Manual for estimating irrigation water use using remote sensing and GIS

including a step-by-step guide

Technical Note No. 3

Lusaka, October 2019
SUMMARY

Authors: Max Karen, Dr. Tobias Godau & Stephen Lungomesha

Title: Manual for estimating irrigation water use using remote sensing and GIS, including a step-by-step guide

Keywords: Irrigation, water use, remote sensing, GIS, QGIS

Abstract
WARMA, as a new institution still in build-up of capacities and assuring its own budget, requires a quick-to-launch, low-budget system to allow valid estimations of groundwater use in farming areas to regulate the groundwater use of the existing farms and give out permits for water use to new and established farmers. A huge challenge to WARMA are the remoteness and accessibility of some locations and the seasonal shift in use of water from rivers and dams to groundwater in the high dry season. Additionally, crops are rotating throughout the year each with different water needs.

The use of remote sensing (RS) and Geographical Information Systems (GIS) for the analysis of environmental questions has been becoming common in the past two decades. However, the choice between different tools and approaches may be a challenge.

This manual provides an easy and repeatable approach based on the use of free open-source software (QGIS) and free satellite imagery (LandSat).

The key concept to the proposed method is that in Zambia there is a distinct dry season where for many months there is virtually no rainfall. Based on the assumption that no rain has fallen for many months for there to be healthy vegetation there must be water. This manual describes the method to identify areas of healthy vegetation and then to distinguish areas that are irrigated with natural healthy dry season vegetation such as areas close to rivers or wetland/dambo areas.

Although examples for this manual concentrate on the Mpongwe Karst area, the chosen approaches are intended to provide WARMA with a blueprint for managing similar tasks in other parts of Zambia.
# Table of Contents

Summary ........................................................................................................................................... 3  
Abbreviations .................................................................................................................................. 6  
List of reports compiled by the project in Phase IV ........................................................................ 7  
Executive Summary ......................................................................................................................... 8  
1. Introduction ................................................................................................................................... 10  
2. Background ................................................................................................................................... 11  
3. Development of the manual ......................................................................................................... 12  
4. Spatial referencing ......................................................................................................................... 12  
5. Method outline .............................................................................................................................. 15  
6. Using Google Earth to digitise agricultural field areas ................................................................. 16  
   6.1. Digitising .................................................................................................................................. 16  
7. Obtaining and using Landsat imagery ............................................................................................ 19  
   7.1. Downloading images from Earth Explorer .............................................................................. 19  
   7.2. Working with Landsat data .................................................................................................... 21  
8. Image and GIS data processing ...................................................................................................... 22  
   8.1. Importing and merging Landsat image bands ......................................................................... 24  
   8.2. Processing the Landsat image to highlight healthy vegetation ............................................... 27  
   8.3. Classifying images ................................................................................................................... 28  
   8.4. Using QGIS to display the classified image and convert to polygons ...................................... 29  
   8.5. Selecting the irrigated polygons to create a new shapefile ...................................................... 31  
9. Spatial reference and calculating area being irrigated .................................................................. 37  
   9.1. Calculating the area being irrigated ......................................................................................... 37  
10. Estimating water use from the area measurement ......................................................................... 38  
11. Checking the data and ground truthing ......................................................................................... 41  
   11.1. Checking area calculations ..................................................................................................... 41  
12. Conclusions and recommendations ............................................................................................. 42  
13. References .................................................................................................................................... 43
List of Figures

FIGURE 1: LONGITUDE AND LATITUDE AND UTM ZONES ................................................................. 13
FIGURE 2: COORDINATE REFERENCE SYSTEMS USED IN ZAMBIA USING QGIS VERSION 2.14 ................................................................. 14
FIGURE 3: DIGITISED FIELDS IN MPONGWE ............................................................................. 17
FIGURE 4: ADD VECTOR LAYER. .............................................................................................. 18
FIGURE 5: ADD GOOGLE EARTH .KMZ FILE .............................................................................. 18
FIGURE 6: SAVE VECTOR LAYER AS ESRI SHAPEFILE. ............................................................. 18
FIGURE 7: LOGIN AND LANDSAT 8 DATA LOCATION. ............................................................... 20
FIGURE 8: SELECTING THE AREA OF INTEREST. ...................................................................... 20
FIGURE 9: DOWNLOADING THE LANDSAT IMAGE. ................................................................. 21
FIGURE 10: LANDSAT IMAGE LOCATIONS IN THE UPPER KAFUE BASIN. ................................. 22
FIGURE 11: RED, GREEN AND BLUE COMPONENTS OF THE FINAL IMAGE. ................................. 23
FIGURE 12: NAME OF PROCESSED IMAGE BANDS. .................................................................. 25
FIGURE 13: CREATING A MERGED IMAGE IN QGIS. ................................................................. 25
FIGURE 14: LANDSAT 8 FALSE COLOUR IMAGE OF THE MPONGWE AREA ............................. 26
FIGURE 15: LANDSAT SCENE AFTER PROCESSING IN QGIS. ...................................................... 27
FIGURE 16: MONTEVERDI AND THE KCLUS CLASSIFICATION. .................................................... 29
FIGURE 17: DISPLAYING THE CLASSIFIED IMAGE. .................................................................... 30
FIGURE 18: SELECTING ONLY THE HEALTHY VEGETATION. ...................................................... 32
FIGURE 19: SAVING THE SELECTED ELEMENTS OF THE SHAPEFILE AS A NEW SHAPEFILE ............................................................................. 32
FIGURE 20: MPONGWE MERGED LANDSAT 5-6-2 (LEFT) AND CLASSIFIED IMAGE WITH SELECTED AREAS (RIGHT)............................... 33
FIGURE 21: AREA WEST OF KITWE VIEWED IN GOOGLE EARTH © ........................................... 34
FIGURE 22: AREA WEST OF KITWE VIEWED USING MERGED LANDSAT 8 BANDS 562. ............... 35
FIGURE 23: COMPARISON OF LANDSAT 52 AND CLASSIFIED IMAGE OF AREA WEST OF KITWE. ............................................................................. 35
FIGURE 24: SPLITTING FEATURES IN A POLYGON LAYER. ............................................................. 36
FIGURE 25: SETTING THE AREA MEASUREMENT UNIT. ................................................................ 37
FIGURE 26: THE FIELD CALCULATOR. ...................................................................................... 38
FIGURE 27: EXPORTING THE AREA DATA FROM THE ATTRIBUTE TABLE OF A SHAPEFILE .......... 38
FIGURE 28: CALCULATING IRRIGATED WATER USE USING MICROSOFT EXCEL © ......................... 40
FIGURE 29: CHECKING THE AREA OF A PIVOT CIRCLE IN QGIS .............................................. 41
FIGURE 30: CHECKING THE RADIUS OF A CENTRE PIVOT USING GOOGLE EARTH © RULER ................................................................. 42

List of Tables

TABLE 1: HOW THE NEW BANDS FROM LANDSAT 8 LINE UP WITH LANDSAT 7 ......................... 24
TABLE 2: RECOMMENDED BAND COMBINATIONS FOR LANDSAT 8 ........................................... 24
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOI</td>
<td>Area of interest</td>
</tr>
<tr>
<td>BGR</td>
<td>Bundesanstalt für Geowissenschaften und Rohstoffe (engl.: Federal Institute for Geosciences and Natural Resources)</td>
</tr>
<tr>
<td>CRS</td>
<td>Coordinate Reference System</td>
</tr>
<tr>
<td>DMS</td>
<td>Degrees, Minutes and Seconds</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agricultural Organisation</td>
</tr>
<tr>
<td>GCS</td>
<td>Geographical Coordinate System</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>GIZ</td>
<td>Gesellschaft für Internationale Zusammenarbeit (engl.: German Corporation for International Cooperation GmbH)</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GReSP</td>
<td>Groundwater Resources Management Support Programme</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>MWDSEP</td>
<td>Ministry of Water Development, Sanitation and Environmental Protection</td>
</tr>
<tr>
<td>RS</td>
<td>Remote Sensing</td>
</tr>
<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
</tr>
<tr>
<td>WARMA</td>
<td>Water Resources Management Authority</td>
</tr>
</tbody>
</table>
## List of Reports Compiled by the Project in Phase IV

<table>
<thead>
<tr>
<th>Date</th>
<th>Authors</th>
<th>Title</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>September 2017</td>
<td>Karen, M., El-Fahem, T. &amp; Tena, T.</td>
<td>Groundwater resources of the Kafue Catchment - Desktop review for the Kafue Catchment Management Plan</td>
<td>Advisory Report 01</td>
</tr>
<tr>
<td>December 2019</td>
<td>Tena, T., Fahle, M., Godau, T. &amp; Mkandawire, V.</td>
<td>Zambian Groundwater Information Management System (GrIMS)</td>
<td>Advisory Report 02</td>
</tr>
<tr>
<td>March 2018</td>
<td>Seeger, S., Bäumle, R., Karen, M., El-Fahem, T. &amp; Namayanga, L.</td>
<td>Re-edition of National Hydrogeological Map 1:1,500,000</td>
<td>Map</td>
</tr>
<tr>
<td>May 2017</td>
<td>Banda, K.</td>
<td>Development of an internal workflow process for WARMA to assess applications for permission to drill.</td>
<td>Consultant Report</td>
</tr>
<tr>
<td>July 2017</td>
<td>Banda, K.</td>
<td>Recommendations to the drafting of the SI under the WRM Act No 21 of 2011</td>
<td>Consultant Report</td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY

In the framework of phase 4 of the Groundwater Resources Management Programme (GReSP) that commenced in 2016 a capacity building program on groundwater resources management tools was carried out together with the Water Resources Management Authority (WARMA).

One of the main objectives of the program was to establish reliable estimates of groundwater abstraction of boreholes used for large-scale irrigation on agricultural areas as a part of the WARMA permitting system based on groundwater management plans per individual river catchment.

This manual provides an easy and repeatable approach based on the use of free open-source or freely available software (QGIS and Google Earth Pro©) and free satellite imagery (LandSat). All tools used are internationally known and documented. The basics for remote sensing (RS) procedures are explained. A Step-by-Step Guide is attached as Annex 1 to this manual summarizing all necessary work steps for obtaining and processing the LandSat imagery.

The Step-by-Step guide was added to streamline the action needed to accomplish the process of estimating irrigated water use. The whole procedure from the manual is described in 19 steps. To understand the full process it is, however, advisable, to start at step 1 and continue to follow the instructions from each step until completion after step 19. In case there is some issue with the processing of each step the correctly processed file is also included on the accompanying DVD.

Before starting the first step relevant basics on cartographic standards and coordinate reference systems for Zambia are explained to facilitate the transfer of field GPS data into georeferenced imagery and/or cartographic projects.

The following steps described in the manual and as such in the Annex 1 are found to be build up on each other as data and images are moved on from each step to the next:

- Introduction and guide to download and use Google Earth Pro© to locate and digitise field crop boundaries.
- Basic fundamentals of GIS and the import function for field crop boundaries digitised in Google Earth Pro© into GIS.
- Access and download of Landsat 8 Imagery.
- Processing remote sensing images within QGIS.
- The use of the Monteverdi add-on to QGIS to classify Landsat 8 images and convert the raster image to a vector file.
- Estimating the irrigated area based on the area of land showing healthy vegetation in the processed satellite imagery.
- Calculation of the irrigation water use based on the irrigated area as identified by the earlier steps.
The whole procedure is strongly dependent on a good data management by the user. Multiple files are processed requiring good work practices in saving files with clear name identification and repeated backup routines.

Using the remote sensing approach will still require ground reference but it is thought to improve planning of field visits and thus reduce expenses and time requirements for such missions. It also allows a justifiable approach to calculate water permits especially for large scale irrigation sometimes using tens or even more than hundred boreholes per farming complex. Expenses for monitoring and metering of the groundwater abstraction can thus be reduced or even be avoided.

It is concluded that GIS software like QGIS is of use to manage commercial groundwater use by digitising and georeferencing the individual farm boundaries. This will have multiple advantages, for example the water permit database could become a spatial database and thus can be used to prioritise compliance visits by field staff. Identifying commercial use of irrigation can also be used to protect the small and large tributaries from over-abstraction if regularly updated.

A dedicated person assigned to RS should continuously work on digitising features and areas of interest. To digitise all the agricultural field in Zambia it is predicted that all the commercial agricultural fields in Zambia could be digitised within one month. Digitising can also continue to include other major water users such as golf courses and mines.

Although examples for this manual concentrate on the Mpongwe Karst area, the chosen approaches are intended to provide WARMA with a blueprint for managing similar tasks in other parts of Zambia.
1. INTRODUCTION

The Zambian Water Resources Management Act of 2011 (GRZ, 2011) called for the creation of a new authority which is since in charge with the monitoring and management of the nation’s resources in surface and groundwater. The Water Resources Management Authority (WARMA) is established since 2013 by the said act under the Ministry of Water Development, Sanitation and Environmental Protection (MWDSEP).

A novelty to the water sector management is the task for WARMA to measure and monitor the groundwater resources for all Zambian catchments and hence provide permits for the abstraction of groundwater for water users. Especially groundwater abstraction for agricultural irrigation stayed long time unaccounted for although there are large-scale commercial enterprises active in the country assuring their production throughout the dry season using boreholes. Neither the boreholes have been thoroughly registered nor the abstraction rates for groundwater have been measured.

WARMA as a new institution still in build-up of capacities and assuring its own budget requires a quick-to-launch, low-budget system to allow valid estimations of groundwater use in those farming areas to regulate the groundwater use of the existing farms and give out permits for water use to new and old farmers. A huge challenge to WARMA are the remoteness and accessibility of some locations and the seasonal shift in use of water from rivers and dams to groundwater in the high dry season. Additionally, crops are rotating throughout the year each with different water needs.

This manual provides an easy and repeatable approach based on the use of free open-source or freely available software (QGIS and Google Earth Pro©) and free satellite imagery (LandSat). All tools used are internationally known and documented. The basics for remote sensing (RS) procedures are explained. The approaches described in this manual may therefore be adopted to the needs required and tools available. However, the manual and the accompanying Step-by-Step guide (Annex 1) are designed in a way to reduce the need for training courses in its application.

Using the remote sensing approach will still require ground reference but it is thought to improve planning of field visits and thus reduce expenses and time requirements for such missions. It also allows a justifiable approach to calculate water permits especially for large scale irrigation sometimes using tens or even more than hundred boreholes per farming complex. Expenses for monitoring and metering of the groundwater abstraction can thus be reduced or even be avoided.

The key concept to the proposed method is that in Zambia there is a distinct dry season where for many months there is virtually no rainfall. Based on the assumption that no rain has fallen for many months for there to be healthy vegetation there must be water. This manual describes the method to identify areas of healthy vegetation and then to distinguish areas that are irrigated with natural healthy dry season vegetation such as areas close to rivers or wetland/dambo areas.

It is beyond the scope of this manual to introduce crop water usage and climate factors and the relevant calculation for irrigated water use. Instead, the manual presents a method that can identify the areas that are being irrigated and make an initial estimate of water use based on the

Although examples for this manual concentrate on the Mpongwe Karst area, the chosen approaches are intended to provide WARMA with a blueprint for managing similar tasks in other parts of Zambia.

2. BACKGROUND

Historically the water permit system in Zambia has been applied to surface water sources such as abstractions from rivers and artificial reservoir dams created to supply irrigation water. This changed in October 2012 when the Water Resource Management Act 21 of 2011 came into force. The act, for the first time, includes regulations on groundwater use. In line with the requirements of the Water Act the Water Resources Management Authority (WARMA) has been founded in 2013. WARMA is in charge to regulate surface water and groundwater abstractions.

The management of groundwater and surface water is now organized based on catchments; within each catchment one of the key objectives has been to quantify the existing water use by expanding and modernising the water permit system. In the last 20 years the quantity of groundwater abstracted from boreholes has grown exponentially (Kang’omba & Bäumle, 2013). Over-exploitation of groundwater might result unless groundwater use is regulated.

Over-exploitation can lead to a lowering of the water table and the water abstracted is part of the water cycle. In Zambia with the distinct wet and dry season an obvious and visual result of the contribution of groundwater is the fact that many rivers are perennial even though there has been no rain in the respective catchment for many months; this illustrates the vital role of groundwater entering the surface water system as baseflow.

The use of remote sensing (RS) is without doubt a useful tool, but it must however be seen as part of a process to understand and quantify water use within a system. Remote sensing and GIS analysis cannot be a substitute for fieldwork. The GIS and remote sensing tools however can and should be used to complement and facilitate field tasks such as identifying areas for field visits.

A further vital role that these techniques can play is to facilitate the management of the water permit database. As of February 2018, only about 10 % of the water permits in the database have geographic coordinates, most still have postal addresses or plot numbers which relate to farm numbers. An essential next step in the process in managing water permits and use will be to identify which of the large water users have water permits and to estimate if the water abstracted complies with the permitted water allocation. The RS method outlined in this manual will not give a definite water use but will identify locations where large volumes of water are being used and give estimates of the water quantities used.
3. DEVELOPMENT OF THE MANUAL

This manual is designed to support water resource managers in Zambia to find out where and to estimate how much water is being used for irrigation. The development of the manual is however a process where lessons should be learned. The main lesson that must be learnt is that in 2015 a similar manual (GIZ, 2015) and training programme was developed, however in 2017 there was no institutional memory of the training and manual found. The key lesson from this, which was incorporated into the development of the manual, was that unless the RS techniques are a useful and reliable tool for day-to-day work routine within WARMA they will not be used.

Under the Groundwater Resources Management Support Programme (GReSP) a training programme was conducted in 2017 to train WARMA personnel. This incorporated a component that focused on water resource management in actual WARAM target areas. The training programme was given excellent feedback in terms of useful skills learnt and how useful the techniques were. However, the mapping of irrigated areas did not continue after the training. The lesson from this exercise was that to map irrigated land it is essential that dedicated personal is selected who have a strong background and interest in GIS and that also they have enough time and motivation to continue the project.

The next stage in the development of the manual was to train interns under the GReSP programme. It was monitored how they were able to follow the manual and which techniques proved to be bottlenecks. The lessons from this exercise were incorporated into the manual and the techniques were refined to cover the needs of personnel with a range of GIS backgrounds.

Finally, a Step-by-Step Guide is attached to this manual (see Annex 1) which shows in a simplified way all the methodological steps which are described with reference to the screenshots of the software in use and addresses the data needed for each operation. For practical purpose, all the software and uncompressed RS images are also included as a DVD along with this manual. The DVD also includes examples from each step and the Microsoft Excel file to facilitate the area calculation.

4. SPATIAL REFERENCING

Before the method steps are described one of the key issues observed during the trainings and on other projects is the subject of spatial referencing. Often users of GIS do not comprehend the importance of spatial referencing and experience events where the data “disappears”; in most cases this is due to user error. It is therefore essential that an introduction to how the data and images fit together in a geographical sense, i.e. the spatial reference, is understood especially within the Zambian context.

In Zambia, there are two main ways that a location is described: this is either in geographical coordinates for latitude and longitude or in projected coordinates of the Universal Transverse Mercator (UTM) system. These methods differ fundamentally but are similar in the way they describe a location. The position is referenced to how far south of the equator the location is and how far east of a reference meridian the location is (Figure 1).
1. The first method, often referred to as the Geographical Coordinate System (GCS), described how far south (or north) of the equator the point is and how far the location is east of the Greenwich Meridian (Figure 1). This method either uses the traditional degrees, minutes and seconds (DMS), which are found on all old maps, or decimal degrees where the minutes and seconds are converted to a decimal number, which is much easier for a computer to work with.

2. The second main method UTM is used extensively in Zambia. The method uses a projection to convert the spherical shape of the earth into a flat format. However, different projections are needed to obtain maps with low distortion (which result from the projection). The world is therefore divided into 60 zones running from north to south in which distortion of the map is low (Figure 1). The proper zone must be selected, and the coordinates are measured with reference to the equator and the central meridian of the zone. The major advantage of this method is that the coordinates are measured in meters (since the map is not distorted) and are written in decimal numbers. UTM due to its metric system can be used to calculate areas, while this is far more complex using degrees.

Meanwhile it is essential that you set the Coordinate Reference System (CRS), sometimes also referred to as Spatial Reference System in other software packages, of your GIS to measure areas in the formats used in Zambia and in this manual.

Figure 1: Longitude and latitude and UTM Zones.

Zambia lies within three zones (34, 35 and 36, see Figure 1). What must also be noted that each of the UTM zones is south of the equator, so for example Zone 35 is written UTM35S. When using a GPS, it is easy to forget the zone, this can place your GPS in the wrong country! Below in the Coordinate Reference System Box (Figure 2) the UTM zones for both North and South are displayed.

Cartography and map making has been a developed science for hundreds of years, for map makers the main issue was how to turn a spherical earth into a flat map. This problem was dealt with in various ways, none of them perfect. What happened over the area of what was Northern Rhodesia
is that the British map makers used a transformation or “datum” that is known as Arc1950. This is the system used in all older maps in Zambia.

With the advent of satellites and global GPS coverage a datum was calculated that can be used over the whole earth, this is the World Geodetic System 1984, this is what can be seen next to the UTM zones, this is denoted as WGS84. It should also be noted that a coordinate reference system recently used also indicates WGS84, this indicates that CRS is a geographic position system using degrees rather that the UTM system.

What can be seen and is visible in the bottom right corner of the main QGIS screen is the EPSG code. This is simply a collection of standard reference system mostly developed for the oil industry. Each system is defined with a number, therefore Geographic Position System using WGS84 would be EPSG:4326, for the purposes of this manual the whole area falls within Zone 35S, which is EPSG: 32735 = WGS84 / UTM35S.

Figure 2: Coordinate Reference Systems used in Zambia using QGIS Version 2.14.

It should be noted that “Enable on the fly CRS Transformation (OTF)” is enabled. If this box is not checked then the unit of measurement may not be accessible. “On the fly” tells your computer to use the first projection and datum system used then to project any defined vector file added later, this enables the layers overlay properly.

During the importing and processing of the Landsat 8 images it was realized that the CRS defined the images as UTM35N i.e. UTM Zone 35 NORTH, as Zambia is in UTM Zone 35 SOUTH this appears to be an issue. In fact, it is not a mistake and there is no need for a re-projection of the image to UTM35S. UTM South scenes have a false Northing of 10,000,000 while in the Landsat imagery the false northing is set to 0. This false northing value effectively shifts the negative value projection Y coordinates to a positive value. It is not necessary to switch the UTM zone to a southern hemisphere zone. If this is done, then the project Y values also need to be adjusted by 10,000,000. This will ensure any coordinate transformation are handled correctly.
5. METHOD OUTLINE

The manual outlines the process that enables satellite imagery to be used in conjunction with GIS software to isolate areas where healthy vegetation is the result of pumping (abstracting) water for commercial agriculture. Where abstraction of water is taking place for commercial use the objective is then to create an estimate of this irrigation water use.

The following tasks have been identified for separate chapters in this manual:

- Background to using Google Earth Pro© and methods to locate and digitise field crop boundaries,
- Basic fundamentals of GIS and import of field crop boundaries digitised in Google Earth© in GIS,
- How to download Landsat 8 Imagery,
- Processing RS images within QGIS,
- Using Monteverdi to classify Landsat 8 images and convert the raster image to a vector file,
- Estimating the irrigated area based on the area of land demonstrating healthy vegetation,
- Calculating the water use based on the irrigated area.

There are various ways to accomplish the objective, many of which use commercial RS and GIS packages. Due to the specialized nature of software packages the cost can be a major constraint in the sustainable use of the method since even medium priced packages can cost many thousands of US Dollars. This manual uses four main programmes that are all free, all are proven software packages that also have an additional advantage since the user groups have also access to a large volume of free instruction videos that are available online on platform such as YouTube©.

The programmes that are key to this method are:

Google Earth Pro© – Google Earth (this short form shall be used throughout the text instead of Google Earth Pro©) is a tool that most people are familiar with but in fact use only a small amount of its potential. This manual shows simple methods that can be learned in minutes and that enable field boundaries and other locations such as mines to be digitised in a format that can easily be transferred to a vector shapefile. Other additional advantages are that Google Earth can easily be linked to QGIS so that georeferenced high-resolution images can be downloaded for offline use and used to quickly upload and download GPS data and locate points and paths to locations, known as tracklogs on Garmin GPS units.

QGIS – Quantum GIS (Homepage: https://www.qgis.org/en/site/) has now evolved into a highly flexible, useful and easy to use GIS software package. With QGIS, it is possible to carry out virtually all the functions of the expensive commercial GIS packages. Almost every function from merging of Landsat images to working with GPS data to calculating areas is possible. It must however be noted that this is not an “introduction to QGIS” manual, it is assumed that the user will be proficient with basic GIS concepts and how to operate the QGIS graphical user interface. In this manual all GIS operations are done using QGIS version 2.14 Essen. It should be noted that earlier and later versions can look significantly different and function can also change location within the graphical user interface.
Monteverdi – Classification of images is a key step in the process of isolating vigorously growing vegetation. The subject of RS and image classification can be intimidating and is a complex field all unto itself. However, for the purposes and the objective of estimating water use Monteverdi provides a method to classify an image literally at the press of a button.

7-Zip – It will be necessary to download and install 7-Zip, this is because the Landsat images are compressed in the .tar.gz format which is a non-standard format that Windows cannot decompress. 7-Zip is a free decompression software. Commercial alternatives are WinZip or WinRAR.

6. USING GOOGLE EARTH TO DIGITISE AGRICULTURAL FIELD AREAS

Google has for many years provided a free service that gives access to high resolution images of the earth’s surface. For most of Zambia, the images are available at high resolution on both computers and on smartphones. Google has recently made the professional version of Google Earth Pro© free to download and use, the programme can be downloaded by typing in the following link:

https://www.google.com/earth/download/gep/agree.html

The high resolution of the images coupled with the numerous features of this programme makes it a very useful tool. The resolution of the images over most of the globe and in Zambia in particular makes remote observation of land use change possible. The images that Google Earth provides also have a major advantage in that they are georeferenced, this mean in practise that any point seen on the computer screen can be located and coordinates derived.

For field work in a country of the size of Zambia finding areas of interest can be time consuming and costly. If the benefits of using these georeferenced images is truly utilised, then work in the field can become far more targeted and therefore efficient using the georeferenced images as a guide.

The first step in estimating water use is to identify areas where commercial water use is taking place. The high resolution of Google images allows the user to visually detect and zoom into areas that have unnatural shapes such as round circles, which are usually centre pivot type irrigated fields, and rectangles. Other types of commercial water use can also be identified such as mining operations or golf courses. All these activities are major water consumers.

6.1. DIGITISING

The first step is to familiarise oneself with the digitising functions in Google Earth©. Figure 3 shows a screen shot of agricultural fields that were digitised in the Mpongwe Farming Area. The steps below describe how agricultural fields are captured digitally using Google Earth.

- First create a folder so that the co-ordinates of each field that is digitised are in a unique file within this folder. To do this right-click on: My Places in the left panel, then press: Add Folder.
• Making sure all the files of the digitised polygons are in a single folder is important because this folder becomes the Google Earth .kmz file that is easily converted into a GIS shapefile containing all the field crop boundary polygons.

• To digitise, click on the third icon located at the top of the Google Earth screen.

• This icon enables the Add Polygon function.

• A window opens called New Polygon.

• Zoom in on the agricultural field using the locational buttons to the right of the screen and digitise a polygon using right-clicks on the mouse.

• To complete the procedure, click on the OK button at the bottom of the New Polygon window.

• Repeat the process to digitise additional fields.

Figure 3: Digitised fields in Mpongwe.

• Note, it is not necessary to give each field a unique ID or name in the New Polygon window.

• Once all the fields in a particular area are complete, ensure to save the work (right-click on Folder then Save).

• The final step is to convert the .kmz file to a GIS shapefile. This is done by importing the file into QGIS and saving it as a vector layer.

• Figure 4 and Figure 5 show how this is done.

• Click on Layer on the toolbar, from the dropdown list select Add Layer, Add Vector Layer.

• Then in the Add vector layer box, click on Browse and Open Folder, and add the .kmz files to the QGIS project by clicking on Open.
Figure 4: Add vector layer.

Figure 5: Add Google Earth .kmz file.

- Figure 6 shows how to convert the .kmz to a shapefile by right-clicking on the .kmz and using the **Save Vector Layer As** option.
- Under **Save as**, **Browse** to the right folder and save the file with the appropriate name by clicking **OK**. Make sure the file format is ESRI Shapefile.

Figure 6: Save vector layer as ESRI Shapefile.
7. OBTAINING AND USING LANDSAT IMAGERY

In order to estimate the amount of water that is being used for irrigation it is necessary to have RS data. The RS data that is required can be seen as a balance between the resolution of the image, the level of detail of the image, the size of the image in terms of megabytes of data and the amount of land that each image covers. For the purpose of water use estimation the Landsat series of satellites provides an excellent tool. The Landsat data also has another major advantage; georeferenced images for virtually the whole globe are free.

This chapter provides instructions on the steps obtaining the Landsat imagery. Then the Open source software QGIS can be used to merge the Landsat bands to create a false colour image that will highlight healthy vegetation. The first step is however obtaining the Landsat Imagery.

Obtaining Landsat 8 imagery can be problematic as each image is approximately 900 megabytes (compressed). A fast internet connection is required as the United States Geological Survey site will time out any download that takes longer than two hours. Imagery can also be obtained from the RS Unit located in the Department of Science and Technology on the Lusaka Airport Road. Note: The RS Unit can also be approached to perform RS tasks as they provide a service to government departments.

The following subchapters describe the steps that should be followed to download imagery. The imagery that will be used for the manual is from the satellite Landsat 8. Landsat is in fact a series of satellites that has been operational almost continuously since the 1970s. The focus of the Landsat satellite was for land cover analysis and therefore it is an ideal tool.

The Landsat satellite has sensors that record different wavelengths of visible and non-visible “light” as so-called spectral bands. The combination of different sets of these bands maybe used for analysing vegetation and other spatial information. For this manual the technical background to RS will not be explained, the objective is to demonstrate the process without including the complexities of RS. The analogy is that it is possible to use a car very effectively without understanding how the engine works. The theory and application of the spectral bands and RS tools can be best read, among many others, in the following textbooks and resources:


7.1. DOWNLOADING IMAGES FROM EARTH EXPLORER

The first step is to locate where the images can be downloaded. The United States Geological Survey (USGS) provides a website called Earth Explorer that provides a portal to search for imagery from numerous satellites. The website provides a user-friendly Graphical User Interface (GUI) that enables to locate the area of interest and displays the coverage of this area by satellite imagery.
The first step is to search for Earth Explorer on your internet browser and register as a user. After completing the registration forms (Figure 7) an email will be sent to you with an activation link. Ensure you activate this link before it expires.

The next process is to log in using username and password. Once you have successfully logged in you need to identify the satellite that your location of interest and provides the information needed. In Figure 7, the Landsat 7 is selected.

Zoom in to your area of interest using the map tool provided and enter the co-ordinates by clicking the mouse on the four corners of the area of interest (Figure 8), this should be done in a clockwise sequence. It is also possible to enter the path and row if you know the satellite image you want. The next step is to define the Date Range (see Figure 8) of the images that are required, i.e. the dry season May to October.

Figure 7: Login and Landsat 8 data location.

Figure 8: Selecting the area of interest.
One of the unavoidable issues that come up with satellite imagery is cloud coverage. During the dry season in Zambia there are days with cloud cover that can make the image unusable if clouds cover the irrigated areas. To reduce this problem, click on Additional Criteria (See Figure 8) and leave all defaults except for Cloud Cover (select Less than 10%) and select Day images only.

Figure 9: Downloading the Landsat image.

You then need to tell the site to search for the images within the range that you have selected. Remember to restrict your search dates as the Landsat images are available multiple times per month or the result will take too long to look through. Once the search is complete click on Search Results (see Figure 9). All available images that meet your criteria are displayed. Choose the icon with the green arrow (Figure 9) and click download. The image is downloaded to your download folder. This is where you need a fast internet connection.

### 7.2. Working with Landsat Data

The downloaded file from the USGS is a double compressed file with a .gz extension. An example of a file name is: LC81730692013178LGN01.tar.gz. To decompress this file, it is necessary to download 7-Zip or a similar software package.

The first decompressing drops the .gz extension and the second decompressing step reveals several .tif files and additional data files. The .tif-files are referred to as spectral bands, each containing a reflective measure of electromagnetic radiation reflected from the earth surface and captured by the satellite using colour filters. There are eight bands for each image with Landsat 7 and 11 bands for Landsat 8 (see Table 1).

The data is captured in raster format with a pixel size of 30 meters by 30 meters on the ground (for the main bands we’ll be working with). These bands are used in various combinations in the image classification process.
At this point it is essential that the way that the files are stored follows an orderly pattern. Working with RS data and GIS will generate literally hundreds of files in a short time, it is essential that the data is stored in logical file structure. It is also essential to have no spaces in the files structure and the names of the files must contain no operators e.g. /=.*%.

The file’s name itself, e.g. LC81730692013178LGN01, contains useful information such as LC8 that identifies this as a Landsat 8 image. As shown in Figure 10, the next numbers are the path number 173 and the row number 069 which are indicating the location of the image. The number after the year 2013 identifies the day the images was taken, this is a number from 1 (1st January) to 365 (31st December).

It is advisable to create an archive of the images in your library to keep track of the images. This can be done with Microsoft Excel. If this is done a separate tab can include the days in chronological order to facilitate identifying the date.

8. IMAGE AND GIS DATA PROCESSING

Image processing using Landsat imagery uses visible and non-visible parts of the electromagnetic wavelength spectrum that interact strongly with vegetation.

Red, green and blue (Figure 11) are how the human eye perceives the world. The colours that we see are all based on how much of each of these wavelengths is either rejected or absorbed.
Healthy vegetation reflects strongly in the green section of the visible spectrum. However, as the plant dies it starts to reflect less green and more red light, i.e. it turns brown.

Figure 11: Red, green and blue Components of the final image.

Any picture taken with an ordinary camera defines its information according to its 3 colour channels in red, green and blue. The spectral bands can be applied in various combinations to these channels to create “false colour images” that are designed to answer specific questions such as how much healthy vegetation there is. They are not displaying the original red, green and blue information but those of the respective wavelengths of the used band. Therefore, the resulting image is of “false colour”.

The two main imagery sources that will be of use are the Landsat platform 7 and 8. It must be noted that Landsat 7 developed a problem at the end of its life span that created stripes that are difficult to remove. This led to the launch of Landsat 8. The bandwidths covered by the respective sensors are found in Table 1. The correlation between the sensors of Landsat 7 and 8 can be found in most textbooks. A good summary is found here:


For identifying healthy vegetation using Landsat, the band combination 5-6-2 is used (see for example: https://www.esri.com/arcgis-blog/products/product/imagery/band-combinations-for-landsat-8/). This is a false colour image that combines Near Infra-Red (NIR), Short Wave Infra-Red (SWIR) and blue. Please note that if you want to carry out the same analysis using Landsat 7 then the band combination 4-5-1 should be used (Table 1).
Table 1: How the new bands from Landsat 8 line up with Landsat 7.

<table>
<thead>
<tr>
<th>Band Name</th>
<th>Bandwidth (µm)</th>
<th>Resolution (m)</th>
<th>Band Name</th>
<th>Bandwidth (µm)</th>
<th>Resolution (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1 Coastal</td>
<td>0.43 – 0.45</td>
<td>30</td>
<td>Band 2 Blue</td>
<td>0.45 – 0.51</td>
<td>30</td>
</tr>
<tr>
<td>Band 2 Green</td>
<td>0.52 – 0.60</td>
<td>30</td>
<td>Band 3 Green</td>
<td>0.53 – 0.59</td>
<td>30</td>
</tr>
<tr>
<td>Band 3 Red</td>
<td>0.63 – 0.69</td>
<td>30</td>
<td>Band 4 Red</td>
<td>0.64 – 0.67</td>
<td>30</td>
</tr>
<tr>
<td>Band 4 NIR</td>
<td>0.77 – 0.90</td>
<td>30</td>
<td>Band 5 NIR</td>
<td>0.85 – 0.88</td>
<td>30</td>
</tr>
<tr>
<td>Band 5 SWIR 1</td>
<td>1.55 – 1.75</td>
<td>30</td>
<td>Band 6 SWIR 1</td>
<td>1.57 – 1.65</td>
<td>30</td>
</tr>
<tr>
<td>Band 7 SWIR 2</td>
<td>2.09 – 2.35</td>
<td>30</td>
<td>Band 7 SWIR 2</td>
<td>2.11 – 2.29</td>
<td>30</td>
</tr>
<tr>
<td>Band 8 Pan</td>
<td>0.52 – 0.90</td>
<td>15</td>
<td>Band 8 Pan</td>
<td>0.50 – 0.68</td>
<td>15</td>
</tr>
<tr>
<td>Band 6 TIR</td>
<td>10.40 – 12.50</td>
<td>30/60</td>
<td>Band 9 Cirrus</td>
<td>1.36 – 1.38</td>
<td>30</td>
</tr>
<tr>
<td>Band 10 TIRS 1</td>
<td>10.6 – 11.19</td>
<td>100</td>
<td>Band 11 TIRS 2</td>
<td>11.5 – 12.51</td>
<td>100</td>
</tr>
</tbody>
</table>

The combination of spectral bands can also be used for many other types of analysis (Table 2) which include identifying Land and Water areas (5-6-4) and the type of vegetation (5-4-3).

Table 2: Recommended Band Combinations for Landsat 8.

<table>
<thead>
<tr>
<th>Natural Colour</th>
<th>4 3 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour Infrared (vegetation)</td>
<td>5 4 3</td>
</tr>
<tr>
<td>Agriculture</td>
<td>6 5 2</td>
</tr>
<tr>
<td>Healthy Vegetation</td>
<td>5 6 2</td>
</tr>
<tr>
<td>Land/Water</td>
<td>5 6 4</td>
</tr>
<tr>
<td>Natural With Atmospheric Removal</td>
<td>7 5 3</td>
</tr>
<tr>
<td>Shortwave Infrared</td>
<td>7 5 4</td>
</tr>
<tr>
<td>Vegetation Analysis</td>
<td>6 5 4</td>
</tr>
</tbody>
</table>

In previous years, processing of Landsat images needed specialist and expensive RS software such as ENVI, ERDAS etc. The specialist software was not easy to use as they assumed previous training in RS and thus processing of Landsat images was largely the domain of specialist; this had the effect of making it expensive to work with satellite images.

QGIS does not replace the specialist software but it includes tools to work with raster images that enable users with only a basic introduction (such as this manual) to import Landsat images, choose the specific bands they want to work with, then to process the image to enhance certain features. The following steps illustrate the process.

To create a false colour image in QGIS it is first necessary to decompress the images (see Annex 1, Step 4), this results in a list of .tif image files and two other documents that give information on the image. If the computer that you’re working on has limited space on the hard drive it is also possible to just decompress the bands 5, 6 and 2; it is recommended that the text file is included so that the data about the image can be displayed easily.

**8.1. Importing and merging Landsat image bands**

Once the Landsat bands are decompressed the process to create an image is simple but there is one vital step that must always be remembered when working with RS and GIS data. RS and especially GIS relies on links to files. The images are not “imported” into the software, only their
location is linked. Meaning you cannot move your software or your GIS-project to another computer and find the images there. All links must be re-established.

A hidden issue that often just leads to error message is the file path must NOT include spaces in folder of file names, *it must have underscores*, for example:

A folder called: Remote Sensing Data must be called – Remote_Sensing_Data.

The name of a processed image band must not be read Landsat 8-Path 071 Row 069-Date-image bands, but what is recommended is that the file names read as follows in Figure 12:

![Figure 12: Name of processed image bands.](image)

To process the Landsat bands into false colour images, you need to “merge” the bands; this function is found in QGIS under the menu **Raster/Miscellaneous/Merge** (Figure 13).

![Figure 13: Creating a merged image in QGIS.](image)

Once you have clicked on the merge function a dialogue box appears. Here you have to select the input files, then select the location for the output files. This sounds like a simple function, but yet it is necessary to emphasise that working with RS images creates a lot of images and data. Hence, it is essential to be very organised with the structure and storage of files.
You should now have a false colour image (Figure 14) that will highlight the presence of healthy vegetation, the objective of this process is to highlight irrigated areas, but it must be remembered that healthy vegetation does occur in the dry season in Zambia over millions of hectares for several reasons. Within the Kafue Basin examples of healthy vegetation will range from the massive swamps and wetlands, such as the Lukanga swamps, seasonally waterlogged depressions, known locally as dambos to the areas next to perennial rivers (usually referred to as the riparian zone).

What is needed is to find a way to distinguish between the results of irrigation from natural healthy vegetation. One of the best methods to do this is to use the power of QGIS to solve this issue in order to quantify the areas that are being irrigated. To do this, it is necessary to understand the fundamental difference between raster images and vector files.

Raster files are made up of pixels and each pixel may have another value assigned to it. In the case of the type of images that are taken with a normal camera it is made up of three layer of pixels (red, green and blue), each layer is then assigned a Digital Number (DN) which has a range from 0 – 255. A pixel information may then look like this: R 100, G 68, B 215.

Vector files are a very different way to display spatial data, they are made up of either points, lines or polygons, they are however all similar in that they are made of nodes, which have a location. Thus, a point is a single node. A line is, at its simplest level, two nodes connected with a line, this can then be extended to a series of nodes and lines that enclose a space, i.e. a polygon.

Figure 14: Landsat 8 false colour image of the Mpongwe area.

A polygon encloses a space on the earth (if the nodes have geographic or project coordinates to enclose areas of interest with nodes and lines). The key difference and the heart of the massive power of GIS is that these vector files can then have data or “attributes” attached to them. For the
purpose of calculating irrigated areas an attribute that can be calculated is area. Other important data can also then be attached such as:

- Who owns the land?
- What water are they permitted to abstract?
- Whether they have a water permit where large-scale irrigation is visible from satellite imagery?

The process of digitising was described in Chapter 6.1.

8.2. **PROCESSING THE LANDSAT IMAGE TO HIGHLIGHT HEALTHY VEGETATION**

The merged image (Figure 14) can be seen to highlight healthy vegetation. However, it is possible to distinguish the colour better within QGIS. There is almost an entire science devoted to processing images, this however is not necessary for our objective and a simple way to make the healthy vegetation more “vivid” is to right-click the mouse on the bands 5-6-2 raster image file to access its **Properties**. In the **Load min/max values** box click on the **Mean +/- standard deviation** button, press the **Load** button and press then the **OK** button. Figure 15 shows the result of the processing.

It is recommended when working with images that when you have a result that you like to save the file and create a duplicate and experiment with this image.

![Figure 15: Landsat scene after processing in QGIS.](image-url)
In order to convert the merged raster image to a vector file it is necessary to process the raster file in such a way that is simplifies the data. The objective is to simplify the millions of colours that are visible in a standard RGB image to a much simpler raster image. The simplest way to visualise this process is that we want to group ranges of colours together, this is the process of image classification.

Image classification is grouped into two main subdivisions: supervised and unsupervised. The simpler method is to use unsupervised classification. Unsupervised classification uses the pixels of the image and groups them together based on similar values. The user only specifies the number of groups or classes. For the supervised classification the user may identify pixels or areas of pixels he or she is looking for. The software will then classify the image according to the selected pixel sample(s).

It is however necessary for both methods to check that what you are looking at on the computer screen does represent reality. This is where Google Earth© comes in very useful to assist with classification, but this does not negate the need to verify that what you are looking at on the computer screen reflects reality. The method to verification is simply a matter of visiting specific locations of e.g. a defined vegetation type identified by classification methods and compare it with your observations using a GPS. This process is called “ground truthing”.

8.3. CLASSIFYING IMAGES

Classifying images is where information is extracted from an image to group similar areas together in a predefined number of classes. There are many ways of classifying images, the method selected is based on the fact that the software is free and easy to use. It can also be used from within QGIS, however experience has shown that a much simpler method is to activate the programme directly from desktop shortcut, the main issue is to know how to load it and where it is initially.

The programme to be used is called Monteverdi, which is part of the Orfeo Toolbox. The software toolbox can be found on the DVD or can be downloaded from the internet site of the Orfeo Toolbox. To activate the programme go to the folder OTB-7.0.0-Win32 (or the respective folder), then double-click the Monteverdi which is a Windows batch file (i.e. with the file ending .bat). A dialogue box may open asking you if you want to run the programme, click Run. If it does not open immediately wait, it should open within 10 seconds.

Once the Monteverdi application is open, click on View, then OTB-Application browser, then type in kmeans (Figure 16) into the box at the top. It will give you options for kmeans classification, then double-click and the dialogue box will open – again if it does not open immediately wait a few seconds.
You need to do three things to classify the image:

1. You need to select the *Input Image*.
2. You need to name the *Output Image* and put it somewhere you can find it – however you must end the file name with .tif or it just won’t work! And it will not tell you why!
3. The output image type must be also changed to – *int16*. There is a dropdown menu – see Figure 16.

Then select the *Number of classes*, ten seems to work well, and press **Execute**.

At this point you are probably wondering what kmeans is? Remember the analogy of a car, you can use a car very effectively to get from A to B without knowing how the engine works, but a basic understanding does help. What kmeans does is to take the massive image file and partition the data based on clusters with a similar mean value, in other words it groups similar numbers together.


Once the programme has finished processing the image you will see a black and white image. It is vital that when classifying the image, you also give it a name and place it in the correct folder or very soon you will not find or even mistake the files you created. It is suggested that the following naming protocol is followed:

p071r069_20170728_L8_562_Class10.tif

(Please note you do no need to make Class ten **BOLD**)

**8.4. Using QGIS to display the classified image and convert to polygons**

In QGIS open the raster image; you will see a black and white image open with ten shades of grey visible. The next step is to look at the results to see if they make sense! Pressing the classification button activates several algorithms, but it is up to the human to make sure it reflects reality. To
assist with analysis the first step is to convert the greyscale image into ten distinct colours. To do this perform the following steps:

- First create a duplicate of the image.
- Right-click on the classified image on the Layers Panel of QGIS, then select Properties.
- Within the Layer Properties dialogue box select Style (Figure 17), the following dialogue will appear. You then need to change the Render type to from singleband grey to Singleband pseudocolor.
- Then change the Color interpolation method from Linear to Discrete using the drop-down menu.
- Then change the Mode to Equal Interval, if you don’t do this the number of classes won’t change!
- Once this is done, change the number of Classes to 10. If you have chosen to use a different number of classes, select the number of classes you selected in Monteverdi for the classification or QGIS will simply follow instruction and group classes together, which may not be correct.
- Press Classify and then OK.

Figure 17: Displaying the classified image.

At this point it is possible to convert the entire classified images to polygons within QGIS using the command polygonise. Before this button is pressed, however the issue of computing speed and volume of data needs to be considered. If an entire Landsat scene is processed it will generate a file of over 1 Gigabyte, this could take up to 30 minutes or more to process. In addition to the processing time, each time the polygon shapefile is clicked on in the layers panel it can take many minutes to display. The question that you should now pose in your own area is do we need to classify work on the entire image?
In the earlier chapter on Google Earth® areas within the Upper Kafue catchment were digitised. This only took a few hours. When these areas are looked at it can be seen that they form clusters. Based on this observation it is possible to identify and delineate Areas of Interest (AOI). These areas can then be delineated by creating a polygon vector file. You could delineate the AOI again within Google Earth® following the same procedure.

If you then have a polygon of the AOIs in your area you can then also use these shapefiles to cut out the areas that you’re interested in, this is called clipping and can be found in the Raster – Extraction location in QGIS. There are several ways to clip the image but using the AOI works well.

The classified raster or the selected clipped AOI can now be converted to polygons. This is called polygonise and the function is in: Raster – Conversion. You will now convert each set of coherent pixels (i.e. of the same class) of the raster image into vector polygons which have an attribute, which is related to the number of classes you chose during classification. Each polygon now has a delineated area and data related to each polygon. As with the previous steps, it is essential that the data is located in a specified folder and the naming convention is followed or data will be confused or lost.

If you left the “Load into canvas when finished” cross, the shapefile will now appear in the QGIS Layers Panel. When this image is displayed it will be rather disappointing because all the colours will be exactly the same. What is now necessary is to display the polygons based on their attributes, this is done based on the following procedure:

- Right-click of the shapefile of the polygonised raster.
- Select Categorised from the top dropdown window.
- Select DN or the column that represent Digital number.
- Then click the Classify button and you will see ten classes appear (0 – 9).

The colour of each class can be selected by either using a colour ramp or selecting individual colours. When this is done you will have a layer that can be visualised along with the raster image. One way of comparing the images is to make the layer partially transparent and thus the polygons will be visualised over the raster image; this is found in the layer rendering part of the same style properties box where you changed the way the polygons looked.

8.5. SELECTING THE IRRIGATED POLYGONS TO CREATE A NEW SHAPEFILE

You now have a polygon layer with only the 10 classes but in fact you only need one class in this image. In the image below (Figure 18) the orange polygons represent the healthy vegetation. In terms of the objective of determining the area of irrigated land you now only need this layer. In the next step we need to separate this polygon class from the other 9 classes and create a separate vector layer.

It is important to note that this will not always be so clear-cut. In some areas the irrigated land may be represented by two or even three classes. It will depend on the type of irrigation and how healthy the natural vegetation in the area is.

The simplest way to do this is to deselect the other classes that are not healthy vegetation. In the example provided in Figure 18, the orange colour represents healthy vegetation so all the other classes were deselected.
The image below shows the .shp-file of the classified image where only polygons of class 9 are visible; this is set against the Landsat 8 false colour image.

Figure 18: Selecting only the healthy vegetation.

All the healthy vegetation polygons should be selected and will be displayed in yellow (unless you have changed the selection colour). Selection can be done with the mouse once you have activated the layer for selection. The final step is now to create a new shapefile layer with just this class, this is done by the following steps:

- Right-click the polygon layer for healthy vegetation, now go to Save as... .
- A new dialogue box will appear, firstly name the new shapefile layer you will be creating something logical that you will remember that also includes the necessary data as outlined above.
- The essential step is then to make sure that the Save only selected features dialogue is checked, see Figure 19.

Figure 19: Saving the Selected Elements of the Shapefile as a New Shapefile.
You should now have a new shapefile that contains all the polygons that correspond to healthy vegetation. The next task is to eliminate the healthy vegetation that occurs outside of the fields. To do this you will use the field boundaries that were digitised in Google Earth© to act as a mask in selecting the healthy vegetation growing in fields.

In some cases, especially where center pivots are involved, the healthy vegetation and the field boundaries provide a very clear picture of where the irrigated land is located. In the example shown in Figure 20, the processed Landsat image clearly demarcates the areas of healthy vegetation which have a much brighter green signature than the river and associated riparian zone to the north and the healthy forest areas. The purple colour also clearly shows the areas where rain-fed agriculture is practiced and where large fields have been harvested. The result of this is that when the image is classified a class that represents healthy vegetation can easily be extracted.

When the healthy vegetation class is converted into polygons and the field boundaries are used as guide it is very simple to select the round polygons. The classified image shows three of the center pivots features selected. What is also clear from the classified image is that the riparian zones give a different signature to irrigated areas, however this is not always the case in all images.

![Landsat 8 562 Merged Image](image1)

![Landsat 8 Classified Image](image2)

Figure 20: Mpongwe merged Landsat 5-6-2 (left) and classified image with selected areas (right).

What should also be noted about this example is that the area of the center pivots cannot simply been taken as the irrigation area. This will not give accurate results. The processed Landsat image shows that many fields have nothing growing on the date the image was collected. What must be kept in mind however is that this could be because of a recent harvest, this emphasises the need for there to be more than one image used to calculate the area being irrigated.
In some cases, fields will be only visible once the Landsat images are processed, in the examples below (Figure 21), the area west of Kitwe is shown as it would be seen in Google Earth®. This image does distinguish easily the center pivots close to Kitwe, however to the west of Kitwe there are what appears to be fields with sharp edges, which are far less easy to distinguish.

Figure 22 shows the same area but using a processed Landsat image. This now makes the healthy vegetation far more visible. During training, when digitising the fields and pivots, the healthy vegetation area was not fully captured in Google Earth® until the Landsat image was processed. The difference in the spectral signature using only visible light does create much contrast with the natural healthy vegetation.

In this case this will necessitate possible additional digitising using either Google Earth® or within QGIS itself. Digitising in Google Earth has the major advantage of improving the speed of the workflow but due to the limitation of visible light it is advisable that the Landsat images are viewed during digitising the field boundaries, ideally on a second screen.

It is important to remember that combining the power of the two platforms can enable the user to assist the field teams in locating areas of interest for field inspections to identify what is being grown and to get information on the owner.

Figure 21: Area west of Kitwe viewed in Google Earth®.
Figure 22: Area west of Kitwe viewed using merged Landsat 8 bands 562.

In Figure 22, an area is highlighted by a red rectangle. The images below (Figure 23) shows the area in more detail. What is apparent is that there are areas of healthy vegetation that show up in purple in the classified image. However, the location of the irrigated land is far less clear. The areas that are colored in a lighter shade of blue also seem to have very healthy vegetation for the middle of the dry season (image was taken on the 28th July 2017). This illustrates the need to check results and if necessary carry out field visits to identify the crop and get details on the owner.

Figure 23: Comparison of Landsat 52 and classified image of area west of Kitwe.
Manually selecting the fields does appear to be inefficient but it is a technique that works. It also has the major advantages of forcing the user to analyze the images, which creates increased familiarity with the areas and can assist with field operation since the areas selected can be viewed with reference to the location. In the example above all that can be said with certainty is that there is healthy vegetation that appears to be growing in unnaturally shaped areas. What is not possible in this case is to simply calculate an area that appears to be irrigated, as in this case it may be an evergreen forest plantation. This illustrates the need for targeted field inspections, so the image data can be augmented by visual checks.

For example, the main junctions and distances to the site can be given to the field teams in order the assist the field inspectors access the site and check permits.

If all the healthy vegetation can be identified as irrigated land, then the next step is the manual selection of all the healthy vegetation within field boundaries. To do this you will need to highlight the new shapefile representing healthy vegetation, using the field boundaries as a guide, then use the select function. To select multiple polygon features from that of the healthy vegetation that fall within the field boundary shapefile you will need to hold down control key while you are selecting the features.

In some cases, it may be necessary to clean the selected features if for example a river crosses an irrigated area or healthy vegetation that is clearly not in a field is joined to an irrigated area during the classification process. The first step is to ensure that the digitising toolbar is available in the plugin menu, once this is done activate the toolbar which is located in: View/Toolbars, then click on digitising toolbar. The cleaning up of polygons and splitting of incorrect polygons can be done by the following procedure:

- Remember always make a back-up of the polygon layer first by using the Save as... option.
- Select polygon feature in edit mode.
- The select the split feature button in the digitising toolbar (Figure 24)
- You then draw a line across where you want to separate.
- Always remember when you finish a line or polygon to use control right-click to end digitizing.

![Figure 24: Splitting features in a polygon layer.](image)

This avoids using the automated intersection function which was found to be unreliable. On first appearance, this may seem like an inefficient method however it is a method that works reliably. Once this is done, it is then possible to create a new shapefile using just the selected features. This is the last spatial operation needed.
9. SPATIAL REFERENCE AND CALCULATING AREA BEING IRRIGATED

The final step is to now calculate the area that is being irrigated. When the shapefile was created it has no area column, this will need to be created within QGIS. However, before this is done there is one step that is essential, or the entire method will create false data.

![Figure 25: Setting the area measurement unit.](image)

In order to calculate an area, you will need to use the UTM projection as described above. Once the CRS is sorted out, you can calculate the area of each polygon. The first operation is to make sure that your measuring unit for areas is **Square meters** (or hectares), this option is found in *Project/Project Properties* then *General* (Figure 25).

Once this is set it is now possible to measure the area of the healthy vegetation that grows within a defined area which are obviously man-made areas where commercial agriculture is taking place. It must however again be emphasised that this technique gives a first pass to estimate reasonably efficient irrigation and most important to identify where large amounts of water are being used in the dry season. There are within Zambia many irrigation methods from highly efficient methods such as drip irrigation to inefficient irrigation where two or three times more water is used, such as commercial sugar cane and banana plantations.

9.1. CALCULATING THE AREA BEING IRRIGATED

To calculate the area you need to select the field calculator (Figure 24). Once the field calculator button is clicked the field calculator dialogue box (Figure 26) appears, then do the following:

- Leave the *Create a new field* ticked.
- Name it *area*.
- Change the field type to **Decimal Number (real)**.
• Expand the Geometry function by pressing +, then double-click on $area$.
• Press OK and QGIS will calculate the area in square meters ($m^2$).

If you would like to get the area in hectares you can repeat the process by going back to the start of this section and selecting hectares in the CRS and create another field calling it “area Ha”.

![Field calculator](image)

Figure 26: The field calculator.

Now that QGIS has calculated the area we need to export the data so we can work with it. To do this first Select All the data (Figure 27) in the attribute table dialogue box (right-click on the polygon layer for healthy vegetation) then press the copy button. You now can simply paste the data into a spreadsheet software such as Microsoft Excel®.

![Select All](image)

Figure 27: Exporting the area data from the attribute table of a shapefile.

10. ESTIMATING WATER USE FROM THE AREA MEASUREMENT

Estimating the water used has many factors, this includes the main factors such as the crop type and the rainfall pattern. The subject of irrigation is a major science and there exists resources within Zambia such as the Department of Irrigation with the Ministry of Agriculture, another good source of information is the Food and Agricultural Organisation (e.g. FAO, 1992) of the United Nations. This subject is quite complex but for an initial estimate of water use a “rule of thumb”
used by most farmers is that for each hectare of irrigated land you need to abstract 1 liter per second.

The RS techniques can also be of great value to identify the location of irrigation, which can then be cross-referenced with the water permit database, in particular where there are large irrigation projects and no permits. Where there are permits, the technique can provide an estimate of the water use, which can then be compared to the granted permit.

One further use of the technique is to estimate the volume of water that is being taken out of the system. In the case of farms located next to rivers and those with surface reservoirs the water being taken out of the hydrological cycle is direct. Estimating the abstracted quantity can be used to set the abstraction in relation to river flow and to determine if and how much more water can be taken out.

For areas where there is no visible surface reservoir or nearby river it is a reasonable assumption that the water for irrigation is coming from groundwater. This information will be useful as the abstraction of groundwater requires a permit and will provide an estimate of the groundwater being abstracted.

When considering groundwater, it must also be remembered that abstraction of water affects the system and can seriously affect baseflow to rivers. RS provides a tool to evaluate and quantify the existing situation as a baseline for future development and expansion, it can also be used to look at the effect of development by using historical data, this is easily possible as the Landsat series has data available that goes back to the 1970s.

The area being irrigated can now be quantified. However, the limitations and possibilities of this approach must be understood. There are several assumptions that are made, these are:

- Estimating water use is only valid during the dry season as rainfall is assumed to meet a major part of the crop water requirement between October/November to March/April. As a first estimate 8 months will be used to estimate irrigated water use.
- The irrigation is assumed to be continuous for the hectare, this does not mean there is continuous water which is clearly not the case for irrigation systems such as centre pivots which can take many hours to complete a circle.
- Some crops, such as sugar cane and bananas do use more that 1l/s per hectare, some which use efficient irrigation techniques such as drip irrigation (tomatoes/citrus) will use less.
- Each image is a single snapshot at the specific date, it is therefore assumed that the irrigation use is continuous, however this is just for an initial rapid estimate and to identify the locations where irrigation is taking place.

The Landsat 8 satellite images the earth every 16 days; this creates a comprehensive dataset of the dry season. The amount of cloud cover still affects the results; however, in the years 2014 to 2016 virtually cloud free images are available. It is therefore advisable to carry out the estimates based on at least three images from the dry season to assess if irrigation is occurring on each date. This will still be an estimate. It is emphasised that this is a tool for an initial estimate and the figures generated area rapid assessment.
Using Spreadsheets to Calculate Irrigation Water Use (Figure 28)

Once the area of healthy vegetation within the identified fields is processed and exported to MS Excel® or any other spreadsheet software, it is possible to calculate the volume of water used for irrigating those areas. The calculation of area can be completed in either square meters or hectares within QGIS. If the calculation is done in m² then the results will need to be divided by 10,000, this is based on a hectare being defined as a square with 100 m sides, i.e. 100 m x 100 m = 10,000 m².

As mentioned above, the estimate of 1 l/s/ha is based on the FAO website (FAO, 1992). To calculate the volume of water the seconds of 1 month, i.e. 60 seconds x 60 minutes x 24 hours x 30 days, have to be calculated. This was then multiplied by the average dry months in Zambia per year.

![Figure 28: Calculating irrigated water use using Microsoft Excel®.](image)

What the figures show is that irrigated water usage in just one area uses a vast amount of water, however this is groundwater from a major carbonate aquifer which does recharge over the wet season. Still, years of abstraction can affect baseflow. In order to manage the surface and groundwater components of the system it is essential that estimates of water use form part of the management in order to facilitate decisions on future allocations of water to new developments.
11. CHECKING THE DATA AND GROUND TRUTHING

Remote Sensing (RS) and GIS are without doubt powerful tools for water resource management; however, the data must be checked to ensure that what is interpreted on the screen is what is on the ground. For image classification, it is especially easy to press a button and generate pretty pictures. However, they must be critically evaluated to make sure they are valid, as the adage says, “rubbish in, rubbish out”.

At this stage, the objective is to make a first estimate of irrigated water use over a large area. The assumptions related to water usage and crop type need to be checked. Therefore, extrapolating a single image over months is valid for a first initial estimate but having two or more images spread over the dry season increases the validity of the interpretation. It will also be essential to involve irrigation and agricultural experts so that the water use calculations can be backed up by local experts.

There are some simple ways to carry out checks that can easily be done at this stage, these are:

- Checking that the area calculation makes sense,
- Make sure that only healthy vegetation is selected within fields,
- Visiting a precise location defined by GPS to make sure the ground data is valid.

11.1. CHECKING AREA CALCULATIONS

As we have calculated the area for each polygon verifying the area can simply be done by selecting a centre pivot and checking the area in m². The image below (Figure 29) shows a center pivot in the Mpongwe area. This was selected, then a new shapefile was created, then the attributes of this new shapefile were displayed.

![Figure 29: Checking the area of a pivot circle in QGIS.](image)

The maroon circle represents the pivot and the new shapefile created, the area works out as 1,207,800 m² which sounds like a lot for one pivot, so the question is does it make sense? The first operation is to convert it to hectares by dividing by 10,000 (100 m x 100 m), the results is 120 hectares, which sounds more reasonable, but we now need to check it.

As the object we need to check is a circle we only need to work out the radius. The Google Earth® image below (Figure 30) shows the same area as the QGIS image. In order to measure the radius this can simply be accomplished by using the measure tool, this gives a radius of 614 meters, so in order to calculate the area of a circle we use the following formula:
\[ \pi r^2 = \text{Area of circle, therefore } 3.14 \times 614m \times 614m = 1,183,767m^2 \text{ or } 118 \text{ hectares} \]

The area is thus 118.4 hectares, when this is compared to the QGIS area calculated area of 120.8 hectares the matching is very close.

One issue that you should be aware of is that all projections have some errors. To get from a round earth to a flat map you must have to make some compromises. The main one is shape accuracy or area accuracy.

![Google Earth Ruler](image)

**Figure 30:** Checking the radius of a centre pivot using Google Earth© ruler.

Another way to do this is to take the coordinates of the center of the pivot and to physically measure it. This illustrates an important point and is a key part of any RS project, you have to go out into the field to make sure what you are analyzing on the screen in Lusaka, Mazabuka, Ndola etc. actually is valid.

12. **CONCLUSIONS AND RECOMMENDATIONS**

This methodology is designed to quantify and estimate irrigation water use. The calculation of the water use assumes 8 months of irrigation; to increase the validity of the method at least three Landsat scenes from the dry season should be used. If three scenes are used, then it can be quantified with more accuracy which areas are irrigated throughout the dry season.

Using Google Earth© in combination with the identified irrigated areas can also be used to identify areas of interest. The advantage is that the areas will have a spatial reference, the GPS coordinates can then be used to assist with field verifications.

One essential next step in managing commercial groundwater use will be to digitise and georeference the farm boundaries. This will have multiple advantages, for example the water permit database could become a spatial database. If this is done, then the locations of water permits can be overlaid within QGIS with irrigated areas. If it is observed that there is no permit but irrigation, these locations can then be prioritised by the field staff to investigate why there is no permit.
Identifying commercial use of irrigation can also be used to protect the small and large tributaries, where reports of over-abstraction are received. The length of the river course can easily be viewed in detail without time consuming field investigation. If healthy vegetation is located this can also be compared to previous years to assess if the abstraction is new. In some sensitive areas other large scale uses of water significantly above the 10,000 liters per day threshold can then be identified.

The staff at WARMA have multiple roles with the most urgent jobs obviously taking priority, the result of this is that the skill learnt during the training were not immediately used. It is recommended that a dedicated person is assigned to this role. It is predicted that this will soon give very useful results.

Nevertheless, this methodology can be refined and adapted regarding different crop types and their irrigation needs. This can be done in collaboration with the Ministry of Agriculture personnel who specialise in irrigation.

A dedicated person assigned to RS can also continue digitising features and areas of interest. To digitise all the agricultural field in Zambia it is predicted that all the commercial agricultural field in Zambia could be digitised within one month. Digitising can also continue to include other major water users such as golf courses and mines.

13. REFERENCES


