

Optimizing visibility analysis for visual impact assessment

M Cloete



orcid.org/0000-0003-3604-6169

Dissertation accepted in fulfilment of the requirements for the degree *Master of Science in Geography and Environmental Management* at the North-West University

Supervisor: Dr DP Cilliers

Graduation May 2021

26062232

Acknowledgement

I would like to sincerely thank the following people for their contributions and suggestions that made the completion of this dissertation possible.

- **Dr. DP Cilliers** for his support and guidance throughout the two years in achieving the possible dissertation of my capabilities.
- **My mother** for her support not just through this period but also all the opportunities she gave me throughout my life. Lief vir mamma.
- **Oom Theuns** wil net dankie se Oom vir alles. Oom sal altyd onthou word.
- **Boksombende en Patria** Thanks for all the support and opportunities.

Abstract

Visibility analysis is a standard procedure used within visual impact assessment (VIA) studies to determine visibility significance. VIA is defined as the procedure to identify the visual effects that a specific development might have on the receiving environment. These visual effects are usually identified through visibility analysis using visibility simulations. Visibility simulations are, however, often limited by the complexity of components included in these approaches, which can all lead to errors and inaccurate descriptions of the possible visual effects. Terrain complexity, interpolation algorithm, resolution, digital elevation model and land cover are all components that can affect these simulations in some manner.

With different visibility analysis approaches available and various variables affecting its accuracy, this study aims to identify an optimal visibility analysis approach for use in VIA. Typical visibility analysis approaches were identified from a sample of VIA reports, with viewshed analysis, cumulative viewshed analysis and line-of-sight (LOS) analysis identified as the approaches most often used in VIA. The different approaches were tested and evaluated in three study areas with different levels of terrain complexity and using different types of digital elevation models at various resolutions.

Visibility analysis approaches based on digital surface models (DSM's) showed a significant improvement in accuracy when compared to those based on digital terrain models (DTM's). The combination of construct sight-lines and LOS proved to be the best overall visibility analysis approach across all terrain complexities and elevation models. The typical approach applied in the majority of the sampled VIA reports was found to be the least accurate.

Keywords: Cumulative viewshed analysis, Digital elevation model, Environmental impact assessment, Line-of-sight analysis, Resolution, Terrain complexity, Viewshed analysis, Visibility analysis approaches, Visual impact assessment,

Table of Content

Acknowledgement.....	i
Abstract.....	ii
List of figures	v
List of tables.....	viii
List of abbreviations	ix
Chapter 1: Introduction.....	1
Chapter 2: Literature review	4
2.1. Visibility analysis.....	4
2.1.1. Defining visibility analysis.....	4
2.1.2. Visibility analysis data requirements	6
2.1.3. Factors affecting visibility analysis accuracy	10
2.1.4. Limitations of visibility analysis.....	14
2.2. Visual impact assessment.....	15
2.2.1. Environmental impact assessment.....	16
2.2.2. The role of specialist studies in EIA	17
2.2.3. Visual impact assessment as a specialist study in EIA.....	18
2.3. Visibility analysis in visual impact assessment.....	20
2.3.1. Line-of-sight analysis use in visual impact assessment.....	20
2.3.2. Viewshed analysis use in visual impact assessment.....	20
2.3.3. Cumulative viewshed analysis use in visual impact assessment.....	21
2.3.4. Fuzzy viewshed analysis use in visual impact assessment.....	21
2.3.5. Higuchi viewshed analysis use in visual impact assessment.....	21
2.4. Literature conclusion.....	22
Chapter 3: Methodology.....	23
3.1. Explore current methodological approaches for visibility analysis used in VIA	23
3.1.1. Report sampling process (Objective 1 - Phase 1)	23
3.1.2. Documentation analysis (Objective 1 - Phase 2).....	24

3.2. Objective 2: Test and evaluate different approaches to visibility analysis across different terrain complexities and using different variables.....	25
3.2.1. Identifying suitable study areas (Objective 2 - Phase 1).....	26
3.2.2. Data collection (Objective 2 - Phase 2)	40
3.2.3. Creating and evaluating Digital Elevation Models (Objective 2 - Phase 3)	45
3.2.4. Testing visibility analysis approaches (Objective 2 - Phase 4)	49
3.3. Objective 3: Determine an optimal visibility analysis approach for use in VIA.....	55
3.3.1. Accuracy assessment through cross-validation.....	56
Chapter 4: Results	57
4.1. Current methodological approaches used for visibility analysis in VIA (Objective 1)	57
4.2. Results from identified visibility analysis simulations (Objective 2)	59
4.2.1. Digital elevation models	59
4.2.2. Visibility analysis results	67
4.3. Comparison of visibility analysis techniques (Objectives 3).....	85
4.3.1. Accuracy assessment of viewshed analysis.....	86
4.3.2. Accuracy assessment of cumulative viewshed analysis.....	88
4.3.3. Accuracy assessment of line-of-sight analysis	92
4.3.4. Summary of accuracy assessment of all visibility analysis techniques	94
Chapter 5: Conclusion.....	100
References	102
Appendix 1.....	116
Appendix 2.....	126
Appendix 3.....	139
Appendix 4.....	142

List of figures

Figure 1: Cumulative visibility analysis incorporating different height values (Rød & Van der Meer, 2009)	6
Figure 2: DEM and TIN comparison (Zhao et al., 2013)	7
Figure 3: Visibility comparison between DTM and DSM (Robert, 2018)	9
Figure 4: Observer placement in DTM and DSM (Bartie et al., 2011).....	14
Figure 5: Methodological procedure of Objective 1	23
Figure 6: Reports sampling methodological procedure.....	24
Figure 7: Documentation analysis methodological procedure.....	25
Figure 8: Methodological procedure of Objective 2	26
Figure 9: Identifying suitable study areas methodological procedure.....	26
Figure 10: Compound terrain complexity index methodological procedure.....	28
Figure 11: Topographical position index methodological procedure	29
Figure 12: ModelBuilder diagram of Topographic position index procedure	30
Figure 13: Compound terrain complexity index values of the three study areas	31
Figure 14: Slope classification of TPI values for all three-study area.....	33
Figure 15: Graph illustrating the landscape class coverage of each study area.....	34
Figure 16: Locality map of identified study areas.....	35
Figure 17: Grootpan study area	36
Figure 18: Photograph of the Grootpan silo.....	36
Figure 19: Syferbult study area	37
Figure 20: Photograph of the Syferbult silo	38
Figure 21: Swartruggens study area	39
Figure 22: Photograph of the Swartruggens silo.....	39
Figure 23: Procedure diagram of the methodology followed to collect data	40
Figure 24: Procedure diagram of the methodology followed to create DEM's.....	45
Figure 25: Procedure diagram of the methodology followed to simulate visibility analysis techniques	49
Figure 26: Viewshed analysis methodological procedure	50
Figure 27: Procedure followed to generated silo boundary points for visibility analysis simulations.....	51
Figure 28: Cumulative viewshed analysis methodological procedure	52
Figure 29: LOS analysis methodological procedure	54
Figure 30: Procedure diagram of the methodology followed to assess visibility analysis simulations.....	56
Figure 31: Accuracy assessment methodological procedure.....	56

Figure 32: Digital terrain models of the Grootpan study area at the different resolutions	60
Figure 33: Digital terrain models of the Syferbult study area at the different resolutions	61
Figure 34: Digital terrain models of the Swartruggens study area at the different resolutions	62
Figure 35: Graph representing the determined RMSE values of each digital terrain model .	63
Figure 36: Digital surface models of the Grootpan study area at the different resolutions ...	65
Figure 37: Digital surface models of the Syferbult study area at the different resolutions	66
Figure 38: Digital surface models of the Swartruggens study area at the different resolutions	67
Figure 39: Viewshed analysis results of the Grootpan study area across the four DTM's	68
Figure 40: Viewshed analysis results of the Syferbult study area across the four DTM's	69
Figure 41: Viewshed analysis results of the Swartruggens study area across the four DTM's	70
Figure 42: Viewshed analysis results of the Grootpan study area across the four DSM's	71
Figure 43: Viewshed analysis results of the Syferbult study area across the four DSM's	72
Figure 44: Viewshed analysis results of the Swartruggens study area across the four DSM's	73
Figure 45: Cumulative viewshed analysis results of the Grootpan study area across the four DTM's	74
Figure 46: Cumulative viewshed analysis results of the Syferbult study area across the four DTM's	75
Figure 47: Cumulative viewshed analysis results of the Swartruggens study area across the four DTM's	76
Figure 48: Cumulative viewshed analysis results of the Grootpan study area across the four DSM's	77
Figure 49: Cumulative viewshed analysis results of the Syferbult study area across the four DSM's	78
Figure 50: Cumulative viewshed analysis results of the Swartruggens study area across the four DSM's	79
Figure 51: Line-of-sight analysis results of the Grootpan study area across the four DTM's	80
Figure 52: Line-of-sight analysis results of the Syferbult study area across the four DTM's.	81
Figure 53: Line-of-sight analysis results of the Swartruggens study area across the four DTM's	82
Figure 54: Line-of-sight analysis results of the Grootpan study area across the four DSM's	83
Figure 55: Line-of-sight analysis results of the Syferbult study area across the four DSM's	84
Figure 56: Line-of-sight analysis results of the Swartruggens study area across the four DSM's	85

Figure 57: Accuracy assessment of viewshed analysis based on DTM's	87
Figure 58: Accuracy assessment of viewshed analysis based on DSM's	88
Figure 59: Accuracy assessment of cumulative viewshed analysis based on DTM's.....	89
Figure 60: Accuracy assessment of cumulative viewshed analysis based on DTM's in terms of the degree of visibility.....	90
Figure 61: Accuracy assessment of cumulative viewshed analysis based on DSM's	91
Figure 62: Accuracy assessment of cumulative viewshed analysis based on DSM's in terms of the degree of visibility.....	92
Figure 63: Accuracy assessment of LOS analysis based on DTM's	93
Figure 64: Accuracy assessment of LOS analysis based on DSM's.....	94
Figure 65: Line graph of Grootpan visibility analysis simulation accuracy.....	95
Figure 66: Line graph of Syferbult visibility analysis accuracy	95
Figure 67: Line graph of Swartruggens visibility analysis simulation accuracy	96

List of tables

Table 1: Slope position classification classes.....	30
Table 2: Compound terrain complexity index values of the three study areas	32
Table 3: Slope classification of Topographic position index values for all three study areas	33
Table 4: Elevation data of each study area	41
Table 5: Land cover classification and height values.....	44
Table 6: Data used to determine the resolution size.....	47
Table 7: Resolution range of each study area	47
Table 8: Visibility analysis simulations with the associated variables.....	50
Table 9: Cumulative viewshed OFFSETA values	53
Table 10: Document analysis results obtained from the VIA reports.....	57
Table 11: Root means square error and test points.....	63
Table 12: Summary of accuracy assessment result for all visibility analysis simulations	96
Table 13: Grootpan observation points and description.....	116
Table 14: Syferbult observation points and descriptions.....	119
Table 15: Swartruggens observation points and descriptions.....	122

List of abbreviations

BA	Basic assessment
CTCI	Compound terrain complexity index
DEM	Digital elevation model
DSM	Digital surface model
DTM	Digital terrain model
EIA	Environmental impact assessment
GIS	Geographic information systems
IDW	Inverse-distance weighting
KOPs	Key observation points
LOS	Line-of-sight
NEMA	National environmental management act
NGI	National Geo-spatial Information
RMSE	Root means square error
S&EIR	Scoping and environmental impact report
SANLC	South African National Land Cover
T2R	Topo to raster
TCI	Terrain complexity index
TIN	Triangulated irregular network
VIA	Visual impact assessment
WGS	World Geodetic System

Chapter 1: Introduction

Different landscape assessment methodologies have been designed over the last few decades to determine and subsequently mitigate the visual impacts of a project on its surroundings (Palmer, 1981; Smardon & Hunter, 1983). The earliest documented computerised technique used to assess visual impact was developed by R. Burton Litton in 1973, incorporating landscape control points and computerised mapping techniques (Jones *et al.*, 1975; Litton, 1973). The early techniques later evolved into techniques incorporating visual contrast to determine an object's visual impact (Smardon & Hunter, 1983; Zube *et al.*, 1982). Its physical and aesthetic attributes define the visual contrast of an object, therefore, each of these visual elements provides computer-based methods with an approach to analyse an object's visual contrast in the surrounding landscape (Felleman, 1982; Orland, 1988). The concept of analysing an object's visual contrast in its surroundings contributed to the establishment of the assessment procedure now known as visual impact assessment (VIA) – a procedure dating back over a few decades with different approaches developed over time to determine a proposed project's visual impact within its setting (Hernández *et al.*, 2004; Pullar & Tidey, 2001).

Mitigating and managing visual impacts determined through VIA plays a critical role in maintaining a well-planned environment (Manchado *et al.*, 2019; Samavatekbatan *et al.*, 2016). Notably, maintaining a well-planned environment is a goal of environmental impact assessment (EIA), which involves a systematic procedure of identifying and managing possible impacts (including visual impacts) related to a proposed development (Münster, 2005; Rodrigues *et al.*, 2010). The systematic EIA procedure involves the consideration of possible project amendments aimed at reducing or altogether avoiding negative impacts through mitigation measures or the implementation of alternatives (Rodrigues *et al.*, 2010; Taheri *et al.*, 2014). Maintaining a well-planned environment through VIA as a component of EIA involves the use of specific tools and approaches developed to assess the visual impacts of a proposed development (Chamberlain & Meitner, 2013).

Different tools and approaches have subsequently been developed over the years to assist in this task. The visibility analysis approach used can differ in terms of the required information necessary for the VIA report, or be influenced by the visual and landscape elements included within the approach (Pardo García & Mérida Rodríguez, 2015). The required information needed to assess visual impacts in a VIA report therefore sets up the approach for visibility analysis and defines how results are presented (Bartie *et al.*, 2010; Nutsford *et al.*, 2015). The visibility analysis approach can determine visibility through, amongst others, viewshed analysis – providing a simple binary code presenting visibility as either visible or not visible

(Chamberlain & Meitner, 2013; Nutsford *et al.*, 2015) – or through cumulative viewshed analysis, where visibility is represented in a non-binary manner with either a focus on the number of objects visible or the amount of an object that is visible (Garnero & Fabrizio, 2015). Another non-binary approach incorporates a distance decay function to determine the significance of visibility over an increase in distance known as fuzzy viewshed analysis (Murphy *et al.*, 2018). Visibility analysis not only provides different approaches to determine the visibility of an object within its setting, but can include different variables as part of the versatility of visibility analysis approaches (Sullivan & Meyer, 2014).

The manner in which the topographical characteristics of the setting is incorporated as a variable in visibility analysis has a significant effect on how visibility is determined (Kantner & Hobgood, 2016; Klouček *et al.*, 2015). These characteristics are mostly incorporated in visibility analysis through the use of a digital elevation model (DEM) (Bartie *et al.*, 2010; Qiang *et al.*, 2019). DEM's are divided into two categories, which are, digital terrain models (DTMs) representing only the bare surface of the terrain, and digital surface models (DSMs) where land cover is included as part of the representation (Qiang *et al.*, 2019; Robert, 2018).

The type of DEM used influences the accuracy of the visibility analysis approach, specifically as visibility tends to be overestimated when based on DTM's that excludes land cover and its screening effects (Danese *et al.*, 2011; Sullivan & Meyer, 2014; Verutes *et al.*, 2014). This is, however, not the only contributing factor towards accuracy, with factors such as the interpolation algorithm, and resolution size used to generate the DEM, also having an influence (Anile *et al.*, 2003; Fisher & Tate, 2006).

According to Fisher and Tate (2006), there is no optimal interpolation algorithm to generate a DEM in a precise manner, as it is not only influenced by the data accuracy and quality, but also the terrain complexity. Terrain complexity is a representation of a surface's turbulence and complexity defined through the roughness, relief and rugosity of the surface (Huaxing, 2008; Zhou *et al.*, 2006). The interpolation algorithm used to generate a DEM should therefore consider the relationship between resolution size and terrain complexity (Fisher & Tate, 2006; Ziadat, 2007), as coarser-resolution sizes may be suitable for areas with minimal terrain complexity while the same resolution size would misinterpret an area with significant topographical features present throughout the area (Fisher & Tate, 2006; Smith *et al.*, 2006). Generating a DEM at a finer resolution may not always be possible due to the elevation data quality, as exceeding its capability will produce artefacts within the DEM (Hirt, 2018). Artefacts are defined as artificial features present in DEM's, for example, spikes, steps, sinks and if present provides one of the problematic imperfections within DEM's (Hirt, 2018).

Different visibility analysis approaches relying on different input variables have been developed over the last few decades to assess visual impacts as part of VIA studies and support the maintenance of a well-planned environment. Currently, different visibility analysis procedures are used to determine the visual extent of an object within its setting and provide necessary information towards the evaluation of visual impacts in VIA studies. The versatility of visibility analysis approaches provides some problematic scenarios, for example, different DEM's provides different representations of visibility. Additionally, the algorithm, resolution size and terrain complexity all affect the accuracy of the DEM, which in turn affect the accuracy of visibility analysis simulations. Generating an understanding of different visibility analysis approaches, and how they are affected by the DEM's, resolution and terrain complexity, is required to optimise the procedure for VIA.

The study, therefore **aims to determine an optimal approach for visibility analysis for use within visual impact assessment**. The following three objectives were determined to achieve the aim of the study:

- Explore current methodological approaches for visibility analysis used in VIA.
- Test and evaluate different approaches to visibility analysis across different terrain complexities and using different variables.
- Determine an optimal visibility analysis approach for use in VIA.

Key concepts pertaining to visibility analysis and VIA, as well as the role of visibility analysis within VIA, are discussed in Chapter 2. This is followed by a description of the methodological approach applied in the study (Chapter 3). The findings of the study are presented in Chapter 4, whereafter conclusions are presented (Chapter 5).

Chapter 2: Literature review

Chapter 2 deals with several concepts central to the study. The concept of visibility analysis is first explored and various approaches, data requirements, accuracy issues, and limitations, discussed. The second concept explored as part of this chapter is the specialist dimension of EIA of which VIA is a component. Finally, some of the visibility analysis approaches often used in VIA are discussed.

2.1. Visibility analysis

As discussed in Chapter 1, the use of computer-based methods to assess visual impacts can be traced back as far as 1973. Since then, new techniques have been developed focussing on the visual elements of the object, as well as the influence of landscape characteristics (Felleman, 1982; Orland, 1988). GIS currently support most of the computer-based approaches used to assess visual impacts (Chamberlain & Meitner, 2013), specifically through its spatial analysis capabilities (Domingo-Santos *et al.*, 2011). Visibility analysis is the specific spatial analysis tool with the capability to resolve spatial analysis problems related to visibility (Chamberlain & Meitner, 2013; Kim *et al.*, 2004; Zhou *et al.*, 2006).

2.1.1. Defining visibility analysis

Visibility analysis determines visibility on the principle of line-of-sight (LOS). For example, a straight line is generated between two points, and if at any point the line is obstructed by the surface, the target point is deemed not visible (Feng *et al.*, 2015; Verutes *et al.*, 2014; Zhao *et al.*, 2013). The two points consist of an observer defined by a specific point in the setting and a target object representing the point for which visibility is determined (Verutes *et al.*, 2014). The area determined as visible through visibility analysis is known as a viewshed and presents the area determined as visible within the setting from the point of which visibility was determined (Feng *et al.*, 2015; Qiang *et al.*, 2019).

Chapter 1 stated that different visibility analysis approaches had been developed over the years to provide adaptability towards determining visibility, for instance, to consider the perspective from which visibility is determined (Pardo García & Mérida Rodríguez, 2015) and the manner in which visibility analysis is presented (Bartie *et al.*, 2010; Nutsford *et al.*, 2015). The perspective from which visibility is determined can either be determined from the observer's perspective or the target object's perspective (Pardo García & Mérida Rodríguez, 2015). The second form of adaptability involves the manner in which the visibility results are portrayed, for example, a simple binary code (Chamberlain & Meitner, 2013; Nutsford *et al.*, 2015), vs. a non-binary code (Bartie *et al.*, 2010; Domingo-Santos *et al.*, 2011; Llobera, 2007).

Visibility analysis, therefore, offers a variety of different approaches to determine the visibility between an observer and a target object. These approaches and the manner in which they are mostly applied are now discussed in more detail.

2.1.1.1. *Simple binary visibility analysis*

The first visibility analysis approach discussed determines whether observers or target objects are either visible or not visible (Gillings, 2015; Pardo García & Mérida Rodríguez, 2015). The approach provides a simple binary result representing visible areas as a value of one and areas not visible as a value of zero (Chamberlain & Meitner, 2013; Nutsford *et al.*, 2015). Determining an optimal location for a telecommunication tower is one of the applications where a simple binary approach is applicable, for instance, different locations can be compared to determine a location providing the largest area of coverage (Miller *et al.*, 2011). The method of classifying visibility in a simple binary manner may be the most common approach (Bennett & Armstrong, 2010), but does not provide detailed results (Garnero & Fabrizio, 2015; Murphy *et al.*, 2018), a shortcoming partially overcome by cumulative visibility analysis (Danese *et al.*, 2011; Möller, 2006).

2.1.1.2. *Cumulative visibility analysis approach*

The cumulative visibility analysis approach is a more comprehensive approach to visibility analysis, producing results that are both non-binary and more detailed than those of regular visibility analysis (Llobera, 2003; Möller, 2006). Cumulative visibility analysis offers two different approaches to define visibility results; either by determining visibility for multiple target objects (Llobera, 2003; Rød & Van der Meer, 2009) or incorporating multiple height values to the same target object (Rød & Van der Meer, 2009). The first approach provides a non-binary visibility result in which the total number of target objects are visible from a specific area or point, for example, results may only indicate that two out of four target objects were visible within a particular area or from a specific observation point within its setting (Llobera, 2003; Möller, 2006). The approach presents visibility as values ranging from zero for areas not visible to a value equalling the highest number of target objects visible from a specific observation point (Rød & Van der Meer, 2009).

The second approach reruns visibility analysis for the same target object, but at different height values (Figure 1), therefore generating multiple visibility layers for the same object (Rød & Van der Meer, 2009). All visibility layers are combined into one final result layer showing the amount of a target object visible from different observation points (Rød & Van der Meer, 2009). One application in which cumulative visibility analysis is often used is to determine the visual impact of wind turbines and subsequently to optimise their placement (Molnarova *et al.*, 2012).



Figure 1: Cumulative visibility analysis incorporating different height values (Rød & Van der Meer, 2009)

2.1.1.3. Fuzzy visibility analysis approach

The third visibility analysis approach considers the significance of visibility decreasing over an increase in distance between the observer and the target object. This is achieved through a distance decay function incorporated into the approach (Murphy *et al.*, 2018). The visual significance is displayed in a non-binary manner through a range of values ranging between zero and one, where values closer to one has a greater visual significance than values closer to zero (Llobera, 2007; Ogburn, 2006). The approach provides some adaptability in terms of the incorporation of distance decay, for example, the distance decay function can potentially be used to either simulate visibility over a distance or to simulate visibility through vegetation (Llobera, 2007; Riggs & Dean, 2007).

In addition to the different approaches discussed above, the variables used must be considered. These variables will now be dealt with in terms of data requirements for visibility analysis.

2.1.2. Visibility analysis data requirements

Visibility analysis relies on two key datasets; (1) an elevation model and (2) observation properties (Fisher & Tate, 2006; Miller *et al.*, 2011). The first represents the terrain of the study area and is the foundation for any visibility analysis simulation (Fisher & Tate, 2006; Miller *et al.*, 2011). The second relates to the information required to represent the observer and the target object in the analysis (Danese *et al.*, 2011; Sullivan & Meyer, 2014). Elevation models are first discussed with a specific focus on different types of elevation models and how they are often used in visibility analysis. This is followed by a discussion on the role of observer properties and the target object in visibility analysis.

2.1.2.1. Elevation models in visibility analysis

Visibility can be determined based either on a Triangulated Irregular Network (TIN) or a Digital Elevation Model (DEM) (Zhao *et al.*, 2013). A TIN represents elevation values on a vector platform through planar and irregular triangular formations known as facets representing an elevation value at each of the facet nodes as illustrated in Figure 2 (Zhao *et al.*, 2013). A DEM, on the other hand, presents elevation values in a grid or raster consisting of rectangular cells of the same size and for which elevation values are allocated (Figure 2) (Zhao *et al.*, 2013).

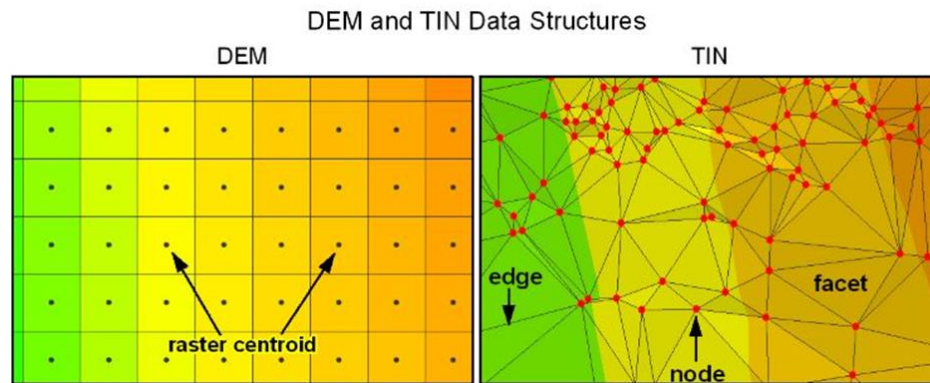


Figure 2: DEM and TIN comparison (Zhao *et al.*, 2013)

TIN's and DEM's have often been compared against one another to determine which is better to use for visibility analysis (Germino *et al.*, 2001; Riggs & Dean, 2007). The decision between TIN's and DEM's is ultimately dependent on the amount of elevation data available in the area as well as the characteristics of the terrain (Chamberlain & Meitner, 2013). According to Evans *et al.* (2001), TIN's provide a better representation of a terrain's surface when faced with a limited amount of elevation data available, while DEM's are more suitable when higher quantities of elevation data are available. This is because a higher quantity of elevation data in an area increases the level of detail at which DEM's can be generated (Evans *et al.*, 2001; Kidner *et al.*, 2001).

TIN's offer an advantage over DEM's as they are able to present peaks and valleys in a more detailed and accurate manner than DEM's (Kidner *et al.*, 2001; Riggs & Dean, 2007). This is because the nodes (e.g., a mountain peak) can be located anywhere in a TIN model, while in DEM's they are limited to the resolution size at which the model was generated. The capability of TIN's to take full advantage of elevation data is, however, limited to the completeness of an elevation dataset, e.g. critical points representing peaks and valleys must be present within the elevation dataset (Kidner *et al.*, 2001; Riggs & Dean, 2007).

DEM's provide a more simplistic manner in which visibility is determined compared to TIN's, for instance, visibility for DEM's are determined from the centre of each cell while TIN's provide four different criteria to determine the visibility of each facet (Maloy & Dean, 2001). Both DEM's

and TIN's are subject to errors and limitations regarding their representations of reality (Riggs & Dean, 2007; Sander & Manson, 2007), but in the context of visibility analysis DEM's are preferred over TIN's as comparisons between the two models revealed higher accuracy when using DEM's (Riggs & Dean, 2007; Sander & Manson, 2007; Zhao *et al.*, 2013). Riggs and Dean (2007) stated that visibility analysis based on DEM's exceed TIN's in its resemblance of field surveyed visibility analysis. DEM's have, in general, become the widely accepted method for presenting elevation data (Chaplot *et al.*, 2006; Sander & Manson, 2007) and also allows for elevation data to be interpolated at different resolutions sizes, something not achievable using TIN.

DEM's can be classified into two categories, namely, digital terrain models (DTM's) and digital surface models (DSM's). As discussed earlier DTMs represent the terrain void of surface features while in DSMs surface features are incorporated (Qiang *et al.*, 2019). The two categories of DEM's are discussed in more detail in the following section.

2.1.2.2. *Digital terrain models (DTM's) and digital surface models (DSM's)*

DTM's represents the terrain of an area as only the bare surface elevation values of the terrain, while DSM's incorporates the height values of surface features (Qiang *et al.*, 2019). DTM's are more commonly used than DSM's as they only require elevation data in the form of either point data, or point and contour data, to be generated – depending on the interpolation algorithm (Klouček *et al.*, 2015). DSM's, on the other hand, are more complicated as they include surface features which height values usually need to be supplemented from other sources (Qiang *et al.*, 2019). Surface features in DSM's include both man-made structures such as buildings, and natural land cover, such as vegetation in its representation of the terrain (Robert, 2018). Additionally, the inclusion of surface features in visibility analysis influence the total visible areas as it incorporates more features capable of screening an object (Robert, 2018).

Figure 3 illustrates the difference between a visibility analysis conducted with a DTM versus a DSM. As illustrated, when using a DTM a much larger area of visibility is generated than when using a DSM. This is because surface features contained in a DSM increase the screening capability of the area (Bartie *et al.*, 2010; Robert, 2018). As surface features have a significant effect on visibility analysis results, it is important to compare the results from analyses using both DTM's and DSM's in this research. Observer properties and the target object as data input requirements for visibility analysis is discussed next.

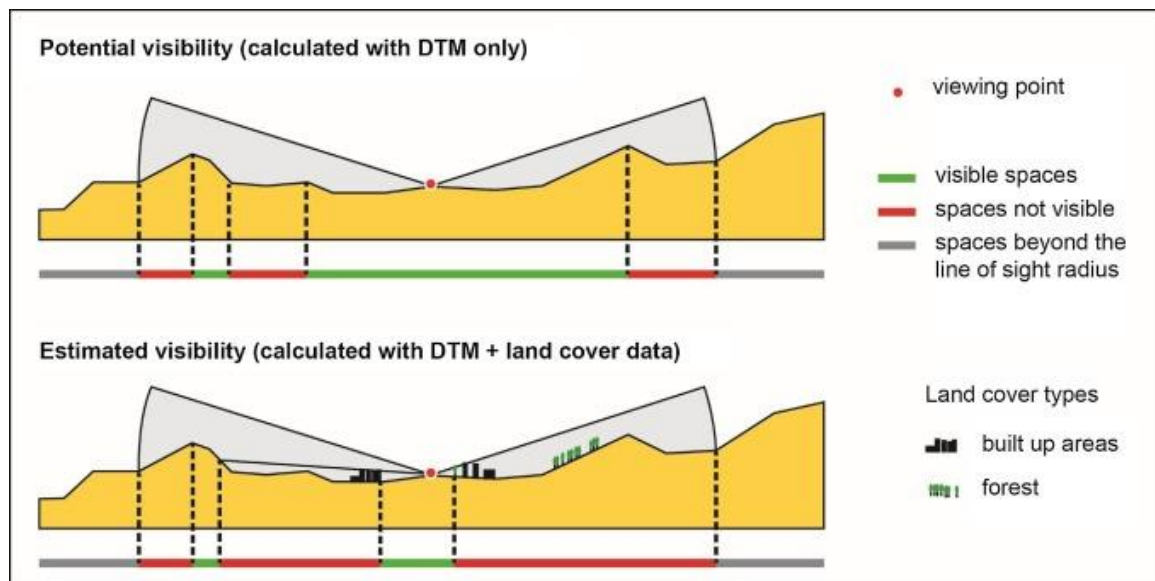


Figure 3: Visibility comparison between DTM and DSM (Robert, 2018)

2.1.2.3. Observation points and the target object in visibility analysis

Observer point/s and target object/s form the basis for any visibility analysis as visibility is determined between these two variables (Gillings, 2015; Pardo García & Mérida Rodríguez, 2015). Each variable has its own set of properties that can significantly influence the visibility analysis (Ervin & Steinitz, 2003; Ogburn, 2006), and it is, therefore, important to discuss both in detail.

The target object's characteristics are defined by Samavatekbatan *et al.* (2016) as a factor that significantly influences visibility analysis results. For instance, the object size (height and width) contributes to visibility analysis results, as an object size will affect the distance at which it can be recognised (Samavatekbatan *et al.*, 2016). In terms of visibility analysis, it is mainly the height of the object that would be considered as it would determine at which point the object would disappear under the horizon due to the curvature of the earth (Danese *et al.*, 2011; Sullivan & Meyer, 2014).

Observers are seen in visibility analysis as the receptors from which perspective visibility of a target object is determined (Kidner *et al.*, 2001; Ogburn, 2006) and can, therefore, be defined as the receivers of the visual impact. Height values are assigned to observers to ensure that, for example, visibility is determined from eye level (Ogburn, 2006; Rød & Van der Meer, 2009). Determining whether a target object is visible from an observation point is not only dependent on the results obtained from the visibility analysis, but also on the visual acuity of the observer (Danese *et al.*, 2011). Visual acuity is defined as the ability of an observer to discern an object (Samavatekbatan *et al.*, 2016) and can be classified into three classes: detection acuity (the

ability of an observer to detect an object); resolution acuity (the ability of the observer to distinguish detailed elements of an object); and recognition acuity (the ability of an observer to identify and recognise an object) (Ogburn, 2006; Rodrigues *et al.*, 2010). Visibility analysis can include visual acuity in its simulations as a method to limit the distance at which visibility is determined or define multiple distances to present the different forms of visual acuity (Sullivan & Meyer, 2014). Visual acuity is, however, most often considered prior to the visibility analysis through ground-truthing and as an approach to further refine the visibility analysis results.

Other factors that can influence visibility at the observation point include environmental conditions such as atmospheric extinction (visibility is affected by the scattering and absorption of light particles) (Samavatekbatan *et al.*, 2016) and the curvature of the earth (Sullivan & Meyer, 2014). Elevation models, observation points, and target objects provide the basis on which visibility analysis is determined. The factors affecting visibility analysis accuracy – and which are related to these inputs – are discussed in the next section.

2.1.3. Factors affecting visibility analysis accuracy

Visibility analysis accuracy is affected by the DEM in terms of the interpolation algorithm used, resolution size used, terrain complexity of the area, and the surface features included in the DEM (Fisher & Tate, 2006; Hengl, 2006; Kidner *et al.*, 2001). The interpolation algorithm is the foundation for creating a DEM and is used to predict values for unknown areas by considering known values and their spatial relationship with one another (Li & Heap, 2014). The second factor influencing accuracy is the resolution size which is defined as the cell size of the DEM (Hengl, 2006; Riggs & Dean, 2007), while terrain complexity is defined as the terrain's roughness, relief and rugosity. The final factor relates to the manner and extent to which surface features such as buildings and vegetation cover are represented in the DEM. The most common interpolation algorithms are discussed first, to determine the algorithm most suited for use when generating DEM's. This is followed by discussions on how resolution size and terrain complexity may affect DEM accuracy after which the effects of the inclusion or exclusion of surface features in DEM's is discussed.

2.1.3.1. *Effect of interpolation algorithm choice on visibility analysis*

As mentioned earlier, there are multiple interpolation algorithms available for use to produce a DEM from elevation data (Chaplot *et al.*, 2006; Childs, 2004). It is, however, important to consider how each algorithm interpolates elevation data as each follows a different approach

(Anile *et al.*, 2003; Fisher & Tate, 2006). Interpolation algorithms are affected by the amount of elevation data available to predict elevation values for unsampled areas. Interpolation algorithms essentially rely on spatial relationships between known values to predict unknown values (Fisher & Tate, 2006; Riggs & Dean, 2007). According to Fisher and Tate (2006), there is no optimal interpolation method for representing terrain data in the most precise manner as the success of the algorithm depends, amongst other things, on the nature of the terrain. Six of the most commonly used interpolation algorithms are Kriging, Inverse-distance weighting (IDW), Natural neighbour, Trend, Spline, and Topo to raster (T2R). Each algorithm is briefly discussed with specific reference to their suitability for creating DEM's.

Kriging predicts unknown values on a surface by calculating the spatial correlation between known points based on their distance and direction (Childs, 2004; Fisher & Tate, 2006). IDW, on the other hand, relies on a function of the weighted average of the distance between points of known and unknown values (Razak *et al.*, 2013). Natural neighbour predicts unknown values through a geometric relationship and weighted value determined by an overlap of neighbouring Voronoi polygons (Razak *et al.*, 2013). In comparison, the Trend interpolation algorithm generates a surface representing statistical trends within the data (Childs, 2004; Li & Heap, 2014) while the Spline interpolation algorithm predicts unknown values through a mathematical equation aimed at creating a 'smooth' surface (Childs, 2004; Fisher & Tate, 2006). Topo to Raster (T2R) is an interpolation algorithm developed specifically to create hydrologically correct surfaces and is based on the ANUDEM algorithm (Razak *et al.*, 2013). These six algorithms are now compared to determine the ideal algorithm for use when creating DEM's.

The Natural neighbour, Trends and Spline interpolation algorithms all provide smoothed out surfaces, which results in topographical features such as ridges and valleys to be smoothed out and misinterpreted (Godone & Garnero, 2013; Razak *et al.*, 2013). Spline interpolation is, therefore, more commonly used to generate surfaces representing temperature values (Childs, 2004), while the Trend interpolation algorithm is more suitable to identify trends within the data than generate a DEM (Li & Heap, 2014). The Kriging interpolation algorithm is not often used to generate DEM's (Miller *et al.*, 2011), but instead as an interpolation algorithm to predict a surface for data with limited values such as soil and geological mapping (Childs, 2004; Lu & Wong, 2008). IDW has been found to be even less suitable for the creation of DEM's than Kriging, as it generally overpredicts unknown elevation values (Kienzle, 2003; Lockhart, 2009). Of the discussed algorithms, T2R is reported as the most capable to accurately interpolate elevation data to represent the terrain (Rishikeshan *et al.*, 2014). According to Childs (2004) and Razak *et al.* (2013) the algorithm can present sudden changes within the elevation data by identifying pits and saddles. Additionally, the algorithm can

incorporate both point and contour elevation data to generate a DEM (Klouček *et al.*, 2015). Rishikeshan *et al.* (2014) evaluated the accuracy of Kriging, IDW, Natural neighbour and T2R in terms of terrain modelling. Although the study regarded IDW and Natural neighbour as suitable options to illustrate smooth surfaces, T2R succeeded in more complex areas and was, therefore, found to be most suited for use in DEM's (Rishikeshan *et al.*, 2014). T2R is subsequently used in this study.

2.1.3.2. Resolution size effect on visibility analysis accuracy

The resolution size at which a DEM is generated is an important factor in terms of providing an accurate elevation model for visibility analysis (Wróżyński *et al.*, 2016). Finer resolution sizes provide DEM's with the capability to generate a more detailed representation of a surface (Hengl, 2006; Riggs & Dean, 2007), although this may not always be possible as the quality of the data in terms of the amount may not always support finer resolution sizes (Kienzle, 2003; Sander & Manson, 2007). Generating DEM's at finer resolution sizes than the capability of the elevation data produces artefacts within the surface (Hengl, 2006), and as stated in Chapter 1, artefacts produce problematic imperfections in DEM's. Producing a DEM at larger resolution sizes may be suitable in some areas with smoother terrain features, but result in an elevation model misinterpreting terrain features such as valleys and peaks in more complex areas (Smith *et al.*, 2006; Thompson *et al.*, 2001).

Determining the optimal resolution size beneficial to terrain modelling is a problematic area, particularly due to the relationship between terrain complexity and data quality (Hengl, 2006; Kienzle, 2003). Hengl (2006) identifies three classifications for a resolution range to interpolate elevation data into legible resolutions usable to generate DEM's accurately. The first classification is the coarsest legible grid resolution, which is the coarsest at which elevation data can be interpolated without compromising on accuracy through the misinterpretation of topographical features in the area (Hengl, 2006). The finest legible grid resolution provides the second classification of resolution range, particularly the resolution size is the smallest that can represent 95% of the topographical features of a terrain (Hengl, 2006). The last classification is the recommended grid resolution, which is the optimal resolution size defined by the median between the two previous classifications (Hengl, 2006).

Visibility analysis simulations are affected by the resolution of a DEM (Wróżyński *et al.*, 2016) as modelling surfaces with larger resolution sizes affects terrain features. For example, steeper gradients are illustrated as flatter areas while lower slopes are illustrated as steeper areas (Kienzle, 2003; Smith *et al.*, 2006). Overall, the resolution size at which elevation data is interpolated plays a significant role in the accuracy of visibility analysis simulations,

specifically as the resolution size determines the accuracy at which the area's terrain complexity can be represented.

2.1.3.3. *Terrain complexity effect on visibility analysis accuracy*

The third factor affecting visibility analysis accuracy is landscape complexity (Fisher & Tate, 2006; Sander & Manson, 2007). An area's terrain complexity reflects the number of topographical features with the ability of screening visibility (Ogburn, 2006; Ziadat, 2007). This means that areas with a higher complexity will include more topographical features that could have a screening effect (Ogburn, 2006; Ziadat, 2007). The resolution size of the DEM also affects the extent to which terrain complexity is represented (Kienzle, 2003; Ziadat, 2007). Higher terrain complexities require finer resolution sizes than areas with a low terrain complexity, as more changes in elevation require finer resolutions to accurately present topographical features in DEM's (Hengl, 2006; Ziadat, 2007). As a result, areas with higher terrain complexities are more sensitive to resolution changes than areas with minimal complexity. By considering the effects that resolution size has on the accuracy of presenting terrain complexity, it is important to understand how they influence each other. In addition to the screening effect of topographical features, the contribution of landscape features to screening must be considered.

2.1.3.4. *Surface features' effect on visibility analysis*

Surface features enhance the screening effect already caused by topographical features (Murphy *et al.*, 2018). As defined in Chapter 2, surface features include both man-made structures and natural land cover. The inclusion of surface features in DEM's allow visibility analysis approaches to model the screening effects of features such as buildings, trees and shrubs (Bartie *et al.*, 2010).

The manner in which surface features are incorporated into DEM's should, however, be considered (Kidner *et al.*, 2001; Sander & Manson, 2007) as surface features will affect visibility in different ways. For example, vegetation will not always completely screen an object (Bartie *et al.*, 2011; Llobera, 2007) while a building will. Adapting visibility analysis simulations to include the concept of partial screening becomes a difficult procedure as vegetation density is affected by the seasonal changes and type of vegetation (Sullivan & Meyer, 2014). Another consideration when dealing with surface features is that of false positioning (Bartie *et al.*, 2011).

False positioning is where the observer point is located on top of vegetation (on the DSM) were in reality, the observer should be located at ground level (Bartie *et al.*, 2011). This creates a misinterpretation of visibility as the observer indicates an area as visible, but in reality is obstructed by the surrounding surface features (Bartie *et al.*, 2011). Figure 4 illustrates this phenomenon by indicating where an observer is located on top of vegetation on the left (T2), while in reality it should be incorporated on the ground level as on the right side (T2) (Bartie *et al.*, 2011).

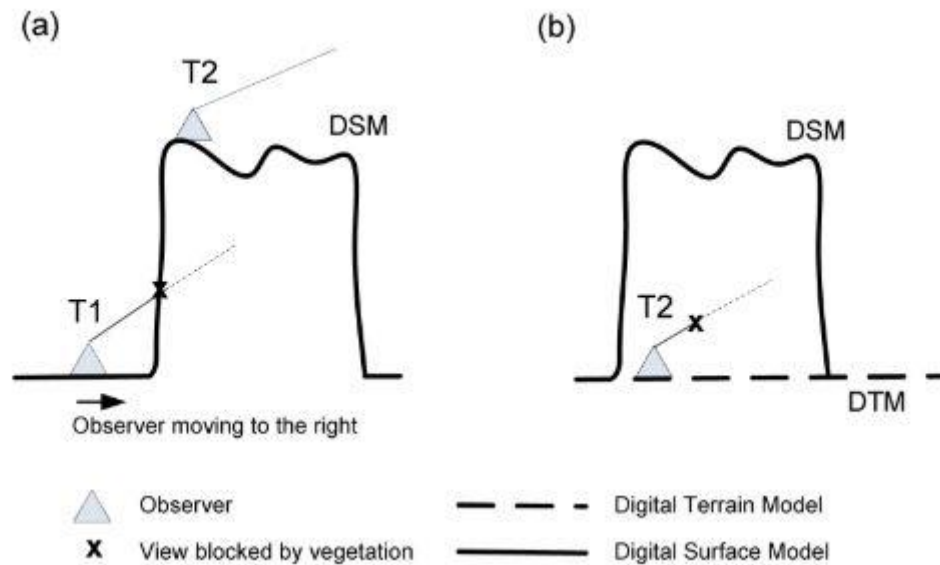


Figure 4: Observer placement in DTM and DSM (Bartie *et al.*, 2011).

Although surface features provide limitations in visibility analysis, it is a critical screening component as visibility analysis simulations that excludes surface features overestimate visibility. As is clear from the discussion, various factors can influence visibility analysis simulations. The following section further elaborates on the limitations of visibility analysis.

2.1.4. Limitations of visibility analysis

In the previous section, interpolation algorithms, resolution size, terrain complexity and surface features were all identified as factors affecting visibility analysis accuracy. There are, however, additional limitations to visibility analysis that should also be considered. Visibility analysis is limited by the approaches defined in the first part of this chapter. The limitation with simple binary viewshed analysis is the representation of its results, specifically as it produces visibility results as a Boolean representation (Garnero & Fabrizio, 2015; Klouček *et al.*, 2015). The method only reflects visibility in terms of visible and non-visible areas with minimal detail or

other factors considered (Klouček *et al.*, 2015). Although other approaches are available to determine visibility in a more detailed manner, for instance, the inclusion of human perspective, they all have their own limitations (Garnero & Fabrizio, 2015; Qiang *et al.*, 2019).

Visibility analysis on its own provides a poor visual significance in terms of the human perspective. For example, objects at a closer distance or with greater contrast to the surroundings have a greater visual influence on a community (Nutsford *et al.*, 2015). Approaches have been developed to include the human perspective in visibility assessment, but it remains a difficult component to include it in visibility analysis (Kantner & Hobgood, 2016). This is mostly because it involves a distance decay function (Nutsford *et al.*, 2015; Ogburn, 2006), which involves several factors of not only human characteristics in terms of eyesight capability, but also the environmental conditions at a specific time (Ogburn, 2006). Environmental factors include lighting and atmospheric, particularly how each can influence the limit of visibility depending on the time of day and the atmospheric conditions of the particular day (Sullivan & Meyer, 2014).

To summarise, as with most modelling techniques, there are various factors that either individually or together introduce some uncertainty and might lead to errors in the results. Errors in visibility results are defined by false positives where areas are identified as visible but in reality are not, and by false negatives where areas are identified as not visible, but in reality are visible (Klouček *et al.*, 2015). Therefore, some sort of validation is necessary to determine visibility analysis result accuracy (Kidner *et al.*, 2001; Llobera, 2003). Providing a complete validation of visibility results is nearly impossible, specifically as each point determined as visible or not can simply not be validated as this would create the process uneconomical and irrelevant (Kidner *et al.*, 2001). Additionally, the fieldwork would replace the purpose of a computerised visibility analysis approach altogether (Kidner *et al.*, 2001).

Understanding how the limitations of visibility analysis affect the accuracy of the procedure is just one component of optimising the approach. Additionally, understanding how VIA works and how visibility analysis is incorporated in VIA is important to optimise the approach.

2.2. Visual impact assessment

Visual impact assessment has been discussed in Chapter 1 as an approach used for identifying and managing visual impacts with the aim of maintaining a well-planned environment. Since VIA is usually done as part of EIA, the EIA concept will first be discussed, followed by discussions on the EIA specialist dimension where VIA is usually employed.

2.2.1. Environmental impact assessment

EIA's are defined in Chapter 1 as the systematic procedure of identifying and assessing possible impacts on the environment with the intention of making a decision whether a proposed development should be approved or rejected (Münster, 2005; Rodrigues *et al.*, 2010). Impacts on the broader environment are considered and EIA is therefore used to detect, predict and evaluate impacts on the physical-, social-, and economic environment (Münster, 2005).

Different types of EIA procedures can be used depending on the type of activity as determined by the National Environmental Management Act (NEMA) of South Africa (Patel & Giordano, 2014). The NEMA guidelines determine whether a basic assessment (BA) report or a scoping and full EIA (S&EIR) is required (Patel & Giordano, 2014). Understanding the systematic procedure of an EIA involves understanding each the following phases; screening, scoping, public participation, identifying alternatives and mitigation measures, determining impact significance, authorisation of EIA and post-decision monitoring (Retief *et al.*, 2011).

The first phase of an EIA is known as the screening phase where the proposed project's nature and scope is considered to determine whether an EIA is necessary and if so, to what extent (Glasson *et al.*, 2005; Retief *et al.*, 2011; Wood & Becker, 2005). Screening would therefore determine whether a BA or S&EIR would be needed for a specific project (Marais *et al.*, 2015). The next phase of the EIA involves the procedure of identifying all possible impacts associated with the project proposal and is known as the scoping phase (Ross *et al.*, 2006; Wood & Becker, 2005). Identifying impacts provide the opportunity for a specialist to be involved in the EIA procedure, where they contribute specific information in a report on the significance of specific environmental impacts (Münster, 2005; Oberholzer, 2005). This phase would involve studies such as VIA where visual impacts are evaluated by a specialist in the specific field (Samavatekbatan *et al.*, 2016; Sullivan & Meyer, 2014).

The next phase of an EIA is the public participation phase which forms part of the evaluation period of an EIA where the public is invited to give feedback on envisaged environmental impacts as communicated towards them (Pardo García & Mérida Rodríguez, 2015; Rodrigues *et al.*, 2010). The feedback from the community provides the EIA practitioner and specialist with additional information on how the local community and the environment are affected by the project proposal (Glasson *et al.*, 2005; Rodrigues *et al.*, 2010). The information collected during the previous phases contributes to the identification of alternative methods and mitigation measures aimed at minimising the potential negative impacts of the proposed project (DEAT, 2002; Münster, 2005). Alternative methods and mitigation measures consider alternative locations, scales, layouts, processes and operational conditions to reduce or

compensate for negative impacts determined in the scoping phase of an EIA (Glasson *et al.*, 2005; Münster, 2005). Wind turbine relocation is one example where mitigation measures have been incorporated to reduce visual impact by relocating towers to areas with better screening capabilities (Klouček *et al.*, 2015; Rodrigues *et al.*, 2010). Subsequently, this leads to the next phase on the EIA procedure, which is determining the significance of identified impacts (Sullivan & Meyer, 2014). The phase involves reflection on the nature of an impact, its duration, magnitude and scope, as well as determining its significance, both before and after alternatives and mitigation measures (Oberholzer, 2005).

The authorisation procedure of the EIA ensures that the correct procedures have been followed to ensure all identified negative impacts are either avoided or reduced (Marais *et al.*, 2015; Patel & Giordano, 2014). This addresses the overall aim of conducting an EIA for a proposed project which is to ensure that the effects of negative impacts were minimised or avoided (Retief *et al.*, 2011). The last phase of an EIA is the post-decision monitoring, which evaluates the effectiveness of the decisions made within the EIA in terms of reducing the overall effects of negative impacts associated with the proposed project (Glasson *et al.*, 2005; Münster, 2005). Auditing forms part of post-decision monitoring by evaluating the predicted outcomes with the actual outcomes. Additionally, this provides an educational purpose as it identifies shortcomings within the EIA, which can be amended in similar projects (Glasson *et al.*, 2005).

In short, understanding how possible impacts influence the environment forms a critical part of the EIA systematic procedure, and specialist's involvement plays a significant role as they contribute information to assist in understanding the significance of possible impacts and how they could be mitigated. This information is important prior to the authorisation of a proposed project. The following section elaborates on the specialist's role within an EIA.

2.2.2. The role of specialist studies in EIA

Specialists are individuals with significant knowledge in a specified study field (DEAT, 2002). Specifically, their role in EIA's includes contributing information to aid good practices to minimise and avoid negative impacts by understanding the impacts within their field of study (DEAT, 2002; Münster, 2005). The role of the specialist is dependent on the timing in terms of the EIA phase they are involved in (DEAT, 2002; Münster, 2005).

Involving a specialist in the early phases of an EIA benefit towards reducing negative impacts, particularly as alternatives for impacts can be proposed in the early stages of planning (Münster, 2005; Oberholzer, 2005). Proposing alternatives as part of planning can reduce

negative impacts and reduce financial strain before significant events take place (DEAT, 2002; Oberholzer, 2005). The role of a specialist in EIAs involves addressing negative impacts identified during the scoping phase and providing information to aid decision-makers in the authorisation phase of the EIA (DEAT, 2002; Kim *et al.*, 2004). The timing of a specialist's involvement in an EIA is further dependent on the reason the specialist is incorporated, specifically as they can support the description of the environment (Münster, 2005; Oberholzer, 2005). The following section focusses on VIA and its role within an EIA.

2.2.3. Visual impact assessment as a specialist study in EIA

As discussed in Chapter 1 VIA involves the assessment of visual impacts through the evaluation of possible changes in the visual attributes of a landscape caused by a proposed project (Depellegrin, 2016). The assessment of an object's visual impact on the landscape's visual properties can either be positive or negative, depending on the observer's view (Sullivan & Meyer, 2014). To understand VIA as a specialist study, the purpose, procedure, and limitations of VIA are each defined in their own sub-section.

2.2.3.1. *Purpose of Visual impact assessment*

The following six fundamentals define the purpose of a VIA report (Sullivan & Meyer, 2014):

1. Describe the region and the project's landscape elements and characteristics.
2. Identify and describe the projects visual extent within the landscape.
3. Identify changes to the landscape's visual quality caused by the visually contrasting object.
4. Determine the viewers experience towards possible effects caused by the visually contrasting objects.
5. Provide alternative methods to avoid visual impacts or mitigation measures to reduce the significance of visual impacts on the landscape.
6. Define whether a project conforms to objectives set out to reduce the visual magnitude.

VIA's purpose is defined by these six fundamentals with different fundamentals associated with different phases of an EIA. Understanding the purpose of VIA is only one part of understanding where visibility analysis can be optimised, with a greater understanding of visibility analysis role in VIA enhanced by VIA's procedure.

2.2.3.2. *The procedure of Visual impact assessment*

The following 11 steps define the procedure of VIA and how it achieves its purpose:

1. Collect information and construct a description of the project within its landscape setting.
2. Review regulatory and planning documents to identify appropriate requirements of impact assessment, with the addition of ensuring compliance with the objective of visual resource management.
3. Collecting information about the object's visual characteristics and the associated visual contrasting contributions.
4. Determine the projects potential visibility in relation to the landscape through visibility analysis.
5. Identify important locations in the area from where visual impact and contrast will be assessed.
6. Collecting information about each location used to assess visual impact, specifically who would view the object, duration of visibility, and potential sensitivity.
7. Generate realistic visual results of visibility analysis to inform decision-makers of the nature and extent of the visual influence.
8. Assessing the nature and extent of visual impacts through the evaluation of visibility simulations.
9. Define the effects of visual impacts on the visual qualities of the landscape, as well as its effect on the surrounding communities.
10. Provide mitigation measures to avoid, reduce or compensate for identified visual impacts.
11. Determine whether the project complies with visual resource management objectives.

Understanding the procedure within VIA provides more detail of the complexity of visual impact assessment. As part of understanding the purpose and procedure of VIA, it is important to understand the limitations of VIA.

2.2.3.3. Limitations of visual impact assessment

Inaccurate or incomplete descriptions of visual impacts or of viewers responses to impacts may arise, as improper methods may have been used or insufficient information collected in terms of observers, observer points or the overall project itself (Sullivan & Meyer, 2014). Limitations can arise if certain steps as defined in the procedure (Section 2.2.3.2) is rushed and information not collected in the correct manner. If the necessary information is not included in the VIA report, a complete analysis of visual impacts may not be achieved as part of the EIA.

The other factor that can limit VIA is the quality and accuracy of visibility analysis approaches used within VIA (Sullivan & Meyer, 2014). The limitations of visibility analysis are defined in the previous sections of this chapter and focused on interpolation techniques, data quality, and elevation models (Fisher & Tate, 2006; Klouček *et al.*, 2015; Sander & Manson, 2007). Limitations originate in both VIA and visibility analysis. The next section deals with visibility analysis in VIA.

2.3. Visibility analysis in visual impact assessment

As discussed within the two previous sections of this chapter, visibility analysis plays a critical role in VIA, and VIA a critical role in EIA. Section 2.1.1 defined visibility analysis as well as some of the common approaches used to determine visibility. Five visibility analysis techniques that have been discussed VIA literature and which are based on the techniques discussed in Section 2.1.1, is further discussed in the following section.

2.3.1. Line-of-sight analysis use in visual impact assessment

LOS was briefly discussed in the previous section of this chapter. It involves drawing a straight line between the observer and the target object, and classifying the target object as visible if at no point the line is obstructed by the landscape (Feng *et al.*, 2015; Verutes *et al.*, 2014). The visibility analysis technique is based on the single binary visibility approach (Feng *et al.*, 2015) and is not commonly used to define an object's visual impact on its surrounding environment as a whole, but rather focus on specific locations within an area providing an understanding of possible impacts from sensitive or specific locations (Nutsford *et al.*, 2015). LOS, on its own, may not be the most commonly used technique in VIAs, but it forms the basic principle of how visibility is determined in the other techniques (Feng *et al.*, 2015).

2.3.2. Viewshed analysis use in visual impact assessment

Viewshed analysis is one of the most common visibility analysis techniques used to evaluate visual impacts in VIA reports (Miller *et al.*, 2011). The visibility technique uses LOS to determine visibility for the whole area, in particular, the visibility of the area is determined by drawing a straight line for each cell of a DEM and determining whether the line was obstructed by the landscape at any point (Pardo García & Mérida Rodríguez, 2015). The technique is a widely accepted method used in VIA to determine the visual significance of a proposed project in a simple binary approach (Bartie *et al.*, 2010; Möller, 2006). For instance, viewshed analysis is commonly used to assess the visual impacts in VIA studies involving photovoltaic power

plants (Fernandez-Jimenez *et al.*, 2015), light pollution analysis (Verutes *et al.*, 2014), and land and marine-based wind park developments (Depellegrin, 2016; Klouček *et al.*, 2015).

2.3.3. Cumulative viewshed analysis use in visual impact assessment

The cumulative viewshed analysis technique is similar to viewshed analysis with the approach used to define visibility being the difference (Depellegrin, 2016). Specifically, cumulative viewshed analysis uses a cumulative approach to define visibility rather than the simple binary approach used by viewshed analysis (Depellegrin, 2016). For instance, visibility results either indicate the total number of objects available from a specific location or the amount of one object (Danese *et al.*, 2011). One example of VIA evaluating visual impacts through cumulative viewshed analysis involves multiple observer locations to assess the visual exposure from multiple areas (Depellegrin, 2016).

2.3.4. Fuzzy viewshed analysis use in visual impact assessment

Fuzzy viewshed analysis is based on the fuzzy visibility analysis approaches, therefore including a distance decay function to determine the loss of visibility significance over an increase in distance (Murphy *et al.*, 2018). The technique is less commonly used as the distance decay function increase the complexity of the technique (Klouček *et al.*, 2015). Although, a distance decay function may not be incorporated in other techniques to display the loss of visibility, a limit on visibility distance may be included (Klouček *et al.*, 2015; Nutsford *et al.*, 2015). Including a distance decay function or a limit on visibility provide a more realistic representation of visibility in terms of a person's loss of visual acuity (Murphy *et al.*, 2018).

2.3.5. Higuchi viewshed analysis use in visual impact assessment

The Higuchi viewshed analysis technique is similar to fuzzy viewshed analysis in terms of representing the loss of visibility over a distance, in particular, it uses three distances zones based on the nature and climate of the area rather than human visibility limitations (Nutsford *et al.*, 2015). The three each define a perspective on visibility clarity, for example, the first zone is the foreground and define clarity as perfect and define the area as having a greater visual significance (Nutsford *et al.*, 2015). The second zone is defined as the middle ground where clarity distinguishes towards the outer edge of the zone; the last zone defines the object as difficult to individually identify as it blends in with the surrounding landscape defined as the background (Nutsford *et al.*, 2015).

2.4. Literature conclusion

The concept of VIA plays a significant role in the understanding of how a project influences the visual attributes of the landscape and how these changes influence the community within the area. The motivation of understanding and improving the concept of VIA contributes to an overall better contextualization of visual impacts and how impacts can be mitigated or reduced to minimize negative visual impacts on a community.

Visibility analysis is a fundamental component of VIA, as it assists in determining the visual significance of a proposed project. However, understanding the visual impact is only as accurate as the visibility analysis approach used. The chapter explored the various factors that influence the accuracy of visibility analysis, and that should be considered when determining an optimal visibility analysis approach. Various visibility analysis techniques used in VIA were identified from the literature. These techniques are further refined by identifying those that are often applied in VIA in South Africa. The identified techniques will be tested and evaluated to determine the accuracy of each technique, and propose an optimized approach to visibility analysis in VIA. Chapter 3 will discuss the methodological approach used in the study to achieve the aim and objectives as defined in Chapter 1.

Chapter 3: Methodology

A mixed-method methodological design was employed to achieve the aim and objectives of the study discussed in Chapter 1. The methodological approaches applied for each of the three objectives are presented in this chapter. The methodological approach applied to Objective 1 is discussed first, followed by the approaches for Objectives 2 and 3.

3.1. Explore current methodological approaches for visibility analysis used in VIA

Various visibility analysis techniques often used in VIA's were discussed in Section 2.3. To determine which of these techniques are most frequently used in South Africa, a number of VIA's were reviewed through a document analysis approach. Document analysis is a procedure of reviewing and evaluating documents for important information or data (Bowen, 2009; Marinai *et al.*, 2005). The process involved identifying and selecting suitable documents (Phase 1), and reviewing selected documents (Phase 2), as illustrated in Figure 5. The two phases are now discussed in more detail.

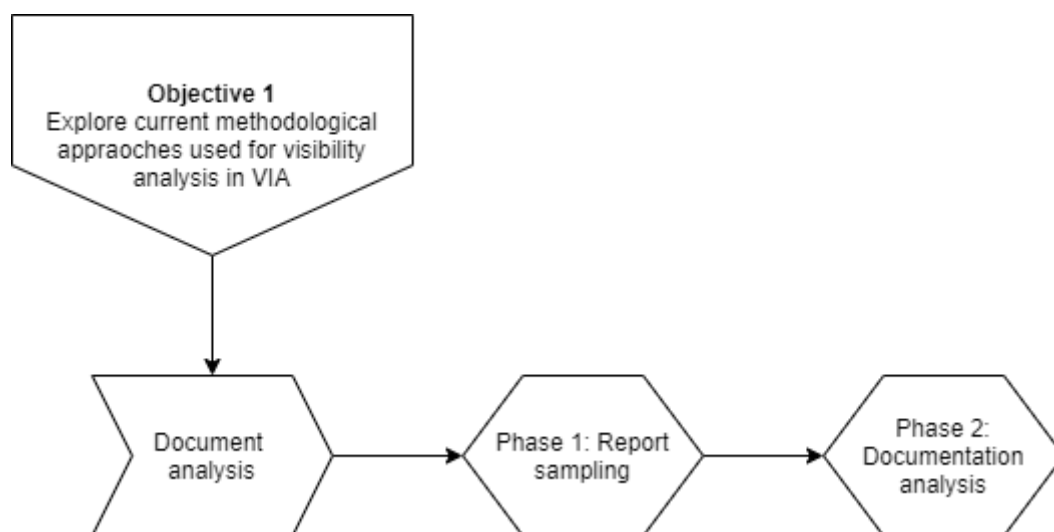


Figure 5: Methodological procedure of Objective 1

3.1.1. Report sampling process (Objective 1 - Phase 1)

A database containing 101 EIA reports were made available by the Department of Environment, Forestry and Fisheries (DEFF) for use in this study. These reports represented EIAs conducted for projects in a variety of sectors, including waste management, energy, bulk

infrastructure, and tourism. As all reports were not suitable for use in the study, the following criteria (Figure 6) were applied to screen the database and select suitable reports:

- 1) A VIA had to be conducted as part of the EIA study.
- 2) The EIA studies had to be representative of different provinces of South Africa.
- 3) VIA studies had to be conducted by various consultants.

A total of 19 EIA reports were subsequently selected, and their associated VIA reports analysed.

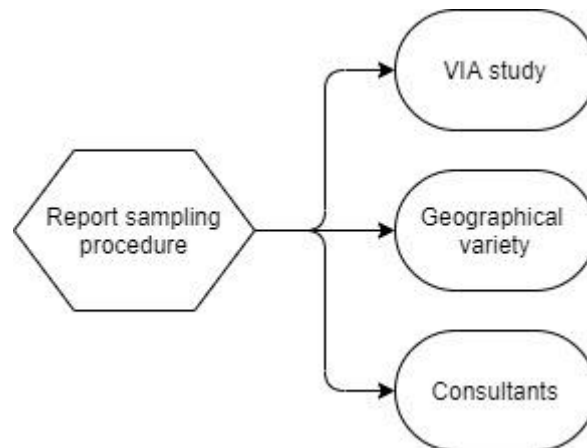


Figure 6: Reports sampling methodological procedure

3.1.2. Documentation analysis (Objective 1 - Phase 2)

The purpose of the document analysis was to identify the visibility analysis techniques and approaches most frequently used in VIAs in South Africa. The VIA reports for the 19 selected EIAs were therefore analysed and the following information extracted (Figure 7):

- 1) The visibility analysis technique used to determine visibility in the report.
- 2) Variables used in the visibility analysis technique, with specific reference to the following variables:
 - Type of DEM used (DTM or DSM);
 - Perspective from where visibility was determined (target object's or observer's location);
 - Manner and extent to which land cover screening was considered in the analysis; and
 - Manner and extent to which visibility limit was included.

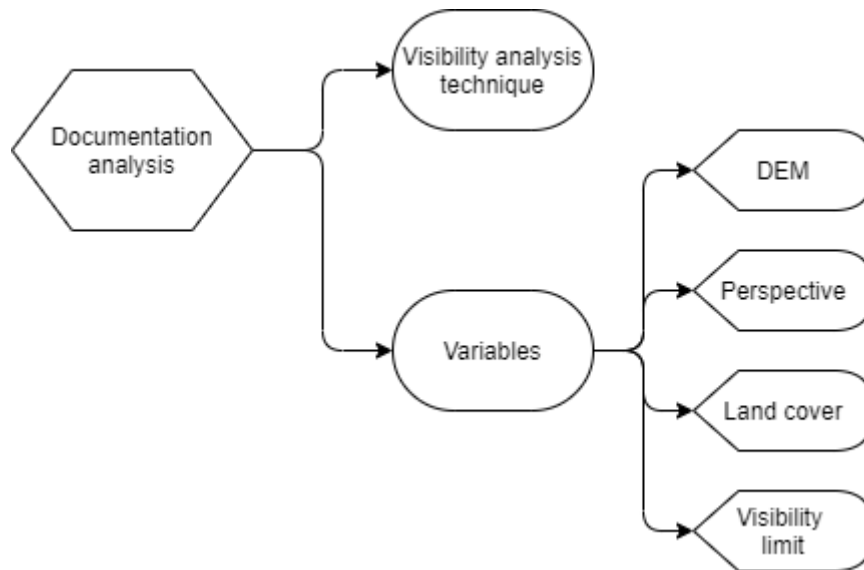


Figure 7: Documentation analysis methodological procedure

The techniques and variables identified through the review informed the methodological design for Objective 2, which involved the testing and evaluation of various techniques and variables.

3.2. Objective 2: Test and evaluate different approaches to visibility analysis across different terrain complexities and using different variables

Through Objective 1, the approaches to visibility analysis most often used in VIA studies in South Africa were identified. The process of testing and evaluating the identified visibility analysis approaches (inclusive of techniques and variables) were adapted from the “Guideline for involving visual and aesthetic specialists in the EIA processes” (Oberholzer, 2005) and “Guide to evaluating visual impact assessment for renewable energy projects” (Sullivan & Meyer, 2014). Specifically, Oberholzer (2005) mentions typical components involved within visual studies and Sullivan and Meyer (2014) provides key steps in preparing a VIA. The information allowed a four phased methodology to be compiled for this study, as illustrated in Figure 6:

- 1) Identify suitable study areas with different terrain complexities;
- 2) Data collection;
- 3) Generate and evaluate DEM's; and
- 4) Test visibility analysis approaches.

The four phases involved in Objective 2 are now discussed.

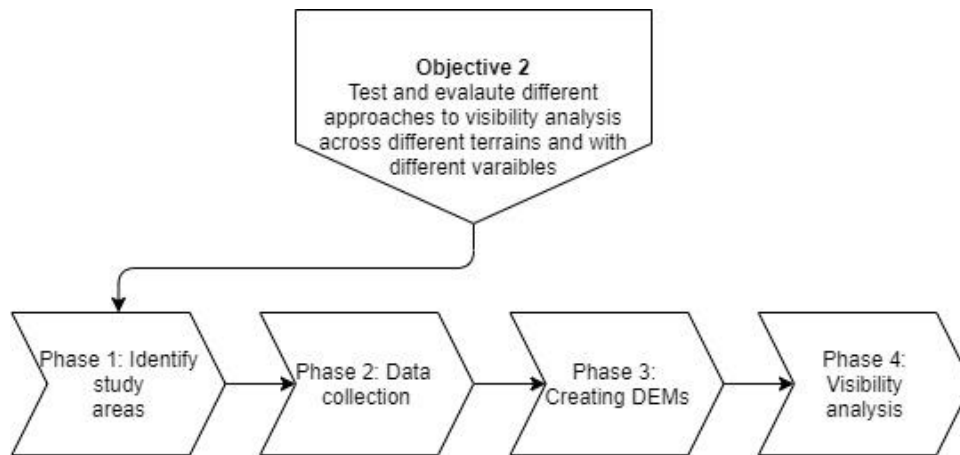


Figure 8: Methodological procedure of Objective 2

3.2.1. Identifying suitable study areas (Objective 2 - Phase 1)

The purpose of identifying suitable study areas was to test and evaluate the identified visibility analysis techniques on areas with different terrain complexities. The procedure used to identify three suitable study areas consisted of two steps, as illustrated in Figure 9. Possible study areas were first evaluated in terms of the presence of a suitable observation object, the elevation change over the area and finally, the land cover types present in the area (Step 1). Three suitable areas with differing elevation characteristics were selected after which their terrain complexity was determined to confirm that they in fact represented areas with different complexity properties (Step 2). The two steps are now discussed in more detail.

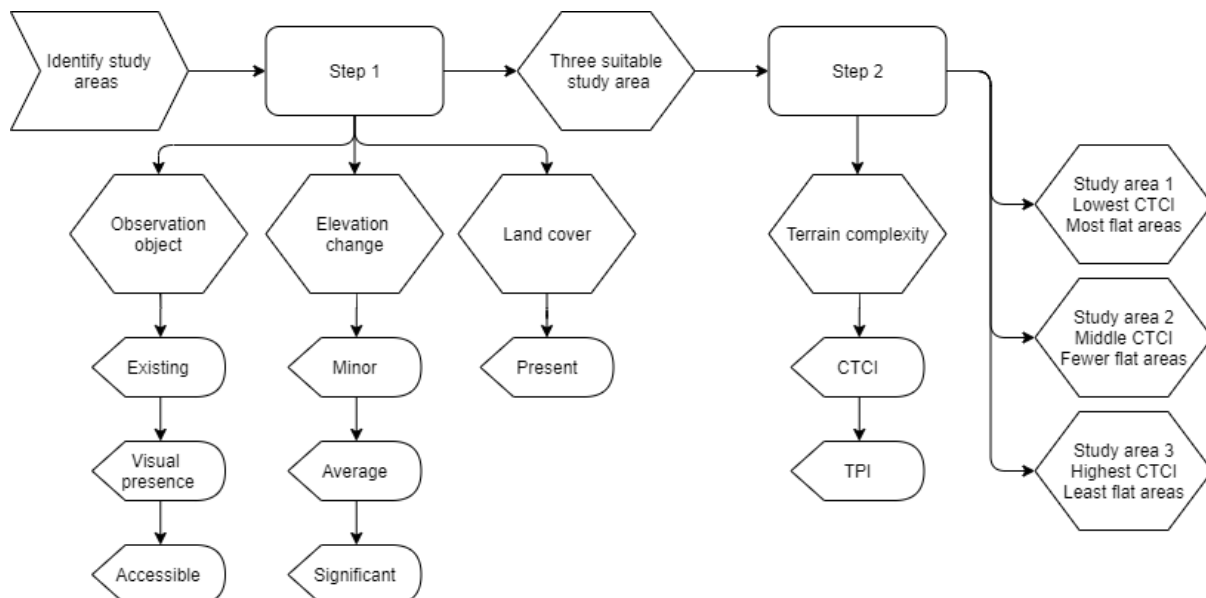


Figure 9: Identifying suitable study areas methodological procedure

3.2.1.1. Step 1: Identifying suitable study areas

The following three sub-steps were followed to identify possible study areas:

Sub-step 1: Possible observation objects were identified based on the following criteria: (1) must be an existing object suitable for use in visibility analysis; (2) must be a significant feature in the landscape offering a visual presence due to its overall height and size; (3) must be a fairly common object present in many landscapes; and (4) must be accessible. Based on these criteria, a silo was decided on as a suitable object for use in the study. The locations of several silo's were mapped for the North West province and compared to road networks. An effort was made to identify silos that were easily accessible and surrounded by enough roads to allow for on-site visibility assessment to be conducted at various distances from the silo. This was because access to private land was a challenge and roads had to be used for field-work. No specific object dimension limits were set for the silos, but they had to be of a height capable of producing a significant visual impact.

Sub-steps 2 and 3: Possible sites identified in the previous step was further evaluated in terms of elevation change and land cover complexity. A square boundary was generated for each study area through the "Graphic buffer" tool in ArcMap, specifically at a 20km distance. The 20km distance was based on the work by Murphy *et al.* (2018) who found visibility to decrease significantly beyond 20km. The square boundary was used to present more information about the locality of the area as well as the terrain, while visibility analysis would be limited to 20km in all directions. The elevation change in each buffered area was evaluated using elevation data, while land cover complexity was evaluated through satellite images. Possible sites were eventually narrowed down to three locations that were characterised by complex land cover and showed either: minor elevation change with minimal topographical features; average elevation change with some topographical features present; or significant elevation change and topographical features throughout the area. The three selected areas were further analysed for terrain complexity (Step 2) to ensure that they did indeed represent areas of varying complexity.

3.2.1.2. Step 2: Define study areas terrain complexity

Terrain complexity for the three study areas was assessed by first determining the terrain complexity through the calculation of a Compound Terrain Complexity Index (CTCI) after which the terrain was classified into landscape classes using a Topographic Position Index (TPI). The procedure for each step is now discussed.

Compound terrain complexity index (CTCI)

CTCI is a method that utilizes four terrain complexity indices (TCI) to create a statistical representation of terrain complexity (Huaxing, 2008; Véga *et al.*, 2015). All TCI values were determined from 5m resolution DTM's generated for the three areas. The CTCI procedure is illustrated in Figure 10 and the process described below.

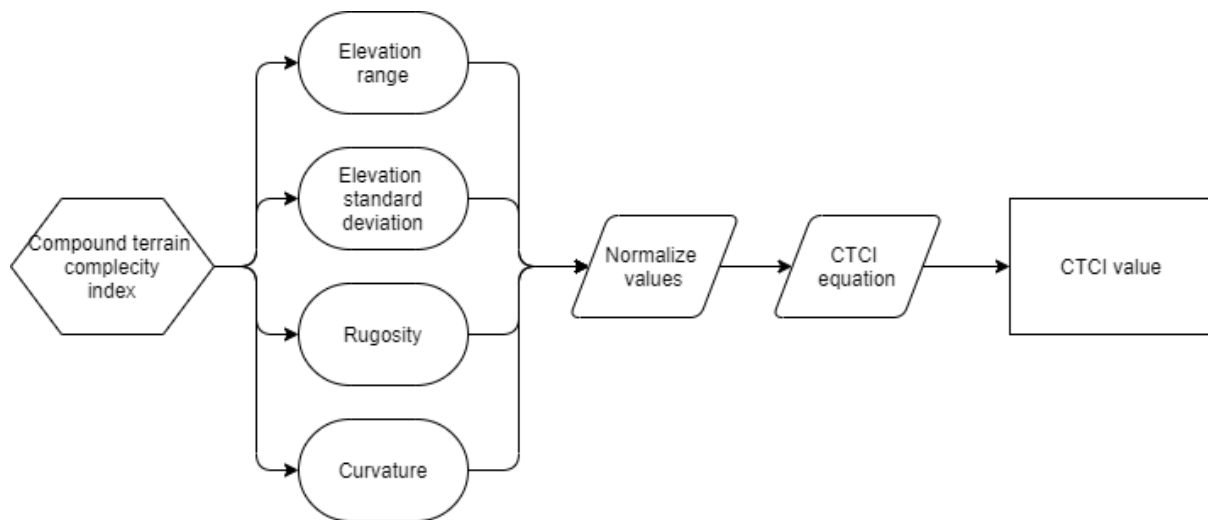


Figure 10: Compound terrain complexity index methodological procedure

- Determine elevation range and elevation standard deviation. “Focal statistics” in ArcMap was used to determine the two TCI values from the DTM, specifically the default 3x3 rectangular neighbourhood size was used.
- Determine the curvature. Total curvature is a representation of the curvature and shape of the slope of an area (Korzeniowska *et al.*, 2018), and was determined by using the spatial analysis tool “Curvature” in ArcMap.
- Determine the rugosity. Rugosity is a measurement of surface roughness determined by the ratio between surface area and planar area (Huaxing, 2008). Rugosity was determined using the “Surface ratio raster” tool in the Jennes Enterprises DEM surface toolbox in ArcMap (Jennes, 2013).
- Normalizing TCI values and determining CTCI value. TCI values had to be normalized as each presented different ranges, and higher values would influence the final value used to classify terrain complexity (Huaxing, 2008). The absolute values of curvature were determined before normalization as the negative values would have affected the results. The normalized value for each TCI was determined through equation 1 using the raster calculator in ArcMap. The CTCI value of each study area was determined

using equation 2 in the raster calculator, therefore adding all normalized layers, and dividing them by the number of layers.

Equation 1

$$NTCI = (TCI - \min TCI) / (\max TCI - \min TCI)$$

NTCI= normalized terrain complexity index

Equation 2

$$CTCI = (N_{tc} + N_{re} + N_{ru} + N_{sd}) / 4$$

CTCI= compound terrain complexity index

tc= curvature

re= elevation range

ru= rugosity

sd= standard deviation

Topographic position index

TPI is the difference between the elevation of a cell and the average elevation of the surrounding cells (De Reu *et al.*, 2013; Nair *et al.*, 2018; Vinod, 2017). The determined value is classified through slope classification to distinguish the areas into six topographical classes (De Reu *et al.*, 2013; Nair *et al.*, 2018; Vinod, 2017). TPI was determined from the DTM5m of each study area. The TPI procedure is illustrated in Figure 11 and discussed below.

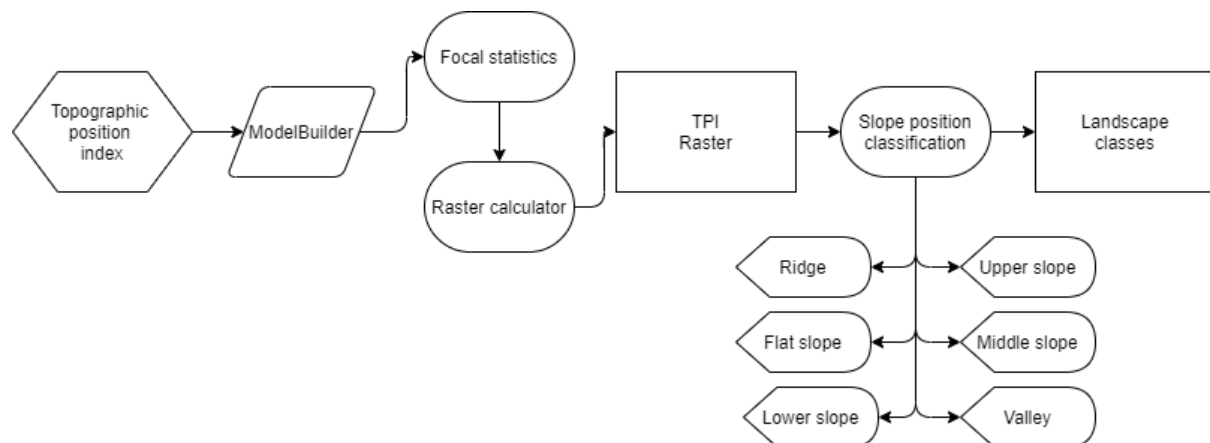


Figure 11: Topographical position index methodological procedure

- Determine TPI values. ModelBuilder in ArcMap was used to create a sequence of steps to calculate TPI values for each of the study areas (Figure 12). The model incorporated “Focal statistics” to determine the mean elevation value of a cell on a 600m circular neighbourhood size. The neighbourhood size was proposed in a study done by De Reu *et al.* (2013) as a neighbourhood size that has the capability to represent most topographical features.

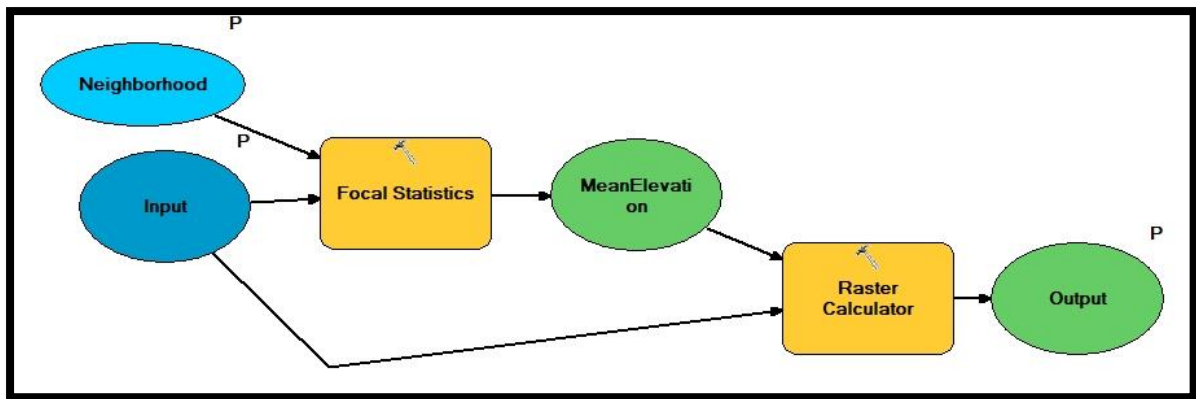


Figure 12: ModelBuilder diagram of Topographic position index procedure

- Classify TPI values by slope position classification. The standard deviation of TPI values defined six slope position classes, two of which (the flat slope and middle slope) includes the degree of slope in their classification (Weiss, 2001). Table 1 indicates the slope classification ranges used to classify the TPI values in landscape classes.

Table 1: Slope position classification classes

Land class	Classification range	
	Standard deviation	Slope degree
Valley	$TPI < -STD^1$	NA ²
Lower slope	$-STD \leq TPI < -0,5STD$	NA
Flat slope	- $0,5STD \leq TPI < 0,5STD$	Value $\geq 5^\circ$
Middle slope	- $0,5STD \leq TPI < 0,5STD$	Value $< 5^\circ$
Upper slope	$0,5STD < TPI \leq STD$	NA
Ridge	$TPI > STD$	NA

¹ STD= Standard deviation

² NA= Not applicable

3.2.1.3. Summary of identifying suitable study areas

Step 1 of identifying suitable study areas narrowed the options down to three suitable areas: Grootpan, Syferbult and Swartruggens. Step 2 was used to verify that each of the options represented a different terrain complexity. The determined CTCI and TPI values are presented in the following figure and tables.

Compound terrain complexity index

Higher CTCI values indicate areas with a greater level of complexity, while lower values indicate less complex areas (Huaxing, 2008).

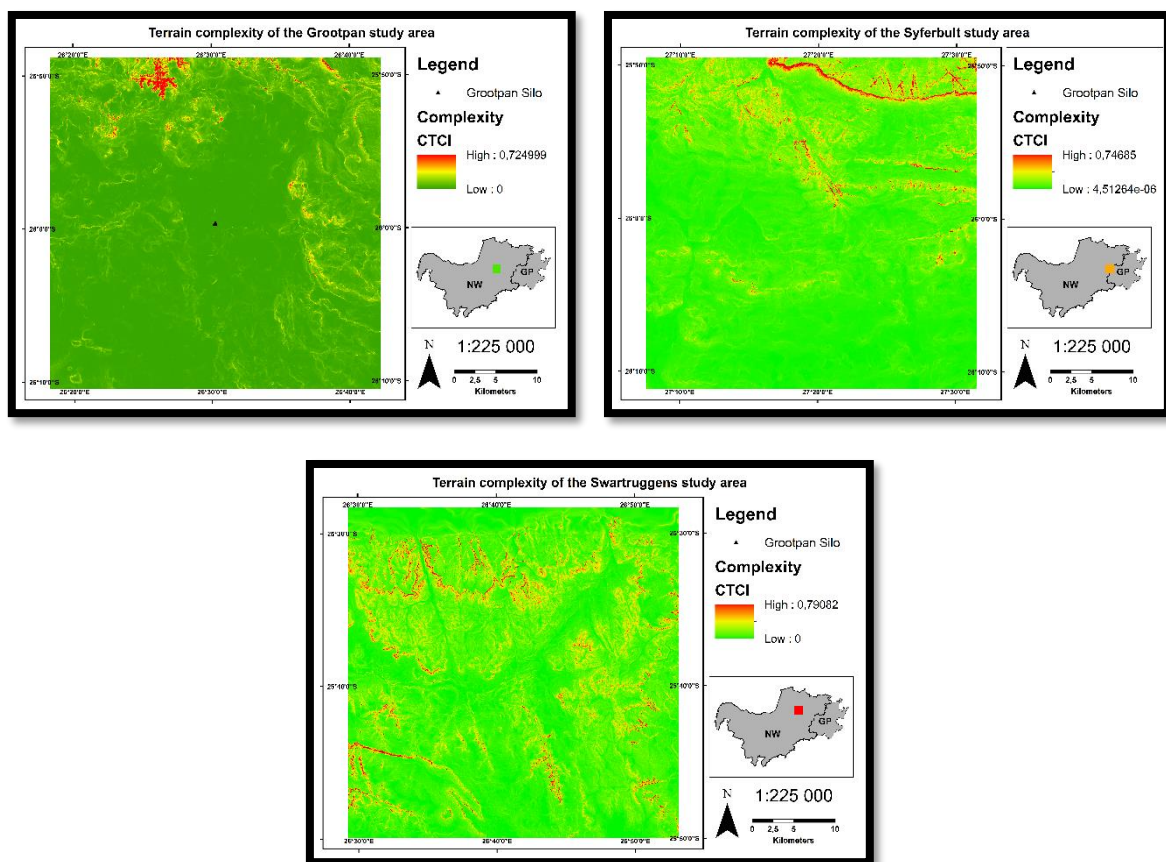


Figure 13: Compound terrain complexity index values of the three study areas

Table 2: Compound terrain complexity index values of the three study areas

Study area	Indices	Minimum	Maximum	Mean	Standard deviation
Grootpan	Elevation range	0.00	8.97	0.21	0.33
	Elevation standard deviation	0.00	2.89	0.07	0.11
	Rugosity	1.00	1.23	1.00	0.00
	Curvature	0.00	33.23	0.03	0.10
	CTCI	0.00	0.72	0.01	0.02
Syferbult	Elevation range	0.00	21.59	0.77	1.06
	Elevation standard deviation	0.00	6.94	0.25	0.34
	Rugosity	1.00	1.97	1.01	0.02
	Curvature	0.00	54.10	0.14	0.33
	CTCI	0.00	0.75	0.02	0.03
Swartruggens	Elevation range	0.00	24.42	1.12	1.23
	Elevation standard deviation	0.00	7.23	0.36	0.40
	Rugosity	1.00	2.05	1.01	0.02
	Curvature	0.00	63.16	0.22	0.40
	CTCI	0.00	0.79	0.03	0.03

The mean CTCI value of Grootpan is the lowest at 0.01 (Table 2); lower CTCI values indicate lower levels of terrain complexity. This is apparent from the fewer red areas present in Figure 13. The map of Grootpan's CTCI values only indicates high CTCI values in the top left area, whereas most of the area has a low CTCI value illustrated in dark green in Figure 13. Syferbult reported a CTCI value of 0.02, which is double that of Grootpan. The higher complexity value can be partially ascribed to the Magaliesberg and smaller hills close to the silo. Figure 13 indicates higher CTCI values, especially to the north of the silo in comparison to Grootpan. Swartruggens showed the highest level of terrain complexity between the three areas at 0.03. Similar to Syferbult, most of the areas are represented by lighter green areas indicating a more intermediate CTCI value, while higher CTCI values in red are present throughout Figure 13.

The three study areas chosen on their terrain complexity is confirmed by the CTCI values of each study area. Additionally, the same technique can be used to compare more study areas visibility analysis results by comparing their respective terrain complexity.

Topographic position index

The findings for the TPI analysis for the three study areas are presented in Figure 14 and Table 3. The slope classification of each study area presents more insight into each area's characteristics (Figure 14). Slope classification determined that 71% of the Grootpan study

area consist of flat slopes, while Syferbult indicated a decrease in flat slopes with 63% of the area classified as flat slopes. Swartruggens' flat slopes only made up 47% of the study area, with the other five classes, each contributing to just over 10%.

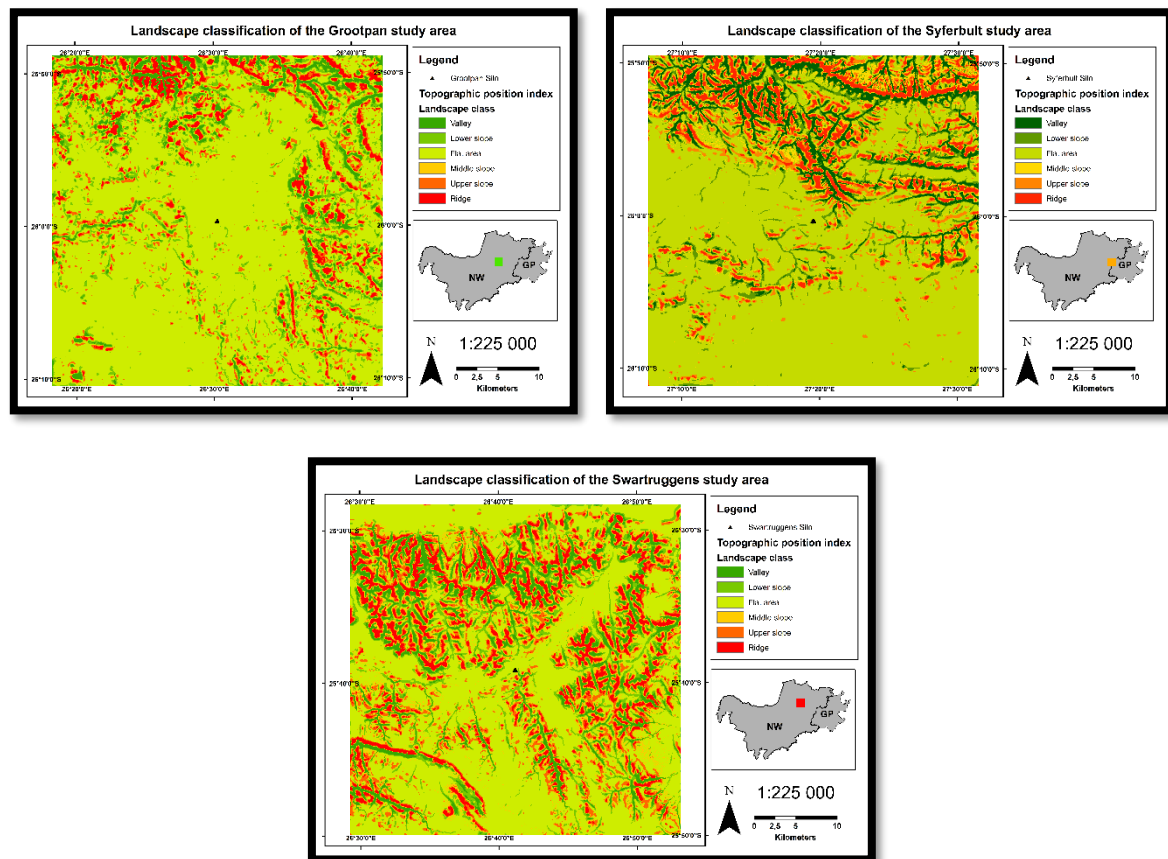


Figure 14: Slope classification of TPI values for all three-study area

Table 3: Slope classification of Topographic position index values for all three study areas

Study area	Slope position	Area (km)	Percentage (%)
Grootpan	Valley	9.88	6.18
	Lower slopes	14.40	9.00
	Flat slopes	113.36	70.85
	Middle slopes	0.47	0.29
	Upper slopes	12.00	7.50
	Ridge	9.90	6.19
Syferbult	Valley	13.20	8.25
	Lower slopes	12.73	7.96
	Flat slopes	101.28	63.30
	Middle slopes	9.31	5.82
	Upper slopes	11.10	6.94

	Ridge	12.37	7.73
Swartruggens	Valley	17.32	10.83
	Lower slopes	17.24	10.78
	Flat slopes	74.66	46.66
	Middle slopes	17.41	10.88
	Upper slopes	16.10	10.07
	Ridge	17.25	10.78

Figure 15 illustrates the percentage coverage of each slope classification of each area. This supports the CTCI values which indicate higher terrain complexities from the Grootpan to Swartruggens area. The decrease in flat slopes of each study area can clearly be seen in the graph, while topographical features defined with higher complexity increase as flat slopes decrease.

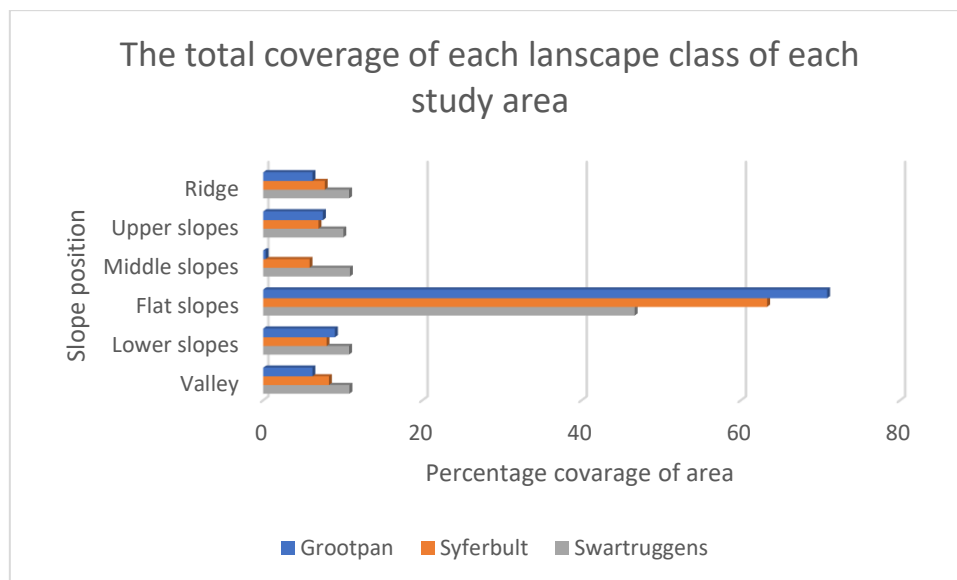


Figure 15: Graph illustrating the landscape class coverage of each study area

The CTCI and TPI values verified the choice of the three study areas identified in Step 1, with Grootpan representing the least complex terrain, Syferbult a terrain of intermediate complexity and Swartruggens the most complex terrain. Figure 16 illustrates the locality of each study area. Overviews of the three study areas are presented next.

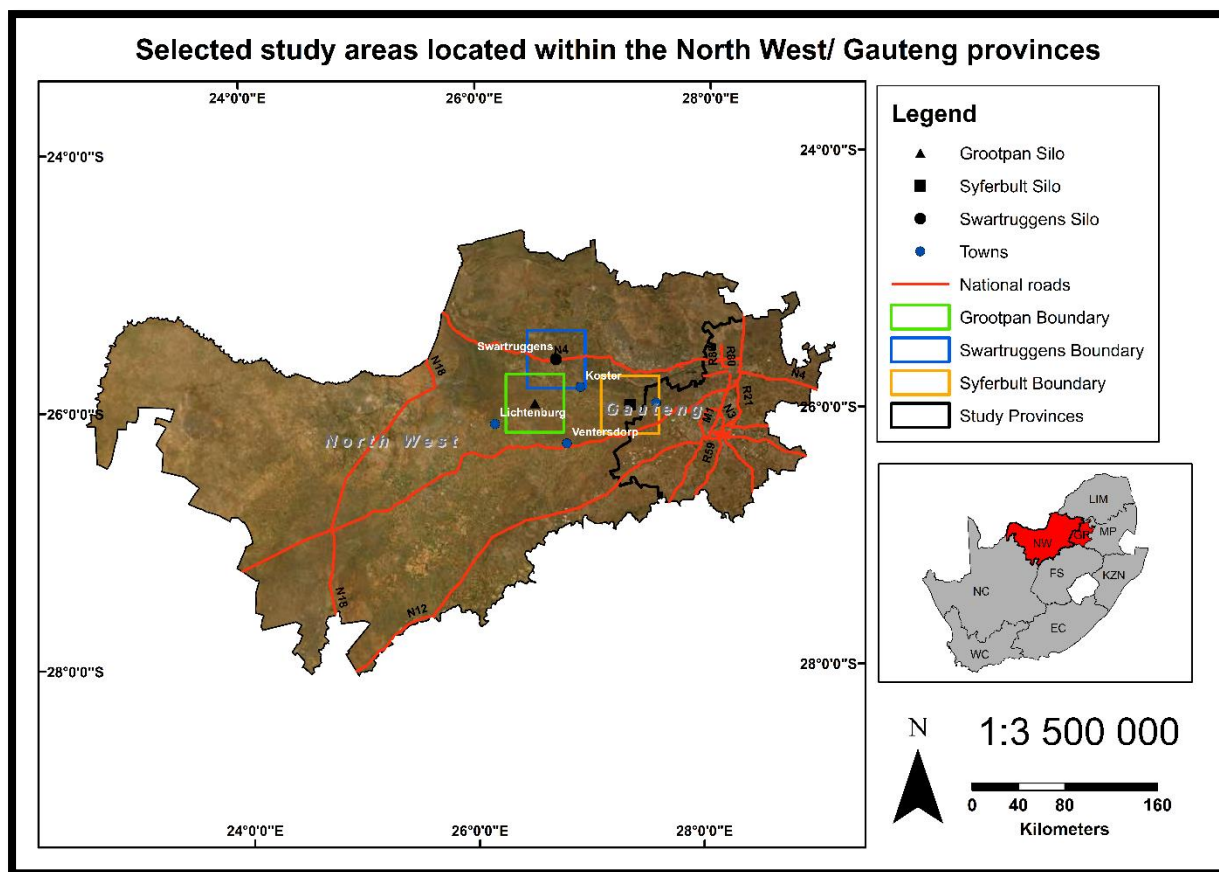


Figure 16: Locality map of identified study areas

3.2.1.4. Study area 1: Grootpan

The NWK Grootpan 1 grain silo is located at 25°59'41" S 26°30'15" E within the Ditsobotla local municipality district of the North West Province. The silo is located 45km from Lichtenburg to the west and 50km from Koster to the east. The study area has an average elevation of 1,537m amsl (above mean sea level) with the base of the silo located at 1,531m amsl. Most of the surrounding area represents small elevation change, except for the north and north-eastern areas where both the lowest point of 1,413m amsl and the highest point of 1,687m amsl are located. The landscape character of the area is dominated with flat open spaced areas with no sudden elevation changes (Figures 13 and 14).

The area is dominated by agricultural activities with irrigation and dry crop fields being some of the most common practices. The rest of the areas are classified as grasslands used for pasture. Taller trees are present near farms, especially around farmhouses which includes the area around the silo. The eastern part of the study area is characterised by shorter trees and shrubs more commonly found in bushveld areas. Figure 17 shows the location of the silo within the study area, as well as the roads in the area.

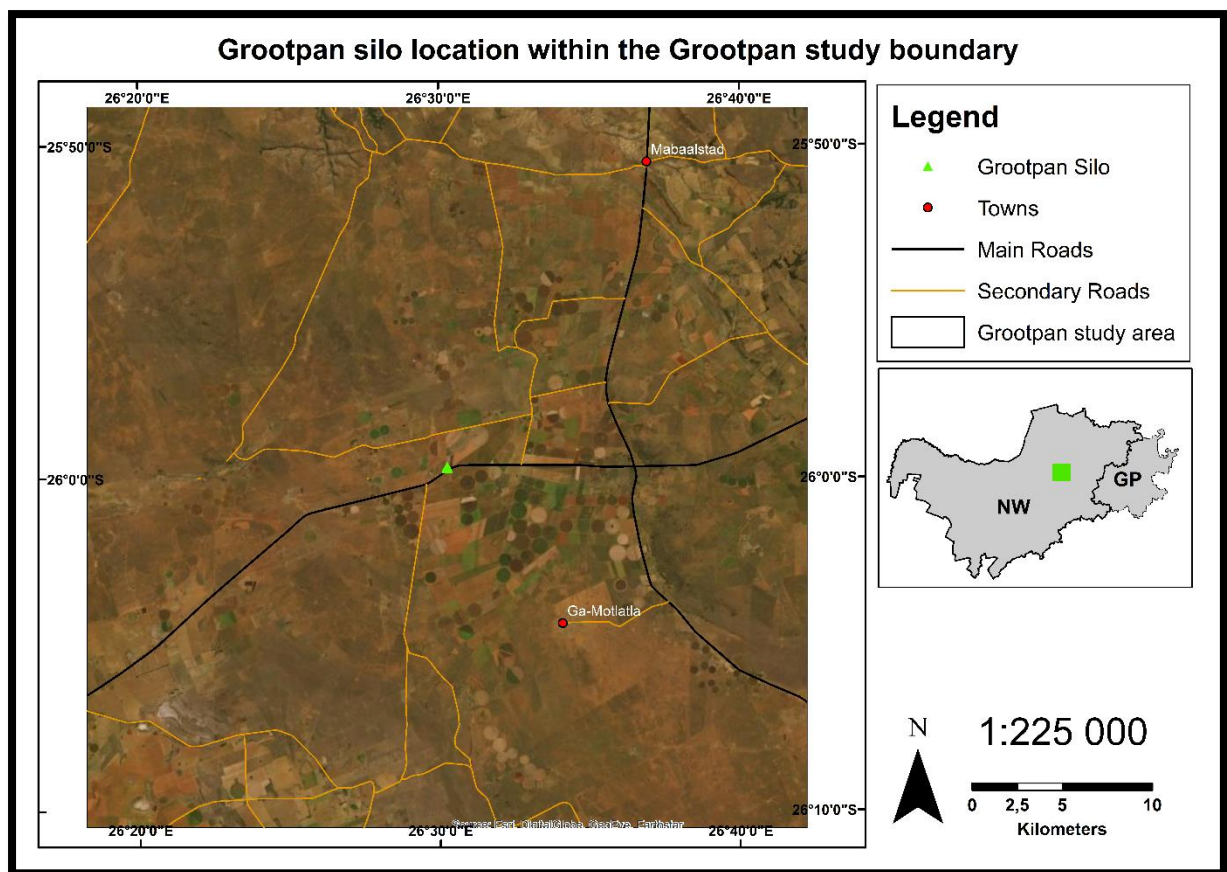


Figure 17: Grootpan study area



Figure 18: Photograph of the Grootpan silo

3.2.1.5. Study area 2: Syferbult

The NWK Syferbult grain silo is located at 26°0'20" S 27°19'30" E within the Rustenburg local municipal district of the North West Province. The silo is located 50km east of the town of Koster. The study area has an average height of 1,529m amsl, with the base of the silo located at 1585m amsl. The highest natural feature in the area is the Magaliesberg mountain, with its highest point at 1,844m amsl. The lowest point is located west of the Magaliesberg at the height of 1,211m amsl. The area is generally characterised by gradually increasing slopes, with prominent topographical features present in the north (Figure 13 and 14).

In comparison to the first study area, more significant elevation changes are observable throughout the area, with prominent landscape features to the north and south of the silo. The silo is located in an area that is slightly lower than the surrounding landscape, which will most likely influence visibility. The area is mostly characterised by agricultural activities, ranging from cultivated fields to game farms. Figure 19 illustrates the location of the silo within the study area.

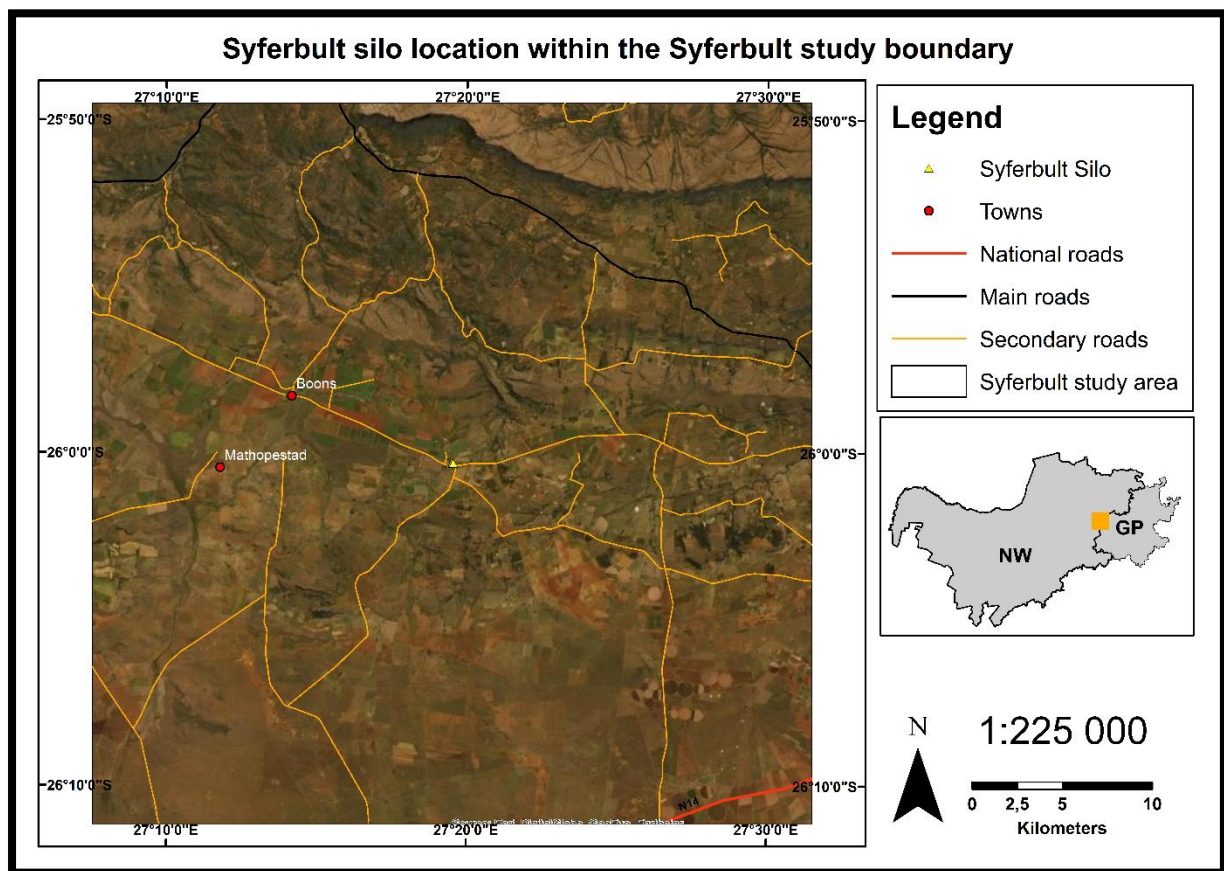


Figure 19: Syferbult study area



Figure 20: Photograph of the Syferbult silo

3.2.1.6. Study area 3: Swaruggens

The NWK Swaruggens grain silo is located at $25^{\circ}39'9''$ S $26^{\circ}41'11''$ E, within the Kgetlengrivier local municipality district. The silo is located 34km north-east of the town Koster. The study area has an average height of 1,359m amsl, with the silo located at 1,255m amsl. The area has significantly more prominent landscape features than the previous two, with most of the northern and eastern parts dominated by valleys and hills. The southern section of the study area shows an increase in elevation up until the highest elevation peak at 1,657m amsl. The lowest part of the study area occurs at the north-eastern corner at 1,047m amsl. A more detailed description of each study areas terrain complexity and topographical features are presented in Figure 13 and 15.

The area is characterised by bushveld areas to the north and east of the silo. The silo is also the only one of the three located within a town. This incorporates the presence of built-up areas as part of the influence of land cover in the study. The study area presented the biggest elevation changes and variety in topographical features of all the areas. The main activities within the area are game farming with other agricultural activities occurring in the south. Figure 21 illustrates the location of the silo in relation to the main roads within the area.

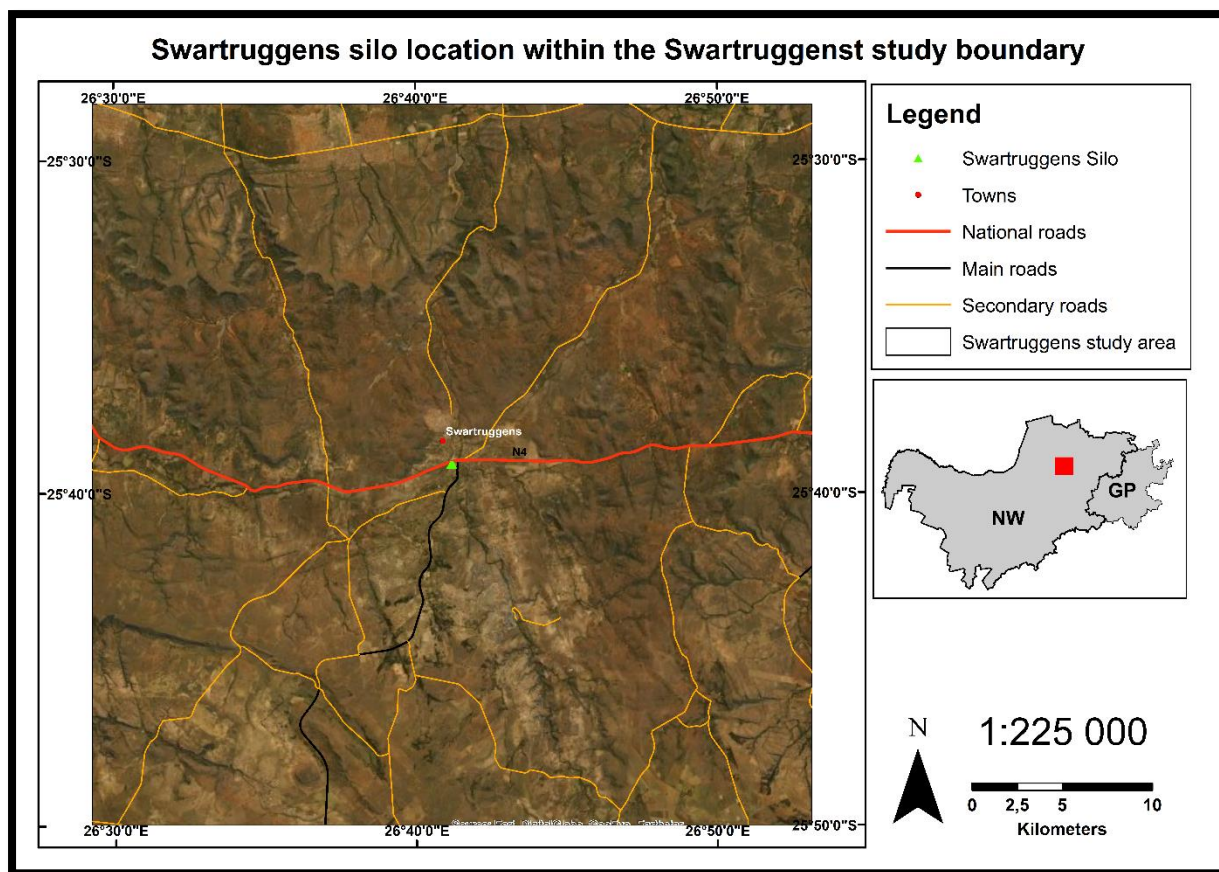


Figure 21: Swartruggens study area



Figure 22: Photograph of the Swartruggens silo

3.2.2. Data collection (Objective 2 - Phase 2)

The second phase of the methodology related to Objective 2 involved data collection (Figure 23). The evaluation of the identified visibility analysis techniques was largely based on existing data (secondary data), although some data capturing also had to be done through fieldwork (primary data). The procedure followed to collect the primary and secondary data is illustrated in Figure 23, and discussed in the following sub-sections. The procedure was compiled by important information required to conduct VIA studies mention by Sullivan and Meyer (2014).

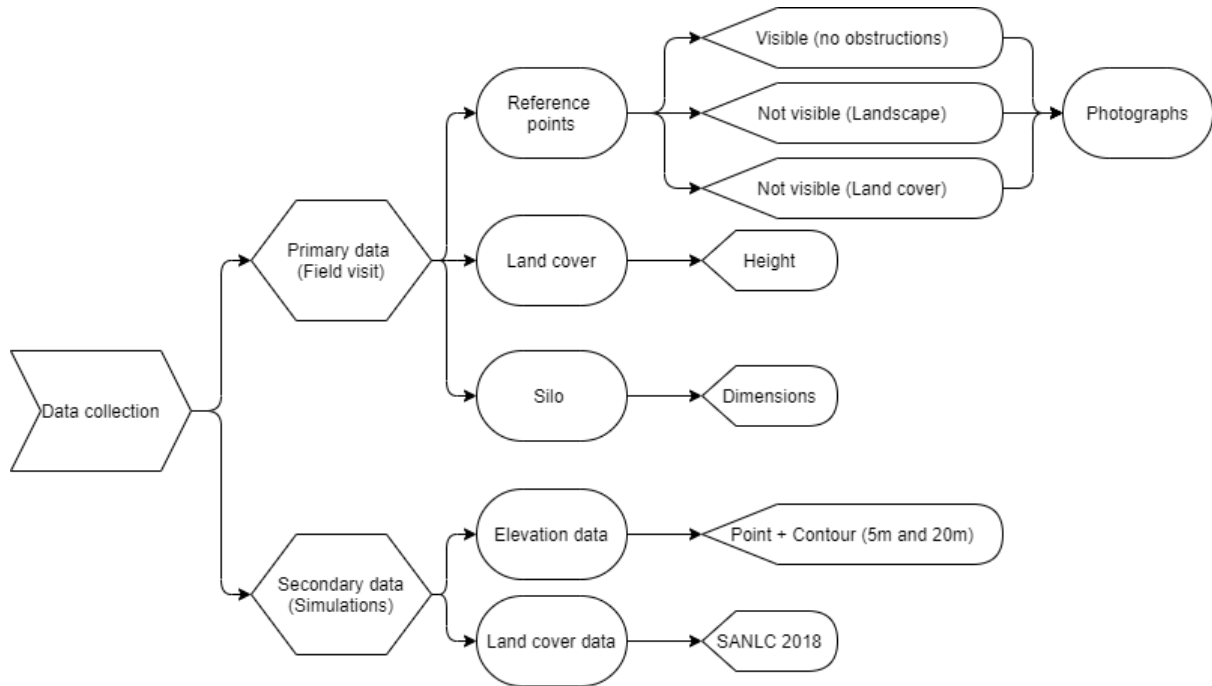


Figure 23: Procedure diagram of the methodology followed to collect data

3.2.2.1. Secondary data

Primary data was supported by secondary data, as they provide the fundamental components on which visibility analysis techniques were simulated. The secondary data collected included elevation values and land cover data for the study areas. The following sub-sections discuss each dataset, and the procedures followed to source and process it.

Elevation data

Elevation data was obtained from the Chief Directorate: National Geo-spatial Information (NGI) national mapping agency of South Africa. Point and contour elevation data at a 5m contour interval was obtained from the NGI for all the study areas except for a small portion of the Swartruggens study area. To address this data gap, point and contour elevation data at a

20m contour interval was obtained to supplement the available 5m data. The area not covered by the 5m elevation data was located on the northern boundary of the area and was not expected to have a significant influence on visibility results.

The point and contour datasets were projected into the WGS 1984 UTM Zone 35S projected coordinate system and clipped according to the square boundary created for each area, as discussed in Section 3.2.1.1. The elevation point data for each study area were randomly divided at an 80/20 ratio to create simulation and evaluation datasets. The simulation datasets (80%) were used (along with contours) to generate DTM's while the evaluation datasets (20%) were used to evaluate the accuracy of the DTM's using root means square error (RMSE) calculations (process discussed in Section 3.2.3).

The 80/20 split was achieved by assigning a unique random value to each point in a dataset using the field calculator python function in ArcMap. The following script was used to assign a value to each point:

Pre-Logic Script Code:

```
import random
def rand():
    return random.random()
SimTest=
rand()
```

The script assigned a random value to each of the elevation points within the attribute table. The "Select by attributes" function in ArcMap was then used to respectively select 80% and 20% of points based on their random values. Table 4 shows the number of elevation points contained in each of the two datasets for the three study areas.

Table 4: Elevation data of each study area

Study area	Simulation points	Evaluation points
Grootpan	4836	1209
Syferbult	1211	302
Swartruggens	2622	655

Land cover data

The South African National Land-Cover 2018 (SANLC 2018) dataset was obtained from the DEFF for use in the study. The dataset contains 73 land-cover classes at a 20m spatial resolution and has a reported accuracy of 90.14% based on 6,570 reference points (Thompson, 2019). The dataset was the most recent land-cover dataset available for the three

areas. It was projected to the WGS 1984 UTM Zone 35S projected coordinate system and clipped to each study area boundary to reduce computation time during further analysis procedures. The land cover dataset was used during the fieldwork to determine relative height values for each class. This was an important step as it ensured the usability of the land cover data for generating DSM's.

3.2.2.2. Primary data

Primary data for each study area was collected on three separate days between the 13th of July 2020 and the 20th of July 2020. Route planning was done before each field visit to ensure that a significant coverage of each area was made. The primary data collected included reference points and a description of the landscape and silo. The following sub-sections provide more detail on what each dataset entails and the procedure used to collect the data.

Reference points

Reference points were collected to evaluate the accuracy of the different visibility analysis technique simulations. A total of 40 reference points was collected for each study area around the silo within the 20km visibility limit as defined in Section 3.2.1.1. The 40 reference points were divided into three groups based on the following visibility and screening criteria:

- 15 Reference points indicating the silo as visible with no screening from either land cover or the landscape;
- 15 Reference points indicating the silo as not visible and screened by the landscape; and
- 10 Reference points indicating the silo as not visible and screened by land cover.

Each reference point was captured on a Garmin eTrex Venture GPS, with a positional accuracy of 3m (Vari, 2002). All points were mapped in the World Geodetic System (WGS) 1984 Geographic Coordinate System and the following information captured:

- X/Y coordinates;
- Description of visibility, as either visible or not visible, with additional information on the amount of silo visible;
- Screening object, as either landscape or land cover, with land cover screening classified as either vegetation or man-made structure;
- Photograph – at each reference point a photograph was taken in the direction of the silo.

The visibility of the silo was considered at a height of 1.8 m, representing the researcher's eye level. All points were documented in an Excel file and transferred to ArcMap Version 10.7 using the WGS 1984 geographic coordinate system. A point feature class was created for each study area's reference points after which the points were projected to the WGS 1984 UTM Zone 35S projected coordinate system. The full information for each observation point is documented in Appendix 1, and all photographs presented in Appendix 2.

Landscape and silo description

For each study area, the following information was collected to generate a description of the area:

- Physical environment: major landforms and vegetation distribution;
- Human environment: the presence of human development and its extent; and
- Land use: description of most common activities occurring within the study area.

In addition to the information collected to generate a description of the study areas, information was collected regarding the relative height values of different land cover types and the dimension values of each silo. The land cover data were collected to generate DSM's for each area and the silo dimensions for the target object height value from which visibility simulations were conducted.

Land cover relative height values were determined using a range finder and the Pythagorean theorem. A Nikon Rifle Hunter 550 rangefinder was used to determine the distance between the researcher and the bottom of the vegetation feature; additionally, the same procedure was repeated to measure the distance to the top of the vegetation feature. The researcher stood at a fixed location during both measurements, while maintaining a 90-degree angle between the observer and feature for the bottom distance measurement.

The method presents some difficulty in certain areas, as the base of trees was not always visible as it would sometimes be screened by grass coverage. In the areas where these factors influenced measurements or the distance between base and top measurement were insignificant, the average height values were estimated. Relative height values for man-made structures were estimated on their classification apart from the silos.

The silo dimensions were obtained from the general manager of each silo. This ensured the correct height and diameter values were incorporated into the simulations. A photograph of each silo was taken during the site visit. Measurements used to aid the determination of vegetation relative height values is documented in Appendix 4.

Table 5: Land cover classification and height values

Class name	Height
Contiguous (indigenous) forest	12m
Contiguous low forest & thicket	5m
Dense forest & woodland	10m
Open woodland	8m
Contiguous & dense plantation forest	15m
Open & sparse plantation forest	15m
Temporary unplanted (clear-felled) plantation forest	0m
Low shrubland (other)	1m
Sparsely wooded grassland	1m
Natural grassland	1m
Natural rivers	0m
Natural pans (flooded @ observation times)	0m
Artificial dams (including canals)	0m
Artificial flooded mine pits	0m
Herbaceous wetlands (currently mapped)	0m
Herbaceous wetlands (previously mapped)	0m
Natural rock surfaces	0m
Dry pans	0m
Eroded lands	0m
Bare riverbed material	0m
Other bare	0m
Cultivated commercial permanent orchards	2m
Commercial annual crops pivot irrigated	2m
Commercial annual crops non-pivot irrigated	2m
Commercial annual crops rain-fed / dryland	2m
Subsistence / small-scale annual crops	2m
Fallow land & old fields (trees)	5m
Fallow land & old fields (bush)	2m
Fallow land & old fields (grass)	1m
Fallow land & old fields (bare)	0m
Fallow land & old fields (low shrub)	1m
Residential formal (tree)	5m
Residential formal (bush)	2m
Residential formal (low veg / grass)	0m
Residential formal (bare)	0m
Residential informal (tree)	5m
Residential informal (bush)	2m
Residential informal (low veg / grass)	0m
Residential informal (bare)	0m
Village scattered (bare & low veg/ grass combo)	0m
Village dense (bare & low veg / grass combo)	0m
Smallholdings (tree)	5m

Smallholdings (bush)	2m
Smallholdings (low veg / grass)	0m
Smallholdings (bare)	0m
Urban recreational fields (tree)	5m
Urban recreational fields (bush)	2m
Urban recreational fields (grass)	0m
Urban recreational fields (bare)	0m
Commercial	4m
Industrial	0m
Roads & rails (major linear)	0m
Mines: surface infrastructure	0m
Mines: extraction pits, quarries	0m
Mine: tailings and resource dumps	15m
Fallow land & old fields (wetlands)	0m

3.2.3. Creating and evaluating Digital Elevation Models (Objective 2 - Phase 3)

The third phase of the methodology to achieve Objective 2 entailed creating DEM's. The methodology is illustrated in Figure 24 and involved three steps:

- Step 1: Create DTM's at four different resolutions sizes;
- Step 2: Evaluate the accuracy of DTM's through RMSE; and
- Step 3: Create DSM's from DTM's.

The procedure applied for each step is now discussed.

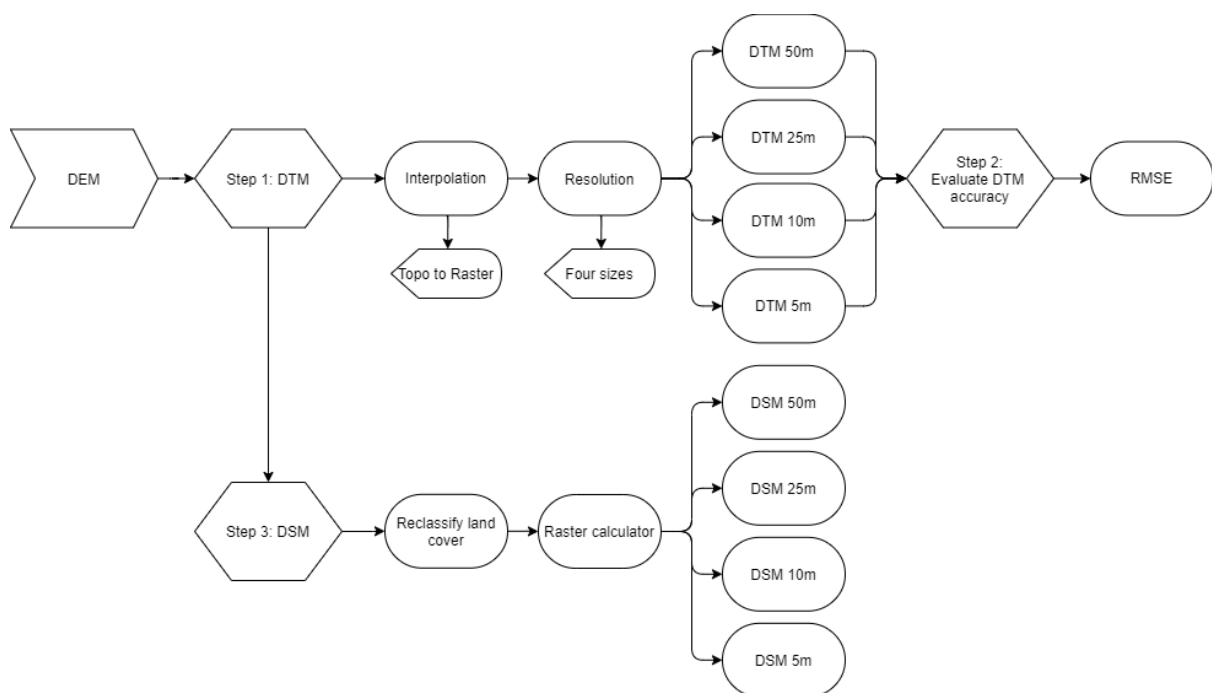


Figure 24: Procedure diagram of the methodology followed to create DEM's

3.2.3.1. Creating Digital Terrain Models (Step 1)

To create a DTM elevation data must be available (Section 3.2.2.2) and a resolution specified (Section 2.1.2.2). The elevation point simulation datasets (80% of points) and contour datasets discussed in Section 3.2.2.2 were used with the 'topo to raster' tool in ArcMap to generate DTM's for the three study areas. The 'topo to raster' interpolation algorithm was used as it was found to be the most suitable interpolation algorithm for terrain modelling, as discussed in Section 2.1.3.1.

DTM's were created at various resolutions, which were determined using the equations developed for this purpose by Hengl (2006):

Equation 3:

$$p = \frac{A}{2(\sum length)}$$

p = Maximum recommended resolution

A = Total area used for the elevation model

$\sum (length)$ = Total length of all contours within the area

Equation 4:

$$pmin = (p * 2)5\% + \text{shortest distance between contours}$$

$pmin$ = Minimum recommended resolution

p = maximum recommended resolution

Table 6 illustrates each study areas total area, total contours, the shortest distance between contours and the number of simulation points used to determine the maximum, recommended and minimum resolution sizes.

Table 6: Data used to determine the resolution size

Study area	Total area (m ²)	Total contours (m)	The shortest distance between contours (m)	Simulation points
Grootpan	1,600,000,000	5,472,270	1.3	4,836
Syferbult	1,600,000,000	19,842,567	0.2	1,211
Swartruggens	1,600,000,000	27,786,135	0.6	2,622

Equation 3 was used to determine the maximum resolution at which the data could be interpolated without compromising on terrain features. Equation 4 was used to determine the minimum resolution that could be used without creating significant artefacts within the elevation model. Hengl (2006) states that the recommended resolution is found between the maximum and minimum resolution values. The resolution range for each study area is illustrated in Table 7.

Table 7: Resolution range of each study area

Study Area	Maximum resolution (m)	Recommended resolution (m)	Minimum resolution (m)
Grootpan	146.2	81.1	15.9
Syferbult	40.3	22.3	4.3
Swartruggens	28.8	16.1	3.5

The resolution range of each study area varied as a result of the difference in total contour length available. This is because areas with longer total contour lengths likely represented areas with more topographical features and generally higher terrain complexities. This significantly influenced the resolution range of the Grootpan study area, which was generally characterised by flatter slopes and a less complex environment. The following four resolution sizes were eventually used to create DTM's of each study area: 50m, 25m, 10m and 5m. Although the resolution range exceeded the maximum resolution value determined for Syferbult and Swartruggens as well as the minimum resolution range of Grootpan, it was used to allow for the creation of DTM's with significant resolution range between each DTM, while still providing a sense of accuracy by staying near to the determined values. As discussed in Section 2.1.3.2 exceeding the minimum resolution size can produce artefacts and may influence DTM's accuracy, additionally generating elevation models at not a fine enough resolution size may misinterpret topographical features. Exceeding the resolution ranges incorporated the capability to evaluate whether the statements are true and how exceeding the recommended range effect visibility analysis techniques. The following section

presents more context on DTM accuracy by validating each DTM to the evaluation dataset created in an earlier section of the methodology.

3.2.3.2. Evaluating Digital Terrain Model accuracy (Step 2)

The RMSE value for each DTM was determined through cross-validation between the evaluation elevation points (20% of points not used in interpolation) and predicted values extracted from the relevant DTM at the locations of each of the elevation points. RMSE is a standard measurement of map accuracy (Eldrandaly & Abu-Zaid, 2011) and is aimed at providing a statistical measurement of vertical accuracy (Razak *et al.*, 2013). The method, therefore, required predicted elevation values to be compared against known values. The “Extract multi-values to points” tool in ArcMap was used to extract the predicted elevation values of each DTM for the locations of each point in the evaluation dataset. This resulted in a known elevation value and a predicted elevation value for the same location that could be compared using RMSE. All values were stored in Excel files where Equation 5 was used to determine an RMSE value for each DTM. The lower the resulting RMSE value, the higher the accuracy of the DTM.

Equation 5:

$$RMSE = \sqrt{\sum_{i=1}^n \frac{(P_i - P_i^*)^2}{n}}$$

RMSE= Root means square error

P_i= Predicted value

P_i^{*}= Evaluation value

n= Number of observations

3.2.3.3. Creating a Digital Surface Models (Step 3)

The method used to create DSM's for each study area were based on studies done by Garnero and Fabrizio (2015), Klouček *et al.* (2015) and Rogge *et al.* (2008). The method utilizes an existing DTM and adds land cover elevation values to the DTM through height values assigned to each land cover class. As part of Section 3.2.2.2 relative height values were determined for the SANLC 2018 dataset through fieldwork.

The land cover dataset was resampled at 50m, 25m, 10m and 5m as the original resolution size of 20m would not allow the DSM10m and DSM5m to be created at the specific resolution sizes. The resampling was not necessary for the DTM25m and DTM50m as it did not affect

the resolution size as with the smaller DTM's, specifically the procedure ensured the same steps were taken for all DTM's to ensure better comparability.

3.2.4. Testing visibility analysis approaches (Objective 2 - Phase 4)

The last phase of the methodological procedure followed to achieve Objective 2 (Figure 8) was testing the different visibility analysis techniques in the three study areas and across different resolutions and DEM's. The document analysis procedure in Section 3.1.2 identified viewshed analysis, cumulative viewshed analysis and LOS analysis (detailed results discussed in Chapter 4) as techniques most often used in VIAs. The three methods were tested using the different DTM's and DSM's generated in Section 3.2.3, as discussed in the sub-sections below. Figure 25 illustrates a summary of the methodological procedure, while a more detailed diagram is presented in each sub-section.

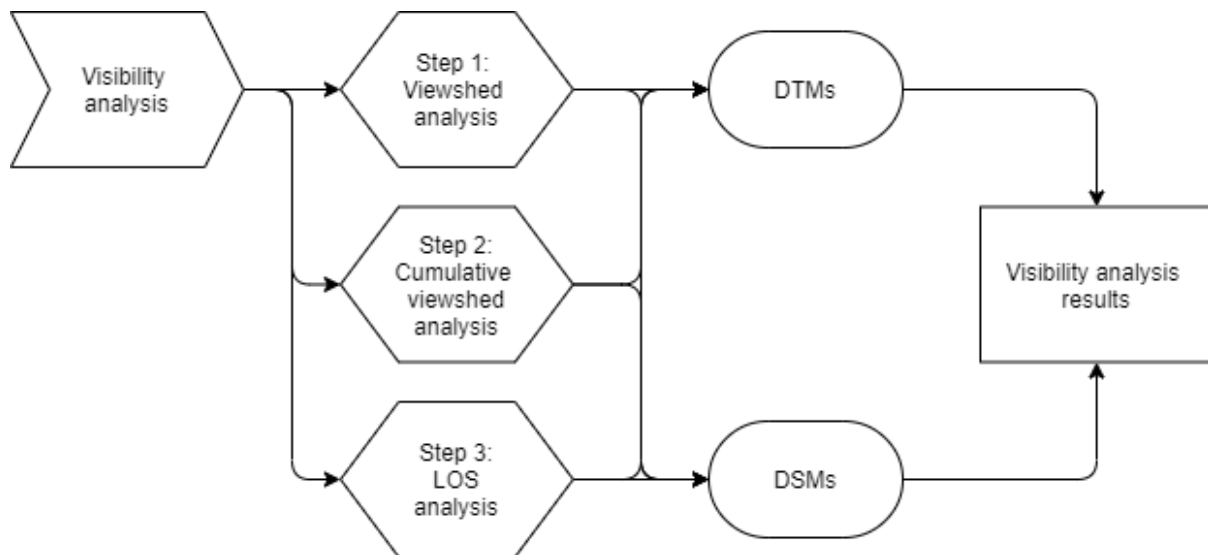


Figure 25: Procedure diagram of the methodology followed to simulate visibility analysis techniques

A total of 72 simulations were conducted distinguished in terms of study area, DEM type and resolution (Table 8). The silo height values were determined during the field visit as described in Section 3.2.2.1, while the observer height was set at 1,8m as this height conforms to the height value used to collect the reference points.

Table 8: Visibility analysis simulations with the associated variables

Study area	Visibility analysis technique	Silo height (m)	Observer height (m)	Simulation number							
				DTM				DSM			
				50m	25m	10m	5m	50m	25m	10m	5m
Grootpan	Viewshed analysis	23	1.8	1	2	3	4	13	14	15	16
Grootpan	Cumulative viewshed analysis	23	1.8	25	26	27	28	37	38	39	40
Grootpan	Line-of-sight analysis	23	1.8	49	50	51	52	61	62	63	64
Syferbult	Viewshed analysis	37	1.8	5	6	7	8	17	18	19	20
Syferbult	Cumulative viewshed analysis	37	1.8	29	30	31	32	41	42	43	44
Syferbult	Line-of-sight analysis	37	1.8	53	54	55	56	65	66	67	68
Swartruggens	Viewshed analysis	37	1.8	9	10	11	12	21	22	23	24
Swartruggens	Cumulative viewshed analysis	37	1.8	33	34	35	36	45	46	47	48
Swartruggens	Line-of-sight analysis	37	1.8	57	58	59	60	69	70	71	72

3.2.4.1. Running viewshed analysis (Step 1)

A total of 24 viewshed simulations were done across the three study areas (Table 8). Figure 26 illustrates the process followed to simulate viewshed analysis which is discussed below.

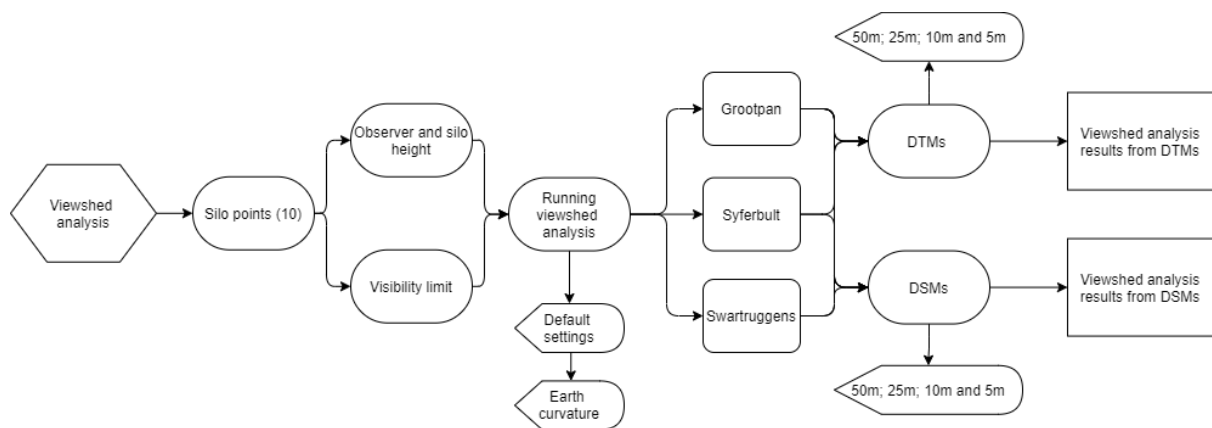


Figure 26: Viewshed analysis methodological procedure

- Sub-step 1: Generated ten points to represent the location of each silo (Figure 27). Polygons were generated to determine the midpoints of the outer silo towers and were

generated from two GPS points representing the furthest points of the silos, as shown in red in Figure 27. A buffer of 15m in diameter was generated for each point to represent the width of the silos as determined during the field visit. Two new points (green) were then generated from the buffers to represent the centre of the outer silo towers. The newly generated points were used to create new buffers at 15m in diameter to represent the outer silo towers. A polygon was generated for each silo by connecting the buffers. The polygons were divided into ten equal vertices using the “Densify” tool in ArcMap. The “Feature vertices to points” tool were used to create ten points from the newly densified polygon represented in blue in Figure 27.

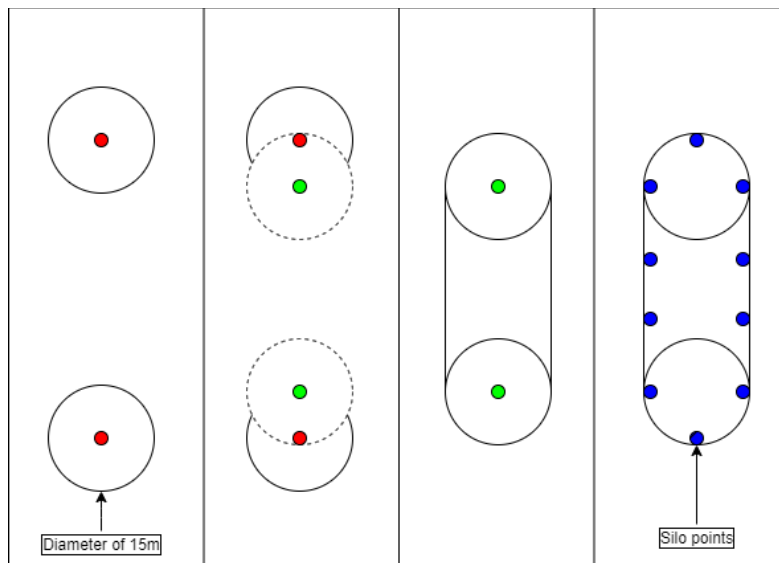


Figure 27: Procedure followed to generate silo boundary points for visibility analysis simulations

- Sub-step 2: Integrate an OFFSETA, and OFFSETB value in the silo points attribute table. An OFFSETA value of 23m was assigned to the Grootpan silo points, and a 37m to the Syferbult and Swartruggens silo points attribute table. The OFFSETA would offer the viewshed tool with the required height values of the silos to determine visibility from. An OFFSETB value of 1.8m was assigned to each study areas silo points attribute table. The 1.8m would be added to each cell in the DEM's to represent the height of an observer – 1.8m was used as it represents the researcher's eye-level height and the height used to collect the reference points during the field visit discussed in Section 3.2.2.1.
- Sub-step 3: Define a limit of visibility distance. A RADIUS2 value of 20 000m was integrated into the same attribute tables as sub-step 2. The distance of 20 000m was used as it was determined in Section 2.1.2.3 as the distance at which visibility significantly decreases.

- Sub-step 4: Simulate viewshed analysis. All settings were kept to the default except for the inclusion of earth curvature. Earth curvature was included as objects disappear under the horizon over an increase in distance, as discussed in Section 2.1.2.3.

3.2.4.2. Running cumulative viewshed analysis (Step 2)

A total of 24 cumulative viewshed simulations were done across the three study areas, as shown in Table 8. Figure 28 illustrates the process followed to simulate cumulative viewshed analysis.

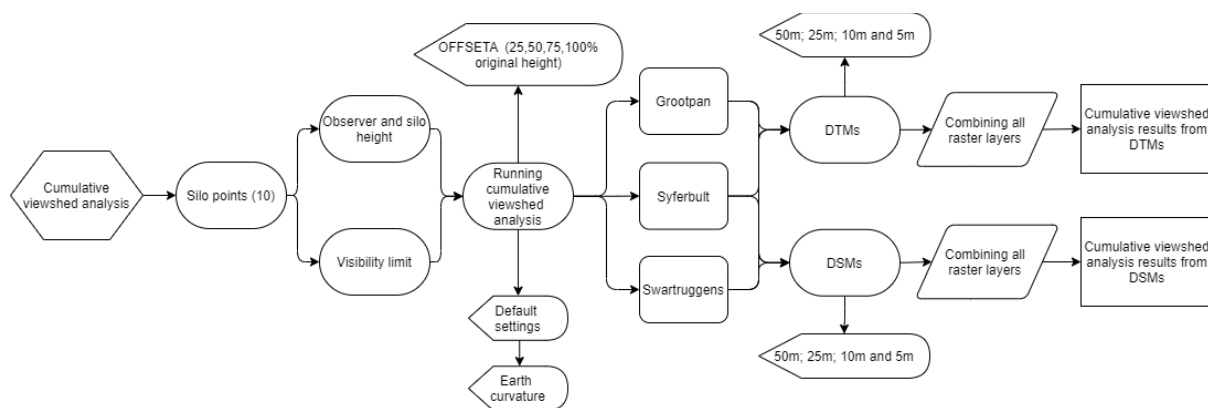


Figure 28: Cumulative viewshed analysis methodological procedure

- Sub-step 1: Silo points. The same silo points generated for viewshed analysis were used in the cumulative viewshed analysis simulations, as well as the same OFFSETB and RADIUS2 values.
- Sub-step 2: Integrate multiple OFFSETA values. Multiple OFFSETA values were assigned to the attribute tables of the silo points; specifically, the values were determined on a 25, 50, 75 and 100% basis of the original silo height value. Table 9 presents the determined values for each study area at specific percentages. A point layer for each height value was generated for simulations.
- Sub-step 3: Simulate cumulative viewshed analysis. All settings were kept to the defaults except for the inclusion of earth curvature. Earth curvature was included as objects disappear under the horizon over an increase in distance, as discussed in Section 2.1.2.3.
- Sub-step 4: Combine cumulative viewshed analysis results in one raster layer. Each simulation run generated four layers illustrating visibility in the study areas at different silo height values. These layers were combined through the raster calculator function

in ArcMap to construct one layer illustrating the degree of visibility in terms of the percentage of silo visible.

Table 9: Cumulative viewshed OFFSETA values

Study area	OFFSETA (25%)	OFFSETA (50%)	OFFSETA (75%)	OFFSETA (100%)
Grootpan	5.75m	11.5m	17.25m	23m
Syferbult	9.25m	18.5m	27.75m	37m
Swartruggens	9.25m	18.5m	27.75m	37m

3.2.4.3. Running Line-of-sight analysis (Step 3)

A total of 24 LOS analysis simulations were done across the three study areas, as shown in Table 8. Figure 29 illustrates the process followed for the LOS analysis.

- Sub-step 1: Define an area limit for the LOS visibility simulations. A buffer was created for each study area at 19 995m from the centre of the study area. The limit of visibility was smaller as the other two techniques to ensure all points generated in Sub-step 2 would be located on the relevant DEM's.

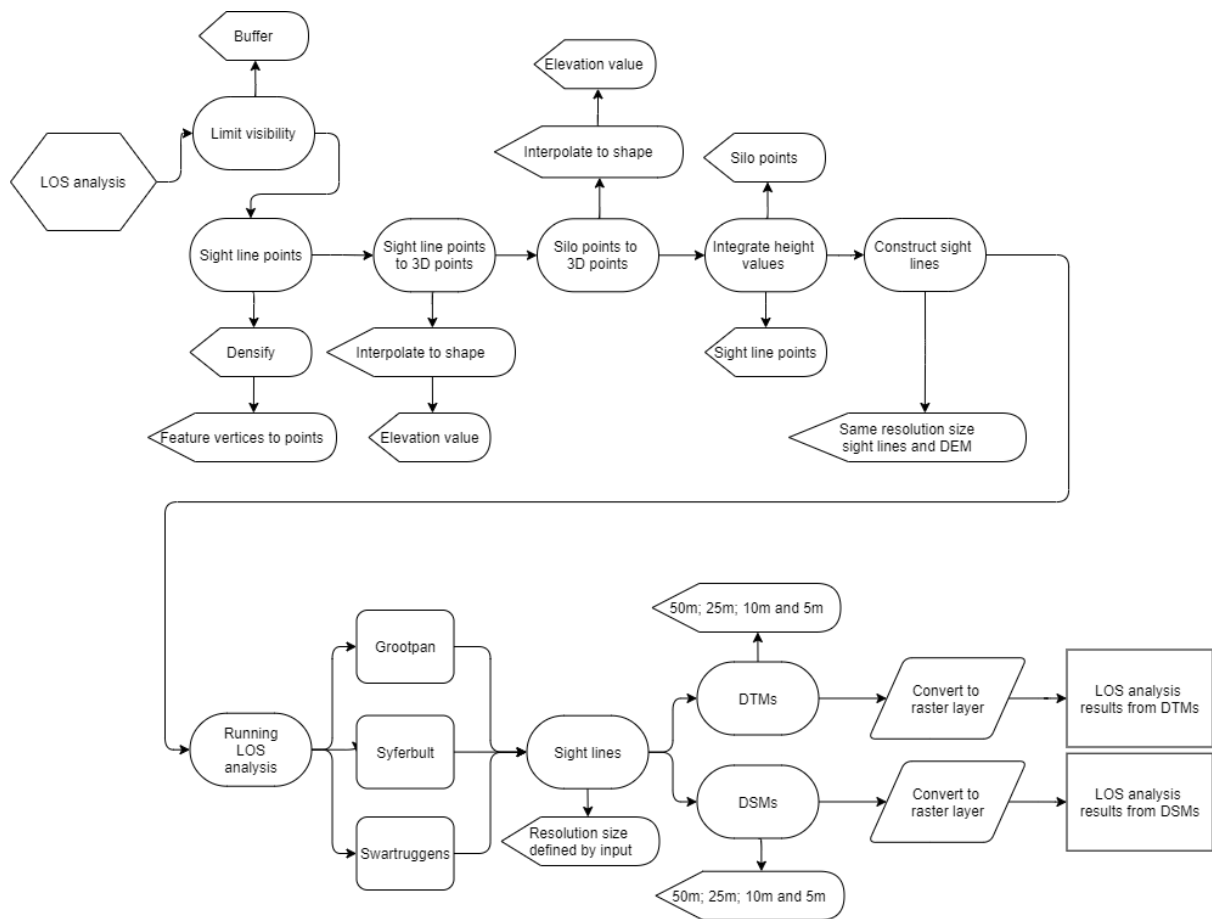


Figure 29: LOS analysis methodological procedure

- Sub-step 2: Generate sightline points. The “Densify” tool in ArcMap was used to divide the buffers generated in Sub-step 1 into vertices of 10m (lying on the boundary of the study area). The newly defined vertices were converted to points through the “Feature vertices to points” tool in ArcMap. The distance of 10m between points was decided on as it presents a close enough distance between points to generate enough sightlines to present visibility, and allowed for the results to be converted to a raster surface at a suitable resolution.
- Sub-step 3: Convert sightline points to 3D points. Sightline points were converted to 3D points based on the DTM’s and using the “Interpolate to shape” tool in ArcMap. Four sightline datasets were converted for each DTM resolution size. Specifically, each of the four datasets would be used in sub-step 5 to present different height.
- Sub-step 4: Convert silo boundary points to 3D points. The silo points generated in Sub-step 1 of viewshed analysis was converted to 3D points. The same procedure followed is Sub-step 3 above was used to convert points to 3D points and assign an elevation value.

- Sub-step 5: Integrate the height values of observers and silos. The height of the observer (1.8m) and height values of the silos (Grootpan 23m; Syferbult 37m; and Swartruggens 37m) were added to the newly created datasets created in Sub-steps 3 and 4. A new field was created in each dataset to represent the height values of the observer or silo. A value of 1.8m was added to the sightline point height determined in Sub-step 3 and integrated into the new field. The same procedure was done for the silo height values.
- Sub-step 6: Construct sightlines. Sightlines were generated between the silo points and the sightline points with the height values assigned to the points in Sub-step 5 used as the input values. The step was repeated for all datasets to generate sightlines for all study areas at the defined resolution sizes.
- Sub-step 7: Simulate LOS analysis. The “Line of sight” tool in ArcMap was used to determine visibility from the sightlines generated in Sub-step 6. The sightlines dataset and the DTM at the same resolution sizes were used to generate a visibility layer. The same sightlines were used with the DSM to ensure the observer (sightline points) and silo points height values were based on the ground surface and not influenced by the additional elevation of land cover features.
- Sub-step 8: Convert LOS results to a raster format. The “Polyline to raster” tool in ArcMap was used to convert the LOS results to a raster surface. The resolution size of the DEM used in the visibility analysis determined the resolution size at which the result layer was converted. The conversion was done to generate a surface comparable to the other methods.

This section explained how the different visibility analysis techniques were tested in the three study areas using different variables. To determine which approach would be most suitable for visibility analysis in VIA, each of the 72 simulations was assessed for accuracy to inform Objective 3.

3.3. Objective 3: Determine an optimal visibility analysis approach for use in VIA

The final objective of the study was to determine an optimal visibility analysis approach for use in VIA. The process of determining an optimal visibility analysis approach involved an accuracy assessment of the 72 visibility analysis results. The methodological approach followed to achieve Objective 3 is illustrated in Figure 30 and discussed.

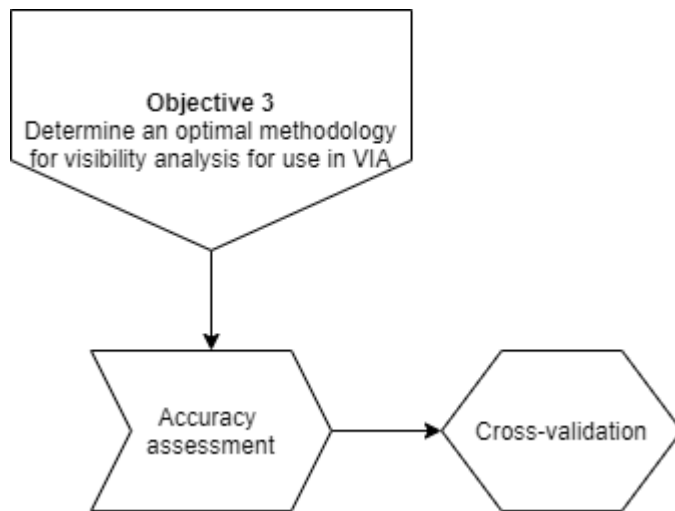


Figure 30: Procedure diagram of the methodology followed to assess visibility analysis simulations

3.3.1. Accuracy assessment through cross-validation

The accuracy of the 72 simulations was assessed through a cross-validation conducted between the visibility results (Section 3.2.4) and the visibility reference points collected during the field visit (Section 3.2.2.1). The approach was followed as Sullivan and Meyer (2014) suggest observation points to be used to evaluate simulations. Figure 31 illustrates the process followed to determine the accuracy of each visibility analysis simulation.

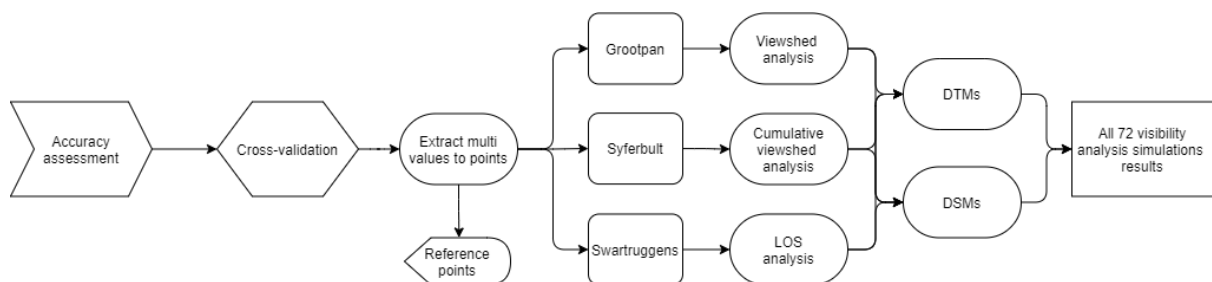


Figure 31: Accuracy assessment methodological procedure

The “Extract multi values to points” tool in ArcMap was used to extract the visibility results for each of the reference points across the 72 simulations. The extracted values were exported to Excel where the predicted visibility could be compared to the observed visibility and an accuracy percentage for each simulation determined. The results of Objective 1, 2 and 3 are next presented in Chapter 4.

Chapter 4: Results

The findings are presented in Chapter 4 and are structured against the three objectives of the study. Results from the document analysis procedure are presented first (Objective 1), followed by the DEM's that were created and the results for the 72 visibility analysis simulations (Objective 2). The results for the accuracy assessment for the visibility simulations are finally presented (Objective 3).

4.1. Current methodological approaches used for visibility analysis in VIA (Objective 1)

The results presented in this section relates to Objective 1 of the study, which was to determine the commonly used visibility analysis approaches often used in VIA in South Africa. Table 10 present the findings obtained from the document analysis procedure discussed in Section 3.1.

Table 10: Document analysis results obtained from the VIA reports

Report reference	Visibility technique	DEM	Perspective	Land cover screening	Visibility limit
12/12/20/777	Viewshed analysis	NIA ³	NIA	No	NIA
14/12/16/3/3/1/909	Viewshed analysis	DTM	Projects	No	Limit
12/12/20/2646	Cumulative viewshed	DTM	Project/Degree of visibility	No	Buffer zones
17/2/3GS-109	Viewshed analysis	DTM	Projects	No	NIA
12/12/20/2085	Cumulative viewshed	DTM	Projects/Amount of objects visible	No	NIA
14/12/16/3/32/336	Viewshed analysis	DTM	NIA	No	NIA
12/12/20/2564	Viewshed analysis	NIA	Projects	No	Buffer zones
14/12/16/3/3/3/211	Viewshed analysis	DTM	Projects	No	Limit
14/12/16/3/3/2/439	Viewshed analysis	NIA	Projects	No	Limit
14/12/16/3/3/3/40	Viewshed analysis	DTM	Projects	No	Buffer zones
12/1/9/2/-GS24	Viewshed analysis	DTM	Projects	No	NIA
12/12/20/2500	Viewshed analysis	DTM	Projects	No	Limit

³ No information available

FSP/EIA/0000386/2014	Cumulative viewshed	DTM	Projects/Different locations	No	Limit
17/2/3N-344	Viewshed analysis	NIA	Observers	No	NIA
14/12/16/3/3/2/962	Viewshed analysis	DTM	Projects	No	NIA
12/1/9/2-W58 (IRON)	Cumulative viewshed; Line of sight	DTM	Project/ Sensitive areas	No	Limit
12/1/9/2-W58 (PLATINUM)	Cumulative viewshed; Line of sight	DTM	Project/ Sensitive areas	No	Limit
14/12/16/3/3/2/390	Cumulative viewshed	DSM	Project / Degree of visibility	Yes	Buffer zones
14/12/16/3/3/1/1730	Field assessment	NA	Observers	No	NIA

Viewshed analysis was identified as the visibility analysis technique most often used in VIAs in South Africa and was applied in 63% of the reviewed VIA reports. Cumulative viewshed analysis was applied in 31% of the reports, while LOS analysis was applied in only two of the VIA reports and always in combination with cumulative viewshed analysis. One VIA report determined visibility through a field visit alone.

DTM's were used in 69% of visibility analysis simulations, making it the most common DEM used for visibility analysis. In comparison, only one VIA report used a DSM to determine visibility. Four other reports provided no information specifying the type of DEM used while the VIA report in which visibility analysis was conducted through a field visit did not use a DEM at all.

Visibility analysis simulations were mostly conducted from the project's (target object's) perspective (79% of VIA's), while visibility analysis conducted from the observer's perspective was done in only two of the VIA reports – which in itself is an interesting finding. Two VIA reports presented no information regarding the perspective from which visibility was determined.

Only one VIA report mentioned the use of land cover as a factor that was considered in the visibility analysis. Most other reports indicated that it would either have no significant impact on visibility or that the worst-case scenario was simulated (which was, however, not verified in any way). Visibility limits incorporated in simulations were more comparable than the other variables with buffers zones used in 21% of reports and a limit on visibility in 37% of VIA reports. Most reports (42%), however, included no information regarding a limit on visibility.

The visibility analysis techniques and variables identified through Objective 1 were evaluated and tested through a series of simulations, the results of which are presented in the following section.

4.2. Results from identified visibility analysis simulations (Objective 2)

The results presented in this section relates to the testing and evaluation of the identified visibility analysis approaches across different terrain complexities and using different variables as described in Section 3.2. The DTM's and DSM's generated for use in the visibility analysis simulations are presented first (Section 4.2.1), followed by the results from the visibility analysis approaches that were tested (Section 4.2.2).

4.2.1. Digital elevation models

The generated digital terrain models (DTM's) (4.2.1.1) and their accuracy results (4.2.1.2) are presented first, followed by the digital surface models (DSM's) that were derived from them (4.2.1.3).

4.2.1.1. *Digital terrain models*

The following maps show the DTM's developed for each study area at the four different resolutions as discussed in Section 3.2.3.1. The DTM's are presented per study area: Grootpan (Figure 32); Syferbult (Figure 33); and Swartruggens (Figure 34).

Grootpan DTM's

The Grootpan study area presents an area dominated by flat slopes with the biggest variations in elevation occurring in the northern part of the area.

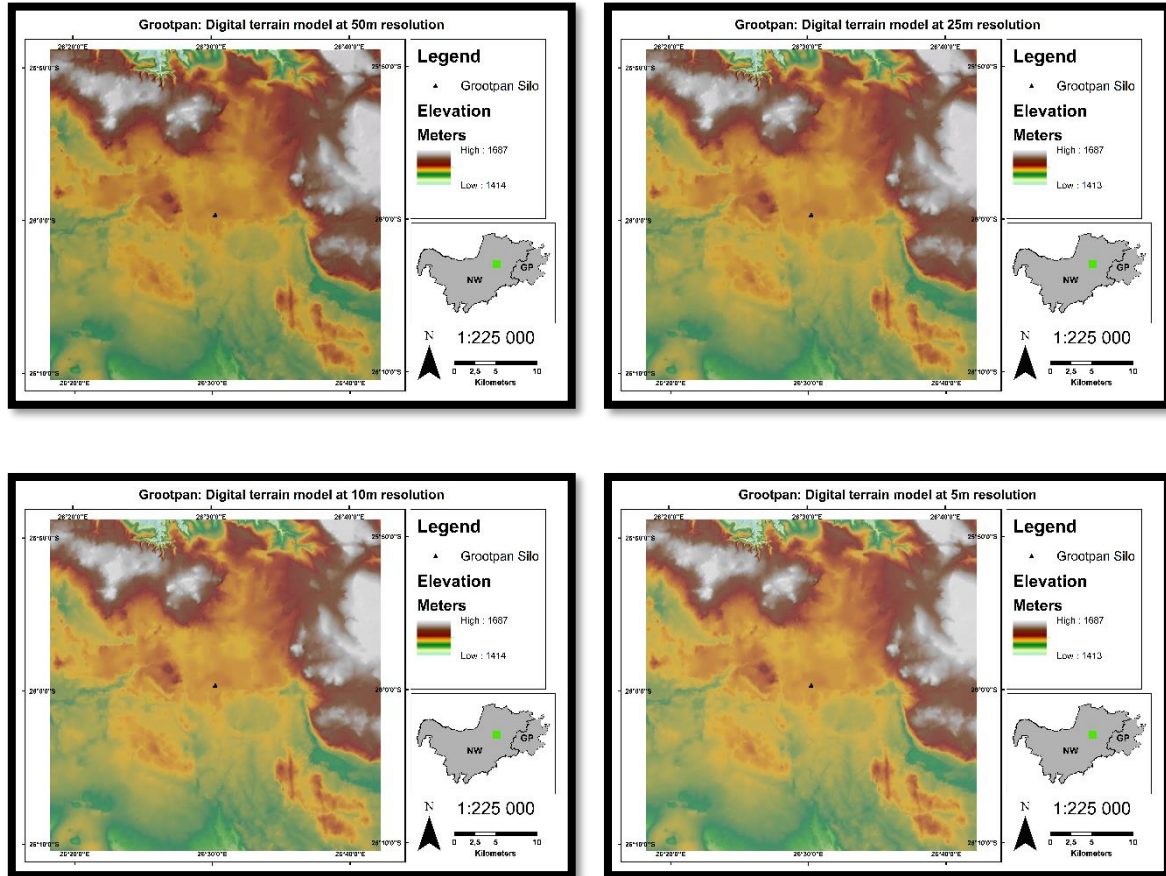


Figure 32: Digital terrain models of the Grootpan study area at the different resolutions

Syferbult DTM's

The Syferbult study area is characterised by significant topographical features to the north and flat slopes to the south.

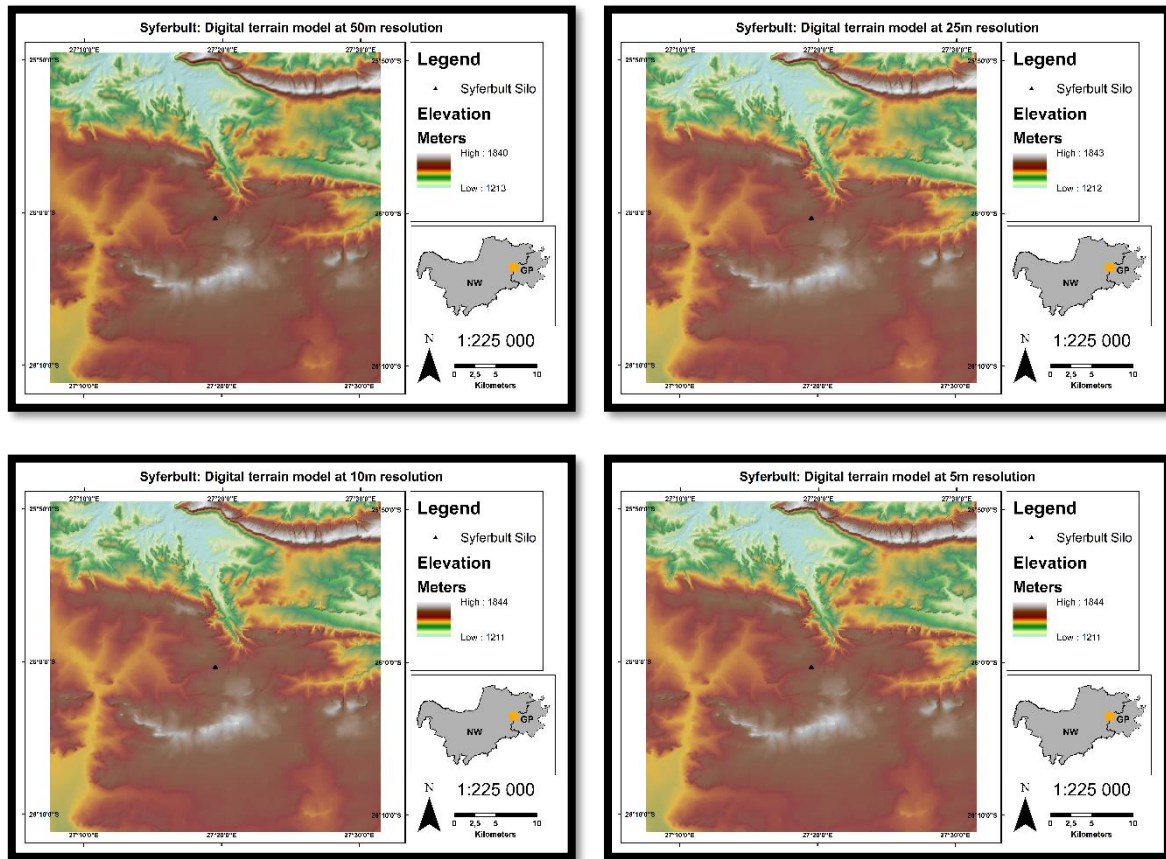


Figure 33: Digital terrain models of the Syferbult study area at the different resolutions

Swartruggens DTM's

The Swartruggens study area is characterised by significant topographical features throughout the area, which includes significant valleys and hills.

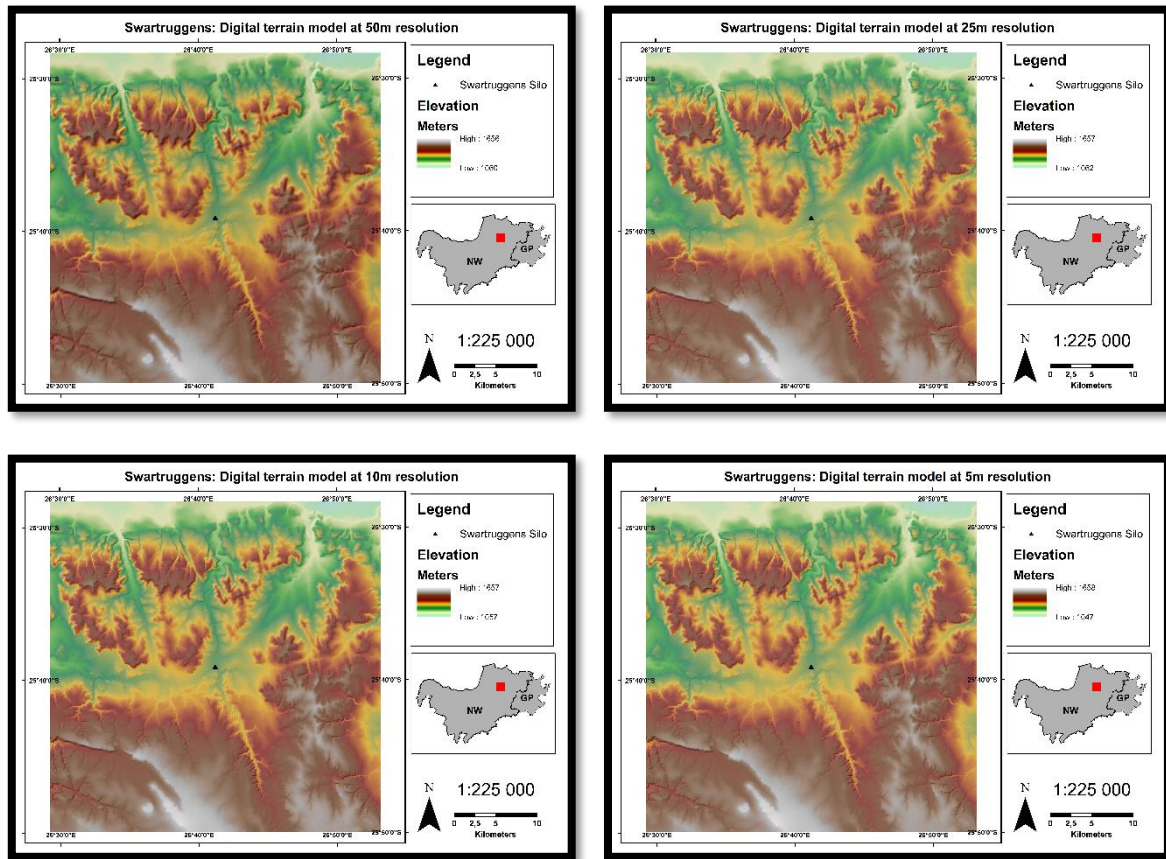


Figure 34: Digital terrain models of the Swartruggens study area at the different resolutions

From a purely visual perspective, very few differences could be observed between the DTM's at different resolutions. It was observed that DTM's at finer resolutions appeared to be clearer. However, important features such as hills and valleys seemed to be present in results at all resolutions. A more prominent difference in DTM's at different resolutions may be more observable from the RMSE calculations that follow.

4.2.1.2. RMSE of digital terrain models

Table 11 and Figure 35 present the RMSE findings determined for each of the DTM's in each study area.

Table 11: Root means square error and test points

Study area	Number of test points	DTM 5m	DTM 10m	DTM 25m	DTM 50m
Grootpan	n= 1209	1.32	1.32	1.52	2.00
Syferbult	n= 302	2.36	3.17	13.16	48.94
Swartruggens	n= 655	1.83	1.95	3.68	10.88

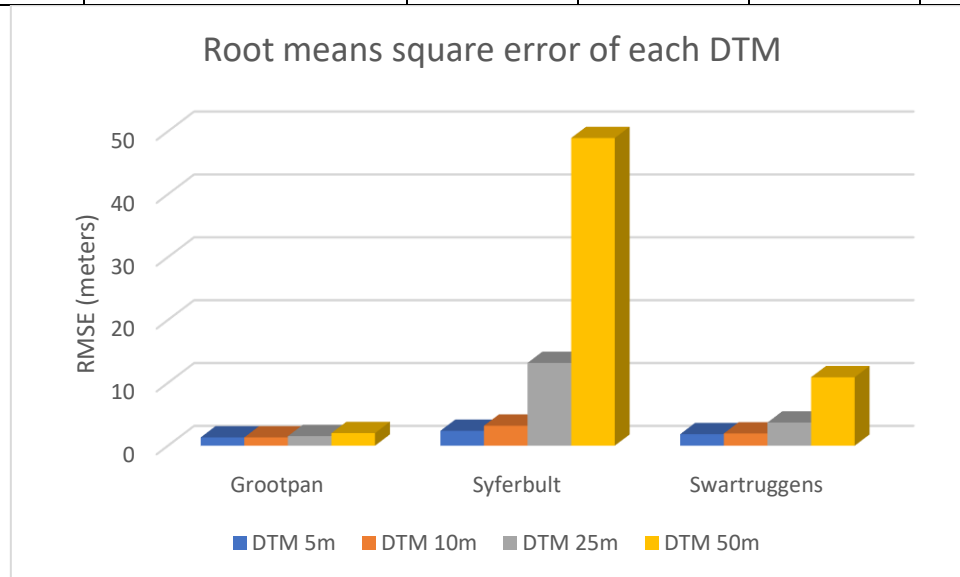


Figure 35: Graph representing the determined RMSE values of each digital terrain model

The RMSE values present more insight into the accuracy of the DTM's generated. The Grootpan study area showed the smallest variation in RMSE scores across the different resolutions, with only a 0.68 m difference between the DTM5m and DTM50m. The other two study areas showed much larger variations with values of 9.05 m and 46.58 m for Swartruggens and Syferbult, respectively.

An overall trend that was observed in all study areas was that the DTM's generated at finer resolutions proved to be more accurate than those developed at coarser resolutions. However, the Grootpan at DTM5m and DTM10m exceeded the resolution range of 15.93 m determined in Section 3.2.3.1, while minimal increases in accuracy were observed. Exceeding the minimal resolution range may, therefore, not always generate a significant increase in accuracy, while exceeding the maximum resolution size may present a different finding.

The Syferbult at DTM5m and DTM10m showed relatively low RMSE scores when compared to the other two study areas. The relatively low RMSE scores were for DTM's close to the

minimum resolution range determined, while the DTM25m resolution size was near the recommended resolution of 22.3m and presented a high RMSE score of 13.16m. The increase in RMSE was even more severe at the DTM50m resolution size, with an RMSE score of 48.9 m. Notably, the DTM50m resolution exceeded the maximum resolution determined at 40.32 m, indicating that exceeding the maximum resolution size results in a significant increase in RMSE. Despite the higher RMSE value, the DTM was included in the simulations to assess its influence on visibility analysis accuracy. The higher RMSE scores may be due to the sudden increase in elevation in the Magaliesberg region.

The Swartruggens study area's determined resolution range was the smallest compared to the other two study areas. This was mainly due to its terrain complexity. When comparing the RMSE scores from Swartruggens to those of Syferbult, all resolutions presented a lower RMSE score. A significant increase in RMSE values was observed in the Syferbult DTM25m and DTM50m resolution, especially when exceeding the maximum resolution size. However, the Swartruggens RMSE scores for the same resolutions presented lower scores although its determined minimum resolution size was 28.79 m. This suggests that the RMSE scores were more affected by the intensity of elevation change in the Syferbult study area rather than the frequency of elevation change in the Swartruggens study area.

Most of the DTM's had acceptable RMSE scores with the exceptions of Syferbult DTM25m Syferbult DTM50m, and the Swartruggens DTM50m. All DTM's were used in the visibility analysis simulations to determine the relationship between DTM accuracy and visibility analysis simulation accuracy.

4.2.1.3. Digital surface models result

The following maps show the DSM's developed for each study area across the four different resolutions, as discussed in Section 3.2.3.1. The DSM's are presented per study area: Grootpan (Figure 36); Syferbult (Figure 37); and Swartruggens (Figure 38).

Grootpan DSM's

The inclusion of land cover is mostly visible to the south of the silo and a few features surrounding the silo, illustrating the capable screening features surrounding the silo.

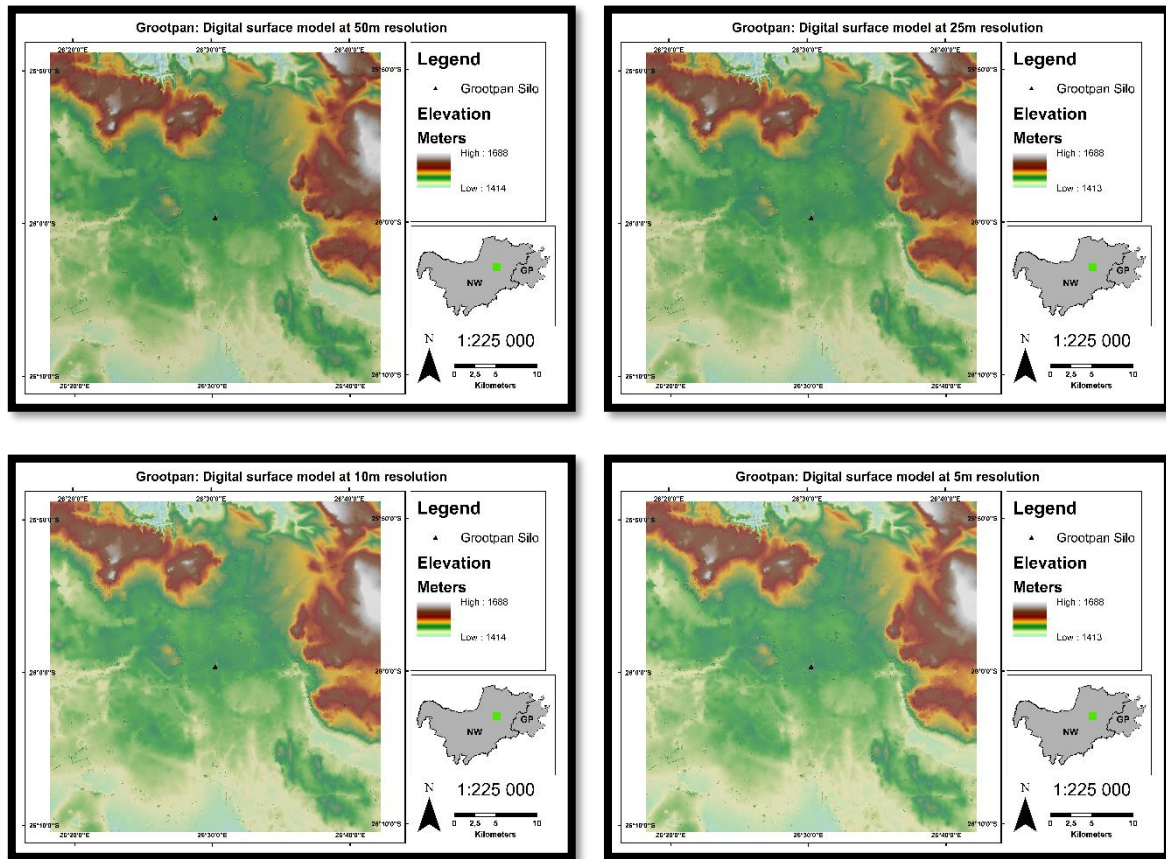


Figure 36: Digital surface models of the Grootpan study area at the different resolutions

Syferbult DSM's

The distribution of land cover across the Syferbult DSM is more significant than in the Grootpan DSM, with more features surrounding the silo. Additionally, the northern section of the study area shows surface features covering the whole section.

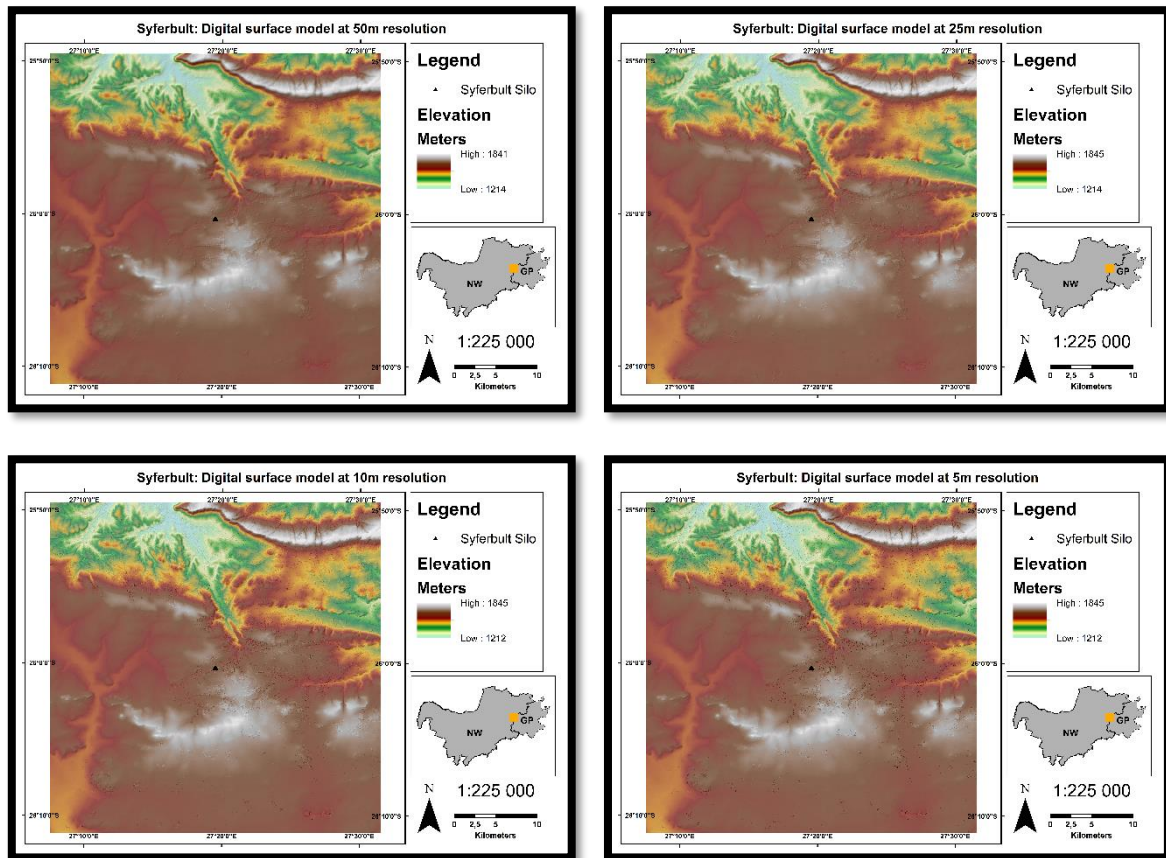


Figure 37: Digital surface models of the Syferbult study area at the different resolutions

Swartruggens DSM's

The Swartruggens study area had the most visible surface features of all three study areas, with small groupings of surface features scattered across the area.

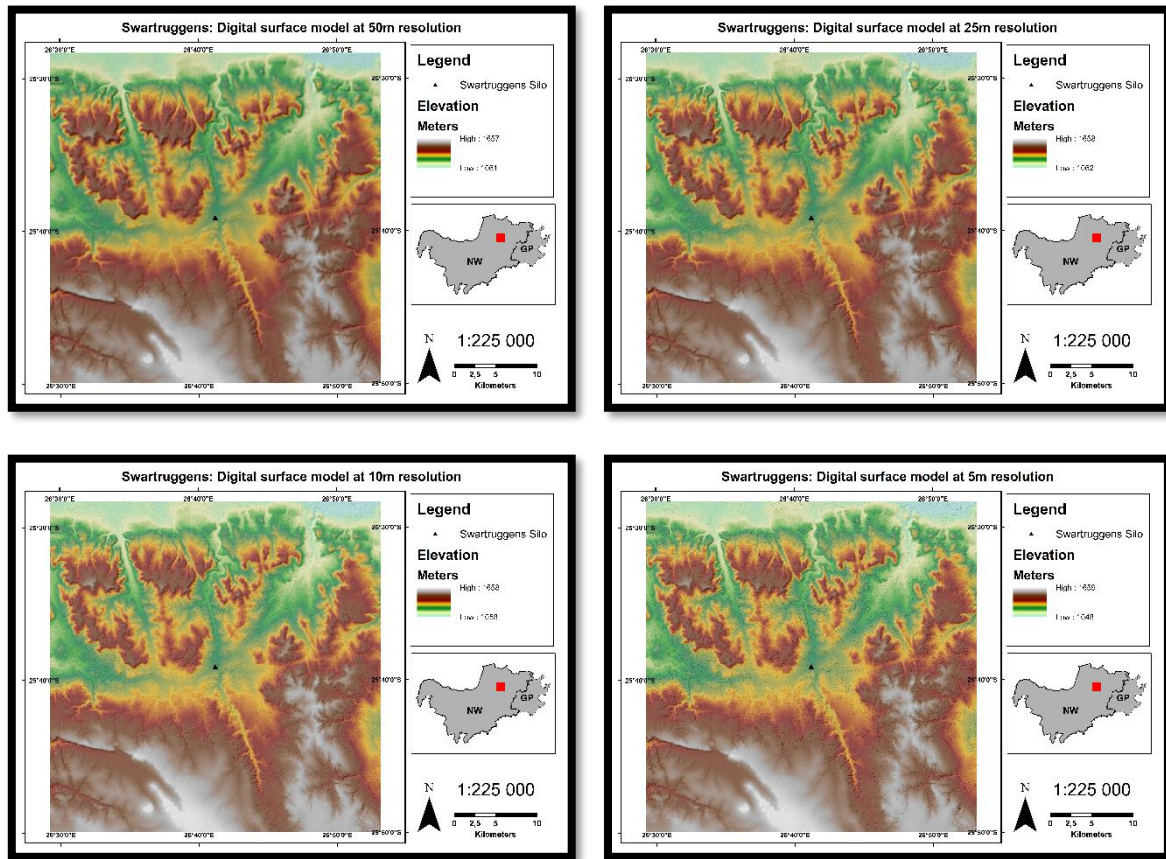


Figure 38: Digital surface models of the Swartruggens study area at the different resolutions

From a visual perspective, certain surface features not reflected in the DTM's were visible in the DSM's. Similar to DTM's, the DSM's at finer resolutions appeared to be clearer, but important topographical features seemed to be present in all DSM's. The effects of DEM accuracy and the inclusion of land cover may be more prominent in visibility analysis simulations, therefore the section that follows present all visibility analysis simulations that were conducted using both DTM's and DSM's.

4.2.2. Visibility analysis results

The results for viewshed analysis are presented first (4.2.2.1) followed by cumulative viewshed analysis (4.2.2.2), and finally, LOS analysis (4.2.2.3). Results are presented per study area and structured around the DEM used.

4.2.2.1. Viewshed analysis

The following maps show the 24 viewshed analysis simulations done for each study area using different DEM's and resolutions, as discussed in Section 3.2.4. The analysis results are presented per study area with DTM results presented first, followed by DSM results: Grootpan DTM (Figure 39), Syferbult DTM (Figure 40), Swartruggens DTM (Figure 41), Grootpan DSM (Figure 42), Syferbult DSM (Figure 43) and Swartruggens DSM (Figure 44).

Grootpan viewshed analysis DTM's

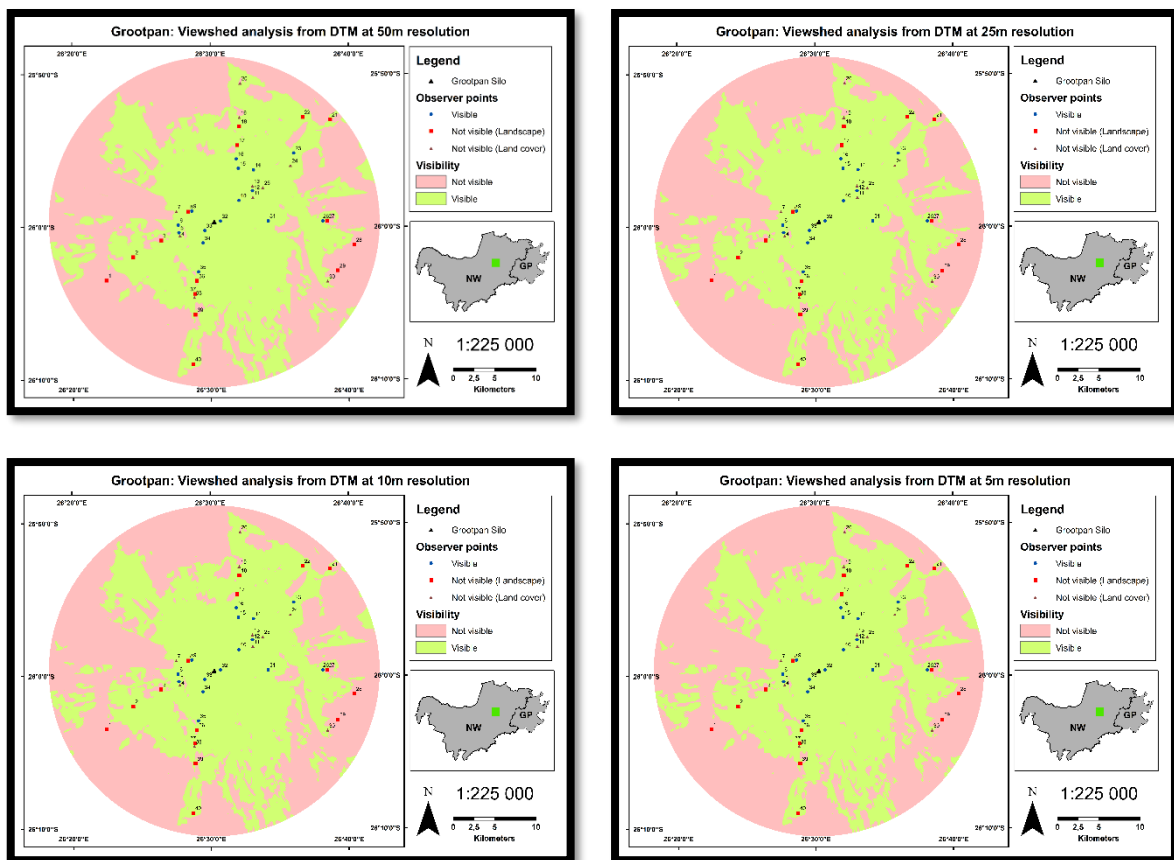


Figure 39: Viewshed analysis results of the Grootpan study area across the four DTM's

Visually most results present similar areas of visibility with small differences occurring in some areas at finer resolutions. The DTM10m presented 33 of the reference points as visible with the other three DTM's presenting 35 reference points as visible.

Syferbult viewshed analysis DTM's

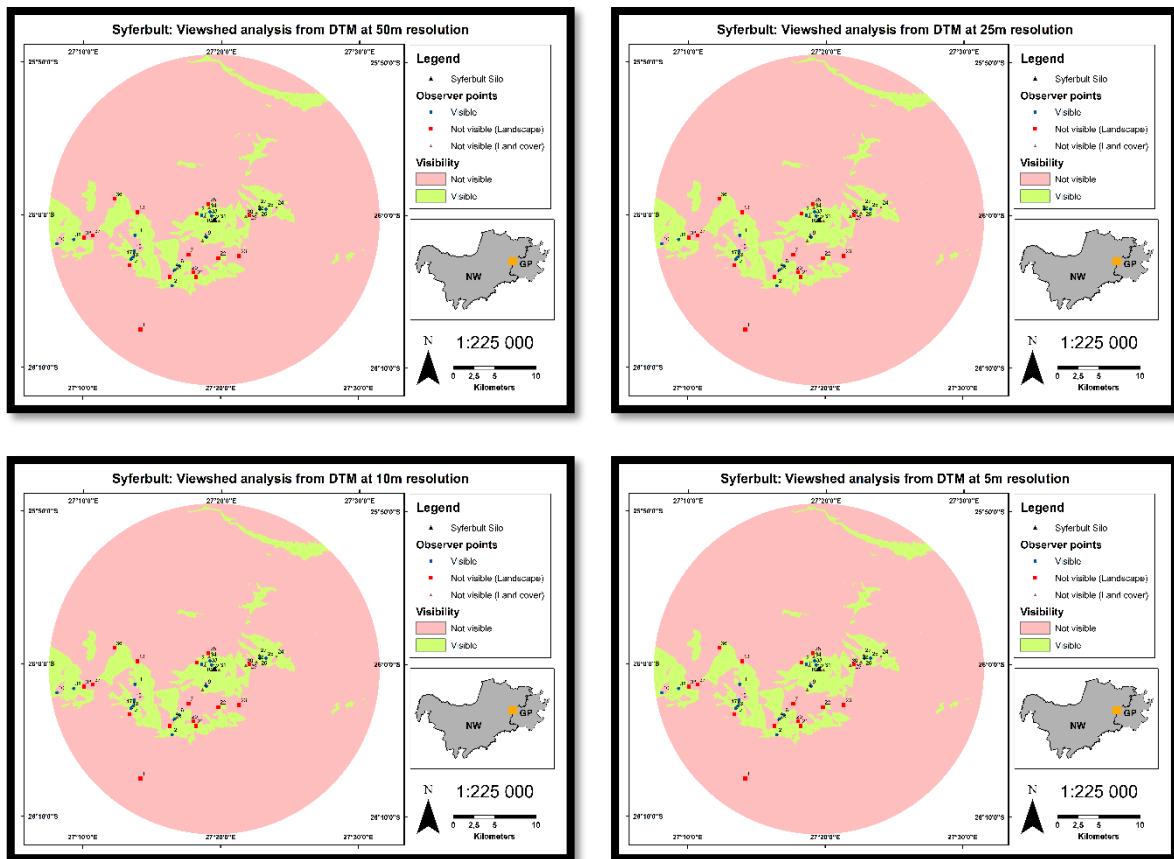


Figure 40: Viewshed analysis results of the Syferbult study area across the four DTM's

Visually most results present similar areas of visibility with small differences occurring in some areas at finer resolutions. Both the DTM25m and DTM5m confirmed 26 reference points as visible while the DTM50m confirmed 27 and the DTM10m 28 as visible.

Swartruggens viewshed analysis DTM's

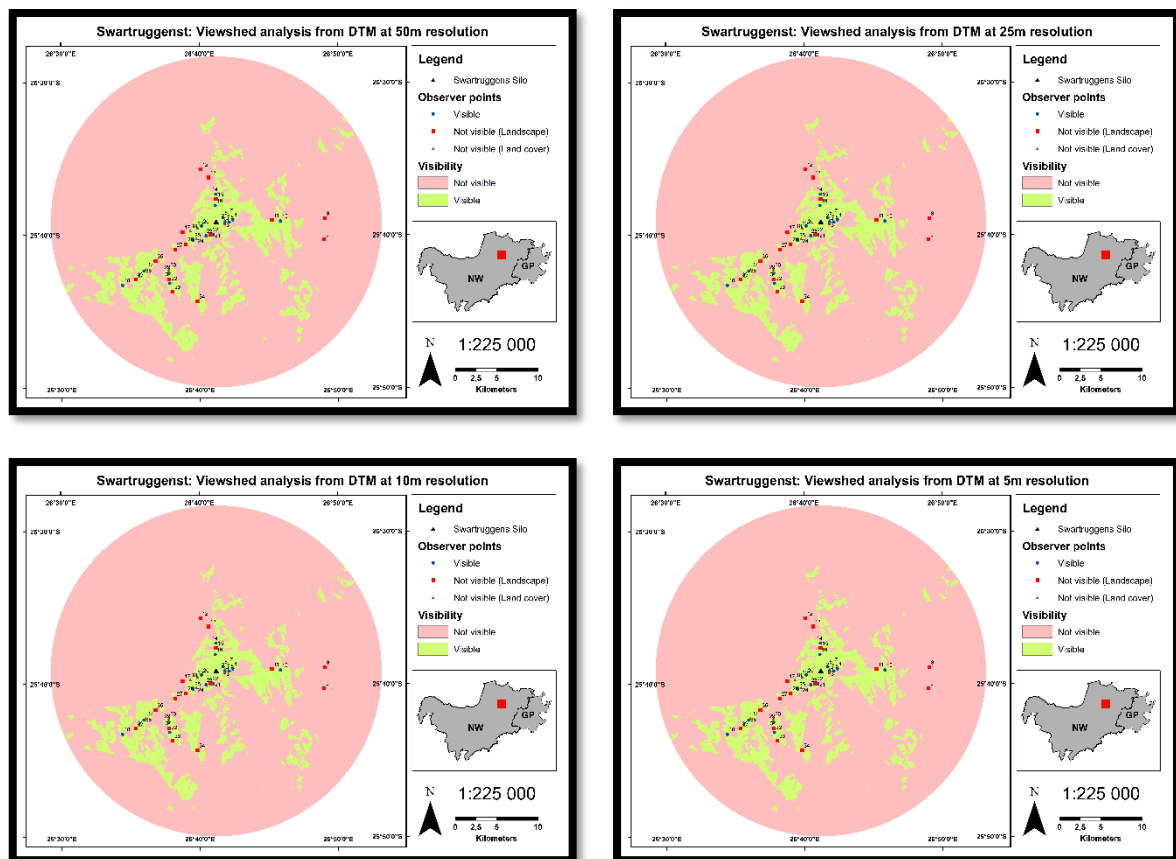


Figure 41: Viewshed analysis results of the Swartruggens study area across the four DTM's

Visually most results present similar areas of visibility with small differences occurring in some areas at finer resolutions. The three finest resolution sizes confirmed 31 reference points as visible while the DTM50m confirmed 33 as visible.

Grootpan viewshed analysis DSM's

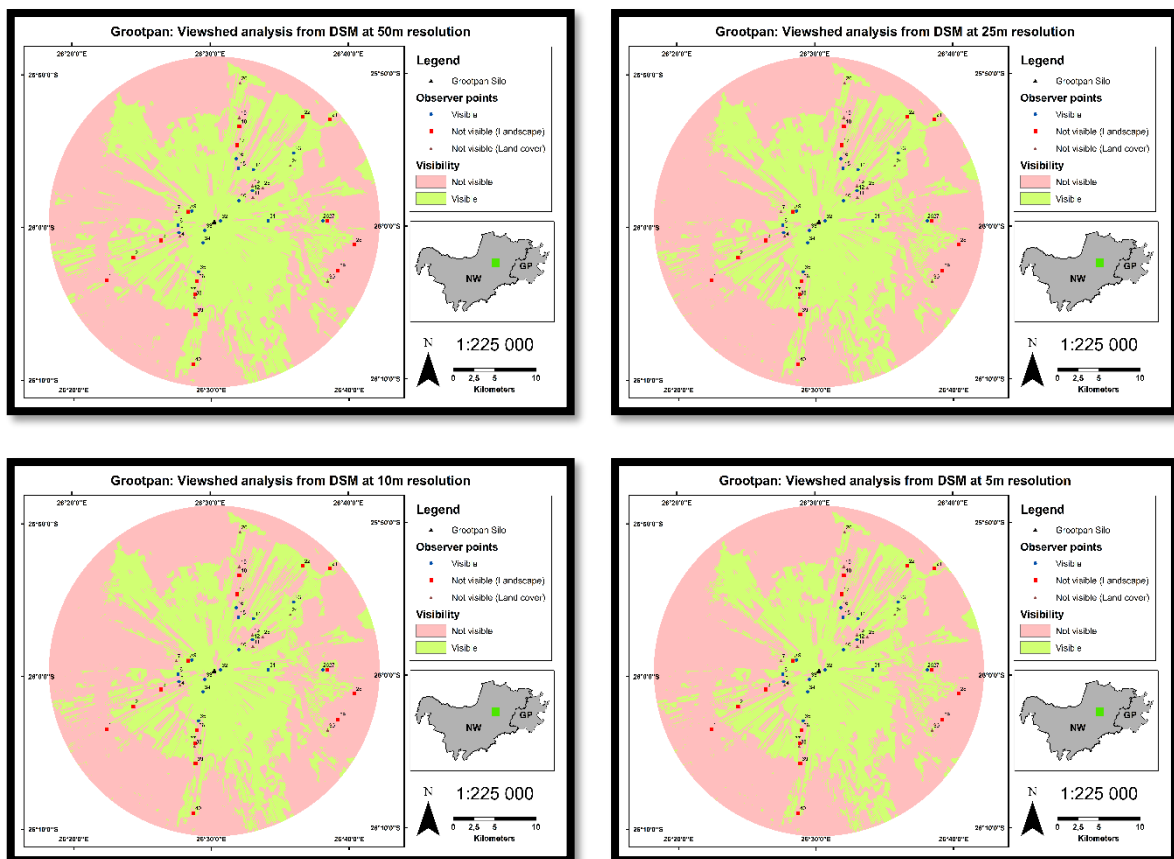


Figure 42: Viewshed analysis results of the Grootpan study area across the four DSM's

Visually the inclusion of land cover significantly increased the amount of area defined as not visible, illustrating the screening capability of land cover. The two finest resolutions confirmed 23 reference points within the visible area, while 22 were visible in the DSM25m and 26 reference points in the DSM50m.

Syferbult viewshed analysis DSM's

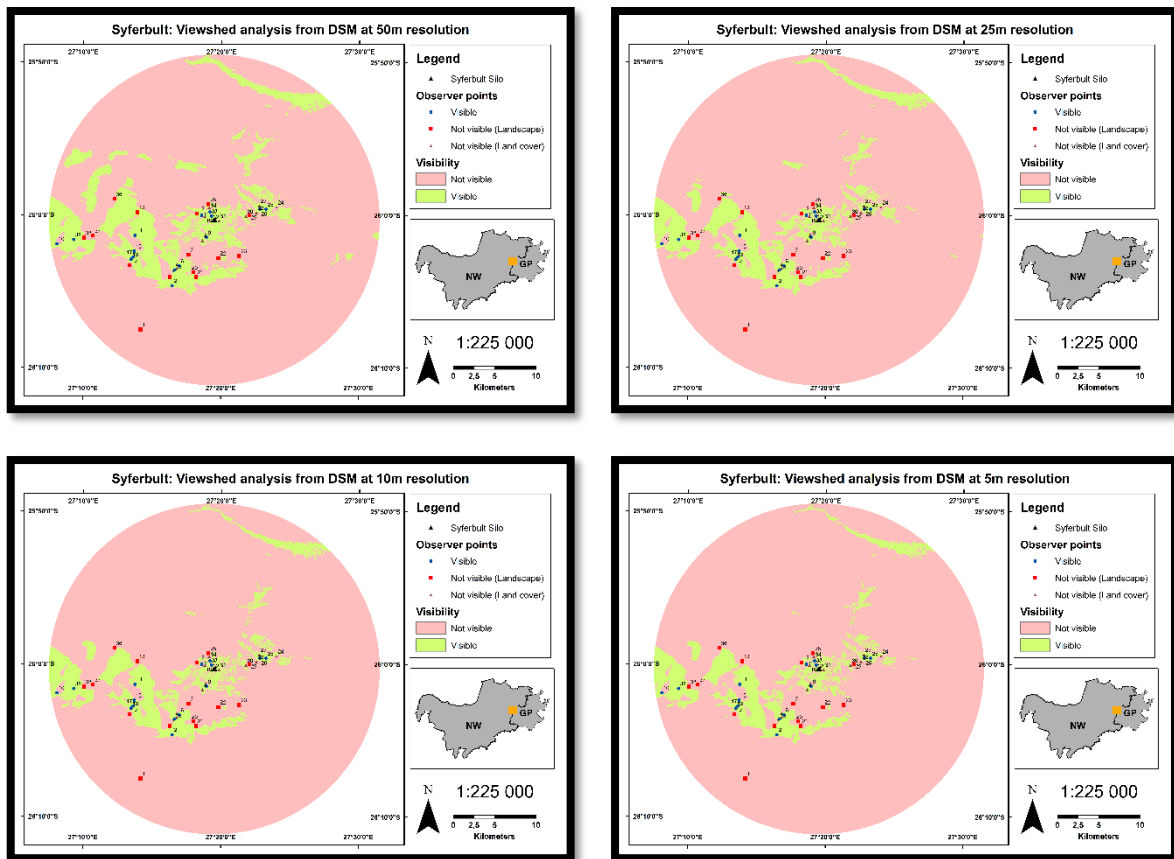


Figure 43: Viewshed analysis results of the Syferbult study area across the four DSM's

Similar to Grootpan, the inclusion of land cover increased the overall size of the areas defined as not visible, illustrating the screening capability of land cover. A decrease in reference points within the visible areas are presented with the number of points decreasing from 25 in the DSM50m, 21 in the DSM25m, 18 in the DSM10m and the fewest at 17 reference points in the DSM5m.

Swartruggens viewshed analysis DSM's

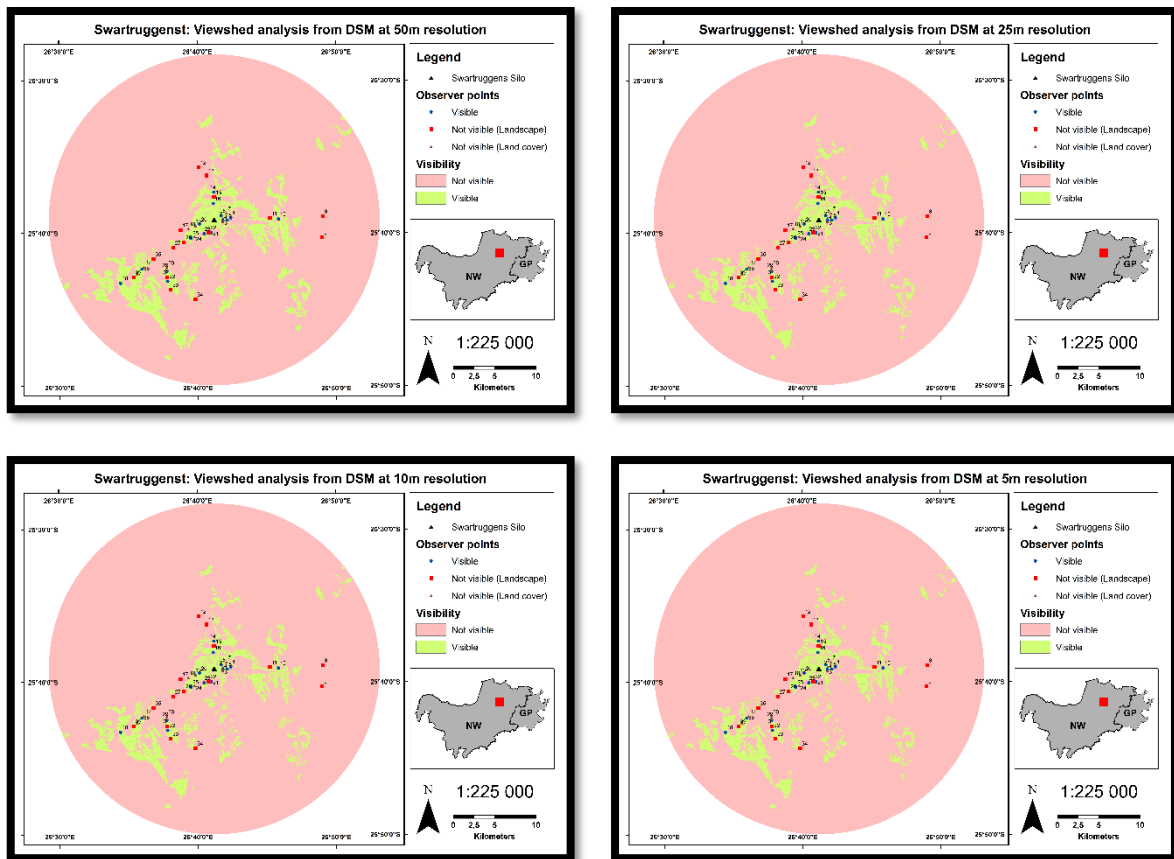


Figure 44: Viewshed analysis results of the Swartruggens study area across the four DSM's

The screening capabilities of land cover in the Swartruggens study area is also significant, with the visible areas decreasing compared to the DTM simulations. Similar to the Syferbult study area, the number of reference points contained within visible areas decrease with finer resolution sizes from 20 indicated as visible in the DSM50m to 15 reference points in the DSM5m.

Results from the viewshed analysis simulations show significant visual differences between DTM's and DSM's. DTM's used in viewshed analysis generally present more reference points in visible areas.

4.2.2.2. Cumulative viewshed analysis

The following maps show the results for the 24 cumulative viewshed analysis simulations done using different DEM's and resolutions, as discussed in Section 3.2.4. The simulations are presented per study area, and DEM used: Grootpan DTM (Figure 45), Syferbult DTM (Figure 46), Swartruggens DTM (Figure 47), Grootpan DSM (Figure 48), Syferbult DSM (Figure 49) and Swartruggens DSM (Figure 50).

Grootpan cumulative viewshed analysis DTM's

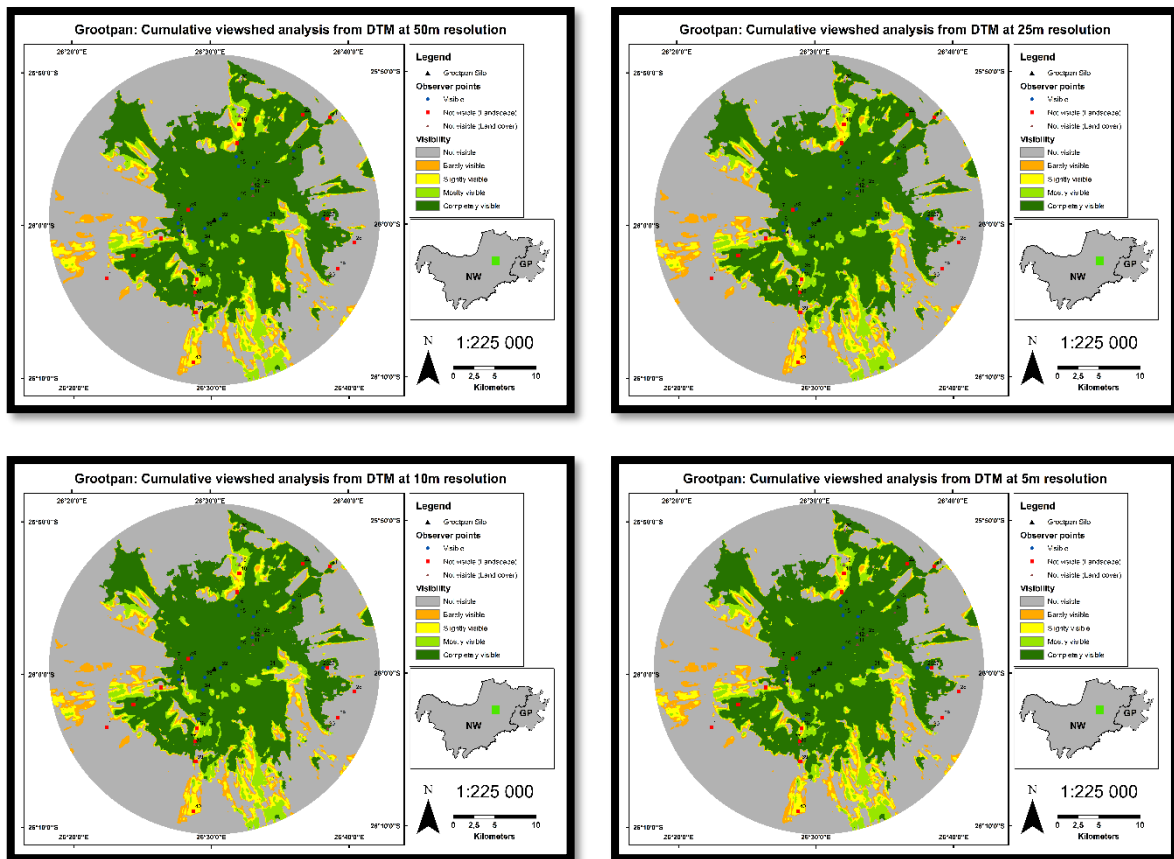


Figure 45: Cumulative viewshed analysis results of the Grootpan study area across the four DTM's

Visually greater differences in visible areas are observed over the four resolution sizes. The DTM10m presented 33 of the reference points as visible with the other three DTM's presenting 35 reference points as visible. Small changes in different degrees of visibility can be observed in the different resolution sizes.

Syferbult cumulative viewshed analysis DTM's

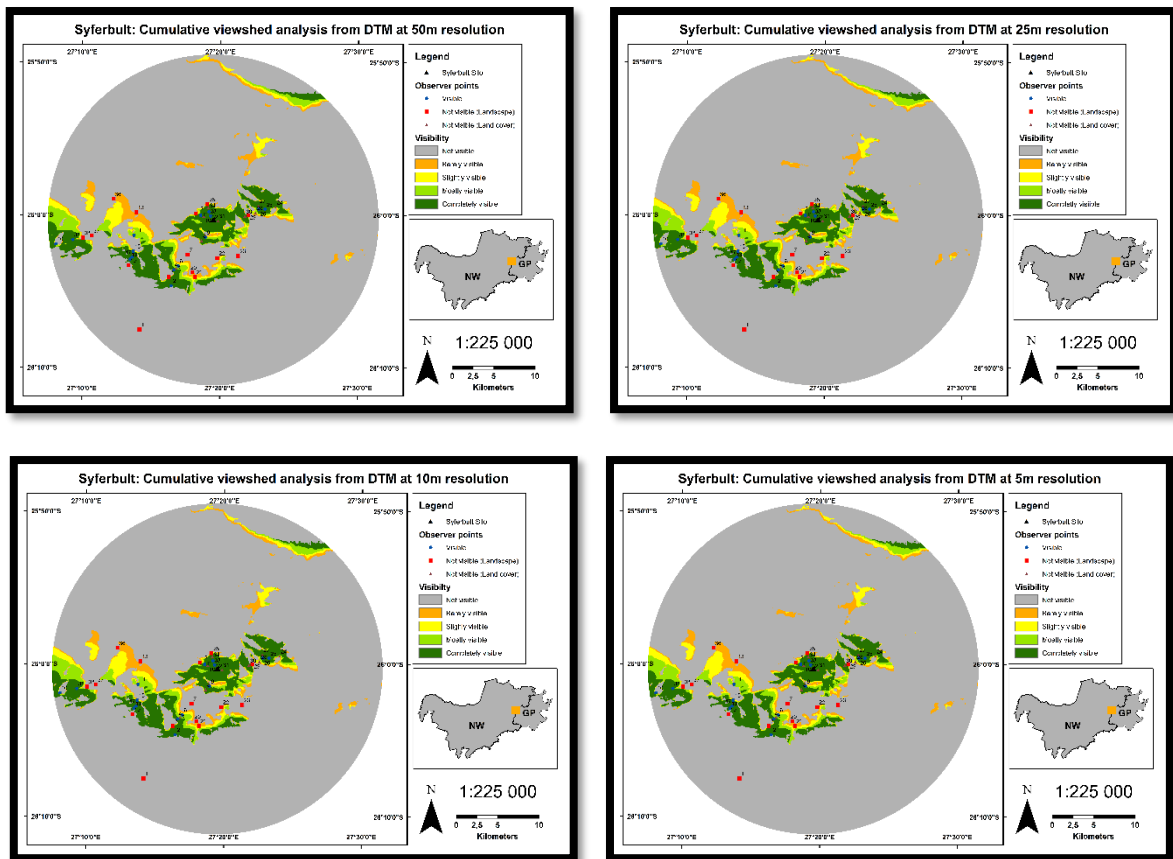


Figure 46: Cumulative viewshed analysis results of the Syferbult study area across the four DTM's

Visually more areas are illustrated barely or slightly visible closer to the silo with finer resolution sizes. Both the DTM25m and DTM5m presented 26 reference points as visible with the DTM50m illustrating 27 and the DTM10m a total of 28 reference points as visible. Similar to the Grootpan Study area changes can be observed in terms of the areas indicated by different degrees of visibility.

Swartruggens cumulative viewshed analysis DTM's

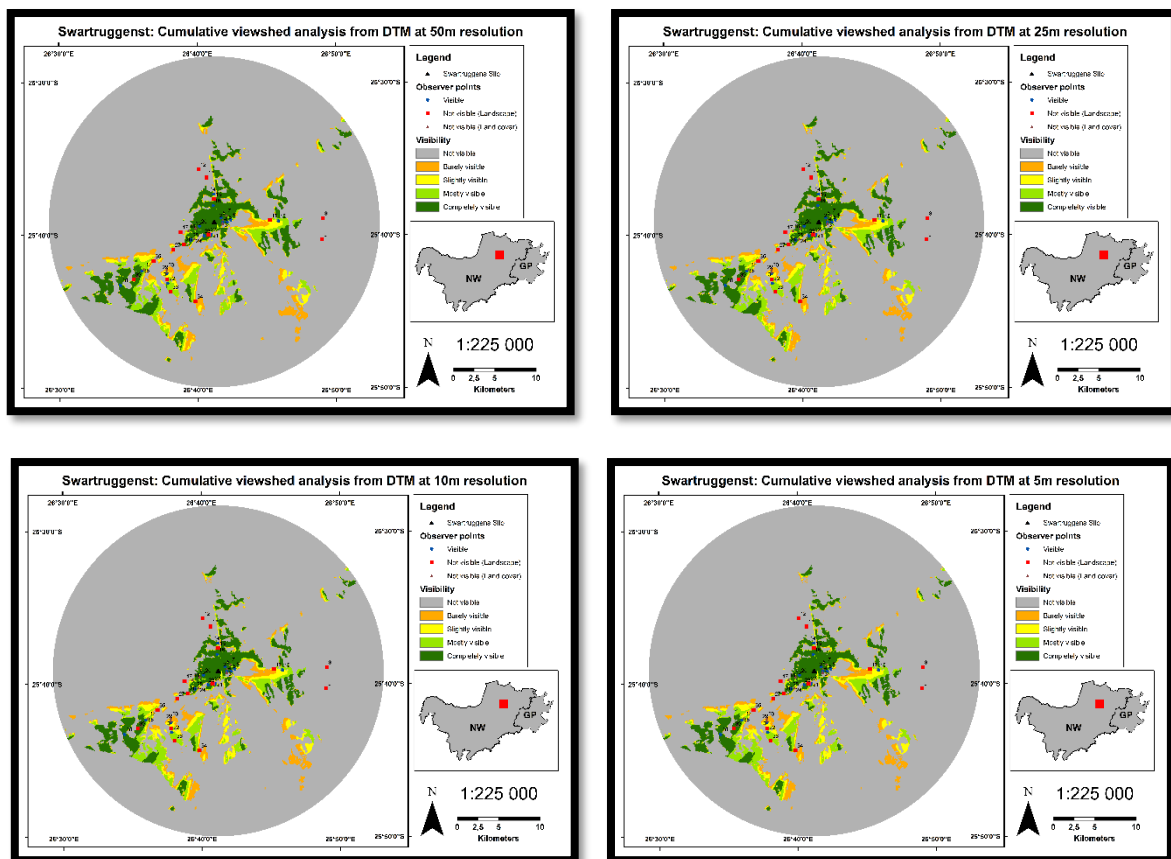


Figure 47: Cumulative viewshed analysis results of the Swartruggens study area across the four DTM's

The visible areas decrease with finer resolution, particularly to the south of the silo. The three finest resolution sizes confirmed 31 reference points in the visible area while the DTM50m presented 33 reference points in the visible area.

Grootpan cumulative viewshed analysis DSM's

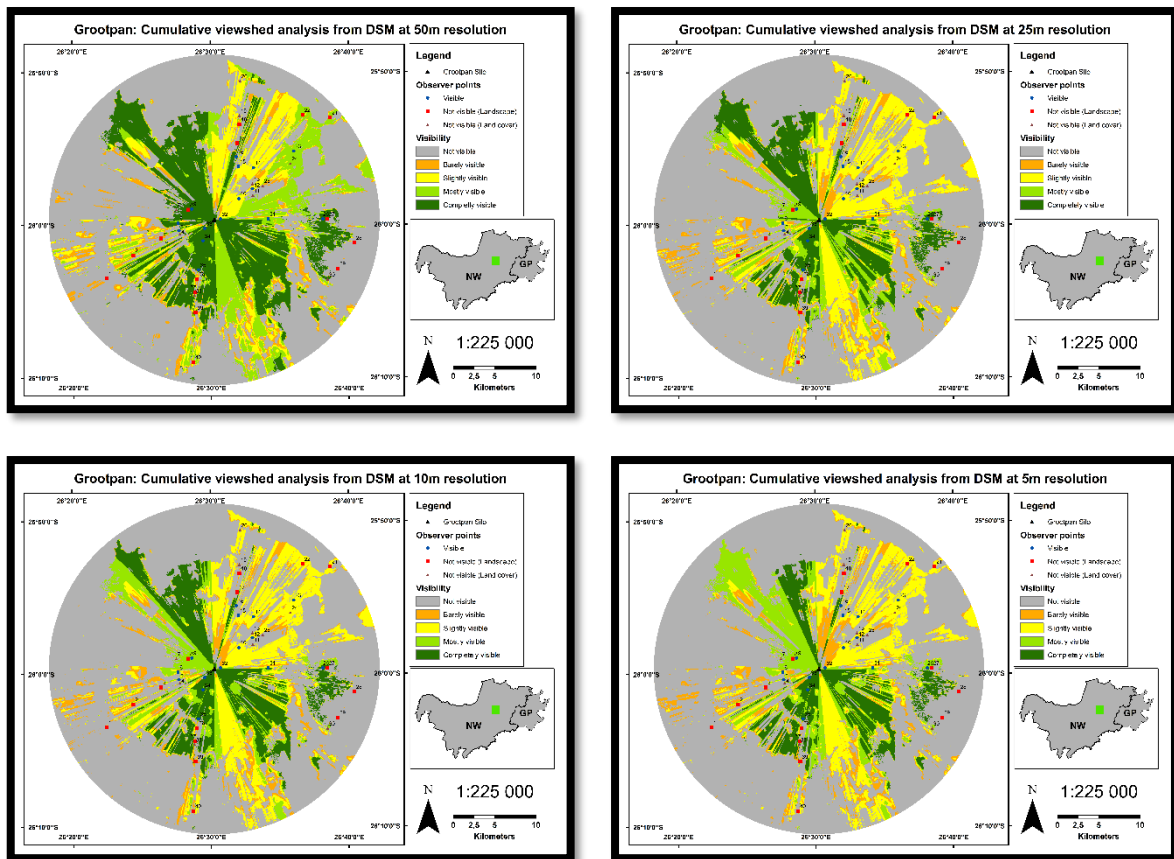


Figure 48: Cumulative viewshed analysis results of the Grootpan study area across the four DSM's

The visual difference between DTM's and DSM's are easily observable in the cumulative viewshed analysis results. The mostly visible and completely visible, further also fluctuate between the different resolutions. The two finest resolutions confirmed 23 reference points as visible, while 22 were visible in the DSM25m and 26 reference points in the DSM50m.

Syferbult cumulative viewshed analysis DSM's

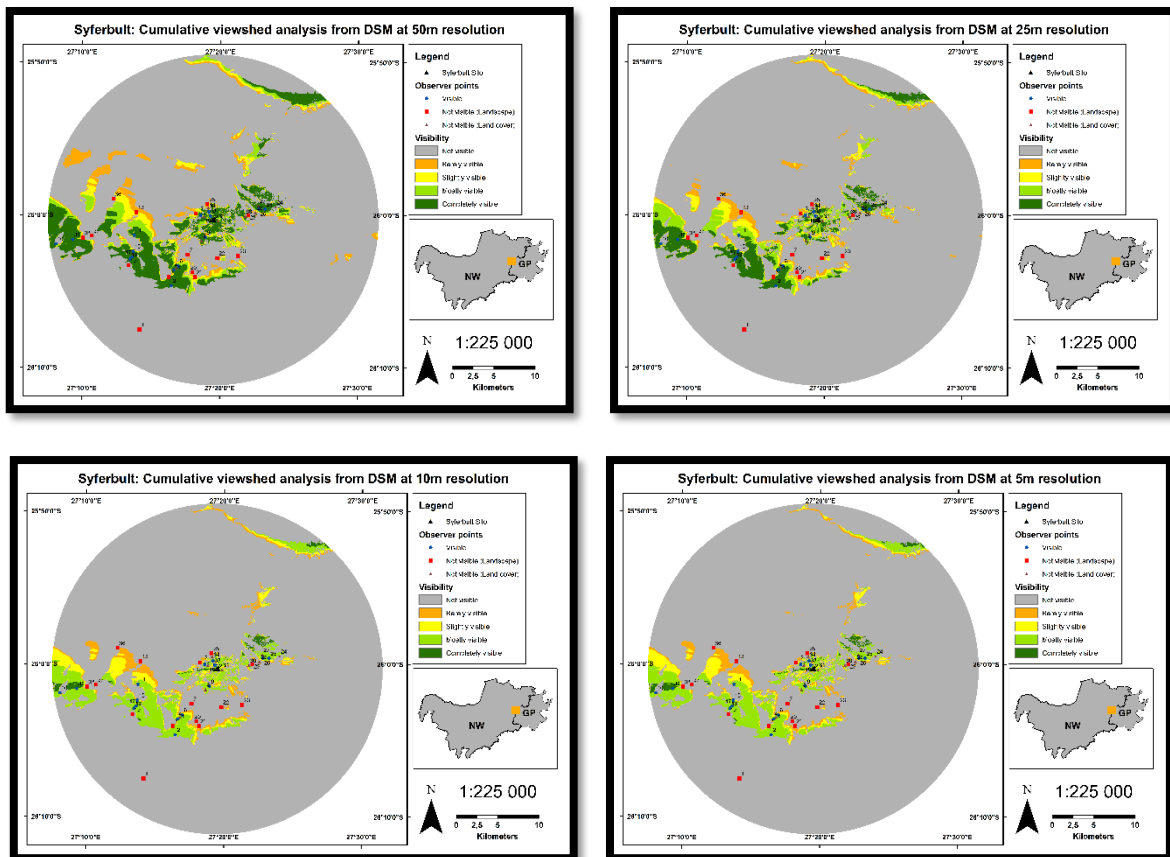


Figure 49: Cumulative viewshed analysis results of the Syferbult study area across the four DSM's

The number of confirmed visible reference points decreases with resolution from 25 for the DSM50m, 21 for the DSM25m, 18 for the DSM10m to only 17 reference points for the DSM5m. The same findings are present as with the Grootpan study area, with completely visible areas changing to mostly visible at finer resolutions.

Swartruggens cumulative viewshed analysis DSM's

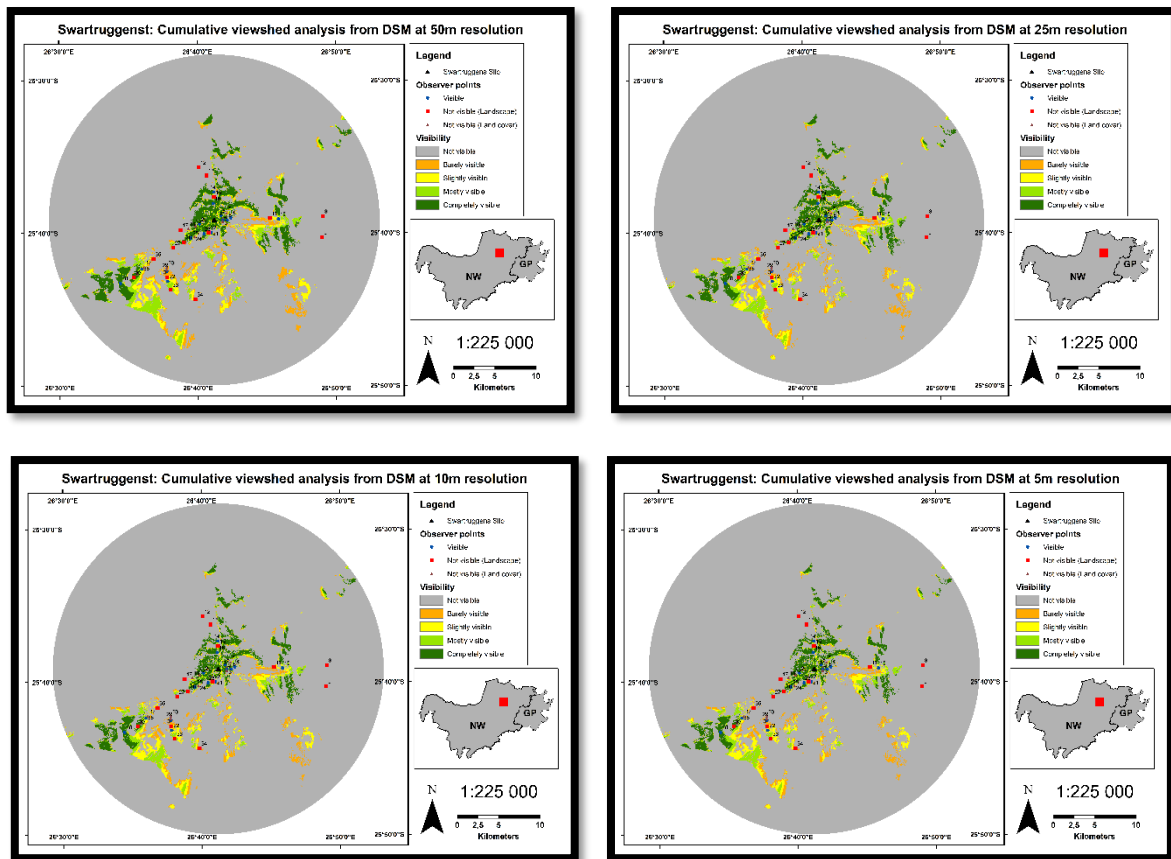


Figure 50: Cumulative viewshed analysis results of the Swartruggens study area across the four DSM's

Visually, fewer changes are observed with resolution change when compared to the other two study areas. Similar to the Syferbult study area, the number of confirmed visible reference points decrease at finer resolution sizes ranging from reference points in the DSM50m to 15 reference points in the DSM5m.

Overall, cumulative viewshed analysis presents visibility in much more detail than viewshed analysis, providing more information regarding the significance of visibility. Additionally, the inclusion of land cover affected the degree of visibility dramatically, illustrating the screening effects of land cover.

4.2.2.3. Line-of-sight analysis

The following maps show the 24 LOS analysis simulations done for each study area using different DEM's and resolutions, as discussed in Section 3.2.4. The simulations are again presented per study area and DEM: Grootpan DTM (Figure 51), Syferbult DTM (Figure 52),

Swartruggens DTM (Figure 53), Grootpan DSM (Figure 54), Syferbult DSM (Figure 55) and Swartruggens DSM (Figure 56).

Grootpan LOS analysis DTM's

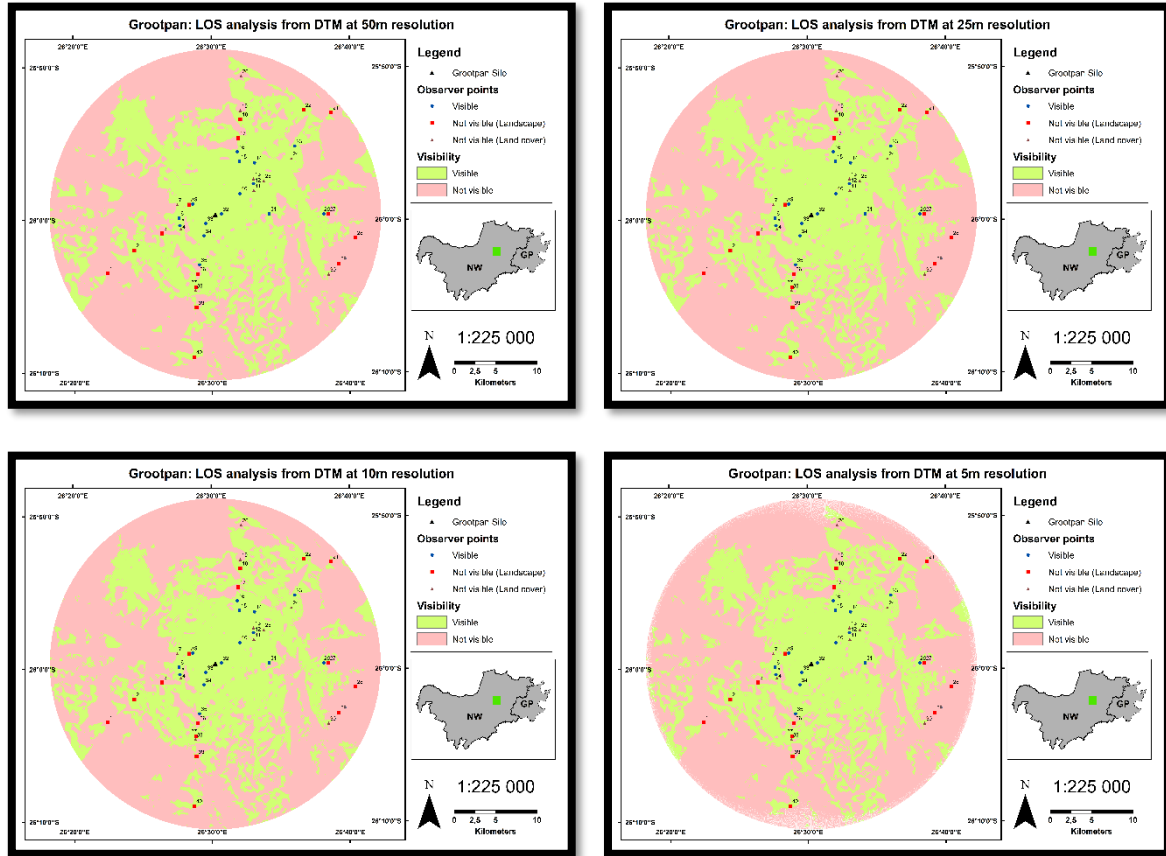


Figure 51: Line-of-sight analysis results of the Grootpan study area across the four DTM's

Visually LOS analysis presents more non-visible areas between visible areas than the other two techniques. Minimal differences can be observed between the four resolution sizes. A total of 31 reference points was confirmed as visible in the DTM50m, with 30 in the DTM25m and DTM10m, and 29 in the DTM5m.

Syferbult LOS analysis DTM's

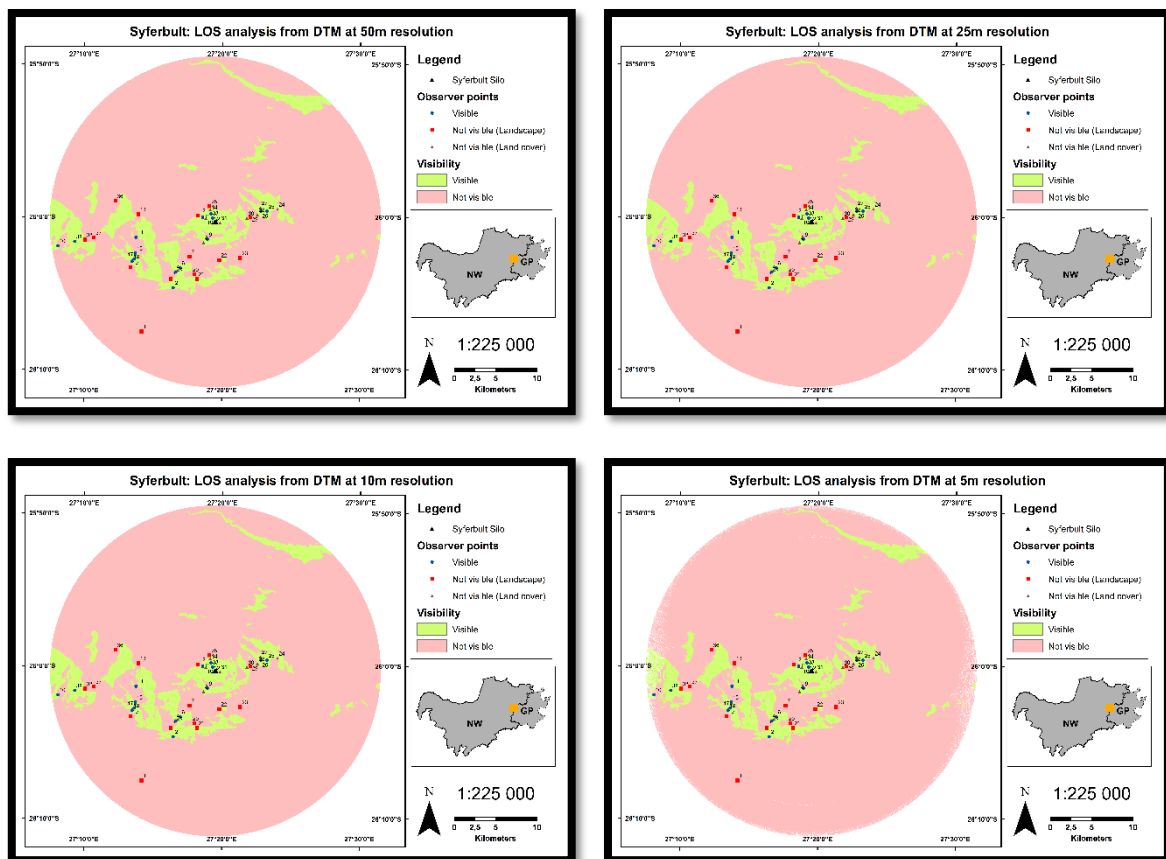


Figure 52: Line-of-sight analysis results of the Syferbult study area across the four DTM's

The DTM5m presented 17 reference points as visible, while all other DTM's presented 16 reference points within the visible areas. From a visual perspective, minimal changes can be observed.

Swartruggens LOS analysis DTM's

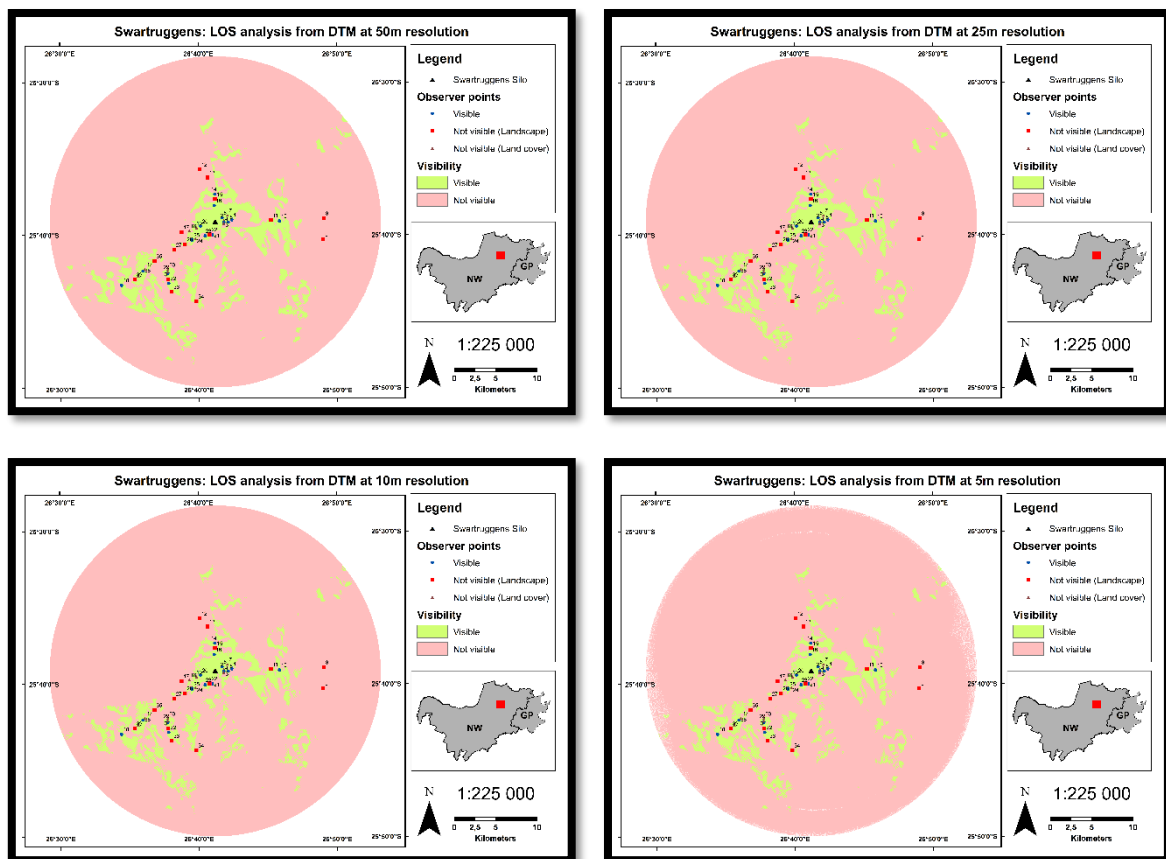


Figure 53: Line-of-sight analysis results of the Swartruggens study area across the four DTM's

Similar to the other two study areas, some changes are visible with different resolution sizes. The coarsest resolution size confirmed the most visible reference points at 27 while the lowest confirmed number was 25 for the finest resolution DTM.

Grootpan LOS analysis DSM's

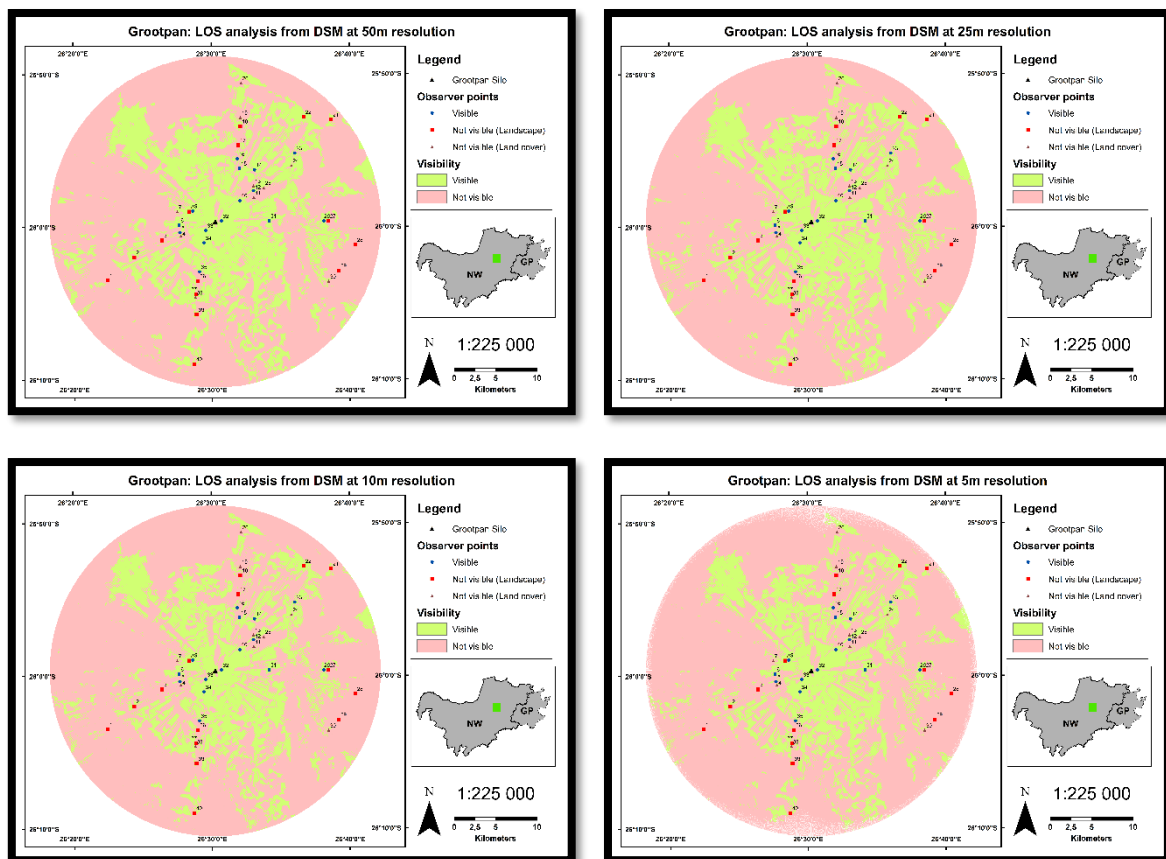


Figure 54: Line-of-sight analysis results of the Grootpan study area across the four DSM's

Visually more areas are illustrated as not visible due to the screening influenced by the inclusion of land cover. Both the DSM50m and DSM25m confirmed 28 reference points as visible, while the other two DSM's confirmed 31 reference points as visible.

Syferbult LOS analysis DSM's

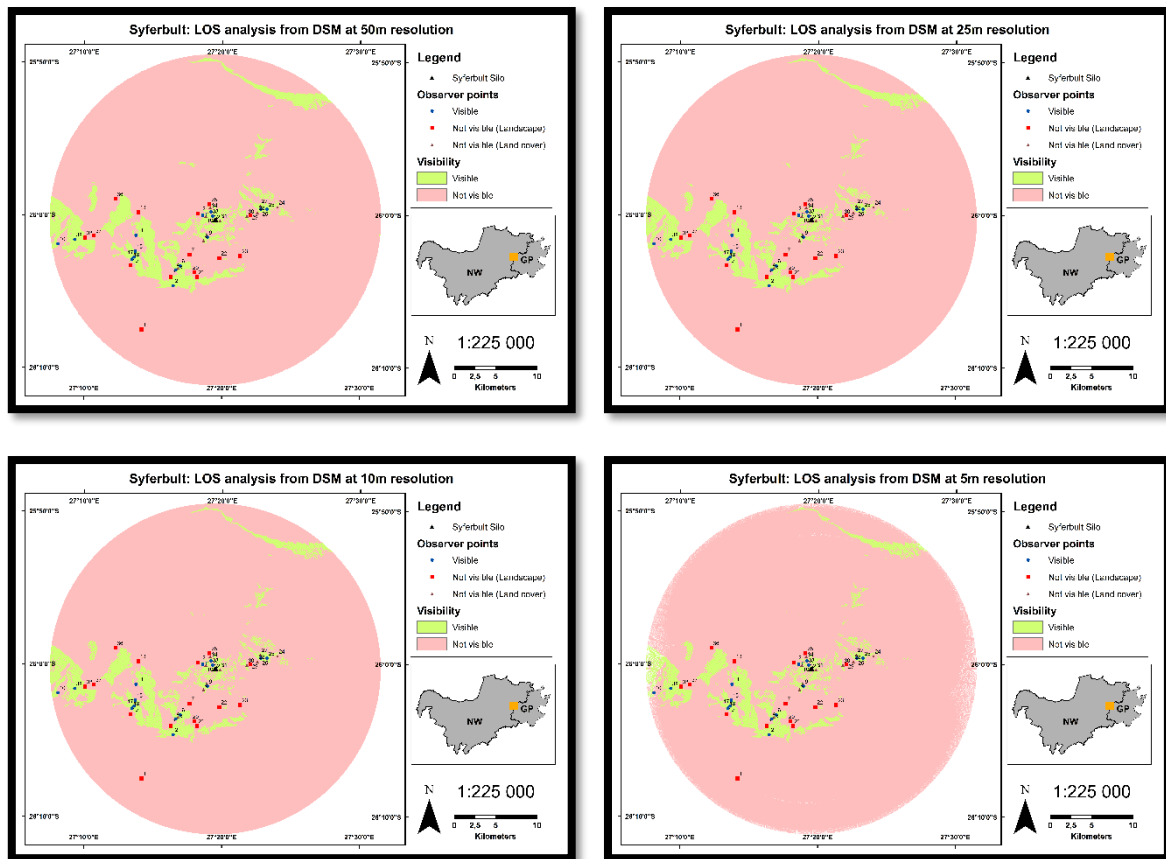


Figure 55: Line-of-sight analysis results of the Syferbult study area across the four DSM's

Visually the most significant difference observed was due to land cover rather than different resolutions. The DSM50m confirmed the smallest number of visible reference points as visible (23) while the other resolution sizes confirmed 27 for the DSM25m and 28 for both the DSM10m and DSM5m resolutions.

Swartruggens LOS analysis DSM's

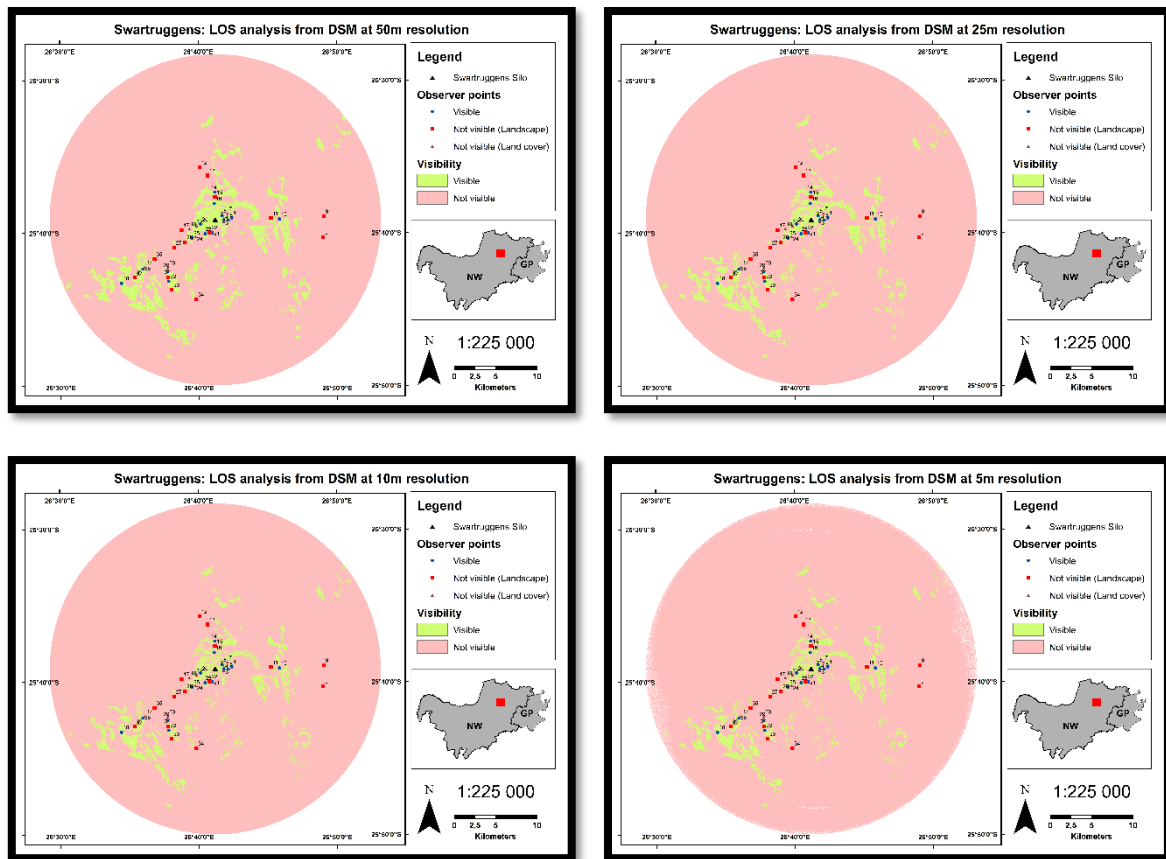


Figure 56: Line-of-sight analysis results of the Swartruggens study area across the four DSM's

Some small changes were observed with visible areas decreasing at finer resolutions, particularly to the south. Similar to the Syferbult study area, the DSM50m confirmed the lowest number of visible reference points as visible at only 16. The DSM25m, however, confirmed 30 reference points as visible while 33 were confirmed in the other two DSM's. A better evaluation of the accuracy would be achieved by comparing the reference points to the prediction of all visibility analysis simulations and is presented in Section 4.3.

4.3. Comparison of visibility analysis techniques (Objectives 3)

The results presented in this section relates to the third and final objective of this study, which was to determine an optimal visibility analysis methodology for use in VIA. Visibility analysis techniques were compared through an accuracy assessment procedure discussed in Section 3.3.1. The accuracy assessment results for each method as applied across different resolutions, DEM's and study areas are discussed first (Section 4.3.1 to 4.3.3) followed by an analysis of accuracy findings for all methods tested (Section 4.2.4).

4.3.1. Accuracy assessment of viewshed analysis

The following graphs show the combined accuracy assessment (Section 3.3.1) results for viewshed analysis using different DEM's and resolutions. The results are presented per DEM with the findings for analysis based on DTM's presented first (Figure 57) followed by the findings based on DSM's (Figure 58).

4.3.1.1. *Viewshed analysis DTM's*

The accuracy assessment of Grootpan is similar through three of the four DTM's, with only the DTM10m presenting an accuracy of 55%, which is 5% higher than the other DTM's. The simulations showed no further increase in accuracy as resolution size decreased beyond 10m. The Syferbult study area performed better than the Grootpan study area, with an accuracy of 62.5% achieved for the 5, 10 and 25m DTM, and 65% for the DTM50m. Similar accuracy results were obtained for the Swartruggens study area, with the 5, 10 and 25m DTM showing accuracy results of 60%, but in contrast to Syferbult, the DTM50m resulted in a less accurate assessment at only 52.5%. The lower accuracy may be due to the DTM exceeding the minimum resolution size, although the same trend was not observed in the Syferbult visibility analysis results.

The Swartruggens study area was generally more complex than Syferbult, but both DTM's exceeded the determined range determined in Section 3.2.3.1. The effect on accuracy may, therefore, be more prominent as the resolution of the DTM exceeds the resolution range determined. In addition, an increase in terrain complexity and larger resolution size can affect the model's capability to present the terrain accurately as defined by the RMSE values in Section 4.2.1.2. Improved accuracy of visibility analysis simulations was expected from the DSM based analysis as ten reference points were collected explicitly in terms of land cover screening, and it was expected that they would be confirmed as such by the DSM.

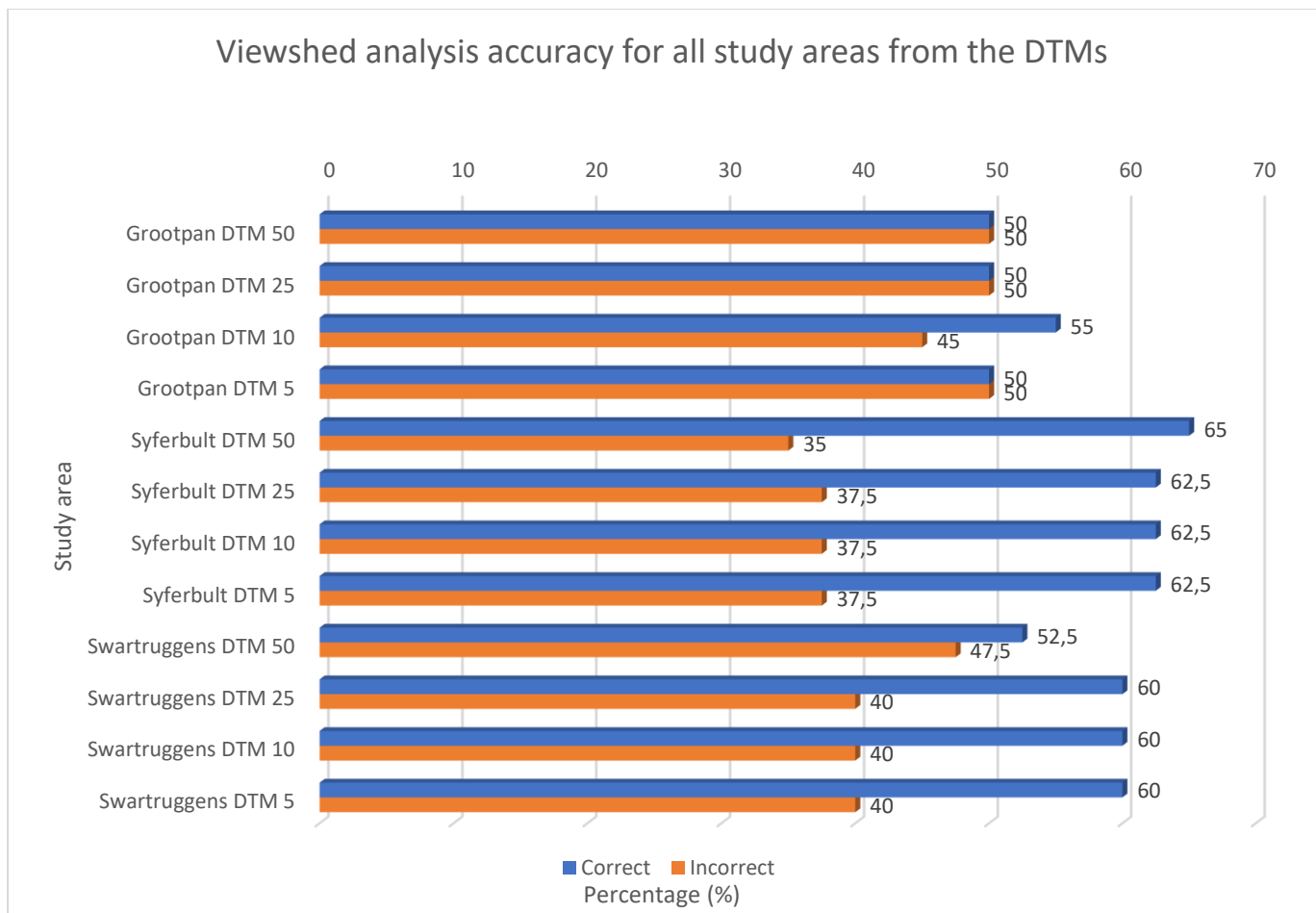


Figure 57: Accuracy assessment of viewshed analysis based on DTM's

4.3.1.2. Viewshed analysis DSM's

Viewshed analysis conducted using DSM's resulted in much higher accuracy scores than scenarios developed using DTM's. The Grootpan study area showed an increase in accuracy scores of 7.5% for the DSM50m, 22.5% for the DSM25m, 20% for the DSM10m, and 25% for the DSM5m when compared to DTM accuracy results—suggesting that the inclusion of land cover played a significant role in screening visibility.

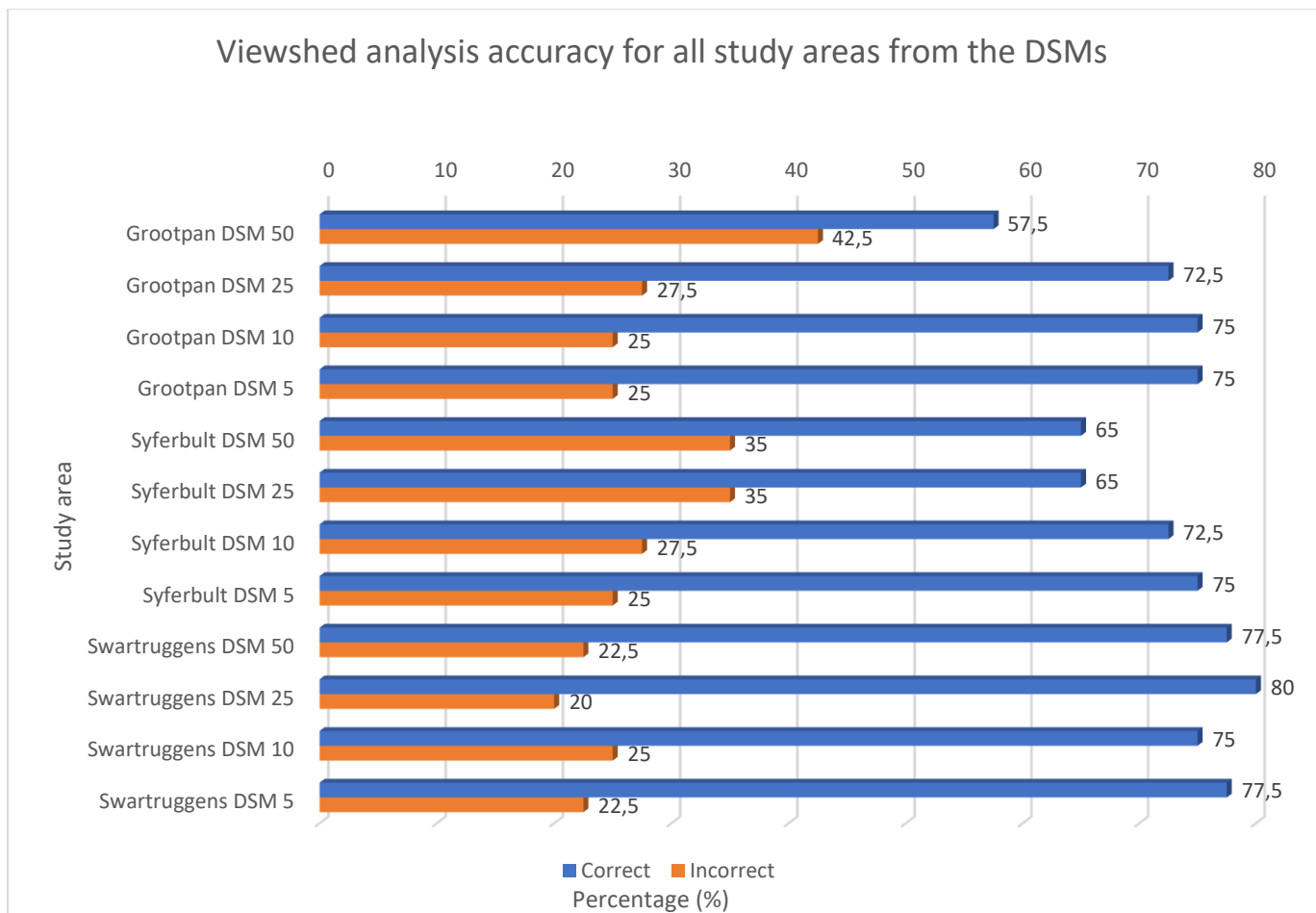


Figure 58: Accuracy assessment of viewshed analysis based on DSM's

A similar finding was reported for the Syferbult study area with an increase of 2.5% for the DSM25m, 10% for the DSM10m and 12.5% for the DSM5m resolution size, with only the DSM50m showing the same accuracy as its DTM counterpart, again indicating an improvement in simulation accuracy over finer resolutions. As with Grootpan, an increase in accuracy was observed as resolution size decreased. Swartruggens presented increases in accuracy of 25% for the 50m, 20% for the 25m, 15% for the 10m and 17.5% for the 5m resolution size. This seems to support the findings from the other two study areas that not only do smaller resolution sizes improve accuracy, but the addition of land cover further improves accuracy. The inclusion of land cover seems to be a much more prominent screening factor from viewshed analysis in less complex terrains, as the likelihood of visibility to be screened by land cover is greater than that of the topography.

4.3.2. Accuracy assessment of cumulative viewshed analysis

The following graphs show the combined accuracy assessment (Section 3.3.1) results for cumulative viewshed analysis using different DEM's and resolutions. The results are

presented per DEM with the findings for analysis based on DTM's presented first (Figure 59) followed by the findings based on DSM's (Figure 61). Figures 60 and 62 present the accuracy findings in terms of the degree of visibility.

4.3.2.1. Cumulative viewshed analysis DTM's

Cumulative viewshed analysis presented the same level of accuracy as viewshed analysis simulations and, therefore, the findings presented in Section 4.3.1.1 is also applicable here. The method was included to produce a visibility prediction with more detail in its result, therefore simulating visibility at various heights to create a map illustrating the amount of object visible as discussed in Section 3.2.4.2. Figure 59 presents the accuracy assessment results in terms of the degree of visibility/amount of object visible.

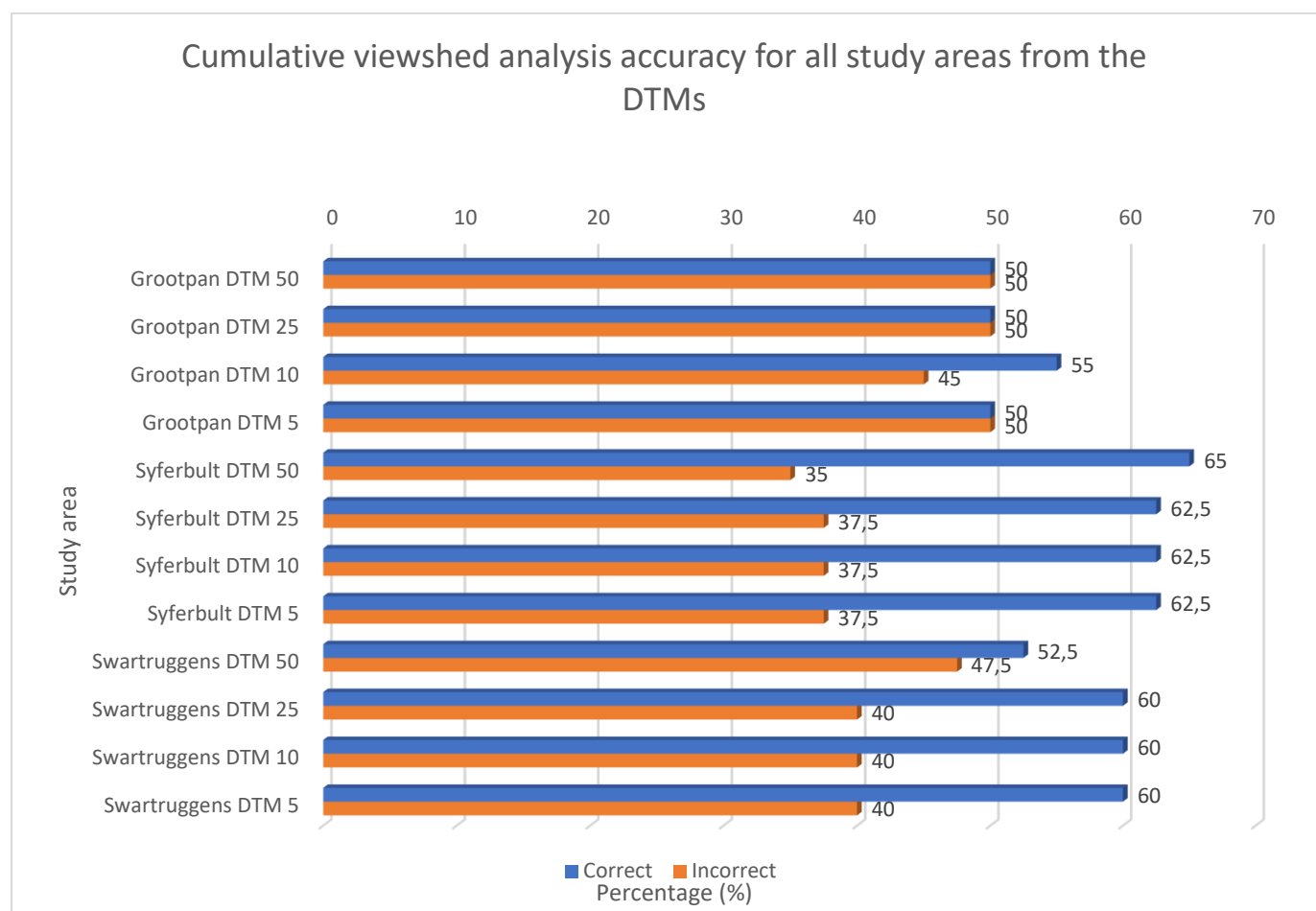


Figure 59: Accuracy assessment of cumulative viewshed analysis based on DTM's

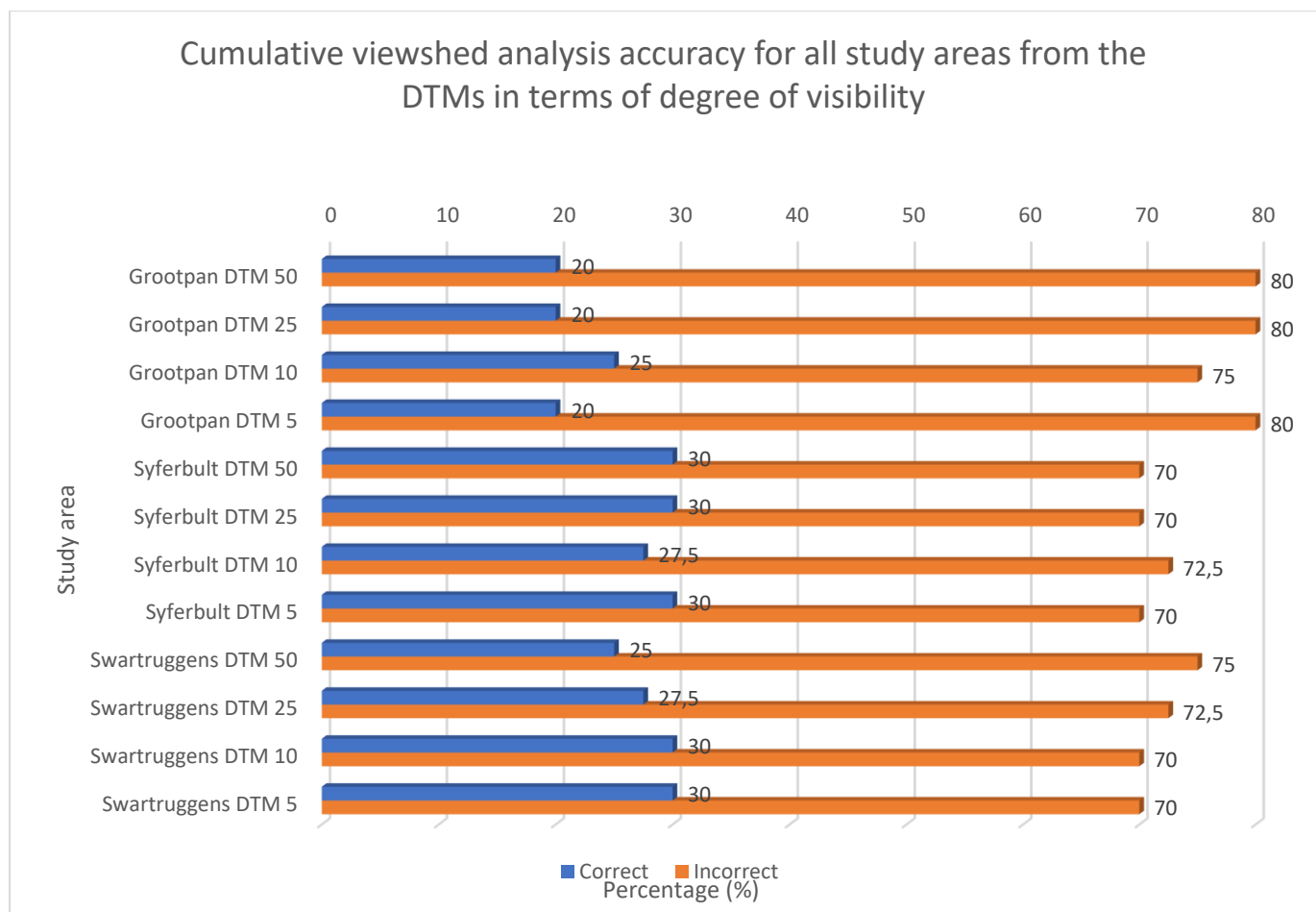


Figure 60: Accuracy assessment of cumulative viewshed analysis based on DTM's in terms of the degree of visibility

The accuracy of prediction was low as it is affected by the method used to assess the degree of visibility, in particular, the information was based on the researcher perception of visibility rather than a specific tool used. The accuracy may be low, but the effect of finer resolution sizes can still be observed in that it generally presented better accuracy. Some findings do, however, suggest that a DTM5m may not always be necessary as the DTM10m present the same level of accuracy. The maps presented in Section 4.2.2.2 provides a clearer assessment of the significance of visibility throughout the area.

4.3.2.2. Cumulative viewshed analysis DSM's

Similar to the cumulative viewshed analysis result based on DTM's in the previous section, visibility prediction was the same as with the viewshed analysis simulations done with DSM's, and is, therefore, the same as the finding presented in Section 4.3.1.2. The method was included to produce a visibility prediction with a more detailed result, therefore simulating visibility at various heights to create a map illustrating the amount of object visible as discussed

in Section 3.2.4.2. Figure 61 present the accuracy assessment results in terms of the degree of visibility/amount of object visible.

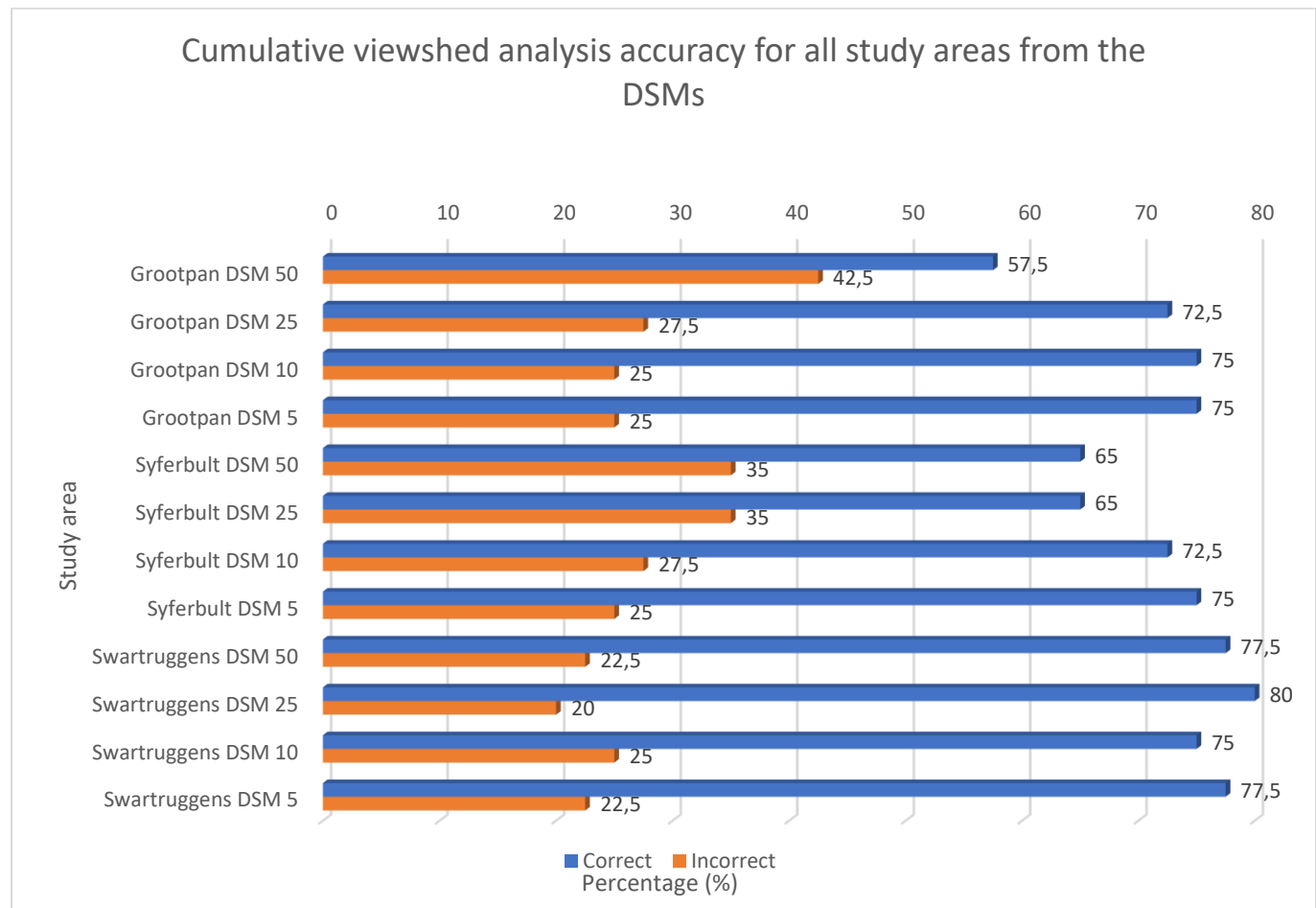


Figure 61: Accuracy assessment of cumulative viewshed analysis based on DSM's

The DSM's accuracy scores for Grootpan were generally higher than the DTM's scores and further increased as resolutions decreased. Increases of 17.5% for the DSM50m, 27.5% for the DSM25m, 17.5% for the DSM10m and 25% for the DSM5m was observed. The increase in resolution size resulted in a more accurate representation of land cover features as land cover was more accurately presented at finer resolution sizes. A similar finding in terms of the degree of visibility was presented by the Syferbult simulations, suggesting an increase in accuracy with finer resolution sizes. Swartruggens only showed an increase in accuracy with the inclusion of land cover and not with finer resolution sizes.

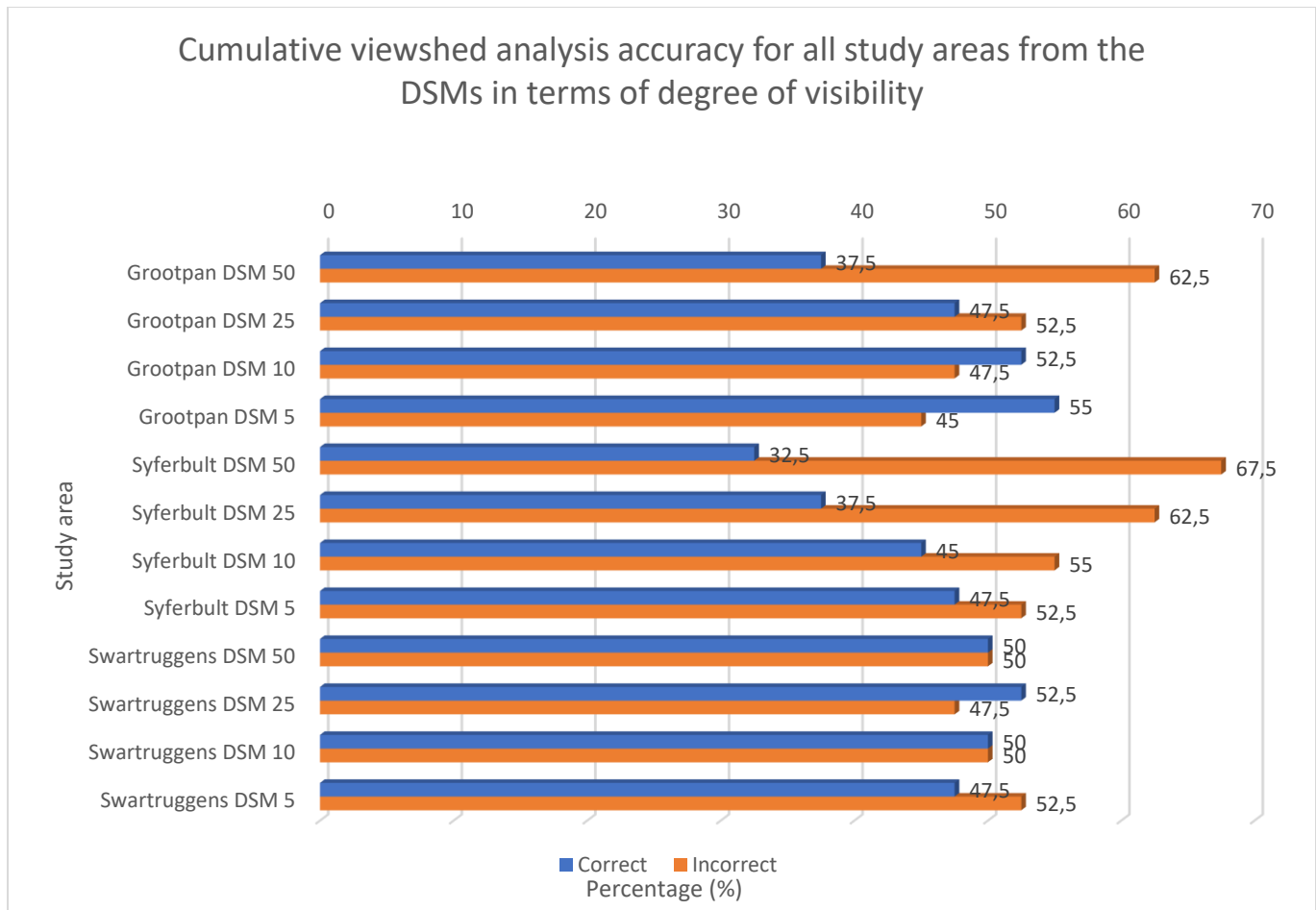


Figure 62: Accuracy assessment of cumulative viewshed analysis based on DSM's in terms of the degree of visibility

4.3.3. Accuracy assessment of line-of-sight analysis

The following graphs show the combined accuracy assessment (Section 3.3.1) results for LOS analysis using different DEM's and resolutions. The results are presented per DEM with the findings for analysis based on DTM's presented first (Figure 63) followed by the findings based on DSM's (Figure 64).

4.3.3.1. LOS analysis DTM's

Similar accuracy results were achieved for all resolution sizes from LOS analysis simulations done in the Grootpan study area, although the DTM25m present a higher level of accuracy than the finer resolution sized DTM's. Syferbult showed the same level of accuracy for the 10, 25 and 50m DTM at 67.5%, with only the DTM5m having a slightly higher accuracy prediction at 70%. This again confirms the finding that finer resolution sizes result in an accuracy increase. A better trend was observed in terms of accuracy increase at finer resolution sizes

in the Swartruggens study area when compared to the other two. LOS analysis presented better accuracy results in complex study areas compared to the other visibility analysis methods.

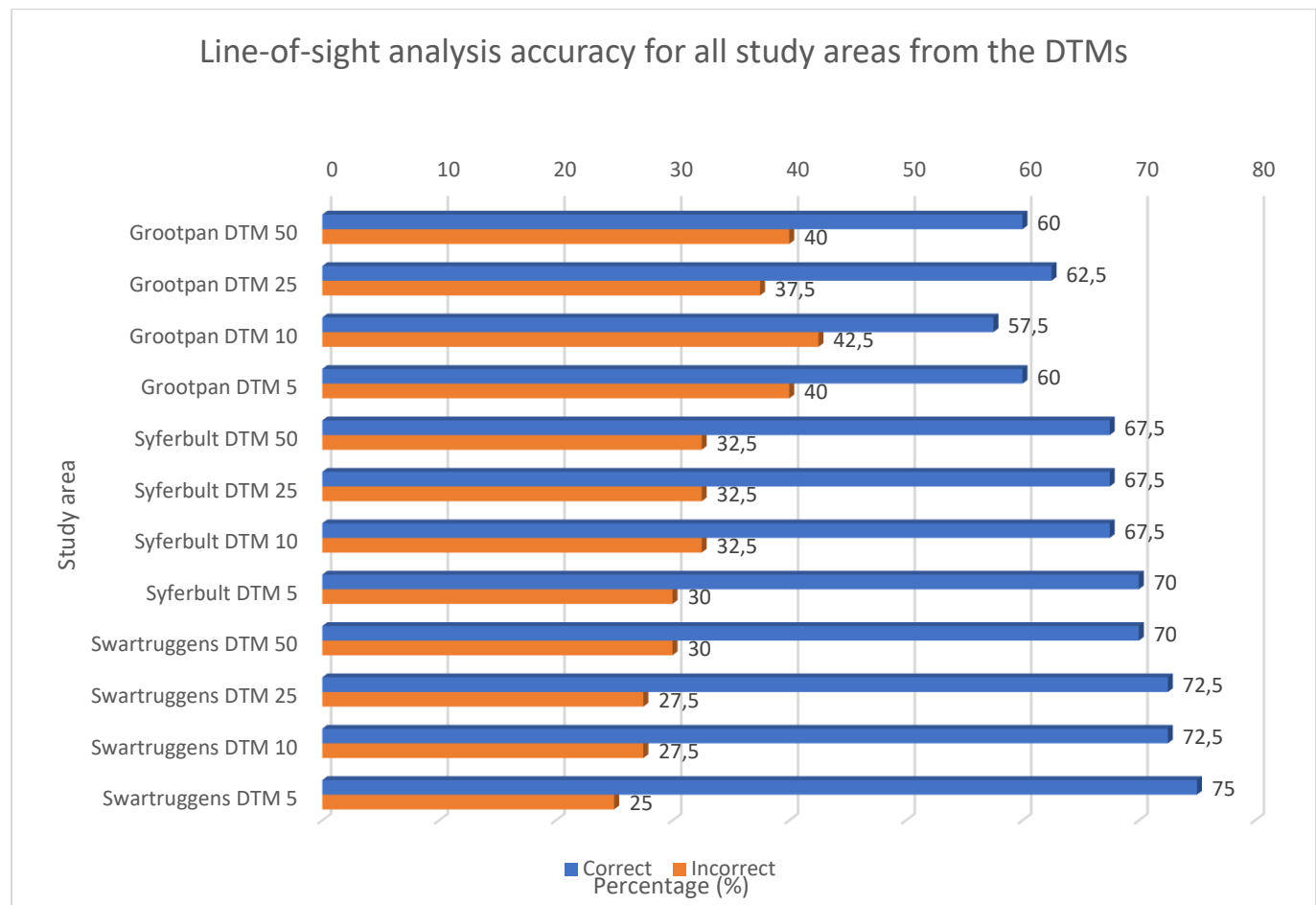


Figure 63: Accuracy assessment of LOS analysis based on DTM's

4.3.3.2. LOS analysis DSM's

The accuracy assessment of LOS analysis based on DSM's again showed an increase in accuracy at finer resolution sizes. Improved accuracies were achieved for three of the four LOS analysis simulations in the Grootpan study, with the only exception being the DSM50m. Accuracies increased for all LOS analysis simulations in the Syferbult study while Swartruggens only had a lower accuracy for the DSM25m. The DSM5m Swartruggens LOS analysis simulation reported the best accuracy of all simulations at 82.5%.

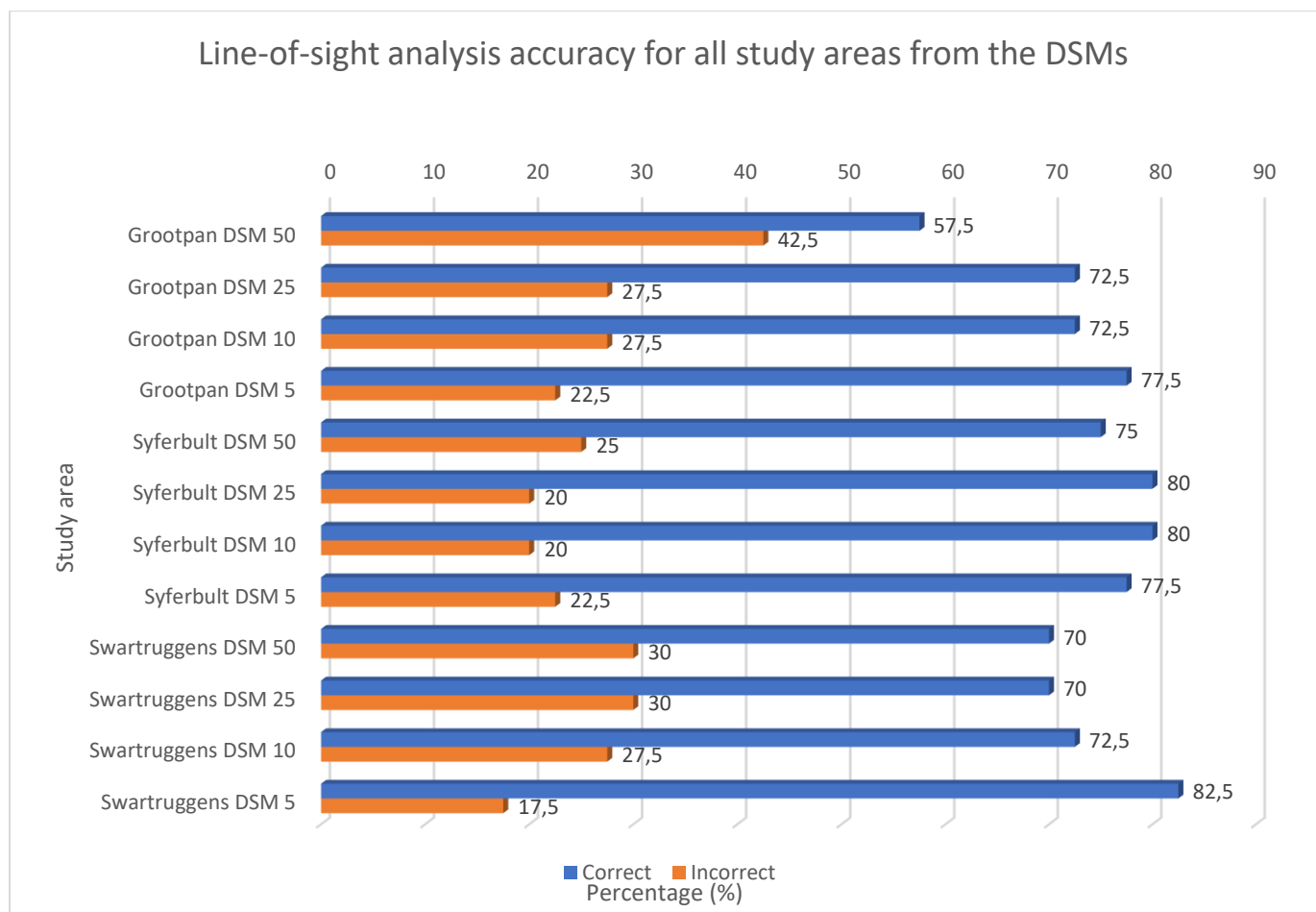


Figure 64: Accuracy assessment of LOS analysis based on DSM's

The LOS analysis technique generally scored better predictions when based on the DSM than based on the DTM. In terms of terrain complexity, the best results were achieved for the intermediate complexity. The assessment of each visibility analysis technique presented substantial insight on how each technique is influenced by terrain complexity, resolution size and the use of either DTM's or DSM's. To better understand the accuracy of each visibility analysis technique used with the various variables, a summary and comparison are presented below.

4.3.4. Summary of accuracy assessment of all visibility analysis techniques

Figures 65 (Grootpan), Figure 66 (Syferbult) and Figure 67 (Swartruggens) present the accuracy of each study areas visibility simulations against their resolutions, while Table 12 presents the accuracy assessment results in detail for all 72 visibility analysis simulations discussed above. This section, therefore, informs Objective 3 which was to determine an optimal visibility analysis approach for use in VIA. The manner in which DEM's affect visibility

analysis is discussed first (4.3.4.1), followed by the effects of resolutions (4.3.4.2) and terrain complexities (4.3.4.3). An optimal approach to visibility analysis is finally presented and discussed (4.3.4.4).

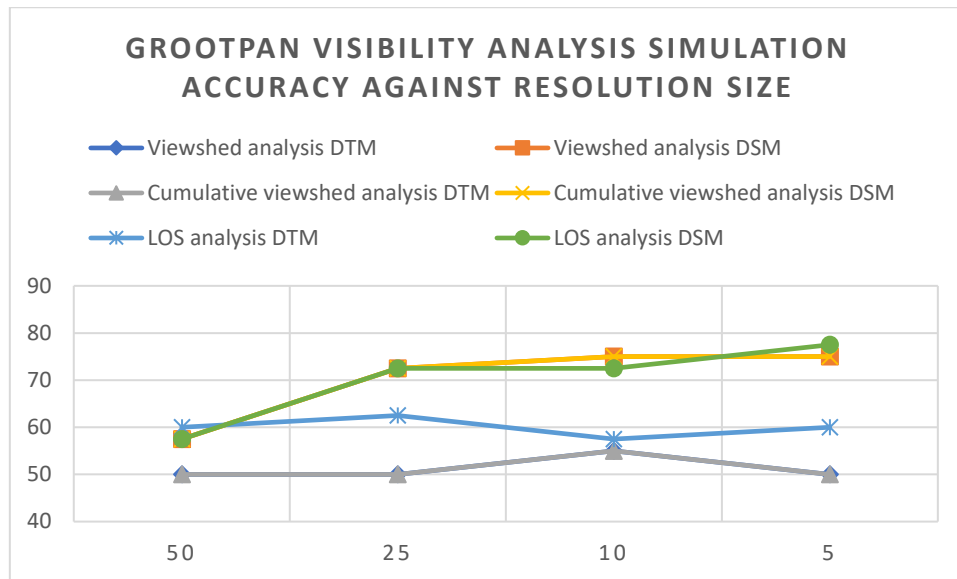


Figure 65: Line graph of Grootpan visibility analysis simulation accuracy

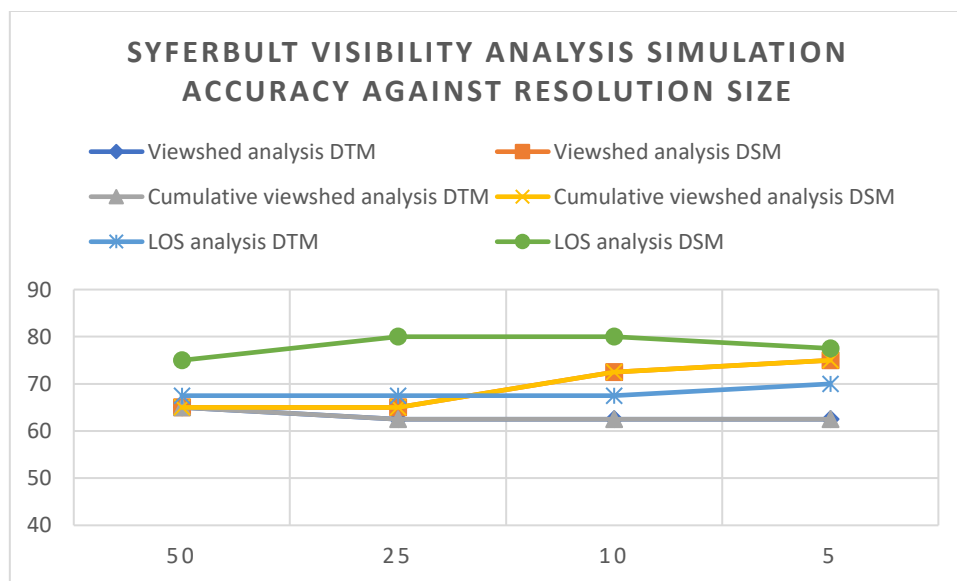


Figure 66: Line graph of Syferbult visibility analysis accuracy

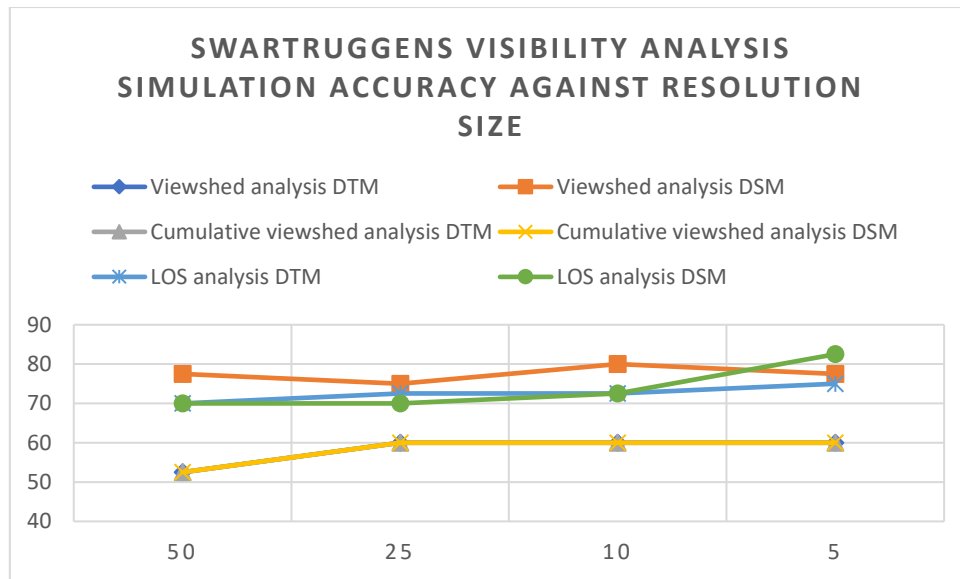


Figure 67: Line graph of Swartruggens visibility analysis simulation accuracy

Table 12: Summary of accuracy assessment result for all visibility analysis simulations

Study area	DEM	Viewshed analysis		Cumulative viewshed analysis		LOS analysis	
		Correct (%)	Incorrect (%)	Correct (%)	Incorrect (%)	Correct (%)	Incorrect (%)
Grootpan	DTM50m	50	50	50	50	60	40
Grootpan	DTM25m	50	50	50	50	62.5	37.5
Grootpan	DTM10m	55	45	55	45	57.5	42.5
Grootpan	DTM5m	50	50	50	50	60	40
Grootpan	DSM50m	57.5	42.5	57.5	42.5	57.5	42.5
Grootpan	DSM25m	72.5	27.5	72.5	27.5	72.5	27.5
Grootpan	DSM10m	75	25	75	25	72.5	27.5
Grootpan	DSM5m	75	25	75	25	77.5	22.5
Syferbult	DTM50m	65	35	65	35	67.5	32.5
Syferbult	DTM25m	62.5	37.5	62.5	37.5	67.5	32.5
Syferbult	DTM10m	62.5	37.5	62.5	37.5	67.5	32.5
Syferbult	DTM5m	62.5	37.5	62.5	37.5	70	30
Syferbult	DSM50m	65	35	65	35	75	25
Syferbult	DSM25m	65	35	65	35	80	20
Syferbult	DSM10m	72.5	27.5	72.5	27.5	80	20
Syferbult	DSM5m	75	25	75	25	77.5	22.5
Swartruggens	DTM50m	52.5	47.5	52.5	47.5	70	30
Swartruggens	DTM25m	60	40	60	40	72.5	27.5
Swartruggens	DTM10m	60	40	60	40	72.5	27.5
Swartruggens	DTM5m	60	40	60	40	75	25
Swartruggens	DSM50m	77.5	22.5	77.5	22.5	70	30
Swartruggens	DSM25m	75	25	75	25	70	30
Swartruggens	DSM10m	80	20	80	20	72.5	27.5

Swartruggens	DSM5m	77.5	22.5	77.5	22.5	82.5	17.5
--------------	-------	------	------	------	------	------	------

4.3.4.1. DEM effect on visibility analysis techniques

The type of DEM used in visibility analysis was found to be an important factor across all visibility analysis techniques. As an example, the use of DTM's in the Grootpan study area resulted in average visibility analysis accuracy scores of 51.3% for viewshed and cumulative viewshed analysis and 60% for the LOS analysis. However, when using DSM's, accuracy results went up to averages of 70% in all cases. The same trend was observed for Syferbult with average accuracy scores increasing from 63.1% to 69.4%, and Swartruggens, where scores increased from 58.1% to 77.5%.

The presence of land cover contained in DSM's, therefore contributed to increased accuracy, stressing the importance of considering the screening effect of land cover in visibility analysis. The effects of screening are clearly illustrated in the maps shown in Section 4.2.2 as the total visible area significantly decreases once land cover is introduced.

4.3.4.2. Resolution size effect on visibility analysis techniques

Finer resolution size was found to generate more accurate results across all visibility analysis techniques with only a few exceptions. For example, smaller DTM resolution sizes in the Swartruggens study area resulted in an increase from 52.5% at the DTM50m to an accuracy of 60% for the DTM5m for viewshed and cumulative viewshed analysis. Exceptions were observed in the Grootpan DTM10m, resulting in an accuracy of 55%, while the DTM5m only achieved an accuracy of 50%. Similarly, Syferbult resulted in better accuracy for the DTM50m at 65%, while the other DTM's only achieved an accuracy of 62.5% for viewshed and cumulative viewshed analysis simulations.

LOS analysis results showed the same trend as the other two visibility analysis techniques with accuracy improving with finer resolutions. For instance, Syferbult increased from 67.5% for the DTM50m to 70% for the DTM5m, and Swartruggens from 70% for the DTM50m to 75% for the DTM5m. Some exceptions were observed where coarser resolutions resulted in better accuracy than finer resolutions. For instance, LOS analysis presented a better accuracy with the DTM25m at 62.5% than for the DTM5m at 60%.

DSM's at finer resolutions also showed the same trend with accuracy improving with a decrease in resolution size. For example, viewshed and cumulative viewshed analysis result improved from 57.5% for the DSM50m to 75% for the DSM5m in the Grootpan study area. The Syferbult study area presented the same findings with accuracy improving from 65% for

the DSM50m to 75% for the DSM5m. Swartruggens was an exception against the trend with DSM10m presenting the highest accuracy at 80% while the DSM5m presented an accuracy of 77.5%.

LOS analysis results indicated the same trend regarding finer resolution sizes with some exceptions occurring in the Syferbult area. As an example, Syferbult presented its highest accuracy with the DSM25m and DSM10m at 80%, while the DSM5m presented an accuracy of 77.5%. The other two study areas presented their highest accuracies at the DSM5m with an accuracy of 77.5% for Grootpan and 82.5% for Swartruggens.

The choice of resolution size had a much more significant effect on visibility analysis simulations done on DSM's than those done on DTM's. In most cases, visibility analysis simulations resulted in similar accuracies at all resolution sizes in terms of DTM's, however, with DSM's most study areas reported a better accuracy at finer resolutions. Overall, most visibility analysis simulations, whether DTM's or DSM's, would have more or less the same accuracy if either a 5m or 1m resolution is used.

4.3.4.3. Terrain complexity effect on visibility analysis techniques

The viewshed and cumulative viewshed analysis based on DTM's presented the best accuracy for the intermediate terrain complexity. For example, Syferbult reported an average accuracy of 63.13% for all four DTM's. Swartruggens presents the second-best representation of accuracy at an average of 58.13%, with the lowest level of accuracy occurring in the least complex area at 51.25%. Simulations done on DSM's showed the best accuracy in the intermediate complex terrain (Syferbult), with reference points accurately predicted at an average of 78.13%. Similarly, Swartruggens had the second-highest average accuracy at 73.75%, while the Grootpan had the lowest average accuracy at 70%.

LOS analysis based on DTM's showed the highest accuracy in the most complex study area (Swartruggens) at 72.5%. Accuracy decreased as terrain complexity decreased, with Syferbult having an accuracy of 68.13% and Grootpan an accuracy of 64%. LOS analysis simulations based on DSM's showed the highest accuracy in the intermediate terrain study area (Syferbult) at an accuracy of 78.13%. Swartruggens presented the second-highest average accuracy at 73.75%. The lowest average accuracy was determined for the Grootpan study area at 70%.

Overall, DSMs produced better levels of accuracy in terms of terrain complexity across all three visibility analysis techniques. Interestingly enough, techniques generally performed better in more complex terrains. The choice of resolution size generally had a bigger effect on

accuracy than terrain complexity. The following section reflects on the optimal approach to visibility analysis for use in VIA.

4.3.4.4. Optimal visibility analysis approach

The findings from the 72 visibility analysis simulations showed LOS analysis based on DSM's to be the optimal approach to visibility analysis for use in VIA. The technique presented the most accurate results for all three study areas (Grootpan DSM5m – 77.5%, Syferbult DSM10 & DSM 25 – 80% and Swartruggens DSM 5m – 82.5%) and presented very good results in areas with high levels of terrain complexity. The results further suggest that a relatively high spatial resolution is advisable when conducting the analysis. Specifically, the results suggested either a 10m or 5m resolution size as the most accurate. The minimum resolution as determined through the Hengl (2006) equation, therefore, indicates the most accurate resolution sizes for visibility analysis.

Chapter 5: Conclusion

The aim of the study was to determine an optimal approach to visibility for use in VIA. Different techniques were evaluated, and the extent to which they were affected by terrain complexity and different input variables considered.

The **first objective** of the study was to explore the current methodological approaches used to determine visibility analysis within visual impact assessment studies. The current approaches were identified through a document analysis procedure described in Section 3.1, where 19 VIA reports were evaluated to determine not only the approach, but also its associated variables. Viewshed analysis was identified as the most common visibility analysis technique used in VIA with a total of 12 VIA incorporating the technique. Similarly, Miller *et al.* (2011) stated that viewshed analysis is one of the most common techniques used in VIA as discussed within Chapter 2. Cumulative viewshed analysis was identified as the second most common technique from the document analysis procedure. The final visibility analysis technique identified was LOS analysis, but which was only included in a few VIA's. The study can conclude that viewshed, although most often used, is not the best approach to use for visibility analysis in VIA. The information collected from the first objective provided the required visibility analysis techniques to be tested as part of the second objective.

The **second objective** of the study was to test and evaluate the identified visibility analysis techniques across different terrain complexities and using different variables. The first part of achieving the second objective of the study was to identify suitable study areas with different terrain complexities. As stated by Fisher and Tate (2006), in Chapter 2, terrain complexity is a factor that can affect the accuracy of visibility analysis. Swartruggens was the most complex area, followed by Syferbult (intermediate complexity) and Grootpan (low complexity).

The second part involved evaluating the different techniques across the three areas using a variety of variables. The differences in variables were mainly focused on the type of DEM, and the resolution size used. These two were used as they provide limitations to visibility analysis, as discussed in Section 2.1.4. DTM's were generated from point and contour elevation data with resolution sizes determined from two equations obtained from work by Hengl (2006). The DSM's were generated from the DTM's by adding the land cover height values to the DTM's (Garnero & Fabrizio, 2015; Klouček *et al.*, 2015; Rogge *et al.*, 2008). The procedure provided the required platform to test and evaluate the different visibility analysis techniques identified from the document analysis procedure.

A total of 72 visibility analysis simulations were done (24 simulations associated with each technique, of which 12 were assigned to each type of DEM). Visibility analysis results generally

increased with the inclusion of land cover and at finer resolutions. These findings are supported by authors such as Domino-Santos *et al.* (2011) and Llobera (2003).

The **third objective** of the study was to identify an optimal approach to visibility analysis for use in VIA studies. The 72 visibility analysis simulations were evaluated against the 40 reference points collected for each study area. The best visibility analysis approach identified was LOS analysis based on a DSM, although viewshed analysis was identified as the most common visibility analysis technique used in VIA reports and DTM was the elevation model most often used. This is an important finding as it contradicts current VIA practice which mainly relies on viewshed analysis and DTM's. The analysis found the most accurate simulations at finer resolutions – a factor that became even more important as terrain complexity increased. Finer resolutions presented more realistic representations of the terrain characteristics and their features capable of screening visibility. In particular, a more realistic representation of the terrain improved accuracy through all three visibility analysis techniques. Not only did smaller resolutions provide a more realistic representation of the terrain characteristics, but the involvement of surface features in DEM's increased the similarity between DEM and the terrain. Understanding the importance of surface features screening capability was easily observed through the comparison between DTM's and DSM's. Understanding how resolution size and surface features affect visibility results accuracy and how they should be incorporated in simulations presents a more optimal approach. An optimal approach for visibility analysis would, therefore, consist of LOS analysis based on a DSM with a relatively small resolution size.

References

- Anile, M.A., Furno, P., Gallo, G., & Massolo, A. 2003. A fuzzy approach to visibility maps creation over digital terrains. *Fuzzy Sets Syst.* 135:63–80.
- Bartie, P., Reitsma, F., Kingham, S., & Mills, S. 2010. Advancing visibility modelling algorithms for urban environments. *Comput. Environ. Urban Syst. Elsevier Ltd.* 34(6):518–531.
- Bartie, P., Reitsma, F., Kingham, S., & Mills, S. 2011. Incorporating vegetation into visual exposure modelling in urban environments. *Int. J. Geogr. Inf. Sci.* 25(5):851–868.
- Bennett, D. & Armstrong, M. 2010. GIS Fundamentals: A first text on geographic information systems. , Bolstad, Paul.
- Bowen, G.A. 2009. Document analysis as a qualitative research method. *Qual. Res. J.* 9(2):27–40.
- Chamberlain, B.C. & Meitner, M.J. 2013. A route-based visibility analysis for landscape management. *Landsc. Urban Plan. Elsevier B.V.* 111:13–24.
- Chaplot, V., Darboux, F., Bourennane, H., Leguédais, S., Silvera, N., & Phachomphon, K. 2006. Accuracy of interpolation techniques for the derivation of digital elevation models in relation to landform types and data density. *Geomorphology.* 77(1–2):126–141.
- Childs, C. 2004. Interpolating surfaces in ArcGIS Spatial Analyst. *ArcUSER.* July-Sept:32–35.
- Danese, M., Nolè, G., & Murgante, B. 2011. Identifying viewshed: New approaches to visual impact assessment. *Stud. Comput. Intell.* 348:73–89.
- De Reu, J., Bourgeois, J., Bats, M., Zwervaegher, A., Gelorini, V., De Smedt, P., Chu, W., Antrop, M., De Maeyer, P., Finke, P., Van Meirvenne, M., Verniers, J., & Crombé, P. 2013. Application of the topographic position index to heterogeneous landscapes. *Geomorphology. Elsevier B.V.* 186:39–49.
- DEAT. 2002. Specialist Studies, Information Series 4, Department of Environmental Affairs and Tourism (DEAT). Pretoria.
- Depellegrin, D. 2016. Assessing cumulative visual impacts in coastal areas of the Baltic Sea. *Ocean Coast. Manag. Elsevier Ltd.* 119:184–198.
- Domingo-Santos, J.M., de Villarán, R.F., Rapp-Arrarás, Í., & de Provens, E.C.P. 2011. The visual exposure in forest and rural landscapes: An algorithm and a GIS tool. *Landsc. Urban*

Plan. Elsevier B.V. 101(1):52–58.

Eldrandaly, K.A. & Abu-Zaid, M.S. 2011. Comparison of six GIS-based spatial interpolation methods for estimating air temperature in Western Saudi Arabia. *J. Environ. Informatics*. 18(1):38–45.

Ervin, S. & Steinitz, C. 2003. Landscape visibility computation: Necessary, but not sufficient. *Environ. Plan. B Plan. Des.* 30(5):757–766.

Evans, W., Kirkpatrick, D., & Townsend, G. 2001. Right-triangulated irregular networks. *Algorithmica (New York)*. 30(2):264–286.

Felleman, J.P. 1982. Visibility mapping in New York's coastal zone: A case study of alternative methods. *Coast. Zo. Manag. J.* :249–270.

Feng, W., Gang, W., Deji, P., Yuan, L., Liuzhong, Y., & Hongbo, W. 2015. A parallel algorithm for viewshed analysis in three-dimensional Digital Earth. *Comput. Geosci. Elsevier*. 75:57–65.

Fernandez-Jimenez, L.A., Mendoza-Villena, M., Zorzano-Santamaria, P., Garcia-Garrido, E., Lara-Santillan, P., Zorzano-Alba, E., & Falces, A. 2015. Site selection for new PV power plants based on their observability. *Renew. Energy. Elsevier Ltd.* 78:7–15.

Fisher, P.F. & Tate, N.J. 2006. Causes and consequences of error in digital elevation models. *Prog. Phys. Geogr.* 30(4):467–489.

Garnero, G. & Fabrizio, E. 2015. Visibility analysis in urban spaces: a raster-based approach and case studies. *Environ. Plan. B Plan. Des.* 42(4):688–707.

Germينو, M.J., Reiners, W.A., Blasko, B.J., McLeod, D., & Bastian, C.T. 2001. Estimating visual properties of rocky mountain landscapes using GIS. *Landsc. Urban Plan.* 53(1–4):71–83.

Gillings, M. 2015. Mapping invisibility: GIS approaches to the analysis of hiding and seclusion. *J. Archaeol. Sci. Elsevier Ltd.* 62:1–14.

Glasson, J., Therivel, R., & Chadwick, A. 2005. Introduction to environmental impact assessment. 3rd ed. Routledge: London.

Godone, D. & Garnero, G. 2013. The role of morphometric parameters in Digital Terrain Models interpolation accuracy : a case study. *Eur. J. Remote Sens.* 46:198–214.

Hengl, T. 2006. Finding the right pixel size. *Comput. Geosci.* 32(9):1283–1298.

Hernández, J., García, L., & Ayuga, F. 2004. Assessment of the visual impact made on the

landscape by new buildings: A methodology for site selection. *Landsc. Urban Plan.* 68(1):15–28.

Hirt, C. 2018. Artefact detection in global digital elevation models (DEMs): The maximum slope approach and its application for complete screening of the SRTM v4.1 and MERIT DEMs. *Remote Sens. Environ. Elsevier*. 207(September 2017):27–41.

Huaxing, L.U. 2008. Modelling terrain complexity. , in: Zhou, Q., Lees, B., Tang, G. (Eds.), *Advances in Digital Terrain Analysis*. Springer Berlin Heidelberg: Berlin. . Springer Berlin Heidelberg: Berlin, pp. 159–176.

Jennes, J. 2013. DEM Surface Tools for ArcGIS.

Jones, G.R., Jones, I., Gray, B.A., Parker, B., Coe, J.C., Burnham, J. b., & Geitner, N.M. 1975. Method for quantification of aesthetic values for environmental decision making. *Nucl. Technol.* 25(4):682–713.

Kantner, J. & Hobgood, R. 2016. A GIS-based viewshed analysis of Chacoan tower kivas in the US Southwest: were they for seeing or to be seen? *Antiquity*. 90(353):1302–1317.

Kidner, D.B., Sparkes, A.J., Dorey, M.I., Ware, J.M., & Jones, C.B. 2001. Visibility analysis with the multiscale implicit TIN. *Trans. GIS*. 5(1):19–37.

Kienzle, S. 2003. The effect of DEM raster resolution on first order, second order and compound terrain derivatives. *Trans. GIS*. 8(1):83–111.

Kim, Y.H., Rana, S., & Wise, S. 2004. Exploring multiple viewshed analysis using terrain features and optimisation techniques. *Comput. Geosci.* 30(9–10):1019–1032.

Klouček, T., Lagner, O., & Šímová, P. 2015. How does data accuracy influence the reliability of digital viewshed models? A case study with wind turbines. *Appl. Geogr.* 64:46–54.

Korzeniowska, K., Pfeifer, N., & Landtwing, S. 2018. Mapping gullies, dunes, lava fields, and landslides via surface roughness. *Geomorphology. Elsevier B.V.* 301:53–67.

Li, J. & Heap, A.D. 2014. Spatial interpolation methods applied in the environmental sciences: A review. *Environ. Model. Softw. Elsevier Ltd.* 53:173–189.

Litton, R.B.J. 1973. Landscape control points: A procedure for predicting and monitoring visual impacts. *USDA For. Serv. Res. Pap.* PSW-91.

Llobera, M. 2003. Extending GIS-based visual analysis: The concept of visualsapes. *Int. J. Geogr. Inf. Sci.* 17(1):25–48.

Llobera, M. 2007. Modeling visibility through vegetation. *Int. J. Geogr. Inf. Sci.* 21(7):799–

Lockhart, D. 2009. Viewshed uncertainty in a forested, mountainous landscape. The University of Georgia.

Lu, G.Y. & Wong, D.W. 2008. An adaptive inverse-distance weighting spatial interpolation technique. *Comput. Geosci.* 34(9):1044–1055.

Maloy, M.A. & Dean, D.J. 2001. An accuracy assessment of various GIS-based viewshed delineation techniques. *Photogramm. Eng. Remote Sens.* 67(11):1293–1298.

Manchado, C., Gomez-Jauregui, V., Lizcano, P.E., Iglesias, A., Galvez, A., & Otero, C. 2019. Wind farm repowering guided by visual impact criteria. *Renew. Energy. Elsevier Ltd.* 135:197–207.

Marais, M., Retief, F.P., Sandham, L.A., & Cilliers, D.P. 2015. Environmental management frameworks: Results and inferences of report quality performance in South Africa. *South African Geogr. J.* 97(1):83–99.

Marinai, S., Gori, M., & Giovanni, S. 2005. Artificial neural network for document analysis and recognition. *Trans. pattern Anal. Mach. Intell.* 27(1):23–35.

Miller, M.L., Carstensen, L.W., Campbell, J.B., & Thomas, V. 2011. Analysis of viewshed accuracy with variable resolution LIDAR digital surface models and photogrammetrically-Derived digital elevation models masters of science in geography. Virginia State University.

Möller, B. 2006. Changing wind-power landscapes: Regional assessment of visual impact on land use and population in Northern Jutland, Denmark. *Appl. Energy.* 83(5):477–494.

Molnarova, K., Sklenicka, P., Stiborek, J., Svobodova, K., Salek, M., & Brabec, E. 2012. Visual preferences for wind turbines: Location, numbers and respondent characteristics. *Appl. Energy. Elsevier Ltd.* 92:269–278.

Münster, F. 2005. Guideline for determining the scope of specialist involvement in EIA processes. , Edition 1. CSIR Report No ENV-S-C 2005 053 A. Republic of South Africa, Provincial Government of the Western Cape, Department of Environmental Affairs & Development Planning, Cape Town.

Murphy, K.M., Gittings, B., & Crow, J. 2018. Visibility analysis of the Roman communication network in southern Scotland. *J. Archaeol. Sci. Reports. Elsevier.* 17(October 2017):111–124.

Nair, H.C., Joseph, A., & Padmakumari Gopinathan, V. 2018. GIS Based landform classification using digital elevation model: a case study from two river basins of Southern

Western Ghats, Kerala, India. *Model. Earth Syst. Environ. Springer International Publishing*. 4(4):1355–1363.

Nutsford, D., Reitsma, F., Pearson, A.L., & Kingham, S. 2015. Personalising the viewshed: Visibility analysis from the human perspective. *Appl. Geogr. Elsevier Ltd*. 62:1–7.

Oberholzer, B. 2005. Guideline for involving visual and aesthetic specialists in EIA processes. Edition 1. CSIR Report No ENV-S-C 2005 053 F. Cape Town.

Ogburn, D.E. 2006. Assessing the level of visibility of cultural objects in past landscapes. *J. Archaeol. Sci.* 33(3):405–413.

Orland, B. 1988. Video imaging: a powerful tool for visualization and analysis,. *Landsc. Archit.* 78,. 78(5):78–88.

Palmer, J.F. 1981. Approaches for assessing visual quality and visual impact. 2nd ed. , in: *Methodology of Social Impact Assessment*. Hutchinson Ross Publishing Company: Stroudsburg. . Hutchinson Ross Publishing Company: Stroudsburg, pp. 294–301.

Pardo García, S. & Mérida Rodríguez, M. 2015. A geospatial indicator for assessing urban panoramic views. *Comput. Environ. Urban Syst.* 49:42–53.

Patel, S. & Giordano, T. 2014. Environmental assessments for the greening of public infrastructure in South Africa. *Dev. South. Afr.* 31(5):721–743.

Pullar, D.V. & Tidey, M.E. 2001. No Title. *Landsc. Urban Plan.* 55(1):29–40.

Qiang, Y., Shen, S., & Chen, Q. 2019. Visibility analysis of oceanic blue space using digital elevation models. *Landsc. Urban Plan. Elsevier*. 181(October 2018):92–102.

Razak, K.A., Santangelo, M., Van Westen, C.J., Straatsma, M.W., & de Jong, S.M. 2013. Generating an optimal DTM from airborne laser scanning data for landslide mapping in a tropical forest environment. *Geomorphology. Elsevier B.V.* 190:112–125.

Retief, F., Welman, C.N.J., & Sandham, L. 2011. Performance of environmental impact assessment (EIA) screening in South Africa: A comparative analysis between the 1997 and 2006 EIA regimes. *South African Geogr. J.* 93(2):154–171.

Riggs, P.D. & Dean, D.J. 2007. An investigation into the causes of errors and inconsistencies in predicted viewsheds. *Trans. GIS.* 11(2):175–196.

Rishikeshan, C.A., Katiyar, S.K., & Vishnu Mahesh, V.N. 2014. Detailed evaluation of dem interpolation methods in GIS using DGPS data. *Proc. - 2014 6th Int. Conf. Comput. Intell. Commun. Networks, CICN 2014. IEEE.* :666–671.

- Robert, S. 2018. Assessing the visual landscape potential of coastal territories for spatial planning: A case study in the French Mediterranean. *Land use policy. Elsevier*. 72(December 2017):138–151.
- Rød, J.K. & Van der Meer, D. 2009. Visibility and dominance analysis: Assessing a high-rise building project in Trondheim. *Environ. Plan. B Plan. Des.* 36(4):698–710.
- Rodrigues, M., Montañés, C., & Fueyo, N. 2010. A method for the assessment of the visual impact caused by the large-scale deployment of renewable-energy facilities. *Environ. Impact Assess. Rev. Elsevier Inc.* 30(4):240–246.
- Ross, W.A., Morrison-Saunders, A., Marshall, R., Sánchez, L.E., Weston, J., Au, E., Morgan, R.K., Fuggle, R., Sadler, B., Ross, W.A., Morrison-Saunders, A., & Marshall, R. 2006. Improving quality. *Impact Assess. Proj. Apprais.* 24(1):3–22.
- Samavatekbatan, A., Gholami, S., & Karimimoshaver, M. 2016. Assessing the visual impact of physical features of tall buildings: Height, top, color. *Environ. Impact Assess. Rev. Elsevier Inc.* 57:53–62.
- Sander, H.A. & Manson, S.M. 2007. Heights and locations of artificial structures in viewshed calculation: How close is close enough? *Landsc. Urban Plan.* 82(4):257–270.
- Smardon, R.C. & Hunter, M. 1983. Procedures and methods for wetland and coastal area visual impact assessment (VIA). , in: Smardon, R.C. (Ed.), *The Future of Wetlands: Assessing Visual-Cultural Values*. Allanheld Osmun: Totowa, NJ. . Allanheld Osmun: Totowa, NJ, pp. 171–204.
- Smith, M.P., Zhu, A.X., Burt, J.E., & Stiles, C. 2006. The effects of DEM resolution and neighborhood size on digital soil survey. *Geoderma*. 137(1–2):58–69.
- Sullivan, R. & Meyer, M. 2014. Guide to evaluating visual impact assessments for renewable energy projects. Natural Re ed. National Park Service: Ft. Collins, Colorado.
- Taheri, M., Gholamalifard, M., Ghazizade, M.J., & Rahimoghli, S. 2014. Environmental impact assessment of municipal solid waste disposal site in Tabriz, Iran using rapid impact assessment matrix. *Impact Assess. Proj. Apprais.* Taylor & Francis.
- Thompson, J.A., Bell, J.C., & Butler, C.A. 2001. Digital elevation model resolution : effects on terrain attribute calculation and quantitative soil-landscape modeling. :67–89.
- Thompson, M. 2019. South African National Land-Cover 2018 Report & Accuracy Assessment. Pretoria.
- Vari, A. 2002. Garmin eTrex Venture personal navigator owner's manual and reference

guide. Garmin.

Véga, C., Vepakomma, U., Morel, J., Bader, J.L., Rajashekar, G., Jha, C.S., Ferêt, J., Proisy, C., Péliissier, R., & Dadhwal, V.K. 2015. Aboveground-biomass estimation of a complex tropical forest in India using lidar. *Remote Sens.* 7(8):10607–10625.

Verutes, G.M., Huang, C., Estrella, R.R., & Loyd, K. 2014. Exploring scenarios of light pollution from coastal development reaching sea turtle nesting beaches near Cabo Pulmo, Mexico. *Glob. Ecol. Conserv. Elsevier B.V.* 2:170–180.

Vinod, P.G. 2017. Development of topographic position index based on Jenness algorithm for precision agriculture at Kerala, India. *Spat. Inf. Res. Korean Spatial Information Society.* 25(3):381–388.

Weiss, A. 2001. Topographic position and landforms analysis. , in: Topographic Position and Landform Analysis. Poster presentation, ESRI Users Conference: San Diego. . Poster presentation, ESRI Users Conference: San Diego.

Wood, G. & Becker, J. 2005. Discretionary judgement in local planning authority decision making: Screening development proposals for environmental impact assessment. *J. Environ. Plan. Manag.* 48(3):349–371.

Wróżyński, R., Sojka, M., & Pyszny, K. 2016. The application of GIS and 3D graphic software to visual impact assessment of wind turbines. *Renew. Energy.* 96:625–635.

Zhao, Y., Padmanabhan, A., & Wang, S. 2013. A parallel computing approach to viewshed analysis of large terrain data using graphics processing units. *Int. J. Geogr. Inf. Sci.* 27(2):363–384.

Zhou, Q., Liu, X., & Sun, Y. 2006. Terrain complexity and uncertainties in grid-based digital terrain analysis. *Int. J. Geogr. Inf. Sci.* 20(10):1137–1147.

Ziadat, F.M. 2007. Effect of contour intervals and grid cell size on the accuracy of DEMs and slope derivatives. *Trans. GIS.* 11(1):67–81.

Zube, E.H., Sell, J.L., & Taylor, J.G. 1982. Landscape perception: Research, application and theory. *Landsc. Plan.* 9(1):1–33.

Anile, M.A., Furno, P., Gallo, G., & Massolo, A. 2003. A fuzzy approach to visibility maps creation over digital terrains. *Fuzzy Sets Syst.* 135:63–80.

Bartie, P., Reitsma, F., Kingham, S., & Mills, S. 2010. Advancing visibility modelling algorithms for urban environments. *Comput. Environ. Urban Syst. Elsevier Ltd.* 34(6):518–531.

- Bartie, P., Reitsma, F., Kingham, S., & Mills, S. 2011. Incorporating vegetation into visual exposure modelling in urban environments. *Int. J. Geogr. Inf. Sci.* 25(5):851–868.
- Bennett, D. & Armstrong, M. 2010. GIS Fundamentals: A first text on geographic information systems. , Bolstad, Paul.
- Bowen, G.A. 2009. Document analysis as a qualitative research method. *Qual. Res. J.* 9(2):27–40.
- Chamberlain, B.C. & Meitner, M.J. 2013. A route-based visibility analysis for landscape management. *Landsc. Urban Plan. Elsevier B.V.* 111:13–24.
- Chaplot, V., Darboux, F., Bourennane, H., Legu  dois, S., Silvera, N., & Phachomphon, K. 2006. Accuracy of interpolation techniques for the derivation of digital elevation models in relation to landform types and data density. *Geomorphology.* 77(1–2):126–141.
- Childs, C. 2004. Interpolating surfaces in ArcGIS Spatial Analyst. *ArcUSER.* July-Sept:32–35.
- Danese, M., Nol  , G., & Murgante, B. 2011. Identifying viewshed: New approaches to visual impact assessment. *Stud. Comput. Intell.* 348:73–89.
- De Reu, J., Bourgeois, J., Bats, M., Zwertvaegher, A., Gelorini, V., De Smedt, P., Chu, W., Antrop, M., De Maeyer, P., Finke, P., Van Meirvenne, M., Verniers, J., & Cromb  , P. 2013. Application of the topographic position index to heterogeneous landscapes. *Geomorphology. Elsevier B.V.* 186:39–49.
- DEAT. 2002. Specialist Studies, Information Series 4, Department of Environmental Affairs and Tourism (DEAT). Pretoria.
- Depellegrin, D. 2016. Assessing cumulative visual impacts in coastal areas of the Baltic Sea. *Ocean Coast. Manag. Elsevier Ltd.* 119:184–198.
- Domingo-Santos, J.M., de Villar  n, R.F., Rapp-Arrar  s,   ., & de Provens, E.C.P. 2011. The visual exposure in forest and rural landscapes: An algorithm and a GIS tool. *Landsc. Urban Plan. Elsevier B.V.* 101(1):52–58.
- Eldrandaly, K.A. & Abu-Zaid, M.S. 2011. Comparison of six GIS-based spatial interpolation methods for estimating air temperature in Western Saudi Arabia. *J. Environ. Informatics.* 18(1):38–45.
- Ervin, S. & Steinitz, C. 2003. Landscape visibility computation: Necessary, but not sufficient. *Environ. Plan. B Plan. Des.* 30(5):757–766.

- Evans, W., Kirkpatrick, D., & Townsend, G. 2001. Right-triangulated irregular networks. *Algorithmica (New York)*. 30(2):264–286.
- Felleman, J.P. 1982. Visibility mapping in New York's coastal zone: A case study of alternative methods. *Coast. Zo. Manag. J.* :249–270.
- Feng, W., Gang, W., Deji, P., Yuan, L., Liuzhong, Y., & Hongbo, W. 2015. A parallel algorithm for viewshed analysis in three-dimensional Digital Earth. *Comput. Geosci. Elsevier*. 75:57–65.
- Fernandez-Jimenez, L.A., Mendoza-Villena, M., Zorzano-Santamaria, P., Garcia-Garrido, E., Lara-Santillan, P., Zorzano-Alba, E., & Falces, A. 2015. Site selection for new PV power plants based on their observability. *Renew. Energy. Elsevier Ltd*. 78:7–15.
- Fisher, P.F. & Tate, N.J. 2006. Causes and consequences of error in digital elevation models. *Prog. Phys. Geogr.* 30(4):467–489.
- Garnero, G. & Fabrizio, E. 2015. Visibility analysis in urban spaces: a raster-based approach and case studies. *Environ. Plan. B Plan. Des.* 42(4):688–707.
- Germino, M.J., Reiners, W.A., Blasko, B.J., McLeod, D., & Bastian, C.T. 2001. Estimating visual properties of rocky mountain landscapes using GIS. *Landsc. Urban Plan.* 53(1–4):71–83.
- Gillings, M. 2015. Mapping invisibility: GIS approaches to the analysis of hiding and seclusion. *J. Archaeol. Sci. Elsevier Ltd*. 62:1–14.
- Glasson, J., Therivel, R., & Chadwick, A. 2005. Introduction to environmental impact assessment. 3rd ed. Routledge: London.
- Godone, D. & Garnero, G. 2013. The role of morphometric parameters in Digital Terrain Models interpolation accuracy : a case study. *Eur. J. Remote Sens.* 46:198–214.
- Hengl, T. 2006. Finding the right pixel size. *Comput. Geosci.* 32(9):1283–1298.
- Hernández, J., García, L., & Ayuga, F. 2004. Assessment of the visual impact made on the landscape by new buildings: A methodology for site selection. *Landsc. Urban Plan.* 68(1):15–28.
- Hirt, C. 2018. Artefact detection in global digital elevation models (DEMs): The maximum slope approach and its application for complete screening of the SRTM v4.1 and MERIT DEMs. *Remote Sens. Environ. Elsevier*. 207(September 2017):27–41.
- Huaxing, L.U. 2008. Modelling terrain complexity. , in: Zhou, Q., Lees, B., Tang, G. (Eds.),

Advances in Digital Terrain Analysis. Springer Berlin Heidelberg: Berlin. . Springer Berlin Heidelberg: Berlin, pp. 159–176.

Jennes, J. 2013. DEM Surface Tools for ArcGIS.

Jones, G.R., Jones, I., Gray, B.A., Parker, B., Coe, J.C., Burnham, J. b., & Geitner, N.M. 1975. Method for quantification of aesthetic values for environmental decision making. *Nucl. Technol.* 25(4):682–713.

Kantner, J. & Hobgood, R. 2016. A GIS-based viewshed analysis of Chacoan tower kivas in the US Southwest: were they for seeing or to be seen? *Antiquity*. 90(353):1302–1317.

Kidner, D.B., Sparkes, A.J., Dorey, M.I., Ware, J.M., & Jones, C.B. 2001. Visibility analysis with the multiscale implicit TIN. *Trans. GIS*. 5(1):19–37.

Kienzle, S. 2003. The effect of DEM raster resolution on first order, second order and compound terrain derivatives. *Trans. GIS*. 8(1):83–111.

Kim, Y.H., Rana, S., & Wise, S. 2004. Exploring multiple viewshed analysis using terrain features and optimisation techniques. *Comput. Geosci.* 30(9–10):1019–1032.

Klouček, T., Lagner, O., & Šímová, P. 2015. How does data accuracy influence the reliability of digital viewshed models? A case study with wind turbines. *Appl. Geogr.* 64:46–54.

Korzeniowska, K., Pfeifer, N., & Landtwing, S. 2018. Mapping gullies, dunes, lava fields, and landslides via surface roughness. *Geomorphology. Elsevier B.V.* 301:53–67.

Li, J. & Heap, A.D. 2014. Spatial interpolation methods applied in the environmental sciences: A review. *Environ. Model. Softw. Elsevier Ltd.* 53:173–189.

Litton, R.B.J. 1973. Landscape control points: A procedure for predicting and monitoring visual impacts. *USDA For. Serv. Res. Pap.* PSW-91.

Llobera, M. 2003. Extending GIS-based visual analysis: The concept of visualsapes. *Int. J. Geogr. Inf. Sci.* 17(1):25–48.

Llobera, M. 2007. Modeling visibility through vegetation. *Int. J. Geogr. Inf. Sci.* 21(7):799–810.

Lockhart, D. 2009. Viewshed uncertainty in a forested, mountainous landscape. The University of Georgia.

Lu, G.Y. & Wong, D.W. 2008. An adaptive inverse-distance weighting spatial interpolation technique. *Comput. Geosci.* 34(9):1044–1055.

- Maloy, M.A. & Dean, D.J. 2001. An accuracy assessment of various GIS-based viewshed delineation techniques. *Photogramm. Eng. Remote Sens.* 67(11):1293–1298.
- Manchado, C., Gomez-Jauregui, V., Lizcano, P.E., Iglesias, A., Galvez, A., & Otero, C. 2019. Wind farm repowering guided by visual impact criteria. *Renew. Energy. Elsevier Ltd.* 135:197–207.
- Marais, M., Retief, F.P., Sandham, L.A., & Cilliers, D.P. 2015. Environmental management frameworks: Results and inferences of report quality performance in South Africa. *South African Geogr. J.* 97(1):83–99.
- Marinai, S., Gori, M., & Giovanni, S. 2005. Artificial neural network for document analysis and recognition. *Trans. pattern Anal. Mach. Intell.* 27(1):23–35.
- Miller, M.L., Carstensen, L.W., Campbell, J.B., & Thomas, V. 2011. Analysis of viewshed accuracy with variable resolution LIDAR digital surface models and photogrammetrically-Derived digital elevation models masters of science in geography. Virginia State University.
- Möller, B. 2006. Changing wind-power landscapes: Regional assessment of visual impact on land use and population in Northern Jutland, Denmark. *Appl. Energy.* 83(5):477–494.
- Molnarova, K., Sklenicka, P., Stiborek, J., Svobodova, K., Salek, M., & Brabec, E. 2012. Visual preferences for wind turbines: Location, numbers and respondent characteristics. *Appl. Energy. Elsevier Ltd.* 92:269–278.
- Münster, F. 2005. Guideline for determining the scope of specialist involvement in EIA processes. , Edition 1. CSIR Report No ENV-S-C 2005 053 A. Republic of South Africa, Provincial Government of the Western Cape, Department of Environmental Affairs & Development Planning, Cape Town.
- Murphy, K.M., Gittings, B., & Crow, J. 2018. Visibility analysis of the Roman communication network in southern Scotland. *J. Archaeol. Sci. Reports. Elsevier.* 17(October 2017):111–124.
- Nair, H.C., Joseph, A., & Padmakumari Gopinathan, V. 2018. GIS Based landform classification using digital elevation model: a case study from two river basins of Southern Western Ghats, Kerala, India. *Model. Earth Syst. Environ. Springer International Publishing.* 4(4):1355–1363.
- Nutsford, D., Reitsma, F., Pearson, A.L., & Kingham, S. 2015. Personalising the viewshed: Visibility analysis from the human perspective. *Appl. Geogr. Elsevier Ltd.* 62:1–7.
- Oberholzer, B. 2005. Guideline for involving visual and aesthetic specialists in EIA processes.

Edition 1. CSIR Report No ENV-S-C 2005 053 F. Cape Town.

Ogburn, D.E. 2006. Assessing the level of visibility of cultural objects in past landscapes. *J. Archaeol. Sci.* 33(3):405–413.

Orland, B. 1988. Video imaging: a powerful tool for visualization and analysis,. *Landsc. Archit.* 78,. 78(5):78–88.

Palmer, J.F. 1981. Approaches for assessing visual quality and visual impact. 2nd ed. , in: *Methodology of Social Impact Assessment*. Hutchinson Ross Publishing Company: Stroudsburg. . Hutchinson Ross Publishing Company: Stroudsburg, pp. 294–301.

Pardo García, S. & Mérida Rodríguez, M. 2015. A geospatial indicator for assessing urban panoramic views. *Comput. Environ. Urban Syst.* 49:42–53.

Patel, S. & Giordano, T. 2014. Environmental assessments for the greening of public infrastructure in South Africa. *Dev. South. Afr.* 31(5):721–743.

Pullar, D.V. & Tidey, M.E. 2001. No Title. *Landsc. Urban Plan.* 55(1):29–40.

Qiang, Y., Shen, S., & Chen, Q. 2019. Visibility analysis of oceanic blue space using digital elevation models. *Landsc. Urban Plan. Elsevier.* 181(October 2018):92–102.

Razak, K.A., Santangelo, M., Van Westen, C.J., Straatsma, M.W., & de Jong, S.M. 2013. Generating an optimal DTM from airborne laser scanning data for landslide mapping in a tropical forest environment. *Geomorphology. Elsevier B.V.* 190:112–125.

Retief, F., Welman, C.N.J., & Sandham, L. 2011. Performance of environmental impact assessment (EIA) screening in South Africa: A comparative analysis between the 1997 and 2006 EIA regimes. *South African Geogr. J.* 93(2):154–171.

Riggs, P.D. & Dean, D.J. 2007. An investigation into the causes of errors and inconsistencies in predicted viewsheds. *Trans. GIS.* 11(2):175–196.

Rishikeshan, C.A., Katiyar, S.K., & Vishnu Mahesh, V.N. 2014. Detailed evaluation of dem interpolation methods in GIS using DGPS data. *Proc. - 2014 6th Int. Conf. Comput. Intell. Commun. Networks, CICN 2014. IEEE.* :666–671.

Robert, S. 2018. Assessing the visual landscape potential of coastal territories for spatial planning: A case study in the French Mediterranean. *Land use policy. Elsevier.* 72(December 2017):138–151.

Rød, J.K. & Van der Meer, D. 2009. Visibility and dominance analysis: Assessing a high-rise building project in Trondheim. *Environ. Plan. B Plan. Des.* 36(4):698–710.

- Rodrigues, M., Montañés, C., & Fueyo, N. 2010. A method for the assessment of the visual impact caused by the large-scale deployment of renewable-energy facilities. *Environ. Impact Assess. Rev. Elsevier Inc.* 30(4):240–246.
- Ross, W.A., Morrison-Saunders, A., Marshall, R., Sánchez, L.E., Weston, J., Au, E., Morgan, R.K., Fuggle, R., Sadler, B., Ross, W.A., Morrison-Saunders, A., & Marshall, R. 2006. Improving quality. *Impact Assess. Proj. Apprais.* 24(1):3–22.
- Samavatekbatan, A., Gholami, S., & Karimimoshaver, M. 2016. Assessing the visual impact of physical features of tall buildings: Height, top, color. *Environ. Impact Assess. Rev. Elsevier Inc.* 57:53–62.
- Sander, H.A. & Manson, S.M. 2007. Heights and locations of artificial structures in viewshed calculation: How close is close enough? *Landsc. Urban Plan.* 82(4):257–270.
- Smardon, R.C. & Hunter, M. 1983. Procedures and methods for wetland and coastal area visual impact assessment (VIA). , in: Smardon, R.C. (Ed.), *The Future of Wetlands: Assessing Visual-Cultural Values*. Allanheld Osmun: Totowa, NJ. . Allanheld Osmun: Totowa, NJ, pp. 171–204.
- Smith, M.P., Zhu, A.X., Burt, J.E., & Stiles, C. 2006. The effects of DEM resolution and neighborhood size on digital soil survey. *Geoderma.* 137(1–2):58–69.
- Sullivan, R. & Meyer, M. 2014. Guide to evaluating visual impact assessments for renewable energy projects. Natural Re ed. National Park Service: Ft. Collins, Colorado.
- Taheri, M., Gholamalifard, M., Ghazizade, M.J., & Rahimoghli, S. 2014. Environmental impact assessment of municipal solid waste disposal site in Tabriz, Iran using rapid impact assessment matrix. *Impact Assess. Proj. Apprais.* Taylor & Francis.
- Thompson, J.A., Bell, J.C., & Butler, C.A. 2001. Digital elevation model resolution : effects on terrain attribute calculation and quantitative soil-landscape modeling. :67–89.
- Thompson, M. 2019. South African National Land-Cover 2018 Report & Accuracy Assessment. Pretoria.
- Vari, A. 2002. Garmin eTrex Venture personal navigator owner's manual and reference guide. Garmin.
- Véga, C., Vepakomma, U., Morel, J., Bader, J.L., Rajashekar, G., Jha, C.S., Ferêt, J., Proisy, C., Pélissier, R., & Dadhwal, V.K. 2015. Aboveground-biomass estimation of a complex tropical forest in India using lidar. *Remote Sens.* 7(8):10607–10625.
- Verutes, G.M., Huang, C., Estrella, R.R., & Loyd, K. 2014. Exploring scenarios of light

pollution from coastal development reaching sea turtle nesting beaches near Cabo Pulmo, Mexico. *Glob. Ecol. Conserv. Elsevier B.V.* 2:170–180.

Vinod, P.G. 2017. Development of topographic position index based on Jenness algorithm for precision agriculture at Kerala, India. *Spat. Inf. Res. Korean Spatial Information Society*. 25(3):381–388.

Weiss, A. 2001. Topographic position and landforms analysis. , in: Topographic Position and Landform Analysis. Poster presentation, ESRI Users Conference: San Diego. . Poster presentation, ESRI Users Conference: San Diego.

Wood, G. & Becker, J. 2005. Discretionary judgement in local planning authority decision making: Screening development proposals for environmental impact assessment. *J. Environ. Plan. Manag.* 48(3):349–371.

Wróżyński, R., Sojka, M., & Pyszny, K. 2016. The application of GIS and 3D graphic software to visual impact assessment of wind turbines. *Renew. Energy*. 96:625–635.

Zhao, Y., Padmanabhan, A., & Wang, S. 2013. A parallel computing approach to viewshed analysis of large terrain data using graphics processing units. *Int. J. Geogr. Inf. Sci.* 27(2):363–384.

Zhou, Q., Liu, X., & Sun, Y. 2006. Terrain complexity and uncertainties in grid-based digital terrain analysis. *Int. J. Geogr. Inf. Sci.* 20(10):1137–1147.

Ziadat, F.M. 2007. Effect of contour intervals and grid cell size on the accuracy of DEMs and slope derivatives. *Trans. GIS*. 11(1):67–81.

Zube, E.H., Sell, J.L., & Taylor, J.G. 1982. Landscape perception: Research, application and theory. *Landsc. Plan.* 9(1):1–33.

Appendix 1

Table 13: Grootpan observation points and description

Field survey Grootpan							
Point number	GPS coordinates		Visibility	Degree of visibility	Screening object	Photograph number	Description
	Latitude	Longitude					
1	26.05834	-26.37406	Not visible	Completely blocked	Landscape	Grootpan 1	The silo is completely blocked by the landscape being at a higher elevation.
2	26.03313	-26.40649	Not visible	Completely blocked	Landscape	Grootpan 2	The silo is completely blocked by the landscape being at a higher elevation.
3	26.01489	-26.44021	Not visible	Completely blocked	Landscape	Grootpan 3	The silo is completely blocked by the landscape being at a higher elevation.
4	26.00990	-26.46291	Not visible	Completely blocked	Vegetation	Grootpan 4	The silo is completely blocked by vegetation.
5	26.00652	-26.46163	Visible	Slightly visible	Vegetation	Grootpan 5	The silo is slightly visible with only the top section visible.
6	25.99828	-26.46079	Visible	Mostly visible	Vegetation	Grootpan 6	The silo is mostly visible with the bottom half being screened by vegetation.
7	25.98355	-26.45848	Not visible	Completely blocked	Vegetation	Grootpan 7	The silo is completely blocked by vegetation.
8	25.98368	-26.47290	Not visible	Completely blocked	Landscape	Grootpan 8	The silo is completely blocked by the landscape being at a higher elevation.
9	25.98290	-26.47729	Visible	Completely visible	Nothing	Grootpan 9	The silo is almost completely visible with only the base of the silo not visible.
10	25.97157	-26.53423	Visible	Mostly visible	Vegetation	Grootpan 10	The silo is mostly visible with the bottom half being screened by vegetation.
11	25.96824	-26.55100	Not visible	Completely blocked	Vegetation	Grootpan 11	The silo is completely blocked by vegetation.

12	25.96101	-26.55058	Visible	Partially visible	Vegetation	Grootpan 12	The silo is only partially visible with only the left towers visible.
13	25.95568	-26.55062	Not visible	Completely blocked	Vegetation	Grootpan 13	The silo is completely blocked by vegetation.
14	25.93817	-26.55186	Visible	Slightly visible	Vegetation	Grootpan 14	The silo is slightly visible with only the top section visible.
15	25.93656	-26.53368	Visible	Slightly visible	Vegetation	Grootpan 15	The silo is slightly visible with only the top section visible.
16	25.92616	-26.53123	Visible	Slightly visible	Vegetation	Grootpan 16	The silo is slightly visible with only the top section visible.
17	25.91127	-26.53228	Not visible	Completely blocked	Landscape	Grootpan 17	The silo is completely blocked by the landscape being at a higher elevation.
18	25.89057	-26.53492	Not visible	Completely blocked	Landscape	Grootpan 18	The silo is completely blocked by the landscape being at a higher elevation.
19	25.88098	-26.53494	Not visible	Completely blocked	Vegetation	Grootpan 19	The silo is completely blocked by vegetation.
20	25.84348	-26.53598	Not visible	Completely blocked	Vegetation	Grootpan 20	The silo is completely blocked by vegetation.
21	25.88366	-26.64454	Not visible	Completely blocked	Landscape	Grootpan 21	The silo is completely blocked by the landscape being at a higher elevation.
22	25.88063	-26.61139	Not visible	Completely blocked	Landscape	Grootpan 22	The silo is completely blocked by the landscape being at a higher elevation.
23	25.92005	-26.60047	Visible	Slightly visible	Vegetation	Grootpan 23	The silo is slightly visible with only the top section visible.
24	25.93343	-26.59657	Not visible	Completely blocked	Vegetation	Grootpan 24	The silo is completely blocked by vegetation.
25	25.95765	-26.56304	Not visible	Completely blocked	Vegetation	Grootpan 25	The silo is completely blocked by vegetation.
26	25.99416	-26.63551	Visible	Mostly visible	Vegetation	Grootpan 26	The silo is mostly visible with the bottom half being screened by vegetation.

27	25.99405	-26.64064	Not visible	Completely blocked	Landscape	Grootpan 27	The silo is completely blocked by the landscape being at a higher elevation.
28	26.02022	-26.67335	Not visible	Completely blocked	Landscape	Grootpan 28	The silo is completely blocked by the landscape being at a higher elevation.
29	26.04824	-26.65335	Not visible	Completely blocked	Landscape	Grootpan 29	The silo is completely blocked by the landscape being at a higher elevation.
30	26.05982	-26.64115	Not visible	Completely blocked	Vegetation	Grootpan 30	The silo is completely blocked by vegetation.
31	25.99386	-26.56952	Visible	Partially visible	Vegetation	Grootpan 31	The silo is partially visible with only a small section of the left side visible.
32	25.99394	-26.51178	Visible	Slightly visible	Vegetation	Grootpan 32	The silo is slightly visible with only the top section visible.
33	26.00423	-26.49289	Visible	Completely visible	Nothing	Grootpan 33	The silo is almost completely visible with only the base of the silo not visible.
34	26.01781	-26.49072	Visible	Completely visible	Nothing	Grootpan 34	The silo is almost completely visible with only the base of the silo not visible.
35	26.04930	-26.48514	Visible	Mostly visible	Landscape	Grootpan 35	The silo is mostly visible with the base screened by the landscape.
36	26.05921	-26.48336	Not visible	Completely blocked	Landscape	Grootpan 36	The silo is completely blocked by the landscape being at a higher elevation.
37	26.07348	-26.48081	Not visible	Completely blocked	Landscape	Grootpan 37	The silo is completely blocked by the landscape being at a higher elevation.
38	26.07728	-26.48013	Not visible	Completely blocked	Vegetation	Grootpan 38	The silo is completely blocked by vegetation.
39	26.09599	-26.48142	Not visible	Completely blocked	Landscape	Grootpan 39	The silo is completely blocked by the landscape being at a higher elevation.
40	26.14988	-26.47861	Not visible	Completely blocked	Landscape	Grootpan 40	The silo is completely blocked by the landscape being at a higher elevation.

Table 14: Syferbult observation points and descriptions

Field survey Syferbult							
Point number	GPS coordinates		Visibility	Degree of visibility	Screening object	Photograph name	Description
	Latitude	Longitude					
1	26.12540	-27.23638	Not visible	Completely blocked	Landscape	Syferbult 1	The silo is completely blocked by the landscape being at a higher elevation.
2	26.07742	-27.27463	Visible	Mostly visible	Landscape	Syferbult 2	The silo is visible with more than half of the object visible. with only the lower part screened by the landscape.
3	26.06799	-27.27189	Not visible	Completely blocked	Landscape	Syferbult 3	The silo is completely blocked by the landscape being at a higher elevation.
4	26.06017	-27.27745	Visible	Slightly visible	Vegetation	Syferbult 4	The silo is only slightly visible with the top section only visible above the vegetation.
5	26.05835	-27.28045	Not visible	Completely blocked	Vegetation	Syferbult 5	The silo is completely blocked by vegetation.
6	26.05581	-27.28299	Visible	Mostly visible	Landscape	Syferbult 6	The silo is visible with more than half of the object visible. with only the lower part screened by the landscape.
7	26.04372	-27.29426	Not visible	Completely blocked	Landscape	Syferbult 7	The silo is completely blocked by the landscape being at a higher elevation.
8	26.02811	-27.31106	Not visible	Completely blocked	Vegetation	Syferbult 8	The silo is completely blocked by vegetation.
9	26.02462	-27.31583	Visible	Partially visible	Vegetation and landscape	Syferbult 9	The silo is partially visible with the lower half screened by the landscape. while the left top sections are screened by vegetation.
10	26.00180	-27.31374	Not visible	Completely blocked	Vegetation	Syferbult 10	The silo is completely blocked by vegetation.
11	26.00055	-27.30998	Visible	Slightly visible	Vegetation	Syferbult 11	The silo is slightly visible with only the top section being visible above the vegetation.

12	25.99857	-27.30402	Not visible	Completely blocked	Landscape	Syferbult 12	The silo is completely blocked by the landscape being at a higher elevation.
13	25.99745	-27.23204	Not visible	Completely blocked	Landscape	Syferbult 13	The silo is completely blocked by the landscape being at a higher elevation.
14	26.02255	-27.22959	Visible	Mostly visible	Landscape	Syferbult 14	The silo is visible with more than half of the object visible. with only the lower part screened by the landscape.
15	26.03988	-27.22852	Visible	Slightly visible	Landscape	Syferbult 15	The silo is slightly visible with only the top section being visible above the landscape.
16	26.04247	-27.22810	Not visible	Completely blocked	Vegetation	Syferbult 16	The silo is completely blocked by vegetation.
17	26.04626	-27.22735	Visible	Partially visible	Vegetation	Syferbult 17	The silo is mostly blocked by vegetation with only the top left section visible.
18	26.04877	-27.22463	Visible	Completely visible	Nothing	Syferbult 18	The silo is almost completely visible. only base of the silo is unseen at the distance.
19	26.05548	-27.22299	Not visible	Completely blocked	Landscape	Syferbult 19	The silo is completely blocked by the landscape being at a higher elevation.
20	26.06298	-27.30047	Not visible	Completely blocked	Landscape	Syferbult 20	The silo is completely blocked by the landscape being at a higher elevation.
21	26.06791	-27.30305	Not visible	Completely blocked	Landscape	Syferbult 21	The silo is completely blocked by the landscape being at a higher elevation.
22	26.04731	-27.33019	Not visible	Completely blocked	Landscape	Syferbult 22	The silo is completely blocked by the landscape being at a higher elevation.
23	26.04496	-27.35544	Not visible	Completely blocked	Landscape	Syferbult 23	The silo is completely blocked by the landscape being at a higher elevation.
24	25.99153	-27.40039	Not visible	Completely blocked	Vegetation	Syferbult 24	The silo is completely screened by a small section of vegetation.
25	25.99397	-27.38762	Visible	Mostly visible	Vegetation	Syferbult 25	The silo is visible with more than half of the object visible. with only the lower part screened by vegetation.

26	25.99380	-27.38012	Visible	Mostly visible	Vegetation and landscape	Syferbult 26	The silo top half is visible. while the bottom half is screened by landcover and vegetation.
27	25.99007	-27.37961	Not visible	Completely blocked	Vegetation	Syferbult 27	The silo is completely blocked by vegetation.
28	25.99756	-27.37615	Not visible	Completely blocked	Vegetation	Syferbult 28	The silo is completely blocked by vegetation.
29	26.00019	-27.36737	Not visible	Completely blocked	Landscape	Syferbult 29	The silo is completely blocked by the landscape being at a higher elevation.
30	26.00139	-27.36337	Not visible	Completely blocked	Vegetation	Syferbult 30	The silo is completely blocked by vegetation.
31	26.00629	-27.33088	Not visible	Completely blocked	Vegetation	Syferbult 31	The silo is completely blocked by vegetation.
32	26.00138	-27.32195	Visible	Partially visible	Vegetation	Syferbult 32	The silo is almost completely screened by vegetation. with only a few parts being visible between vegetation.
33	25.99667	-27.32007	Visible	Partially visible	Vegetation	Syferbult 33	The silo is screened by tall vegetation. but is visible through the vegetation as its not dense at the base.
34	25.99199	-27.31920	Not visible	Completely blocked	Vegetation	Syferbult 34	The silo is completely blocked by vegetation.
35	25.98859	-27.31822	Not visible	Completely blocked	Landscape	Syferbult 35	The silo is completely blocked by the landscape being at a higher elevation.
36	25.98300	-27.20455	Not visible	Completely blocked	Landscape	Syferbult 36	The silo is completely blocked by the landscape being at a higher elevation.
37	26.02313	-27.17867	Not visible	Completely blocked	Landscape	Syferbult 37	The silo is completely blocked by the landscape being at a higher elevation.
38	26.02523	-27.16779	Not visible	Completely blocked	Landscape	Syferbult 38	The silo is completely blocked by the landscape being at a higher elevation.
39	26.02725	-27.15546	Visible	Mostly visible	Landscape	Syferbult 39	The silo is mostly visible with the lower part screened by the landscape.
40	26.03188	-27.13514	Visible	Mostly visible	Landscape	Syferbult 40	The silo is mostly visible with the lower part screened by the landscape.

Table 15: Swaruggens observation points and descriptions

Field survey Swaruggens							
Point number	GPS coordinates		Visibility	Degree of visibility	Screening object	Photograph number	Description
	Latitude	Longitude					
1	25.65036	-26.70643	Visible	Partially visible	Landscape and vegetation	Swaruggens 1	The silo is only partially visible with a combination of vegetation screening the top section and landscape the base.
2	25.65070	-26.69694	Not visible	Completely blocked	Vegetation and buildings	Swaruggens 2	The silo is completely screened by vegetation and buildings.
3	25.65279	-26.69704	Visible	Partially visible	Vegetation	Swaruggens 3	The right silo towers are only visible. while the left side is screened by vegetation.
4	25.65438	-26.69671	Not visible	Completely blocked	Vegetation	Swaruggens 4	The is completely screened by vegetation.
5	25.65282	-26.70211	Visible	Completely visible	Nothing	Swaruggens 5	The silo is almost completely visible with only a few trees screening the bottom far right tower.
6	25.64799	-26.69478	Visible	Mostly visible	Vegetation and buildings	Swaruggens 6	The top half of the silo is visible with bottom section being screened.
7	25.64537	-26.70128	Not visible	Completely blocked	Vegetation and buildings	Swaruggens 7	The silo is completely screened by vegetation and buildings.
8	25.64882	-26.81719	Not visible	Completely blocked	Landscape	Swaruggens 8	The silo is completely blocked by the landscape being at a higher elevation.
9	25.67193	-26.81648	Not visible	Completely blocked	Landscape	Swaruggens 9	The silo is completely blocked by the landscape being at a higher elevation.
10	25.65165	-26.76393	Visible	Partially visible	Landscape and vegetation	Swaruggens 10	The silo is only partially visible with a combination of vegetation screening the silo.
11	25.65088	-26.75362	Not visible	Completely blocked	Landscape	Swaruggens 11	The silo is completely blocked by the landscape being at a higher elevation.

12	25.59527	-26.66776	Not visible	Completely blocked	Landscape	Swartruggens 12	The silo is completely blocked by the landscape being at a higher elevation.
13	25.60420	-26.67733	Not visible	Completely blocked	Landscape	Swartruggens 13	The silo is completely blocked by the landscape being at a higher elevation.
14	25.62220	-26.68614	Visible	Slightly visible	Landscape	Swartruggens 14	The silo is only slightly visible with only the top section being visible.
15	25.62770	-26.68632	Not visible	Completely blocked	Landscape	Swartruggens 15	The silo is completely blocked by the landscape being at a higher elevation.
16	25.63460	-26.68555	Visible	Mostly visible	Vegetation	Swartruggens 16	The silo is mostly visible with only the bottom section being screened by vegetation.
17	25.66359	-26.64607	Not visible	Completely blocked	Landscape	Swartruggens 17	The silo is completely blocked by the landscape being at a higher elevation.
18	25.66209	-26.65545	Not visible	Completely blocked	Landscape and vegetation	Swartruggens 18	The silo is completely blocked by a combination of landscape and vegetation.
19	25.65911	-26.66403	Not visible	Completely blocked	Vegetation	Swartruggens 19	The is completely screened by vegetation.
20	25.65730	-26.66893	Visible	Partially visible	Vegetation	Swartruggens 20	The silo is partially visible with only the far right tower being visible.
21	25.66661	-26.68305	Visible	Slightly visible	Vegetation	Swartruggens 21	The silo is only slightly visible with only the top section being visible.
22	25.66624	-26.67978	Not visible	Completely blocked	Landscape	Swartruggens 22	The silo is completely blocked by the landscape being at a higher elevation.
23	25.66777	-26.67441	Visible	Slightly visible	Vegetation	Swartruggens 23	The silo is only slightly visible with only the top section being visible.
24	25.67089	-26.66286	Not visible	Completely blocked	Landscape and vegetation	Swartruggens 24	The silo is completely blocked by a combination of landscape and vegetation.
25	25.67211	-26.65871	Visible	Mostly visible	Landscape	Swartruggens 25	The silo is mostly visible with only the bottom section being screened by the landscape.

26	25.67686	-26.65020	Not visible	Completely blocked	Landscape	Swartruggens 26	The silo is completely blocked by the landscape being at a higher elevation.
27	25.68287	-26.63684	Not visible	Completely blocked	Landscape	Swartruggens 27	The silo is completely blocked by the landscape being at a higher elevation.
28	25.70831	-26.62947	Visible	Partially visible	Landscape and vegetation	Swartruggens 28	The silo is only partially visible between vegetation.
29	25.70703	-26.62940	Not visible	Completely blocked	Landscape and vegetation	Swartruggens 29	The silo is completely screened by vegetation and the landscape.
30	25.70440	-26.62933	Not visible	Completely blocked	Landscape and vegetation	Swartruggens 30	The silo is completely screened by vegetation and the landscape.
31	25.71506	-26.62968	Not visible	Completely blocked	Landscape	Swartruggens 31	The silo is completely blocked by the landscape being at a higher elevation.
32	25.71945	-26.63024	Visible	Mostly visible	Landscape	Swartruggens 32	The silo is mostly visible with only the base being screened by the landscape.
33	25.72887	-26.63409	Not visible	Completely blocked	Landscape	Swartruggens 33	The silo is completely blocked by the landscape being at a higher elevation.
34	25.73923	-26.66374	Not visible	Completely blocked	Landscape	Swartruggens 34	The silo is completely blocked by the landscape being at a higher elevation.
35	25.69518	-26.61339	Not visible	Completely blocked	Landscape	Swartruggens 35	The silo is completely blocked by the landscape being at a higher elevation.
36	25.70603	-26.59952	Visible	Mostly visible	Landscape	Swartruggens 36	The silo is mostly visible with only the base being screened by the landscape.
37	25.70405	-26.60173	Not visible	Completely blocked	Vegetation	Swartruggens 37	The is completely screened by vegetation.
38	25.71114	-26.59380	Not visible	Completely blocked	Vegetation	Swartruggens 38	The is completely screened by vegetation.

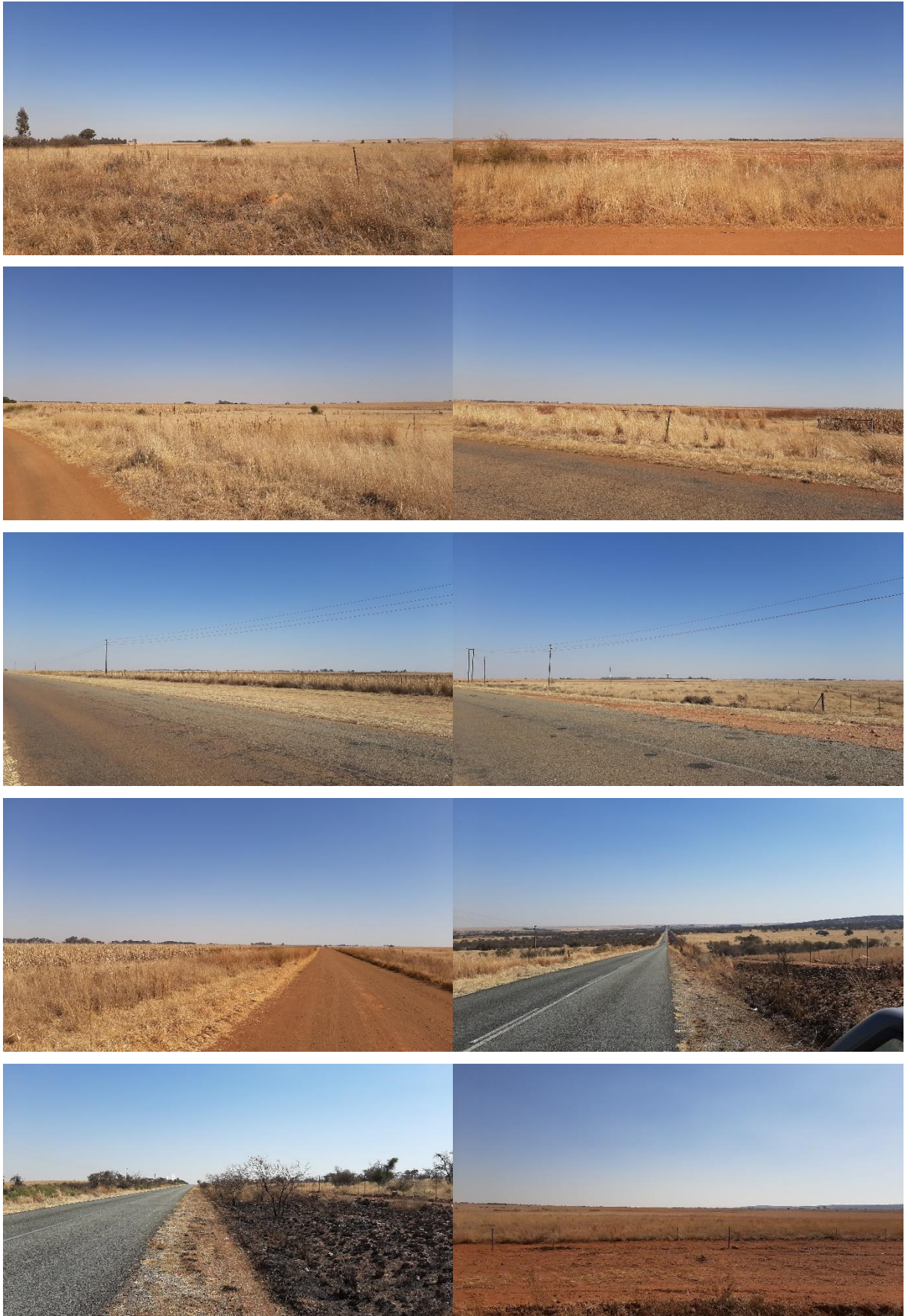
39	25.71516	-26.58932	Not visible	Completely blocked	Landscape	Swartruggens 39	The silo is completely blocked by the landscape being at a higher elevation.
40	25.72152	-26.57358	Visible	Mostly visible	Landscape	Swartruggens 40	The silo is mostly visible with only the base being screened by the landscape.

Appendix 2

Grootpan study area observation points photographs. starting at observer point 1 up to point 40











Syferbult study area observation points photographs. starting at observer point 1 up to point 40











Swartruggens study area observation points photographs. starting at observer point 1 up to point 40









Tables illustrating results obtained for each observation point from the various visibility techniques

[illegible]

Syferbult study area

[illegible]

Swartruggens study area

[illegible]

Appendix 4

Class name	Height	Distance bottom		Distance top	
		Measurement 1	Measurement 3	Measurement 3	Measurement 1
Contiguous (indigenous) forest	12m	50	51	71	52
Contiguous low forest & thicket	5m	Based on observation	Based on observation	Based on observation	Based on observation
Dense forest & woodland	10m	10	19	19	13
Open woodland	8m	19	24	20	21
Contiguous & dense plantation forest	15m	Based on observation	Based on observation	Based on observation	Based on observation
Open & sparse plantation forest	15m	Based on observation	Based on observation	Based on observation	Based on observation
Temporary unplanted (clear-felled) plantation forest	0m	NA	NA	NA	NA
Low shrubland (other)	1m	Based on observation	Based on observation	Based on observation	Based on observation
Sparsely wooded grassland	1m	Based on observation	Based on observation	Based on observation	Based on observation
Natural grassland	1m	Based on observation	Based on observation	Based on observation	Based on observation
Natural rivers	0m	NA	NA	NA	NA
Natural pans (flooded @ observation times)	0m	NA	NA	NA	NA
Artificial dams (including canals)	0m	NA	NA	NA	NA
Artificial flooded mine pits	0m	NA	NA	NA	NA
Herbaceous wetlands (currently mapped)	0m	NA	NA	NA	NA
Herbaceous wetlands (previously mapped)	0m	NA	NA	NA	NA
Natural rock surfaces	0m	NA	NA	NA	NA
Dry pans	0m	NA	NA	NA	NA
Eroded lands	0m	NA	NA	NA	NA
Bare riverbed material	0m	NA	NA	NA	NA
Other bare	0m	NA	NA	NA	NA
Cultivated commercial permanent orchards	2m	Based on observation	Based on observation	Based on observation	Based on observation
Commercial annual crops pivot irrigated	2m	Based on observation	Based on observation	Based on observation	Based on observation
Commercial annual crops non-pivot irrigated	2m	Based on observation	Based on observation	Based on observation	Based on observation
Commercial annual crops rain-fed / dryland	2m	Based on observation	Based on observation	Based on observation	Based on observation
Subsistence / small-scale annual crops	2m	Based on observation	Based on observation	Based on observation	Based on observation
Fallow land & old fields (trees)	5m	Based on observation	Based on observation	Based on observation	Based on observation
Fallow land & old fields (bush)	2m	Based on observation	Based on observation	Based on observation	Based on observation
Fallow land & old fields (grass)	1m	Based on observation	Based on observation	Based on observation	Based on observation
Fallow land & old fields (bare)	0m	NA	NA	NA	NA
Fallow land & old fields (low shrub)	1m	Based on observation	Based on observation	Based on observation	Based on observation
Residential formal (tree)	5m	Based on observation	Based on observation	Based on observation	Based on observation
Residential formal (bush)	2m	Based on observation	Based on observation	Based on observation	Based on observation
Residential formal (low veg / grass)	0m	NA	NA	NA	NA
Residential formal (bare)	0m	NA	NA	NA	NA
Residential informal (tree)	5m	Based on observation	Based on observation	Based on observation	Based on observation
Residential informal (bush)	2m	Based on observation	Based on observation	Based on observation	Based on observation
Residential informal (low veg / grass)	0m	NA	NA	NA	NA
Residential informal (bare)	0m	NA	NA	NA	NA
Village scattered (bare & low veg/ grss combo)	0m	NA	NA	NA	NA
Village dense (bare & low veg / grss combo)	0m	NA	NA	NA	NA
Smallholdings (tree)	5m	Based on observation	Based on observation	Based on observation	Based on observation
Smallholdings (bush)	2m	Based on observation	Based on observation	Based on observation	Based on observation
Smallholdings (low veg / grass)	0m	NA	NA	NA	NA
Smallholdings (bare)	0m	NA	NA	NA	NA
Urban recreational fields (tree)	5m	Based on observation	Based on observation	Based on observation	Based on observation
Urban recreational fields (bush)	2m	Based on observation	Based on observation	Based on observation	Based on observation
Urban recreational fields (grass)	0m	NA	NA	NA	NA
Urban recreational fields (bare)	0m	NA	NA	NA	NA
Commercial	4m	Based on observation	Based on observation	Based on observation	Based on observation
Industrial	0m	Silo measurement	Silo measurement	Silo measurement	Silo measurement
Roads & rails (major linear)	0m	NA	NA	NA	NA
Mines: surface infrastructure	0m	NA	NA	NA	NA
Mines: extraction pits, quarries	0m	NA	NA	NA	NA
Mine: tailings and resource dumps	15m	120		121	
Fallow land & old fields (wetlands)	0m	NA	NA	NA	NA