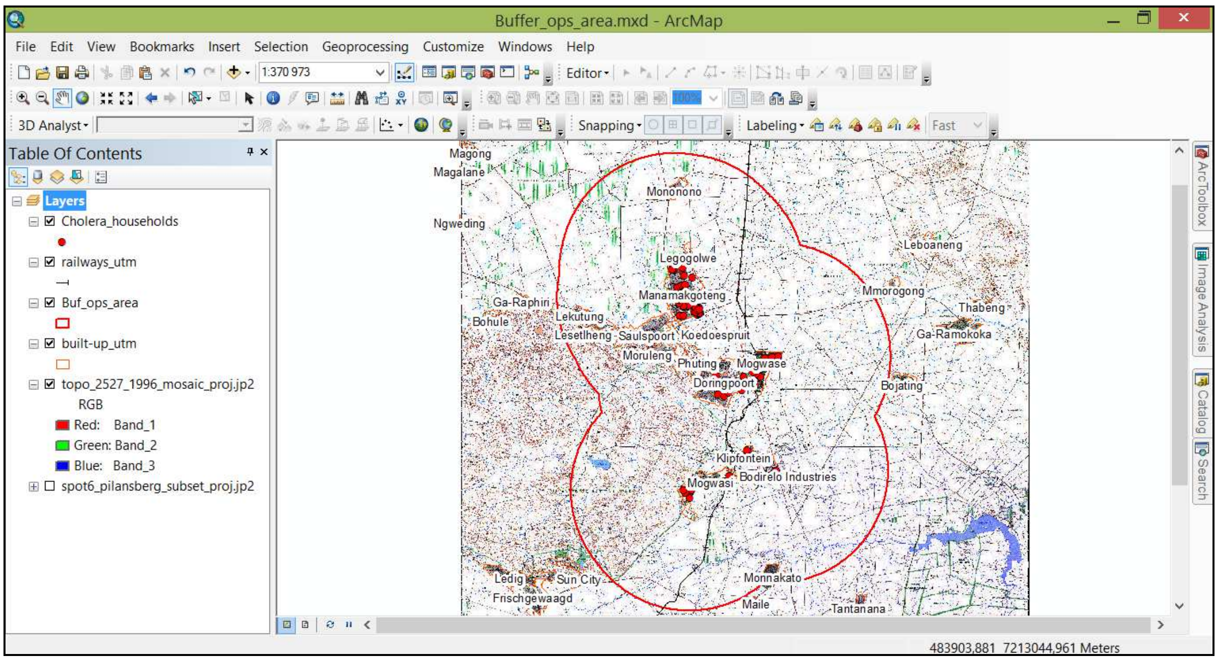

Figure 4.1: Buffering result obtained – ArcGIS

4.2.1.2 QGIS test 1 results: buffering

Buffering is also one of the standard geoprocessing tools in QGIS. Although the process itself is very similar to that in ArcMap, the GIS user will have to take note of the fact that the buffer process will not work correctly in QGIS if the data used are not in a projected coordinate system. The user will also not be able to specify the unit of measurement like in the ArcGIS software, and must therefore have a basic knowledge of coordinate systems and measurements. The user has to know what the QGIS settings are. As UTM was used, all measurements are in meters. The user should also take note of the fact that if he/she prefers the edge or outline of the buffer to appear smooth, the “segments to approximate” field should not be left at the default value of 5. For this specific use case, a value of 99 was selected. This is the maximum value that can be used. This number delivers the smoothest outline and one that is closest in appearance and area size to the product that was delivered by using ArcGIS. This result is illustrated in Figure 4.2.

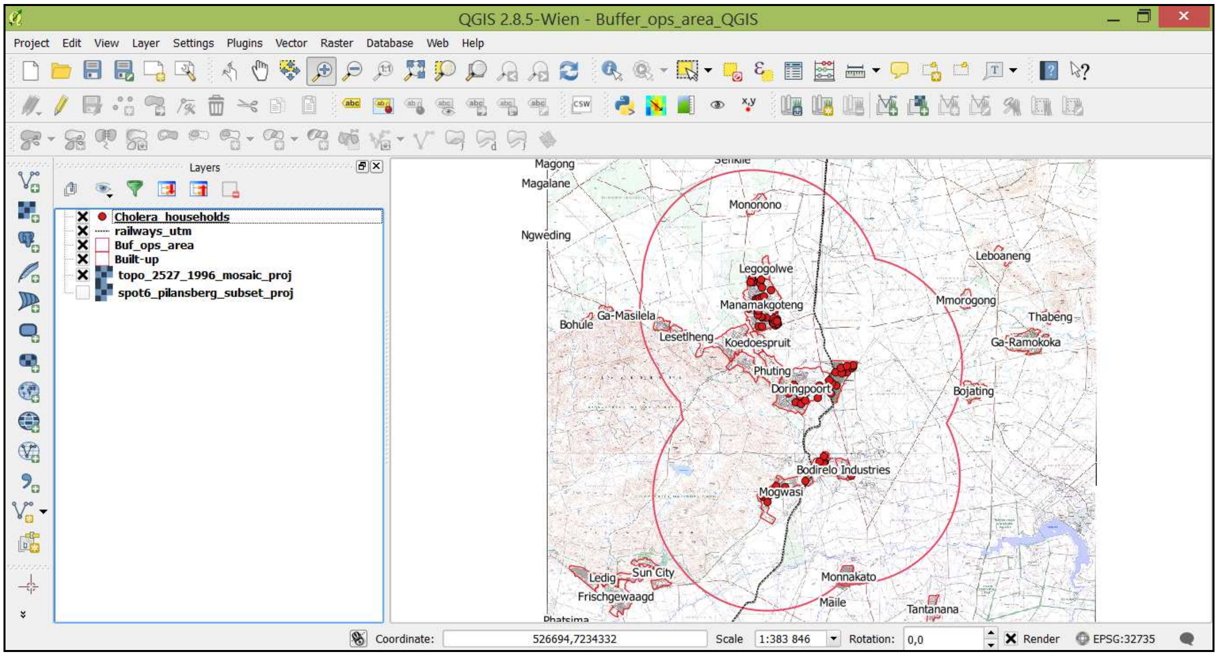

Figure 4.2: Buffering result obtained – QGIS

4.2.1.3 Analyses of test 1 results

The results obtained when using both systems were satisfactory. Both software products obtained a very similar result and would have satisfied the operational request as stated in the use case. Figure 4.3 illustrates the results that were obtained from both software products. The results were overlaid and it was found to be an exact match. The two buffer layers were given different colours, and the fill in ArcGIS was made transparent to see the QGIS result. The QGIS result was given a green fill colour.

In order for the GIS operator to successfully complete the buffering process in QGIS, he/she will need to have a basic understanding of coordinate reference systems (see paragraph 4.2.1.2). This will assist GIS operators in comprehending why the buffer will only be successful once the data are projected. This is not needed in ArcGIS.

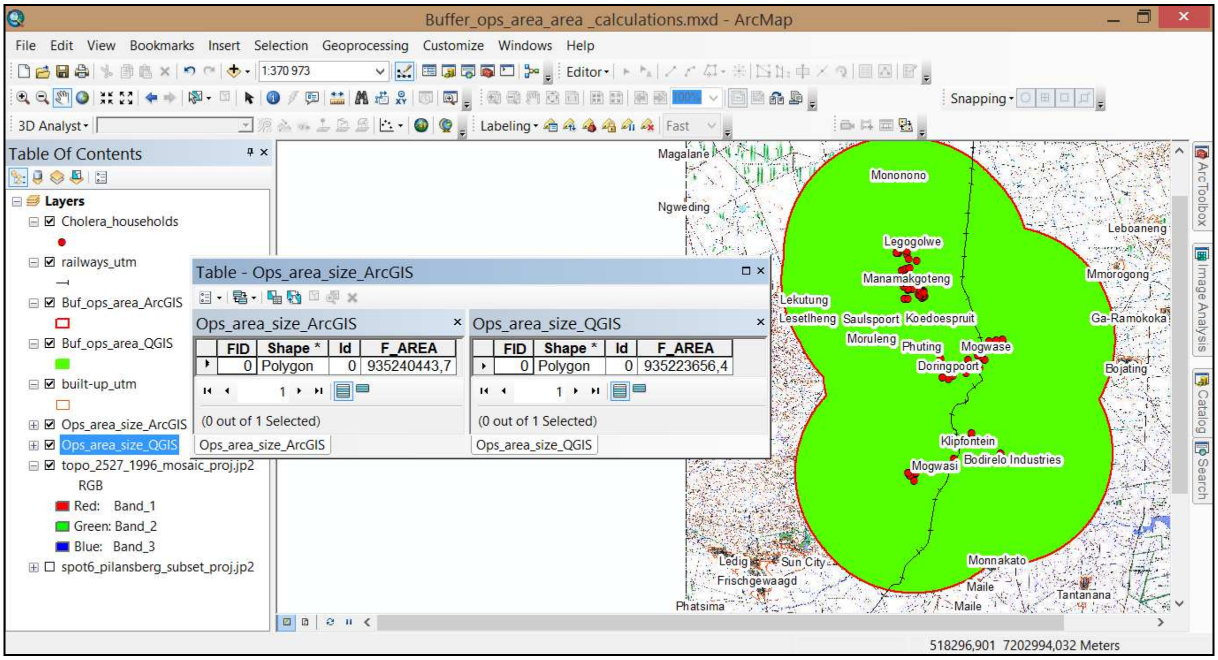

Figure 4.3: Buffering results overlay

4.2.2 Test 2: Cholera hotspot analysis

One of SAMHS' tasks is the categorisation of patients based on a set of evaluations in order to determine priorities for emergency evacuation and treatment. This process may change continuously, in view of the fact that the condition with regard to casualties can improve, worsen or spread to other areas. The SAMHS commander must constantly be informed of which areas in the operational area take priority. The hotspot analysis can therefore serve as an extremely valuable tool (Lin et al., 2010) in order to assist the commander when doing operational planning and in determining areas for the deployment of SAMHS treatment centres. Therefore the GIS commander must be able to show the operational commander the high-risk Cholera areas in the area of operations. A "hotspot" analysis is therefore vital. This analysis will allow the commander to see which areas have a higher than average incidence of Cholera.

According to Chainey et al. (2008), "hot spot mapping is a popular analytical technique …" A number of different techniques are used for the identification of hot spots, including, among others, Kernel Density Estimation, point mapping and grid thematic mapping. Kernel Density Estimation (KDE) was used for this particular Cholera hot spot project. This analysis computes the density of features in a neighbourhood of cells around those features. In this test, hot spots were calculated for point features; however, it can also be used for line features. The density value is highest at the location of the point (the reported Cholera household) and it reaches zero at the search radius furthest from that specific point. The search radius was specified at 1 500 m for this test. The default unit of measurement used by the tool is based on the input feature's projection definition. The input unit that was used in this case was meters and therefore the output area unit defaulted to square kilometres. See Appendix A, paragraph 10.1.2 for details of this test procedure.

4.2.2.1 ArcGIS test 2 results: hot spot analysis

As stated above, the "Kernel Density" tool was used in ArcMap in order to perform the hot spot analysis. Kernel Density is one of the tools available in the "Spatial Analyst" extension in ArcMap. It was found that in order to obtain the best results with this particular tool in ArcMap (see Figure 4.4), the environment settings must be set before performing the analysis (see Appendix A, paragraph 10.1.2 for environment setting parameters). The processing extent was set to "same as display". If this is not done, the hot spot display will be incomplete in some places. In order to further enhance the visual effect of the analysis results, the first class colour was set to "no colour". If the first value or class is not set to "no colour", the background data that must provide the military commander with a frame of reference is covered. It is important to note that in ArcMap the kernel function is based on the quadratic kernel function.

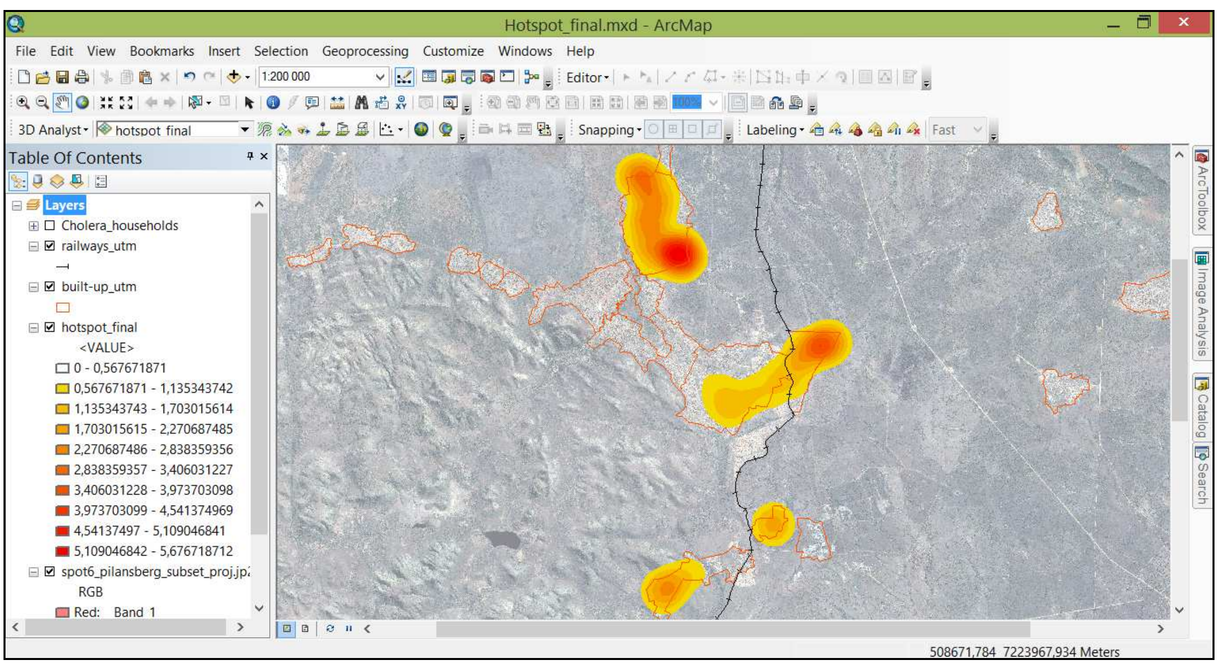

Figure 4.4: Hot spot analysis result obtained – ArcGIS

4.2.2.2 QGIS test 2 results: hot spot analysis

The “Heatmap” plugin was downloaded in order to perform the hot spot analysis in QGIS. This plugin uses Kernel Density Estimation in order to create a density raster (“heatmap”) of an input point layer. The Quartic (biweight) function was specified as the kernel function in QGIS. There are also other Kernel shapes to choose from in QGIS like the triangular, uniform, triweight and the Epanechnikov kernels. It is important to note that the initial output product will appear as a black and white (single band greyscale) raster image. The properties of this raster layer must then be changed to a single band pseudocolor and classified by using the equal intervals method according to the number of classes that the user requires (see Figure 4.5). Ten classes were used, as in the ArcGIS test, and the first class’ colour was also set to “no colour”, which was the same as in the ArcGIS test.

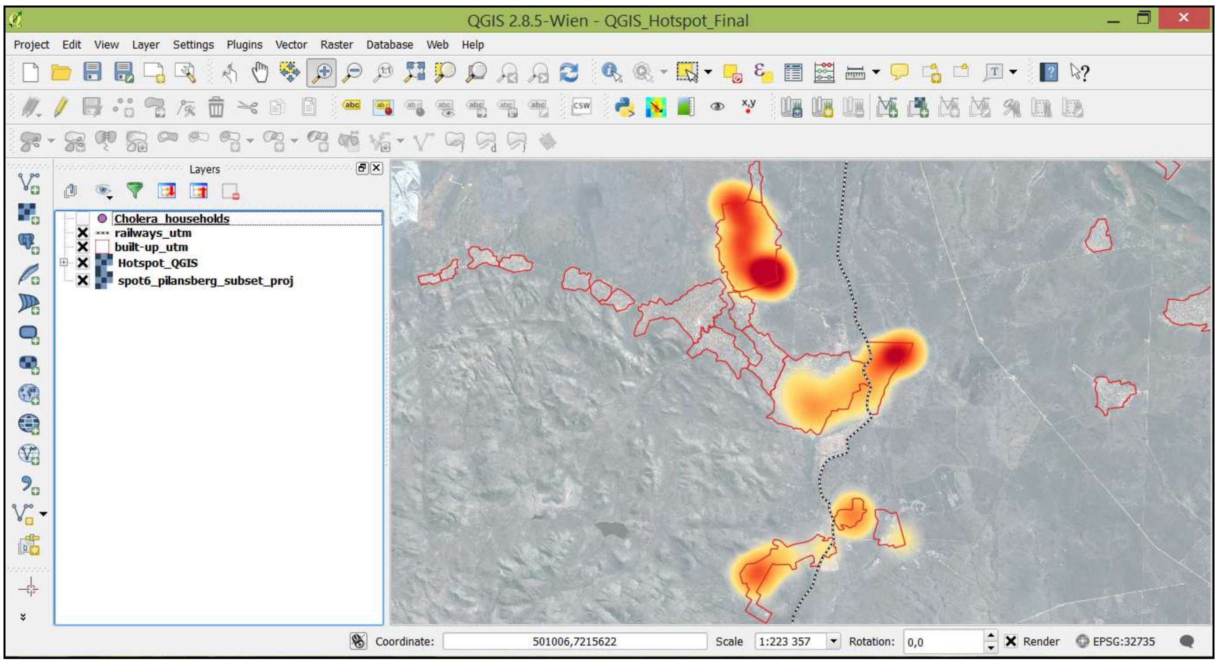

Figure 4.5: Hot spot analysis result obtained – QGIS

4.2.2.3 Analyses of test 2 results

The Cholera hot spot analysis could be completed successfully in both ArcGIS and QGIS. Although there is a difference (see Figure 4.6) in the manner in which hot spot results were displayed in the two software products, both results are suitable for determining priorities for emergency evacuation, among others. It is, however, interesting to note the reasons for the difference in these results, since a Kernel Density analysis was done in both software product tests. In QGIS, more areas are included in the analysis result. In ArcGIS, the KDE is based on the quadratic kernel function, and in QGIS the researcher chose the Quartic (biweight) function/shape. In an e-mail conversation on 03 March 2016, J.S. Evans suggested that this has to do with the degree of polynomial in each KDE function. According to Evans (2016), a quartic kernel is fourth order polynomial whereas a quadratic can, theoretically, take any form, but generally represents a lower order (second) polynomial. As in trend functions, lower order polynomials will not pick up as much localised detail given the same bandwidth parameters.

The results from both systems will give the commander the ability to see areas of higher density of Cholera. The researcher experimented with the radius as well as displaying colours in order to obtain the best results from both systems.

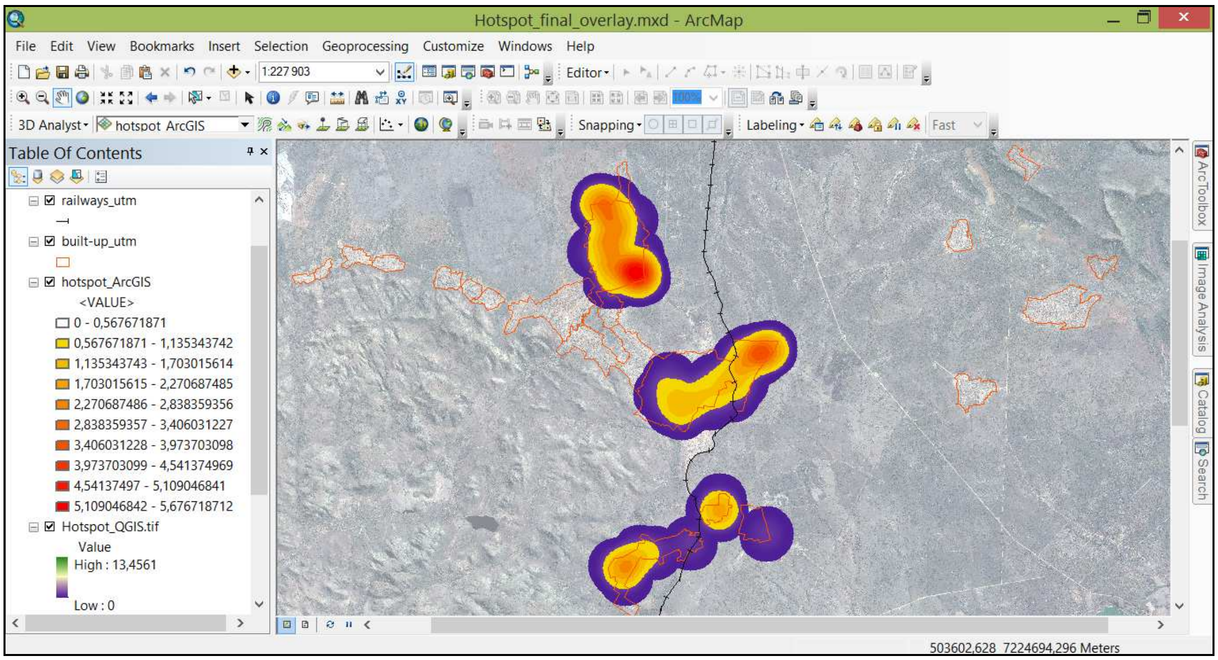

Figure 4.6: Hot spot analysis results overlay

4.2.3 Test 3: Hillshade analysis

It is pivotal for the commander of the operation to be knowledgeable about the terrain in the area of operations. Terrain analysis assists the commander in developing the operational plan. This includes aspects such as navigation and planning for logistical requirements, for example selecting vehicles that are suitable for the specific terrain. The requirement would therefore be to provide the commander with a three-dimensional (3D) view of the operational area. Using the DEM to produce the Hillshade layer allows for a 3D illustration of the terrain. Such a layer will illustrate the mountainous areas in relation to the rest of the terrain surroundings by taking into account the illumination source angle and shadows. See Appendix A (paragraph 10.1.3) for details of this test procedure.

To execute test 3, the azimuth was set to 315° and the altitude to 45°. The azimuth and altitude are the angles of the light source. The azimuth is expressed in positive degrees from 0 to 360, measured clockwise from north. Altitude is the angle of the light source above the horizon, which is also expressed in positive degrees with 0° at the horizon and 90° directly overhead. The Z factor was left as 1. The rule is that if the x, y and z units are in the same units of measure, the z factor is 1.

4.2.3.1 ArcGIS test 3 results: Hillshade analysis

In ArcMap, the “Hillshade” tool is one of the surface tools in the “Spatial Analyst” extension. The azimuth and altitude values mentioned in paragraph 4.2.3 are the default values in ArcMap. The result is illustrated in Figure 4.7

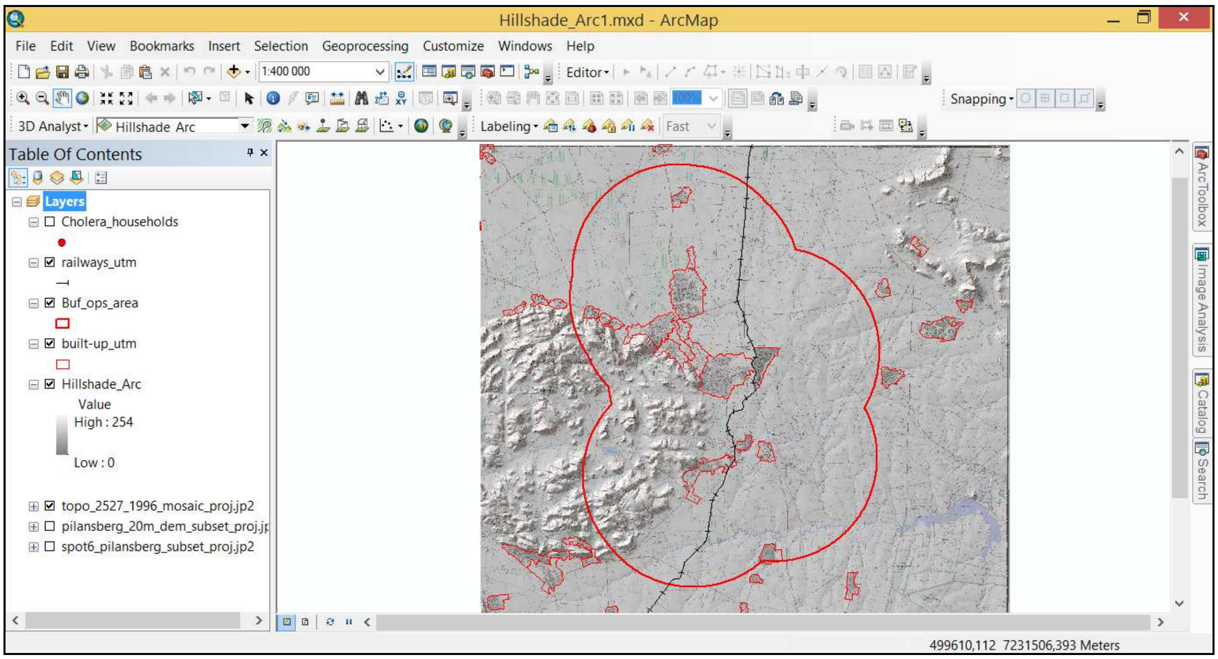

Figure 4.7: Hillshade analysis result obtained – ArcGIS

4.2.3.2 QGIS test 3 results: Hillshade analysis

In QGIS, the “Hillshade” tool can be found under the “Raster” tab under “Terrain Analysis”. The same illumination source input parameters were used than in ArcGIS in order to achieve the same hillshade result (see Figure 4.8). The parameters ("Azimuth" and "Altitude") are similar to the ones described above in paragraph 4.2.3.

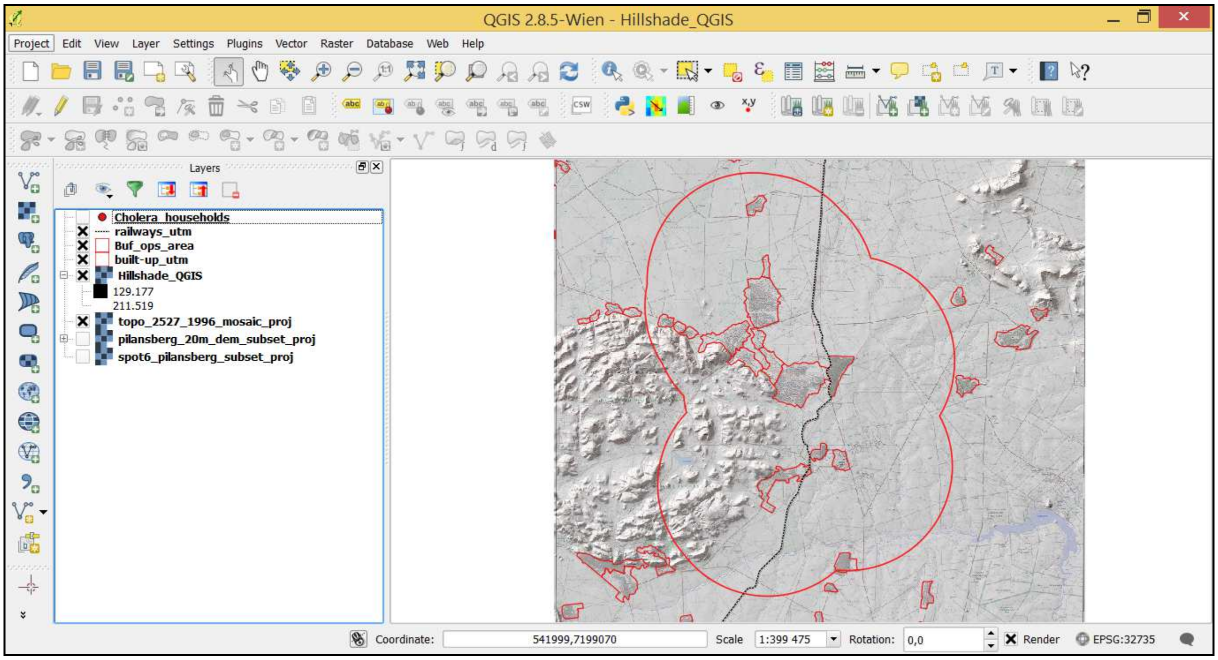

Figure 4.8: Hillshade analysis result obtained – QGIS

4.2.3.3 Analyses of test 3 results

The Hillshading processes in ArcGIS and QGIS are very similar. Both software products produced a Hillshade layer that is suitable for terrain analysis and that will assist the commander in developing his operational plan. Hillshade products are created to illustrate the amount of light being reflected by the topographical layout of the geographical region.

A pixel-to-pixel comparison was done between the ArcGIS and QGIS Hillshade results. It was determined that for all practical reasons the two products are the same. The permissible input parameters for the illumination source were the same and therefore similar output results were achieved. However, very small differences do exist (see Figure 4.9). These differences are so small that they are almost impossible to identify with the naked eye. These areas were therefore zoomed in on and are indicated by means of the red, blue and yellow circles (Figure 4.9). The comparison used the elevation source as a backdrop for orientation purposes. The pixel-to-pixel comparison shows "green areas" that indicate less than 1% decrease changes from the ArcGIS result to the QGIS result. The "red areas" indicate less than 1% increases. It is evident that the pixel value differences between these two software products are minimal, which is an indication that both these software products produces good Hillshading results that will be plausible for use during any military operation. The user can also experiment with the manner in which the Hillshade raster displays by changing the base layer and setting different transparencies. This will have the effect of displaying any underlying layer, for example a topographical map or satellite image. The advantage of changing the display is that it provides easy navigation reference to surrounding areas. This will once again assist the military commander when analysing the terrain.

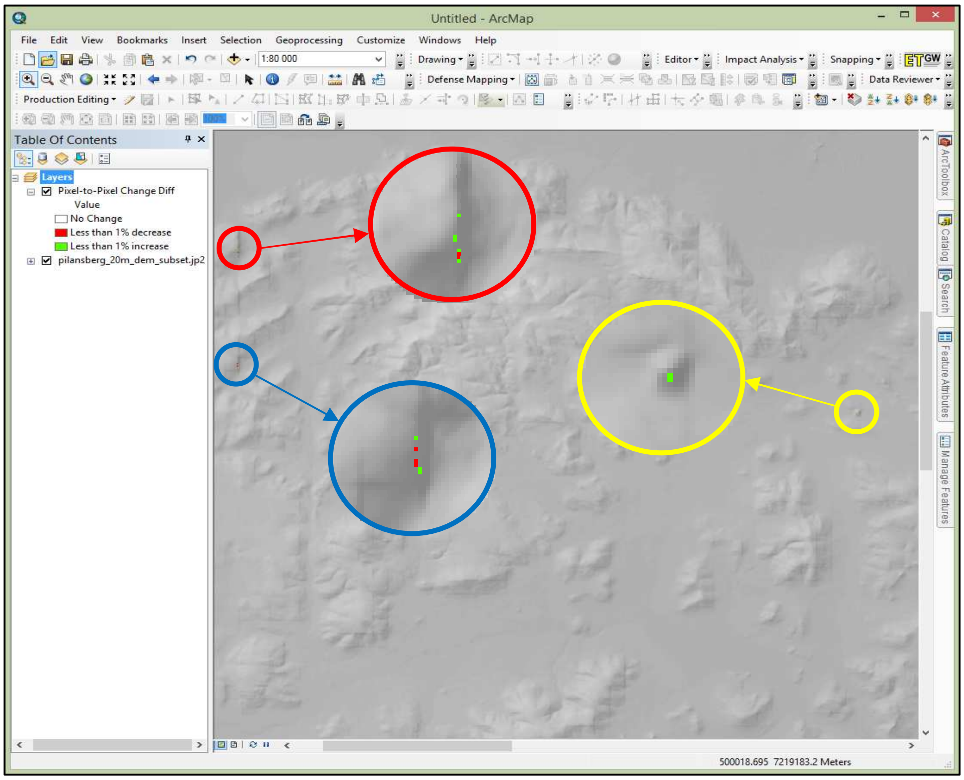

Figure 4.9: Hillshade analysis results comparison

4.2.4 Test 4: creating a flood layer using raster calculator

In this scenario, where Cholera is concerned, the commander will be interested to know the extent to which rivers, among other water sources, might rise in case of a flood. Since the spread of Cholera increases faster in heavy rains and floods (Lamond and Kinyanjui, 2012), the commander must be briefed on which areas will be affected when water levels rise. The “Raster Calculator” tool was used to make calculations based on the general height above sea level in the area of operations. The researcher acknowledges the use of other more sophisticated flood simulations and models. These simulations and models often use flood data, which will not always be available to the military GIS operator, especially when assisting with operations in Africa. To make the project more realistic, and since flood data are very often not available in situ, the researcher zoomed in on one of the rivers (Mogwase River) in the area of operations. Figure 4.10 illustrates the location of the Mogwase River in relation to the rest of the area of operations. A conditional statement was used to calculate values using the 20 m DEM that was received from TOMTOM SA (see paragraph 3.4.1). This method is a simplified flood model that can be used even when other flood data are not available. See Appendix A, paragraph 10.1.4 for details of this test procedure.

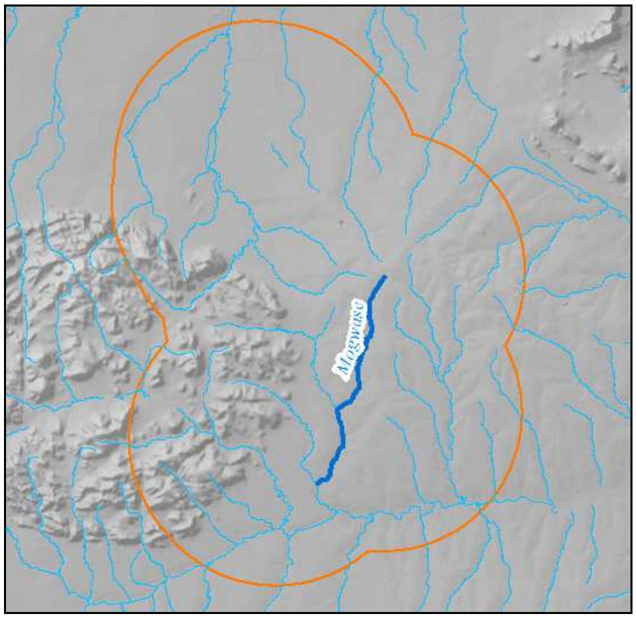

Figure 4.10: Mogwase river in relation to the rest of the area of operations

4.2.4.1 ArcGIS test 4 results: creating a flood layer using the raster calculator

The "Raster Calculator" tool was used in order to create flood layers for a small segment of the Mogwase River. The raster calculator can be found as one of the Map Algebra tools in the "Spatial Analyst" extension.

The researcher used the current height value (1 152 m) for the Mogwase River in the specific area that was zoomed in on. "Flood layers" were then made in order to indicate which specific areas will be flooded if the water level increased respectively to 1 153 m, 1 157 m and 1 160 m above mean sea level. These results (see Figure 4.11) were set to 70% transparency in order for the operational commander to still be able to see the topographical map as a backdrop.

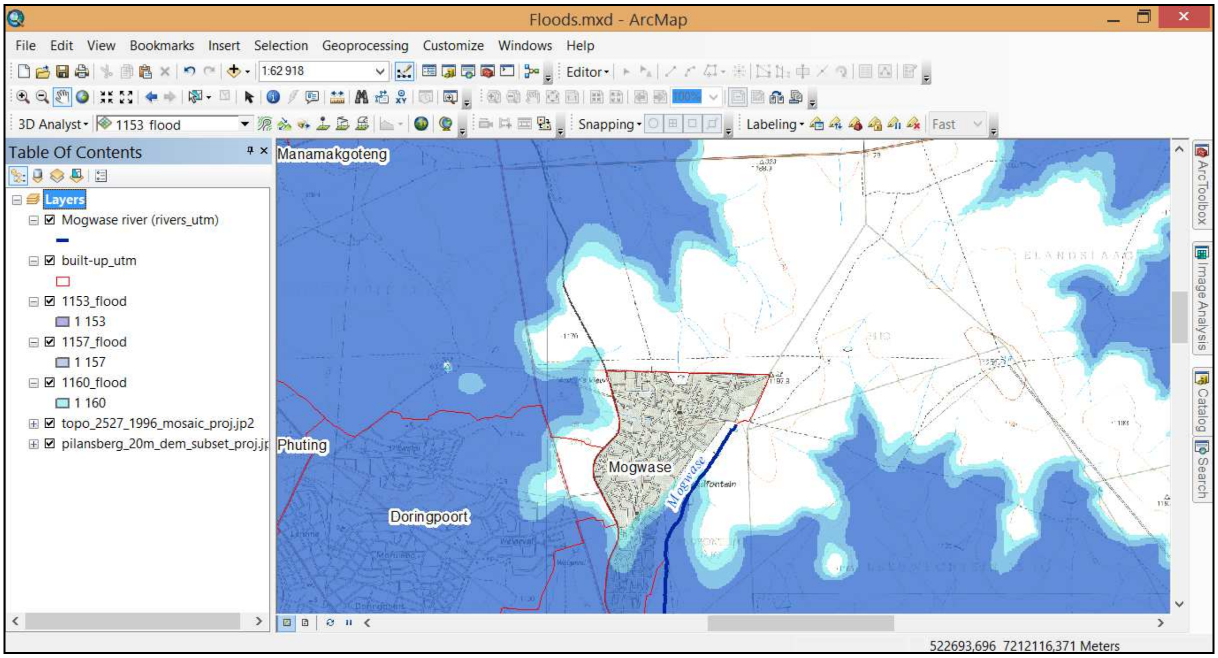

Figure 4.11: Creating a flood layer using the raster calculator result obtained – ArcGIS

4.2.4.2 QGIS test 4 results: creating a flood layer using the raster calculator

In QGIS, the raster calculator can be found under the “Raster” tab. The same input variables were used in QGIS than in ArcGIS. The mathematical expression might appear slightly different than that used in ArcGIS (see Appendix A, paragraph 10.1.4), but the results are the same. The initial results in QGIS appear as a single band greyscale image (see Figure 4.12).

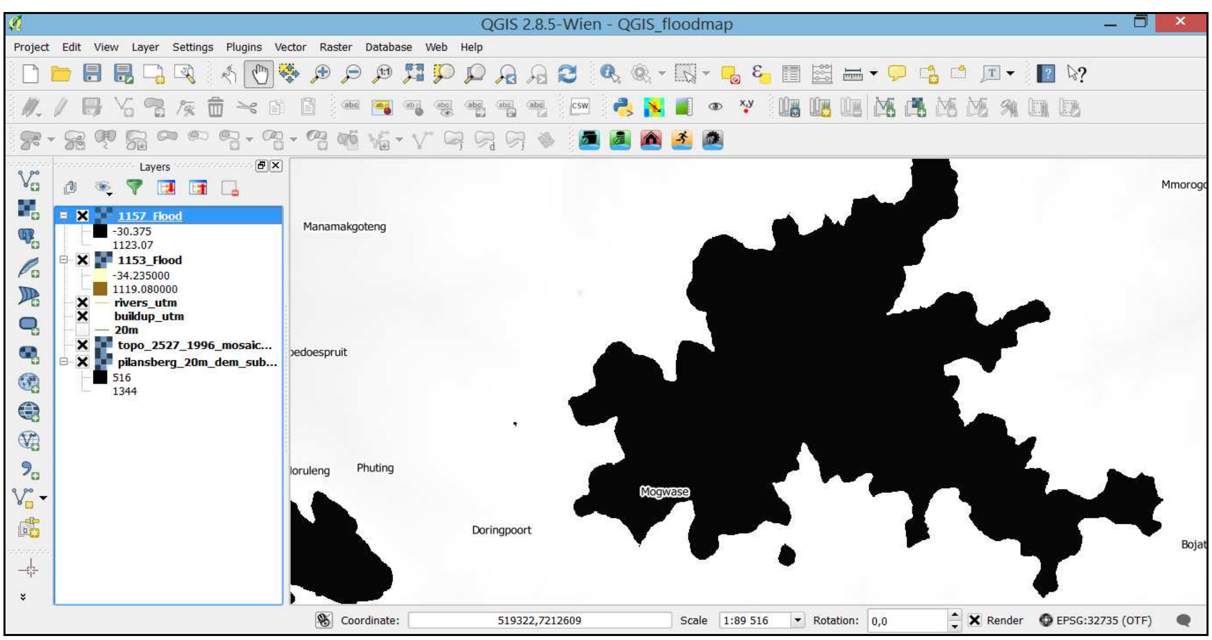

Figure 4.12: Initial flood layer appear as a single band greyscale image in QGIS

However, the properties of the layer can easily be changed and the colours can then be selected to produce the final flood layer, as is illustrated by Figure 4.13.

In Figure 4.13, the area is zoomed in on more than in Figure 4.12 in order to indicate a similar extent than was illustrated in ArcGIS (Figure 4.11). In addition, in Figure 4.12 the topographical data are not yet visible in the background, since changes to the properties of the resulting raster layer were not yet made to make it transparent.

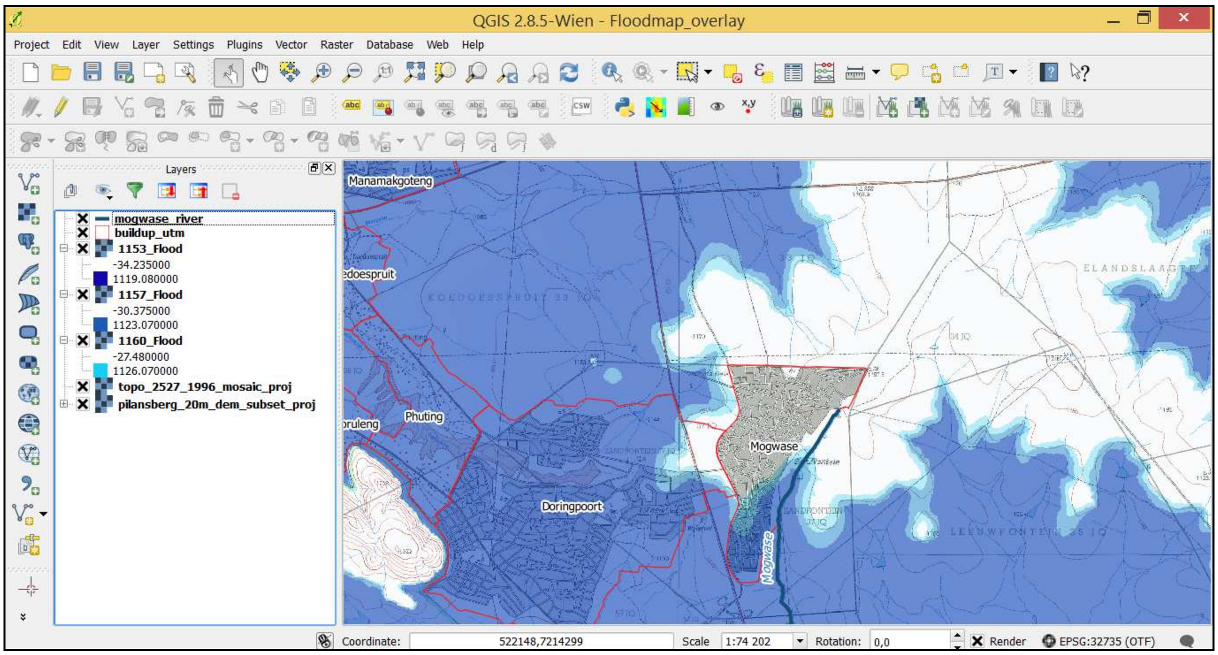

Figure 4.13: Flood layer using the raster calculator produced in QGIS

4.2.4.3 Analyses of test 4 results

Both software products obtained similar results, even though the expression for creating the flood layer looks slightly different in the two software products. Figure 4.14 illustrates these results. It is evident that the ArcGIS and QGIS software produced flood layers that are alike.

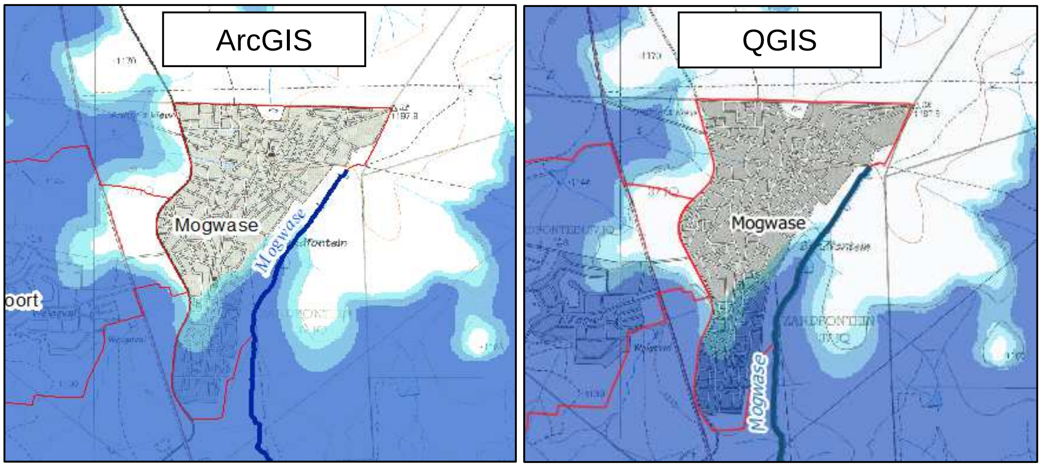

Figure 4.14: ArcGIS and QGIS flood layer comparison

However, there are minimal differences between the two results, which were expected, since different software products – each with their own parameters and expressions – were used to create the flood layers. These differences are illustrated in Figure 4.15, by means of examining each individual flood layer representing the various heights (that is, 1 153 m, 1 157 m and 1 160 m) created and overlaying the different software product results. For this illustration, the ArcGIS flood layers (light blue) were overlaid on top of the QGIS layers (dark blue). It is evident that in each case the QGIS flood layers are a little bigger than the ArcGIS layers, which is measured at an average difference of ~10 m. These differences are minor and barely visible, which is an indication that both software products produced similar satisfactory results.

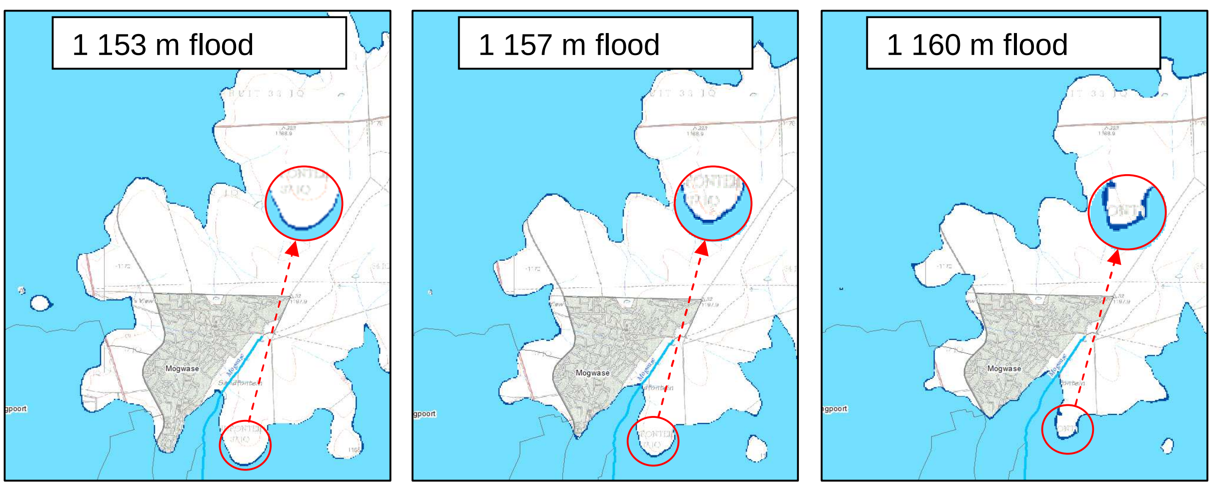

Figure 4.15: ArcGIS and QGIS individual flood layer comparison

The analyses of the test 4 results show that both the ArcGIS and QGIS software products produced comparable flood models. These results were expected, due to the fact that the same elevation source was used in both cases. Both these products will be suitable as a source of information to the commander for planning to prevent the spread of Cholera during heavy rains and floods. As a concluding note it should be mentioned that when producing these flood layers, the GIS operator will have to be a more advanced GIS user, since knowledge of rasters, bands and mathematical expressions are some of the functions required for flood modelling.

4.2.5 Test 5: Creating a visibility layer

Visibility analysis (Kim et al., 2004) is a vital and dynamic tool for the military. In this scenario, it was used to see whether radio communications would be possible in all operational areas away from the main HQ. The Madutle Primary School (*MadutleP_School*) was chosen as the ideal HQ position, due to the fact that it is in the centre of the Cholera outbreak, has all the necessary infrastructure that the SANDF needed and has a sport field that can possibly serve as a helicopter landing zone. This school was made a separate point layer, which was used as the “observer point” for the visibility analysis.

Radio communications work on the principle of “line-of-sight”; therefore areas with no visibility will have poor or no radio signal. In areas that the radio signal will not reach, relay stations should be deployed. In other military situations, the visibility analysis can also be used, for instance, to determine artillery observer positions and the extent to which the artillery observers will be able to see and gather intelligence (visible terrain for targets and plotting of enemy positions). The antenna height was specified at 10 m, and it should be noted that if the antenna height is too high, the antenna could become unstable and unpractical. The radius from the HQ was specified as 20 000 m. This is the radius distance from the HQ position from where the visibility analysis will be done. See Appendix A, paragraph 10.1.5 for details of this test procedure.

4.2.5.1 ArcGIS test 5 results: creating a visibility layer

In ArcGIS, the “Visibility” tool in the “3D Analyst” extension was used to perform this test. Certain fields must be added to the Madutle Primary School’s (observer point) attribute table before attempting to do the visibility analysis. This step was included in the analysis because in a military scenario, it is desirable for the commander to be able to specify the height of the observer point (in this case the height of the antenna for VHF radios) as well as the radius distance from the observer point. If, however, a person is only interested in a visibility analysis from the current height of the observer point and would like to include the whole study area in the analysis, the “Viewshed” tool in ArcGIS is sufficient.

The “Interactive Visibility” tool add-in was downloaded, which helped a lot to add the observer and input specifications in a more “automatised” and faster way than adding fields to the attribute table by manually typing it in. The radius from the HQ was specified as 20 000 m and height of the antenna as 10 m. The rest of the default values were accepted. ArcGIS automatically creates a classification layer that displays visible areas as “Visible” and areas that are not visible as “Not Visible”. The default colours were changed to display as red (not visible) and green (visible). This process is illustrated in Figure 4.16.

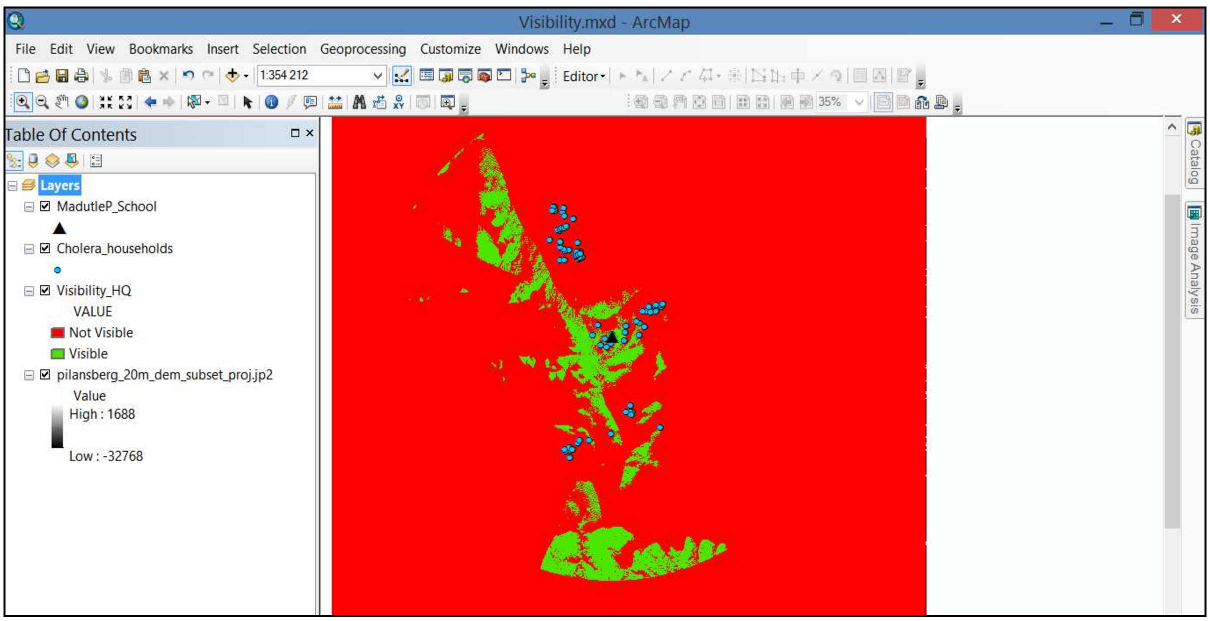

Figure 4.16: Visibility layer result obtained – ArcGIS

4.2.5.2 QGIS test 5 results: creating a visibility layer

The “Viewshed analysis” plugin was downloaded for this analysis in QGIS. In the “Viewshed analysis” plugin, the user can specify all the observer parameters and choose what type of model he/she wants to apply. The researcher specified the observer parameters to be the same as with the ArcGIS test; therefore the search radius was made 20 000 m and the observer height 10 m. A binary viewshed was done. Figure 4.17(a) indicates the result of the process before adjustments were made to the raster layer properties. In Figure 4.17(b), the final result can be seen.

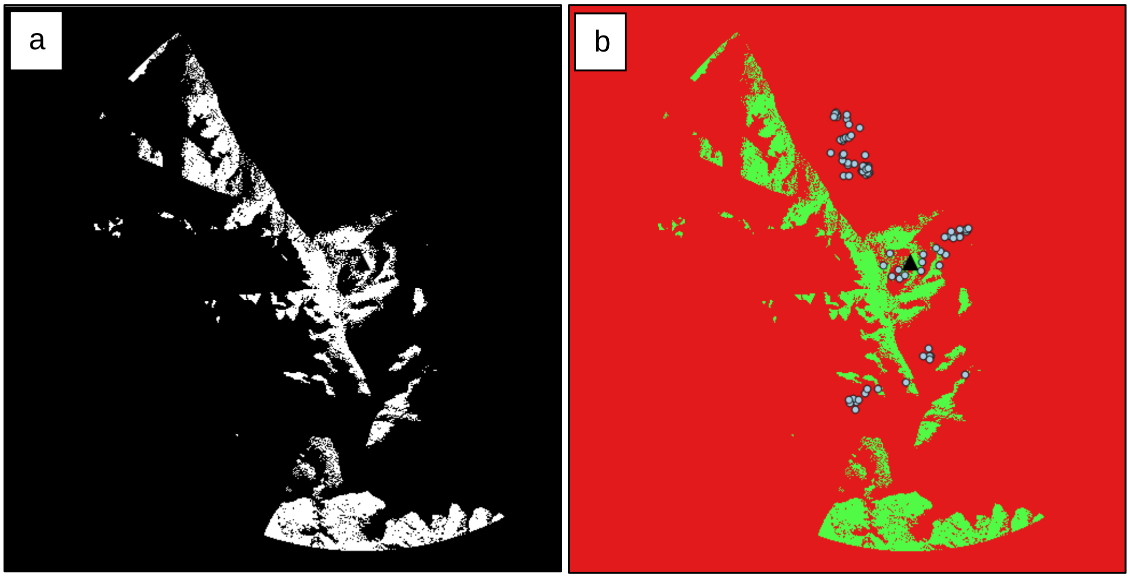

Figure 4.17: Visibility layer result obtained – QGIS

In Figure 4.18, an example was made to show other possibilities for presenting the results to the commander. In this example, the green areas represent visible areas or areas where radio signals will be good, with the topographical map as base layer for good orientation. Areas with no visibility were made transparent.

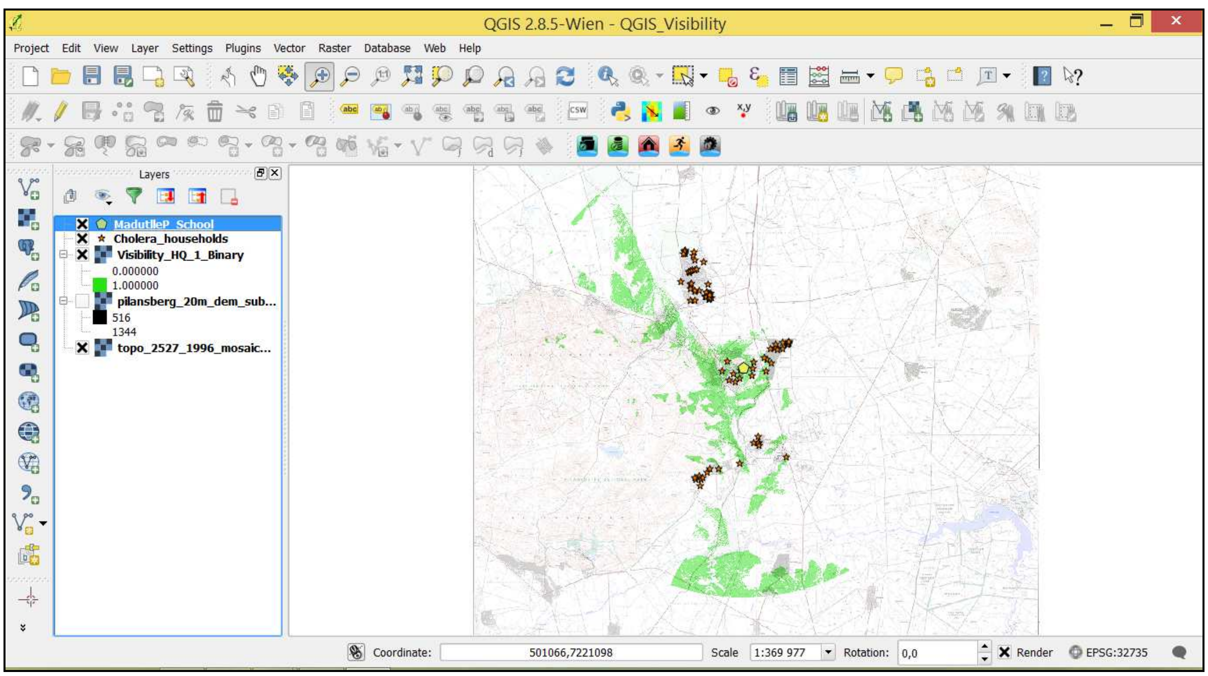

Figure 4.18: Visibility layer combined with the topographical map

4.2.5.3 Analyses of test 5 results

The desired end result could be achieved satisfactorily with both software products. The end results achieved with both software products were superimposed, and slight differences were observed. Figures 4.19(a) and (b) illustrate these differences. Firstly, Figure 4.19(a) illustrates the Visibility product created by using ArcGIS (in green), while the red indicates the areas where the QGIS Visibility product differs from the ArcGIS product. Secondly, Figure 4.19(b) is a vice versa illustration of the first explanation provided. It illustrates the Visibility product created by using QGIS, represented by yellow, while the red areas indicate the differences in the ArcGIS Visibility product. In Figure 4.19(a), green represents the ArcGIS visibility product, while the red areas are where the QGIS product differs from it. In Figure 4.19(b), yellow represents the QGIS visibility product, whereas the red areas indicate the difference when compared to the ArcGIS product.

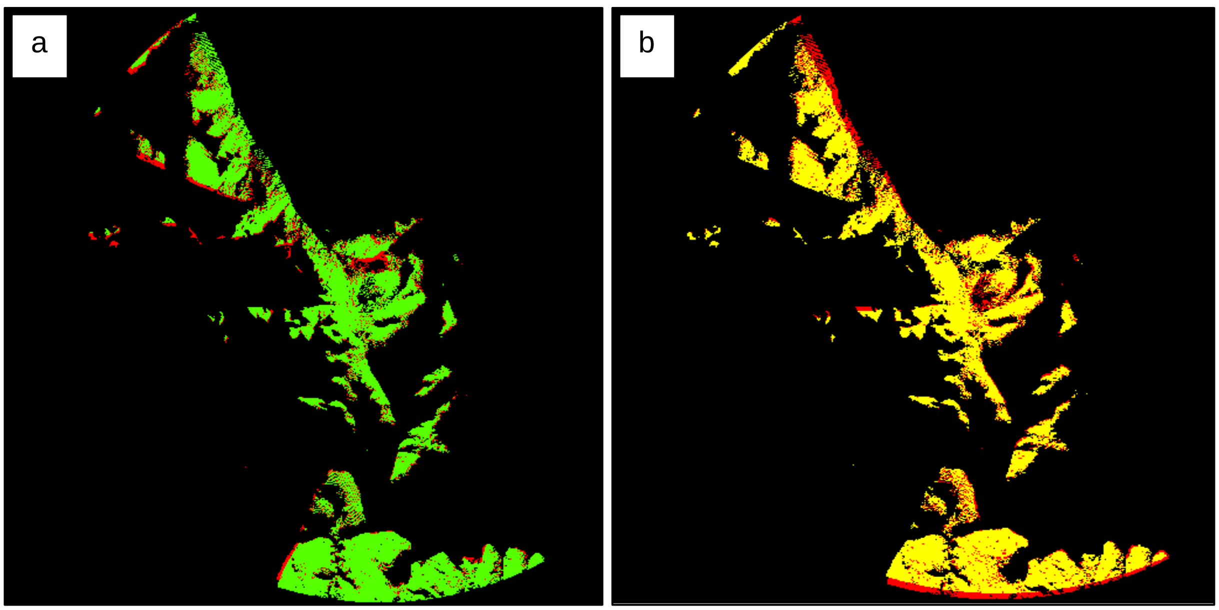

Figure 4.19: Differences in visibility products created using ArcGIS and QGIS

In a practical informal investigation (in a different area that was readily accessible in Tshwane) into visibility differences between ArcGIS and QGIS, performed by Colonel A.F. Van Niekerk (Senior Staff Officer – Mapping and GIS from the Directorate Geospatial Information) on 19 July 2016, it was found that areas in the lower altitudes of the observed area were less accurate in QGIS than in ArcGIS. Areas identified by QGIS as “Not Visible” were in fact visible. In terms of the specified Cholera use case and the use of the visibility analysis for communication purposes, the results achieved with both software products would be acceptable. However, if visibility analysis was calculated for other operational uses such as determining the placement of artillery observer posts, the result achieved from using QGIS might not have been acceptable (A.F. Van Niekerk 2016, personal communication, 19 July).

In an article linked to the “About” tab in the QGIS Viewshed analysis plugin, the author states that “the size of inconsistencies is easily discernible” in this algorithm. It is further stated that “the problem most probably lies in the interpolation of height values in the pixels in the observer’s vicinity” (Fisher, 1993; Kaučič and Zalik, 2002).

In ArcGIS 10.2, the process of initially entering the input values for the observer point is a bit more complex than in QGIS, since the values must be added as new fields to the attribute table of the observer point specified. The “Interactive Visibility Add In” that was downloaded helped to simplify the process since it guides the user towards entering the desired values for the observer point’s fields. In QGIS, these fields were automatically available in the “Viewshed analysis” plugin. However, according to research done, a new tool is available in ArcGIS 10.3 (Viewshed 2) that is similar to the dialog box available in QGIS, where input parameters for observers can just be completed without adding additional fields to an attribute table.

The styling in QGIS is slightly more complex than in ArcGIS, but certainly not difficult (preferably the user must understand rasters to some extent). In QGIS, the result displays as a single band greyscale, which must then be changed to a single band pseudocolour and classified into two colours according to the equal intervals method. The displaying colours were set to the desired ones. The legend in QGIS must also be renamed to indicate “Visible” and “Not Visible”, which is easy to do; this was, however, done automatically in ArcGIS.

4.2.6. Test 6: Creating layers for helicopter landing zones (HLZs), hospitals and medical post (HQ), police stations, roadblocks and water purification plants

As stated in the use case scenario (refer to Chapter 3, paragraph 3.5), the operational commander would like to determine the possible areas in which to set up HLZs, hospitals, police stations, roadblocks and water purification plants in order to assist with his planning process. Since the SANDF would normally first use existing infrastructure (in order to save time and costs), in most of these test cases, a search was first done in order to find existing features. If existing infrastructure was found to be insufficient, additional features were added to the layer. These steps were performed by doing an attribute search and by way of digitising. The same coordinates were used to digitise features. This ensured that all features represented similar locations in both software products. The symbology was then changed to make it more appropriate and legible.

4.2.6.1 Test 6 results

HLZ. For HLZs (see Figures 4.20 and 4.21), the POI layer was used in order to locate existing helipads in the area of operations. Two additional HLZs were digitised; one using the sports ground at Madutle Primary school (the HQ position) and the other using a sports ground in the north. The SPOT 6 image was used to identify the sports fields. The styling for the HLZ layer and other visible layers was adjusted in order for symbols to appropriately represent the various features identified on the different layers.

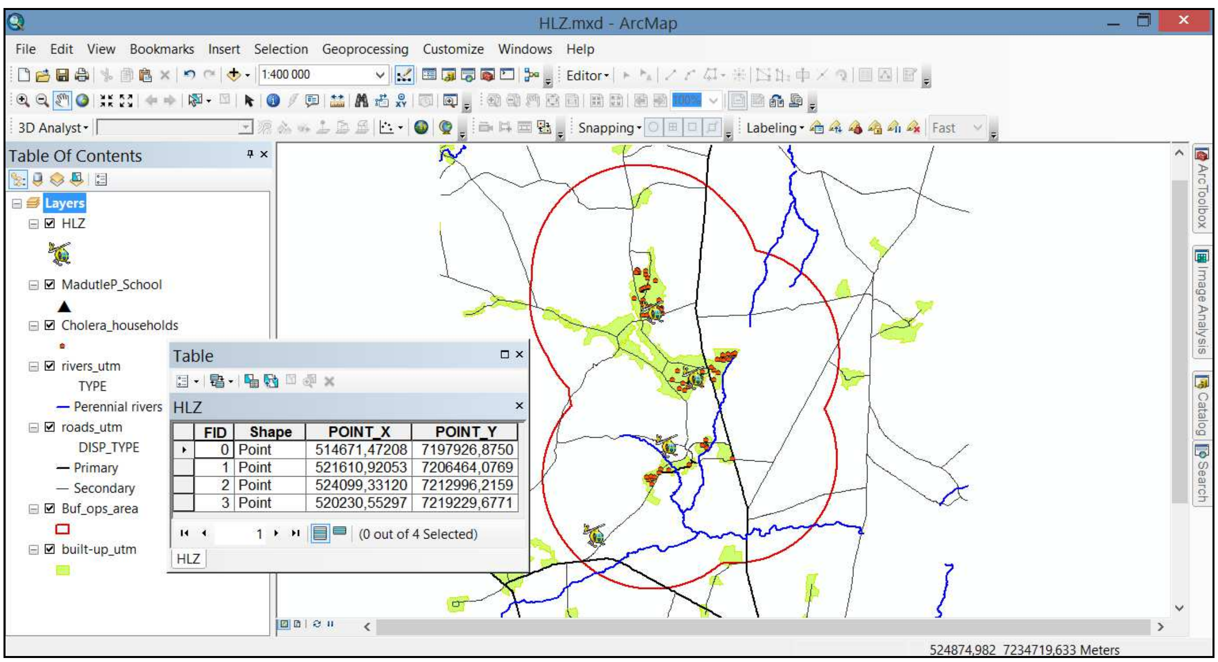

Figure 4.20: ArcGIS – HLZ layer

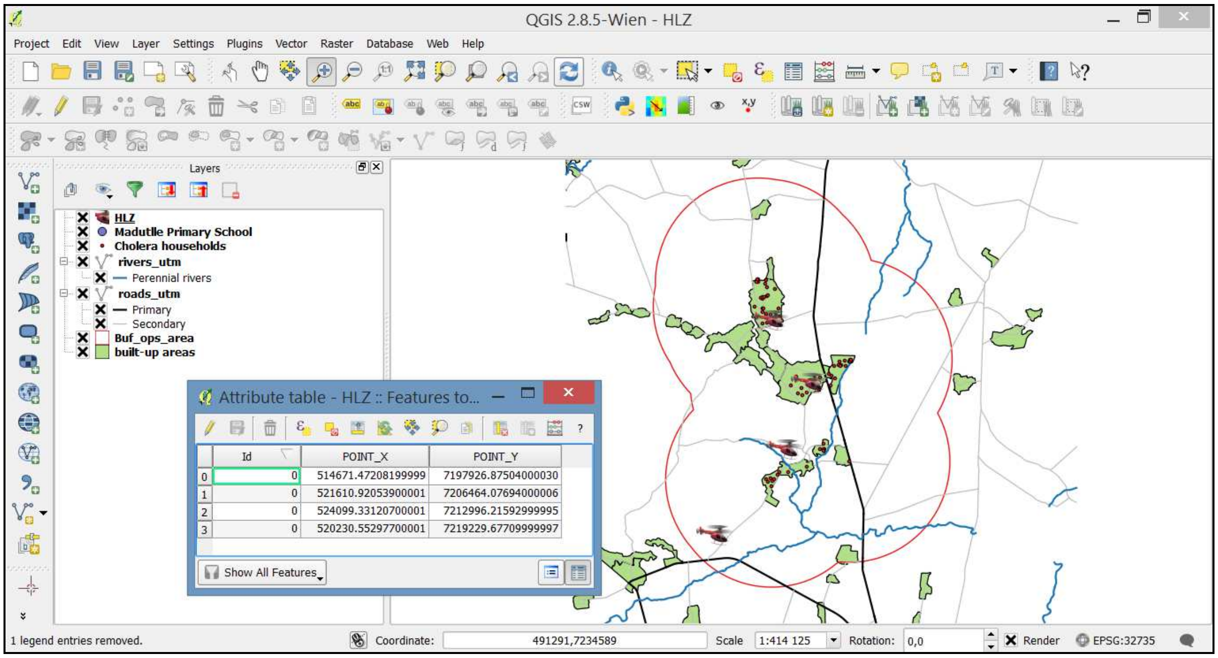

Figure 4.21: QGIS – HLZ layer

Hospital/medical post (HQ). The existing Hospital in the area of operations (George Stegmann Community Hospital) was selected from the POI layer (using the "Select by Attribute" tab), and the current HQ position (Madutle Primary School) was designated as the medical post for the SAMHS. Two points are thus indicated on the map (see Figures 4.22 and 4.23) as possible medical facilities to use during this operation.

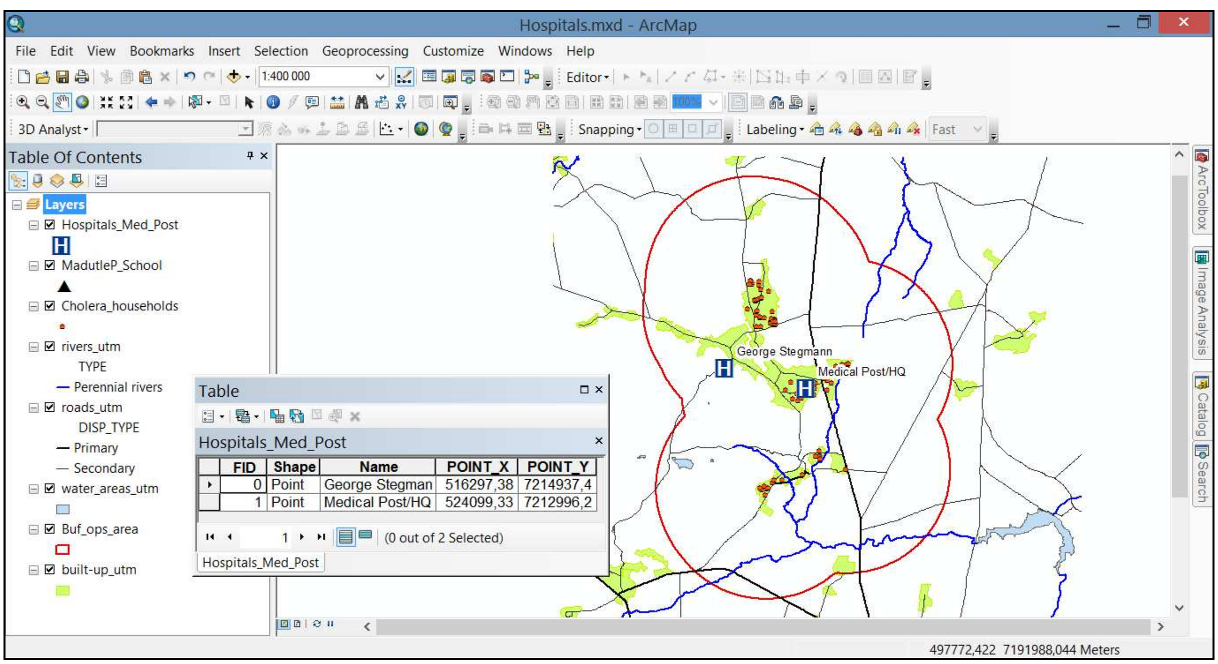

Figure 4.22: ArcGIS – Hospital/medical post (HQ) layer

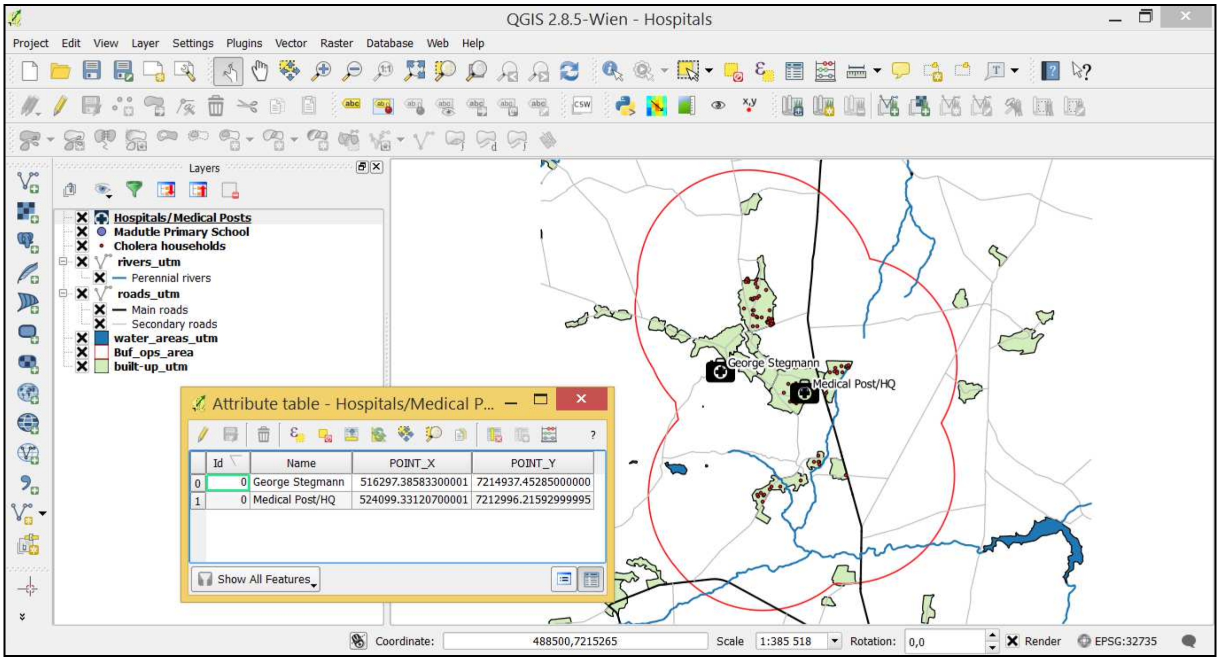

Figure 4.23: QGIS – Hospital/medical post (HQ) layer

Police stations. It is also essential for the military commander to know the location of all the police stations in his/her area in operations. A search was therefore also done to find police stations in the area of operations using the POI layer, which is illustrated in Figures 4.24 and 4.25.

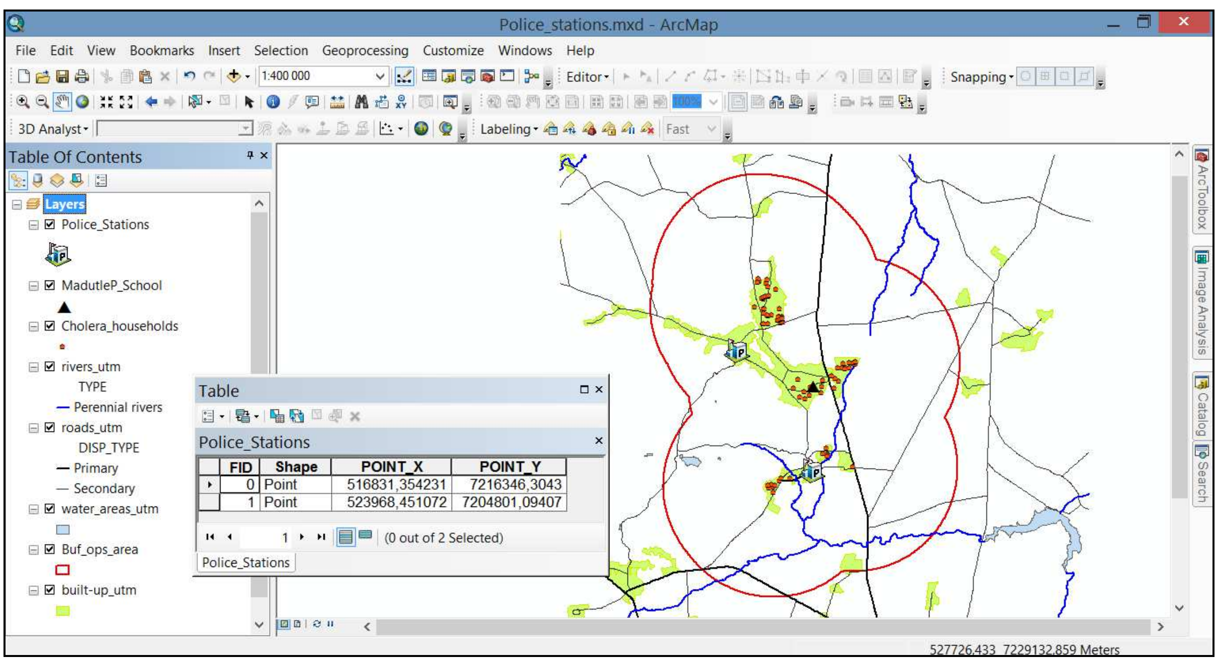

Figure 4.24: ArcGIS – Police stations layer

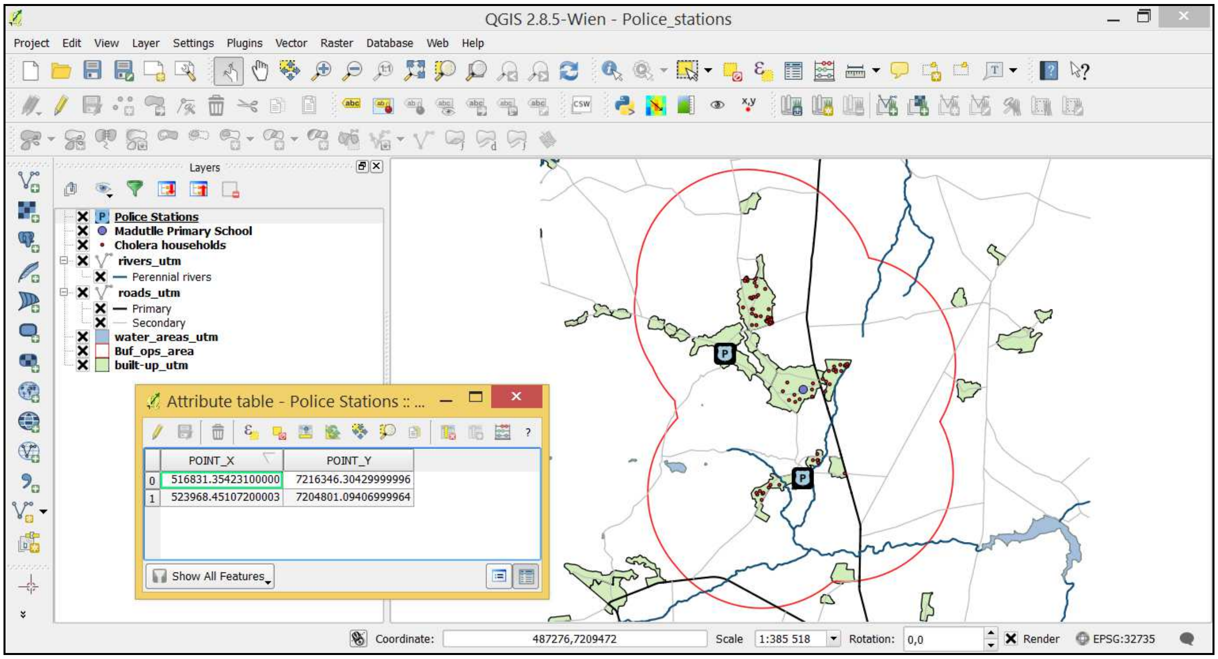

Figure 4.25: QGIS – Police stations layer

Roadblocks. The commander must indicate the location of roadblocks where infantry troops will be deployed. The area of operations, as well as the northern (Platoon 1 location) and southern crossings (Platoon 2 location) of the main road, were digitised to indicate where roadblocks were placed (see Figures 4.26 and 4.27). All other secondary roads will be closed.

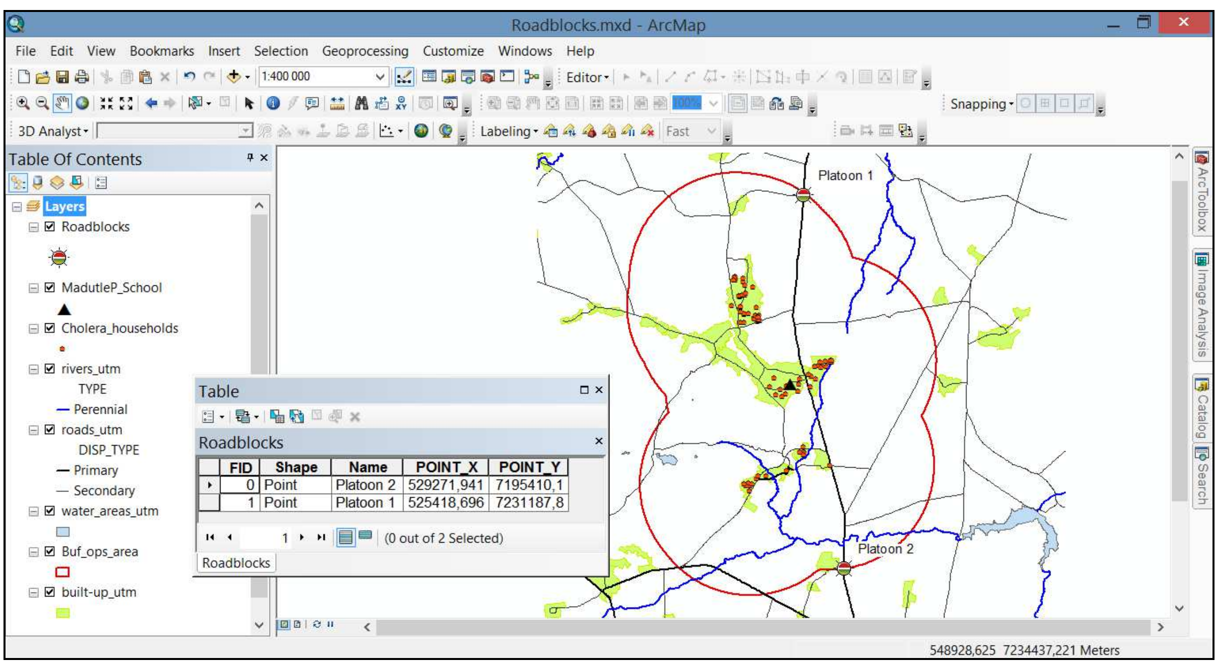

Figure 4.26: ArcGIS – Roadblocks layer

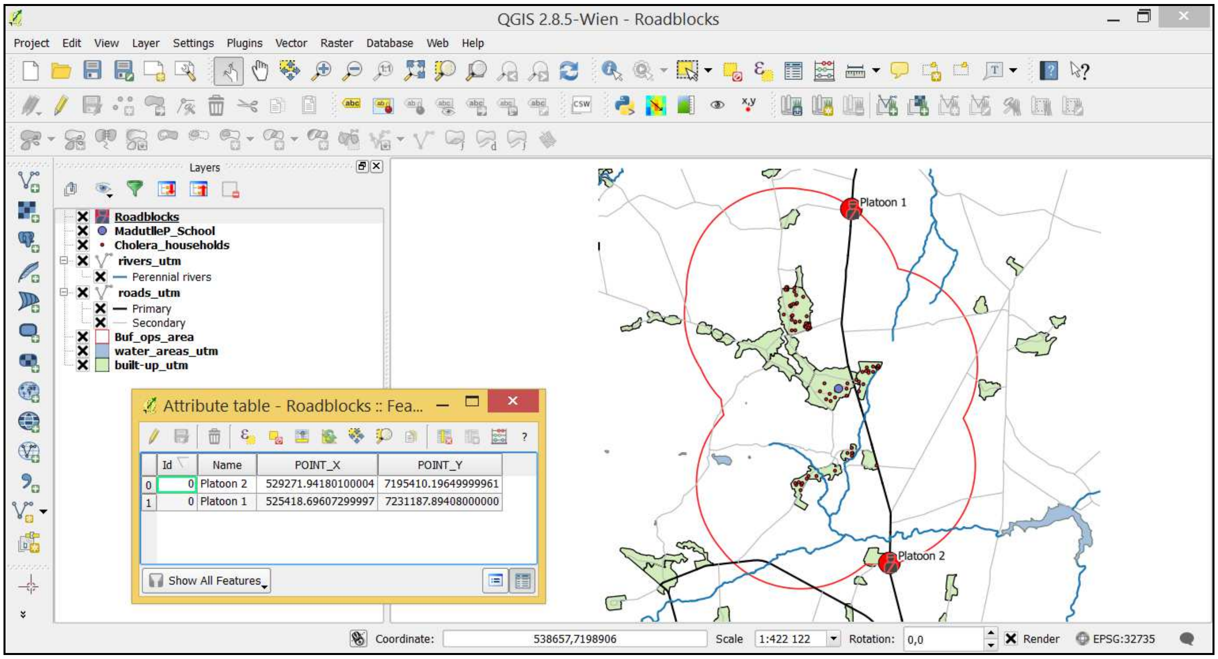

Figure 4.27: QGIS – Roadblocks layer

Water purification plants. The SA Army Engineer Formation must deploy water purification plants in the Cholera-affected areas. The SAAEF commander requires advice on the ideal location for placing these water purification plants. The specifications for the terrain where the plant must be placed are that it must be a flat surface (approximately 100 m x 100 m in size) and located close to the river. These specifications were confirmed by the SAAEF (J.D. Cilliers 2016, personal communication, 20 July).

The GIS operator will therefore firstly do a slope analysis. The slope of the chosen area close to the river must be less than 5 degrees. Thereafter individual water purification plants were digitised (see Figures 4.28 and 4.29) close to the perennial river area. See Appendix A, paragraph 10.1.6 for details of this test procedure.

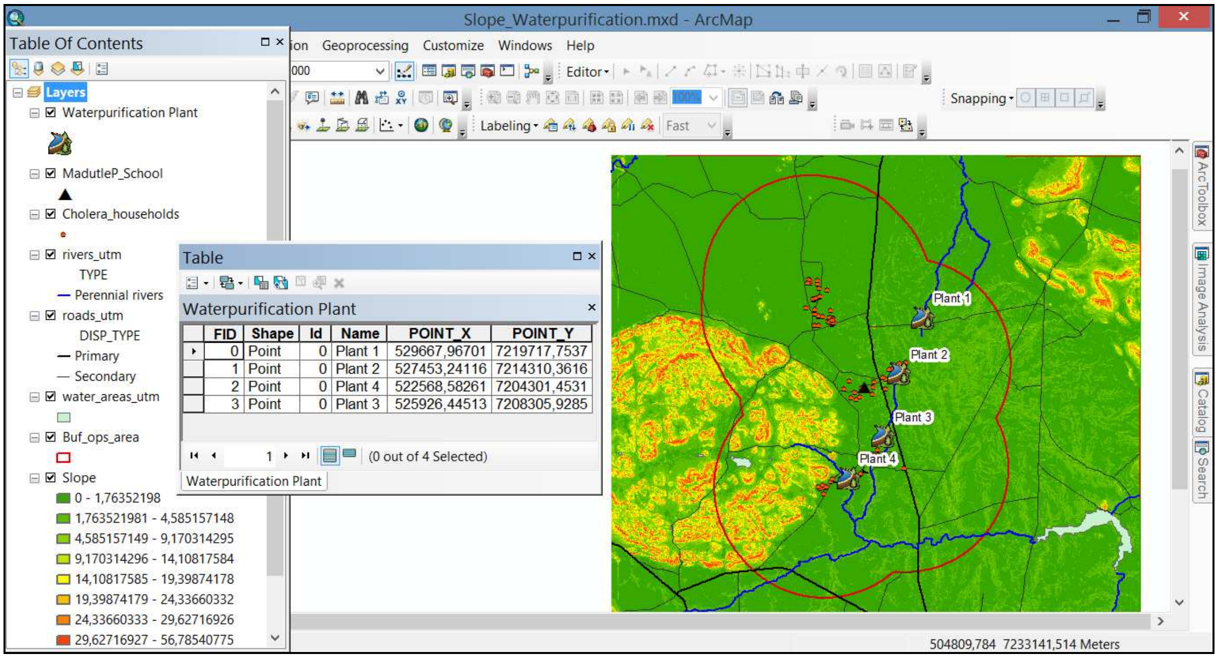

Figure 4.28: ArcGIS – Water purification plants layer

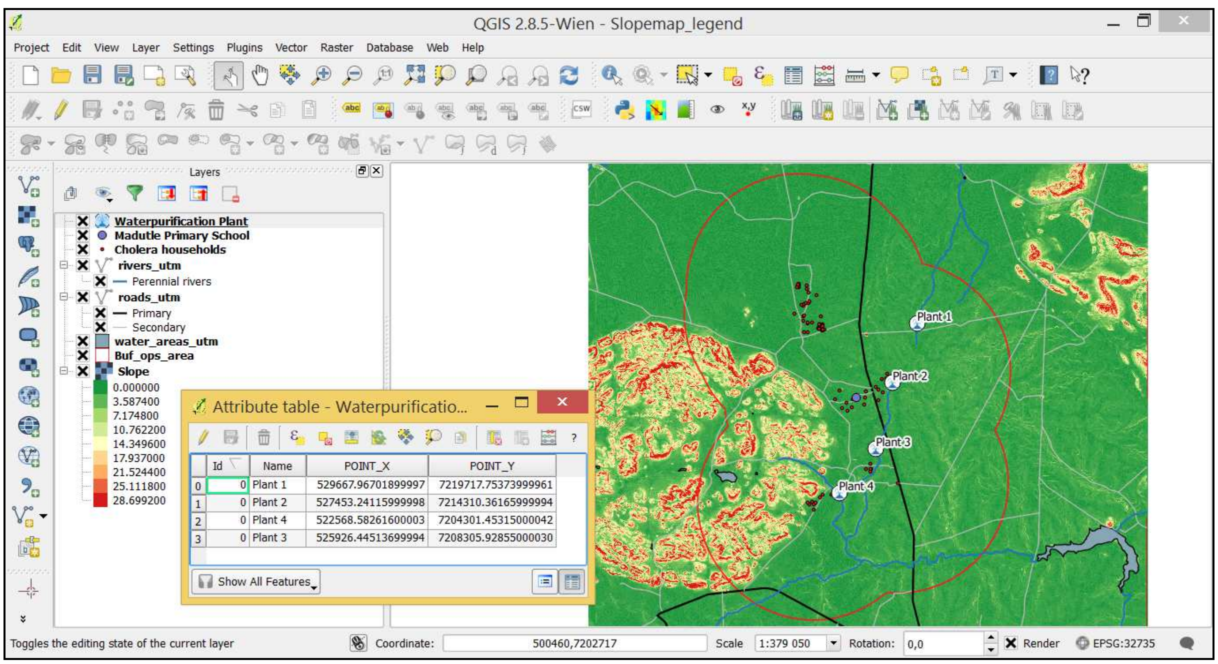

Figure 4.29: QGIS – Water purification plants layer

4.2.6.2 Analyses of test 6 results

In ArcGIS, the "Select by Attributes" tab was used to conduct queries regarding attributes for example existing hospitals, police stations etc. In QGIS, the "Select Feature using an expression" button in the attribute table of each feature was used to do the same. In

ArcGIS, the styling of the point symbols was made easy by the wide variety of symbols available from the existing symbols in the symbol selector dialog box. In QGIS, the number of point symbols for point features like hospitals and police stations were limited. After research into the topic, additional point symbols were downloaded from the Internet in .SVG format. Once the .SVG symbol was downloaded from the Internet, it was copied to the SVG folder located in the program files in QGIS (C:\Program Files\QGIS Wien\apps\qgis-ltr\svg). This extended the range of point symbols in QGIS extensively. These symbols are freely available from a wide variety of Internet sites (see Appendix A, paragraph 10.1.6). The user must, however, take note of the fact that when a QGIS project containing .SVG symbols is taken to another computer, the .SVG files must also be copied from one computer to the next. Failure to do this will result in the mentioned symbols not displaying. In addition, if a user installs another version of QGIS and deletes the previous version without copying the .SVG files that were located in its program files, the same will happen. This is not possible in ArcGIS. In a military operation where Internet services might not be available, this part of the process will have to be done when deployment preparation is done. On the plus side of symbology in QGIS, the user can easily create new symbols when combining more than one symbol. See, for example, the Roadblock sign that the researcher created by combining one of the downloaded '*.SVG' symbols with a simple red dot symbol.

The slope analysis (needed to determine the ideal location of water purification plants) in both ArcGIS and QGIS was very effective in applying a degree slope, which was the required output in this use case. However, in the ArcGIS "Slope analysis" tool, there is also an option to perform a "percent slope" analysis. Figure 4.30 illustrates a pixel-to-pixel change difference performed between the ArcGIS and QGIS slope analysis results. The "black areas" indicate *No Change*, the "green areas" indicate less than 1% decrease from the ArcGIS result to the QGIS result, and the "red areas" indicate less than 1% increase. At first, when looking at Figure 4.30, it appears as though there are huge differences between these two results, but this is not true. Most of the green areas show differences that were caused due to tonal variances between the two results. Conversely, even when considering these variances, all differences between these two results are less than 1%. It is therefore quite noteworthy that these two results are very similar and that the software products performed adequately in this test.

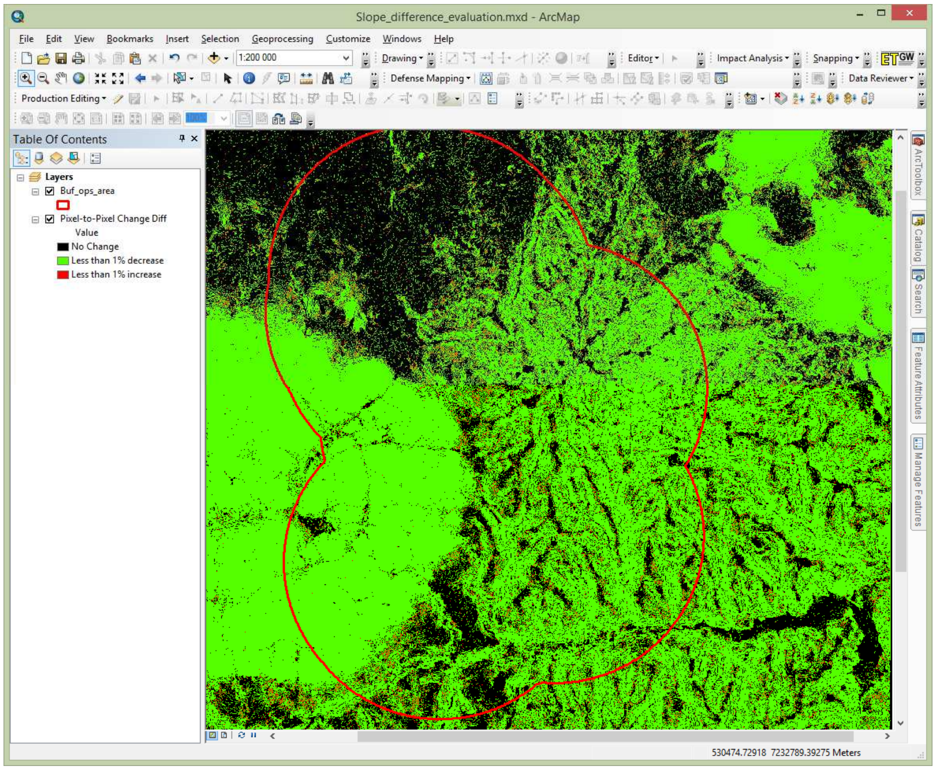

Figure 4.30: Water purification plants layer results analysis

4.3 TESTING USER-FRIENDLINESS

In paragraph 1.4.1, 10 criteria were listed that are being used to evaluate whether software products are “user-friendly” or not (Wallen, 2010). The ArcGIS and QGIS software were evaluated in terms of these criteria and the results will now be discussed. The operating system used was Windows 8.1 Single Language.

Simple to install. In order for the installation of software to be perceived as “simple to install”, the process of installation should be easy to understand and well documented (Wallen, 2010). In terms of the Cholera use case specified, the installation of software should form part of the GIS team’s pre-deployment preparation. The reasons for this are threefold.

a. Internet access might be limited or not available in the area of operations (in this case the Pilanesberg area). Internet access is needed for the initial installation of both ArcGIS and QGIS. In the case of ArcGIS, the authorisation code must be obtained by means of the Internet. Where QGIS is concerned, Internet access is needed to download the complete software application initially. Once QGIS is downloaded, it can be saved on a storage device and installed at a later stage.

b. Extensions (in ArcGIS) and the plugins and .SVG symbol files that QGIS needs will also have to be installed and activated before the deployment team leaves for the operation.

c. Once the team arrives in the operational area, time cannot be wasted on the installation of software, extensions or plugins.

The researcher, on the same computer system as described in Chapter 3, performed the process of installation for both ArcGIS and QGIS. The installation process of both software products adheres to the abovementioned criteria. The installation of both ArcGIS and QGIS is easy to understand and very well documented (online support or help in this regard is also available), and therefore both software products are evaluated as being "simple to install".

Easy to update. Updates should also be easy to perform. When a user does not update his/her software, the user misses out on new features and the software can become less trustworthy and secure (Wallen, 2010). In an operational scenario, all software updates will have to be done before the start of the operation as far as possible. The "update" process in ArcGIS is fairly automated (the user follows the instructions in the license manager), unless you want to install the new version on a machine that is different from the one on which the previous version of ArcGIS 10.X was installed. In such a case, the previous product must first be de-authorised before authorising the new one. In QGIS, you can choose to uninstall the previous version and load the newest version. The user should take care to copy .SVG files when updates are being done on QGIS (see paragraph 4.2.6.2.). Both these software products are therefore easy to update.

Intuitive. According to Wallen (2010), "software is only as good as its GUI". People will have issues with using the software if the GUI is poorly executed. Wallen (2010) mentions that a well-designed GUI can often overcome a "less-than-friendly underlying structure (or poor coding)", but it still means that the software must be working as expected. In both these software products, the GUI is very well designed. With regard to the basic functionality, such as adding and displaying data, zooming, panning and working with the attribute table, the two software products "look" and "feel" fairly similar (see paragraph 3.4). Concerning the more advanced functionality, such as the spatial and 3D analysis functions, the functionality may be located in different tabs and buttons and even use different extensions and plugins. In QGIS, the Plugin Manager can be used to inspect available plugins and to get a description of each. In ArcGIS, the relevant tool is easily located when using the "Search" function. The GUI in both software products can be customised to fit the user's need. Furthermore, saving works similar to that of other Microsoft software makes the GUIs more understandable to most people. Intuitiveness is a concept that is subjective in nature and one that is influenced by the experience and knowledge of the GIS user. Based on the general description of intuitive (Wallen, 2010), both these software products are evaluated as intuitive. In terms of the specified use case, the only manner in which the operation is affected by the GUI is when GIS operators are not familiar with the particular GUI. GIS operators must be fully trained on the particular software product, and in particular the GUI, in order to save time when completing a product for the operational commander.

Efficient. Software should work as expected (be effective) and also be efficient. It must be able to work "seamlessly with underlying structures and subsystems" (Wallen, 2010). Efficiency is the product's ability to perform in the best manner with the least waste of time and effort. The efficiency and effectiveness of the software is also tied to "intuitiveness". In terms of the specified use case, no benchmark tests were done because of the many variables involved in efficiency; therefore effectiveness was tested. Both ArcGIS and QGIS could produce all the required output products. Both these software products were therefore evaluated as effective.

Pleasant, easy-to-navigate GUI. The GUI of the software must be both effective and intuitive. The primary function of the GUI should be to make the job easier for the end user. It does not help the end user if the design is trendy but makes for an unpleasant experience (Wallen, 2010). In both ArcGIS and QGIS the design of the GUI is trendy and definitely makes the job easier for the end user. In both cases the buttons' design already gives the user an idea of what it is used for and, if the cursor hovers over it, it tells you the name of that button. As mentioned earlier, the GUIs of both these software products are customisable. In ArcGIS, this can be done by using the "Customize" dialog box. The user can choose to hide certain toolbars or even create a custom toolbar or menu. In QGIS, the "Customization" dialog box can be found under the "Settings" tab. In both these software products, the GUI is divided into five main areas, namely Menu Bar, Tool Bar, Map Legend, Map View and the Status Bar (see Chapter 3, paragraph 3.4).

Easy to remove. The software removal process should be simple, otherwise the software becomes a burden (Wallen, 2010). The “uninstall” process in both these software products is simple with no difficulties. In both cases an “uninstall” utility can be used to uninstall the software product. For both ArcGIS and QGIS, one can use the control panel, select program and features, navigate to the software product that needs to be uninstalled and choose to uninstall. A user can also inspect the program files on his/her computer, search for the software and delete it. As stated earlier, if the user plans to reuse .SVG symbols, he/she should remember to copy and save this folder before deleting QGIS. The uninstall process will not work differently given the specified use case. However, on SANDF computers, the installation and uninstalling of new software are done by a system administrator. The system administrator delivers technical support and is the only person with the authority to alter the set-up of military computers, as is required by the security measures implemented in the SANDF.

Does not need third-party software. When a software product needs third-party software to keep it running, your computer can become exposed. This can generate a level of complication that average end users cannot handle (Wallen, 2010). ArcGIS 10.2 needs **“**Microsoft .NET Framework 3.5 SP1” as a minimum requirement for installation (Esri, 2016a). This FOSS software product is, however, very easily obtainable, at no cost, on the Internet. QGIS does not need any third-party software to install and run.

Easy to troubleshoot. According to Wallen (2010), “No software is perfect”. If there is a software problem, it is imperative that the end user can call support to have the issue resolved (Wallen, 2010). In terms of this criterion, the result may not be a simple “yes” or “no”. In terms of ArcGIS, troubleshooting certainly has a number of advantages. The user can access the Esri help files that are available to him/her, and if Internet access is available to the operation, the user can also access the Esri online support. Since the SANDF is paying the ArcGIS license fees, the operators will also be able to call Esri SA in such an event. If, however, the problem is coupled to a development issue in the software, the user might have to wait to see if it will be addressed when a newer version of the software is released. In terms of QGIS, the user manual can be downloaded before an operation to assist with questions that might arise. If Internet access is available during the operation, GIS operators can also pose their question to the active QGIS support mailing list. The members of the mailing list are not required to answer any questions posted. In addition, if a bug in the software is reported, developers can decide whether to fix it or to develop additional functionality. As a result, the QGIS team encourages commercial support contracts with third parties. The QGIS website contains a list of such commercial support contractors with links to their respective websites. These companies offer QGIS product support and services to their clients.

Adheres to standards. Standards are important in order to make interconnectivity between applications or hardware easy (See Chapter 2, paragraph 2.4.5). Complications emerge when developers do not adhere to standards. In such circumstances, end users will experience difficulty because their tools will not be able to communicate with other tools that do comply with the standards (Wallen, 2010). Both QGIS and ArcGIS support the relevant standards needed to complete the tests in this use case (for example, standards for shapefiles, GeoTIFF files and to support the feature model). Most standards are hidden from the end user.

Effective error handling. The manner in which software handles a problem when it occurs is significant. The software must be able to warn the users and let them know what they can do to solve it. The software should not only "time out" and close (Wallen, 2010). Considering the Cholera use case and the tests that were run using both these software products, neither of them ever "timed out" nor "closed". In cases where the researcher did not complete a required field in a dialog box, the software guided the researcher to the problem area.

4.4 ANALYSES OF THE USER-FRIENDLINESS AS COMPARED BETWEEN ARCGIS AND QGIS

Ten criteria were compared in order to determine the "user-friendliness" of both ArcGIS and QGIS. The researcher measured all 10 criteria against the specified Cholera use case. Some of the criteria are general in nature and not only true for this particular operation. Some of the criteria are also very closely related to one another. These are "pleasant, easy- to- navigate GUI", "intuitive" and "efficient" as well as "simple to install" and "easy to remove". However, in terms of the criteria "does not need third-party software", ArcGIS does need third party software for its installation and the like.

It was found that although the GIS operator supporting an operation such as the one specified in the use case will definitely have to note some of the details mentioned in paragraph 4.3 (such as budgeting for commercial support for QGIS), both ArcGIS and

QGIS can generally be considered to be “user-friendly”. The researcher also does not consider ArcGIS’ requirement for software, as stated in paragraph 4.3 to be a limiting factor in terms of the “user-friendliness” of the software, since this software is freely available to users.

4.5 TESTING COSTS

The cost factor was one of the main reasons for conducting this research project. Cost factors were not compared in military operations in general, but only using the SANDF use case to compare costs. QGIS is subject to the GNU license, and it is an open source GIS product that can be installed on as many workstations as needed in order to support the Cholera operation, as specified in the use case (Chapter 3, paragraph 3.5). All plugins that will be needed to complete the products, as specified in the use case (see paragraph 4.2), can also be installed at no cost (except costs involved in obtaining Internet access).

In terms of costs for QGIS training, the SANDF developed an introductory course (see Chapter 1, paragraph 1.4.3). For more advanced courses, the SANDF can attend courses at commercial contractors such as Kartoza, as specified on the QGIS website. According to the course outcomes specified on the Kartoza website (Kartoza, 2015), the five-day course, “Advanced GIS with FOSS”, will be suitable in order to complete the tasks as specified in the use case. This course cost amounts to R9 250 per person (as stated on 10 February 2016) and includes, among others, topics such as image processing, advanced editing, advanced spatial analysis, production workflows and more. There are also opportunities for free online courses such as the one being offered on the Canvas website (https://canvas.instruc-ture.com/enroll/LA4DR9). Canvas is an open-source learning management system.

In terms of QGIS, the researcher suggests that military institutions should include the costs that are needed to obtain extra commercial support during their initial budgeting process for an operation in case this type of support is needed during the operation.

In terms of ArcGIS, the researcher acknowledges the fact that Esri SA currently has an end user license agreement (EULA) with the SANDF, which means that licenses for an operation such as the one mentioned in the use case will be supplied to the SANDF at a special discounted rate. The exact details and amounts regarding this agreement cannot be disclosed in this study, due to confidentiality agreements. However, in order to provide a general idea of the costs involved for ArcGIS, the following prices were provided on the Esri online store on 09 February 2016: the cost of a ArcGIS 10.3.1 Basic Desktop license was $1 500, and the costs of extensions such as Spatial analyst and 3D Analyst were $2 500 each (Esri, 2016c).

In terms of existing training on ArcGIS, the researcher also acknowledges the fact that current GIS operators in the SANDF have, through the years, done quite a number of courses both in the SANDF itself and at Esri SA. The current knowledge base of present-day GIS operators in the SANDF with regard to ArcGIS is therefore quite extensive. New members are continuously joining this pool of GIS operators; therefore costs relating to ArcGIS courses will still be discussed. The SANDF itself offers the basic introductory course, and various free online courses are also being offered to ArcGIS users. In terms of the requirements for this use case, members will at least have to do courses at Esri SA up to the advanced level, performing analysis, designing maps with ArcGIS and working with rasters. In addition, members will have to do courses relating to the extensions “spatial analyst” and “3D analyst” (Esri SA, 2016). These courses should provide operators with basic as well as advanced knowledge of the software, enabling them to perform basic tasks, map compositions and editing, as well as some more advanced spatial analysis functionalities and knowledge relating to the extensions that were used during this use case, namely spatial analyst and 3D analyst. (Refer to the “test case specifications” for each specific test in Appendix A.) The costs for these courses, as stated on 10 February 2016, are listed below. (Note that the SANDF also receives a discounted rate when group bookings are made.) The amounts shown below are the normal rates and amounts to a total of R47 500.

a. ArcGIS Standard, R9 700 for a five-day course
b. ArcGIS Advanced, R10 700 for a five-day course
c. Spatial Analyst, R7 600 for a two-day course
d. Working with 3D analyst using ArcGIS, R7 100 for a two-day course
e. Designing maps with ArcGIS, R4 900 for a two-day course
f. Performing analysis, R7 500, for a two-day course

The EULA will cover the cost for ESRI support during this operation.

4.6 ANALYSES OF COSTS AS COMPARED BETWEEN ARCGIS AND QGIS

In terms of the costs involved in acquiring software, as well as the costs for some of the training requirements, QGIS has a definite advantage over ArcGIS. In terms of the use case, the ArcGIS license and extensions needed will amount to a total of US$6 500, and the total cost of training needed will amount to R47 500. QGIS licenses are freely available and the cost for training amounts to a total of R9 250. However, once the initial ArcGIS purchase is made, the support when troubleshooting and so on occur, will be included in the EULA as part of the subscription fees.

4.7 EVALUATING THE ADVANTAGES AND RISKS OF USING FOSSGIS IN RELATION TO THE CHOLERA USE CASE

During the literature study in Chapter 2, paragraph 2.4.2.2, the general advantages and risks of FOSS were discussed. Considering the information collected during empirical studies, these aspects are revisited in this section.

The undeniable advantage of FOSSGIS is the fact that that an organisation can save money on licensing costs, since the user can acquire as many licenses as needed for free. Costs related to the maintenance of software are also eliminated when using QGIS.

The development cycle of QGIS is very short; by the time use case tests were completed, the next version of QGIS was available for download. The user has the freedom to switch between various versions of the software at no additional cost. The next higher-level functionalities (for example hillshading, slope analysis and visibility analysis) needed to complete the tests, were available at no additional costs.

The quality of the FOSSGIS, in this case QGIS, is very high. All specified test outcomes could be achieved with ease. No “system crashes” or other bugs were experienced while performing the use case tests.

FOSSGIS provides an opportunity for research, learning and knowledge-sharing that might not have been possible without its existence.

Disadvantages of FOSSGIS are mainly related to the rendering of support and symbology. Technical support, which must be available on "standby" during operations, is crucial to the military. This support can be "expected" from proprietary venders but not necessarily from FOSSGIS providers. Apart from support available on blogs, among others, the SANDF will have to budget for additional support. With regard to symbology, although the user can create additional symbols or download it from the Internet, the initial symbol library is not as advanced as the one offered by the compared proprietary software (ArcGIS).

4.8 CHAPTER SUMMARY

In this chapter, the GIS functionalities, "user-friendliness" and costs were evaluated and then analysed. (See Table 4.1 below for a summary of the GIS test results.) The researcher combined the evaluation and analysis of these functionalities in order to form a more cohesive and clear picture. In terms of the criteria mentioned in Chapter 3, Table 3.1, it is evident that when comparing proprietary GIS and FOSSGIS, one must consider each of these criteria individually, given that each might have its own advantages and/or disadvantages.

In the next chapter, the researcher will revisit the research objectives identified in Chapter 1, paragraph 1.4.3, in order to determine whether these objectives were achieved. Conclusions, recommendations and aspects to consider during future research will also be made.

Table 4.1: Summary of analysis of ArcGIS and QGIS test results

TEST NAME	SUMMARY OF ANALYSIS OF GIS TEST RESULTS
Buffering an area of operations (4.2.1).	• The results obtained in terms of both software products would have satisfied the operational request and are similar (see area calculations). • In order for the GIS operator to successfully complete the buffering process in QGIS, he/she should have a basic understanding of coordinate reference systems. • The unit of measurement in QGIS cannot be chosen in the "Buffer analysis" dialog box; in ArcGIS this can be done. • In QGIS, the smoothness of the buffer's outline can be set according to user preferences in the "segments to approximate" field.
Cholera hot spot map (4.2.2)	• The Cholera hot spot analysis was completed successfully in both ArcGIS and QGIS, and will give the commander the ability to see areas of higher density of Cholera. • A difference in the results obtained was observed. In QGIS, more detail is visible and appears slightly "smoother". In ArcGIS, the KDE is based on the quadratic kernel function (by default), and in QGIS the Quartic

	(biweight) kernel function/shape was chosen. QGIS has five kernel shapes to choose from, but the quadratic kernel is not one of them.
Hillshade analysis (4.2.3)	• The hillshading process in ArcGIS and QGIS is very similar and was successfully achieved in both software products. • The user can also experiment with the manner in which the hillshade raster displays by changing the base layer and setting different transparencies. This can be done by both software products.
Creating a flood layer using raster calculator (4.2.4)	• Similar results were obtained from both the software products. • The raster calculator expression looks slightly different in the two software products, but delivers the same result. It can, however, be done with ease by both software products. • The GIS operator will have to be a more advanced GIS user, since knowledge of rasters, bands and mathematical expressions is necessary to operate both software products.
Creating a visibility layer (4.2.5)	• The desired end-result could be achieved with both software products, although differences were observed in the results. • In ArcGIS, the process of initially entering the input values for the observer point is a bit more complex than in QGIS than in ArcGIS 10.2, since the values must be added as new fields to the attribute table of the observer point specified. The researcher downloaded the “Interactive Visibility Add In”, which helped to simplify the process. In QGIS, these fields were automatically available in the “Viewshed analysis” plugin. However, according to research done, ArcGIS 10.3 addressed this with the new “Viewshed 2” tool. • The inexperienced user might consider the styling in QGIS to be more complex than in ArcGIS. The result in QGIS displays as a single band greyscale, which must then be changed to a single band pseudocolour and classified. • The legend in QGIS must also be renamed to indicate “Visible” and “Not Visible”, which was done automatically in ArcGIS.
Creating layers for HLZs, hospitals/medical post (HQ), police stations, roadblocks and water purification plants (4.2.6)	• In ArcGIS, the “Select by Attributes” tab was used to make queries about attributes, for example existing hospitals and police stations, among others. • In QGIS, the “Select Feature using an expression” button in the attribute table of each feature was used to do the same. • In ArcGIS, the styling of the point symbols was made easy by the wide variety of existing symbols available. • In QGIS, the number of point symbols for point features such as hospitals and police stations were limited. After research on the topic, additional point symbols were downloaded from the Internet in .SVG format. Users must remember to copy these .SVG symbol files together with a particular project for use on another computer or to copy it when another version of QGIS is installed. The reason for this is that .SVG files are located in the QGIS program files. • In a military operation where Internet services might not be available, this part of the process will have to be done during deployment preparation. • On the plus side of symbology with regard to QGIS, the user can also create new symbols when combining more than one symbol. • The slope analysis (needed to determine the ideal location of water purification plants) in both ArcGIS and QGIS was very effective when applying a degree slope. • The ArcGIS “Slope analysis” tool also has an option to perform a “percent slope” analysis.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

The researcher initiated this dissertation by examining GIS and the military, and more specifically the role of GIS during military operations. This study was divided into two phases, namely a literature study and the empirical research.

The literature study consisted of performing research on relevant topics that pertain to this study, and concluded with an investigation into the evolution, development, licensing, standards and testing of GIS software. The empirical research constituted various GIS test that were performed and analysed; it also entailed the development of a use case. The use case was developed to test and compare GIS functionalities using both proprietary GIS and FOSSGIS. The use case scenario was composed to simulate GIS support rendered during a military operation. The user-friendliness and costs of both these types of software were also compared.

In this chapter, the researcher provides insight into the results obtained from the empirical research phase of this study and provides recommendations for future research. Some of the research discussed in this dissertation has already appeared in an article for the FOSS4G 2016 conference (Henrico et al., 2016), published as part of the process of writing this dissertation.

5.2 MAIN RESULTS AND RECOMMENDATIONS

The literature study provided an important contribution to this research. It assisted in solving the objectives as stated in Chapter 1, paragraph 1.4.3. Objective 1 of this dissertation was to establish and identify the GIS capabilities needed for use in military operations. Objective 2 was to describe the GIS capabilities at the operational level of war. The literature study described the differences between the various levels of war and the different roles that GIS can play at all three these levels of war. The literature study also provided practical examples of GIS products based on the level of operations in which they were used.

Insight was provided into the reasons why the operational level of war is important and why it is considered a vital link between the strategic and tactical levels of war. The responsibilities of the GIS commander supporting the operational commander were also explained, as well the products produced and the physical environment in which these GIS products are created.

The next section of the literature study assisted in resolving Sub-objective 3.1, which was to investigate and describe the differences between FOSSGIS and proprietary GIS software products. The literature research provided a brief description of GIS' history from a global perspective as well as in the South African context. Proprietary and FOSS software products were compared by referring to their respective software development models and licensing. Software testing, standards, the advantages and risks of FOSS as well as issues to consider when selecting GIS software products were also discussed.

Objective 3 was to investigate whether open source GIS can provide the capabilities established by Objective 2, as well as to evaluate the functionalities, user-friendliness and cost of FOSSGIS versus proprietary GIS for a test case in military operations (Sub-objective 3.2). From the empirical study and by considering the use case, certain operational level GIS functionalities were identified. These functionalities were tested on both proprietary GIS software (ArcGIS) and FOSSGIS (QGIS), and the outcomes were qualitatively compared. The following conclusions were derived from the abovementioned study:

a. Firstly, that all the operational GIS functions as prescribed by the use case could successfully be performed using both ArcGIS and QGIS.
b. Secondly, it is acknowledged that some of these GIS functions were at an advanced level and that operating both software products will require specific training. On a positive note, it should also be mentioned that currently a significant number of GIS users in the SANDF are trained up to an advanced level in ArcGIS.
c. Thirdly, although all GIS functionalities could be performed using both software products, it is important to note that in most cases the properties of the raster end results produced in QGIS needed further styling adjustments. This was essential since the raster output in QGIS will first display a single band greyscale image that needs to be altered to a coloured thematic display. Although this is not significantly difficult to perform, the GIS user will have to be trained on the subject and be a more experienced user in order to change the manner in which the raster result displays.

The additional styling requirements means that time spend on these tasks performed in QGIS might be longer.

d. Fourthly, ArcGIS' default symbology library (especially for point symbols) is more comprehensive than that of QGIS. The fact that the native symbology functionality in ArcGIS exceeds those in QGIS, may possibly make ArcGIS the software of choice when it comes to extensive military cartographic products. However, it is also possible to expand this function in QGIS in two ways (again this needs further training and subject matter experience is imperative), namely by
   i. downloading additional symbols in a .SVG format (see paragraph 4.2.6.2), and
   ii. designing custom-made symbols.
e. Lastly, minor differences were observed in the results obtained from raster output products. However, these differences are expected, since two different software products were used to produce the results. Both products met the use case requirements.

Concerning the GIS functionalities tested (see Table 4.1), it can be concluded that the military environment can successfully deploy FOSSGIS to units and directorates (especially those who are limited with regard to funds) to expand the existing GIS capabilities in the military. This process will, however, require guidance and training. Without proper training and guidance, any GIS can become a "dangerous tool".

In terms of user-friendliness, the researcher found that although the GIS operator supporting an operation such as the one specified in the use case will definitely have to note some of the details mentioned in paragraph 4.3, both ArcGIS and QGIS can generally be considered to be "user-friendly".

GIS is an important planning tool in the military and one that no military unit or directorate should be denied. FOSSGIS gives all units and directorates in the military access to GIS. The advantage and privilege of exploring GIS without limits cannot go without mention.

FOSSGIS gives the user access to even advanced GIS functionalities without additional licensing costs. The user therefore does not have to pay extra to have the next level of functionalities (for example advanced spatial and terrain analysis functions).

The researcher recognises the fact that when users pay certain fees to a proprietary software vendor, they can also expect to receive a certain level of service and support from that company. This means that if a user encounters a problem with the software product (for example a bug in its development), the user can report it and, although the problem might not always be fixed, the user can at the very least expect an answer. This can become crucial when troubleshooting in a military operation. However, the FOSS community also acknowledges this need, and one of its solutions is the commercial support that is being offered by a variety of companies on the QGIS website. This does, however, mean that defence forces will have to budget for GIS support being rendered if they want to use QGIS or FOSSGIS.

FOSSGIS, and more specifically QGIS, opens a world of possibilities to the military environment. It now affords institutions that would normally be deprived of this great planning tool because of costs access to it. These units can now have access to the analytical power of an advanced GIS tool with all the functionalities needed to answer a commander's questions. Although military institutions' level of employment of FOSSGIS will vary, the researcher recommends that it should be used in collaboration with proprietary GIS software when used in support of military operations. In general, new GIS users in the military should find that, in most cases, QGIS will meet all their needs.

QGIS is a growing GIS tool and its use in the military environment will grow. The defence force should employ more of its resources to train its members in the use of QGIS in order for the knowledge base to increase to the same level as the current level of knowledge in terms of proprietary software. FOSSGIS can be considered a force multiplier[6] in military operations!

5.3 RECOMMENDATIONS FOR FURTHER RESEARCH

During the literature study and the empirical research done in this dissertation, the issues below were identified that warrant future research.

a. <u>Conducting a study in order to measure people's perceptions of free and open source software</u>: In Chapter 3 paragraph 3.7, one of the identified limitations of this

[6] "A capability that, when added to and employed by a combat force, significantly increases the combat potential of that force and thus enhances the probability of successful mission accomplishment".
<u>Source</u>: The Military Factory (2016).

study was found to be that it does not formally assess people's general attitude towards FOSS, since it is beyond the scope of this study. A formal study assessing the public's attitude towards FOSS, and more specifically towards FOSSGIS, might prove to be very interesting.

b. Testing other GIS functionalities than the ones prescribed by the use case in this dissertation: Not all GIS functionalities used in the SANDF were assessed in this research study. The reasons for this were discussed in Chapter 2. The GIS operational functionalities that were tested are therefore limited to those prescribed in the specific use case. The possibilities of use for GIS in the military environment are quite extensive and other "use cases" can and should be investigated.

c. Performing similar GIS tests using a larger area of study: In this use case, the area of operations was the Pilanesberg area. In other military operations, the area of operations might be very large (mosaic data sets and maps might have to be built) and have different characteristics. The extent to which the software products will still perform optimally in such a scenario should be tested.

d. Testing open data: A similar study could be done using open data versus proprietary data.

e. Performing the same tests using a variety of GIS software products (both proprietary and FOSS) and different operating systems: As explained in paragraph 1.4, only two software products were compared in this study. In future studies, other software products and different operating systems can also be compared using the same tests.

f. Performing the same tests in an operational environment with defence force equipment: Since other challenges can arise when supporting an operation with GIS, the same tests can be performed while taking part in an exercise or operation using defence force equipment.

g. Performing user-friendliness tests using a wider user base: A user study can be done to test user-friendliness quantitatively by involving a larger sample of users.

5.4 CHAPTER SUMMARY

All the study objectives stated in Chapter 1, paragraph 1.4.3 were successfully achieved. The operational GIS functionalities as prescribed by the use case can be performed using FOSSGIS. However, the study indicated that although FOSSGIS can perform all identified operational functionalities, the SANDF should consider certain crucial aspects (see paragraph 5.2).

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APPENDICES

APPENDIX A: USER ACCEPTANCE TEST

Military Operational GIS Functionalities

User Acceptance Test Plan for ArcGIS & QGIS

Version 2.0

Doc. No.:002

Revision History

Date	Version	Description	Author
2015-09-15	1.0	Initial draft	Susanna Jacoba Henrico
2016-02-16	2.0	Second draft	Susanna Jacoba Henrico

1. INTRODUCTION

1.1 Purpose of this document

The purpose of this document is to provide testing information related to the acceptance testing of ArcGIS and QGIS according to the stipulated military operational functions. All test requirements and test cases are gathered in this document.

1.2 Intended audience

This document is intended for

- research purposes – as a part of the methodology,
- GIS users/potential users in the SANDF, and
- GIS users in other domains interested in this research.

1.3 Scope

The scope covered by this document is all test cases related to the acceptance testing of basic and advanced GIS functions as stipulated in the use case (Chapter 3).

1.4 Definitions and acronyms

1.4.1 Definitions

Keyword	Definitions
Attribute	A characteristic of a feature that comprises values for that specific feature. It is a column in a table (Clarke, 1997).
Buffering	It is a zone surrounding a point, line or area feature (Clarke, 1997).
Digitising	The process when data are "geocoded" manually (Clarke, 1997).
Clipping	With this function the user can "clip" a shape according to the shape of another polygon feature class or specified coordinates.
Flood simulation	Flood simulation is used for planning and design, as well as for forecasting floods, in order to take measures in time. Simulation can also be used to simulate other disasters such as fires, volcanoes and stampedes.

Hillshading	The hypothetical illumination of a surface according to a specified azimuth and altitude for the sun. Hillshading creates a three-dimensional effect that provides a sense of visual relief for cartography, and a relative measure of incident light for analysis (Esri, 2016b).
Raster data	A data structure used for maps consisting of grid cells (Clarke, 1997).
Slope analysis	The measurement of the incline or steepness of a surface.
Spatial analysis	To analyse a variety of spatial data using specified parameters.
Vector data	It is a file structure that can be used produce “a file containing co-ordinate pairs (x:y) that represent individual point features (or the points used to construct lines or areas) …”(Haywood et al., 1998)
Visibility analysis	The shape of a terrain surface determines the parts of the surface that can be seen from a given point. This is important when determining the location of communication towers/antennas and when deploying military forces (Esri, 2016b).

1.4.2 Acronyms and abbreviations

Acronym or abbreviation	Definitions
ArcGIS	Proprietary geographical information system
QGIS	Open source geographical information system
HLZ	Helicopter landing zone
DEM	Digital elevation model

1.5 References

All documents related to this study are documented on the reference list.

2. TEST-PLAN INTRODUCTION

Firstly, acceptance criteria had to be established. This was done during the literature study of this research. The actual testing and evaluation of the results then follow. On completion, a report must be written on the results.

3. TEST ITEMS

The software products that are discussed in the paragraphs that follow were evaluated against the set list of criteria as stipulated in the use case (see Chapter 3).

3.1 ArcGIS

The proprietary GIS software product that was evaluated.

3.2 QGIS

The open source GIS software product that was evaluated.

4. FEATURES TO BE TESTED

The following list of features should be tested:

- buffering an area of operations;
- cholera hot spot analysis;
- hillshading;
- creating a flood layer using raster calculator;
- visibility analysis; and
- a map showing locations of
    - ✓ helicopter landing zones (HLZs),
    - ✓ hospitals/medical posts,
    - ✓ police stations,
    - ✓ nearest airports (a search query was done – no airports were found in the area of operations),
    - ✓ roadblocks, and
    - ✓ water purification plants.

5. FEATURES NOT TO BE TESTED

Various GIS functionalities will not be tested; only those stipulated in the use case test criteria (see Chapter 3, table 3.1) will be tested.

6. APPROACH

The approach to testing is that Beta tests will be done during which two different GIS software products will be compared against a set list of acceptance criteria as determined in the use case.

6.1 Approach to configuration and installation

The researcher will personally do the installation.

7. ITEM PASS/FAIL CRITERIA

An item will pass the test if the functionality is available and the desired products could be produced.

7.1 Installation and configuration

The testing of the software product depends on the successful installation of the software.

7.2 Documentation problems

Available documentation on the software functions (for example software help files), can assist the tester in executing the function in less time.

8. SUSPENSION CRITERIA AND RESUMPTION REQUIREMENTS

Should the researcher find that the software product does not have a specific function, the specific test will be suspended in terms of the particular software product. However, if a test fails due to the tester providing the wrong parameters, the test will be repeated and resumed.

9. ENVIRONMENTAL NEEDS

The environmental factors include those factors that must be in place for testing to be successfully performed (hardware, software, other specific infrastructure such as a wireless network; example – a computer with an operating system installed, software needed for performing the testing and more).

9.1 Hardware

A computer (laptop or PC): it is imperative that identical hardware products (for example the computer used to perform the tests on) are used to test both the software products (ArcGIS and QGIS).

9.2 Software

The two software products that will be tested are

- ArcGIS version 10.2, and
- QGIS version 2.8.5 (Wien).

Since QGIS is an open source software product, it will be downloaded from the Internet. The ArcGIS software license is obtained through the University of Pretoria as a student license.

9.3 Other

A connection to the Internet will be needed in order to download the QGIS software as well as some plugins on the QGIS online repository. With regard to ArcGIS, Internet access will also be required in order to obtain the initial authorisation file needed for installation. Internet access is also beneficial to both software products while testing in order to have access to online help files, blogs and the like.

10. TEST PROCEDURE

10.1 Test case specifications

In this section, each of the specific UATs will be discussed according to their test specifications. Each of these will be discussed according to the following test specifications:

- description (short test description);
- test type (whether the test is "positive" or "negative");
- preconditions (for the test to be successful);
- input definition (the name of the function tested can be different the in various software products. The input definition might also be different for ArcGIS and QGIS);
- output definition (the output that is expected if the tested atomic functionality is successfully executed); and
- remarks (additional comments concerning the particular test).

TESTS

10.1.1 Test 1: Buffering

a. Description: Buffering is a spatial analysis process that involves proximity. A zone is created around a specific map feature. In this test, a buffer of 10 km (10 000 m) will be placed around predetermined Cholera cases in order to determine the "area of operations".

b. Test type: Positive – the function must succeed under the preconditions.

c. Preconditions
   - The data must remain the same for all tests.
   - The data (randomly selected points) for the Cholera households/cases must be digitised before the test commences.
   - Both the software products must be tested on the same computer hardware.
   - Coordinate systems must be the same for both software products and for all data used during the test: *WGS84 UTM 35S*.

d. Input definition for ArcGIS 10.2

- ArcMap is open and running.
- Make sure that the Cholera_households layer is added to ArcMap.
- Under the "Geoprocessing" tab, select "Buffer".
- See the "Buffer" screenshot in Figure A.1. In the "Input Feature" text box, click on the drop-down arrow and select "Cholera_households".
- Click on the browse button in the "Output Feature Class" text box. Navigate to the folder in which you want to save the output file; in the "Name" text box, type "Buf_ops_area" as the specified name for the buffer. The "Dissolve Type" should be set to "ALL".
- The buffer will be 10 000 m in radius.
- Leave the rest of the parameters at their default setting and click on "OK".

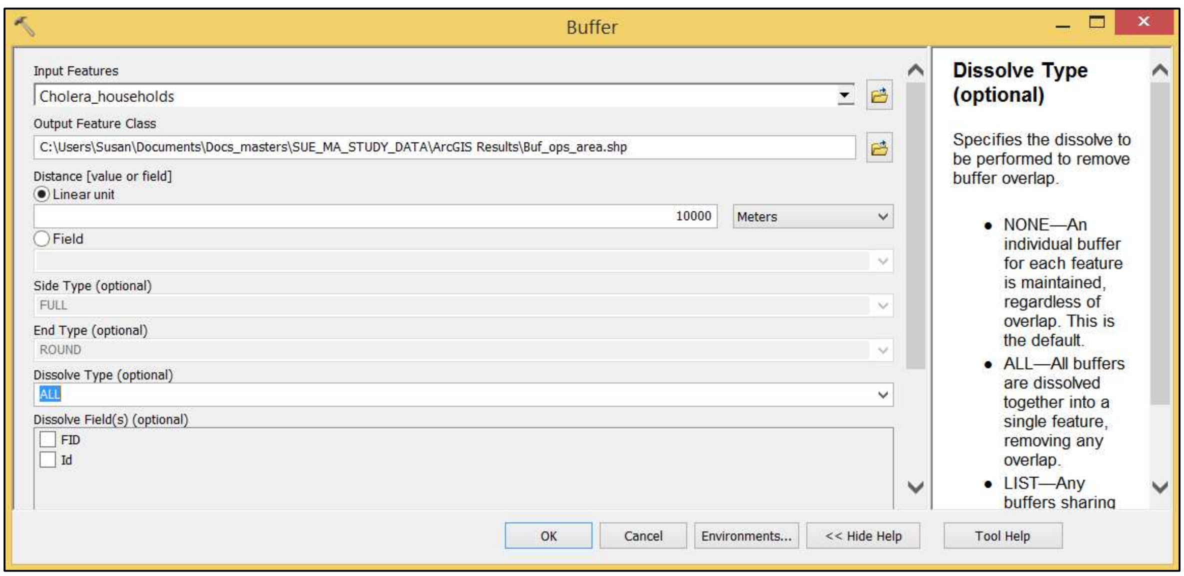


Figure A.1: ArcGIS Buffer

e. Input definition for QGIS 2.8.5 (Wien)

- QGIS is open and running.
- Make sure the Cholera_households layer is added to QGIS.
- Open the "Vector" tab and select "Geoprocessing" tools, "Buffer(s)".
- See the Buffer screenshot in Figure A.2. The "Input vector layer" is specified as "Cholera_households".
- Set "Segments to approximate" to 99.
- The "Buffer distance" is set to 10000.

- Tick the option to dissolve the buffer results and to add the results to canvas. The rest of the default settings are accepted.
- In the "Save As" text box, browse to your data, name the layer "Buffer_ops_area" and click on "Save".

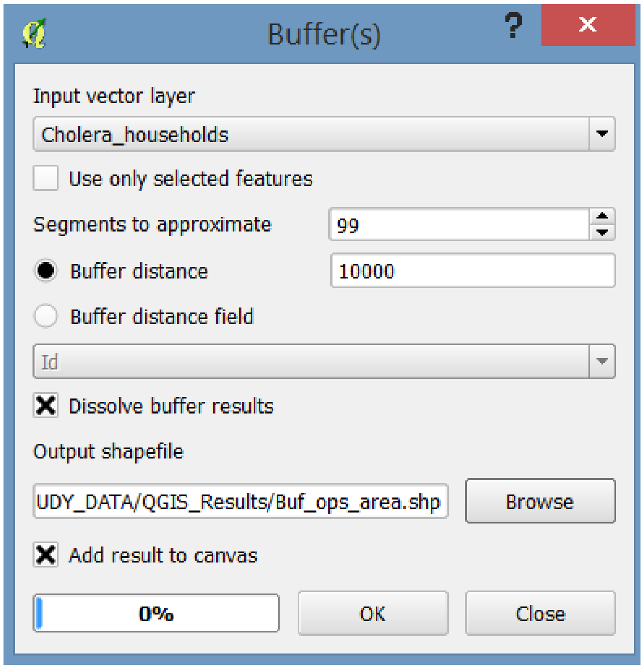


Figure A.2: QGIS Buffer

f. Output definition: No error log or message should display and the buffer must be visible in the map view window.

g. Remarks: When the buffer is successfully completed and visible, the properties of the layer can be changed.

10.1.2 Test 2: Hot spot analysis

a. Description: Hot spot analysis is an analytical tool with which to show areas of higher densities.

b. Test type: Positive – the function must succeed under the preconditions.

c. Preconditions

- The data must remain the same for all tests.
- The data (points) for the Cholera households/cases must be digitised before the test commences.
- Both the software products must be tested on the same computer hardware.

- Coordinate reference systems must be the same for both software products and for all data used during the test: *WGS84 UTM 35S*.
- In ArcGIS, the “Spatial Analyst” extension must be activated, and in QGIS the “Heatmap” plugin.

d. <u>Input definition for ArcGIS 10.2</u>

- Set the environment in ArcMap (Figure A.3). Click on “Processing Extent” and set the extent to “Same as Display”.
- Open “ArcToolbox” (Figure A.4). Expand “Spatial Analyst” and select and open the “Kernel Density” tool.

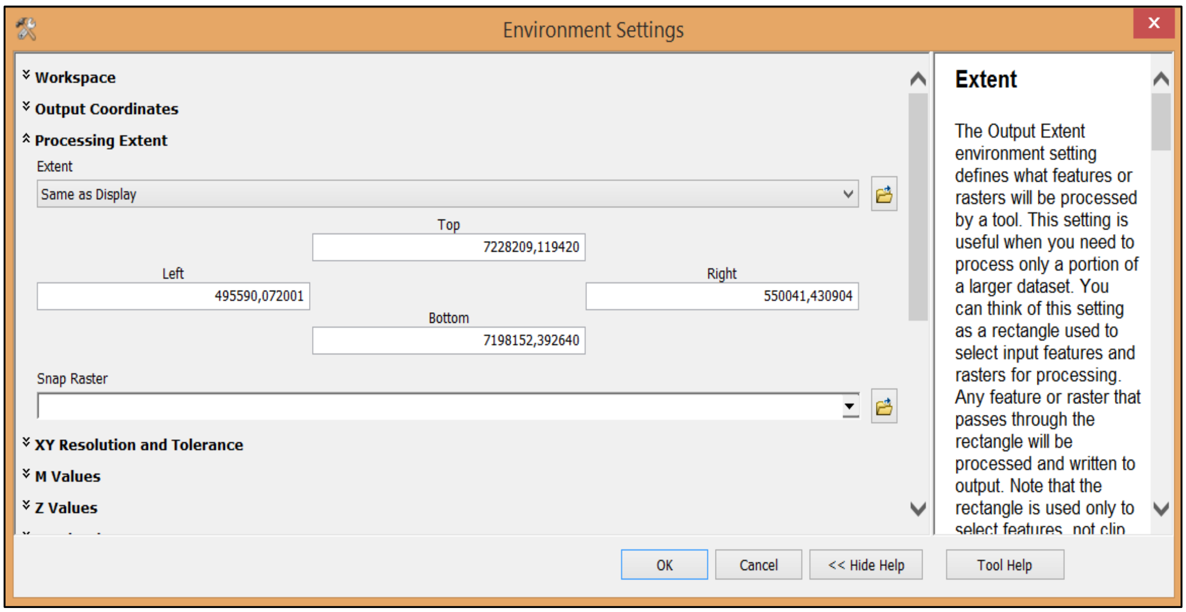


Figure A.3: ArcGIS Environment Settings

- See the Kernel Density screenshot in Figure A.5. In the “Kernel Density” tool, the researcher specified the “Input Point” as the “Cholera_households” layer that was digitised earlier.
- In the output raster, the file name and location of storage are specified.

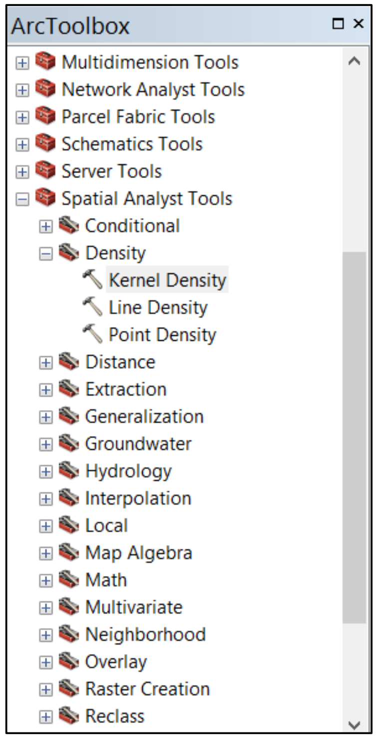


Figure A.4: ArcToolbox Kernel Density tool

- The search radius was set to 1 500 and the output cell size to 20.
- Once the results of this process were obtained, the properties of the hot spot layer were set in order to make it more presentable.
- The number of interval classes was set to 10 and the first class colour was set to no colour.

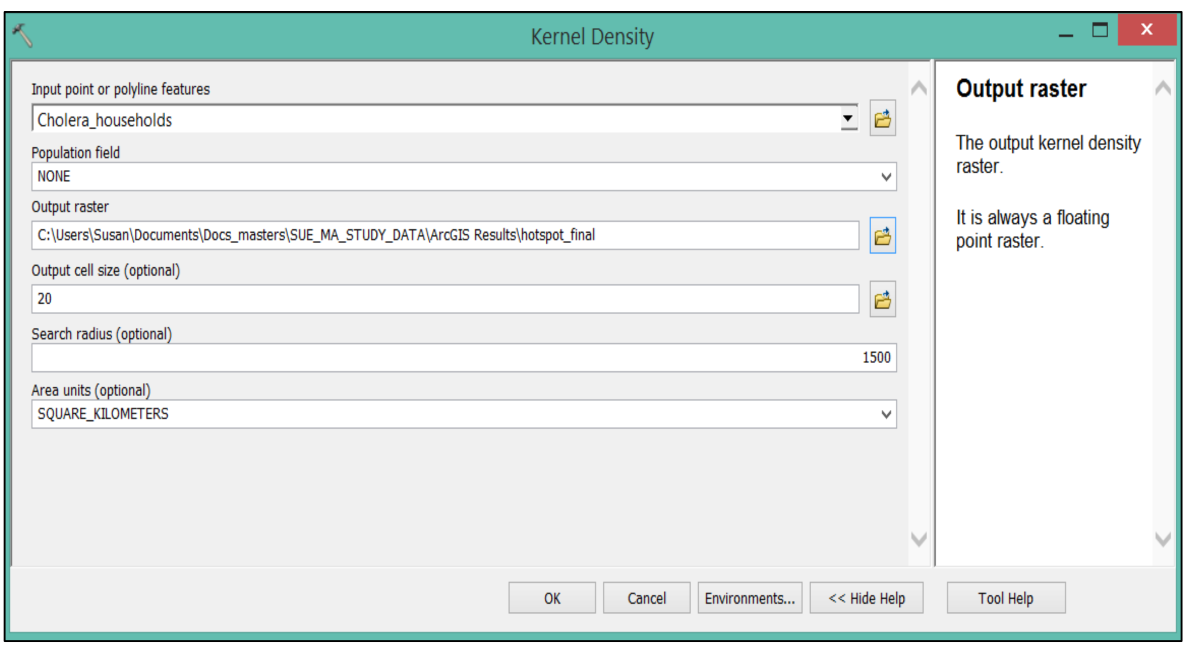


Figure A.5: ArcGIS Kernel Density

e. <u>Input definition for QGIS 2.8.5 (Wien)</u>

- Under the “Raster” tab, select the “Heatmap” plugin.

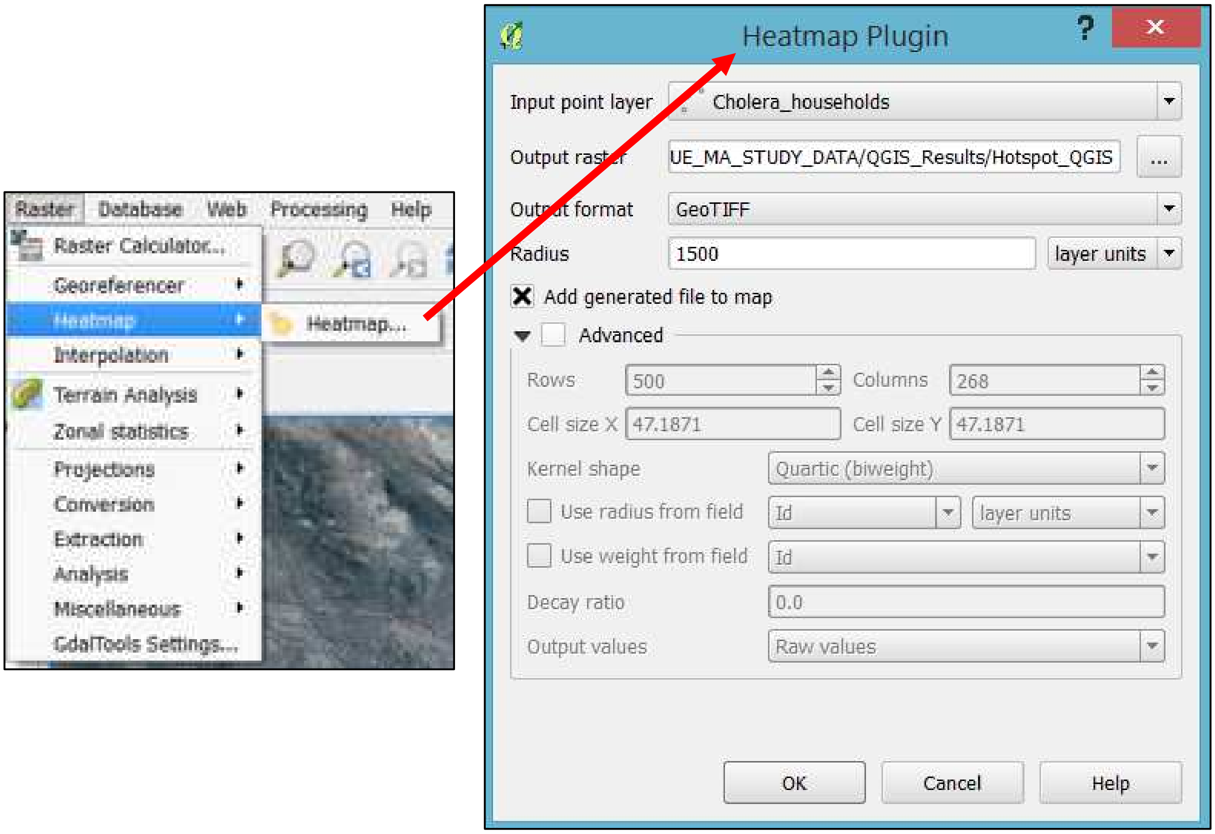


Figure A.6: QGIS Heatmap Plugin

- See the “Heatmap Plugin” screenshot in Figure A.6. In the Heatmap plugin, the researcher specified the “Input point layer” as “Cholera_households”, which was digitised earlier.
- In the “Output raster”, the file name and location of storage were specified.
- The radius was set to 1500.
- Once the results of this process were obtained, the researcher set the properties of the hot spot layer in order to make it more presentable. The render type was set to single band pseudocolor and an orange to red colour ramp was chosen. The mode was set to “Equal interval” and the number of interval classes was set to 10. The first class colour was set to no colour. (To achieve this, the first class opacity must also be set to 0).
- <u>Output definition</u>: No error log should display and the “hot spot map” must be visible in the map view window.

- Remarks: When the hot spot analysis is successfully completed and visible, the properties of the layer can be changed (Figure A.7).

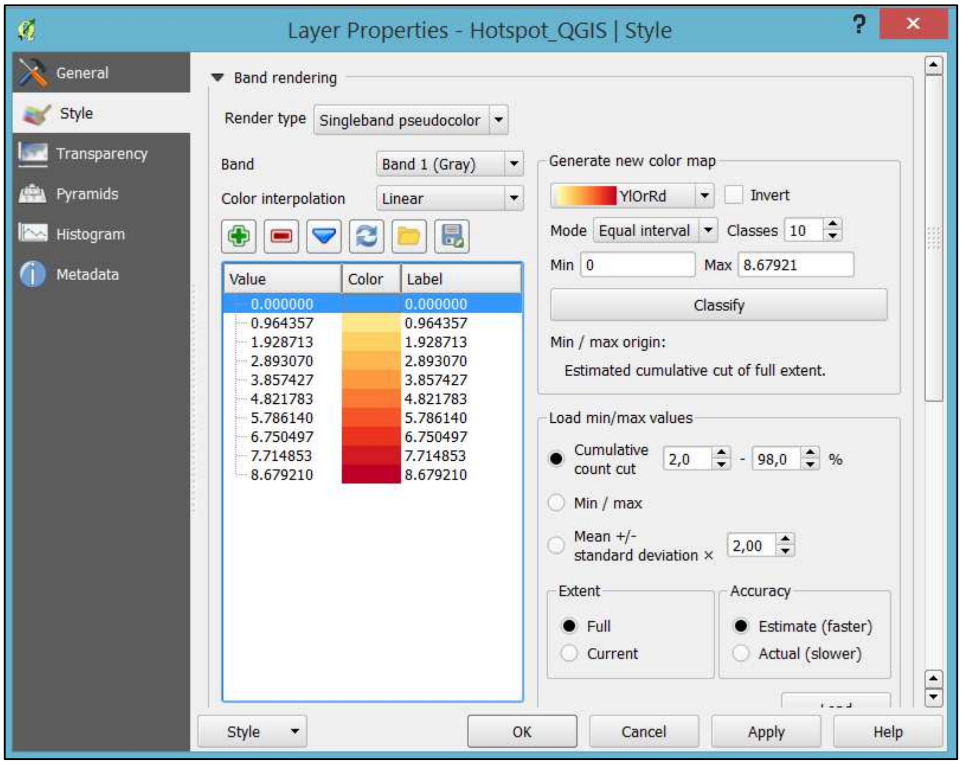


Figure A.7: Layer Properties – Hotspot_QGIS I Style

10.1.3 Test 3: Hillshade analysis

a. Description: Hillshading uses a surface raster (DEM) to create a shaded relief, bearing in mind the illumination source angle and shadows.

b. Test type: Positive – the function must succeed under the preconditions.

c. Preconditions

- The data must remain the same for all tests.
- A DEM of the study area is required.
- Both the software products must be tested on the same computer hardware.
- Coordinate reference systems must be the same for both software products and for all data used during the test: *WGS84 UTM 35S*.
- In ArcGIS, the “Spatial analyst” extension must be activated, and in QGIS the “Raster Terrain *Analysis”* plugin.

d. Input definition for ArcGIS 10.2:

- A DEM of the study area must be added to ArcMap.

- In "ArcToolbox", expand "Spatial Analyst Tools", expand the surface tools and then select the "Hillshade" tool (Figure A.8).

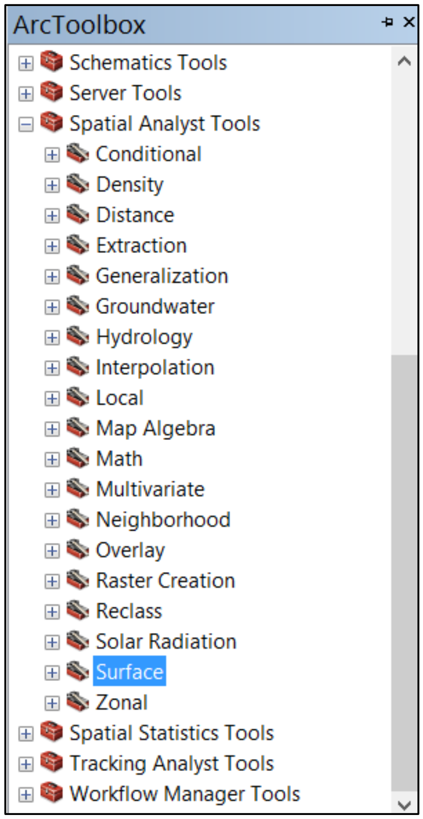


Figure A.8: ArcToolbox Surface tool

- See the Hillshade screenshot in Figure A.9. The input raster should be specified as the DEM. In the output raster, the file name is given as the name and it is saved in the correct file location.
- "Azimuth" was set to 315 and "Altitude" to 45.
- The Z factor was left as 1. Click on "OK".

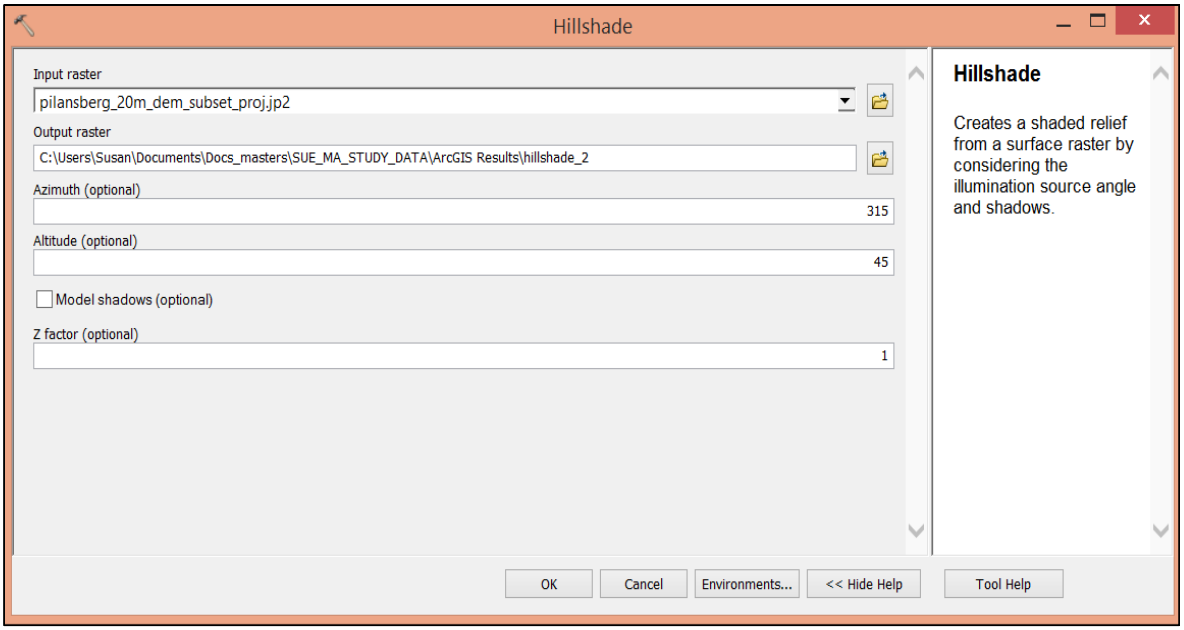


Figure A.9: ArcGIS Hillshade

e. <u>Input definition for QGIS 2.8.5 (Wien)</u>

- Add the DEM to QGIS.
- Open the "Raster" tab and select "Terrain Analysis". Then open "Hillshade".
- See the screenshot of Hillshade dialog box in Figure A.10. Specify the elevation layer as the DEM and specify the output layer by naming it and saving it in its correct file location.
- Specify "Azimuth" as 315 and the vertical angle as 45.
- The Z factor is left as 1.

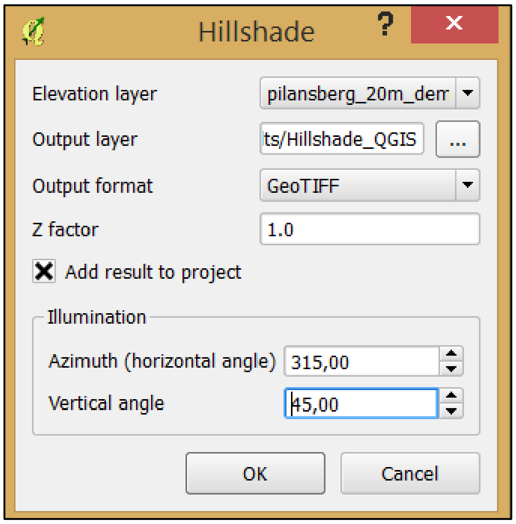


Figure A.10: QGIS Hillshade

f. Output definition: No error log should display and the hillshade analysis must be visible in the map view window.

g. Remarks: When the hot spot analysis is successfully completed and visible, the properties of the layer can be changed. The hillshade layer can be made transparent and the DEM placed underneath it for a different effect. The illumination angles can also be changed according to the user's preference.

10.1.4 Test 4: Creating flood layers using raster calculator

a. Description: The "Raster Calculator" tool was used to do calculations based on the general height above sea level in the area of operations.

b. Test type: Positive – the function must succeed under the preconditions.

c. Preconditions

- The data must remain the same for all tests.
- The topographical map must be placed as a background layer. The built-up layer must be added, labelled and set to no colour in order that only its labels must be visible.
- A DEM of the study area is required.
- The general height above sea level for the area of the river that was zoomed in on was 1 152 m above sea level. The height was obtained using the DEM.
- Both the software products must be tested on the same computer hardware.
- Coordinate reference systems must be the same for both software products and for all data used during the test: *WGS84 UTM 35S*.
- In ArcGIS, the "Spatial Analyst" extension must be activated.

d. Input definition for ArcGIS 10.2

- Add the DEM to ArcMap.
- In ArcToolbox (Figure A.11), expand "Spatial Analyst Tools", "Map Algebra" and then open the "Raster Calculator" tool.

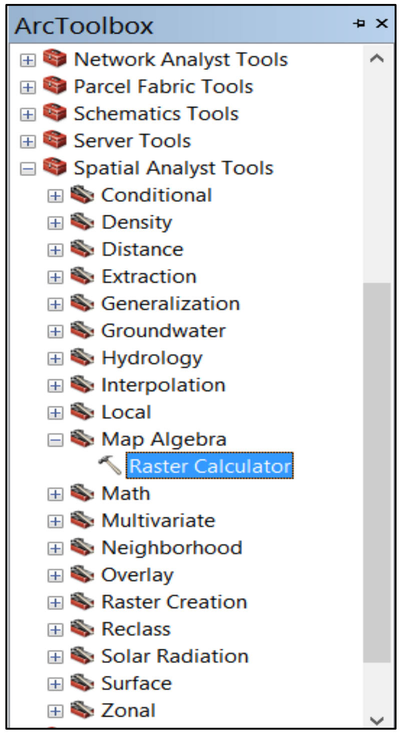


Figure A.11: ArcToolbox Raster Calculator tool

- See the screenshot of the raster calculator dialog box in Figure A.12. In "Raster Calculator" set the expression. Double-click on "Con", select the DEM, click on the smaller and equal to sign and enter 1153 as the flood level.
- Also set the output raster – state the name of the file and the location.

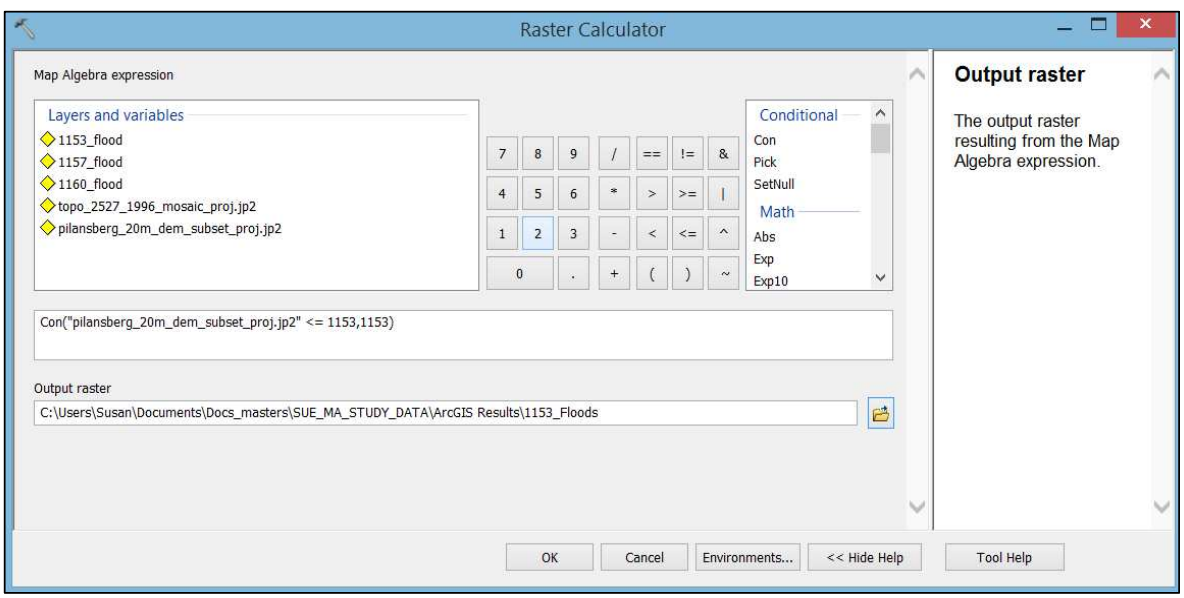


Figure A.12: ArcGIS Raster Calculator

- The previous two steps were repeated in order to do calculations for 1 157 m and 1 160 m above sea level.

- The colours of the results, as well as its transparency levels, can be altered to get the desired display result. The transparency was set to 70%.

e. <u>Input definition for QGIS 2.8.5 (Wien)</u>

- Add the DEM to QGIS as well as any other layers that you might need in your analysis.
- Under the “Raster” tab, open the “Raster calculator" tool.

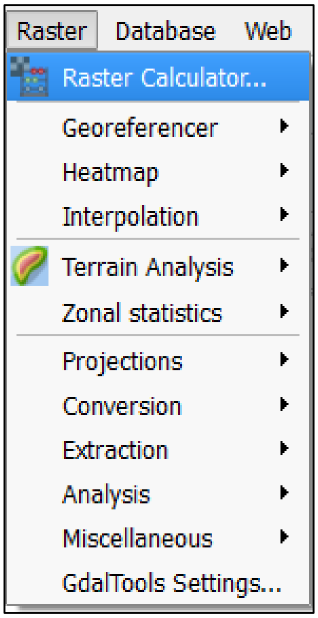


Figure A.13: QGIS Raster tab

- In the raster calculator dialog box, complete the expression as shown below (see the screenshot of the “Raster calculator” dialog box in Figure A.14) and specify the output file name and location. Click on “OK”.

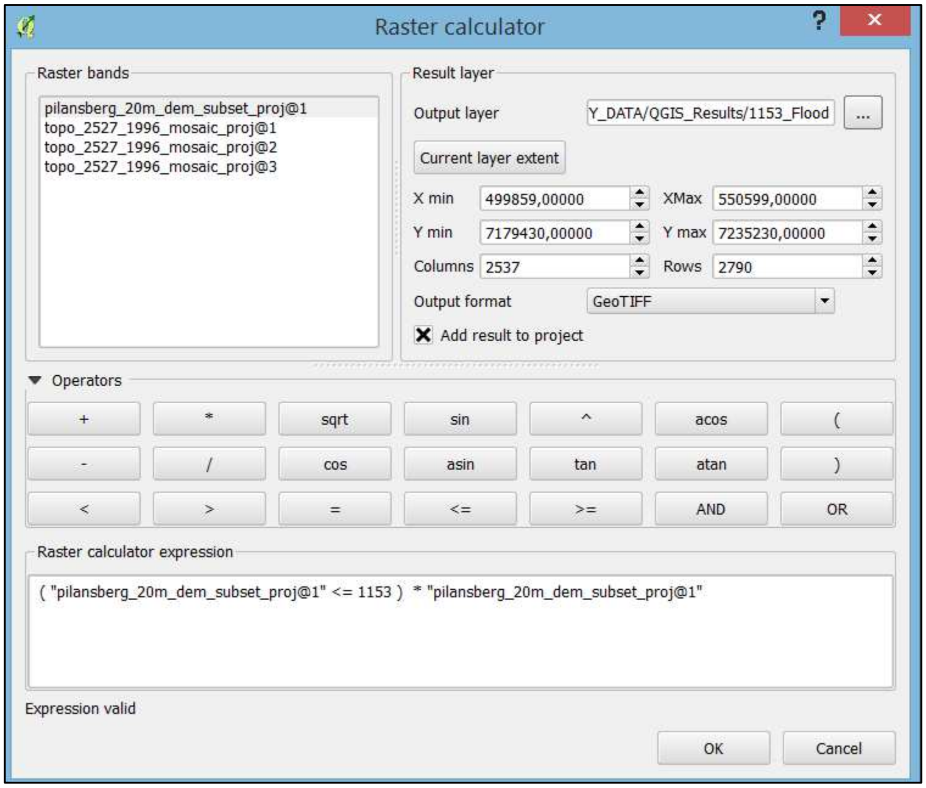


Figure A.14: QGIS Raster calculator

- The result displays as a single band greyscale image (black and white); therefore its properties are changed to a single band pseudocolor and then classified into two bands using equal intervals. The colours for the bands can then be chosen (Figure A.15).

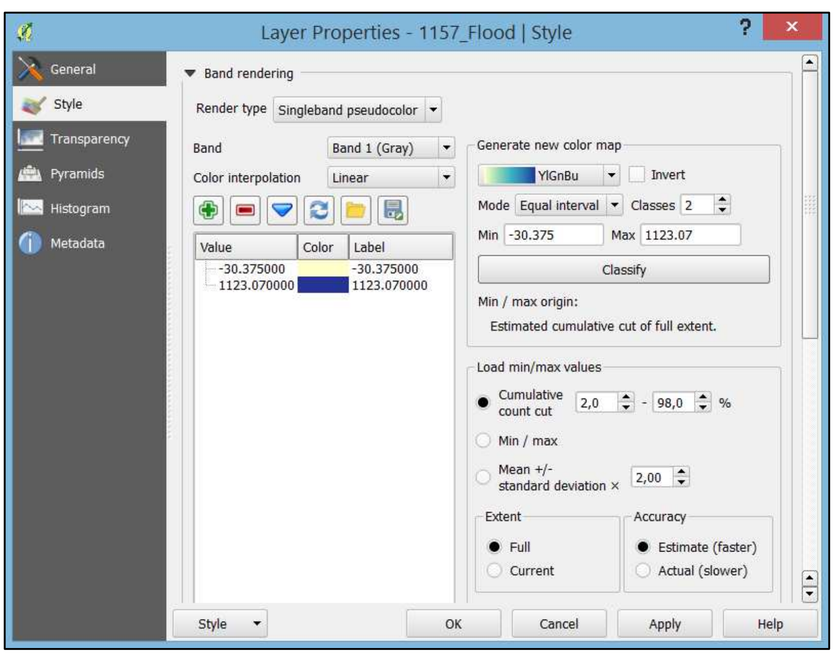


Figure A.15: QGIS Layer Properties – 1157_Flood I Style

- The steps (raster calculations) were repeated to determine flood levels at 1 157 m and 1 160 m above sea level. The new layer's transparency was set to 70%.

f. Output definition: No error log should display and the "flood layers" must be visible in the map view window.

g. Remarks: When the raster calculations are successfully completed and visible, the properties of the layer can be changed. Additional flood levels can also be calculated.

10.1.5 Test 5: Creating a visibility layer

a. Description: The "Raster calculator" tool was used to do calculations based on the general height above sea level in the area of operations.

b. Test type: Positive – the function must succeed under the preconditions.

c. Preconditions

- The data must remain the same for all tests.
- A DEM of the study area is required.
- Both the software products must be tested on the same computer hardware.
- Coordinate reference systems must be the same for both software products and for all data used during the test: *WGS84 UTM 35S*.
- In ArcGIS, the "Spatial Analyst" extension must be activated. When using ArcGIS 10.2, it is advisable to download the "Interactive Visibility" tool add-in. In QGIS, the "Viewshed analysis" plugin must be downloaded.
- The Madutle Primary School was chosen as the ideal HQ position, in view of the fact that it is located in the centre of the Cholera outbreak, has most of the infrastructure that the SANDF needs and has a sports field that can possibly serve as a helicopter landing zone. A separate point layer was created for this school that was used as the "observer point" for the visibility analysis.
- The symbology of the school and the Cholera_households layers must be changed to be more prominent once the visibility raster is added.

d. Input definition for ArcGIS 10.2

- Add the DEM and all other shapefiles necessary for this exercise.
- Certain fields must be added to the Madutle Primary School's (observer point) attribute table before attempting to do the visibility analysis. The researcher

included this step in the analysis, seeing that in a military scenario, the commander would prefer to specify the height of the observer point (in this case the height of the antenna for VHF radios), as well as the radius distance from the observer point. If, however, a user would only be interested in a visibility analysis from the current height of the observer point and would like to include the entire study area in the analysis, the "Viewshed" tool is sufficient. The researcher found that the downloaded "Interactive Visibility" tool add-in assisted in adding the observer input specifications in a more automatised and quicker way than adding fields to the attribute table by manually typing it in.

- Next the observer parameters in the "Interactive Visibility" add-in were expanded and completed. (See the "Observer Parameters" screenshot in Figure A.16). This step automatically adds the fields to the MadutleP_School layer, which means that they are then ready to be used as observer parameters in the "Visibility analysis" tool. (See screenshot of the MadutleP_School attribute table in Figure A.17).
- The radius from the HQ was specified as 20 000 m and the height of the antenna was specified as 10 m. The rest of the default values were accepted.

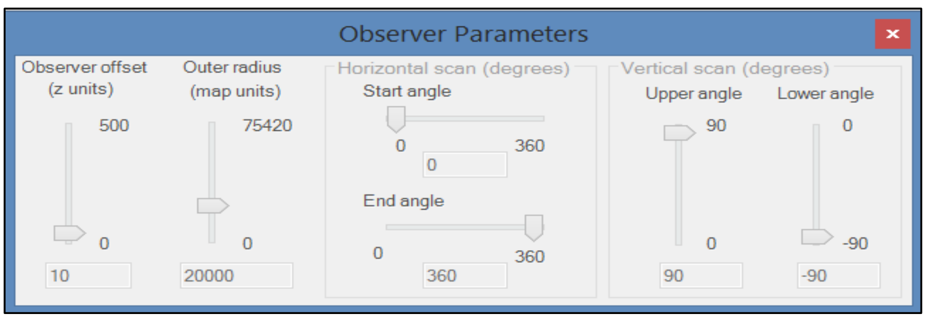


Figure A.16: ArcGIS Observer Parameters

- Open "ArcToolbox", expand the 3D Analyst tools and open the "Visibility" tool (Figure A.18).

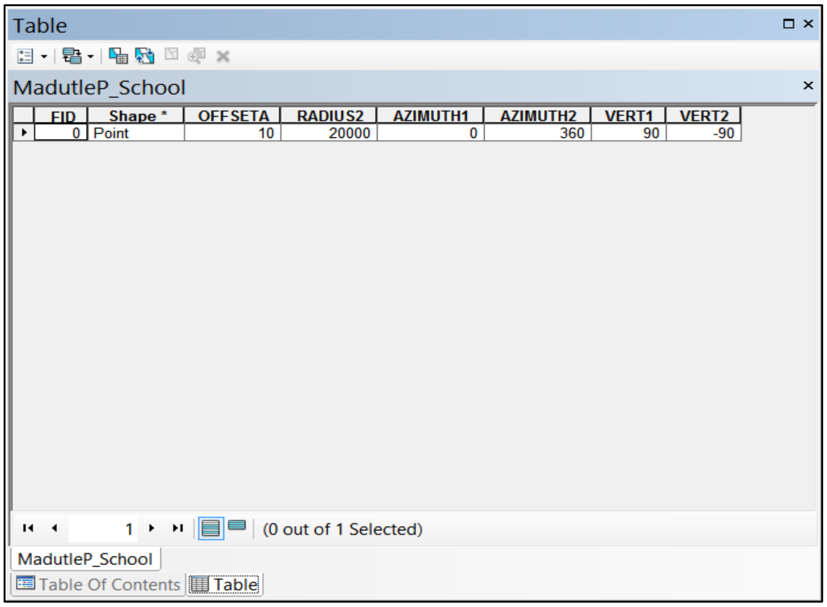


Figure A.17: MadutleP_School table

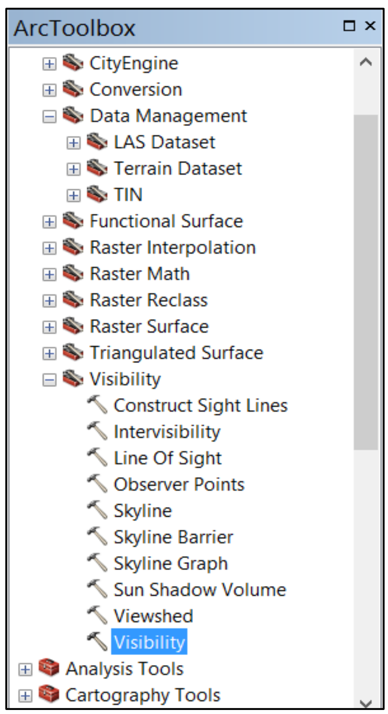


Figure A.18: ArcToolbox Visibility tool

- See the screenshots for the “Visibility" tool in Figure A.19. The DEM is specified as the input raster and the MadutleP_School point layer as the input point.
- The output raster was named (Visibility_HQ) and saved to the correct file location. The rest of the default values in ArcMap were accepted.

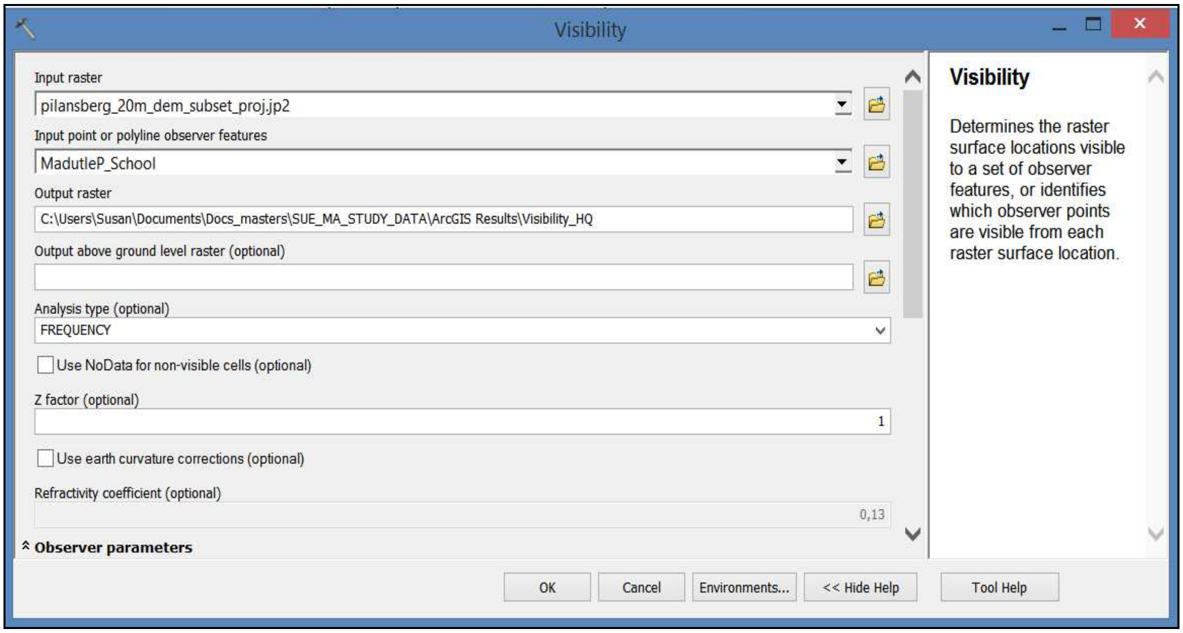


Figure A.19: ArcGIS Visibility dialog box (a)

- Next the observer parameters in the "Visibility" tool were expanded and completed. Since the fields were correctly completed by means of the "Interactive Visibility" tool, they are now available for selection by way of drop-down arrows. The radius from the HQ was specified as 20 000 m and the height of the antenna was specified as 10 m. The rest of the default values were accepted. Click on "OK".

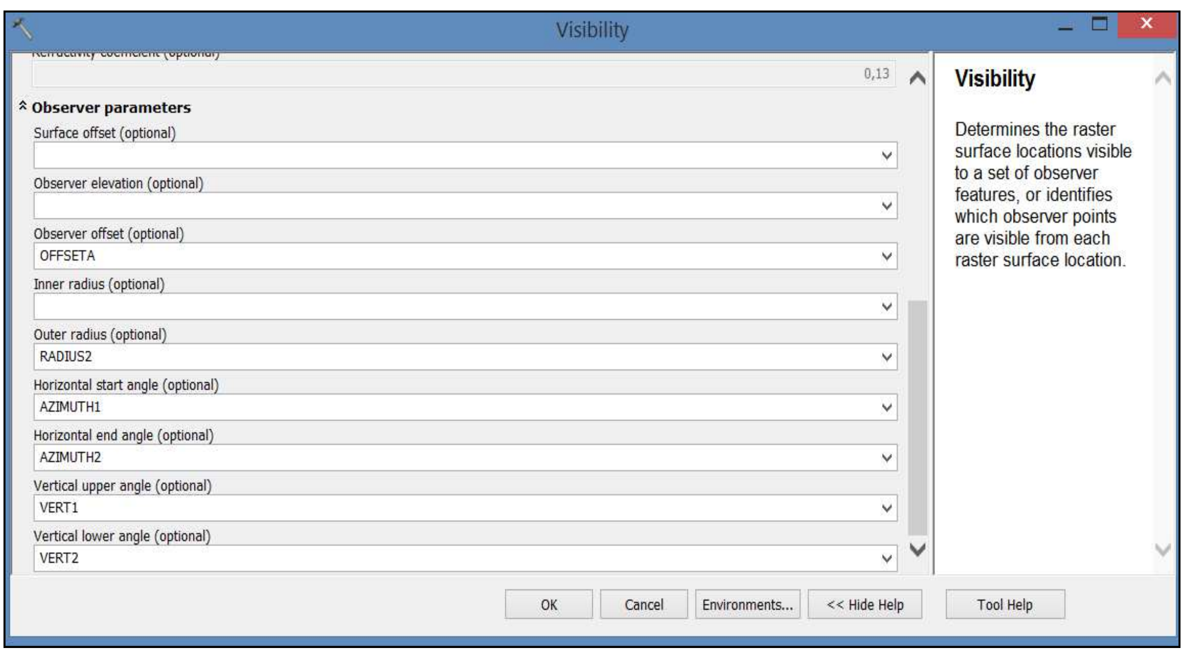


Figure A.19: ArcGIS Visibility dialog box (b)

e. <u>Input definition for QGIS 2.8.5 (Wien)</u>

- Add the relevant shapefiles and the DEM to QGIS.
- Click on the "Viewshed analysis" plugin to open the Viewshed analysis dialog box.
- See the screenshot of the "Advanced viewshed analysis" plugin in (Figure A.20). Specify the search radius as 20 000 m and the observer height as 10 m.

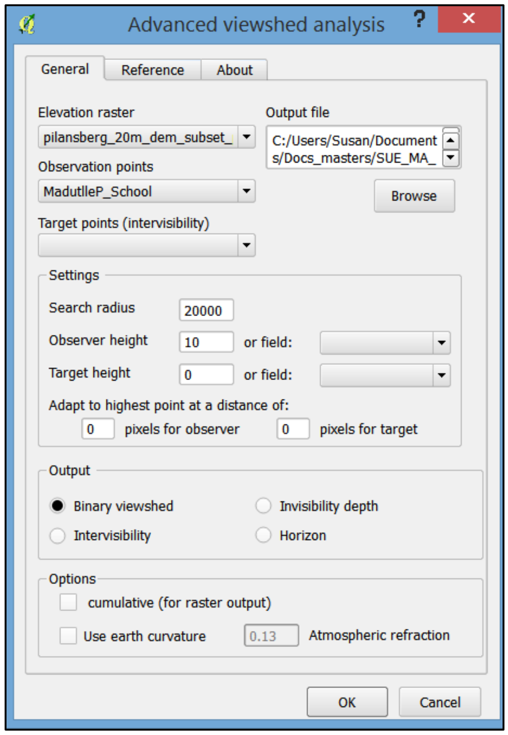


Figure A.20: QGIS Advanced Viewshed analysis

- Select the option to create a binary viewshed and leave the rest of the values at the defaults. Click on "OK".
- The output raster appears as a black and white image. The researcher changed the layer properties to match the green and red colours specified in ArcMap. The band was changed to single band pseudocolour and the equal intervals method was used to classify two classes. The labels were changed to "Visible" and "Not Visible". (See the screenshot of the Layer Properties dialog box in Figure A.21).

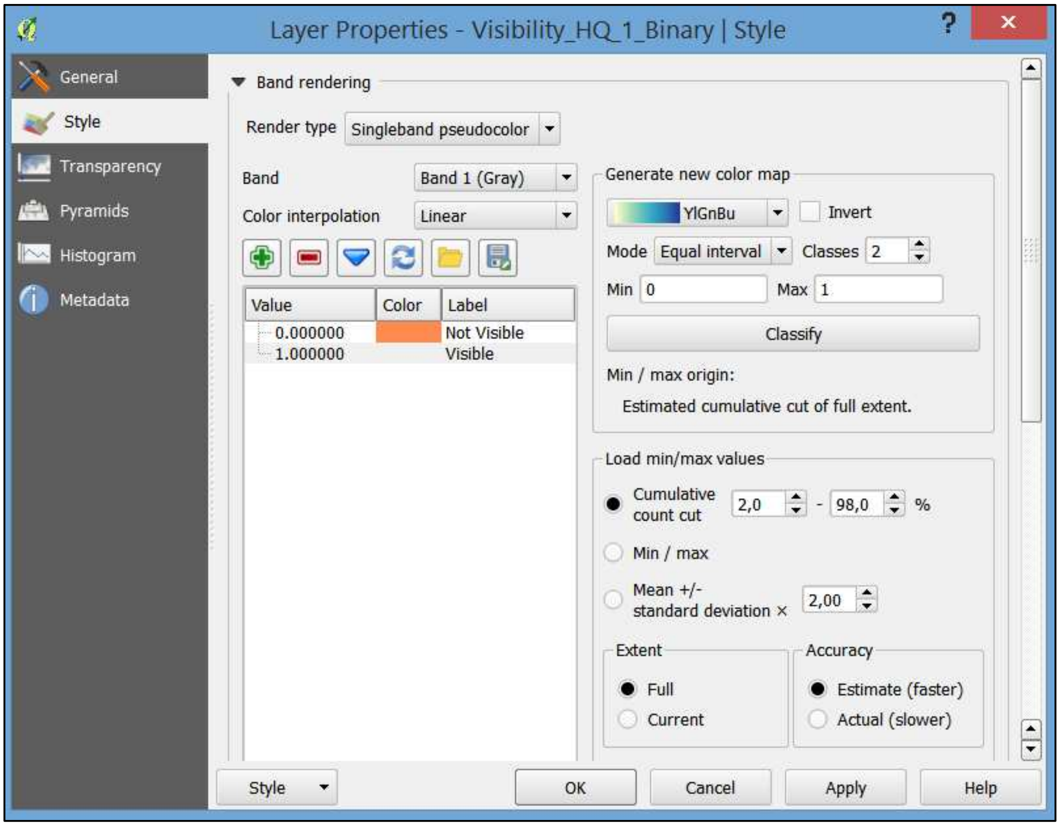


Figure A.21: Layer Properties - Visibility_HQ_1_Binary I Style

f. <u>Output definition</u>: No error log should display, and the “visibility layers” must be visible in the map view window.

g. <u>Remarks</u>: When the raster calculations are successfully completed and visible, the properties of the layer can be changed. The areas that are not visible can be set to “no colour” in order to have the 1:50 000 topographical map as background.

10.1.6 Test 6: Creating layers for helicopter landing zones (HLZs), hospitals and medical post (HQ), police stations, roadblocks and water purification plants

a. <u>Description</u>: Since the SANDF would normally first use existing infrastructure (in order to save time and costs), a search was first done in most of these cases in order to find existing infrastructure. If existing infrastructure were found to be insufficient, additional options were added to the layer. These steps were performed by doing an attribute search as well as with digitising. The symbology was then changed to make it more appropriate and legible.

b. Test type: Positive – the function must succeed under the preconditions.

c. Preconditions

- The data must remain the same for all tests.
- Both the software products must be tested on the same computer hardware.
- Coordinate reference systems must be the same for both software products and for all data used during the test: *WGS84 UTM 35S*.
- In QGIS, point symbols (in .SVG format) must be downloaded from the Internet and added to the SVG folder in QGIS' program files.
- The same coordinates must be used to digitise features in both ArcGIS and QGIS.

d. Input definition for ArcGIS 10.2

i. HLZs

✓ The POI layer was added to ArcMap.

✓ For HLZs, the POI layer was used in order to locate existing helipads in the area of operations. Two additional HLZs were digitised; one using the sports ground at the Madutle Primary school and the other using a sports ground in the north, northeast from the Joy Christian Church. The SPOT 6 image was used to identify the sports fields. The researcher adjusted the styling for the HLZ layer and other visible layers.

✓ See the screenshot of the "Select By Attributes" dialog box in Figure A.22. The Select by Attributes tab was used in order to identify existing Helipads.

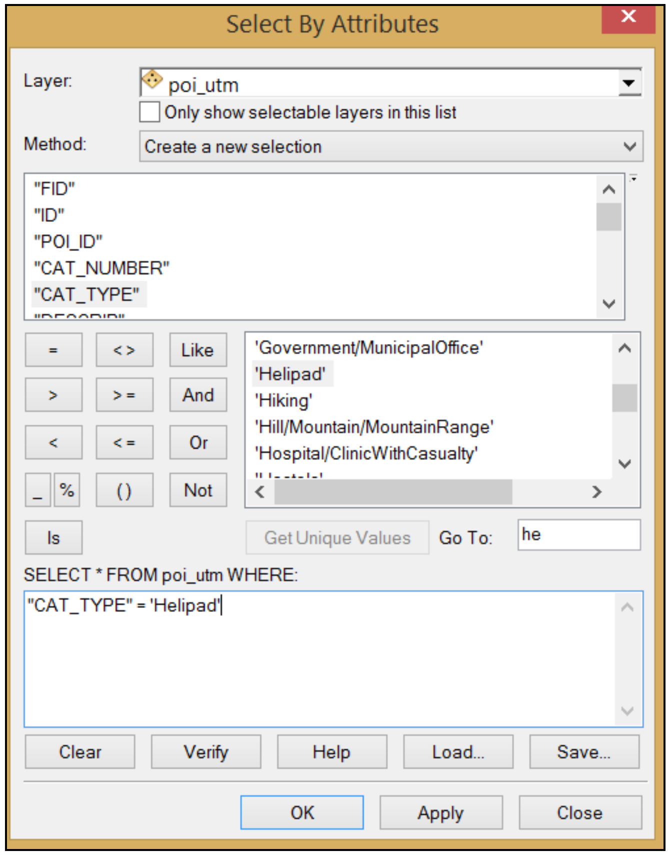


Figure A.22: ArcGIS Select By Attributes (HLZs)

- ✓ The HLZ shapefile (layer) was created in ArcCatalog as a new shapefile. The existing coordinate system was imported as a reference system for the new point layer.
- ✓ The selected helipad, as well as the sports ground at the Madutle Primary School (HQ position), was then selected as the other HLZ position; both were digitised to the newly created shapefile.
- ✓ In order to digitise the new points, an edit session must be started in ArcMap. Select "Editor", then "Start Editing". Specify the HLZ as the layer to which points will be added (See Figure A.23).

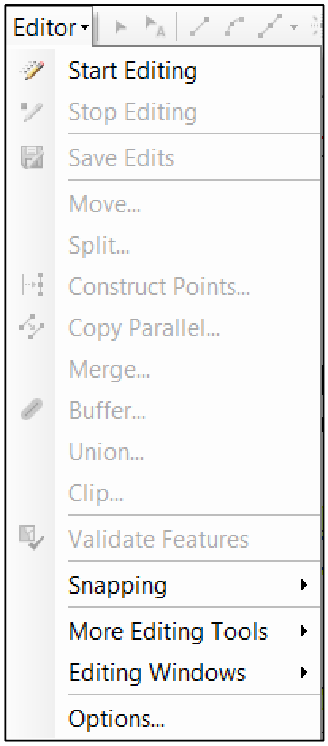


Figure A.23: ArcGIS Editor

- ✓ When done with capturing the two points, remember to "Save" the "Edits" and "Stop Editing".
- ✓ Appropriate point symbols for the HLZs were chosen in the layer properties.
- ✓ The styling for roads and rivers was also changed in order to include only perennial rivers and main and secondary roads.

ii. Hospitals/medical post

- ✓ The POI layer was added to ArcMap.
- ✓ The existing hospital in the area of operations (George Stegmann Community Hospital) was selected from the POI layer (by using the "Select By Attribute" tab - see screenshot in Figure A.24) and the current HQ position (Madutle Primary School) was chosen as the medical post for the SAMHS. See previous steps for creating and digitising new point layers. (Refer to the HLZ steps.) Two points are therefore indicated on the map as possible medical facilities.

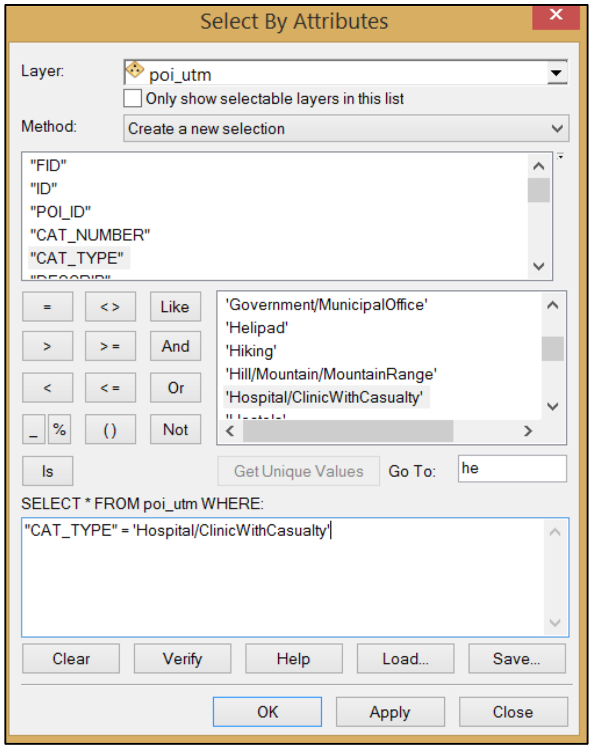


Figure A.24: ArcGIS Select By Attributes (Hospitals/medical post)

iii. Police Stations

- ✓ The POI layer was added to ArcMap.
- ✓ Existing police stations were selected by using the “Select By Attributes” tab. (See the Select By Attributes screenshot in Figure A.25). They were then digitised to a police stations layer. (See detailed steps in the HLZ layer.) The same steps were followed to create police stations by selecting existing police stations from the POI layers. (Again, refer to the steps followed to create the HLZ.)

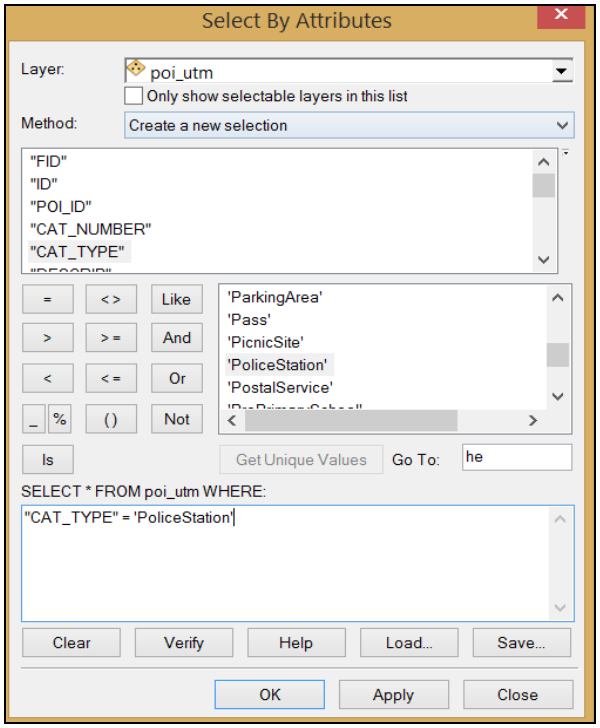


Figure A.25: ArcGIS Select By Attributes (Police Stations)

iv. Roadblocks

- ✓ The northern and southern crossings of the main road with the border of the area of operation were digitised in order to indicate where roadblocks to the area would be placed.
- ✓ Labels were also added to indicate which roadblock will be manned by Platoon 1 and which one by Platoon 2. All other secondary roads will be closed.

v. Water purification plants

- ✓ Make sure that the DEM is added to ArcMap.
- ✓ Set the styling in the properties of the river layer in order to make only perennial rivers visible on the map view.
- ✓ In ArcToolbox, expand “Spatial Analyst” tools then expand the “Surface” tools and open the “Slope” tool (Figure A.26).

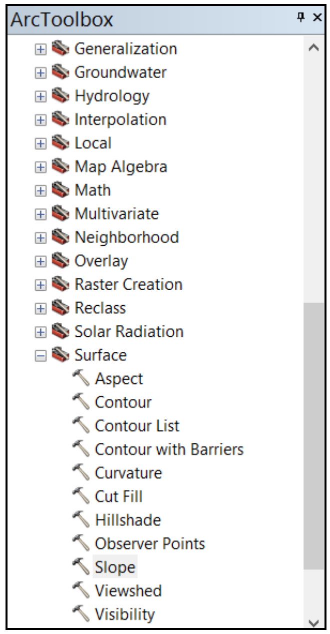


Figure A.26: ArcToolbox Slope tool

- ✓ See the Slope dialog box in Figure A.27. The input raster should be specified as the DEM.
- ✓ Specify the file location for storage as well as the name in the output raster.
- ✓ The output measurement was specified as “Degree”.
- ✓ The rest of the default values were accepted. Click on “OK”.

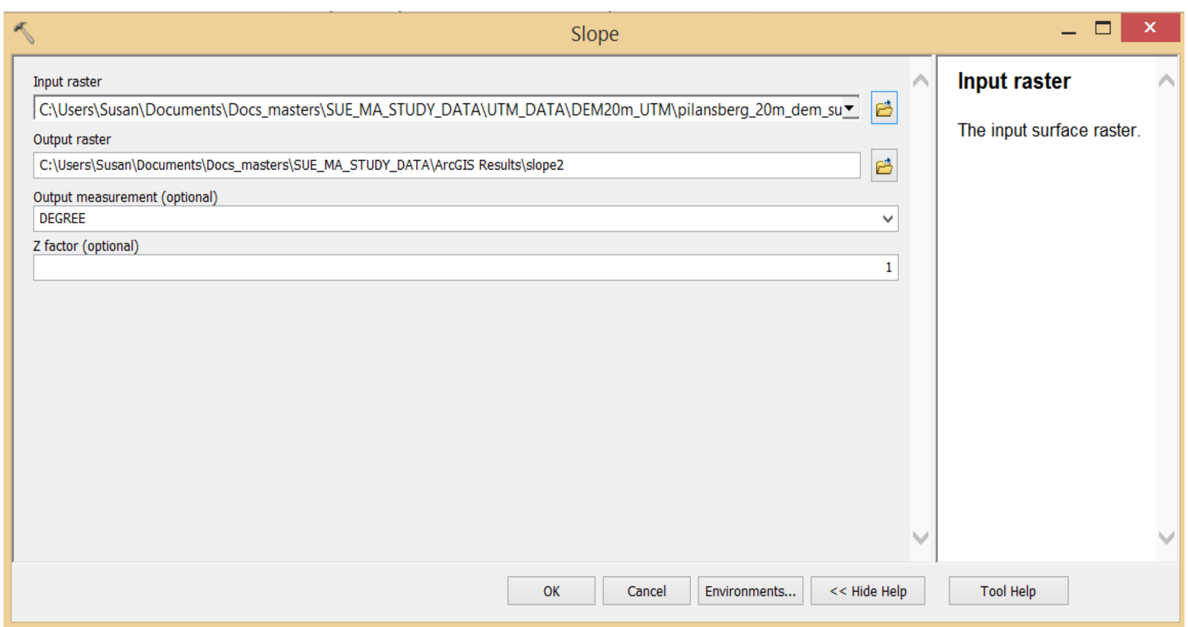


Figure A.27: ArcGIS Slope dialog box

- ✓ Flat areas (less than a five-degree slope) close to perennial rivers were zoomed in on and inspected. Four suitable areas were chosen for the placement of water purification plants 1 to 4.
- ✓ A new point shapefile was created. The four water purification plants were then digitised at the location identified in the previous step.
- ✓ The symbology of the purification plant was then changed to a more suitable symbol.
- ✓ A new "Name" field was added to the attribute table for the water_pur_plant. The individual plants were specified as Plant 1, Plant 2, Plant 3 and Plant 4.
- ✓ Labels for the water_pur_plant layer were switched when using the name field, and a white halo was place around it.

e. <u>Input definition for QGIS 2.8.5 (Wien)</u>

i. HLZ

- ✓ The POI layer was added to QGIS (Figure A.28).

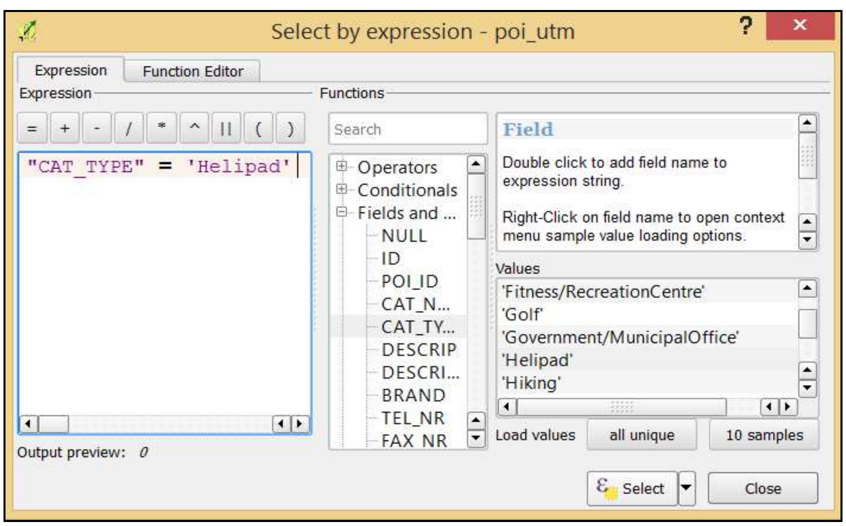


Figure A.28: QGIS Select by expression – poi_utm

- ✓ In order to firstly identify the existing helipads, the attribute table of the POI layer was opened. The  select feature, using an expression button, was used in order to select the desired attributes in order to identify existing helipads.

- ✓ The HLZ shapefile (layer) was created by using the “New Shapefile Layer” button (Figure A.29). The existing coordinate system was imported as a reference system for the new point layer.

Figure A.29: QGIS New Shapefile Layer…

- ✓ The selected helipad, as well as the sports ground at the Madutle Primary School (HQ position), was then selected as the other HLZ position, and both were digitised to the newly created shapefile.
- ✓ In order to digitise the new points, an edit session must be started in QGIS. Click on the “Toggle editing” button to start an edit session in QGIS. Specify/highlight the HLZ as the layer to which points will be added.
- ✓ When done with capturing the two points, remember to “Save the Edits” and “Stop Editing”. In order to stop editing, click on the “Toggle editing” button again.
- ✓ The symbology of the HLZ was changed to make it more appropriate. The researcher downloaded extra point symbol files from the Internet (.SVG files) and copied and pasted it into the SVG folder in QGIS’ program files. This was done to increase the range of available point symbols. Downloadable symbols can be found on the following websites:
  1. http://www.flaticon.com;
  2. http://www.mapbox.com/maki; and
  3. http://www.sjjb.co.uk/mapicons/contactsheet.

ii. Hospitals/medical post

- ✓ The POI layer was added to QGIS.
- ✓ In order to firstly identify the existing hospitals in the area of operations, the attribute table of the POI layer was opened. The select feature,

using an expression button, was used to select the desired attributes in order to identify existing hospitals.

- ✓ The existing hospital in the area of operations (George Stegmann Community Hospital) was selected from the POI layer, and the current HQ position (Madutle Primary School) was chosen as the medical post (Figure A.30) for the SAMHS. (See previous steps for creating and digitising a new point layer. Refer to the HLZ steps.) Two points are therefore indicated on the map as possible hospitals/medical post.

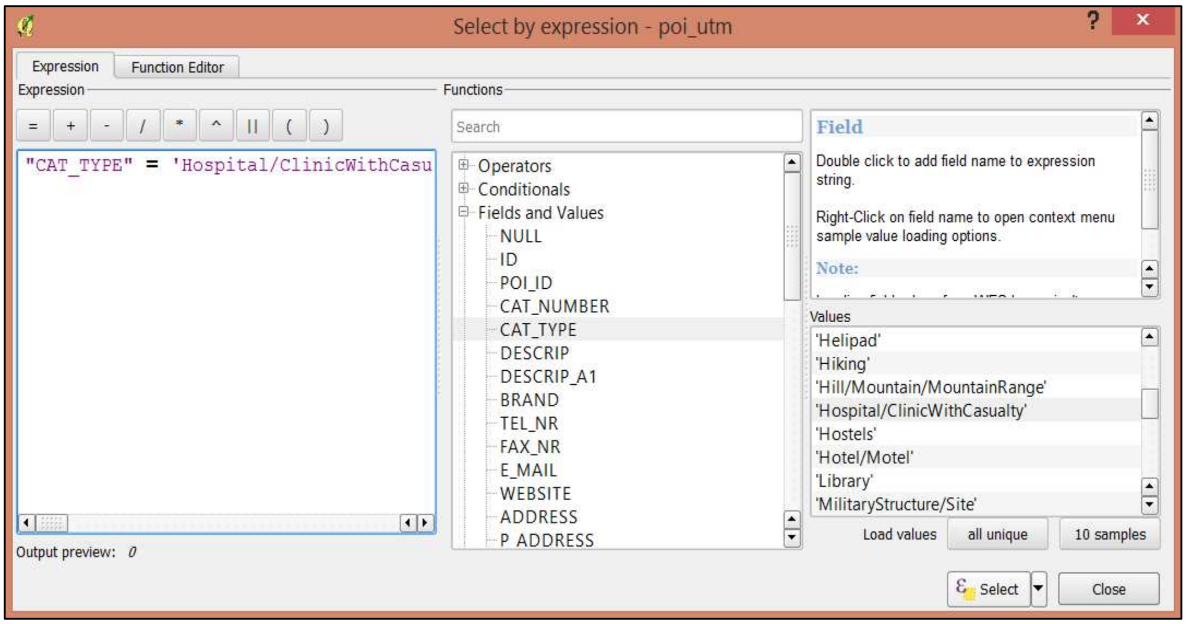
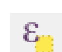


Figure A.30: QGIS Select by expression – poi_utm

iii. *Police stations*

- ✓ The POI layer was added to QGIS.
- ✓ Existing police stations were selected using the  select feature by using an expression button in the attribute table of the POI layer. (See “Select by expression” screenshot in Figure A.31).
- ✓ They were then digitised to a police stations layer. (See detailed steps by referring to the steps performed in the HLZ layer.)

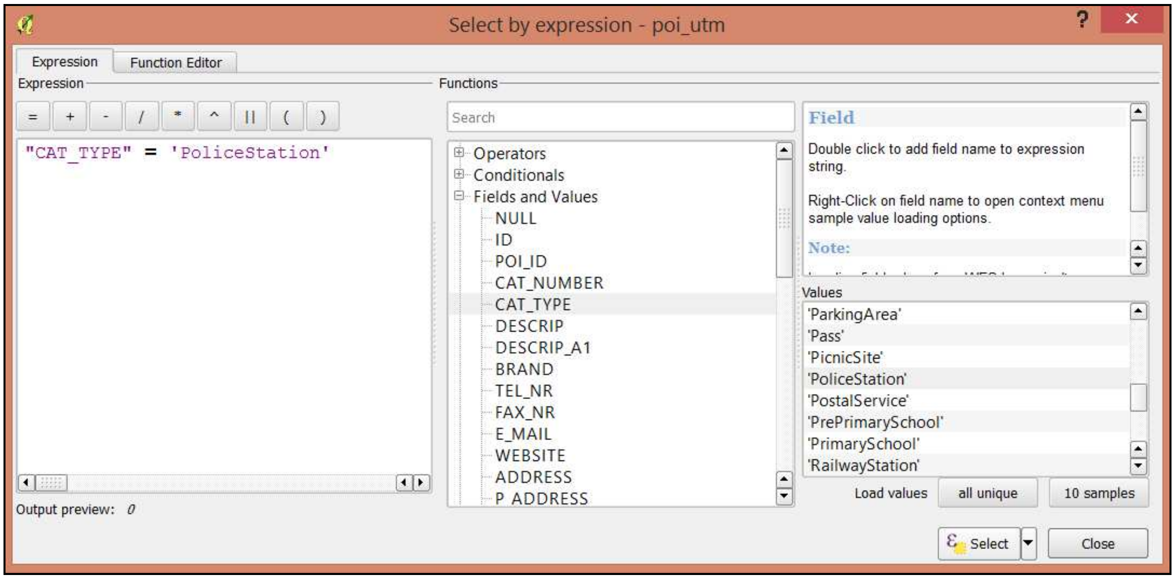


Figure A.31: QGIS Select by expression – poi_utm

iv. *Roadblocks*

- ✓ The northern and southern crossings of the main road with the border of the area of operation were digitised in order to indicate where roadblocks to the area would be placed.
- ✓ Labels were also added to indicate which roadblock will be manned by Platoon 1 and which one by Platoon 2. All other secondary roads will be closed.

v. *Water purification plants*

- ✓ Make sure that the DEM is added to QGIS.
- ✓ Set the styling in the properties of the river layer in order to make only perennial rivers visible on the map view.
- ✓ Under the “Raster” tab, select “Terrain Analysis” and open the “Slope” tool.

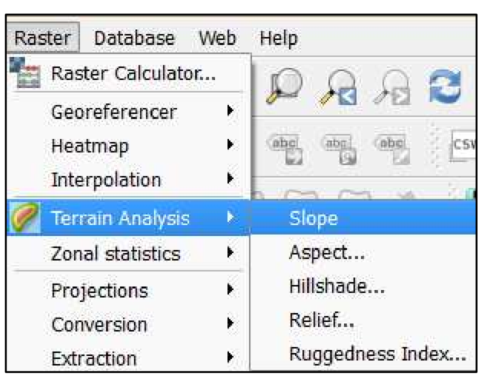


Figure A.32: QGIS Slope tool

- ✓ See the Slope dialog box in Figure A.33. The input raster should be specified as the DEM.
- ✓ In the output raster, specify the file location for storage as well as the name.
- ✓ The rest of the default values were accepted. Click on “OK”.

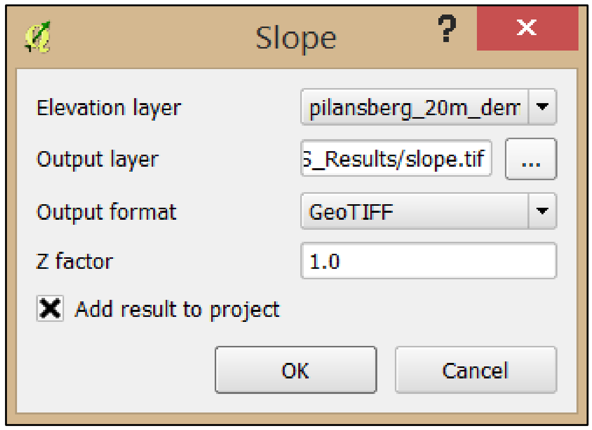


Figure A.33: QGIS Slope

- ✓ The result appears as a single band greyscale raster image. (See screenshot in Figure A.34.)

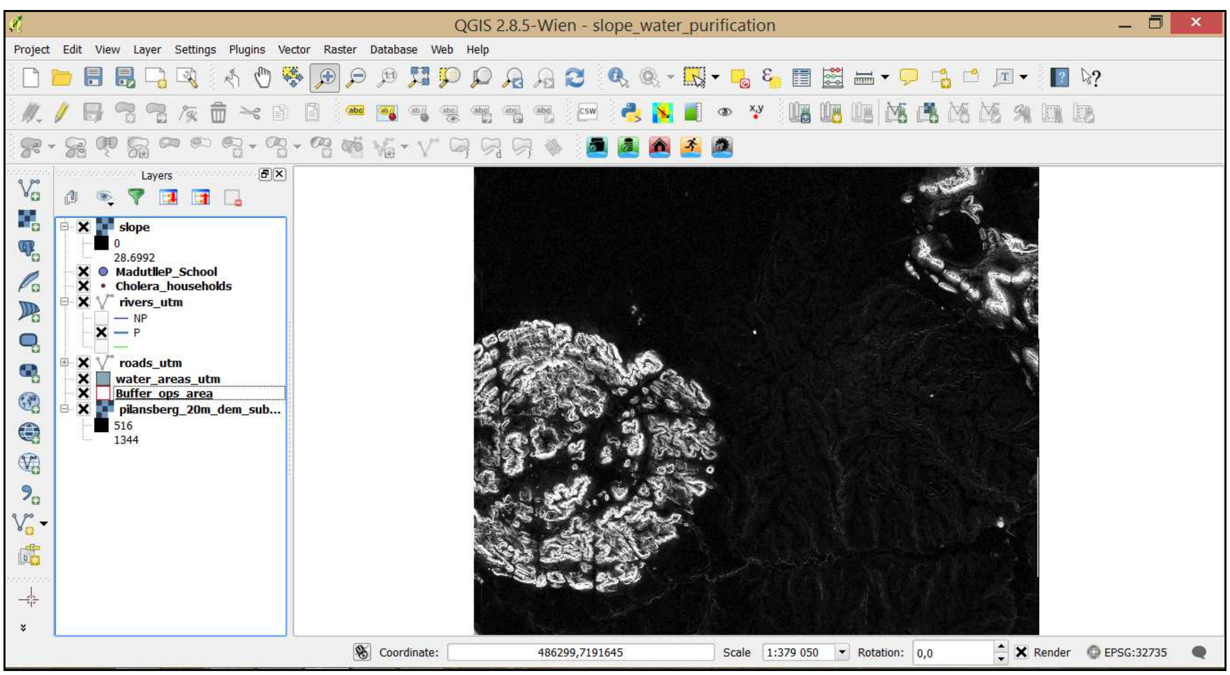


Figure A.34: QGIS Greyscale raster image of slope analysis

- ✓ The layer properties of the slope result must be changed. Set the render type to single band pseudocolor, and then classify the layer into nine classes using the equal interval method. The red to green colour ramp was used and inverted.

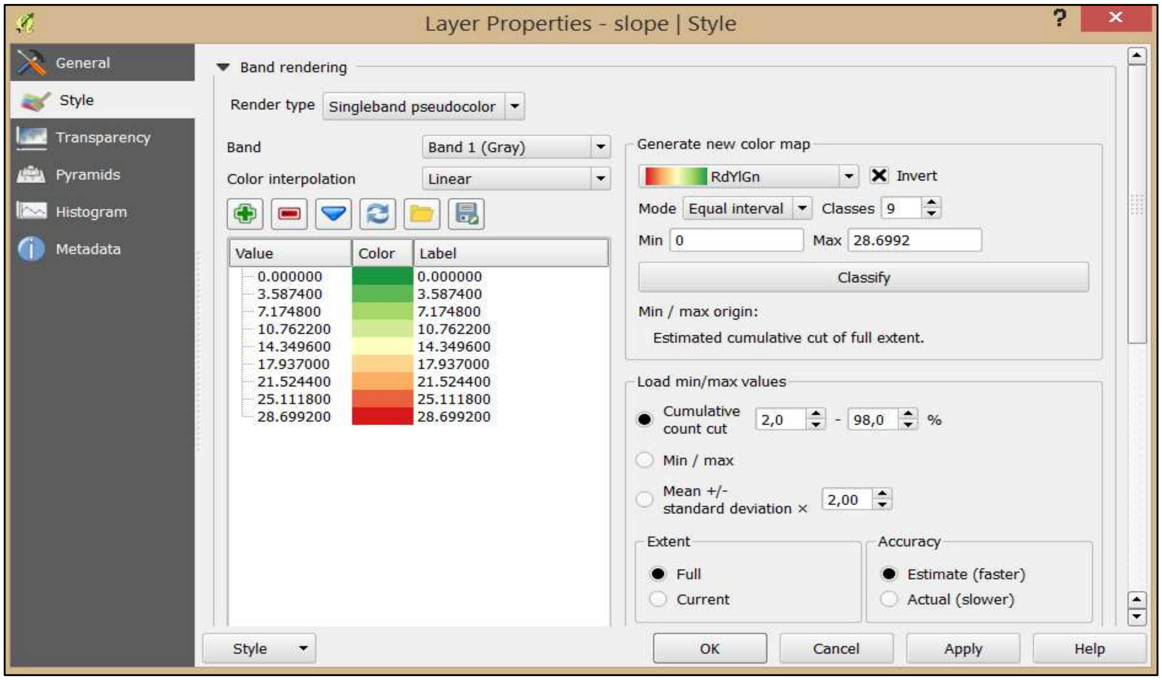


Figure A.35: QGIS Layer Properties – slope I Style

- ✓ Flat areas (less than a five-degree slope) close to perennial rivers were zoomed in on and inspected. Four suitable areas were chosen for the placement of water purification plants 1 to 4.
- ✓ A new point shapefile was created. The four water purification plants were then digitised at the locations identified in the previous step.
- ✓ The symbology of the purification plant was then changed to a more suitable symbol.
- ✓ A new "Name" field was added to the attribute table for the water_pur_plant. The individual plants were specified as Plant 1, Plant 2, Plant 3 and Plant 4.
- ✓ Labels for the water_pur_plant layer were switched when using the name field, and a white halo/buffer was placed around it.

f. Output definition: No error log should display, and the various different layers must be visible in the map view window.

g. Remarks: When the raster calculations are successfully completed and visible, the properties of the layers can be changed.

11. RESPONSIBILITIES

11.1 Developers

The developers will not be involved in this testing, given that this will be a user acceptance test.

11.2 User representative

The user representative is the researcher herself, Mrs SJ Henrico.

12. RISKS AND CONTINGENCIES

The tester (the researcher) was not deployed in an operational area while performing the software tests and was therefore not exposed to the challenges that GIS operators might experience during such an operation.

13. APPROVALS

Name	Title	Date	Signature
Prof S Coetzee	Associate Professor	16-08-2016	SMCoetzee
Mr AK Cooper	Extraordinary Lecturer, University of Pretoria, & Principal Researcher, CSIR	16-08-2016	

APPENDIX B: LETTER OF REQUEST

LETTER OF REQUEST

To: Mr Etienne Louw
General Manager TomTom Africa

18 November 2015

From: Susan Henrico (susanhenrico@webmail.co.za)
MA Geography Registered Student: University of Pretoria

Mr Etienne Louw

PERMISSION TO ACQUIRE AND UTILISE VECTOR & 20M ELEVATION DATA OVER THE PILANESBERG AREA FOR GEOGRAPHY STUDIES

1. I am currently registered at the University of Pretoria for my MA degree in Geography. As part of my studies, I need to perform GIS software tests that are based on an artificial scenario in the Pilanesberg area.

2. For this reason, I hereby kindly request to make use of the vector data as well as 20m elevation data covering the abovementioned area.

3. Your kind consideration is highly appreciated.

Regards

Susan Henrico

APPROVED / ~~NOT APPROVED~~

Strict copyright rules apply. Only to be used by you for this specific study. TomTom South Africa to be given recognition in your final thesis.

(ETIENNE LOUW)
General Manager: TomTom Africa