UNIVERSITY OF CAPE TOWN

Analysing the road reserve encroachment in Maseru Lesotho using remote sensing and image analysis

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Declaration of Authorship

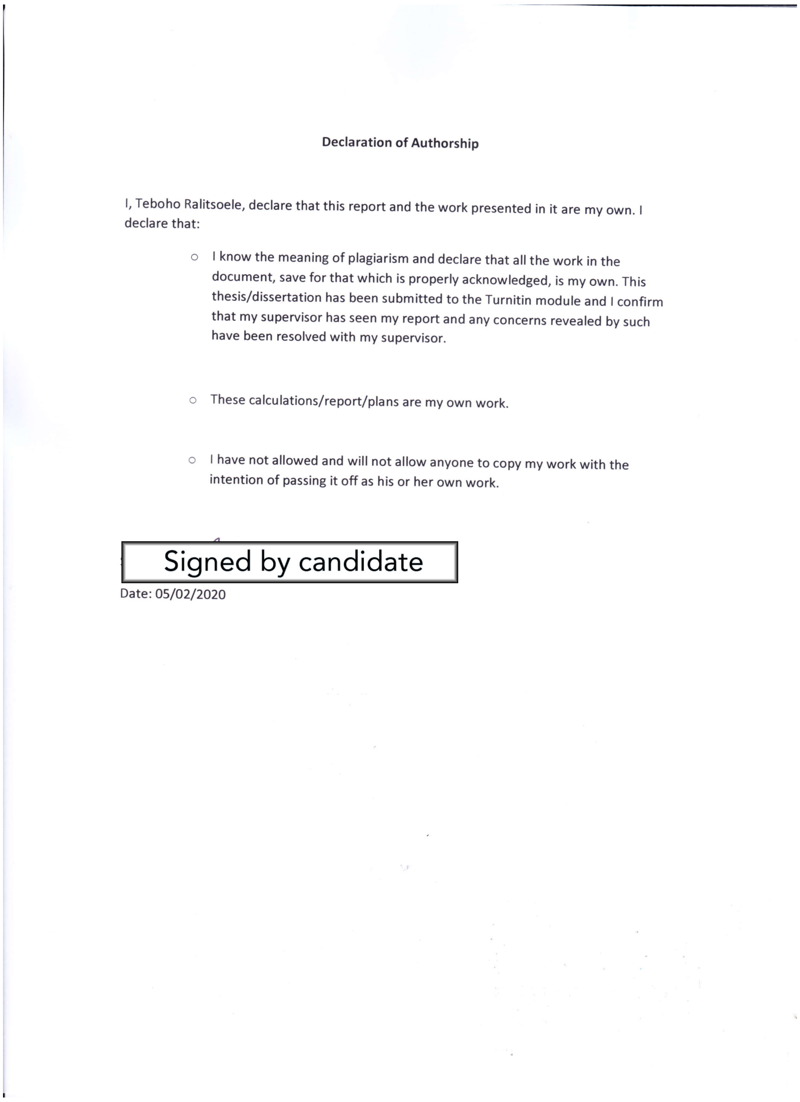

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Figure 1: Declaration of Authorship

Acknowledgements

I would like to thank my supervisor Dr George Sithole for showing me support and guidance.I would also like to thank my colleagues and most importantly my aunt for her support through out my journey at the University of Cape Town.

Abstract

The increasing rate of urbanization and the problem of road reserve encroachment mean that there is no space for road expansion and sometimes for maintenance and road furniture, these and other problems have exposed the problem of road reserve encroachment.

The main aim of this study was to investigate methods of finding the road reserve encroachment in Maseru Lesotho using aerial photos. The study used single image analysis and multiple image analysis methods. In single image analysis, the study used three methods of image classifications to find objects that are in the road reserve. Under classification, the study used both supervised and unsupervised image classifications. For supervised classification, the study used the direct image classification method where the aim was to look for every object found in the road reserve. For the indirect approach, the study looked for the ground to find objects in the road reserve. For unsupervised image classification, the study assumed that small clusters are encroachment.

In multiple images analysis, the study used the 2015 and 2017 images to determine permanent objects found to have encroached road reserves. Here the assumption was that encroachment does not change over time, which means that unchanged objects during the change detection have encroached on the road reserve. The confusion matrix was used to tell the best performing method and the results show that the indirect method, both in Qoaling and Maqalika performed best. All the methods showed that there was an encroachment on a road reserve, and found that permanent objects were; houses, shops, and shopping centers. The study recommended the use of images with higher resolution and more bands, also that images be taken frequently.

Key words:
Road reserve; Encroachment; Qoaling; Maqalika; Maseru; Lesotho; Remote Sensing; GIS; Image analysis

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List of abbreviations and/or acronyms

MCC	Maseru City Council
NGI	National Geospatial Information
LAA	Land Administration Authority
UN	United Nations
RD	Roads Directorate

CHAPTER 1

INTRODUCTION

1.1. OBSERVATION

According to United Nations (2014) report, the majority of the world population (54%) lives in an urban area. By the year 2050, the population will have increased to 66%, United Nations (2014). For example, UN Projections show that because of Urbanization and increase of world population, there might be approximately 2.5 billion people who will be in urban areas by the year 2050. In Asia and Africa alone, there could be up to 90% increase in urban population.

The same report suggests giving settlements of all kinds attention by having an urban planning agenda. The cities regulated well will be beneficial in that they will provide developments such as good infrastructure, services like water and sanitation. This happens easily when a place has a high population density because it is cheaper to provide service than in a dispersed area.

Similar to other countries, Lesotho has experienced the growth of urban population as well; this is shown by the figure 1.1 below that since the 1950s, the urban population has been increasing while rural population has been decreasing. This situation will continue well beyond the year 2050.

The estimations show that should the current situation continue, the services and infrastructure in Maseru that are already stressed are going to be overwhelmed even more. Lesotho has poor urban settlement planning, where there have been planned developments urban population tends to shy away from such development.(United Nations Habitat 2015)

In recent times people have been migrating to Maseru city and taking advantage of the stressed services and infrastructure. In Leduka (2012*a*) (cited in United Nations Habitat (2015)) he states that the facilities dedicated to the pedestrians such as sidewalks are not

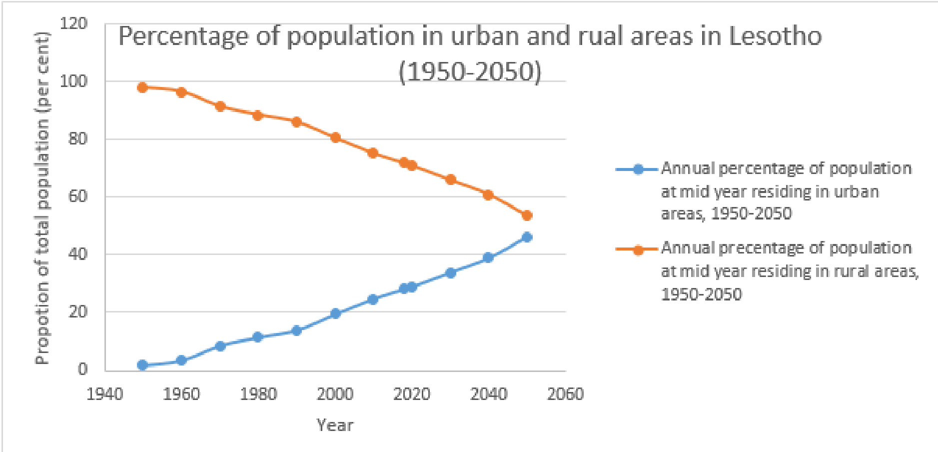

Figure 1.1: Percentage of population in urban and rural areas in Lesotho. The figure shows rural population declining while urban population is increasing.

available.

Leduka (2012*b*) stresses that the physical development in Maseru city, about 80 percent is unplanned settlements due to informal land purchases. These unplanned developments have caused problems of underdeveloped transport infrastructure, which in turn restrict traffic flows and other socio-economic and environmental services around Maseru. When it comes to housing 75% is unplanned, (Leduka 2012*b*). These housing developments are informally owned and are not surveyed but allocated on croplands.

Programme, Labour-intensive Urban Upgrading and Council, Maseru City (2000) added that there is a problem of human settlement management together with the failure of practices of legislation enforcement. It also pointed out the problems that are a result of the placement of facilities such as water pipes and power lines, those are due to lack of proper procedures, guidelines, and location plans for their placement. Consequently, when there is a need to locate, maintain and service them, the road networks are interrupted causing traffic congestion.

Encroachment means the use of resources illegally Chauhan et al. (2017). For this study, it is the illegal use of the road reserves. According to the (Roads Directorate 2016, p,1) “Road reserve is the full width of a road, including roadways, shoulders, side drains, roadsides, and sidewalks and the air space above such roadways, shoulders and sidewalks, space below such roadways, shoulder and sidewalks and all other areas within the road reserve boundary". While The (The local government and municipal knowledge base n.d., p.1) defines Road reserve as "a legally described area within which facilities such as roads, footpaths, and associated features may be constructed for public travel. It is the total area between boundaries shown on a cadastral plan".

Table 1.1 below shows road categories and their different road reserve widths in Lesotho according to the Roads Directorate (2016). It shows different road classes and road reserve widths, from 10 meters square smallest to 20 meters of road reserve width.

Road Classification	**Definition**	**Width on each side of the road centreline**	
		Road reserve (Width in meters)	Building restriction area (Width in meters)
A	These primary roads connect 10 districts of Lesotho's big towns and main border posts.	15 m	30 m
B (Major)	These secondary roads connect neighbouring districts in Lesotho and providing network and local centres.	15 m	30 m
B Minor)		10 m	20 m
C	These are the sub-district roads; they give support by connecting secondary and primary roads within the districts.	10 m	20 m
D	These roads connect the villages and settlement.	10 m	20 m

Table 1.1: The declaration of the road reserve and building restriction. The table shows that the roads are classified into 5 different categories;A,B(major), B(minor), C and D.

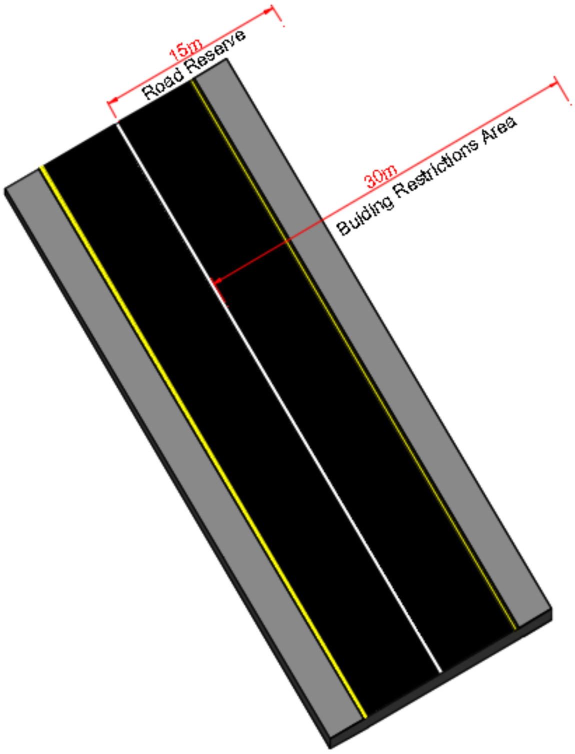

Figure 1.2: Road reserve of class A category with a width of 15 meters from the road center line and it also shows the building restriction area which is 30 meters from the road center line.

1.2. STUDY AREA

The British colonial government established Maseru, the capital city of Lesotho, around the year 1870, the reason behind this was the establishment of the administrative center, (Leduka 2012*a*). The population of Maseru is 459760, this is according to the World population review (2016). Maseru covers an area of 4276 km2. Figure 1.3 below shows Maseru city location.

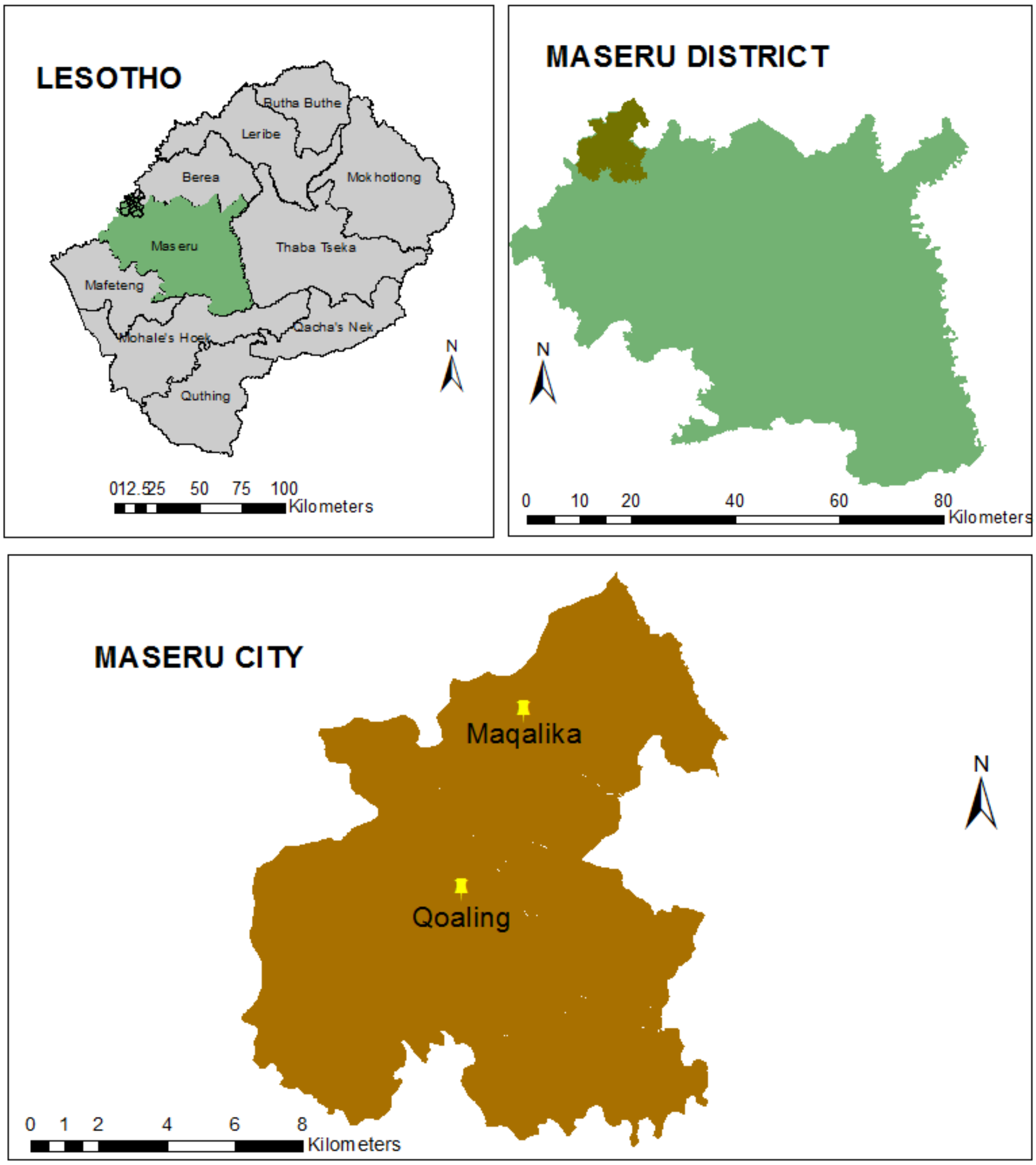

Figure 1.3: Location map showing the map of Lesotho, Maseru district, and Maseru City. Qoaling is where the study was conducted and Maqalika is where the methodologies were tested.

1.3. PROBLEM STATEMENT

Road reserve encroachment has been a problem for a long time now in Maseru, Lesotho; this is due to unplanned towns and settlements in and around Maseru. The avoidance strategy by authorities such as the Maseru city council (MCC) when it comes to the upgrading of roads to minimize compensation has made the situation worse, (Leduka 2012*b*). Consequently, this has lead to environmental hazards such as "narrow roads, poor alignment with blind corners, limited roads reserves and encroachment into the same housing development, poor drainage, lack of bus stops, lack of street lights and poor road safety." (Leduka 2012*b*, p.150).

All these and other problems such as the increasing rate of urbanization have exposed the need to expand the roads to accommodate the increasing number of cars on the roads, which has led to heavy traffic jams during the peak hours of morning and afternoon. These have left questions as to how to solve the traffic jam seen during peak hours as well as the lack of road furniture in the streets. The lack of space for road expansion indicates that there is a lack of road reserve due to encroachment that is a problem that needs addressing.

Because of road reserve encroachment, the authorities responsible for constructing the roads such as Roads Directorate (RD) and Maseru City Council (MCC) face the problems of expanding roads and installing road furniture, this is because of various objects in the road reserve area. This study, therefore, aimed to find out the methods of detecting road reserve encroachment in Maseru Lesotho using High-Resolution Satellite Images and Aerial photos.

1.4. HYPOTHESIS

Using High-Resolution Satellite Images and Aerial photos, the study can identify objects that do not belong in the road reserve.

1.5. OBJECTIVE OF THE STUDY

The study aimed to investigate the methods to detect road reserve encroachment in Maseru using high-resolution satellite images and aerial photos.

1.6. RESEARCH QUESTIONS

- Besides images, what other data do the study need to use to detect road reserve encroachment?
- What methods of image analysis do the study need to use to find objects that do not belong in the road reserve?
- How to tell the difference between the permanent and temporary objects inside the road reserve?
- What are the best methods to classify objects in the road reserve?
- How is the methodology used going to be tested?

1.7. SCOPE OF THE STUDY

The study reviewed the following acts of Lesotho; Roads Act 1969 of Lesotho, Lesotho Land Act 2010, Land Regulation 2011, Lesotho Government Gazette Vol 59, and Roads and Roads Reserve Notice 2014. From these acts and regulations, the study was able to say what legally constitutes an encroachment. The study dealt only with objects that are inside road reserve encroachment.

The study also looked into what other researchers have used as their inputs, methodologies, and their results in trying to analyze different types of encroachments using Remote sensing.

The study used only Orthophotos of two different years (2015 and 2017) to detect if any changes had taken place between those years. Here the study used Maximum likelihood and Isodata classification to extract permanent, and temporary objects. To extract the objects, the study used Envi, Erdas, and ArcGIS software.

1.8. SIGNIFICANCE OF THE STUDY

Since the study aimed to investigate the methods of road reserve encroachment detection in Maseru using high-resolution satellite images and aerial photos, the study will not only contribute to the body of knowledge by introducing different approaches to finding temporary and permanents objects that are encroaching on road reserve but the study will also contribute by introducing this topic because there is little to no studies into the encroachment of road reserve using images. The Municipality and local Authorities will benefit by learning the ways of tackling the encroachment of road reserve.

1.9. DELIMITATION OF THE STUDY

In Maseru, the study chose Qoaling and Maqalika areas only as of the testing of the methodology. The study chose only these two areas because looking at the images these areas showed a lot of encroachment especially because of big buildings that seemed to have encroached on the road reserve. Due to time constraints also, the study did not manage to look for other places that still suffer from encroachment for thorough investigations.

Due to lack of servitude data for mapping of the road reserve, the study used a road layer where a centerline was used to map the road reserve extent. There was a complication of the definition of the road reserve because of misalignment of the road centerline with the aerial photographs the study was using. This led the study to the use road layer extracted from the classified image and use it to fine road centerline.

1.10. RESEARCH ETHICS

The ethical problems the study faced were that the data could be used for other purposes rather than the current study so the study assured the organisations providing the data that the data would be kept confidential and that the study has been approved by the ethical committee of the EBE faculty. The organisations in return were given an option to give out their restrictions to the use of data they provided for the study.

The research ethics issues the study faced were that the data used for the study could be used for other purposes besides the current study so the mitigation to this was that the study uses the data for the purpose stipulated in the consent letter.

The study got the data-set from the organizations (Parastatals) by providing them with a letter from the department for data collection and informed consent letters. Confidentiality was ensured and the consent letter was provided to the institution to sign if they agree to provide data-set in this study.

The study provided the organisations with the informed consent letter, see (appendix A) where they were given an option to provide the study with the data-sets. The letter clearly stated that the organisation was free to stop giving out the data at any time they feel the need to do so. To accept to provide the study with the data-set, a representative of the organisation signed the consent form. The research was done with consideration of the University of Cape Town (UCT) and the EBE faculty.

1.11. RESEARCH OUTLINE

Chapter 1 presents the problem of the study

Chapter 2 Reviews the literature, it describes the concepts of encroachment, what it is, how it can be avoided. It describes the encroachments in different areas.

Chapter 3 Reviews the data the study used, methods used in the study to find the objects in the road reserve, and how they are analysed.

Chapter 4 Will analyse and presents the results of the study

Chapter 5 Is the discussion of the study

Chapter 6 Conclusion of the study and recommendations

CHAPTER 2

LITERATURE REVIEW

2.1. ENCROACHMENT DEFINITION

(Legal Dictionary 2008, p.1) describes Encroachment as “an illegal intrusion in a highway or navigable river, with or without obstruction. An encroachment upon a street or highway is a fixture, such as a wall or a fence, which illegally intrudes into or invades the highway or encloses a portion of it, diminishing its width or area, but without closing it to public travel”. In real estate, Chen (2019) defines encroachment as a situation whereby the landowner violates the rights of the neighbor’s property, this could be onto private or public land.

2.1.1. Key drivers of Encroachment

Encroachment can happen intentionally and unintentionally. Chen (2019) Unintentional encroachment occurs when the property owner uses invalid survey plans thereby carrying out renovations and extensions onto the neighbour’s property. This is because the survey outlines the property boundary in meters, suffice to say invalid information on survey plans may cause the encroachment onto private and public space. Sometimes it is because the encroacher is not familiar with the property lines. With intentional encroachment, the property or developments carried by the neighbour such as stairways or retaining walls might extend onto another person’s property without their consent.

Key drivers of Property Encroachment as stated by Smith (2019) and Nordmeyer (n.d.)

- When a neighbour directly builds on your property, this could be without the owner’s blessing or sometimes extending your property line beyond its survey lines.
- When owners of the property do not know their property line because they have a property survey that is invalid when installing retaining walls and fences.
- Sometimes during the erection of the building and the retaining wall, the contractor

may not understand or may misinterpret the survey line or the owner's instructions.

- Someone may violate property rights by encroaching someone's property knowingly.
- In some cases the encroachment is agreed upon by the parties involved because they would have talked and agreed upon it.

2.2. PREVIOUS STUDIES

2.2.1. Introduction

This section will discuss previous work in which remote sensing was used to analyse encroachment. This is the thematic literature review of different types of encroachments; namely, bush encroachment, agricultural encroachment, and right of way encroachment. It will do this by examining their research objectives, methodologies, and their results. Most of the literature reviewed here achieved their objectives but the study could not find the use of remote sensing in road reserve encroachment.

2.2.2. The use of remote sensing to monitor bush encroachment

Laliberte et al. (2004) conducted a study in New Mexico in the United States of America, they aimed to use aerial photographs to map shrub encroachment, then they looked at the bush cover of 2003 using satellite image for ground estimation. Hudak & Wessman (2001) Conducted a similar study on bush encroachment, the aim was to establish the technique for bush encroachment in the Savanna. Mpati (2015) also did a similar study in South Africa in Limpopo Province; the aim was the assessment of the bush encroachment on biomass productivity. To achieve this the researcher used both the remote sensing techniques in the monitoring and the assessment of bush encroachment, simultaneously to find out the impact the bush encroachment has on the decline of rangeland productivity.

These studies used high-resolution images as their inputs to conduct their studies. Andrea

S and Laliberte et al. (2004) used 11 high-resolution aerial photos from 1937 to 1996 while Hudak & Wessman (2001) used Spot panchromatic images of 1990 and 1996. 1955, 1970, and 1984 aerial photographs were scanned and the linear stretch was conducted. To achieve textural analysis, the study used a 3 x 3 standard deviation filter to get the results. Mpati (2015) used 7 (1989-8008) Landsat Thematic Mapper images. To detect the changes that have occurred in that period, the researcher used unsupervised classification as well as the Normalized Difference Vegetation Index.

Laliberte et al. (2004), Hudak & Wessman (2001) and. Mpati (2015) results show that there was increase of encroachment. Laliberte et al. (2004) results show that there was increase of 12.0 % of shrub encroachment and the grass cover decline of 16.6 %. Hudak & Wessman (2001) shows that there was increase of 30 % encroachment.

Laliberte et al. (2004)'s choice of using the high-resolution image and object-based classification helped with the detection of shrubs, this played a major role in their study. The use of image texture benefited the study in the detection of encroachment but the drawback was the images taken in different years so their radiometric properties compromised quantification of the encroachment (Hudak & Wessman 2001).

2.2.3. The use of remote sensing to monitor right of way encroachment

Lukowski et al. (2004) used polarimetric SAR imagery to monitor the right of way encroachment of the pipeline. The data acquired was on a single pass. The image was acquired at the slant range at 5.6-meter resolution was after it was calibrated. Oyinloye et al. (2017) conducted the same study where they used a questionnaire method to collect data from the people who reside near the pipeline right of way. They used Google Earth Imagery of 2016.

The aim of Lukowski et al. (2004) was to detect the fabricated objects that are encroaching on the right of way of the pipeline so they used full polamentric information for the image scene. They employed three methods for detection purposes; Firstly Polamentric whitening filter secondly Cameron decomposition and lastly was Even Bounce analysis. For analysis, Oyinloye et al. (2017) used ArcGIS software and used buffer analysis to identify people who encroach on the pipeline right of way. They created three buffers, 15 m buffer for most vulnerable, 30 m buffer for vulnerable, and 90 m buffer for those that are least vulnerable.

The first method used was a Polametric whitening filter where the threshold was pre-defined and the aim was the detection depending on bright magnitude targets. The second method was Cameron decomposition to show separately the symmetric scatter. The last method used was Even Bounce analysis, where the aim was the detection of the structures that causes the radar signal to bounce twice on the target (Lukowski et al. 2004).

Lukowski et al. (2004)'s study succeeded in detecting the objects in the fields but could not identify the objects uniquely because the images had small separation. This study fails to tell what the objects are from the use of polametric SAR image. The study results from Oyinloye et al. (2017) showed that those that are vulnerable to incidents like explosions were 30 percent of the people from that area. To conclude, the study suggested the use of aerial photos often to monitor the pipeline right of way and the displacement and compensation of households that have encroached pipeline right of way.

2.2.4. The use of remote sensing to monitor encroachment on agricultural land

Khamis et al. (2015), aims to look at the expansion of agricultural land encroachment that happened after the revolution that took place in Cairo in 2011. Khamis et al. (2015) carried out this study using three different types of images, namely Land sat 30 m, Rapid Eye 5 m, and Geo Eye 0.5 m. These images were Layer stacked, mosaicked, and geo-referenced before they could process.

The study then applied an unsupervised classification technique called Iso-data and the classification method called maximum classification. In order to find the changes that have taken place the study used Image differencing as well as class aggregation. For results validation, the study used the ground-truthing technique.

The results of this study were that they were able to detect the newly constructed buildings since the revolution.

2.2.5. Discussions

The studies covered in this section all reached their objectives which were to detect encroachments. All of these studies used high-resolution satellite images and aerial photos. Some combined low-resolution with high-resolution images. While some studies used low-resolution images that could help with the detection but not telling what the objects are.

However, in this study, the main aim was to investigate the methods to detect the road reserves encroachment in Maseru using High-Resolution Satellite images and aerial photos. The study did so by finding out the objects that are permanent, semi-permanent and those that are temporary, using two images of 2005 and 2016, wherein analyzing the images, permanent objects will be buildings and temporary objects will be cars and trees. The study produced the algorithm and map that showed the extend of road reserve encroachment in Qaoling and Maqalika.

CHAPTER 3

RESEARCH METHODS

3.1. INTRODUCTION

The chapter carries out the methods conducted in this study to investigate methods to detect road reserve encroachment in Maseru. The study tried to find different ways or methods of detecting the road reserve encroachment in Maseru. The main assumption the study was operating under was that with the aid of the images acquired at different times, the study would be able to distinguish between permanent objects and those that are temporary.

This study put more emphasis on the analysis of two images, figures 3.1 and 3.2 below will give a comprehensive look as to how the study achieved its objective. The study used both primary and secondary data. The structure that followed from data collection to the realization of the product is shown. Finally, the study found a way to test the model in one of the areas in Maseru to show that the model could be used in other areas.

3.2. RESEARCH OVERVIEW

The reserve overview below shows the format the study followed. The study used three methods. Two methods were followed using (figure 3.1), which is the Direct method and Indirect method. Former, supervised classification was used but more emphasis was on every object in the road reserve (classification of every object in the road reserve). The latter used supervised classification as well but its emphasis was on the ground (Classification of the ground). The difference here is that for direct methods the study looked for every object in the road reserve whereas in the indirect approach the study looked for the ground more. The third method (figure 3.2) used unsupervised classification whereby the small clusters were considered encroachment. All the steps of the methods conducted will be explained in detail in the pages below, from the first step of data collection to the last step of methods testing.

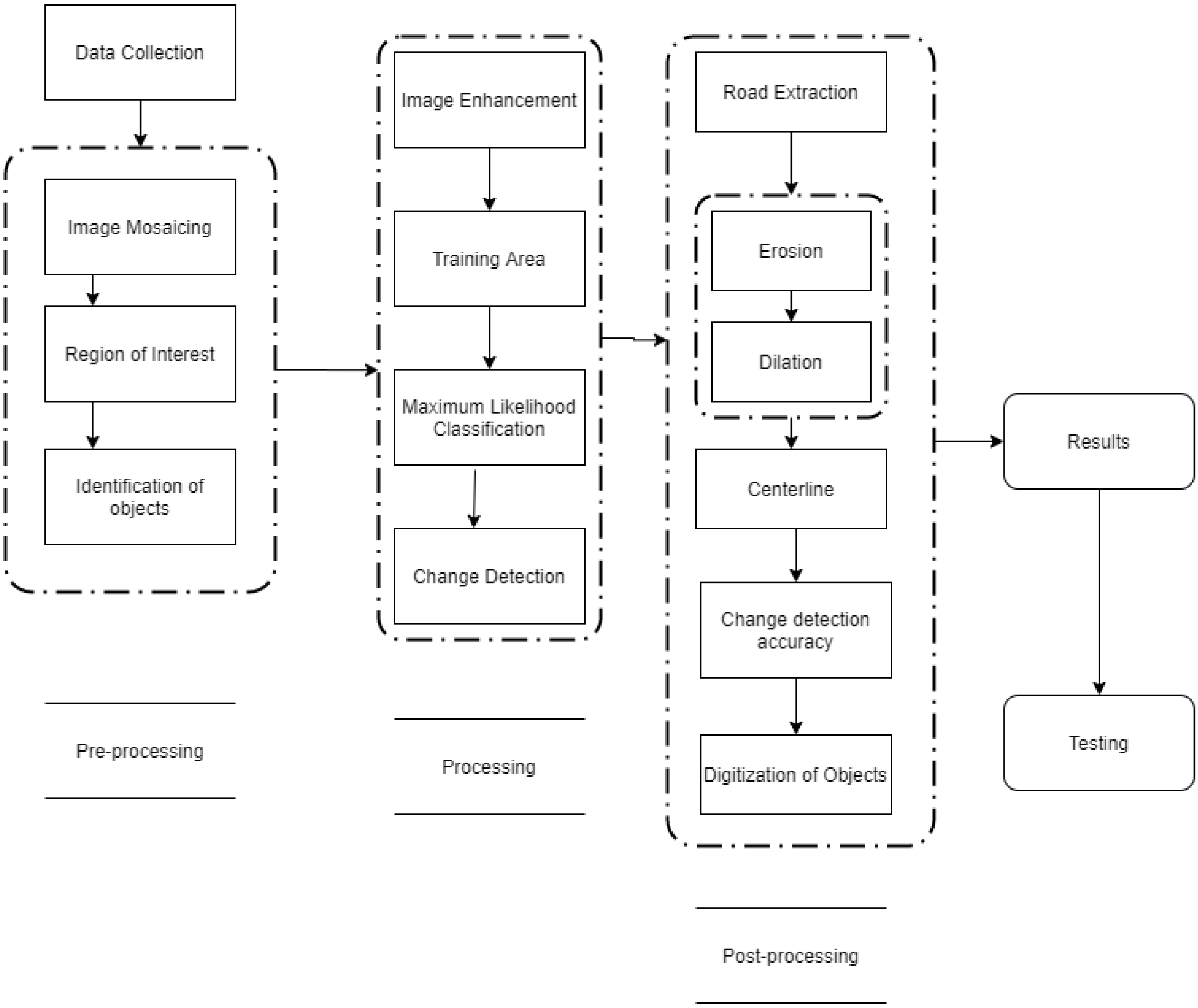

Figure 3.1: Research overview showing two methods, direct method, and indirect method. The former emphasized every object in the road reserve while the latter emphasized the ground more. The process started with pre-processing, followed by processing of data lastly post-processing of data. The results of the method were tested in another area in Maseru.

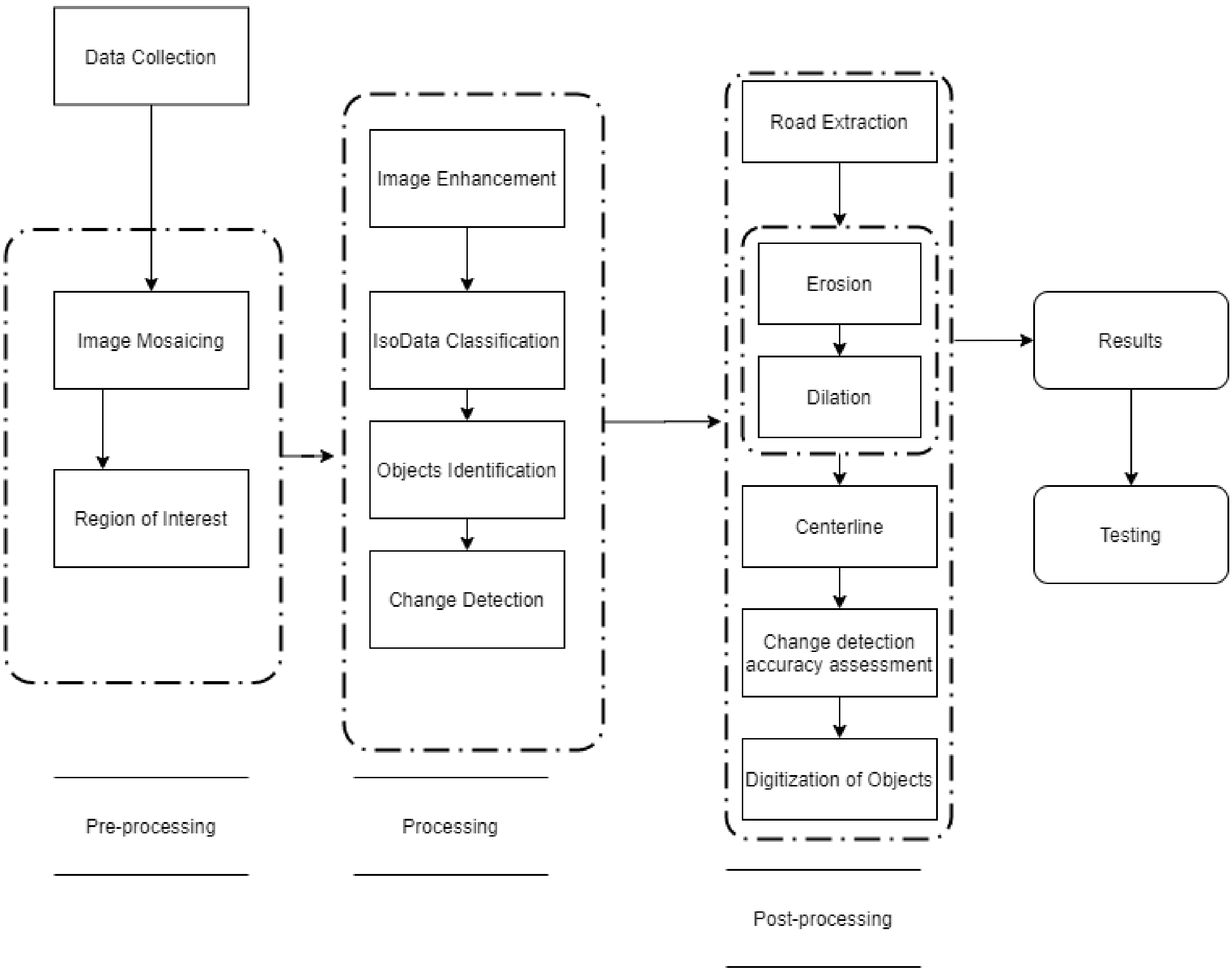

Figure 3.2: Research overview showing unsupervised method steps followed by the study. The processes involved were pre-processing, processing of the data and post-processing of the data. The results of the unsupervised method were tested in another area in Maseru

3.3. DATA ACQUISITION

Table 3.1 shows the data the study used besides images, their format and where the data was acquired.

Data	Format	Source
2015 and 2017 Orthophotos	ECW file	NGI
Roads Layer	Shape file	Roads Directorate
The Roads Act 1969	Book	Roads Directorate
Declaration of Roads Reserve Notice 2014	Book	Roads Directorate
Know the Road Reserve	Leaflet	Roads Directorate

Table 3.1: Data sources and format. The table shows the data the study used, the data format and where the data was sourced.

The study acquired two images and these images were used primarily to look for the objects in the road reserves around Maseru. The purpose of multi-temporal images was to look at the objects that did not change over time. This strategy made it easier to identify permanent objects and those that were temporary.

The road layer in this study was used to find the road centerline so that buffering analysis could be used to find the road reserve extent. The road reserves extent according to Roads Directorate (2016) differ as follows: classes A, B, C and D.

The Road Act 1969, Declaration of Roads reserve notice 2014 and Know the road reserve leaflet were used to find the width of the road reserves of different road classes. For example, the Declaration of road reserve notice 2014 by Roads Directorate (2016) show that class A width is 15 meters, class B(Major) is 15 meters, class B(Minor) 10 meters, class C 10 meters and class D is 10 meters as well, as shown in table 1.1.

3.4. SOFTWARE USED IN THE STUDY

The study used three softwares to help conduct this study, they are ArcGIS, Envi and Erdas softwares.

3.5. IMAGES METADATA

A researcher needs to study the data that is going to be used in the study to make sure that the data is accurate for the current study. Metadata is defined as “information about data”, (Kalantari et al. 2009, p,629), the important role played by metadata is in its description of not only the contents but also the attributes of any data. It does this by giving potential users the knowledge about the data-sets beforehand, as well as accessing updated spatial data and information without difficulty (Kalantari et al. 2009). Bhatta (2011)regarded it as the first step of data set the assessment for the user to determine whether it meets his objectives.

Jensen, J. R. and Jenson (2013) listed the following 10 elements that should be in most spatial datasets.

- Spatial data structure (Raster or Vector),
- Projections,
- Coordinate system,
- Datum conversion or transformation (Nad27 to Nad83),
- Scale of original data,
- When data was created,
- How data was collected,
- Database field names and properties (values and value limits, data types, formats),
- Data quality/error reports,
- Accuracy and precision of the instruments used to collect the data.

The study used data in Table 3.1 to show the images the study managed to acquire for this project which was of different years, the first one was the 2015 image and the second one was the 2017 image. The 2015 and 2017 images are raster files that had three bands namely Red, Green and Blue (RGB). The Images had the following Coordinate system; Datum: D WGS 1984 and Projection is Transverse Mercator and the Unit is in Meters. The pixel resolution is 0.5 for the 2015 image. The 2017 image has similar metadata to that of 2015 except that the spatial resolutions had improved to 0.25 meters. Both images had a Tiff file format.

3.6. IMAGE PRE-PROCESSING

In the pre-processing stage, we have two sections, section one will talk about image mosaicking and section two will talk about choosing a region of interest. This will be done with the aid of ancillary data e.g Roads and Roads Reserve Notice, 2014.

3.6.1. Image Mosaicing

The research got hold of the series of images that were not assembled, so the study decided to mosaic them to make it easier to choose the area of the study. Kent (2009) defines Image Mosaicing is a combination of two or more images that are overlapping. “Mosaicing is the blending together of several arbitrarily shaped images to form one large radiometrically balanced image so that the boundaries between the original images are not seen.” (Inampudi 1998, p,1)

Figure 3.3 below shows the stages of image enhancement that the study used. The images that were collected from NGI were ECW format and they already had WGS 84 coordinate system so they were mosaicked together using ArcGIS software and the final image format was Tiff file.

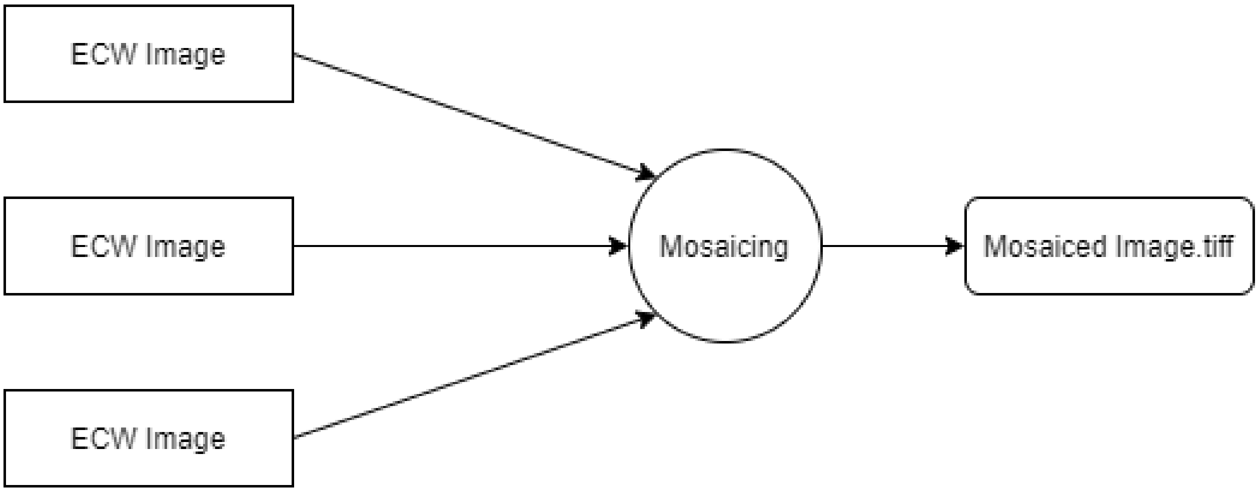

Figure 3.3: Data mosaicing process the study followed. The input was the series of images in ECW image format. They were mosaiced together to make bigger single image.

3.6.2. Region of Interest

The images were cropped to the desired area of the study, this is particularly important in this study since we were dealing with road reserve we wanted to know exactly the objects in the roads reserve, hence the subset. Francisco (2013) gave the advantage of a region of interest as that the use of image subset for this study was to reduce data volume to allow processing to be faster, and also to cover the specific area of interest or study area, figures 3.4 and figure 3.5

The image subset of the interest area was overlaid with the road feature layer from the Roads Directorate. Since the road the study was working on is class B road, its Road reserve is 10 meters from the centerline, as said in table 1.1. The buffer analysis was applied on the road layer and set to 30 meters from the centerline so that the study captured the entirety of the objects falling within the road reserve. Figures 3.4 and figure 3.5 below show study areas where the road centerline, Road reserve 10 meters and buffer of 30 meters are shown.

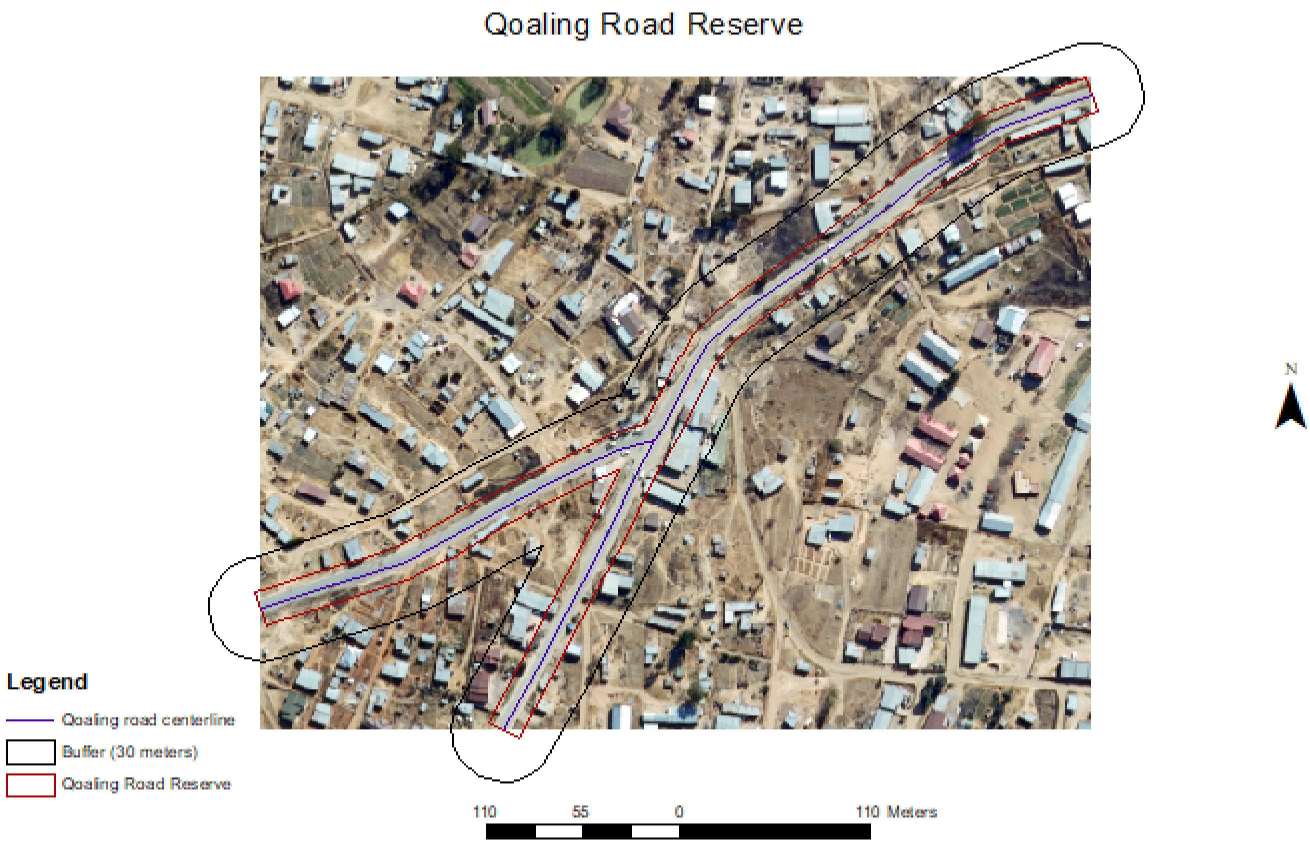

Figure 3.4: Image showing Qoaling Road Reserve before being processed, road centerline, buffer of 30 meters to cover every objects in the road reserve in full.

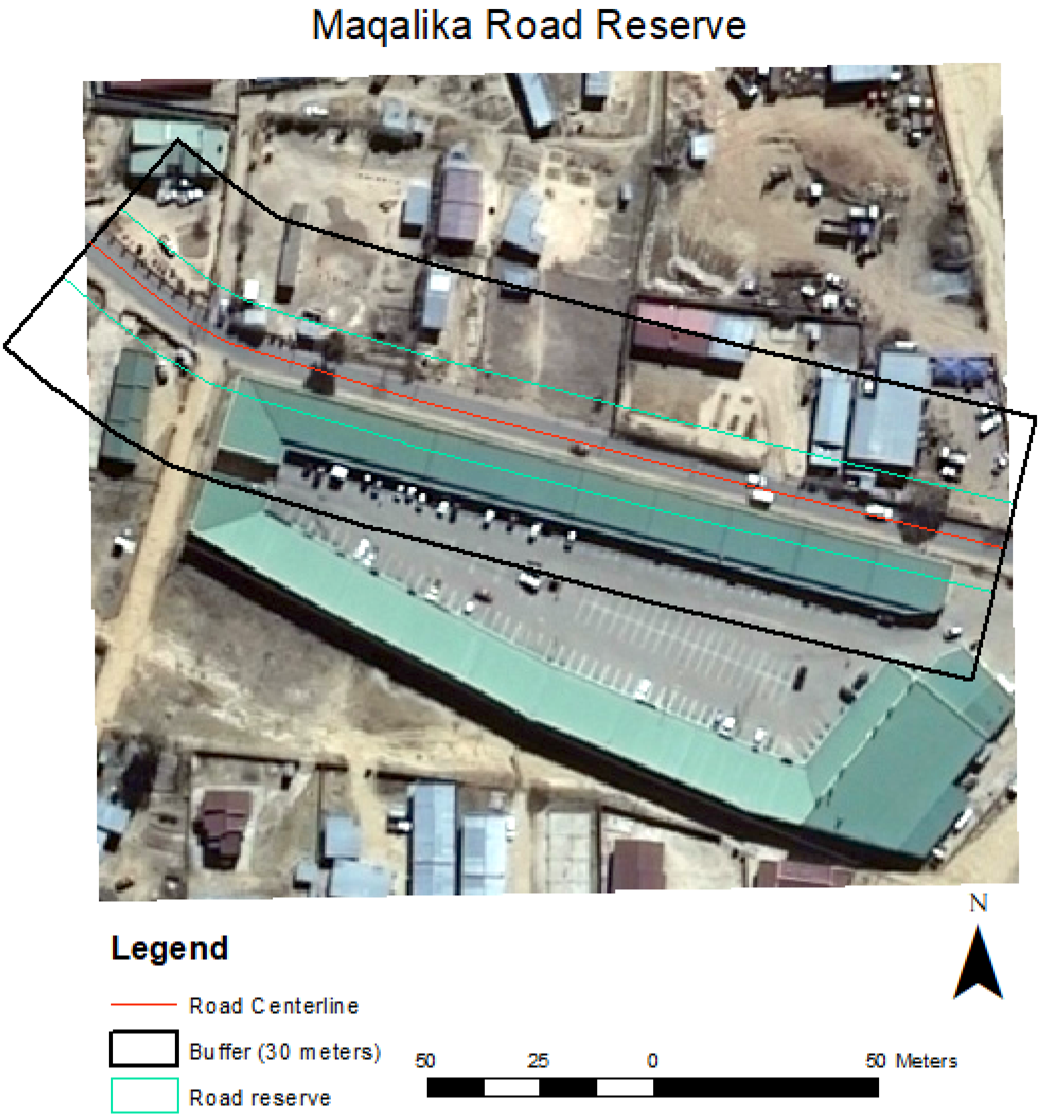

Figure 3.5: Image of Maqalika Road Reserve before being processed, showing the road reserve in green, centerline in red and buffer of 30 meters in black.

3.7. IMAGE PROCESSING

3.7.1. Image Enhancement

The process of image enhancement better shows the objects in the image that were not visible in the original image. Das & Cannon (2015) further describes this field as a problem specific due to the use of different enhancement techniques having advantages and disadvantages when applied to certain problems. The images procured for this study were not clear so the study decided to enhance them to make the identification of the objects easier. Image processing is described as the restoration, recovery and enhancement even the identification of the objects in the image.

In this section of the enhancement, the study used as input the image subset created from the section before this one. Figure 3.6 below shows the stages of image enhancement that the study went through to produce an enhanced image. The study decided to use Hue, saturation and value (HSV) enhancement technique to make clear objects that were not clear enough for identification.

The HSV model uses hue (h) saturation (s) and value(v) to try to explain the use of colour. The dominant wavelength seen here is hue (h), giving out colours red, green, orange and magenta. The saturation(s) as explained by (Bajpai & Soni 2017, p.8) refers to "the degree of purity of a colour and its diffusion." The colour's brightness is measured by intensity. HSV is used often in image enhancement because of its human colour observation. When the colour is saturated, it is considered pure.

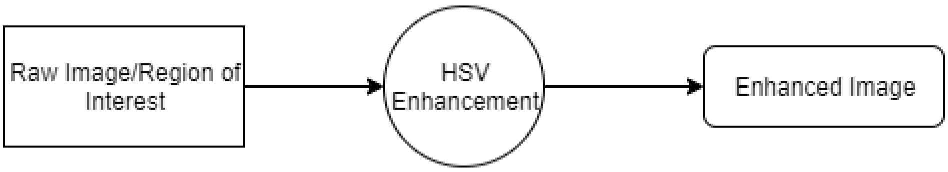

Figure 3.6: Image Enhancement. Input is region of interest then processed using HSV image processing technique the the results are enhanced image.

HSV is useful in two ways, that is according to Bhatta (2011), as image enhancement and as a means of co-registering two images taken from two different sources. For this study, HSV was used only for image enhancement. In image enhancement, the raw image that has been subset to the region of interest or study area was used as an input. The second step was processing where HSV was applied to give out the enhanced image that was used as an input in the classification step below.

3.7.2. Image Classification

Adewuyi et al. (2017) describes Image Classification as a process whereby all image pixels from remotely sensed data are grouped according to their respective categories, and then allocated names. "The purpose of the classification process is to group all pixels in a digital image into one of different land cover classes/themes. This grouped data can be used to produce thematic land cover maps present in an image." (Adewuyi et al. 2017, p.1)

There are different types of Image Classification and in this study, the Maximum Likelihood Classification was chosen as it showed the object in the road reserve best and because of its robustness and simplicity. Maximum Likelihood Classification uses statistics as the assumption that the classes or training areas that the user trained are normally distributed, thereafter it assigns the pixel to different classes based on the probability calculations.

For supervised classification of work, there is a need for Training areas, these are areas on a map that are created by the user, they represent a certain land cover type that is of interest to the study. Then the spectral signatures of the training data are determined. Then this data is used to calculate the mean-variance of the classes based on the input bands (Kanaga 2012). For this study, the training areas are shown in figure 3.8.

The figure below 3.7 shows the steps followed when classifying the images. The first step was the input of enhanced image, followed by the training stage. the third step was image classification using maximum likelihood classification and then the degree of satisfaction. Here the qualitative analysis of the image was done by comparing the classification results with the original image, if the results are not satisfactory then process goes back to the training stage but if the results are satisfactory the process goes to the output stage.

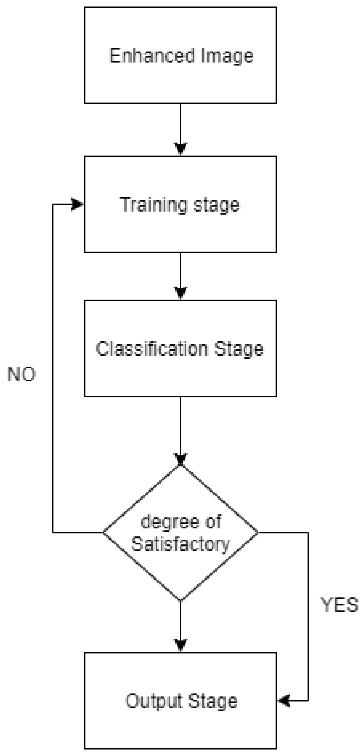

Figure 3.7: Supervised classification stages where input is an enhanced image, it is trained according to the user's needs to choose the method of classification suitable for study.

3.7.3. Objects to be classified in the road reserve

Figure 3.8 below represents the land cover of the area of interest and the following classes were made.

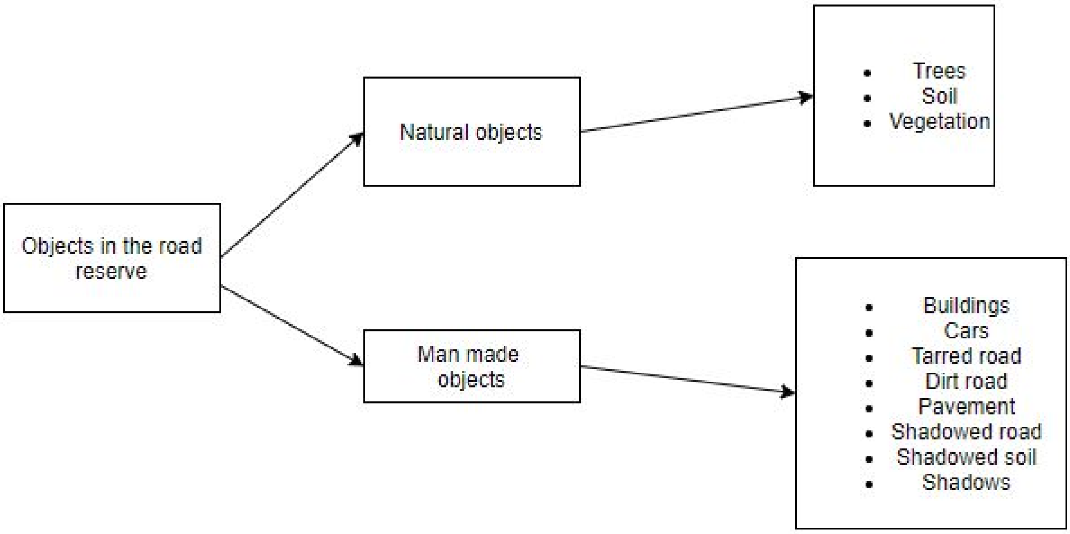

Figure 3.8: Objects that are in the road reserve are categorised into two; natural objects and man made objects

3.7.3.1. Land cover of Qoaling and Maqalika road reserves :

Natural Objects :

- Trees are defined here as woody vegetation that has a height of more than 1 meter or freestanding plant that can grow up to several meters.
- Soil is made up of the immediate surface of the earth and this includes bare soil sand and gravel and may consist of footpaths.
- Vegetation cover is areas dominated by bushes, shrubs, and grass. The vegetation cover may vary in height of less than a meter.

Man-made objects :

- Buildings are defined here as shopping centers/shops and places of residential areas. The buildings' rooftops are tiles and corrugated iron.
- Tarred roads are road surfaces made up of asphalt sometimes called paved roads.
- Dirt road is a hard surface made up of gravel and stones that are crushed and are sometimes called unpaved roads.
- Pavement is paving that is made up of concrete blocks.
- Shadowed soil is a dark area produced by building on soil.
- Shadowed road is a dark area produced by a tree on a road.
- Cars are vehicles

3.7.4. Classification Accuracy Assessment: Confusion matrix

Every image classification undergoes the image accuracy assessment, this ensures that the classification process was acceptable. Congalton (2001) explains that the importance of the confusion matrix is that it compares the Rows and columns that show the relationship between two samples taken from the field where the classification took place. The confusion matrix columns show the data collected from the orthophotos while the rows show the data allocated by the classifier. The overall accuracy of the classification is derived by the division of the sum of main diagonal entries of the confusion matrix by a total number of samples, (Lillesand & Kiefer 1979).

3.7.5. Unsupervised Classification

Unsupervised classification is defined by characterising the data without the user interfering by selecting the training data. Foody (2007); the user's influence is in selecting the number of clusters that the study needs. Nijhawan et al. (2018) explained that it is an iterative process that is used in the calculation of the euclidean distance so that each could be assigned a cluster. When the process is finished, the multidimensional space is assigned to the closest mean. "The computer uses techniques to determine which pixels are related and groups them into classes. The user can specify which algorithm the software will use and the desired number of output classes but otherwise does not aid in the classification process. However, the user must know the area being classified when the groupings of pixels with common characteristics produced by the computer have to be related to actual features on the ground (such as wetlands, developed areas, coniferous forests, etc.)."(Kanaga 2012)

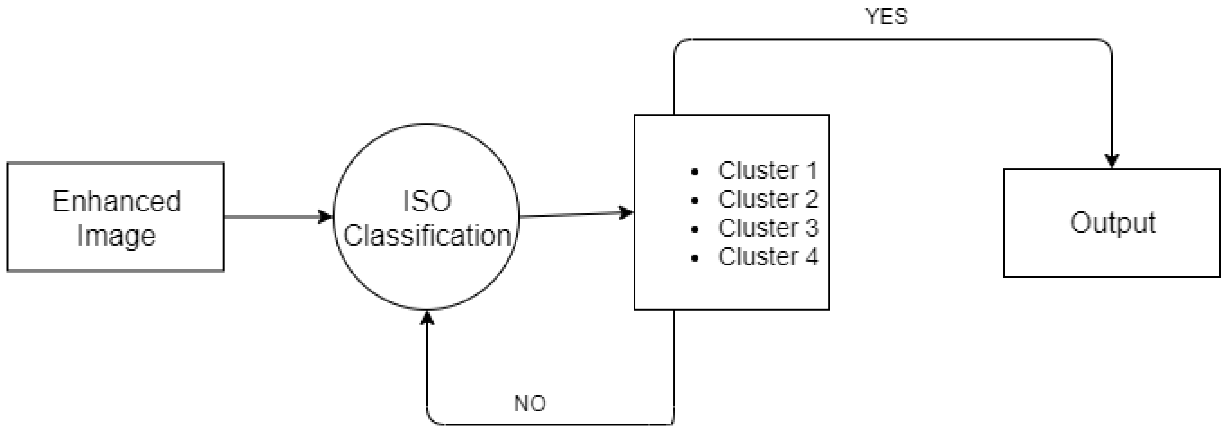

Figure 3.9: Unsupervised classification process where the input was enhanced image and the classifier used was Isodata to give out the results.

3.8. IMAGE ANALYSIS

The study used a single image and multiple images to analyse the road reserve encroachment. First, it used an analysis of a single image followed by the analysis of multiple images (2015 and 2017). The assumption for single image analysis was that there was more ground than encroachment.

3.8.1. Single image analysis

The study used both supervised classification and unsupervised classification. With the use of a single image, the assumption was that there was more ground than encroachment. Under supervised classification, the study used two approaches. The first one was the Direct Approach, here the study looked directly at the objects that were in the road reserve. The second one was an indirect Approach, here the study looked at the ground to see if there had been loss or gain over time. With the use of unsupervised classification, the study looked for small clusters in the road reserve.

3.8.1.1. Direct Approach

In the direct approach, the study identified the following land use classes. The input in this section was the enhanced image (HVS enhanced image). The study trained the following 10 classes

- Tarred road shadowed
- Dirt road
- Pavement
- Soil Shadowed
- Soil
- Vegetation Cover
- Trees

- Cars
- Buildings
- Tarred roads

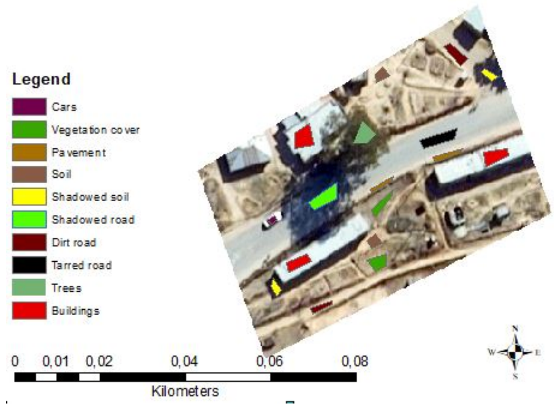

Figure 3.10: Examples of training areas the study used in the direct method.

3.8.1.2. Indirect Approach

The indirect approach of land use classification identified the classes listed below. The input was enhanced HSV image and the trained 6 classes were used in the classification process.

- Build-up areas
- Soil
- Vegetation cover
- Trees
- Tarred road
- Shadows

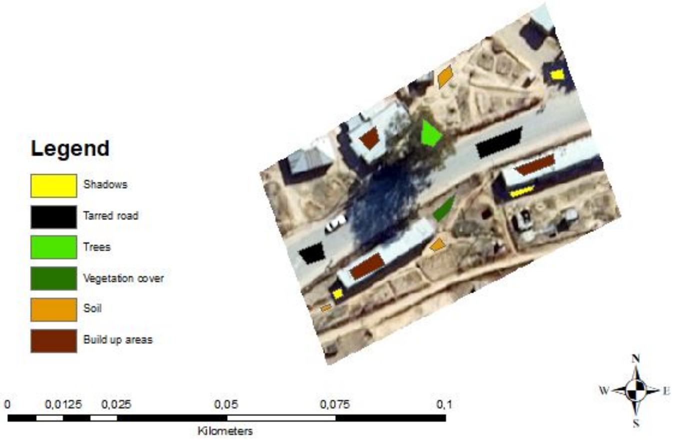

Figure 3.11: Examples of training areas the study used in the indirect method.

3.8.2. Unsupervised Approach

The unsupervised approach used the IsoData algorithm where the parameters were;30 initial clusters, iteration was 100 and the standard deviation was set at seven. The input was the HSV enhanced image. After the classification, the clusters were combined and came up with 5 clusters, namely;

- Trees
- Buildings and Road
- Soil
- Vegetation
- Shadows

3.8.3. Multiple Images Analysis

In this section we dealt with multiple images (2015 and 2017) images, the assumption here was that encroachments do not change over time. The inputs here were the results of the classifications of the two images of 2015 and 2017. Then Image Differencing technique was used to find the objects that do not change over time. Image differencing as explained by Karthik & Shivakumar (2017) is a technique where Digital numbers of one image are subtracted from one another. These images were of the same place but acquired at different times and they were spatially registered.

In this study, the 2015 image was subtracted from the 2017 image (see figure 3.12 and figure 3.13). The focus of this study was to look for objects that do not move. In order words where there was a difference between digital numbers of the 2015 image and 2017 image, the focus was where the digital numbers were zero (0) which represented no change, thereby naming those objects permanent. Where there was change the results will be positive or negative, thereby the study named those as temporary objects.

For this study, the image differencing was applied to Supervised classification results for both direct and indirect approaches as well as the unsupervised classification.

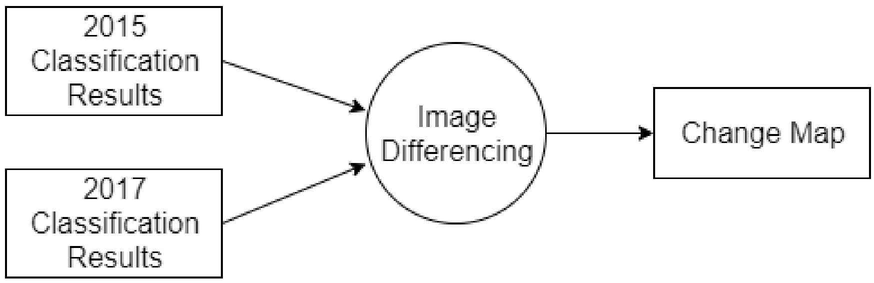

Figure 3.12: Image Difference process where two images (2015 and 2017) were processed and the outcome was change map

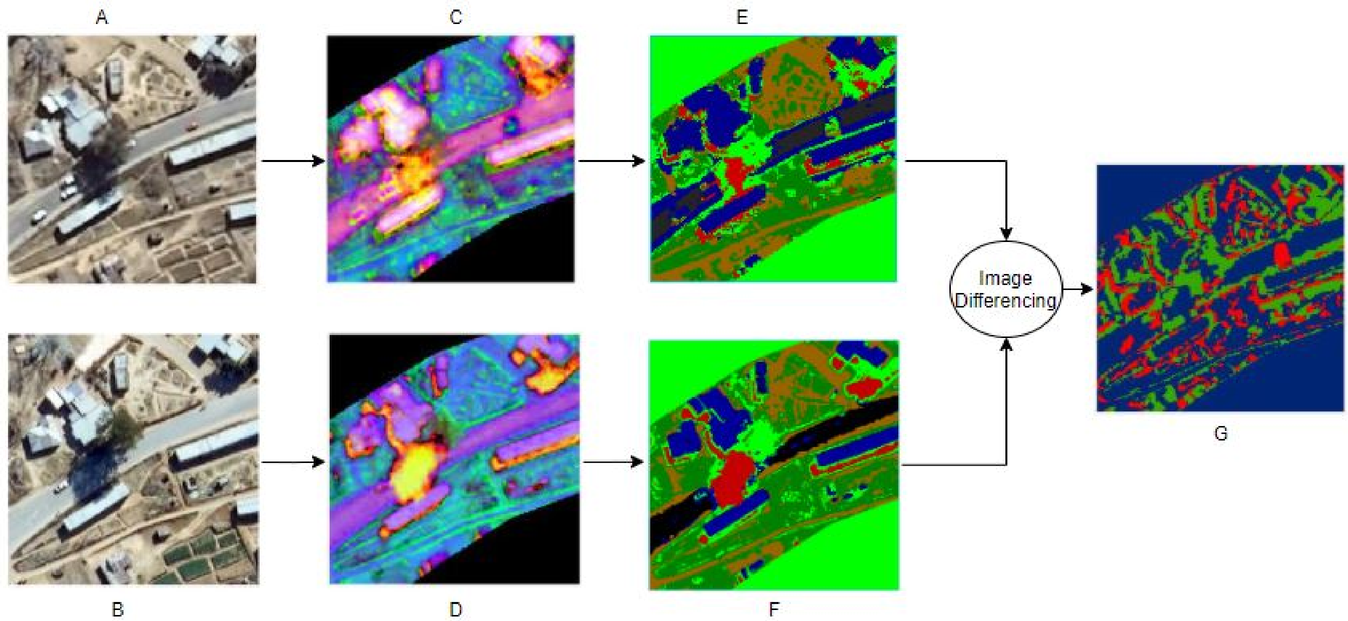

Figure 3.13: The processes conducted to distinguish between temporary and permanent objects. (A) Images of 2015 and (B) 2017 showing all objects in the road reserve. (C) The 2015 and (D) 2017 image enhancement technique called HSV applied to better show other objects in the road reserve. (E) 2015 and (F) 2017 HSV enhanced images were subtracted from one another using Image Differencing to check if there has been any change that happened between 2015 and 2017. (G) shows the changes that have taken place between 2015 and 2017 in the road reserve.

3.8.4. Post Processing

3.8.4.1. Road extraction

After the classification of the images was done, the results were taken and the road class was extracted using the Extraction tool in the ArcGIS software (see figure 3.14) . The main aim of this tool was to build a logical expression that chooses only the part of the raster that one is interested in. Under the extraction tool, the study used extract by attribute where the input layer was a classified image. The query builder, also known as SQL expression was used to extract road class. In this case, the output was road class.

3.8.4.2. Morphological processes

The road class was uploaded into Erdas software for further processing where Morphological operators were used (see figure 3.14). Under Morphological operators, the study used Erosion and Dilation. The study used these operators to clean up the road class that was extracted from the classified image so that the remaining part could be processed further.

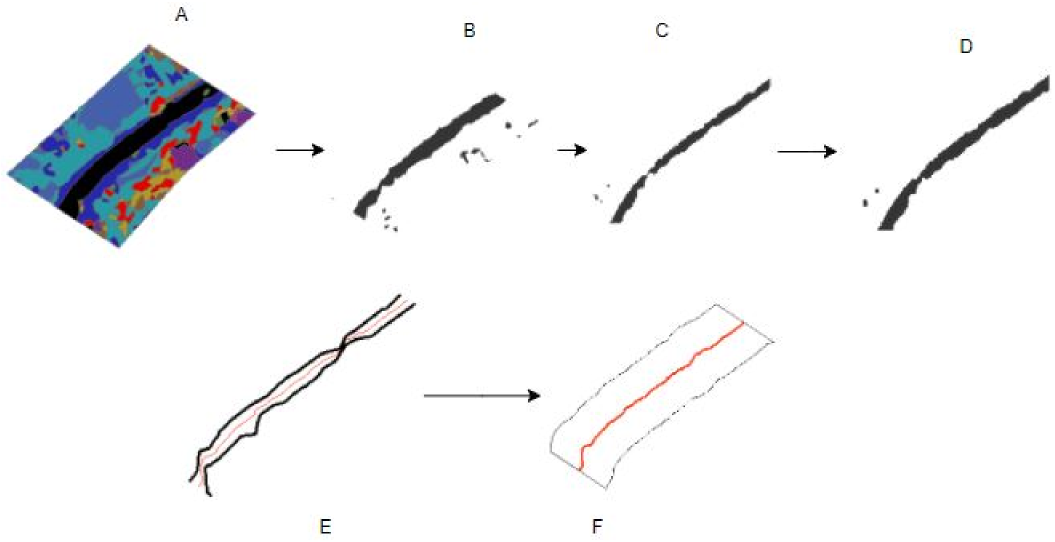

Figure 3.14: This is a Morphological process followed. (A) shows the classified image where the road will be extracted from, (B) shows the extracted road layer that was then taken in erosion as input, (C) this is the erosion process where extracted road layer is processed to remove misclassified objects and peninsulas. (D) the dilation process expands the boundary of the eroded object. (E) The output of the dilation process was converted from raster to vector (polygon), then a tool Collapse dual line to a line. Here the polygon was used to find the centerline of the polygon. (F) The centerline here was used to find the road reserve, it was buffed to 10 meters.

The erosion was used for removal of the peninsula, fingers and small objects that were misclassified and unwanted for the study, and the evening of the road boundary in this case. This was done by shrinking the sizes of the objects and sometimes removing them completely. The study used as input the road layer extracted from the classified image and the kernel of 5 by 5 was used as a structuring element.

The second step of Morphological operations was Dilation where the input was the output of the erosion, this time around the input expanded the boundary of the objects, and the holes caused by erosion were closed. The kernel size used for dilation was 5 by 5. The outcome was processed further to come up with the road centerline.

3.8.4.3. Centerline

The input was a raster file so it was converted into a polygon and that output of the polygon was converted into a line. From there a tool called Collapse dual lines to centerline was used. This tool was used to derive the centerline from the line layer or created to find the centerline. This happened because the digitized road layer from Roads Directorate was not accurately aligning with the road centerline from the orthophotos and the centerline would be used to assess the accuracy of the change detection and was used as a road reserve boundary after being buffered.

3.9. DATA ANALYSIS

In remote sensing, imagery analysis involves identification and recognition of the objects captures by the sensors, the examples being points, lines and polygons. "Image interpretation is the extraction of qualitative and quantitative information in the form of a map about the shape, location, structure, function, quality, condition, the relationship of and between objects, by using human knowledge or experience" (Bhatta 2011).

Bhatta (2011) summarised elements of image interpretation into 8 and they are as follows: location, size, shape, shadows, tone/colour, texture, pattern and association. For this study, the element that is going to be used in shape analysis.

3.9.1. Shape Analysis

The shape or form of an object was easily identified using one of the image interpretation elements; shape interpretation. Lillesand & Kiefer (1979) states that shape tells the form of a certain feature on an image or its external form. The shapes of most natural features have irregular shapes while most man-made features have regular shapes. In this study, the shape interpretation was used to identify man-made features that were regarded as permanent objects.

3.9.2. Comparison of Supervised Methods

The study did a comparative analysis where the supervised classifications were compared to see which one was better at showing the objects in the road reserve. The comparison was between the direct approach and the indirect approach.

3.9.3. Multiple images

Here the study will use the change detection of multiple images. The assumption being that encroachment does not change over time. The results of that change analysis were used to identify objects in the road reserve that did not move from 2015 to 2017. The study considered the objects that did not change or move over time as permanent objects while the objects that did move over time as temporary.

3.9.4. Accuracy assessment

The ArcGIS software was used to digitize the permanent objects that did not change over time. The aim of digitization was so that these objects could be identified by their functions and also calculate the area they occupy so that the size of the encroached area could be known.

3.9.5. Testing of the model

The study was first carried out in Qoaling village, after the results were received, the study tested the model in another village in Maseru called Maqalika. It was important to test the model because the study wanted to know if the same model could be used in other areas.

CHAPTER 4

RESULTS AND ANALYSIS

This chapter will present the analysis and the results of the study of the two images that were taken in 2015 and 2017 respectively. The ancillary data were used to aid the analysis of the study to help find the extent of the road reserve using high-resolution images and analysis of those images.

The section is divided into two major sections. Section one deals with road reserve encroachment in Qoaling village and the second section deals with road reserve encroachment in Maqalika village. The analysis of this study was done using Envi software, Erdas software, and ArcGIS software, the results will be presented in maps, tables, and histograms.

4.1. QOALING ROAD RESERVE

The images below show all the objects that are in the road reserve, so to determine if the objects in the road reserve are permanent or not we used the 2015 image and 2017 image.

4.1.1. Direct Approach Qoaling

In this area, the objects that are found to have encroached the road reserve in 2015 and 2017 were classified using the Maximum likelihood supervised classification. The direct approach looked for every object that was in the road reserve at a particular point in time and 10 classes were identified. The assumption here was that there was more ground than encroachment. The (figure 4.1) below shows the Qoaling land use in 2015 and (figure 4.2) shows Qoaling land use in 2017.

4.1.1.1. Single Image of 2015

In the classified image below of 2015 shown in (figure 4.1) the study detected the following objects in the road reserve; buildings, cars, pavement dirt road, Soil shadowed, tarred roads, tarred road shadowed, trees, vegetation cover, and soil.

The assumption for Single image analysis is that there is more ground than encroachment. In this section, the ground classes were grouped (soil, vegetation, pavement, dirt road, soil shadowed, and tarred road shadow). All these ground classes combined covered the area of 29390 meters square while encroachment classes were grouped as well, (Buildings and trees). They covered an area of 5745 meters square. The two classes that were not included in this are cars and roads because they are not of any use at this stage.

Since this section was working under the assumption that there is more ground than encroachment, that assumption is true because we saw that the ground covered more area than the encroachment. The ground covered 29390 meters square while encroachment covered 5745 meters square

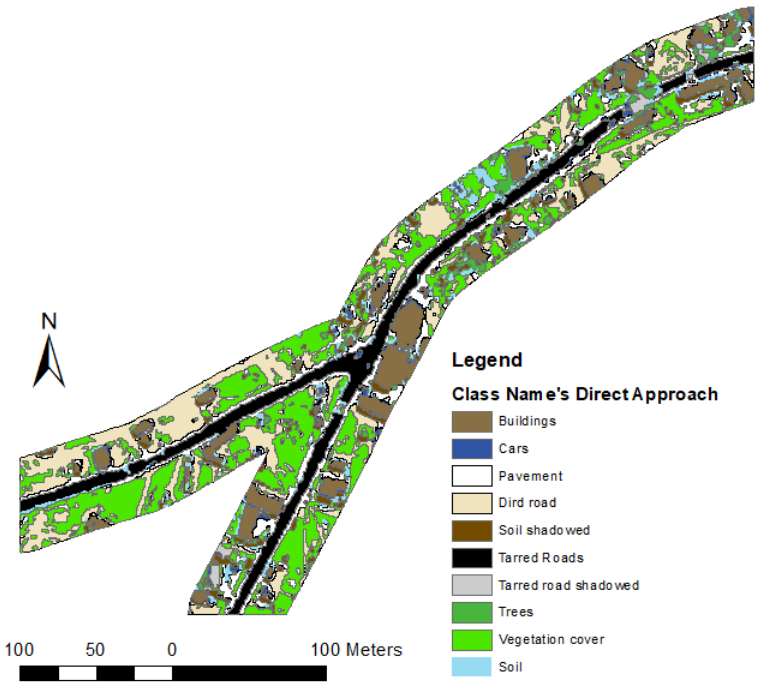

Figure 4.1: Direct Approach Qoaling land use of 2015. The classes shown here are buildings, cars, pavement, dirt road, soil shadowed, tarred road, tarred road shadowed, trees, vegetation cover and soil.

4.1.1.2. Qaoling 2015 Direct method Accuracy Assessment

The (table 4.1) represents ten classes of Qoaling in 2015, namely; soil shadowed, pavement, dirt road, vegetation cover, tarred road shadowed, soil, trees, cars, buildings, and tarred road. The number of pixels that is the Row Total for each class for the 2015 Qoaling direct classification is 353, 477, 1265, 3636, 437, 1594, 595, 633, 12283, and 3721 respectively. This brings the total column to 24994 pixels. The row total of 2015 Qoaling direct classification show 614 pixels classified as soil shadowed 1379 as pavement, 1890 as a dirt road, 3940 as vegetation cover, 1158 as tarred road shadowed, 1664 as soil, 1021 as trees, 1218 as cars, 7776 as buildings and 4334 as a tarred road. The pixels classified correctly by the confusion matrix are the ones displayed diagonally and in bold soil shadowed 75, pavement 402, dirt road 1140, vegetation cover 3265, tarred road shadowed 208, soil 1480, trees 319, cars 355, buildings 7723, and tarred road 3619. The overall accuracy of the classification is $(75 + 402 + 1140 + 3265 + 208 + 1480 + 319 + 355 + 7723 + 3619)/24994 = 18486/24994 = 73.9618\%$. This means that 73.9618% of the image classification was correct and Kappa Coefficient of 0.6687.

Class	Soil Shadowed	Pavement	Dirt road	Vegetation cover	Tarred Road Shadowed	Soil	Trees	Cars	Buildings	Tarred Road	TOTAL
Soil Shadowed	**75**	0	7	34	0	0	17	3	431	47	**614**
Pavement	8	**402**	28	0	1	91	6	22	781	40	**1379**
Dirt road	51	0	**1140**	187	0	1	146	18	347	0	**1890**
Vegetation cover	76	19	14	**3265**	193	21	89	24	239	0	**3940**
Tarred Road Shadowed	41	0	7	0	**208**	0	18	60	824	0	**1158**
Soil	5	56	23	4	23	**1480**	0	0	73	0	**1664**
Trees	69	0	36	146	12	0	**319**	31	408	0	**1021**
Cars	5	0	10	0	0	0	0	**355**	933	15	**1218**
Buildings	6	0	0	0	0	1	0	46	**7723**	0	**7776**
Tarred Road	17	0	0	0	0	0	0	174	524	**3619**	**4334**
TOTAL	**353**	**477**	**1265**	**3636**	**437**	**1594**	**595**	**633**	**12283**	**3721**	**24994**

Table 4.1: Direct Approach confusion matrix of Qoaling 2015 composed of ten information classes: soil shadowed, pavement, dirt road, vegetation cover, tarred road shadowed, soil, trees, cars, buildings, and tarred road.

4.1.1.3. Single Image 2017

In the classified image below of 2017 shown in (figure4.2) the study detected the following objects in the road reserve; buildings, cars, pavement, dirt road, Soil shadowed, tarred roads, tarred road shadowed, trees, vegetation cover, and soil.

The single image analysis assumption is that there is more ground than encroachment. The classes that represent the ground were grouped(soil, vegetation, pavement, dirt road, soil shadowed, tarred road shadowed). These ground classes were combined and they covered an area of 31676 square meters while encroachment classes were grouped as well (building and trees), they covered an area of 5947 square meters. The two classes that were not included are cars and roads because they are not of any use at this stage.

This section was working under the assumption that there was more ground than encroachment. The assumption is correct because we saw that the ground covered more area than the encroachment. The ground covered 31676 meters square while encroachment covered 5947 meters square.

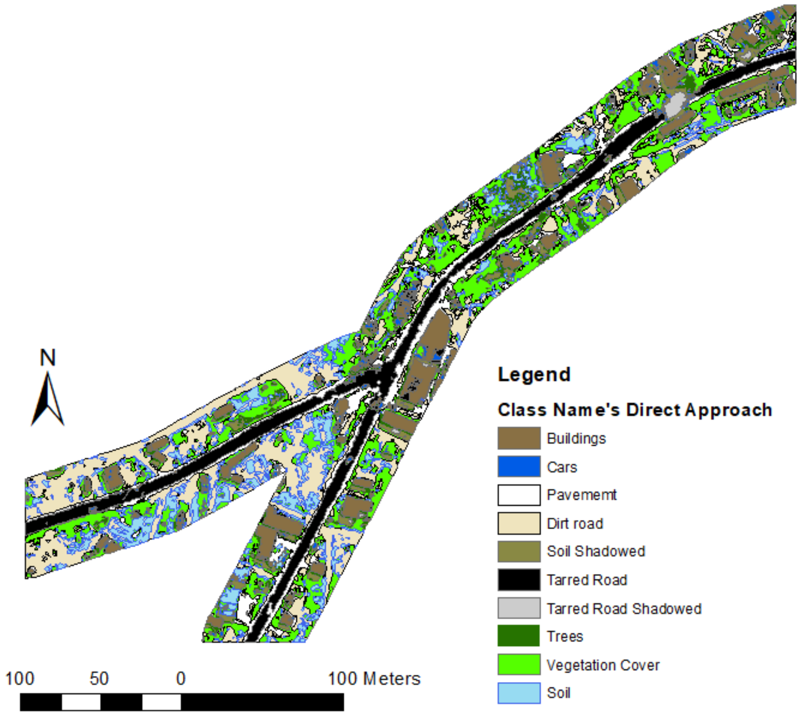

Figure 4.2: Direct Approach Qoaling land use 2017. The classes shown here are buildings, cars, pavement, and dirt road, soil shadowed, tarred road, tarred road shadowed, trees, vegetation cover and soil.

4.1.1.4. Qaoling 2017 Direct method Accuracy Assessment

The (table 4.2) represents ten classes of Qoaling in 2017, namely, tarred road shadowed, soil shadowed, pavement dirt road, soil, vegetation cover, trees, cars, buildings, and tarred road. The number of pixels that is the Row Total for each class for the 2017 Qoaling direct classification is 1431, 777, 998, 5740, 8418, 23934, 2363, 1878, 41941, and 16481 respectively. This brings the total column to 103961 pixels. The row total of 2017 Qoaling direct classification show, 1967 pixels as tarred road shadowed, 12753 pixels classified as soil shadowed, 4459 as pavement, 8470 as a dirt road, 10548 as soil, 10568 vegetation cover, 5627 as trees, 3929 as cars, 23857 as buildings and 18783 as a tarred road. The pixels classified correctly by the confusion matrix are the ones displayed diagonally and in bold, tarred road shadowed 1395, soil shadowed 724, pavement 959, dirt road 5022, soil 6700, vegetation cover 7577, tree 1092, cars 667, buildings 26382 and tarred road 16013. The overall accuracy of the classification is (1395 + 724 + 959 + 5022 + 6700 + 7577 + 1092 + 667 + 26382 + 16013)/103961 = 66531/103961 = 63.9961%. This means that 63.9961% of the image classification was correct and the Kappa Coefficient is 0.564.

Class	Tarred Road Shadowed	Soil Shadowed	Pavement	Dirt Road	Soil	Vegetation Cover	Trees	Cars	Buildings	Tarred Road	TOTAL
Tarred Road Shadowed	**1395**	0	0	517	0	0	0	32	23	0	**1967**
Soil Shadowed	0	**724**	15	38	98	8316	570	70	2922	0	**12753**
Pavement	0	13	**959**	0	1534	36	0	55	1462	400	**4459**
Dirt Road	36	0	0	**5022**	0	1838	672	44	858	0	**8470**
Soil	0	14	3	0	**6700**	3614	0	0	217	0	**10548**
Vegetation Cover	0	10	0	21	86	**7577**	29	0	2845	0	**10568**
Trees	0	15	0	132	0	2481	**1092**	423	1484	0	**5627**
Cars	0	1	0	0	0	61	0	**667**	3186	14	**3929**
Buildings	0	0	2	10	0	11	0	398	**26382**	54	**23857**
Tarred Road	0	0	19	0	0	0	0	189	2562	**16013**	**18783**
TOTAL	**1431**	**777**	**998**	**5740**	**8418**	**23934**	**2363**	**1878**	**41941**	**16481**	**103961**

Table 4.2: Direct Approach confusion matrix of Qoaling 2017 composed of ten information classes: road shadowed, soil shadowed, pavement, dirt road, soil, vegetation cover, trees, cars, buildings, and tarred road.

4.1.1.5. Multiple image analysis: Direct change detection 2015-2017

The study used multiple images taken at different times (2015 and 2017) so that the study could distinguish between permanent objects and temporary objects. For this study, the permanent objects were those that do not change over time, which the study focuses on. While those that change were regarded as temporary.

Change detection was conducted and the results are shown in (figure 4.3) below. The objects that declined from 2015 to 2017 are shown in green colour and those that increased are shown in red colour. The objects that did not change and were found to be permanent were shown in blue colour, and those were buildings and the road. These were identified using one of the image interpretation elements; shape. The road was identified because of its elongated shape while the buildings were identified because of their rectangular and square shapes. The buildings were further classified into Houses and Shops, still using shape analysis the houses are rectangular in shape and the shops are square.

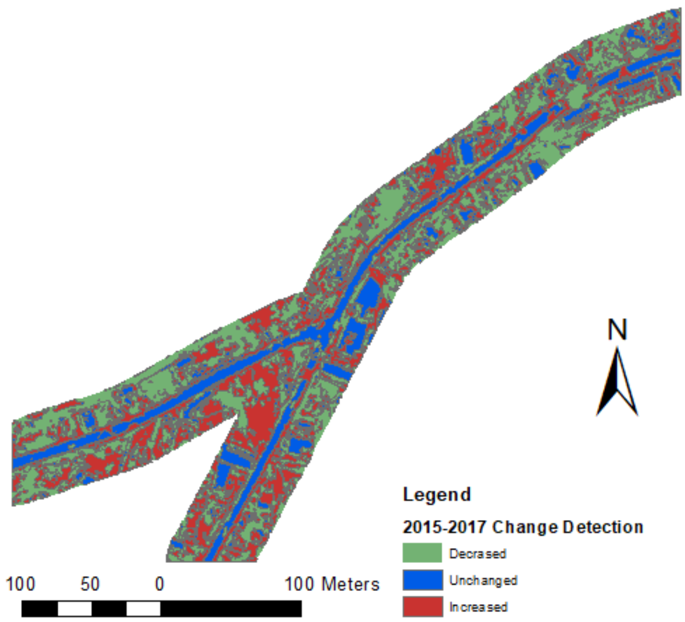

Figure 4.3: Direct Approach Qoaling Change detection between 2015 and 2017. Showing objects in the road reserve that decreased, that increased and those that remained the same (unchanged).

4.1.1.6. Determination of centerline and road reserve using Morphological processes

Figure 4.4 shows the centerline of Qoaling road. The erosion and dilation processes were used to create the road reserve. Road reserve (buffer of 20 meters) was created using road centerline. The centerline shows the middle of the road from where the road reserve is measured. In this case, since the Qoaling road is type B class (see figure 1.1 the road reserve (buffer)is 20 meters.

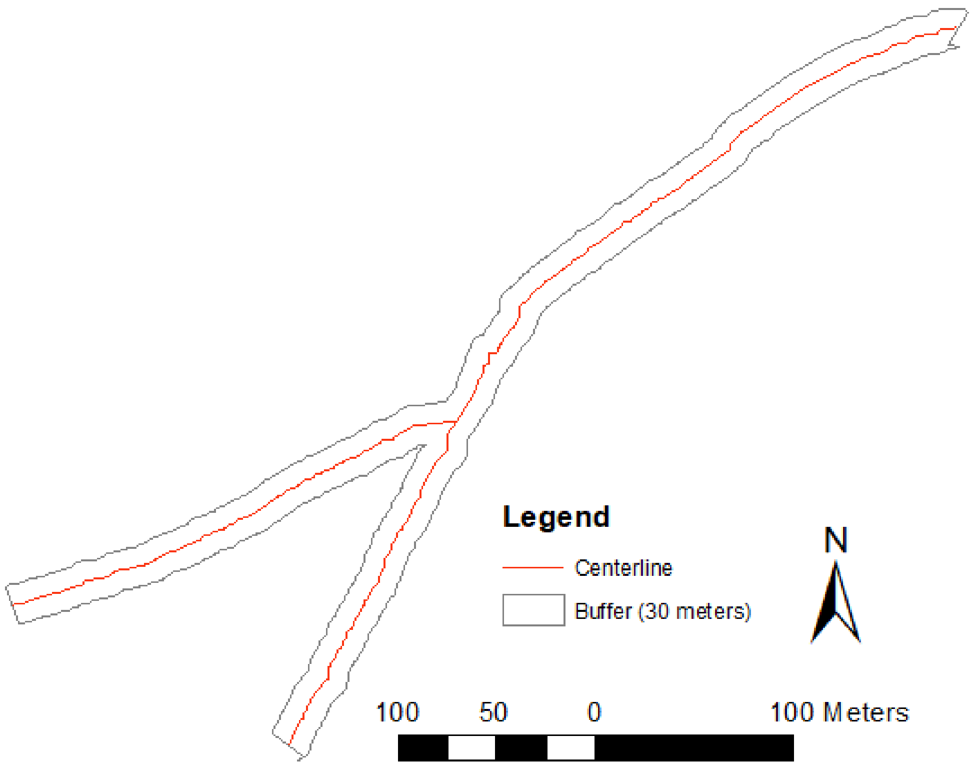

Figure 4.4: Qoaling road centerline crated using morphological processes called erosion and dilation. Show here are the centerline and the road reserve used by direct method.

4.1.1.7. Direct Approach: Change Detection Accuracy

The results of the change detection were overlaid with the road reserve shown in (figure 4.5). It shows the objects that declined in green and those that increased in red. The objects that did not change were shown in blue between 2015 and 2017. It shows that the road reserve boundary of 10 meters in yellow colour and all the buildings that are found to be in the road reserve, which is 10 meters on both sides of the road from the centerline.

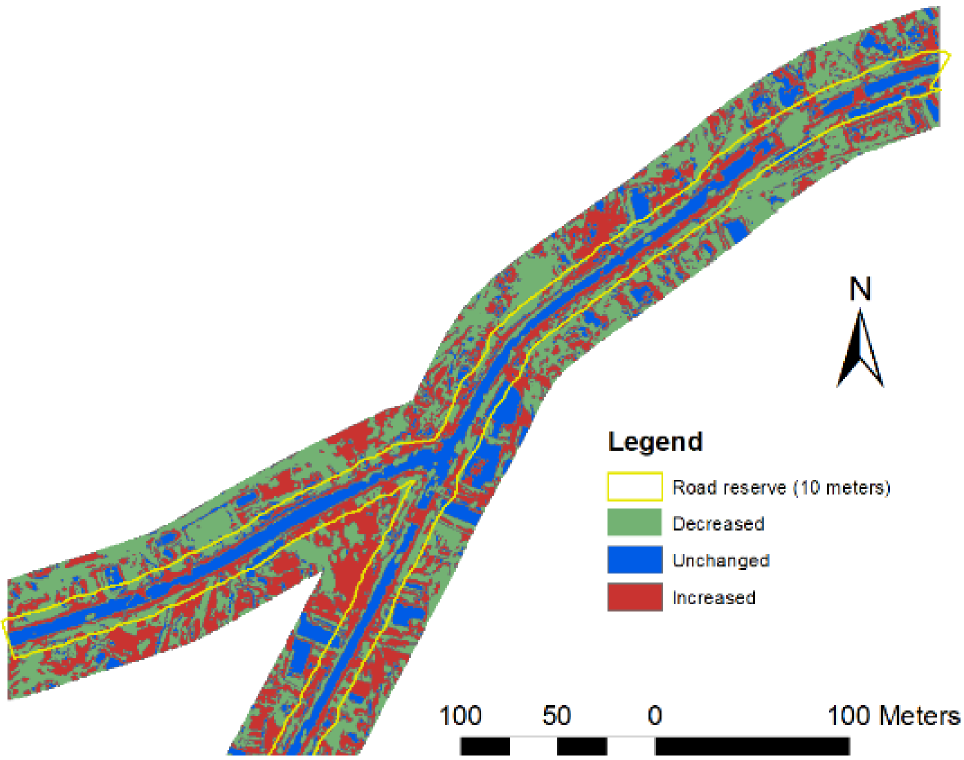

Figure 4.5: Qoaling direct approach method to testing accuracy of change detection. The road reserve from the morphological process is overlaid on change detection map to see its accuracy.

4.1.1.8. Digitised Properties that have encroached the road reserve

In (figure 4.6) the study digitized houses and shops that were found to be in the road reserve. The buildings were classified using shape analysis into houses shown in orange and shops in light blue. The digitized objects are those that did not change and were considered permanent objects. The study found 19 houses that have encroached the road reserve while the numbers of shops were only two.

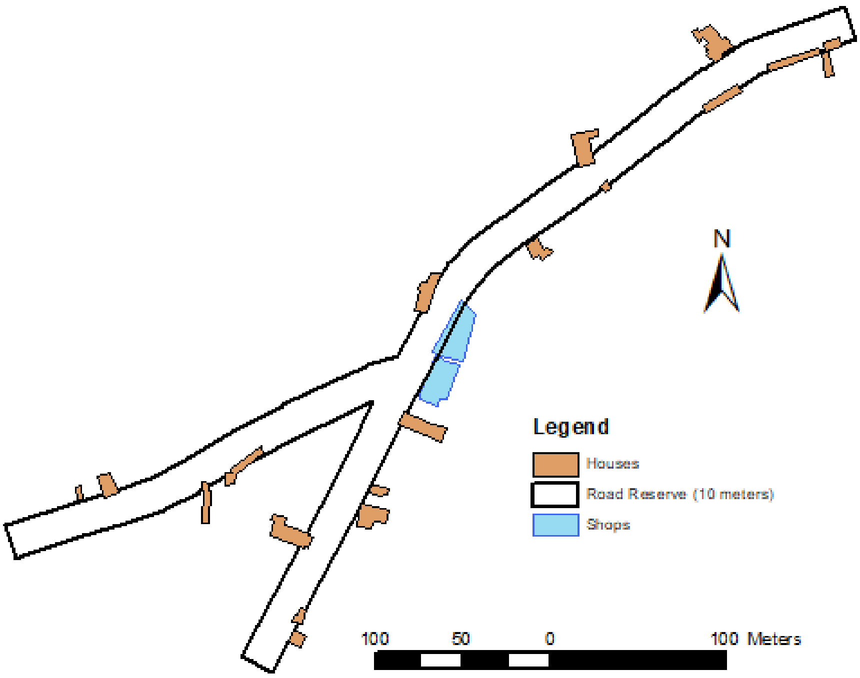

Figure 4.6: Qoaling direct classification road reserve encroachment show here the digitized encroaching permanent objects as houses in orange and shops in sky blue and the road reserve which is 10 meters. The numbers of houses detected were 20 while the shops were only 2.

4.1.1.9. Results of the direct approach

The size of the road reserve affected by encroachment is shown in (figure 4.7) below where property type is put against meters square do determine the area they occupy in the road reserve. The results of the objects found in the road reserve direct classification show that the permanent objects that are in the road reserve are houses and shops. The houses are found to occupy an area of $3222\,m^2$ while shops occupy an area of $822\,m^2$. This shows the road reserve that has been encroached by buildings in Qoaling to be a total area of $4044\,m^2$.

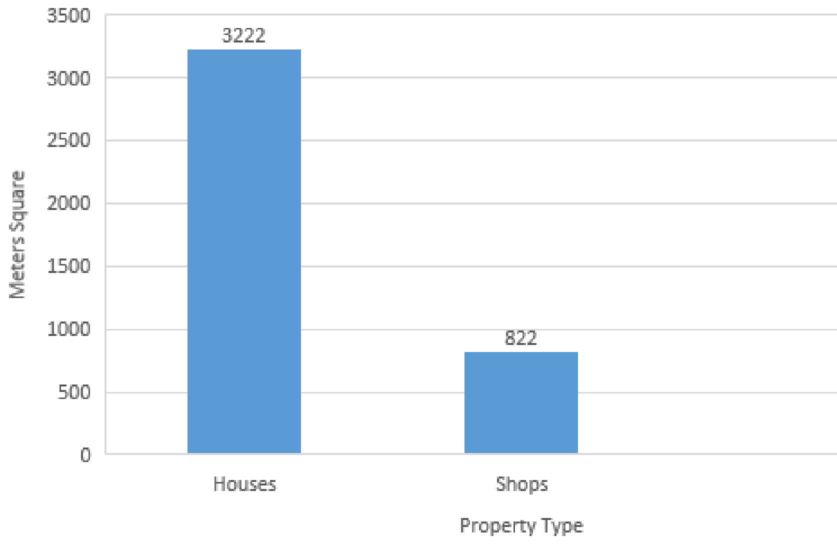

Figure 4.7: Qoaling direct approach results, where the houses encroached the road reserve by $3222\,m^2$ and the shops encroached by $822\,m^2$.

4.1.2. Indirect Approach Qoaling

The land use of Qoaling in 2015 and 2017 was conducted this time around using the indirect approach, it focused on the ground more than the objects in the road reserve. The study classified six land uses this time. The assumption here is that there is more ground than encroachment. The (figure 4.8) below shows Qoaling land use in 2015 and (figure 4.9) shows Qoaling land use in 2017.

4.1.2.1. Indirect Approach Single Image 2015

The classified image below (figure 4.8) show the objects that were detected from the 2015 image of Qoaling village they are shadows, tree, vegetation cover, soil, build-up areas, and tarred road.

This section of single image analysis assumes that there is more ground than encroachment. The classes that represented the ground were grouped, (shadows, soil, vegetation). All these grouped classes combined cover the area of 26394 square meters. The classes that represent encroachment were grouped as well and are (build-up areas and trees). They covered an area of 7066 square meters. The road class of the study was ignored because it was not useful at this stage.

The single image analysis assumes that there is more ground than encroachment, the assumption is true because the ground cover is more than the encroachment. The ground covered an area of 26394 square meters and the encroachment covered an area of 7066 meters square.

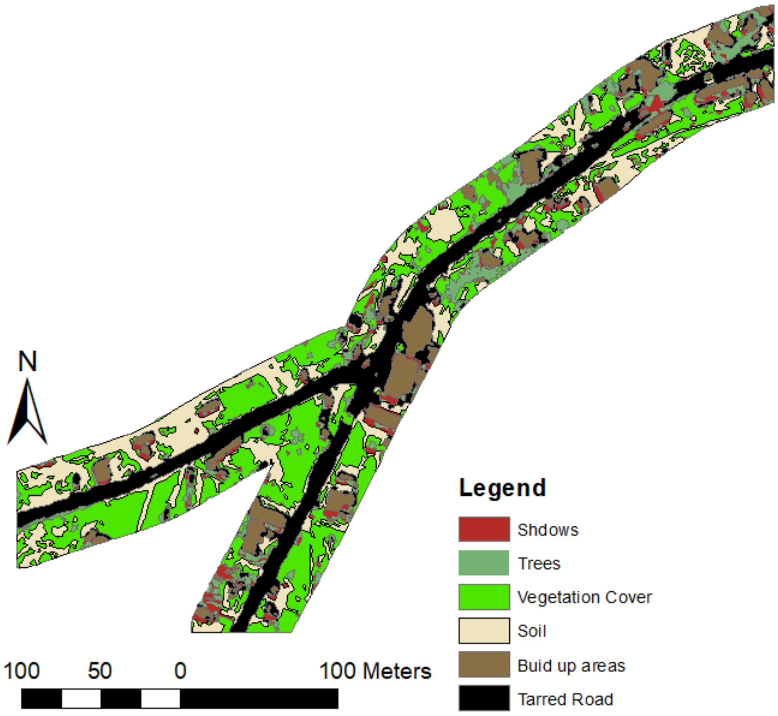

Figure 4.8: Indirect Approach Qoaling land use 2015. The encroaching objects shown on a map are shadows, trees, vegetation cover, soil, build up area and tarred road.

4.1.2.2. Qoaling 2015 Indirect method Accuracy Assessment

The (table 4.3) represents six classes of Qoaling in 2015, namely, shadows, trees, vegetation cover, soil, build-up area, and tarred road. The number of pixels that is the Row Total for each class for the 2015 Qoaling indirect classification is 2323, 579, 6433, 2373, 11514, and 3778 respectively. This brings the total column to 27000 pixels. The row total of 2015 Qoaling indirect classification show, 2910 pixels as shadows, 2072 pixels classified as trees, 6410 as vegetation cover, 2692 as soil, 6964 as build-up area, 5942 as a tarred road. The pixels classified correctly by the confusion matrix are the ones displayed diagonally and in bold, shadows 1713, trees 469, vegetation cover 5826, soil, 2274, build-up area 6916, tarred road 3594. The overall accuracy of the classification is (1713 + 469 + 5826 + 2274 + 6916 + 3594)/27000 = 20792/27000 = 77.0074 percent. This means that 77.0074 percent of the image classification was correct and the Kappa Coefficient of 0.7063.

Class	Shadows	Trees	Vegetation Cover	Soil	Build up area	Tarred Road	Row TOTAL
Shadows	**1713**	38	80	0	1062	27	**2910**
Trees	412	**469**	411	0	748	32	**2072**
Vegetation Cover	106	66	**5826**	68	343	1	**6410**
Soil	53	3	116	**2274**	167	79	**2692**
Build up area	3	0	0	0	**6916**	45	**6964**
Tarred Road	36	3	0	31	2278	**3594**	**5942**
Column TOTAL	**2323**	**579**	**6433**	**2373**	**11514**	**3778**	**27000**

Table 4.3: Indirect approach confusion matrix of Qoaling 2015 composed of six information classes: shadows, trees, vegetation cover, soil, build up area and tarred road.

4.1.2.3. Indirect Approach Single Image 2017

(Figure 4.9) below shows the land use of Qoaling in 2017 that was detected and are as follows; shadows, trees, vegetation cover, soil build-up areas, and tarred road. The single image assumed that there was more ground than encroachment. The classes that represented the ground were grouped (shadows, soil, vegetation cover). All these classes were combined and they covered an area of 28230 square meters. The classes that represented encroachment were grouped as well and they are (build-up area and trees). They covered an area of 7739 square meters. The road class was ignored at this stage because it was not part of encroachment. The ground covered an area of 28230 square meters and the encroachment covered an area of 7739 square meters. Since the single image analysis assumed that there was more ground than encroachment, the assumption is true because there is more ground than encroachment.

4.1.2.4. Qoaling 2017 Indirect Accuracy Assessment

The (table 4.4) represents six classes of Qoaling in 2017, namely, shadows, trees, vegetation cover, soil, build-up area, and tarred road. The number of pixels that is the Row Total for each class for the 2017 Qoaling indirect classification is 4397, 2037, 22213, 8293, 34929, and 15426 respectively. This brings the total column to 87295 pixels. The row total of 2017 Qoaling indirect classification show, 5743 pixels as shadows, 5124 pixels classified as trees, 23285 as vegetation cover, 10170 as soil, 25821 as build-up area, 17152 as a tarred road. The

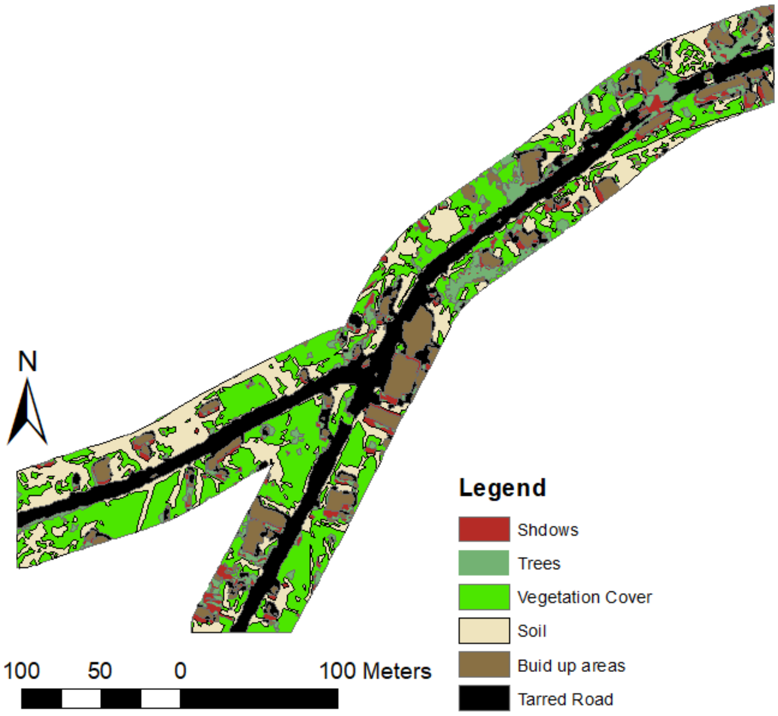

Figure 4.9: Indirect Approach Qoaling land use 2017. Showing the following classes; Shadows,Trees, Vegetation cover, Soil, Build up areas and Tarred road.

pixels classified correctly by the confusion matrix are the ones displayed diagonally and in bold, shadows 4177, trees 1388, vegetation cover 17798, soil, 8077, build-up area 25004 and tarred road 14885. The overall accuracy of the classification is (4177 + 1388 + 17798 + 8077 + 25004 + 14885)/87295 = 71329/87295 = 81.7103%. This means that 81.7103% of the image classification was correct and the Kappa Coefficient was 0.7604.

Class	Shadows	Trees	Vegetation Cover	Soil	Build up area	Tarred Road	TOTAL
Shadows	**4177**	486	342	0	738	0	**5743**
Trees	208	**1388**	1768	0	1760	0	**5124**
Vegetation Cover	8	160	**17798**	159	5153	7	**23285**
Soil	0	3	1763	**8077**	221	106	**10170**
Build up area	4	0	346	39	**25004**	428	**25821**
Tarred Road	0	0	196	18	2053	**14885**	**17152**
TOTAL	**4397**	**2037**	**22213**	**8293**	**34929**	**15426**	**87295**

Table 4.4: Indirect approach confusion matrix of Qoaling 2017 composed of six information classes: shadows, trees, vegetation cover, soil, build up area and tarred road.

4.1.2.5. Multiple image analysis: Indirect change detection 2015-2017

The study used multiple images that were taken at different times (2015 and 2017) to tell apart objects that are permanent and temporary. In this case, the objects that do not change are taken as permanent while those that change are taken to be temporary.

The results of the change detection that was conducted are shown in (figure 4.10) below. The objects that decreased are shown in green colour, those that increased are shown in red colour, while those that did not change are shown in blue colour. The objects that did not change in this case are the buildings and the road. The road was recognised because of its elongated shape while the buildings were recognized by their rectangular and square shapes. The buildings were classified according to their types, which are houses and shops. Houses were recognised because of their rectangular shapes while shops were recognised because of their square shapes.

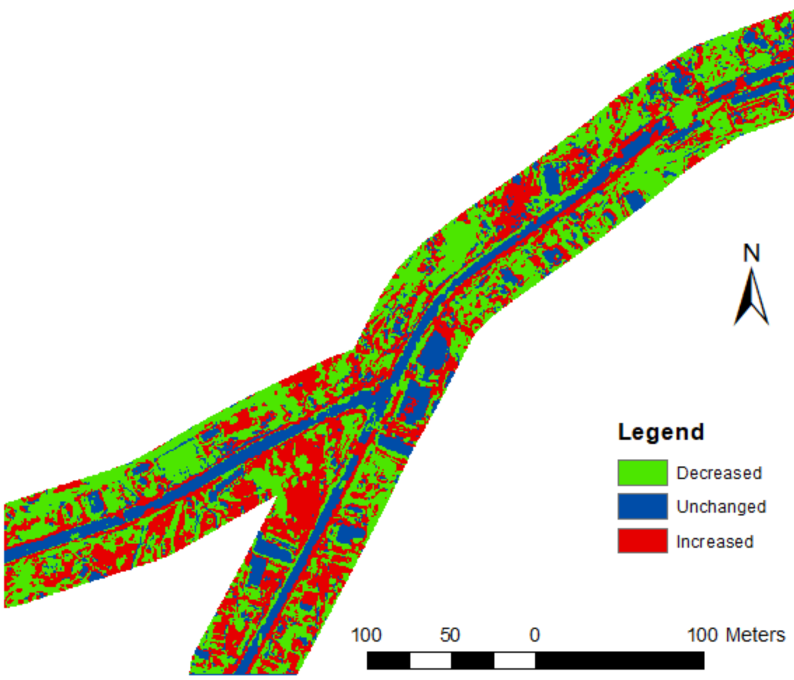

Figure 4.10: Indirect Approach Change Detection between 2015 and 2017. Showing objects that decreased, increased and those that did not change over time

4.1.2.6. Indirect approach :Determination of centerline

Figure 4.11 shows the centerline of the Qoaling road. Road reserve (buffer of 10 meters) was created using the road centerline. The centerline shows the middle of the road where the road reserve is measured from. In this case, since the Qoaling road is type B class (see figure 1.1 the road reserve (buffer)is 10 meters.

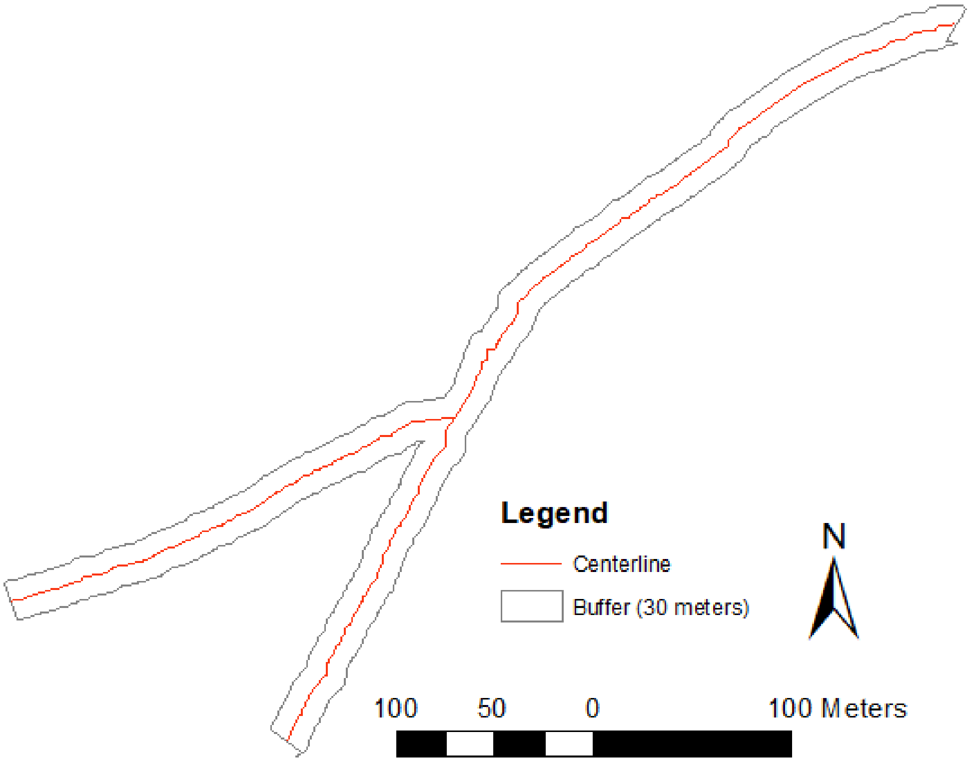

Figure 4.11: Qoaling road centerline crated using morphological processes called erosion and dilation. Shown here are the centerline and the road reserve used by indirect method.

4.1.2.7. Indirect Approach: Change Detection Accuracy

The results of change detection are shown in (figure 4.12) where they are overlaid with road reserve. It shows that there are objects that are in the road reserve. These are objects that did not move overtime during the period of 2015 and 2017 are shown in blue colour. These objects are identified as buildings. Those that did show change are in green colour saw a decline while those in red colour saw an increase.

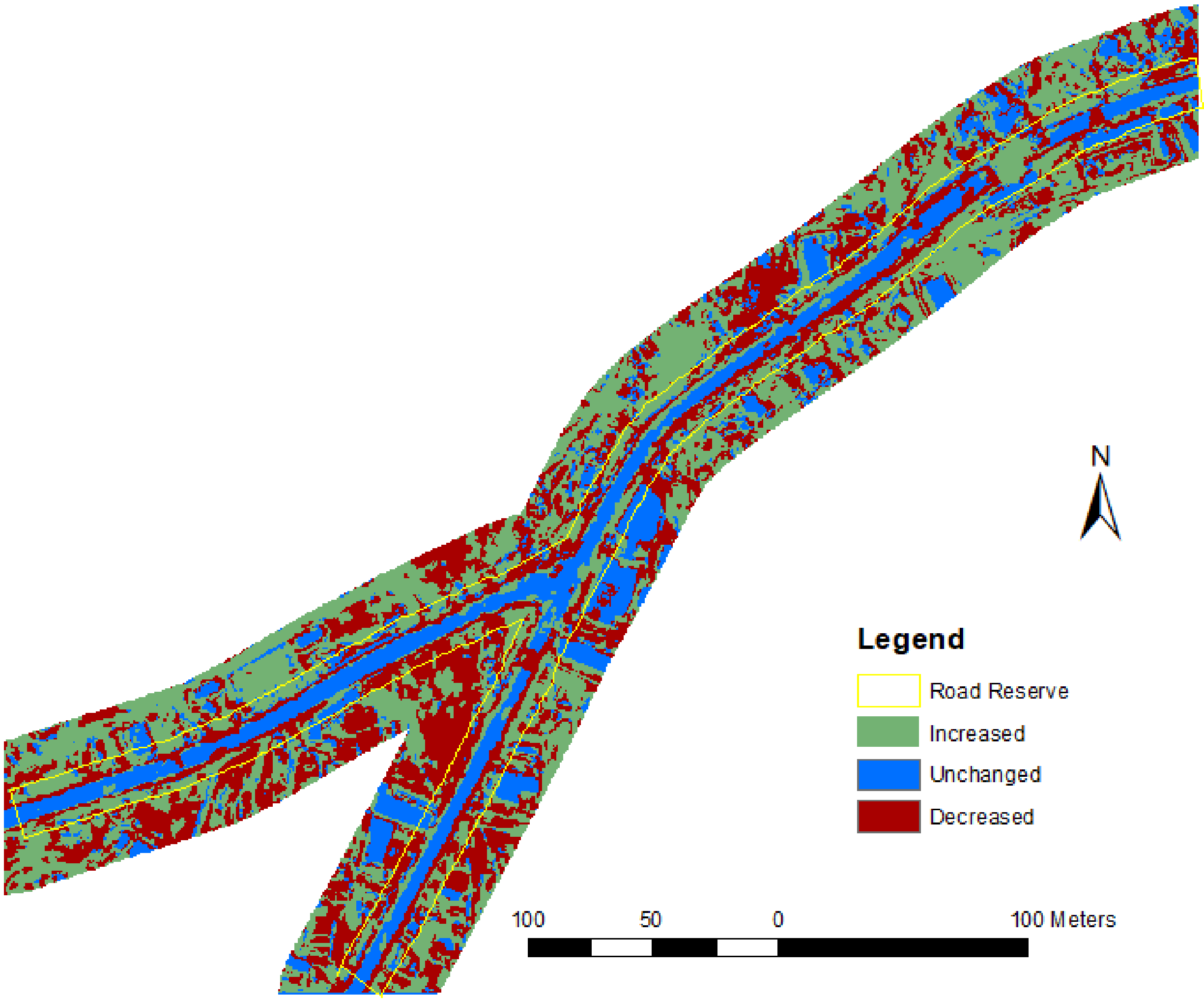

Figure 4.12: Qoaling indirect approach change detection map between 2015 and 2017 was overlaid with road reserve from morphological process.

4.1.2.8. Digitisation of Object in the road reserve in Qoaling using Indirect method

In (figure 4.13) the study digitised houses and shops that were found to be in the road reserve. The buildings were classified using shape analysis into houses shown in orange and shops in light blue. The digitised objects are those that did not change over time and were considered permanent objects. Eighteen houses and two shops that have encroached the road reserve in Qoaling using the Indirect method were digitized.

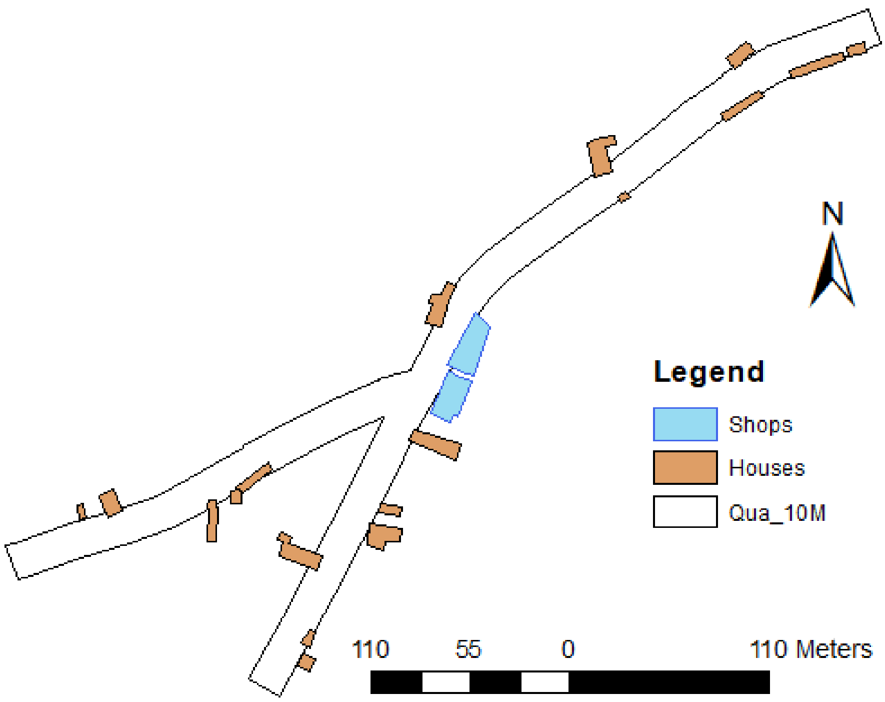

Figure 4.13: .Qoaling indirect road reserve encroachment shows the permanent digitized objects that have encroached the road reserve, which is shops in sky blue and houses in orange as well as the road reserve which is 10 meters. This shows the number of objects that have encroached the road reserve as 18 houses and 2 shops.

4.1.2.9. Qoaling results of the indirect approach

The size of the road reserve affected by encroachment in Qoaling is shown by (figure 4.14) where property type is put against the square meters the properties occupy in the road reserve. The results show that the permanent objects that are found in the road reserve are houses and shopping centers. The houses in the road reserve are found to have encroached on an area totaling to 760 m^2 while the shopping centers have encroached the space of 4891 m^2. The total road reserve encroached by houses and shopping centers is 5651 m^2.

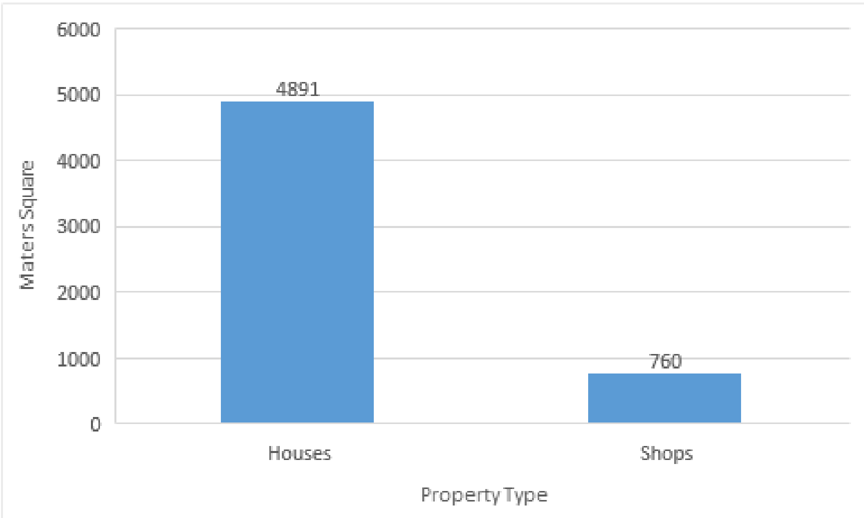

Figure 4.14: Qoaling indirect approach results show houses have encroached 4891 m^2 of the road reserve in Qoaling while the shops have occupied 760 m^2.

4.1.2.10. Comparative analysis between direct and indirect approach methods in Qoaling

The two approaches (table 4.5) dealt with the land use of Qoaling village between 2015 and 2017. The direct approach and the indirect approach. The direct approach looked at objects that were in the road reserve while the indirect approach looked for the ground more instead of objects. The images used were not of the highest quality so the direct approach in looking for every object in the road reserve did not detect all those objects. On the other hand, since the indirect approach did not look for every object, but rather the ground mostly managed to detect every object that was trained. Between the two approaches, the one that was better for detecting encroachment was the indirect method. The accuracy assessment of the two methods is shown in (table 4.5)below where the Indirect method performed better both in 2015 and 2017 images with 77.0074% and 81.7103% respectively. This shows the Indirect method was better than the Direct method.

Classification Method	**Accuracy Assessment 2015**	**Accuracy Assessment 2017**
Qoaling Direct Classification method	73.9618%	63.9961%
Qoaling Indirect Classification method	77.0074%	81.7103%

Table 4.5: Comparison of methods between coaling direct method and indirect method

4.1.3. Qoaling Unsupervised

The unsupervised approach in detecting road reserve encroachment was done using the 2015 and 2017 images, here the IsoData classifications were conducted. The clusters that were detected here were 30 and they were combined are as follows. The buildings, dirt road, pavement, road, shadows, and soil, trees, and vegetation.

4.1.3.1. 2015 IsoData classification

In the unsupervised classification, the assumption was that the small clusters were encroachment. These small clusters were combined and given the names of the matching objects. These were the clusters found in the road reserve; buildings, dirt road, pavement, road, shadows, soil, trees, and vegetation.

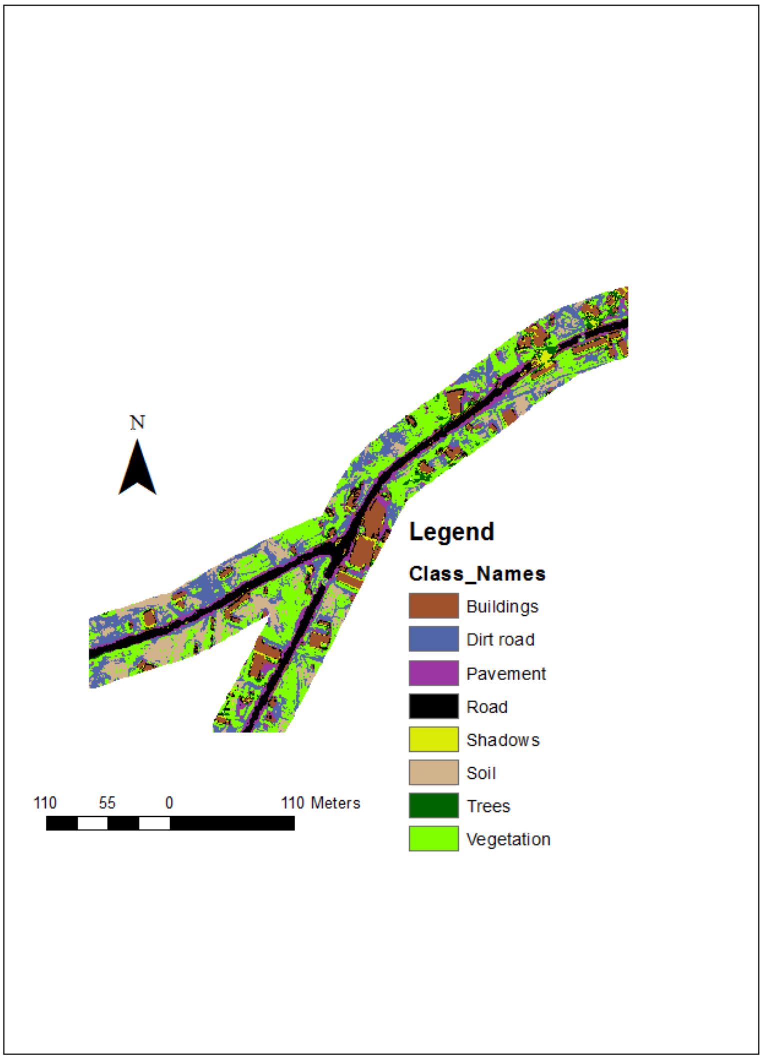

Figure 4.15: Qoaling Unsupervised classification results of 2015 where Isodata technique was used showing buildings, dirt road, pavement, road, shadows, soil, trees, and vegetation

4.1.3.2. 2017 IsoData classification

The land use of 2017 as shown in figure 4.16, IsoData classification showed the clusters that were detected, the road and building clusters were detected as the same, so the study here used image interpretation element of shape to tell them apart. The road was identified and elongated shape while the buildings were square and rectangular. Other clusters were soil, vegetation, dirt road, shadows, pavement, and trees. The unsupervised image classification assumed that small clusters are encroachment.

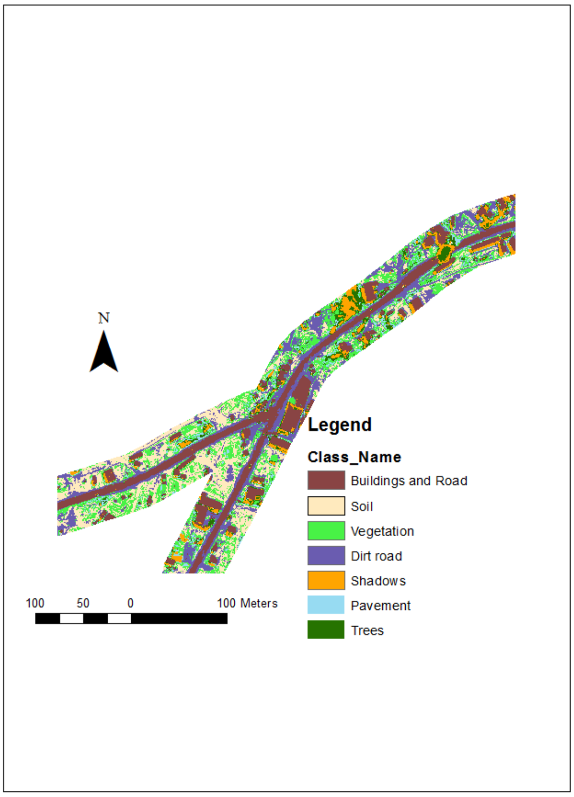

Figure 4.16: Qoaling Unsupervised Isodata classification method results of 2017 showing buildings, soil, vegetation, dirt road, shadows, pavement and trees.

4.1.3.3. Multiple image analysis: Unsupervised change detection 2015 - 2017

The figure 4.17 below shows the changes that have taken place in Qoaling village between 2015 and 2017. Here we see the unchanged objects in red colour, these are taken to be permanent objects. The increased object shown in navy blue and green were taken as temporary as well as those that saw a decrease shown in light blue and maroon colours. The objects that did not change over time were identified as buildings because of the shapes, which are square and rectangular and shown in red colour.

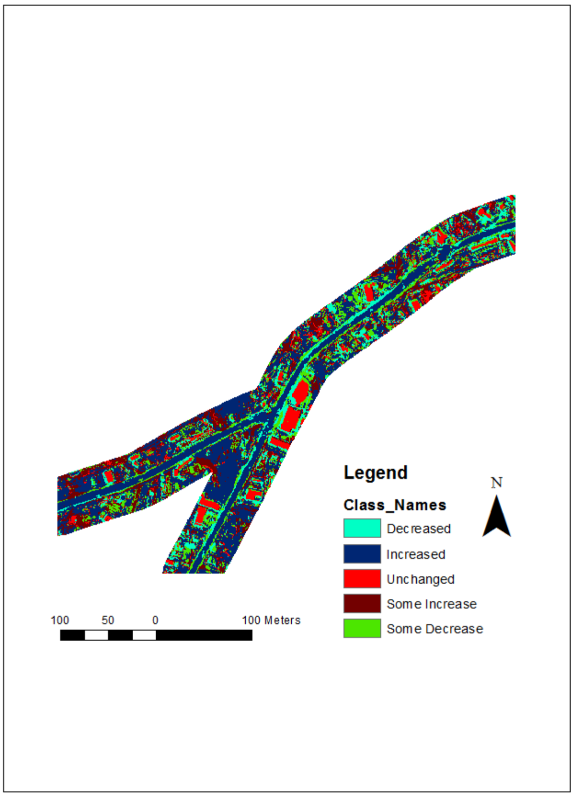

Figure 4.17: Qoaling Change detection 2015 - 2017 showing areas where there was a big changes first; decreased, increase and unchanged. Lastly showing areas where there was small changes; some increase and some decrease.

4.1.3.4. Centerline

The map shown in (figure 4.18) shows the Qoaling road centerline in black colour and the road reserve of 10 meters (see figure 1.1) is shown in red colour. This is used to assess the classification and to make sure that objects in the road reserve are detected correctly.

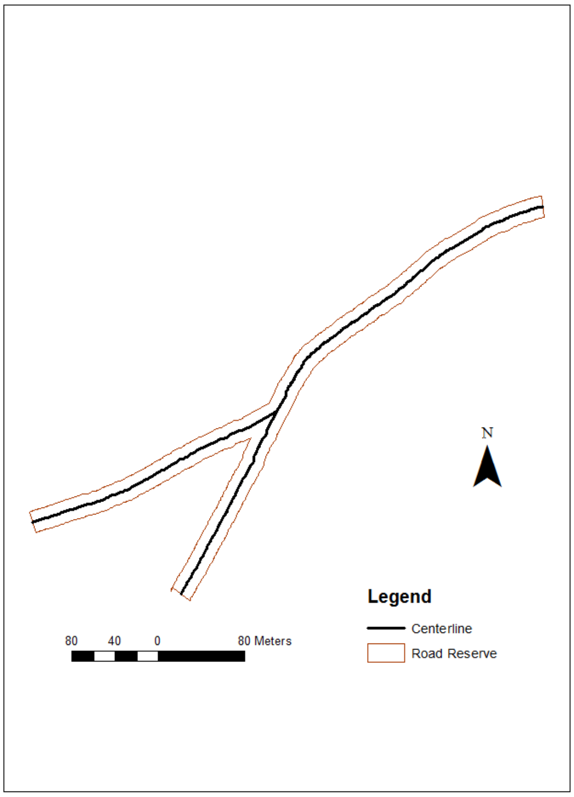

Figure 4.18: Qoaling road centerline created using morphological processes called erosion and dilation. Show here are the centerline and the road reserve used by Unsupervised method.

4.1.3.5. Change detection accuracy

The overlay of change detection results and the road reserve (figure 4.19) is shown, here unchanged objects (red colour) which are buildings are clearly in the road reserve. This is shown where the road reserve boundary in (yellow colour) runs over the buildings.

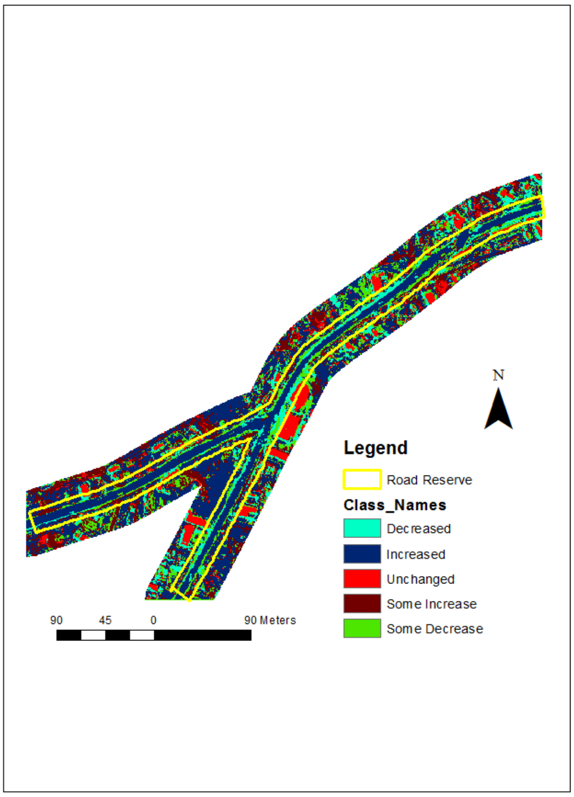

Figure 4.19: Qoalinng Unsupervised approach change detection map between 2015 and 2017 was overlaid with road reserve from morphological process

4.1.3.6. Digitisation of buildings

In figure 4.20 the digitised objects are those that did not change over a period between 2015 and 2017. The digitized buildings in the road reserve were divided into houses and shops according to their functions. The houses are shown in blue while the shops are shown in green.

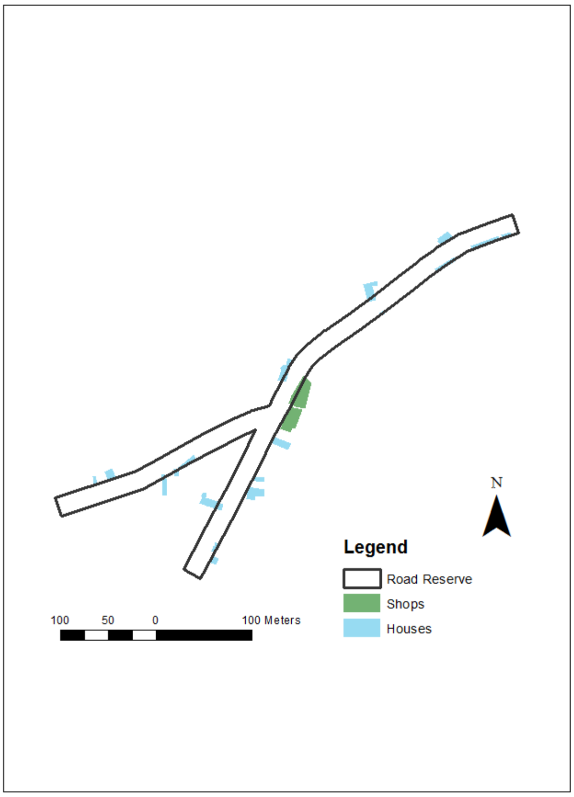

Figure 4.20: Qoaling road reserve encroachment showing digitized objects that have encroached the road reserve, those are shops in green and houses in sky blue. Here 17 houses and 2 shops were detected.

4.1.3.7. Results of Unsupervised classification

Figure 4.21 below show the results of the unsupervised approach to road reserve encroachment and the extend of the encroachment. The property type and the size it occupies are shown. The shops in Qoaling village have encroached an area of 819 m^2 while the houses have encroached an area of 1924 m^2. The total area encroached by these buildings in Qoaling is 2743 m^2.

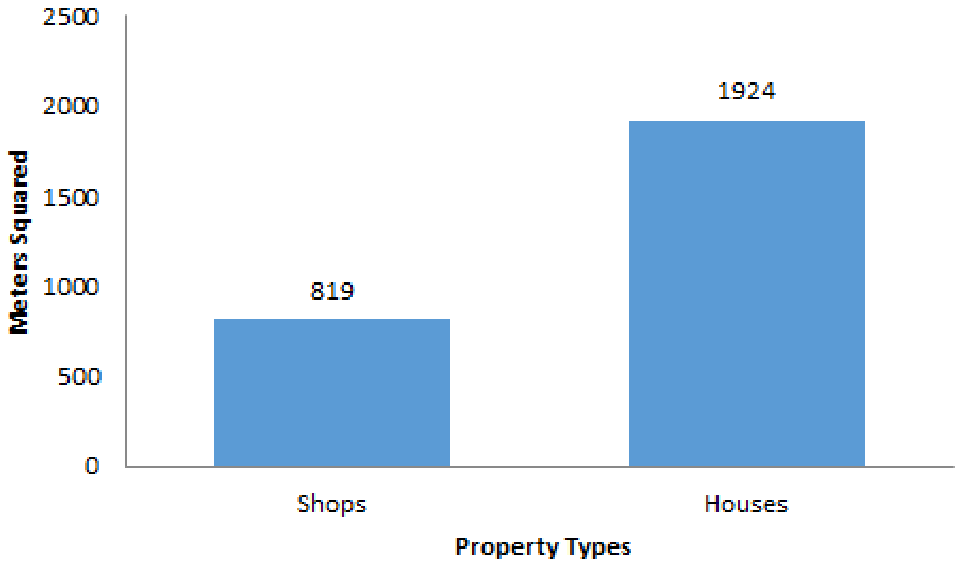

Figure 4.21: Qoaling unsupervised method results showing areas being encroached by shops as 819 m^2 and houses as 1924 m^2.

4.2. MAQALIKA ROAD RESERVE

This section deals with the Maqalika road reserve, it tells the Maqalika village land use and to find the objects in the road reserve in this village. It uses the 2015 and 2017 images to find the objects found in the road reserve.

4.2.1. Direct Approach Maqalika Village

The land use of 2015 and 2017 was conducted to determine the objects that are in the road reserve. The maximum likelihood classification was used and the results are shown below. The direct approach identifies everything that is in the road reserve or area of interest. Seven classes of land use were detected as falling in the area of interest.

4.2.1.1. Maqalika Single Image of 2015

The land use of 2015 shown below in (figure 4.22) was detected to be in the road reserve. Those classes are buildings, dirt road, pavement, road, shadowed road, soil shadowed, trees, and vegetation.

When analysing the single image in this study, the assumption was that the ground was more than encroachment. The land uses found to fall under the category of ground use were grouped and are as follows: (dirt road, pavement, shadowed road, soil shadowed, and vegetation). The category of encroachment included (buildings and trees). The combination of ground classes covered an area of 7128 square meters while the category of encroachment covered an area of 3415 square meters. The road class and car class were not included because they are not part of the road reserve.

Under this section the assumption is that there is more ground than encroachment, the statement is true because the ground area is 7128 square meters while the encroachment area is 3415 square meters.

4.2.1.2. Maqalika 2015 Accuracy Assessment

The (table 4.6) represents nine classes, namely, cars, soil shadowed, dirt road, vegetation, pavement, road shadowed, trees, tarred road, and buildings. The number of pixels that is the Row Total for each class from the 2015 Maqalika direct classification is 151, 834, 757, 2538, 1921, 285, 432, 2269, and 2053, respectively. This brings the total column to 11240 pixels. The row total of 2015 Maqalika direct classification show 268 pixels classified as cars,

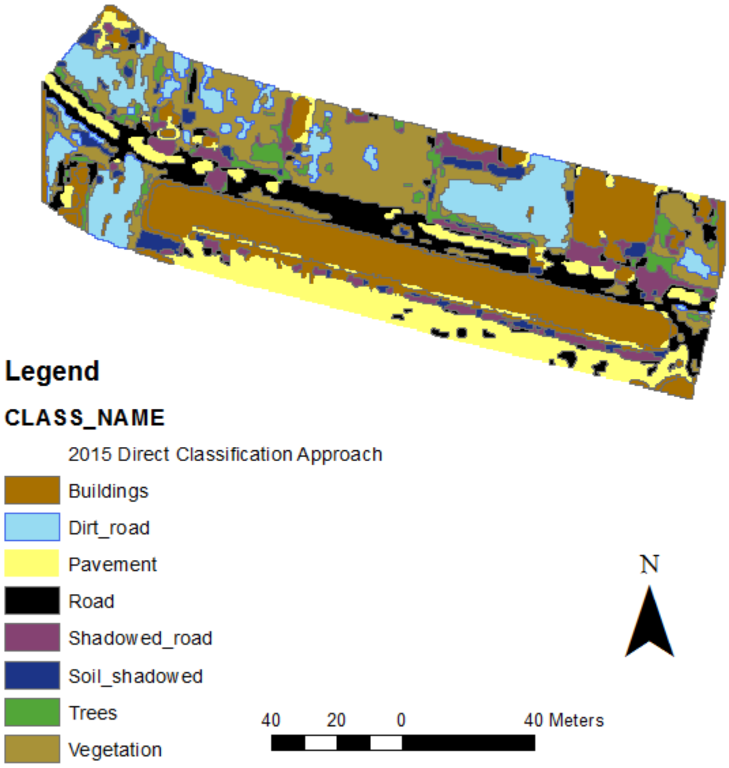

Figure 4.22: Maqalika direct classification of 2015 using maximum classification showing buildings, dirt road, pavement, road, shadowed road, soil shadowed, trees and vegetation.

629 as soil shadowed, 1077 as a dirt road, 2349 as vegetation, 2560 as pavement, 657 as road shadowed, 184 as trees, 1574 as tarred road, and 1942 as buildings. The pixels classified correctly by the confusion matrix are the ones displayed diagonally and in bold; Cars 103 pixels, Soil Shadowed 549 pixels, dirt road 725, vegetation 2168 pixels, pavement 1723 pixels, road shadowed 244 pixels, trees 151 pixels, tarred road 1377 and buildings 1942 pixels. The overall accuracy of the classification is $(103 + 549 + 725 + 2168 + 1723 + 244 + 151 + 1377 + 1942)/11240 = 8982/11240 = 79.9110\%$. This means that 79.9110% of the image classification was correct and Kappa Coefficient of 0.7611.

Class	Cars	Soil Shadowed	Dirt Road	Vegetation	Pavement	Road Shadowed	Trees	Tatted Road	Buildings	Row TOTAL
Cars	**103**	38	2	0	25	0	2	44	54	**268**
Soil Shadowed	17	**549**	0	0	1	16	46	0	0	**629**
Dirt Road	0	7	**725**	342	0	0	0	3	0	**1077**
Vegetation	12	35	30	**2168**	0	0	25	79	0	**2349**
Pavement	3	0	0	0	**1723**	6	15	758	55	**2560**
Road Shadowed	15	205	0	0	17	**244**	168	8	0	**657**
Trees	0	0	0	28	0	5	**151**	0	0	**184**
Tarred Road	1	0	0	0	155	14	25	**1377**	2	**1574**
Buildings	0	0	0	0	0	0	0	0	**1942**	**1942**
Column TOTAL	**151**	**834**	**757**	**2538**	**1921**	**285**	**432**	**2269**	**2053**	**11240**

Table 4.6: Direct approach confusion matrix of Maqalika 2015 composed of nine information classes: soil shadowed dirt road, vegetation, pavement, cars, road shadowed, trees, tarred road and buildings.

4.2.1.3. Maqalika Single Image of 2017

The image below figure 4.23 shows the land use of Maqalika village in 2017 where seven land-use types were detected. Those seven classes are buildings, road, dirt road, pavement, shadowed road, soil shadowed, trees, and vegetation.

Under single image analysis the assumption is that there is more ground than encroachment. The classes that represent the ground were grouped (dirt road, pavement, shadowed road, shadowed soil, and vegetation). The classes that represent encroachment were grouped as well (buildings and trees). The combination of ground classes covered an area of 5783 square meters while the class combination of encroachment covered an area of 4438 square meters.

The statement that says there is more ground than encroachment is true because the analysis found that ground covered an area of 5783 square meters while encroachment covered 4438 square meters.

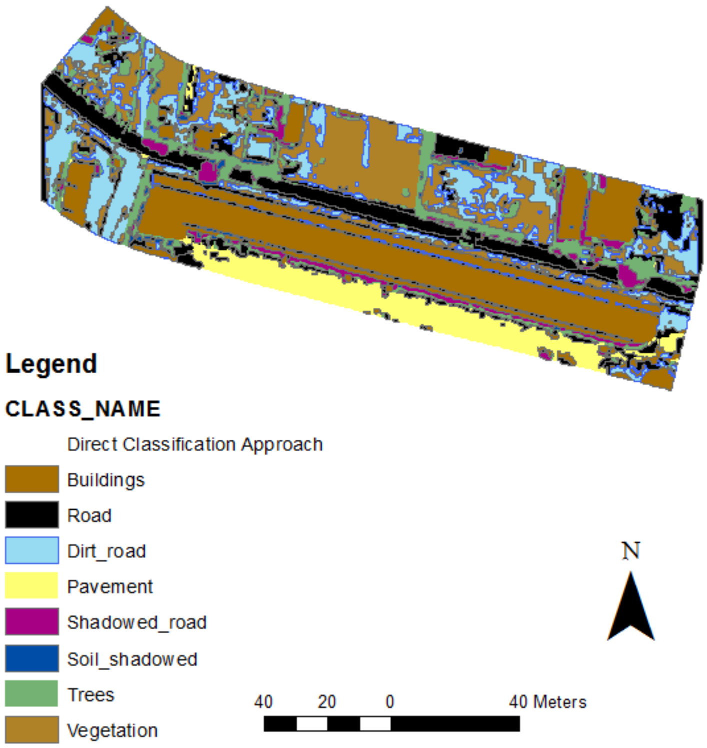

Figure 4.23: Maqalika direct classification of 2017 using maximum classification showing buildings, dirt road, pavement, road, shadowed road, soil shadowed, trees and vegetation.

4.2.1.4. Maqalika 2017 Accuracy Assessment

The (table 4.7) represent nine classes of Maqalika in 2017, namely, soil shadowed, dirt road, vegetation, pavement, cars, road shadowed, trees, tarred road, and buildings. . The number of pixels that is the Row Total for each class form the 2017 Maqalika direct classification is 2965, 2763, 9931, 7315, 519, 1047, 1634, 8477 and 7772 respectively. This brings the total column to 42423 pixels. The row total of 2017 Maqalika direct classification show 668 pixels classified as soil shadowed, 5157 as a dirt road, 9663 as a dirt road, 7109 as pavement,3590 as cars, 1352 as road shadowed, 2950 as trees, 4097 as tarred road, and 7807 as buildings. The pixels classified correctly by the confusion matrix are the ones displayed diagonally and in bold; soil shadowed 487 pixels, dirt road 2276 pixels, vegetation 7497 pixels, pavement 7035 pixels, cars 172 pixels, road shadowed 677 pixels, trees 1021 pixels, tarred road 3924 and buildings 7413 pixels. The overall accuracy of the classification is (487 + 2276 + 7497 +

Class	Soil Shadowed	Dirt Road	Vegetation	Pavement	Cars	Road Shadowed	Trees	Tarred Road	Buildings	TOTAL
Soil Shadowed	**487**	0	20	0	8	90	57	6	0	**668**
Dirt Road	109	**2276**	1687	0	21	25	100	948	21	**5187**
Vegetation	585	485	**7497**	0	48	33	45	970	0	**9663**
Pavement	40	0	0	**7035**	0	0	0	34	0	**7109**
Cars	252	0	326	53	**172**	46	301	2106	334	**3590**
Road Shadowed	498	0	0	22	5	**677**	110	36	4	**1352**
Trees	864	2	327	2	127	176	**1021**	431	0	**2950**
Tarred road	15	0	0	20	138	0	0	**3924**	0	**4097**
Buildings	115	0	74	183	0	0	0	22	**7413**	**7807**
TOTAL	**2965**	**2763**	**9931**	**7315**	**519**	**1047**	**1634**	**8477**	**7772**	**42423**

Table 4.7: Direct approach confusion matrix of Maqalika 2017 composed of nine information classes: soil shadowed dirt road, vegetation, pavement, cars, road shadowed, trees, tarred road and buildings.

7035 + 172 + 677 + 1021 + 3924 + 7413)/42423 = 30502/11240 = 71.8997%. This means that 71.8997% of the image classification was correct and Kappa Coefficient of 0.6699.

4.2.1.5. Multiple Image Analysis: Direct Approach Change Detection 2015 - 2017

The multiple images taken at different times (2015 and 2017) were used to distinguish between permanent and temporary objects found in the road reserve. During change detection, the objects that do not move are considered permanent while those that move, decline, or increase are considered temporary.

Figure 4.24 below shows the results of the change in objects in the road reserve that took place between 2015 and 2017 in Maqalika village. They show that some objects decreased in the road reserve, shown in green colour while other objects increased in the road reserve, shown in med yellow. The objects that did not change during this period are shown in blue colour. The objects that did not move over time were identified as buildings and tarred roads. They were easily identified because of image interpretation elements, the road was found to be elongated and the buildings because of their rectangular and square shapes. The buildings were classified further using shape and the study found that there were a shopping center and private houses identified.

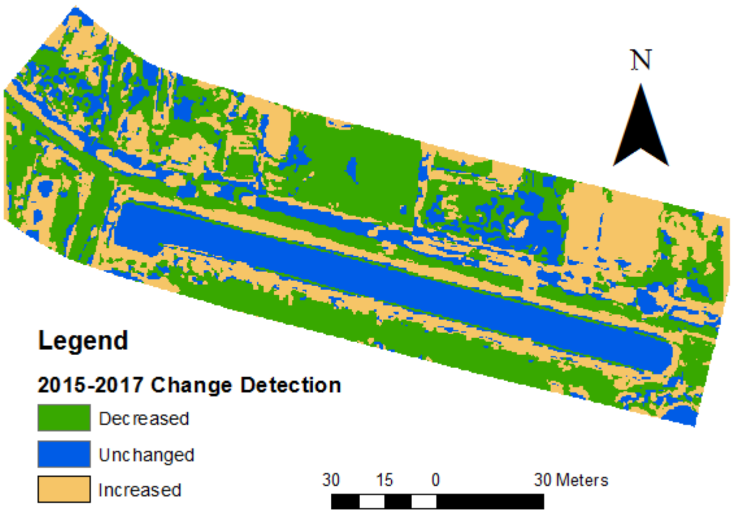

Figure 4.24: Maqalika direct approach Change detection 2015 - 2017 showing areas where there was decrease of encroachment and increase of encroachment. The unchanged objects are shown blue colour.

4.2.1.6. Maqalika Determination of Centerline and Road reserve

The determination of the road center-line helps to find the road center-line from the road class. The centerline was buffered 10 meters to show the road reserve of this particular road, since it is a class B road (see figure 1.1), its road reserve width is 10 meters.

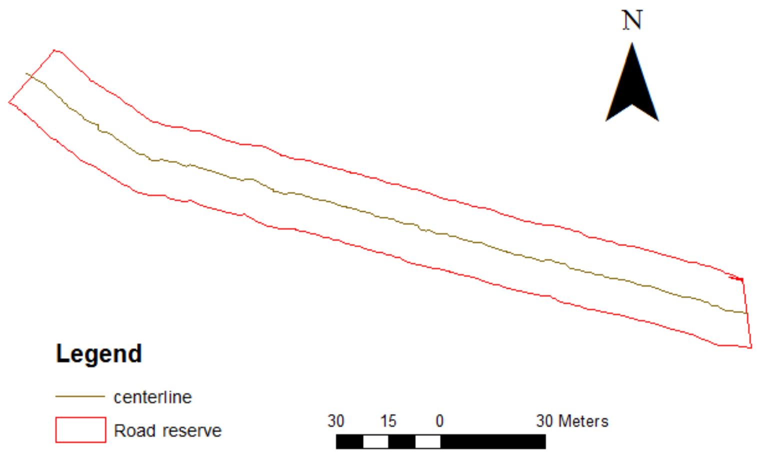

Figure 4.25: Maqalika road centerline crated using morphological processes called erosion and dilation. Shown here are the centerline and the road reserve used by direct method.

4.2.1.7. *Change Detection Accuracy*

The overlay of the change detection results is shown in (figure 4.26) where during the period of 2015 and 2017 the object that declined are in green colour while those that increased are in med yellow. The objects that did not move are shown in blue. The road reserve boundary cuts across the buildings or objects that did not move.

The (figure 4.26) shows the buildings that are in the road reserve. These objects are those that did not move over the period of 2015 and 2017, they were digitised so that they could verify those that were classified.

The digitised objects buildings on the left which are shopping center is shown in both images, classifies and digitised while the shops on the right-hand side of the road reserve do not appear on the change detection image 4.26, figure 4.27 shows the buildings that are not shown 2015 - 2017 time period. This shows that change detection in this section was not good because it detected permanent objects as temporary.

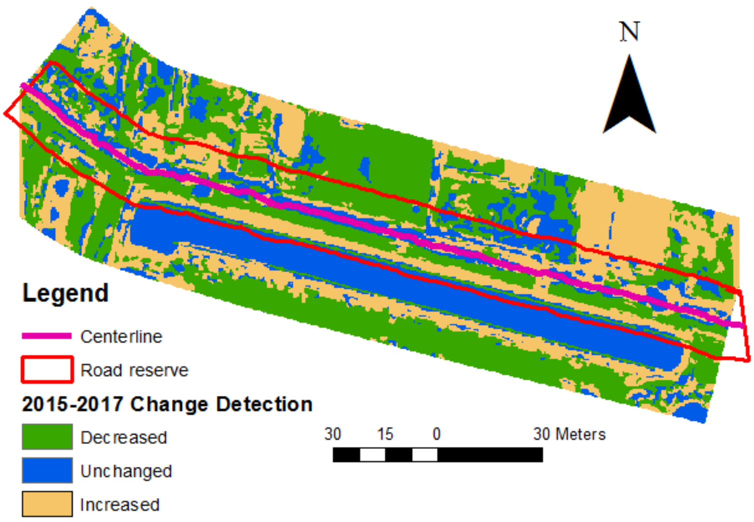

Figure 4.26: Maqalika direct approach change detection map between 2015 and 2017 was overlaid with road reserve from morphological process

4.2.1.8. Digitised Maqalika properties

The digitization of the permanent objects in figure 4.27 shows the houses in brown colour and the shopping areas in yellow colour. The houses were identified by their small shape and shopping areas by their big shape. The objects that have encroached the road reserve are three houses and two shops/shopping centers

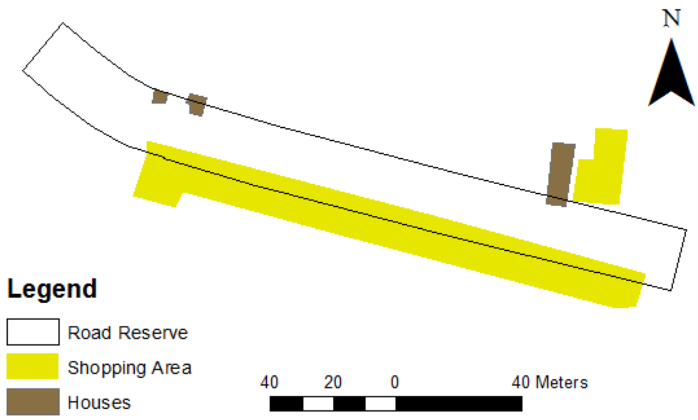

Figure 4.27: Qoaling direct method shows properties that have encroached the road reserve. These properties are two shopping areas/shops and three houses.

4.2.1.9. Maqalika results of the direct approach

The size of the road reserve affected by encroachment in Maqalika is shown by (figure 4.28) where property type is put against the square meters the properties occupy in the road reserve. The results show that the permanent objects that are found in the road reserve are houses and shopping centers. The houses in the road reserve are found to have encroached on an area totaling to 180 m^2s while the shopping centers have encroached the space of 2566 m^2. The total road reserve encroached by houses and shopping centers is 2746 m^2.

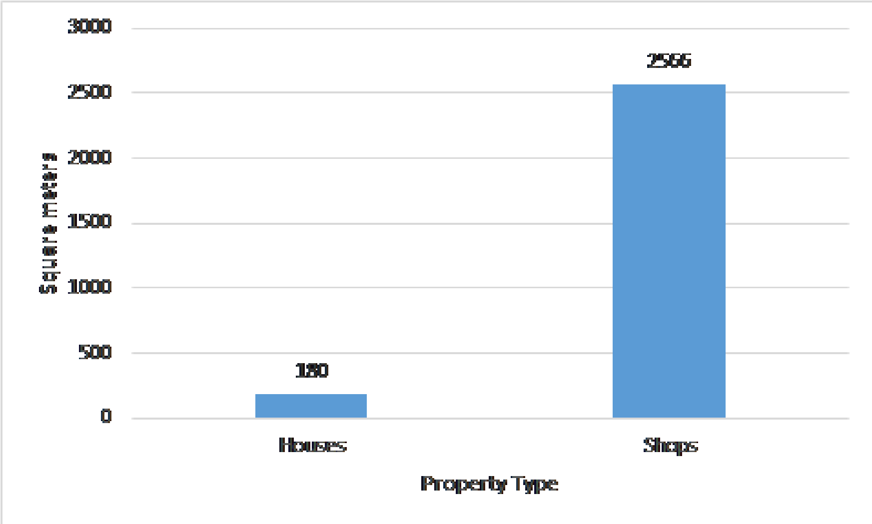

Figure 4.28: Maqalika direct method results showing the area encroached by houses as $180\,m^2$ and shops encroached an area of $2566\,m^2$.

4.2.2. Indirect Approach Maqalika 2015

Maqalika land use of 2015 and 2017 was conducted, this time Indirect approach was used, it focuses on the ground more than the objects that are in the road reserve.

The assumption on analysing a single image (2015) is that the ground is more than encroachment. The (figure 4.29) below shows the land use of Maqalika in 2015. The classes that represented the ground were grouped, (pavement, shadows, soil, and vegetation). All these grouped classes combined cover the area of 6337 square meters. The classes that represented encroachments were grouped as well (buildings and trees). They covered an area of 4119 square meters. The road class was not considered at this stage.

Single image analysis assumed that there is more ground than encroachment, the assumption is true that the ground cover is more than encroachment. This is because the ground covered 6337 square meters while encroachment covered 4119 square meters.

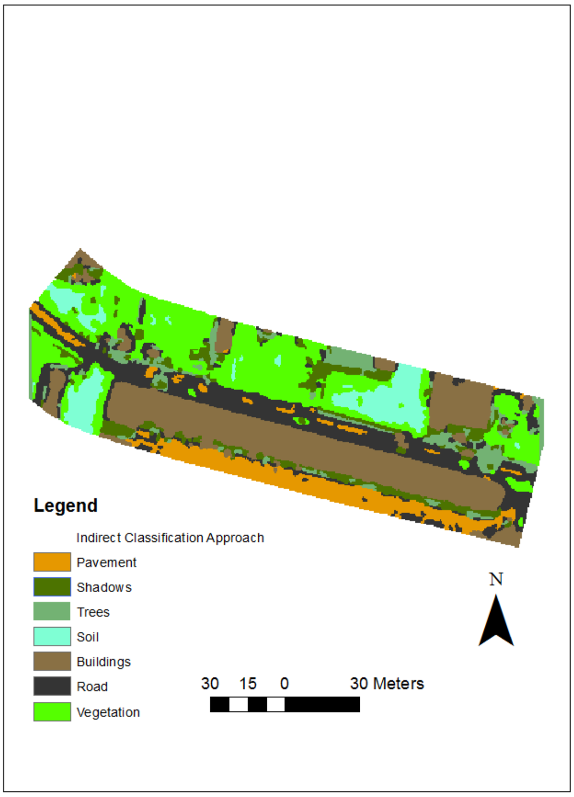

Figure 4.29: Indirect approach of Maqalika land use of 2015 showing pavement, shadows, trees, soil, buildings, road and vegetation

4.2.2.1. Maqalika Accuracy 2015 of the Indirect approach

The table represents seven classes of Maqalika in 2015, namely, pavement, shadows, trees, soil, buildings, road, and vegetation. The number of pixels that is the Row Total for each class from the 2015 Maqalika indirect classification is 1372, 1284, 798, 2622, 7112, 1940, and 3322 respectively. This brings the total column to 18150 pixels. The row total of 2015 Maqalika indirect classification show 1345 pixels classified as pavement, 1704 as shadows, 231 as trees, 1832 as soil, 6569 as buildings, 2671 as tarred road, and 3798 as vegetation. The pixels classified correctly by the confusion matrix are the ones displayed diagonally and in bold; pavement 1037 pixels, shadows 1166 pixels, trees 3 pixels, soil 1597 pixels, buildings 6468, road 1750, vegetation 2890. The overall accuracy of the classification is (1037 + 1166 + 3 + 1597 + 6448 + 1750 + 2890)/18150 = 14891/18150 = 82.0441%. This means that 82.0441% of the image classification was correct and the Kappa Coefficient was 0.7986.

Class	Pavement	Shadows	Trees	Soil	Buildings	Road	Vegetation	TOTAL
Pavement	**1037**	25	0	8	163	112	0	**1345**
Shadows	3	**1166**	344	14	37	34	106	**1704**
Trees	0	10	**3**	0	179	6	33	**231**
Soil	0	0	2	**1597**	2	0	231	**1832**
Buildings	17	67	0	3	**6448**	34	0	**6569**
Road	315	16	9	248	271	**1750**	62	**2671**
Vegetation	0	0	140	752	12	4	**2890**	**3798**
TOTAL	**1372**	**1284**	**498**	**2622**	**7112**	**1940**	**3322**	**18150**

Table 4.8: Confusion matrix of the Indirect classification method of 2015. Showing the following classes and their total pixels; Pavement, Shadows, Trees, Soil, Buildings, Road and Vegetation.

4.2.2.2. Indirect Approach Maqalika 2017

Maqalika land use for 2017 is shown in (figure 4.30) where the following were detected; pavement, shadows, soil, vegetation, buildings, trees and road. A single image analysis assumed that there was more ground than encroachment. The following classes represented the ground (Pavement, shadows, soil and vegetation). The combination of these classes covered an area of 7560 square meters. The classes that represented encroachment were grouped as well and they covered an area of 4153 square meters. The road class was not used for this particular analysis.

The single image analysis assumed that there is more ground than encroachment. There is indeed more ground than encroachment. The ground covered 7560 square meters while encroachment covered 4153 square meters.

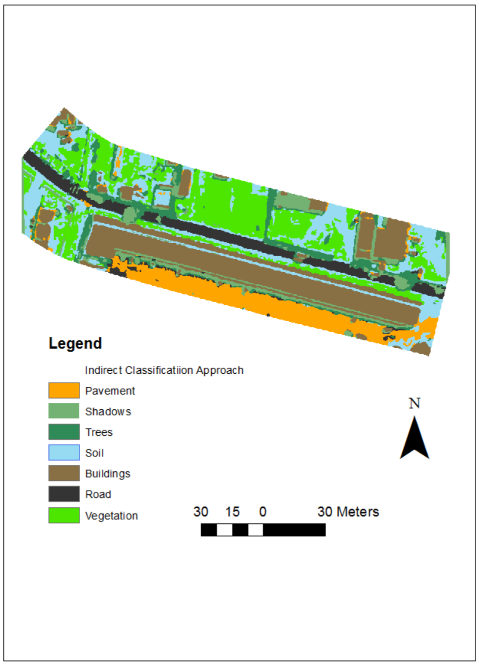

Figure 4.30: Indirect approach of Maqalika land use of 2017 showing pavement, shadows, trees, soil, buildings, road and vegetation.

4.2.2.3. Maqalika Accuracy 2017 of the indirect approach

The (table 4.9) represents seven classes of Maqalika in 2015, namely, pavement, shadows, trees, soil, buildings, road and vegetation. The number of pixels that is the Row Total for each class form the 2017 Maqalika indirect classification is 8755, 5284, 2398, 15150, 23337, 4678 and 13358 respectively. This brings the total column to 72960 pixels. The row total of 2017 Maqalika indirect classification show 8796 pixels classified as pavement, 4751 as shadows, 3942 as trees, 9302 as soil, 22737 as buildings, 4728 as tarred road, and 18704 as vegetation. The pixels classified correctly by the confusion matrix are the ones displayed diagonally and in bold; pavement 8416 pixels, shadows 3034 pixels, trees 2175 pixels, soil 6439 pixels, buildings 19759, road 4575, vegetation 12327. The overall accuracy of the classification is $(8416 + 3034 + 2175 + 6439 + 19759 + 4575 + 12327)/72960 = 56725/72960 = 77.7481\%$.

This means that 77.7481% of the image classification was correct with the Kappa Coefficient of 0.7227.

Class	Pavement	Shadows	Trees	Soil	Buildings	Road	Vegetation	TOTAL
Pavement	**8416**	0	0	124	256	0	0	**8796**
Shadows	127	**3034**	205	92	1261	2	30	**4751**
Trees	20	1194	**2175**	256	93	29	175	**3942**
Soil	0	2	1	**6439**	1962	72	826	**9302**
Buildings	47	1039	2	1890	**19759**	0	0	**22737**
Road	145	8	0	0	0	**4575**	0	**4728**
Vegetation	0	7	15	6349	0	0	**12327**	**18704**
TOTAL	**8755**	**5284**	**2398**	**15150**	**23337**	**4678**	**13358**	**72960**

Table 4.9: Confusion matrix of Indirect classification method of 2017. Showing the classes and their pixel numbers; Pavement, Shadows, Trees, Soil, Buildings, Road and Vegetation.

4.2.2.4. Multiple Image Analysis: Indirect Change Detection 2015 - 2017

The use of multiple images taken at different times (2015 and 2017) were used to identify objects that are permanent and temporary. The objects that changed over time were considered temporary and those that did not move were considered permanent.

The results of change detection in (figure 4.31) below show the objects that moved over time and those that did not. The objects that decreased are shown in green while those that increased are shown in yellow. The objects that did not move over time are shown in blue. The objects that did not move were identified as buildings and the road. Its elongated shape identified the road while the buildings were identified by their rectangular and square shapes. The buildings were classified into their property type as houses and shopping centers. The houses were identified because of their square shape while the shopping center by their rectangular shape.

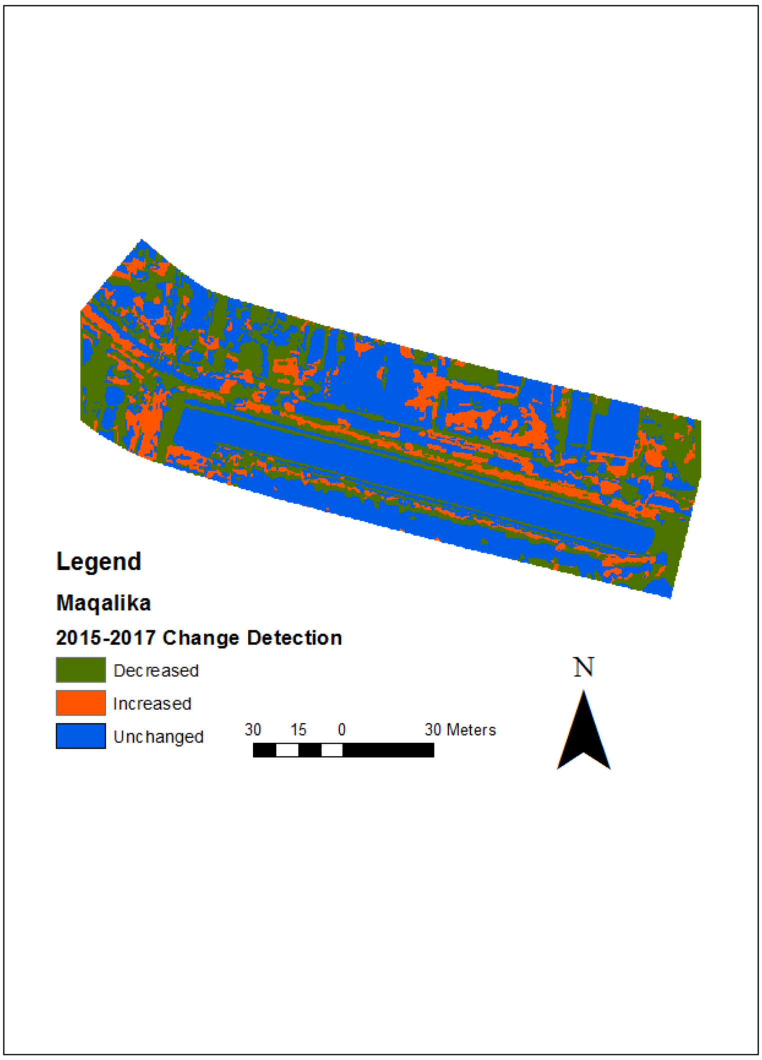

Figure 4.31: Maqalika indirect method change detection 2015 -2017. It shows the decreased objects and the increased objects in the road reserve as well as the unchanged objects.

4.2.2.5. Indirect Approach: Determination of the centerline

The centerline in (figure 4.34) below shows the middle of the road. The road reserve shown in black was determined by buffering the centerline (yellow) to 10 meters (see figure 1.1).

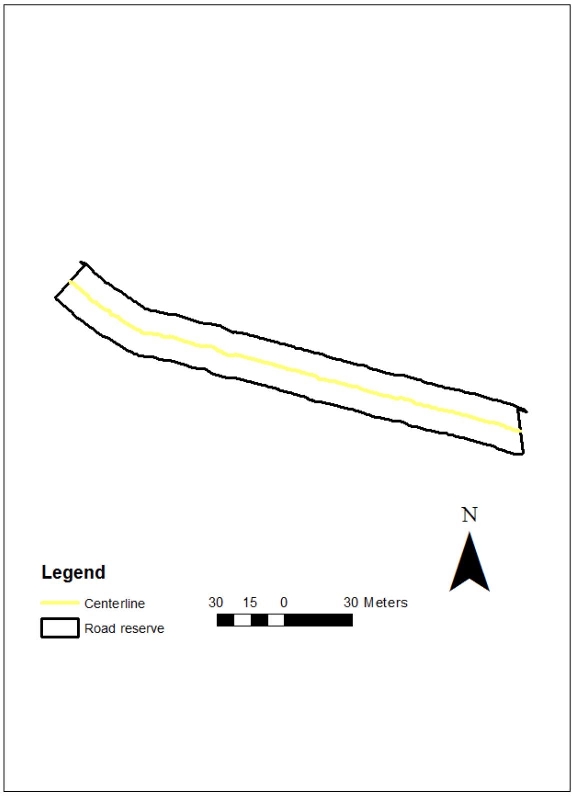

Figure 4.32: Maqalika indirect method centreline created using morphological processes called erosion and dilation. Shown here is the centreline and road reserve.

4.2.2.6. Indirect Approach: Change Detection Accuracy

Figure 4.33 shows the road reserve boundary over change detection results to show the buildings that have encroached in the road reserve in Maqalika. The buildings are shown in blue colour while the road reserve is shown in black colour. This shows that the properties that are in the road reserve.

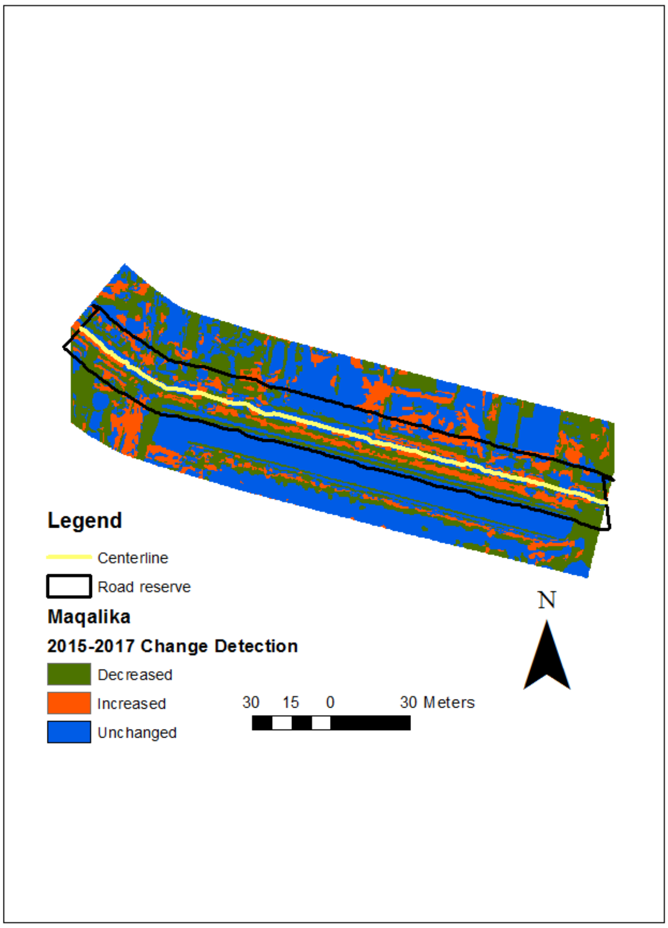

Figure 4.33: Maqalika indirect approach change detection map between 2015 and 2017 was overlaid with road reserve from the morphological processing.

4.2.2.7. Digitisation

This section shows the permanent objects that did not change over time in Maqalika in the road reserve. These are houses shown in sky blue colour and the shopping areas are shown in yellow colour.

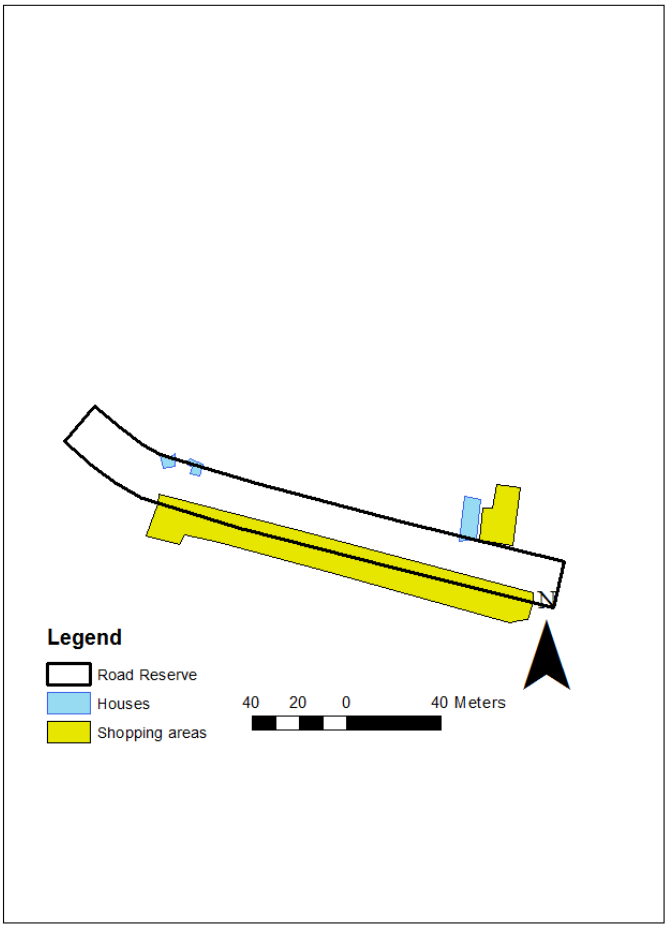

Figure 4.34: The digitized Maqalika properties that encroached the road reserve. These properties are houses in light blue colour and shopping areas/shops in yellow colour.

4.2.2.8. Results of the Indirect Approach

The results of the indirect approach in (figure 4.42 show the size of the Maqalika road reserve affected by the encroachment. Property type is put up against the square meter to know the size of land encroached buildings. The results show that houses have encroached an area of 185 m^2 in Maqalika while shopping area/centers have encroached an area of 2671 m^2. The total land that is encroached in Maqalika is 2856 m^2.

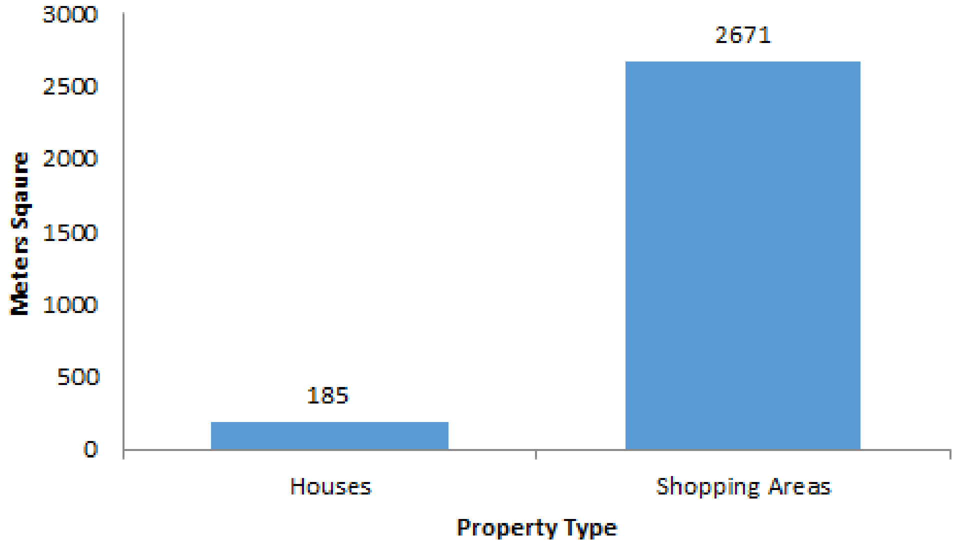

Figure 4.35: Maqalika indirect results showing area encroached by the properties. Houses encroached the road reserve by 185 m^2 and shopping areas/shops by 2671 m^2.

4.2.2.9. Comparative analysis between direct and indirect methods approach in Maqalika

Direct and Indirect methods dealt with the land use of Maqalika between 2015 and 2017. The direct approach looked at every object that was in the road reserve while the indirect approach looked for the ground more than the objects. The images used were not of the highest quality so the direct approach was looking for every object in the road reserve did not detect all the objects in the road reserve. On the other hand, since the indirect approach did not look for every object but the ground more, it managed to detect every object that was trained. The indirect approach was better between the two methods in detecting the objects in the road reserve. The accuracy assessment of the two methods is shown in (table 4.10) below where the Indirect method performed better both in 2015 and 2017 images with 82.0441% and 77.7481% respectively. This shows the Indirect method was better than the Direct method.

Classification Method	Accuracy Assessment 2015	Accuracy Assessment 2017
Maqalika Direct Classification method	79.9110%	71.8997%
Maqalika Indirect Classification method	82.0441%	77.7481%

Table 4.10: Comparison of accuracy assessment between direct method and indirect method in Maqalika 2015 and 2017.

4.2.3. Unsupervised Maqalika

The unsupervised approach in detecting road reserve encroachment was done using the 2015 and 2017 images, here the IsoData classifications were conducted. The clusters that were detected here were 30 and they were combined are as follows. The building and the roads, shadows, soil, vegetation and trees. The assumption here is that the small clusters are encroachment.

4.2.3.1. IsoData 2015

IsoData classification results of Maqalika show five clusters that were combined from 30clusters. These clusters were buildings, roads, shadows, soil, vegetation and trees. Buildings and roads share the same cluster, in this case, their shape identified the buildings, which are square and rectangular for houses and elongated for the road. Encroachment in this case equals small clusters.

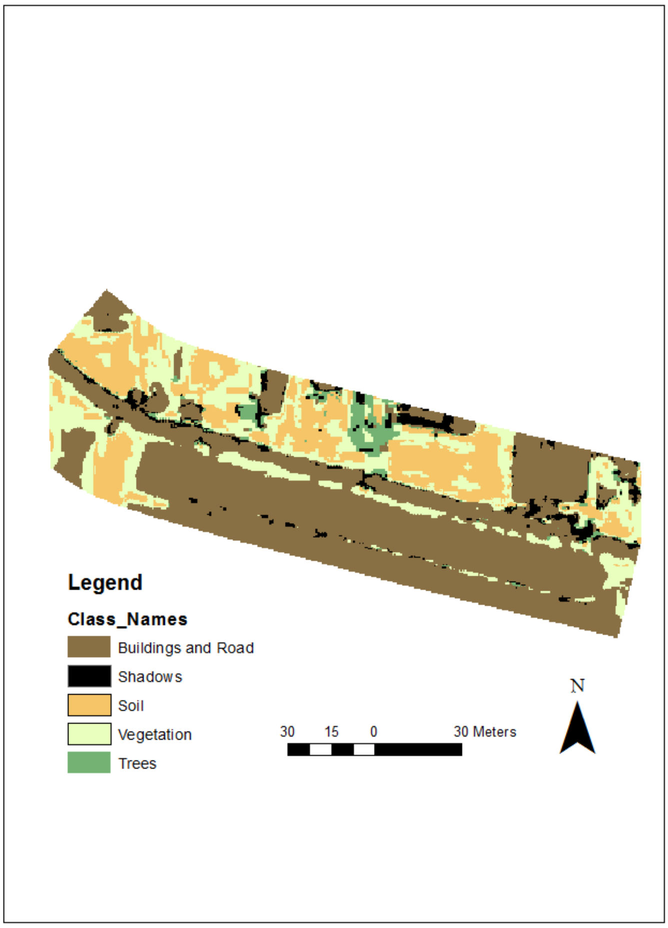

Figure 4.36: Maqalika unsupervised land use of 2015. Showing buildings and road, shadows, soil, vegetation and trees.

4.2.3.2. IsoData 2017

Under Unsupervised classification, a small cluster is considered as encroachment. The study detected 20 clusters and were combined to form the following clusters; Trees, soil, vegetation, shadows. Buildings and road clusters were detected as the same cluster.

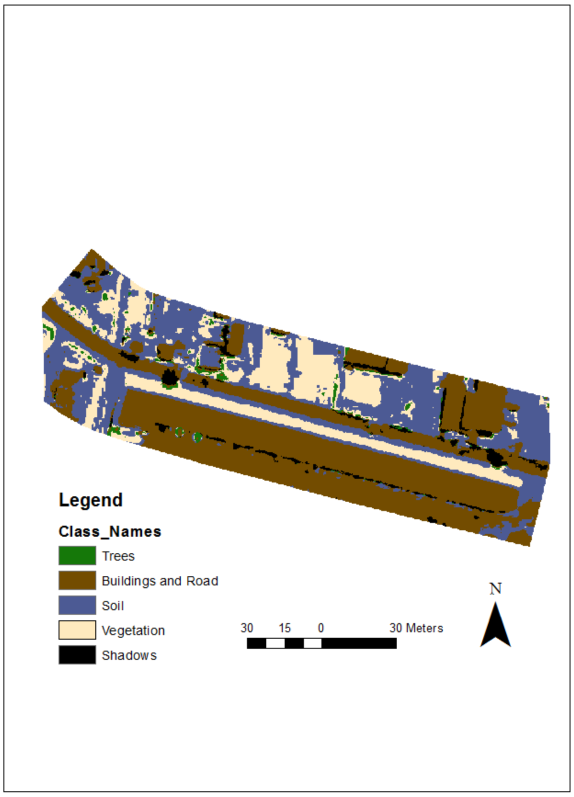

Figure 4.37: Maqalika unsupervised land use of 2017. Showing trees, buildings and road, soil, vegetation and shadows.

4.2.3.3. Maqalika change detection 2015-2017 IsoData Classification

The change detection results figure 4.38 shows the objects that did not change over time (sky blue) are buildings (square) and the road (elongated shape). The results show a shopping center as temporary with some increase in blue colour. . Some temporary objects are in green and shown to be on the decline.

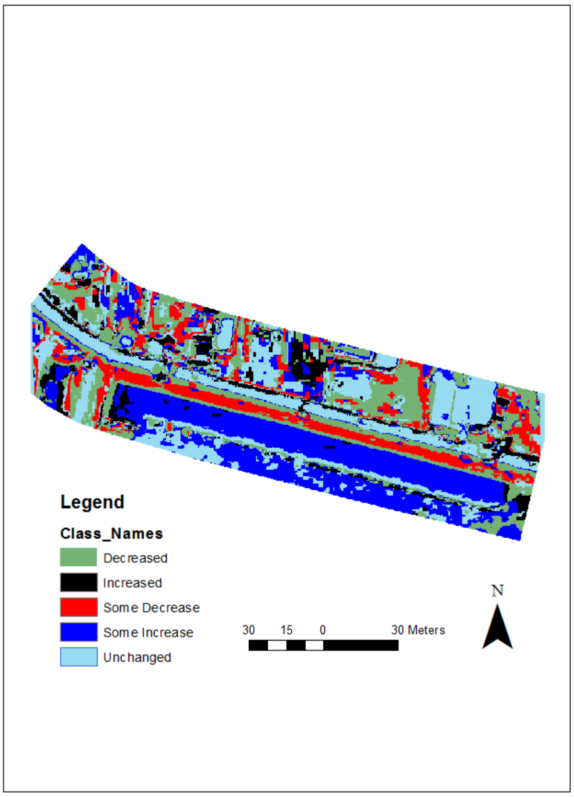

Figure 4.38: Maqalika unsupervised change detection of 2015 – 2017 where encroached objects decrease, increased, where the was some increase and some decrease and the objects did not change.

4.2.3.4. Determination of centerline: Unsupervised classification

The road centerline was extracted from the road cluster and buffered 10 meters to form a road reserve boundary to be used as an assessor for change detection.

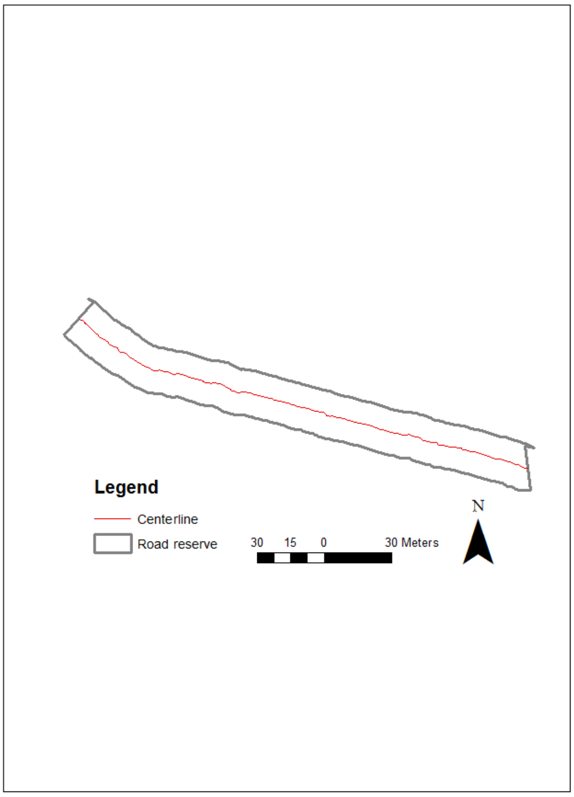

Figure 4.39: Maqalika unsupervised centreline derived from morphological processes showing road centreline and road reserve.

4.2.3.5. Change detection accuracy

The overlay of the road reserve boundary and change detection results show permanent objects that have encroached the road reserve. Figure 4.40 shows that the unchanged objects are buildings(square) on the right of the road reserve shown in sky blue and the road (elongated). The shopping center on the left of the road reserve (see figure 4.41) for digitised permanent objects are shown as a temporary object here but it is not.

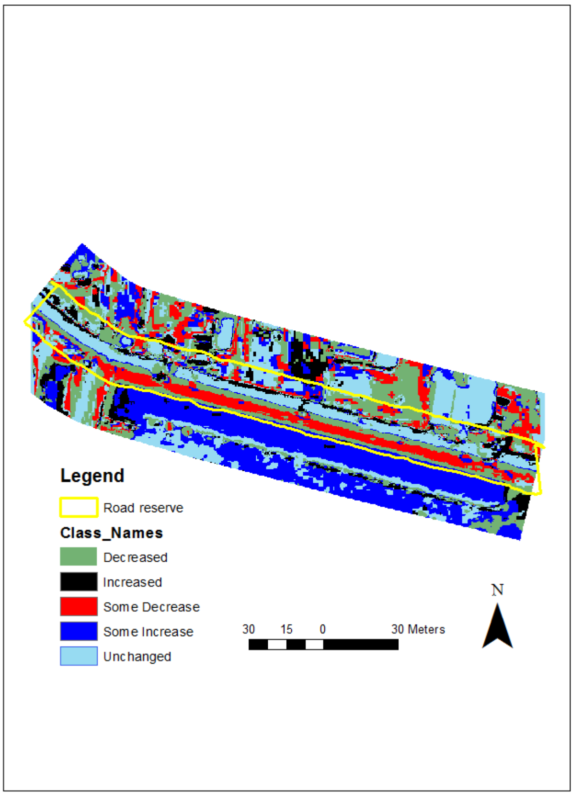

Figure 4.40: Maqalika unsupervised road reserve overlay with change detection map of 2015 – 2017.

4.2.3.6. Digitisation of Maqalika properties

The digitization of the permanent objects that are houses (flame red) and shopping centers(Orange) is in the road reserve in Maqalika.

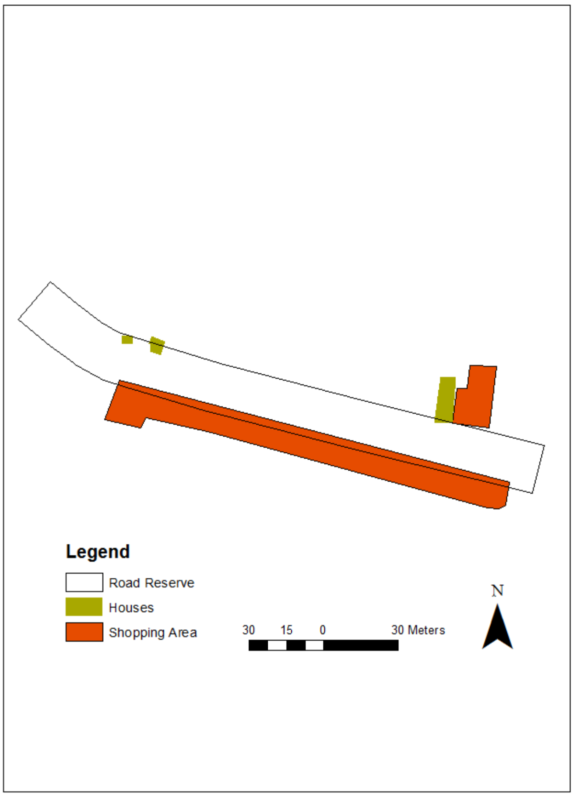

Figure 4.41: Digitized Maqalika properties that have encroached on the road reserve using unsupervised method. Maqalika unsupervised method showing the permanent digitized objects that have encroached the road reserve, which are two shops and three houses.

4.2.3.7. Results of Maqalika Unsupervised

The results shown here are for the Unsupervised classification where the size of the affected road reserve is shown by figure 4.42. It shows the property type against square meters to determine the size of the road reserve encroached. The results show the permanent objects; houses and shopping centers. The houses have encroached on an area of 178 m^2 and the shopping center has encroached an area of 2322 m^2. The total area encroached by permanent objects is 2500 m^2.

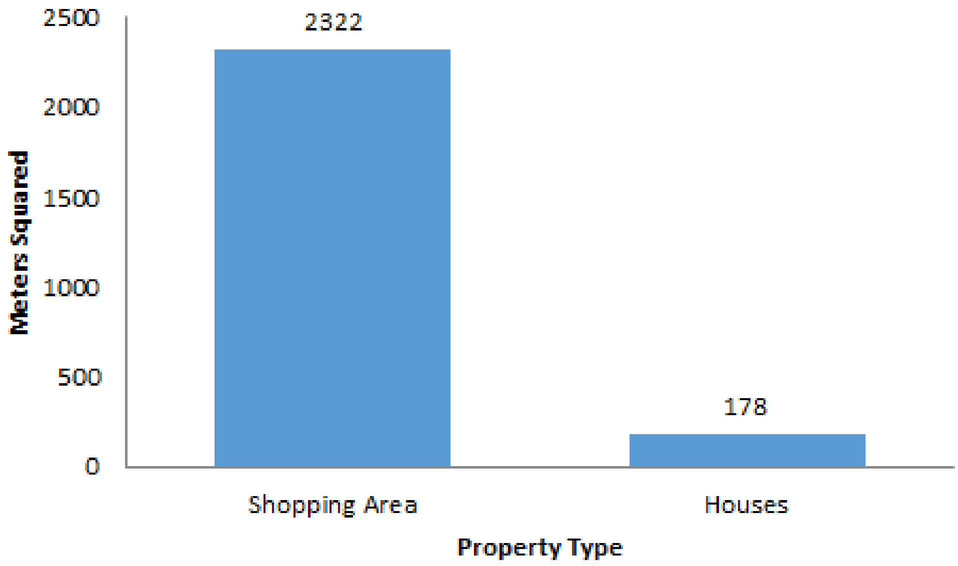

Figure 4.42: Maqalika unsupervised results showing the area encroach by shops and houses. The shops encroached an area of 178 m^2 and the shopping area/shops have encroached 2322 m^2 of the road reserve.

CHAPTER 5

DISCUSSION

5.1. RESEARCH HYPOTHESIS AND TESTING

5.1.1. Using High-Resolution Satellite Images and Aerial photos, the study can identify objects that do not belong in the road reserve.

In this study, High-resolution images were used, Orthophotos with spectral resolutions of 0.35 meters for the year 2015 and 0.25 meters resolution for the year 2017. These images were classified and the results were used in the change detection process. The focus was on the objects that did not change over time and those were taken as encroachment.

The results of the change detection showed the objects that did not change over time as encroaching objects. The study found out that those objects are buildings and their property types were houses and shops/shopping centers. The hypothesis holds true that using high-resolution aerial photos, the study can identify objects that do not belong in the road reserve.

5.2. THE STUDY AIMS TO INVESTIGATE THE METHODS OF FINDING THE ROAD RESERVES ENCROACHMENT IN MASERU USING HIGH-RESOLUTION SATELLITE IMAGES AND AERIAL PHOTOS

The findings of the study have shown that the affected road reserve is known, shown in (table 5.1) below. The study investigated three methods to detect the road reserve encroachment in two areas of study, the extent of the road reserve encroachment was found. In Qoaling using the direct method, the study found an area of $2746\,m^2$ has encroached. Indirect method showed $2856\,m^2$ and the third method showed $2500\,m^2$ have been encroached. In Maqalika using the direct method, the study found that the area of $4044\,m^2$ have encroached, the indirect method found an area of 5651 m^2 have encroached while Unsupervised classification found an area of 2743 m^2 have encroached.

Table 5.1: Table showing the results of the three methods used in Qoaling and in Maqalika where the methodology was tested.

Area	**Direct method**	**Indirect method**	**Unsupervised method**
Qoaling	2746 m^2	2856 m^2	2500 m^2
Maqalika	4044 m^2	5651 m^2	2743 m^2

5.3. RESEARCH QUESTIONS

5.3.1. Besides images, what other data does the study need to use to find the road reserve encroachment extent?

The importance of using ancillary data in this study was that it could assist with both spatial and non-spatial data. The spatial data used was the Roads layer to help with the road centerline. The non-spatial data used were The roads Act 1969, Declaration of Roads reserve Notice 2014, and a leaflet called Know the road reserve. These ancillary data explained the legal definition and the width of the road reserve, which is 15 meters in class A road and class B (major), 10 meters in class B (minor), class C and Class D. It explained the importance of road reserve.

5.3.2. What methods of image analysis do the study need to use to find the objects that do not belong in the road reserve?

The study has shown that various objects were detected during the classification process. The study used a Shape analysis to find objects that do not belong to the road reserve. With the help of the shape analysis, the study identified those objects as buildings, and those buildings were used for different purposes for example the study using shape analysis detected buildings used for housing and those used as shops or shopping centers.

5.3.3. How to tell the difference between the permanent and temporary objects inside the road reserve?

In Multiple image analysis, the study used two images, 2015 and 2017 images. Here the assumption was that encroachments do not change over time. The study did change detection analysis where the Image differencing technique was used. The rule here was that during change detection the objects that do not change are permanent. The study managed to find that these objects that do not change over time are houses and shopping centers that are found to have encroached the road reserve.

5.3.4. What are the best methods to classify objects in the road reserve?

The study carried out three methods of detecting road reserve encroachment in Maseru using Remote sensing and image analysis, these methods were; Direct classification method, Indirect classification method, and Unsupervised classification method. All three methods were able to classify objects in the road reserve and were able to distinguish between temporary and permanent objects. Eventually, they determined the objects that encroached the road reserve. The method that best classified the objects in the road reserve are shown in (table 5.2) below, both in Qoaling and Maqalika was the Indirect method where the accuracy assessment is shown in (table 5.2) below. The overall accuracy assessment on Qoaling indirect classification of 2015 was 77.0074 % and in 2017 was 81.7103 %. In Maqalika as well, the indirect method produced an accuracy of 82.0441 % in 2015 and 77.7481 % in 2017. The accuracy of this method is higher than that of the direct classification method.

Classification method	**Accuracy Assessment 2015**	**Accuracy Assessment 2017**
Qoaling Direct classification method	73.9618%	63.9961%.
Qoaling Indirect classification method	77.0074%	81.7103%
Maqalika Direct classification method	79.9110%	71.8997%
Maqalika Indirect classification method	82.0441%	77.7481%

Table 5.2: Classification accuracy assessment methods of 2015 and 2018 images.

5.3.5. How is the methodology used going to be tested?

The study researched two areas around Maseru City, namely Qoaling Village in the South of Maseru and Maqalika Village in the East of Maseru. The method was used in Qoaling village first and tested in Maqalika village. This was done to test if the methodology could work in other places.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1. CONCLUSION

The main aim of the study was to investigate the methods to find the road reserves encroachment in Maseru using High-Resolution Satellite Images and Aerial photos. The study assumed that using high-resolution images, the study could identify objects that did not belong in the road reserve. The study achieved the results by using high-resolution images of 2015 and 2017. The study used three methods, namely, Direct classification, Indirect classification, and unsupervised classification. The best method that was best able to classify objects that were permanent and temporary in the road reserve was indirect classification. The study found that the objects that were encroaching on road reserve were buildings (houses and shops shopping centers).

The results showed that there was road reserve encroachment in Maseru, the results of change detection at an instant in time, and the road reserve width was overlaid on the change detection layer to reveal the encroachment extent. Then this gave maps and histograms as a result to show the extent of the road reserve encroachment in Maseru.

It is concluded that there is a need for road reserve encroachment monitoring using satellite images and aerial photographs and these images should be taken yearly to make monitoring easier. The study used images with 3 bands, RGB, however, the use of very high-resolution images with more bands is recommended to identify small objects easier in the road reserve. The study would have found better results if the Object-oriented classification was used and the Ecognition software was used as well. Further studies on road reserve encroachment are needed and to sensitize the population at large about the importance of the road reserve for future use and the expansion of the road to curb traffic on the roads.

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APPENDIX A

CONSENT LETTER

Dissertation title: Analyzing the road reserve encroachment in Maseru Lesotho using remote sensing and image analysis

To whom it may concern:

My name is Teboho Ralitsoele and I am currently registered for the masters programme in Geomatics at the University of Cape Town, South Africa. As a masters' student the thesis does form part of my official study requirement. I am considering a research on finding out about the extent of the road reserve encroachment in Maseru Lesotho with the help of the remote sensing and image analysis and would like to invite you to provide data for this study. The study will firstly find out the methods of finding the extent of road reserve encroachment, secondly, the results will show the objects that are encroaching the road reserve and thirdly, the methods on how to monitor road reserve encroachment in other areas of Lesotho, last but not least, the study will contribute to the body of knowledge because there are not many studies that are primarily focusing on road reserve encroachment in the field of remote sensing. The study will require the following imagery and vector data:

- Aerial Photos of Maseru (Two latest images of different years)
- High resolution satellite Images of Maseru (two latest images of different years
- Latest cadastral Map of Maseru
- Latest road of Maseru (shapefile)

The data requested is going to be used by me, the researcher (Teboho Ralitsoele) to find out the methods of finding road reserve encroachment in Maseru. It is going to do so by using Remote sensing and Image analysis. Your provision of data in this study is voluntary. Your organization is free to stop providing data in this study at any time. For confidentiality purposes the dataset that the study will receive from your organization will be kept confidential and be used for this study only. After the completion you will receive the copy of the study. Please indicate the restrictions on the use of dataset provided

. . . .

Should you have any questions regarding this research project, please feel free to contact the researcher by email or cellphone:

Sincerely,

Teboho Ralitsoele Researcher / Geomatics (Masters) Student, (UCT) Geomatics division University of Cape Town Email: rltteb001@myuct.ac.za Cell: +27 632730789 (South African Number) Cell: +266 58451574 (Lesotho Number)

Statement of the person giving consent :

I have read and understood the objectives of this study/research, talked to the researcher and I understand that providing dataset is voluntary. I know the purpose of this study is to find the extent of road reserve encroachment in Maseru using Remote sensing and Image analysis, how the data is going to be used and I know the implications of this study. All information provided will be kept strictly confidential.

....

Signature of the person giving consent, Name and Surname

....

Position in the organisation