A visual assessment tool for mine development

The development of an evaluation tool to compare the visual impact of opencast mining operations in the pre-feasibility phase

E. van Hooijdonk

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By

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Preface

The basis for this research has been my interest in enabling the mining industry to move forward towards sustainable and environmentally conscious goals. The mining industry does not have a good reputation, but this does not accurately represent the industry. By informing ourselves and assessing all the facets of the environmental impact of mining operations, it is possible to begin mitigating and reducing the impact caused. As a mining engineer educated at the Technical University of Delft, the moto

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own."

has always rung true to me and must find a place in this thesis and any further work I conduct in my professional career. I hope this study can serve as further research material for students and researchers who are interested in this field, and hopefully it can find a place in industry as well to guide companies to make more informed decisions.

E. van Hooijdonk

Delft, January 2021

Glossary

Guidance document – A document which gives advice or information aimed at resolving a problem, which does not have to be legally binding

Visual amenity – The views and surroundings that create the backdrop to an area

Visual impact assessment professional – Any person who conducts a visual impact assessment, this does not require any qualifications or prior experience

Area of influence – The total area which is visually impacted by a feature

Feature – an object, attribute or specific project in the landscape

Zone of interest – The total area which must be assessed in the visual impact assessment. This is usually equal to or based on the area of influence

Visual impact range – The total range of the visual impact of a feature

Receptors – People which are affected by the visual impact range

Viewpoint – A position or location from where a person can look at something

Subjective factors – factors which are assessed based on personal feelings, tastes or opinions

Quantifying judgement – a judgement which expresses a quantity of the object being assessed

Intervisibility – Two features which are visible to one another, with no visual obstruction between them

Line of sight calculations – a calculation which determines whether there is an unobstructed straight line between an observer and an object

Digital terrain model – A 3D computer graphics representation of elevation data which represents terrain

Visibility value – A value which describes the Intervisibility between two points

Observer points – location on the landscape from which the observer views a target.

Target points – location on the landscape which is being viewed by the observer.

Good practice – a practice that has been proven to work well and produces good results and is therefore recommended as a model.

Chromatic contrast – differences between the chromatic properties of two features.

Solid angle – the measurement of the amount of the field of view of a person is taken up by a specific object.

Euclidean distance – The length of a line segment between two points in a 3D space.

Colourspace – A specific organization of colours, usually in a 2D or 3D space.

Raster – a rectangular pattern of parallel lines creating rectangular cells.

Indices – a feature to describe or measure a characteristic.

Zones of visual influence (ZVI) – A description of the total zone which is influenced visually by a specific object, the same as an area of influence.

Zones of theoretical visibility – A description of the total zone from which the object is theoretically visible (according to the algorithm or analysis used).

Stakeholder – a party with an interest in a scenario due to which they can be affected.

Visual impact – the chance in the appearance of the landscape as a result of a development.

Lvi (Level of visual impact) – a term designed by Dentoni et al to describe the combined perceived value of two parameter which describe the physical change in the landscape.

GISGeography – A company which provides a software tool for GIS work.

True-colour image – A representation of satellite data which shows the data as a true colour image. A true colour image is an image which shows the colours how they are perceived by humans.

Macro class – A class which groups together different features into a descriptive class. For example, the class vegetation groups all trees, grass, bushes and other vegetation together.

Heat map – A data visualization technique that shows magnitude of a phenomenon as colours in two dimensions. Usually used to show elevation, but in this case used to display severity of visual impact. A heat map is very suitable to quickly give an overview of the result of an analysis which is made up of many data points.

Scihub – A shadow library website that provides free access to several datasets and academic papers.

Abstract

Surface mining operations can have a significant visual impact on the surrounding landscape and communities. There have been numerous cases of local populations pushing back against the development of mining operations near their communities. This study aims to determine whether it is possible to assess the visual impact of surface mining operations before the development has started. With this assessment it would become possible to make informed decisions as to pitshell development and selection in terms of visual impact. A tool was developed to determine whether it is possible to make this assessment. This tool must be able to be used to determine the visual impact of two or more scenarios in the pre-feasibility phase of development to assist in the decision of which scenario will be developed further in the feasibility phase. In this context, the visual impact is defined as the perceived change in the landscape as a result of mine development on local communities around the surface mine development. The scenarios are defined as the option of pitshells designed during the pre-feasibility phase of mine development.

The tool makes a distinction between the physical changes in the landscape caused by the surface mining operation and how this physical change is perceived by anyone viewing the operation.

The tool is GIS based and utilizes the free open-source software QGIS to calculate the physical change in the landscape. The tool calculates the vertical and horizontal visibility angle. The visibility angle describes the extent that the change in the landscape takes up in the view of an observer. In addition to that, the tool calculates the contrast between the changed colour in the landscape and its surroundings, which describes how much the change stands out. It requires two sets of data to work: a digital elevation model of the prospected surface mine pitshell and the surrounding landscape and a RGB satellite image of the surrounding area. The DEM provides elevation data for every square metre of the landscape to the GIS, while the satellite image provides RGB colour data. All other data can be generated from the previously mentioned data features.

The tool is tested using a case study, in which several distinct pitshell scenarios are compared against one another on their visual impact. The case study is based on the extension of a limestone quarry in Belgium, which aims to secure reserve for future operations. The area of interest is surrounded by several small to medium size villages, which would be affected visually by the extension. Therefore, a comparison should be made regarding the visual impact of the several pitshell scenarios. The results showed it is possible to determine the visual impact of surface mining operations before the development has started. On this basis, it is possible to compare different pitshell scenarios and determine which scenario would be least impactful in terms of visual impact on the local community and surrounding landscape. The reliability of the tool can only be assessed theoretically, however a high level of accuracy is achieved by adhering to guiding principles which are set out in this thesis.

Acknowledgements

I would like to thank Julien Vanneste for his support whilst I was working with Lhoist, especially during the COVID-19 pandemic and with a high workload of his own. I would like to thank Lhoist for providing me with all the necessary data to conduct a full case study and allowing me a lot of freedom to create my own method and Olivier Hercot for his assistance in Leapfrog and QGIS. Furthermore, I would like to thank Dr. Buxton for his guidance and expertise.

1 Introduction

The extractive industry is an industry which extracts raw materials from the earth for the benefit of society. The need for metals, minerals and aggregates is only expected to grow in the coming decades due to the growth of the world's population and the increase in modernisation in the developing world. Mining must also play a vital role in the development of the sustainable energy market. Solar panels, for example, are made using silica, aluminium, copper, cadmium and many more metals and materials. All these metals minerals and elements must be mined in vast quantities to supply the world with the ability to produce sustainable energy. Without mining, the sustainable energy transition cannot happen.

The mining industry is a global industry. The industry is limited by the quality, accessibility and location of the minerals and metals available for extraction. When minerals and metals are found in heavily populated areas, these mines can have an impact on the local population. This impact can either be positive or negative. A positive impact is the creation of jobs for the local community. However, mining operations can have a severe negative impact on the environment and local community if it is not controlled correctly.

1.1 Environmental impact of surface mining operation

The mining industry has been known to have a negative impact on the environment due to the nature of its operations. In recent decades there has been a great push to reduce the negative impact on the environment caused by humans, due to a better understanding of global warming and other environmental concerns. Studies have been conducted into how this impact can possibly be controlled or mitigated. However, due to the increasing demand for metals, minerals and aggregates, further mining operations must be opened and operated. Surface mining operations are extremely invasive in the landscape and environment due to their nature. The opening of surface mining results in severe degradation of the earth in both environmental and aesthetical aspects (Nazan Kuter, 2013). Kavourides et al (2002) name several negative effects of surface mining on the environment:

- Occupation of large (farming) areas needed for excavation and dumping operations;
- Alteration of land morphology;
- The disturbance of fauna and flora native to the area;
- Alteration of water balance, both ground and surface water;
- Relocation of residential areas and infrastructure;
- Pollution of the air, water and soil.

Besides the impact on the environment, the effects mentioned by Kavourides et al have an impact on additional *stakeholders* as well. The additional stakeholders are the local community, living around the surface mine; and the employees, working at the surface mine. The following diagram shows a variety of different negative impacts and the stakeholders they affect.

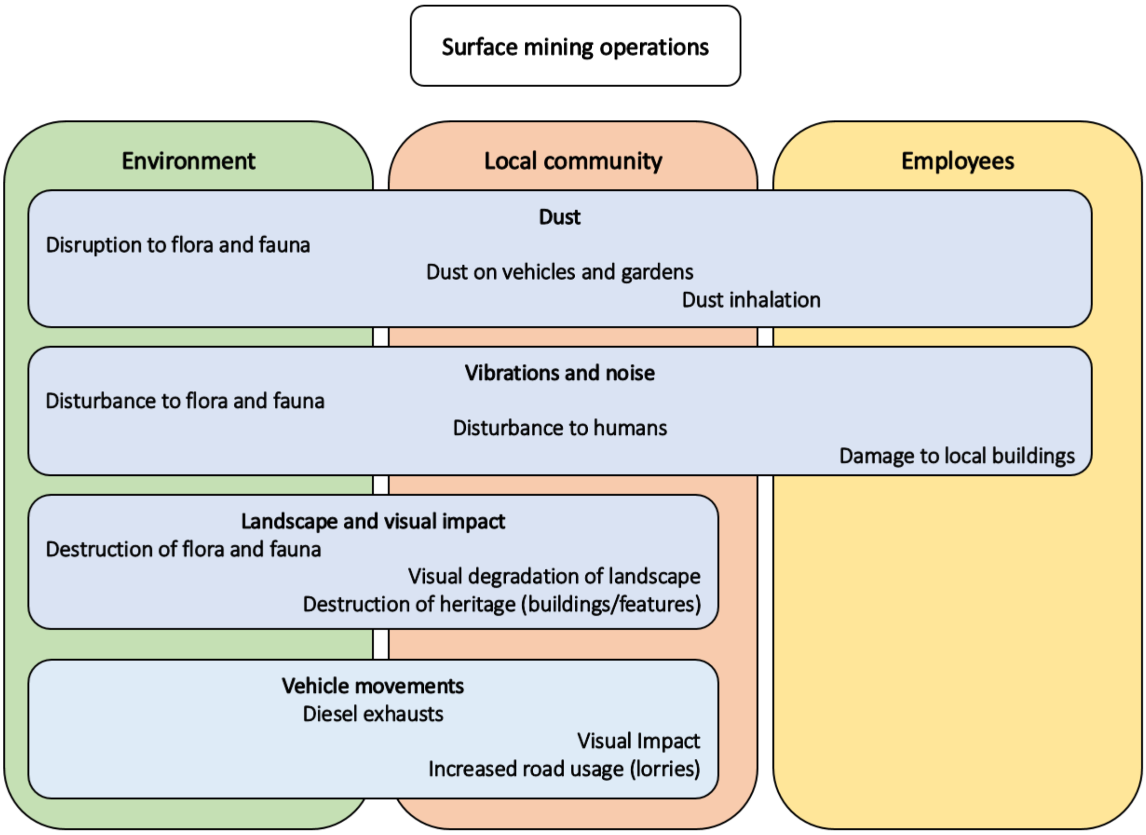


FIGURE 1.1: NEGATIVE IMPACTS OF SURFACE MINING OPERATIONS (VAN HOOIJDONK., 2021)

These negative impacts of the surface mining operations on the local community, its employees and the environment can have a negative impact on the mining operations. Legislative limits are set to these negative effects and, if breached, could result in a fine, penalty or even the demand to stop operations.

A negative impact of mining operations is the visual impact. Surface mining operations create a large opening in the ground. In addition to that, large waste heaps, stock piles and other infrastructure are placed on the landscape. This can have a significant visual impact on the surrounding community. This visual impact can be deemed negative, as it disrupts the nature landscape, with the natural landscape often being deemed as more desirable.

Many of the negative environmental impacts have been studied in great detail. Vibrations, dust and noise and vehicle movements can be measured and thus quantified in a very simple way. The visual impact of surface mining operations cannot be measured or quantified in a simple way. Visual degradation of the landscape is subjective and therefore cannot be quantified using a numerical value.

In addition to that, the visual impact cannot be assessed in the planning phases and cannot easily be adjusted to meet legal or social requirements. Moreover, the nuisance caused to the local community won't be known until the operations are already in place. There is no standardised, objective method of estimating the expected visual impact of scenarios of surface mining operations. This means that it is not possible to adjust the planning scenario of a surface mine based on the visual impact, or to compare different scenarios against one another.

1.2 Negative public perception

The relationship between the local community and the mining operation is vital. Negative public relations can result in complaints, protests or investigations into the operations. Furthermore, the local community has some say in the granting of operation permits and planning permissions. Therefore, if relations are poorly between the community and the mine site, additional planning permission could become hard to acquire.

It can take decades of positive communication to establish a good public relationship with the local community. An example would be continuous monitoring, communication and feedback acceptance to demonstrate that the mine site has the interest of the community at heart. However, it only takes one incident for the positive relationship to break down.

Companies can experience negative public perception for various reasons. The scale of the negative perception can be local, national or even global. A recent example of extremely negative perception on a global scale is the recent scandal of Rio Tinto. In May of 2020, Rio Tinto destroyed two sacred aboriginal caves in Western Australia (Khalil., 2020). The caves, which have significant historical and cultural importance and are considered sacred to the aboriginal people, were destroyed to access around eight million tonnes of high-grade iron ore. The scandal was reported on across the world and has caused stakeholders and the public to condemn the actions of the global mining giant. The scandal has also caused the Australian parliament to instigate an inquiry into the actions of Rio Tinto and could result in financial consequences to the company. Furthermore, it could result in more difficulty when Rio Tinto attempts to acquire further planning permission or extraction rights. It will take years for Rio Tinto to re-establish its relationship with the aboriginals of Western Australia and the Australian government.

Negative public perception can also occur on a more local scale. The previously mentioned effects on the local community can result in relations breaking down between mining companies and the local communities. A report by Hunter Acoustics (2019) describes the concerns of the local population around Bryn quarry in Wales, whom are concerned about blast vibrations potentially damaging their houses. When relations between the quarry and the local community broke down regarding this issue, a third party contractor was brought in to monitor blast vibrations for six months. The results of the monitoring were used to show the local community that no damage was being done to their homes and no legal limits were breached. In addition to that, the third party made recommendations to reduce the nuisance caused by the blasting in the report. The company has shown to accept and work in concurrence with these recommendations. This has significantly improved the relationship between the quarry and the local community and can be seen as a great example of community relationship building.

1.3 Legal obligations

The rules and limits regarding environmental and community impact are recorded in law. These laws and limits can vary depending on the country the operations are being executed in.

Smaller mining companies, with mines and quarries in the same area which fall under the same legal jurisdiction can use the relevant local laws and regulations. However, larger mining companies, with mines and quarries across the world and in different countries have mostly decided to create a best practice guidance that all its mines and quarries have to adhere to. An example of this is the Lafarge

Holcim code of conduct (LafargeHolcim, 2021). This best practice guidance must minimally meet all legal requirements for every country they operate in, but usually goes even further than that.

Each mining company makes up their own best practice guidance, however the international council on mining and metals (ICMM) has create an example good practice guidance. The purpose of this guidance is to help companies improve their environmental and social performance (ICMM., 2021). The ICMM gives guidance on five main topics, namely:

- Biodiversity and ecosystems
- Climate change
- Mine closure
- Tailings waste
- Water

The guidance is not legally binding, however, the guidance helps companies set up their own best practice standards to try and reduce or mitigate any negative impacts on the environment. The first step of reducing or mitigating the negative effects on the environment is to accurately assess and estimate the severity of the impact.

One of the tools which is used to assess the environmental impact of projects is the Environmental Impact Assessment (EIA). The EIA is defined by El Haggar (2005) as “the systematic examination of unintended consequences of a development project or program, with the view to reduce or mitigate negative impacts and maximize positive ones.”

The EIA can be used as a tool to accurately assess and catalogue the potential effects that a project can have on the environment. The EIA cannot give a recommendation on whether to move forward with the project, however it can be used as relevant documentation to support moving forward or terminating a project.

The European Union has mandated in the Directive 2011/92/EU that projects in the European Union which fall under certain characteristics are obligated to perform an EIA. The European Union defines the EIA in the following manner:

“The environmental impact assessment shall identify, describe and assess in an appropriate manner, in the light of each individual case and in accordance with Articles 4 to 12, the direct and indirect effects of a project on the following factors:

a) Human beings, fauna and flora;
b) Soil, water, air, climate and the landscape;
c) Material assets and the cultural heritage;
d) The interaction between the factors referred to in points (a), (b), and (c).”

The EIA is a legal requirement to receive a planning permit to start mining operations (Overton, 2021). Companies must prove that a sufficient EIA has been executed in order to receive planning permission. Furthermore, the company must prove that the negative impacts found in the EIA must be reduced or mitigated.

1.4 Reduction and mitigation of negative effects

Mitigation methods are interventions which reduce something which is harmful or manage its harmful effects. The first step of designing effective mitigation interventions is to estimate the potential negative of any activities in the mining operation. The following table lists negative impacts and the estimation and mitigation related to the impact. This assessment can be done in the planning stages of the project.

TABLE 1.1: NEGATIVE IMPACT ESTIMATION AND MITIGATION

Negative Impact	Estimation	Mitigation
Dust	- Climate. - Frequency, number of and timing of vehicle movements. - Crushing/conveying operations.	- Reduce vehicle movements. - Reduce conveyors/crushers. - Water dust suppression. - Adjust operating times. - Monitoring.
Vibrations and noise	- Frequency and number of blasts. - Frequency and number of plant movements. - Size of blasts. - Method of blasting. - Proximities to buildings. - Geology.	- Size reduction of blast. - Blasting only at certain hours. - Warning sirens. - Monitoring. - Reduce frequency and number of plant movements. - Only have plant movements in certain time periods.
Landscape impact	- Locate important heritage. - Locate potential stakeholders impacted by visual degradation.	- Avoid mining in important heritage. - Communicate with potential stakeholders.
Vehicle movements	- Frequency and number of vehicle movements. - Exhaust amount and composition. - Frequency of vehicle movements on public roads.	- Reduce vehicle movements. - Employ exhaust reduction devices. - Utilize trains instead of lorries. - Limit time window in which vehicles movements occur.
Visual Impact	- Determine number of buildings in near vicinity.	- Build visual barriers.

By conducting the assessment of the negative impacts in the planning stages, it becomes possible to compare scenarios against one another. An example of this could be the negative impacts of blasting vibrations. An estimation in the planning phases of a project regarding blast vibrations can come with the conclusion that, at the chosen rate of extraction, blast vibrations would come close to breaking the legal limit. A different extraction rate scenario can be designed in order to stay below the legal limit, and compared against the first scenario to see if a change is made.

There are many options to assess and mitigate different negative impacts of mining operations. However, it is currently not possible to assess the negative *visual impact* of mining projects in the planning stages of the project. It is important to be able to assess the visual impact of mining operations, as it could have a big impact on the local community living around the mine site.

As it is not possible to assess the visual impact in the planning phases of the project, it is also not possible to attempt to reduce or mitigate the impact in an organised manner. If it were possible to assess the severity of the visual impact, it would become possible to:

- Define different pitshell scenarios and compare their visual impact.
- Assess effectiveness of reduction measurements like screening banks or vegetation.
- Inform the local government and local community of the visual impact severity and what has been achieved to reduce or mitigate the impact.

This would all assist in acquiring the necessary planning permits and would great goodwill between the company and the local community.

1.5 Problem Statement and hypothesis

It is currently not possible to objectively assess and compare the visual impact of surface mining pitshells in the pre-feasibility phase of projects. This makes it difficult to make informed choices in terms of potential pitshells and their negative visual impact on the local population and landscape. This can results in concerns and opposition from local populations. The opposition can result in local councils not giving out planning permission to open a new surface mine.

To address the problem formulated in the previous paragraphs a hypothesis is formulated. The hypothesis of this thesis is:

“It is possible to assess the visual impact of potential pitshell designs at the pre-feasibility phase of development to minimise the negative perception of the visual impact on the local environment.”

The goal of this thesis is to determine whether it is possible to assess the severity of the visual impact of mining operations in the pre-feasibility phase within an objective, well defined method.

1.6 Method Description

To confirm this thesis hypothesis, the study will uphold the following method:

1. Research questions: Firstly, research questions are formed which will assist in confirming and validating the hypothesis. By answering these questions later on, the hypothesis can be confirmed or rejected.
2. Literature review: A literature review will assess the current available knowledge and determine if the knowledge can be used for this study.
3. Gap analysis: Following the literature study, a gap analysis will be conducted which identifies the gaps in the current knowledge and aims to set goals to bridge this gap.
4. Guiding principles: The guiding principles are defined; these are the lesson learned from the gap analysis and literature study. The guiding principles serve as regulation on which the method is developed and to which it must adhere to in all aspects.
5. Methodology: In the methodology the method will be developed and described in full.
6. Case study: Following the method being developed in the methodology chapter, the method will be tested using a case study of a potential limestone quarry in Belgium. The case study serves as the first test of the validity of the method.
7. Conclusion: In the conclusion, the conformance with the guiding principle is determined. Furthermore, the research questions will be answered using the information found during this study and with the answering of the research questions, the hypothesis will be accepted or rejected.
8. Discussion: In the discussion any issues or opportunities not yet discussed will be identified and described. The discussion serves as a basis for further research on the topic and further confirmation or rejection of the hypothesis.

1.7 Research Questions

From this hypothesis, five research questions follow which are used to confirm the hypothesis.

- Is it possible to compare visual impacts of different surface mining operations?

- Is it possible to determine the physical change of the landscape before this physical change has occurred?
- Is it possible to eliminate the use of subjectively chosen viewpoints in the visual impact assessment of surface mining operations in the pre-feasibility phase?
- Is it possible to define perception, a subjective element, as an objective element in the visual impact analysis of surface mining operations?
- Can the visual impact be described in a numerical value which can be compared against one another?

In this thesis, an attempt will be made to develop a universal tool which can assess the significance of and the effects of change resulting from open pit mining developments on people's views and visual amenity in a structured and pre-defined way. This tool must be able to be used globally and as the standardized way of investigating, assessing and comparing the visual impact of open pit mining developments. This method should also be able to serve as the basis on which decisions are made when it comes to deciding which surface mining scenario is more visually impactful than another.

1.8 Scope

The thesis and the tool developed in this thesis is only related to surface mining operations. The tool could, in the future, be relevant to underground mining and the structures, tailings and solid tips. However the scope of this study is only related to surface mining operations.

Several aspects of the visual impacts of surface mining operations on the local populations are not included in this study. These aspects are:

- Increased traffic and trucks transporting material and people around the mining operations.
- Infrastructure and buildings related to the mining operations but not included in the pitshell.
- Destruction of culturally important landscape or buildings due to the development of the surface mining operation.

The coverage of this study encompasses the pre-feasibility phase of surface mining developments and thus works with limited data available in this phase of the project. In the current scope of the study, only pitshells created in the pre-feasibility phase are included in the analysis. This means that the pitshells have limited geotechnical information, no ramps included and no sequencing in the design.

This study covers surface mining operations and focusses, due to the case study, on (limestone) quarrying operations.

2 Literature Review

Assessing the visual impacts of projects is also relevant in other industries and projects which are not related to the mining industry. Research has been done into different methods of assessing the visual impact of a diverse range of projects. This literature review reviews the available methods, tools and guidance

2.1 Intervisibility and line of sight

One of the principle concepts in the visual impact analysis is the *intervisibility* analysis. The intervisibility analysis determines the visibility between two or more points using a *line of sight calculations* (Dentoni et al., 2018). To conduct an analysis, one must place points on the landscape which are connected to one another with line of sight lines. If these lines are broken by the landscape, the two viewpoints are not visible to one another, if the lines connect between the two viewpoints and are not broken, the viewpoints are visible for one another. This principle is used to determine whether an object or feature is visible from a location on the landscape and is used in many industries.

2.2 Intervisibility in GIS

Dentoni et al (2018) utilize an algorithm to determine intervisibility between several points on the landscape. This algorithm places observer and targetpoints on a *digital terrain model (DTM)*. A digital terrain model is a digital representation of a landscape which can be managed and analyzed in a *geographic information system (GIS)*. A GIS is a framework for gathering, managing and analyzing data. GIS applications are computer-based tools that are able to digitize spatial locations to visualize the landscape of the earth. The data inserted into GIS mostly has a geographic component. GIS enables the user to manage, create and analyze spatial information. The geographic information system is only as accurate as the data it is given and must be assessed for accuracy.

In this vertical cross-section of a generated surface and viewpoints created by Dentoni et al. (2018) the concept of the analysis is shown. The algorithm gives a *visibility value* for each connection between the *observerpoints* and the *targetpoints*. If there is intervisibility between the two points, the visibility value is one (1). If there is no intervisibility between the two points, the visibility number is zero (0). The surface area shown as green shows the area from which the target (house) is visible. It is not possible to see the house from the red surface.

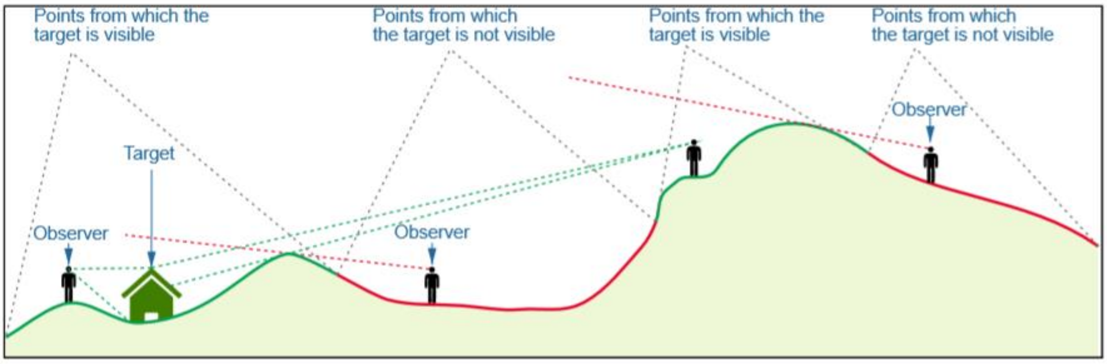


FIGURE 2.1: INTERVISIBILITY LINE OF SIGHT NETWORK (DENTONI ET AL., 2018)

Dentoni et al. (2018) utilize a Geographic Resources Analysis Support System (GRASS) environment to conduct this analysis. GRASS is a free and open source geographic information system technology, in which connecting visibility between two points is denoted as a 1 (binary). If the connecting visibility between two points is broken, the visibility value is denoted as 0 (binary).

By doing so, Dentoni et al. (2018) manage to determine visibility of a single object on the landscape. The result is a binary result, yes or no (1/0) and does not give an idea about the severity of the visibility. It can be concluded that for the observers in the image standing closer to the house, the house would look relatively bigger than the observer standing on the hillside in the image.

Dentoni et al. (2018) attempt to gather more information about a potential visual impact severity by adding more observerpoints into the equation. By doing so Dentoni et al. allow the algorithm to determine visibility between the observerpoints and the *targetpoints*. The results of the analysis are separated into areas where there is no visibility of the targetpoints (binary: 0) and areas where there is full visibility (binary: 1). For the areas where there is binary 1 result, all of the targetpoints are visible. Furthermore, they determine areas in which the visibility value > 0, meaning at least one targetpoint is visible.

In conclusion, Dentoni et al (2018) determine that by adding more observerpoints it becomes possible to give a clearer idea of the locations from which the object or feature is visible. However, the number of observerpoints merely gives a binary result and does not give a definite severity of visual impact on the landscape.

2.3 Intervisibility in the windmill industry

Landscape and visual impact analyses are important not only in the mining industry, but in many other industries. One of these industries is the wind energy industry. One of the most limiting factors in the development of windfarms is the visual impact that the windmills will have on the landscape and the local population surrounding the project site and consequent opposition of the local population and action groups against windfarms (Simos, et al 2019).

Because of this (effective) opposition, the windmill industry, environmental action groups and expert technological entities have been working together to produce guidelines to identify and assess the visual impact of windfarms in order to reduce opposition and positively influence public opinion of windfarms (Hattam, et al, 2015). One of such guidelines is a document set up by Envision & Horner + Maclennan (2006), two independent consultants, landscape architecture companies that are experts in the visual impact of projects on the landscape. The *visual representation of windfarms: Good practice guidance* was commissioned by Scottish Natural Heritage, The Scottish Renewables Forum and the Scottish Society of Directors of Planning.

The guidance was derived from research reported within the publication Visual Assessment of Windfarms: Best Practice, by the University of Newcastle (2002). The guidance is meant to be a *good practice* handbook of assessing the visual impact of windfarms. The document mentions specific guidelines and legislation in the appendix, as well as the “Guidelines for Landscape and Visual Impact Assessment”, and attempts to build a method to inform judgement on the potentially significant effects of a proposed windfarm on the landscape and visual resource (Envision & Horner, et al, 2006).

The guidance gives a broad overview method of acquiring data to assess the visual impact of windfarms and dedicates much of the report to the specifics of gathering, assessing and reporting on data. Some examples of guidelines this report provide are:

- The difference between a panorama and a planar perspective: to acquire landscape images.
- How to free-hand sketch a landscape: to represent the visual impact.
- How to determine a suitable viewing distance: to determine viewpoint locations.
- How to choose visualisations for each individual viewpoint: to report on viewpoint effects.

The guideline gives advice on how to effectively identify and analyse the visual impact of windfarms. It works as a reference book which assists landscape and visual impact professionals when conducting their analysis on windfarm projects. The guideline can be used to determine a good method of gathering and assessing the data used in the visual impact assessment.

While this guideline is useful and allows VIA professionals to gain insight into a robust and structured method of assessing the visual impact of windfarms, it is difficult to translate this method into one for mining operations.

The reason for the difficult translation is the fact that windfarms are regarded as single points in the landscape, the geometry of windmills are seen as 2-dimensional (pinpoint location and height) objects. This makes the intervisibility calculation very straight forward. Mining operations, however, are spread out across the landscape and cannot be seen at singular points in the landscape, but as 3-dimensional, length, width and depth, objects in the landscape.

Furthermore, this analysis only provides a binary result of yes, or no, visibility between a point and the landscape. The analysis gives no information about the severity of the visibility. In order to accurately assess the visual impact of an object or feature, the severity must be quantified. The next paper attempts to quantify the severity of the visual impact using several methods.

2.4 Visual impact analysis in the mining industry

Dentoni, et al (2008) have determined that the visual impact perception of surface mines and quarries mainly depends on the extent of the visible landscape alteration and the *chromatic contrast* between the bare rock exposed by the excavation and the surrounding natural area. This determination will serve as the basis for the determination of the physical extent of the altercation to the landscape.

Dentoni and Massacci use this theory in their research from 2012 to investigate the visual impact of surface in photographs. These photographs are taken at chosen viewpoints. The viewpoints are situated along a public road running past the mine site. These viewpoints are chosen by the VIA professionals as they deemed these viewpoints as representative of the “average” view which will be experienced by the receptors. Dentoni and Massacci photograph the surface mine operation at the location of the viewpoints to represent the situation on site. Their research focuses around the numbers of pixels included in the altered area and the total number of pixels in the image. Furthermore, to assess the contrast between the bare rock exposed by the excavation and the surrounding natural area, the pixels in the photographs are used to determine the contrast of RGB value between the rock and the surrounding landscape (Dentoni and Massacci, 2012). This inexplicitly links the evaluation of the severity of the visual impact with these subjectively chosen viewpoints and photographs.

In Dentoni and Massacci’s work, the extent of the visible alteration is defined as the *solid angle* subtended by the visible altered area in relation to the human visibility threshold (average field of vision for a person).

The chromatic contrast is the *Euclidean distance* in the CIE LAB *colourspace* between the average colour of the surrounding landscape and the average colour of the alteration related to the chromatic contrast between black and white (Dentoni and Massacci, 2004). The CIE LAB colourspace is a three-dimensional colour ordering system which describes colours using three axis with numerical values. (Bishop, 1997).

Dentoni and Massacci (2004) describe these parameters and their relation to one another in the following (simplified) formula:

$$L_{vi} = \frac{\Delta E_{\mu}}{\Delta E_{EW}} \times \frac{\Omega_v}{\Omega_0}$$

ΔE_{μ} = The mean of the Euclidean distance between the altered area and the surrounding landscape
ΔE_{EW} = The Euclidean distance between black and white
Ω_v = The solid angle subtended by the visible altered area
Ω_0 = The human visibility threshold under maximum contrast conditions

Dentoni and Massacci (2004) create a standardized method of quantitively assessing the visual impact of a mining operations and utilize this method on photographs taken at viewpoints. While this method is structured and standardized, the viewpoints are still selected subjectively by the VIA professional and do not cover the entire impact of the mining operations, merely the effect in singular points in the landscape. In addition to this, as the viewpoints are chosen subjectively the method cannot be used for an objective analysis.

2.5 Elimination of the use of photographs in the visual impact analysis in offshore wind farms projects

López-Uriarte, et al (2019) conducted a study in which quantitative indicators are used to assess the visual impact of windfarms over large (continuous) areas. The aim of this study was to create a “Multi Criteria Decision Support System (DSS)” tool to find the optimal location of potential offshore windfarms. The study identifies visual inventory and from this inventory develops several visual *indices* which give a quantitative value to the visual impact of the windfarm at all potential locations (López-Uriarte, et al, 2019).

The study of López-Uriarte, et al (2019) created a *raster* over the area where the windfarm could potentially be placed. Each raster cell represents a 25-by-25-meter area on the landscape (in this case, off the coast in the sea). The study aimed to assess which of these raster cells are most suitable to place the windfarm on in terms of reduced visual impact.

The windfarm must be placed on multiple of the raster cells. The study attempted to determine the visual indices for each of the raster cells in order to grade the visual impact severity if the windfarm is placed in any of these raster cells. The visual indices include:

a) Magnitude of Visual Effect (MVE)
b) Length of Road Affected
c) Land Surface Affected
d) Area of affected population Affected

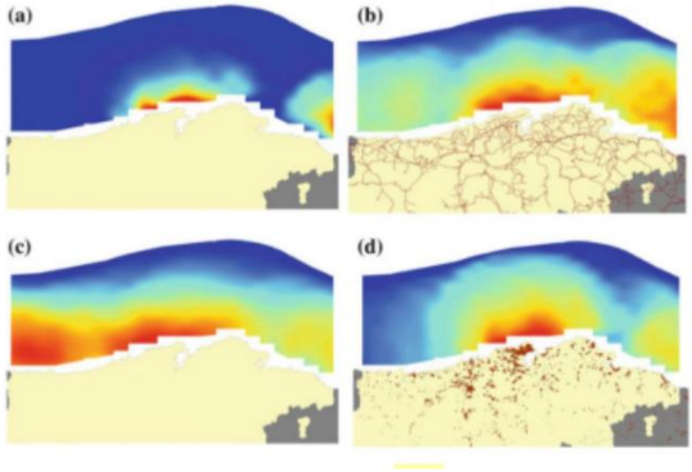


FIGURE 2.2: VISUALISATION OF THE VISUAL INDICES (LÓPEZ-URIARTE, ET AL, 2019)

In the images, the red colour represents raster cells in which the impact of the visual index is high, the blue colour represents raster cells in which the impact of the visual index is low or non-existent. With this analysis method it is possible to determine which raster cells have a high impact and which raster cells have a low visual impact. By combining the visual indices results it is possible to determine the optimal location for the windfarm.

While this method of position selection is optimal for a windfarm, where the location of the windmills does not matter extremely much (the orientation of the blades is more important than the location), this method would not work for a mining operation. Mining operations are bound in location by the orebody. The shape of the mining operation is bound by several factors like the orebody, the method of extraction, the geotechnical situation, land ownership and use and permits. Therefore, it is not possible for the VIA professional to assess the optimal location for the pitshell in terms of visual impact. The analysis must be conducted the other way around. The VIA professional must attempt to assess and compare different, already existing, pitshell designs, instead of basing the pitshell design on the visual impact analysis.

However, the approach of analysing raster cells in terms of visual impact and other visual indices, could be very useful to assess the visual impact of surface mines. Instead of placing the raster cells on the location of the proposed project, the raster cells can be placed on the surrounding landscape. Therefore, it is possible to assess the visual impact of the project on the raster cells representing the landscape.

Another interesting part of the analysis done by López-Uriarte, et al (2019) is the addition of the human perception into the analysis. In this study, a visual index analysis was made for the raster cells which relates to the quantity of the population which can view that raster cell. By doing so, the perception of the human observer can be included in the analysis. If a raster cell has zero or low visibility from the populated areas, the visual severity can be graded as less severe than a raster cell which is highly visible for the population.

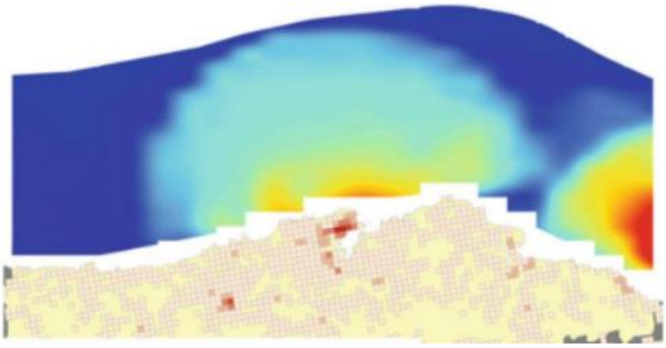


Figure 2.3: Visualisation of affected population (López-Uriarte, et al, 2019)

The analysis results in some useful indices which can give quantitative information about the visual effect on the landscape. However, the targetpoints in this study are still limited to only singular points in the landscape, every 25 by 25 meters. This is suitable to represent a windfarm, with a regular grid of windmills. It is however not suitable to describe a three dimensional surface mining operation.

These indices give an interesting perspective on the visual impact of windmill project and give an indication of an ideal location of the farm. However, by combining these indices the result could be more holistic. A second study which has developed method of combining several visibility factors is the Moyses (Modeller and Simulator for Visual Impact Assessment) v4.0 study conducted by Manchado, et al (2014) which will be discussed in the next paragraph.

2.6 Combining indices in Moyses v4.0

Manchado, et al (2014) developed a software package which can automatically calculate a defined severity of factors related to the visibility analysis of windfarm projects. Moyses v4.0 is the fourth version of the software.

One of these improvements is the calculation of the *Zones of Visual Influence (ZVI)* or *Zone of Theoretical Visibility (ZTV)* using a Digital Terrain Model (DTM). By calculating the zones of visual influence, it is possible to determine which areas of the landscape are visually affected by the project and which areas are not visually impacted at all. This result is a binary one, where the answer to the question of visibility is either yes or no (Y/N) (Manchado, 2014) in the image on the next page, an example of a ZTV is shown.

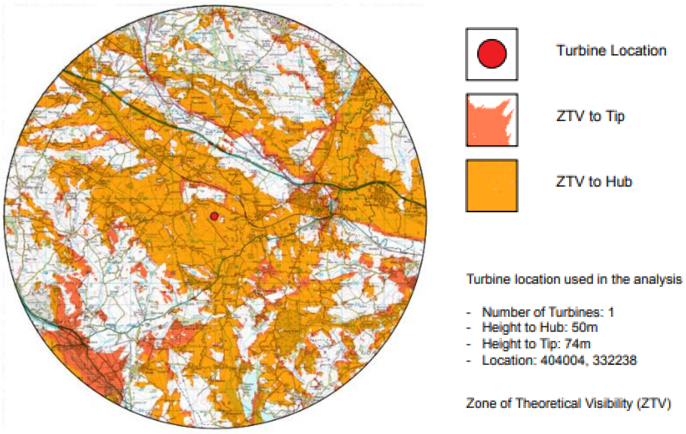


Figure 2.4: ZTV Analysis on a single windmill in the landscape (2B, 2013)

The ZTV analysis in this case was conducted by 2B, a landscape visual impact assessment business, and shows the zone of visual influence of the wind turbine tip and hub on the landscape. The ZVI can quickly, in a visual manner, show the extent of the visual impact of an object in the landscape.

While this analysis gives information about the visibility of the project, it does not quantify the severity of this visible impact. This could result in a situation in which the total area of visibility is much smaller in one project compared to another, however the severity of this smaller visibility area is much more impactful than the severity of the visibility in project two. This does not allow for a complete comparison and could result in ambiguous results.

The software calculated the ZVI and used the visual inventory data to calculate the position of characteristic viewpoints which represent the “average” or important visual impact of the windfarm. This data set can include population centres, built areas, roads, vantage points, protected areas, etc (Manchado, 2014). The software then ran a calculation which resulted in a numerical value which classifies the visibility area, the population affected and the road area with visibility of the project.

Moyses v4.0 then builds on the work of Hurtado (2004) and Tsoutsos (2009) to quantify the visual impact. The Spanish method, proposed by Hurtado, has been implemented in the moyses v4.0 application to conduct this calculation. This process numerically quantifies the impact based on parameters of general visibility, built-up area with visibility, relative position, distance and population.

In conclusion, the Moyses v4.0 software enables to user to calculate the visual impact of potential windfarm projects and is able to relate this visual impact to the perception of the local population and humans who encounter the project either on the road or while walking in protected areas. This gives the possibility for the VIA professional to put the project into perspective against how the local population will perceive the project and thus, how much opposition can be expected.

Furthermore, the method of assessing the ZTV and then relating this to prominent features in the landscape (population centres, built-up areas, roads, etc) allowed for the VIA professional to present a more holistic result and eliminates the selectivity of the viewpoint selection.

However, the Moyses v4.0 project utilizes only one targetpoint to describe the feature in the landscape. This limits the ability to assign a severity of the impact to the feature if the feature is large in size and 3-dimensional.

2.7 Visual impact assessment

A *guidance document* exists that can be used to identify and assess the significance of and the effects of change resulting from development on both the landscape as an environmental resource in its own right and on people’s views and *visual amenity*. This guidance is a book written by the Landscape Institute and the Institute of Environmental Management & Assessment. The guidebook was written to create guidance for professionals who are attempting to determine the landscape and visual impact of different projects which have an impact on the environment.

The landscape institute and the Institute of Environmental Management & Assessment made a distinction between two components of the landscape and visual impact analysis (Landscape Institute & Institute of Environmental Management & Assessment, 2013):

1. **Landscape effects:** assessing effects on the landscape as a resource in its own right;
2. **Visual effects:** assessing effects on specific views and on the general visual amenity.

The Landscape Institute & Institute of Environmental Management & Assessment will be abbreviated to LIIEMA. In this study there will be a focus on the visual effect aspect of the LVIA study. The landscape effects will not be covered in this study. The LVIA guidebook dedicates a chapter to describing the analysis of the visual impact of projects on the landscape.

While there are guidelines available for the visual impact assessment, these guidelines can be described as ambiguous. The guidelines serve more as an outline of required data which should be gathered and assessed, not a step-by-step plan of how this must be executed. As is described in the book Guidelines for Landscape and Visual Impact Assessment: “It is not intended to be prescriptive, in that it does not provide a detailed 'recipe' that can be followed in every situation” (LIIEMA, 2013).

The analysis is conducted by a *visual impact assessment (VIA) professional*. The VIA professional does not have to have any competence or certification in order to conduct the analysis. The VIA professional can be a landscape specialist or simply someone who has experience in carrying out visual impact assessments. The Guidelines for Landscape and Visual Impact Assessment (LVIA) leaves a great deal of leeway for the professional to work with.

The Guidelines for LVIA guidebook makes a distinction between several important factors. These factors are divided into 3 components which follow from one another. These components build upon each other, resulting in a judgement of severity of the visual impact. In order to meet the requirements of the LVIA guidelines with the method developed in this thesis, these components will be analyzed and evaluated.

The first component is related to the total *area of influence*. This area of influence describes the area which is visually impacted by the surface mine. This zone of influence can be determined in multiple ways and the result of the analysis should be an outline of the affected area. After determining the *zone of interest* for the project and the *visual impact range*, the people within this area must be identified. The LVIA guidebook denotes these people, who are affected by the visual impact, as *receptors*.

Receptors can be people in the following situations (LIIEMA, 2013):

- People living in the area;
- People who work in the area;
- People passing through or commute on road, rail or other forms on transport;
- People visiting the surrounding landscape or attraction sites;
- People engaged in recreational activities in the area;
- LVIA makes a distinction between several important factors.

These people are classified as receptors when they are affected by the visual impact of the surface mining operation. The assessment of these receptors is done by a site study of the area. This study will consider the local roads and other transport infrastructure (local pathways, cycling lanes, local roads and major roads and highways). The VIA professional will also assess infrastructure related to living and working (buildings, industry, cultural, recreational or residence) and the VIA professional should evaluate touristic or scenic elements of the local surroundings like scenic walking routes and associated *viewpoints*. The guidelines give no clear method of assessing these elements, therefore, in practice, the analysis is done based on *subjective factors* chosen by the VIA professional.

The assessment of the location and role of the receptor is done purely on the conviction of the VIA professional. This choice is entirely subjective, as there are no strict guidelines of determining the location and role of the receptor. Therefore, it is impossible to guarantee repeatability. This thesis will attempt to develop a systematic and objective method of assessing the location and significance of the receptors inside the zone of influence.

Following this receptor analysis, the VIA professional must give a *quantifying judgement* over the visual impact cause by the change in the landscape. The LVIA guidebook advices to do this using viewpoint. These viewpoints must represent the average change in the landscape or must represent a specific change caused by the project. An example could be a historic tower which will be obstructed by the proposed project, or a viewpoint along a road passing the proposed project. Viewpoints will be chosen by the VIA professional. These viewpoints should be representative of the views which will be experienced by the receptors. While there are characteristics of the viewpoints which must be considered for the selection of the viewpoints, there are no clear direct guidelines. As mentioned in the guidebook for LVIA:

“It is not possible to give specific guidance on the appropriate number of viewpoints since this depends on the context, the nature of the proposal and the range and location of visual receptors.”

From these representative viewpoints, the severity of the visual impact will be assessed and evaluated. The LVIA assessment guidelines speak of three components which should be assessed for each effect of the surface mining operation to combine into the visual impact. The components are named as (LIIEMA, 2013):

- **The scale of the change** in the view with respect to the loss or addition of features in the view and changes in its composition including the proportion of the view occupied by the proposed development;
- **The degree of contrast or integration of any new features or changes in the landscape** with the existing or remaining landscape elements and characteristics in terms of form, scale and mass, line, height, colour and texture;
- **The nature of the view of the proposed development** in terms of the relative amount of time over which it will be experienced and whether views will be full, partial or glimpses.

Like the selection of the viewpoints and the assessment of the receptors, the severity of the visual impact is again judged subjectively by the VIA professional.

In conclusion, while there is a guideline available which guides professionals to assess the visual impact of projects, all decision made at every step of the visual impact assessment are made subjectively and at the discretion of the VIA professional. There is no clear step by step process in which the nature and severity of the visual impact is assessed objectively and methodically. The professional conducting the analysis is left much leeway to make his or her own decisions in selecting the method of assessing the visual effects and impact.

2.8 GAP analysis

The overarching LVIA guidebook, which serves as a guideline for the visual impact assessment of all projects impacting the landscape, does not provide a quantifiable or repeatable guide to assess the visual impact of projects. The guideline does not give a specific way to quantify the visual impact and does not allow different projects or scenarios to be compared against one another. This is due to the fact that the analysis is based on subjective choices to be made by the VIA professional. There is no concrete plan or guideline available to allow VIA professionals to use the same method and arrive at comparable results.

Some available methods of determining the visual impact of mining operations are limited to the analysis of photographs, taken at specific viewpoints. This makes it very difficult to compare two scenarios against one another, first of all, the photographs are taken of surface pit mines which already exist and therefore this method cannot be used for pre-feasibility planning studies. Secondly, the photographs can only compare two different scenarios from the same viewpoint, not the overall visual impact of the entire proposed pitshell on the surrounding landscape. However, Dentoni et al (2008) have developed a quantifying and repeatable method of assessing the visual impact on the basis of two physical parameters in photographs, these parameters will be built upon in the tool developed in this study.

A significant issue with the method of taking photographs at selected viewpoints is the subjectivity with which the viewpoints are chosen. When subjective choice is involved in the process, it becomes impossible to accurately compare two different scenarios against one another. This will be explained further in the next chapter.

A more systematic method of assessing visibility, the intervisibility analysis, is often used only for single point objects like windmills. These objects are easy to describe with a singular targetpoint. For example, a VIA professional can place targetpoints along the base, middle section or top of the windmill and compare this against the landscape. A mining operation, however, is much harder to describe accurately using singular targetpoints. The object is very large and would create a very large amount of data if modelled in a ZVI analysis using multiple targetpoints. A better way of describing surface mining operations with targetpoints in an intervisibility analysis must be determined and used in the tool developed in this study.

An avenue which has already been explored in visual impact studies in other industries is the digitalization of the analysis by modeling the scenario in GIS software. GIS software is shown to be very promising in visibility studies, especially in the pre-feasibility phases of projects, and will thus be used in the development of the tool in this study.

Lastly, in order for this method to be a useful addition to the current available literature, is for the method to be useable by all stakeholders without ambiguity and subjectivity. Whenever an analysis is made, the VIA professional must have no issues in objectively gathering data or executing the method in order for this method to be used to compare different scenarios and impacts.

The gap analysis comes to a few standards which must be included in the tool which is developed in this study. These standards are described as guiding principles in the following chapter. The tool must meet all standards set out in the guiding principles in order to be accepted as a suitable tool to assess the visual impact.

3 Guiding Principles

In order to create a standardized tool of assessing the visual impact of surface mining projects this thesis attempts to set out a best practice guidance. When this best practice guidance is upheld by the tool developed in this thesis, the method can be used to assess and compare different pitshell scenarios in terms of visual impact. The standards are defined as five guiding principles. By combining the current knowledge on visual impact assessments and measuring the current knowledge against the guiding principles, a tool is developed. The following paragraphs explain all five guiding principles.

3.1 Repeatability

Repeatability is immensely important when comparing two results of two different scenarios. If an analysis is not repeatable, the results cannot be compared accurately. This measurement denotes the precision of a test and considers the absolute difference between a pair of repeated test results (Timmer, 2006). When a scenario of a possible surface mine operation's visual impact on the landscape is tested, repeatability demonstrates that the results are not expected to change over time or when repeated by another VIA professional. Furthermore repeatability proves that the tool is robust and generates the same outcome for each analysis of a specific scenario. Repeatability is currently not a requirement in LVIA regulation, which means it becomes impossible to accurately compare two separate surface mining operations in terms of visual impact. A VIA professional could simply re-assess the same scenario using a different approach, criteria or evaluation strategy, or a company could hire a biased VIA professional, who will assess the impact as being less severe. Additionally, the time at which the analysis is done also influences the results, like the time of day, or the season. Therefore, the method developed in this thesis will have to uphold the principle of repeatability.

Repeatability: "The evaluation and result of an assessment of the visual impact of a surface mine operation must be able to be reproduced when the same data is utilized."

3.2 Objectivity

As seen from Dentoni, et al (2008), previous studies are focused around using viewpoints and assessing the visual impact of the surface mine operation from that viewpoint. The selection of these viewpoints is however a subjective choice of the VIA professional who is conducting the analysis. In the guidebook of LVIA the selection of the location of the viewpoints is described as such (Institute of Environmental Management and Assessment & Landscape Institute, 2013):

"The detailed location of each viewpoint should be carefully considered and should be as typical or representative as possible of the view likely to be experienced there."

While the instruction and the desired goal of the viewpoint is clear, the selection of the location of the viewpoint remains subjective and fully at liberty for the VIA professional. Furthermore, the characteristics and number of required viewpoints isn't described distinctly by the guidebook (Institute of Environmental Management and Assessment & Landscape Institute, 2013):

"The viewpoints used need to cover as wide a range of situations as is possible, reasonable and necessary to cover the likely significant effects. It is not possible to give specific guidance on the

appropriate number of viewpoints since this depends on the context, the nature of the proposal and the range and location of visual receptors."

Concluding, the selection of viewpoints adds a subjective choice into the process of assessing the visual impact of surface mining operations. Two separate VIA professionals conducting the analysis might define the representative view of the surface mining operation differently and therefore subsequently choose a different number of viewpoints at different locations.

Subsequently, with subjectivity in the analysis, it becomes unfeasible to compare the results of different scenarios with each other. Even when the same VIA professional is conducting both the assessments for each scenario, subjectivity brings the influence of perspective, values and experience into the assessment (Allen, 2017). It can't be guaranteed that the researcher will assess both scenarios in identical ways. Therefore, the method developed in this thesis will have to uphold the principle of objectivity.

Objectivity: "The evaluation and result of an assessment of the visual impact of a surface mine operation must be reached by taking exclusively objective decisions."

3.3 Comparability

Comparative research aims to describe and analyze the relationship between distinct elements by documenting and observing characteristics of each element (Capri & Egger, 2008). The VIA professional must assess and quantify the relationship between them. However, one of the limitations of comparative study method is the control of other variables that might influence a study (Capri & Egger, 2008).

When it is possible to compare the impact assessments of different pitshell scenario, it would also be able to determine which pitshell scenario would be the better option in terms of visual impact. Without a standardized method of data acquisition it is impossible to accurately compare two scenarios of pitshell with each other. Therefore, the method developed in this thesis will have to uphold the principle of comparability.

Comparability: "Two distinct data sets, evaluations and results of an assessment of the visual impact of a surface mine operation must be comparable between one another."

3.4 Universality

The book "guidelines for LVIA handbook" acknowledges the fact that the regulatory framework of legislation, regulations and policies for EIA differ for different regulatory regions (Institute of Environmental Management and Assessment & Landscape Institute, 2013). This complicates the comparability of different scenarios as there is no standardized method of assessing this visual impact of surface mining operations. In order to develop a method which can function as a standardized method of visual impact assessment, the method must be universally accessible and usable globally.

Universality: "The evaluation and result of an assessment of the visual impact of a surface mining operation must be universally accessible and usable globally."

3.5 Pre-feasibility

It is in the interest of companies to determine the visual impact before any work has begun. Therefore, the tool must be able to assess the visual impact of mining projects in the pre-feasibility phase of the project.

Pre-feasibility: “The data collection, evaluation and results phase of the tool must be able to be executed in the pre-feasibility phase of the project.”

4 Methodology

The study aims to develop a technique to assess the visual impact of surface mining operations in the pre-feasibility phase of mining projects. The research is done on the basis of examined literature and is therefore explanatory. The study aims to develop and validate a new tool and is therefore inductive research.

4.1 Methodology structure

The following subjects will be covered in the methodology chapter:

- Conceptualization of visual impact: from the literature study into currently available knowledge and the following guiding principles, the visual impact of surface mining operations is conceptualized. By conceptualizing the visual impact, it becomes possible to see the important and relevant aspects of the topic.
  - Physical factor: the physical factor is defined for the physical change in appearance.
  - Perception filter: the perception filter is defined for the perceived change in appearance.
- Concretizing of visual impact: the conceptualization of important aspects of the visual impact is concretized in order to define a tangible element of the visual impact. By creating a tangible element, it allows the VIA professional to measure and quantify this aspect of the visual impact.
  - Visual angle: describes the physical change in the landscape.
  - Chromatic contrast: describes the colour change between the landscape and the surface mining operation.
  - Cadastre: represents the areas in which the population spends time.
  - Classification algorithms: represents the areas in which the population spends time.
- Define the necessary steps to assess the concretized visual impact: by defining the practical steps necessary to analyze the concretized aspects, any VIA professional can conduct the analysis on his own.
- Case study: is used as an example and a validation case for the tool.
- Conclusion: in the conclusion the research questions are repeated and answered on the basis of the methodology and case study chapter. Furthermore, the guiding principles are compared against the tool. With this information, the hypothesis is either accepted or rejected.

4.2 Aims of the thesis

This thesis aims to design and test a tool with which the severity of the visual impact of mining operations can be tested. In this chapter the principles on which the tool is built and the tool itself are described.

The tool aims to assess the visual impact on the landscape around the surface mining operations. Ideally, the severity of the visual impact of the surface mining operation must be known for the entire zone of theoretical influence. By knowing the severity for the entire zone of theoretical influence, the selection of subjectively chosen viewpoints is no longer necessary. However, it would create an enormous workload to go to every square centimeter of the affected area and take photographs of the surface mine location. This is completely unnecessary and time consuming work. In the following paragraphs I will explain how this severity will be measured and how the '*viewpoints*' are chosen in the tool developed in this thesis.

4.3 Modelling Reality

To avoid this workload, a model of the situation and landscape can be made digitally. Models are designed to represent the situation at location. Neumann (1995) has described models as a "mathematical construct which, with the addition of certain verbal interpretations, describes observed phenomena". Models will always simplify the situation on site and must reasonably resemble the real-life situation in order to be accepted. By modelling the situation on site in become possible to do the analysis without visiting the site. In the case of this thesis, the base model used will be a digital elevation model as was done by Manchado, et al (2014). A digital elevation model or DEM is a 3d computer graphic representation of elevation data to represent terrain, most commonly of the earth (Balasubramanian, 2017). DEMs are imported in geographic information systems to carry out operations with the data (Anon, 2020). In this tool, the chosen type of digital elevation data will be a raster so as to conform to requirements for operations in the chosen GIS (geographic information system) software. In further chapters, more information will be given about the specifics of the DEM.

The digital elevation model represents the landscape, however, the viewpoints also need to be modelled digitally to fit in the GIS software. In reality, there are an infinite number of viewpoints across the terrain, representing a person moving through the landscape and viewing the operation. This is impossible to represent completely accurately in modelling. When creating an infinite (or close to infinite) amount of points, the information density becomes too large for the model and GIS software to handle. Therefore, a balance must be found between adequate data density to reasonably represent reality and limit the amount of data points to reduce the pressure on the process in terms of processing time and hardware/software capabilities. In further chapters, more information will be given about the specifics of the viewpoints.

One such software (GIS) to manipulate and document the information mentioned above is QGIS. QGIS is a free and open source (FOSS) geographic information system (Anon, 2020). QGIS is used to manage, visualise, edit, analyse data and create graphic printable images inside a projected (world) coordinate system. This allows users to insert coordinate sensitive data and use this data to analyse the real-world situation digitally. As one of the guiding principles in this thesis is to ensure that the tool created is usable universally, the use of Free Open Source Software is crucial. Furthermore, QGIS enables the VIA professional to conduct the visibility analysis fully remotely. Removing the need to go on site to take images and analysis of the landscape. This brings some advantages with it.

- Site visits have the possibility to alarm the local population of potential plans to open a new surface mining operation. When the analysis is done completely remotely, this risk is averted.
- The workload is focused only on a desk study, which greatly reduces the time necessary for site visits used in other methods.
- There is no requirement to hire any equipment to record or take photographs of the landscape, which reduces differences in, for example, camera's used.
- The results are no longer based on a snapshot moment, which reduces differences in for example weather and season at the moment of the snapshot being taken.

In conclusion, the tool developed in this thesis will utilize the free open source software QGIS to manage, visualise and analyse data; namely DEMs and viewpoints to assess the visual impact of surface mining operations.

4.4 Conceptualization of Visual Impact

In order to assess the visual impact of surface mining operations, the severity of the impact must also be defined. It is important to quantify the impact in a way which is understandable for humans on a human scale. In this thesis, two components of the assessment of the visual impact of surface mining operations are defined. These two components are fully standalone and will be assessed and evaluated separately from one another, before being combined into the final result. This allows for a more systematic and objective method of determining the visual impact, because the subjective selection and assessment of the perceived change are disconnected and made objective factors and filters.

- **Factors**: are defined as the physical aspects of the visual impact and are tangible changes to the landscape and the environment. These effects are non-subjective and remain identical regardless of human perception.
- **Filters**: are defined as the subjective interpretation of the factors. The filters give additional weight to the factors by multiplying them with the intensity in which the factors are perceived by people. These aspects consider the human factor of the visual impact and the perception associated with the changes the factors make.

In this thesis the factors (physical alteration to the landscape) and the filters (human perception of the alteration to the landscape) are disconnected in order to better assess the changes in the landscape and to be able to compare different scenarios with one another. The factors and filters must be defined in a way which quantifies this data and creates the possibility to relate this data to the human scale.

Dentoni and Massacci (2004) introduce the indicator *Lvi (level of visual impact)* to describe the impact of the operation on the visibility in the landscape. The indicator Lvi consists of two physical parameters which, according to Dentoni and Massacci (2004), are combined to describe the perceived alteration in the landscape. These physical parameters are:

- The extent of the visible alteration (spatial factor value),
- The chromatic contrast between the alteration and the surrounding landscape (chromatic factor value).

In this thesis, the focus will be on determining a tool with which it is possible to extract the two physical parameters in a standardized way using the digital model in QGIS, to ensure that the guiding principles of **objectivity**, **repeatability** and **comparability** are met. The physical parameters are reassessed and distilled to their basic elements to translate them into parameters which can be acquired using QGIS. Firstly, the extent of the visible alteration is defined by Dentoni and Massacci (2004) as the solid angle in relation to the human visibility threshold determined from the photographs taken at the viewpoints. While the solid angle is a way to describe the surface area of the alteration in the landscape, it is difficult for humans to conceptualize this parameter on a human scale. One of the guiding principles of the tool is that the tool should be able to be used universally. Which also means it should be able to be understood for any person interested in the visual impact of surface mining operations. Therefore, the parameter is simplified into a concept which is more recognizable on the human scale.

4.5 Quantifying the Physical Component

The physical changes in the landscape are described with the spatial factor value**.** The spatial factor value is defined at the extent which the surface operation takes up in the field of vision of the observer. This extent is described using a visual angle subtended by the maximum visual alteration caused by the operation. This visual angle is divided into two separate aspects;

- The vertical visibility angle;
- The horizontal visibility angle.

The vertical visibility angle is the angle subtended by the largest visible vertical alteration caused by the operation in the landscape. When an observer is viewing the operation from a viewpoint, the largest visible vertical length in the landscape which is affected by the operation is the length which is used to subtend the vertical visibility angle from.

FIGURE 4.1: CONCEPT VERTICAL VISIBILITY ANGLE

The same principle is used for the horizontal visibility angle. The horizontal visibility angle is the angle subtended by the largest visible horizontal alteration caused by the operation in the landscape. When an observer is viewing the operation from a viewpoint, the largest visible horizontal length in the landscape which is affected by the operation is the length which is used to subtend the horizontal visibility angle from.

FIGURE 4.2: CONCEPT HORIZONTAL VISIBILITY ANGLE

It is crucial that the vertical and horizontal visibility angle are purely vertical and horizontal respectively, to ensure the correct results are found. The vertical and horizontal visibility angle will then be classified into severity ranges. These ranges represent the impact of the physical alteration of the landscape and are chosen based on how the severity is perceived by human beings. The larger the visible angle of alteration, the higher the severity grade. It is possible to then combine the vertical and horizontal severity grade into a combined severity grade. This combined severity grade describes the total impact of the geographical changes to the landscape caused by the operation.

4.5.1 Combined Visibility Factor

By having the two 1-dimensional vertical and horizontal visibility angles, it would be ideal to transform this in a 2-dimensional visibility factor. This can be done by combining the vertical and horizontal visibility angles. The combination is done by multiplying these values together.

FIGURE 4.3: CONCEPT COMBINED VISIBILITY ANGLE

The visibility angles are combined by multiplying the two severity grades, as one would do when calculating the area of a square, to result in the combined visibility severity. It functions as a maximum square impact, as the two maximum values of vertical and horizontal impact are combined by multiplication.

This combined value will be further explained in the subchapter discussing the systematic approach to quantifying the physical component of the visual impact analysis.

4.5.2 Chromatic difference

Dentoni and Massacci (2008) determined that half of the perceived visual impact of the landscape consist of the chromatic difference between the surrounding landscape and the visible overburden and ore. When the difference in colour of the landscape and the ore is large, the eyesore of the surface mine will also be larger.

There have been decades of research into colour and how colours can be compared to one another. One of the most significant inventions in colour science has been colour models. Colour models allow for the description of colours as number or letter combinations using an abstract mathematical model (MacEvoy, 2005). Examples of colour models are RGB and CMYK. The colour model is used to describe the colours in a mathematical way, however colours must also be able to be compared to one another in order to find the chromatic difference. This comparison is made by placing the colours in a colourspace. A colourspace is a mapping function related to a colour model in which colours can be placed and compared against one another (Bourke, 1995). By extracting the colour of the overburden and ore and comparing this against the extracted colour of the landscape, the chromatic difference can be determined.

4.6 Quantifying the Perception Filters

This tool focusses on assessing the physical and tangible aspect (factors) of the operation first, and secondly the subjective interpretation of the physical aspect (filters) second. As the factors have now been defined it is time to move on to the filters and define these according to the guiding principles of this tool.

In the guidebook for LVIA the subjective perception of the physical impact of the operation is described in the early stages of the analysis. The guidebook does this to decide on where the subjectively chosen viewpoints will be located, so they can be representative for the human perception of the operation.

The guidebook for LVIA describes the human perception as the following (Institute of Environmental Management and Assessment & Landscape Institute, 2013):

"People generally have differing responses to changes in views and visual amenity depending on the context (location, time of day, season, degree of exposure to views) and purpose for being in a particular place (for example recreation, residence or employment, or passing through on roads or by other modes of transport).

During passage through the landscape, certain activities or locations may be specifically associated with the experience and enjoyment of the landscape, such as the use of paths, tourist or scenic routes and associated viewpoints."

In this thesis it will be attempted to create a systematic method of establishing the severity of filters for each person viewing the operation in different locations and under different circumstances. Two main aspects which are taken from the definition in the LVIA guidebook are the purpose of the observer and the location of the observer. This thesis will attempt to create a method which establishes these two aspects in a systematic way. This systematic way utilizes two parameters:

- The average time spent at a location.
- The setting in which the operation is viewed.

Understandably, the visual impact is more significant for a receptor (person) to look at the quarry from his home or garden than it is when driving home from work. Not only is the time spent looking at the operation longer, the setting in which the operation is viewed (recreation at home versus commuting) is different. The perception of the receptors will be incorporated in the tool as filters. The perception filter will be multiplied with the physical changes in the landscape to determine the total visual impact. Now the value of the filters and how to acquire these filters in a way that corresponds with the five leading principles set out in this thesis must be determined. Filters will be based on two factors:

- The setting in which the preceptor is viewing the surface mine from.
- The duration of the viewing of the surface mine by the preceptor.

Firstly, a closer look will be taken into the setting in which the preceptor is viewing the surface mine. As this study is in an early stage, there will be only two settings that will be explored. These settings are:

- Travelling and commuting on roads and paths.
- Inside buildings, regardless of function of the building.

The duration of the viewing will also be linked directly to the setting in which the surface mine is viewed. The goal of this thesis is to establish a tool which can determine these settings and the linked duration in line with the five guiding principles. To achieve a method which can establish these filters, but also the factors mentioned above, a systematic way of acquiring data must be developed. This systematic way must assure the five principles of: **objectivity, repeatability, comparability,**

universality and pre-feasibility. In the following chapter this systematic method will be outlined in detail.

4.7 Systematic Method Description

It is highly important that the method is executed correctly and systematically in order to realize the guiding principles that were set out the start of this document. Firstly, a closer investigation is done into the required software and data used to analyze the factors and filters.

The tool utilizes QGIS to manipulate and analyze the data. The DEM must correspond with the software requirements of QGIS and any plugins used. In QGIS, the free open source plug-in "Visibility Analysis" will be utilized to assess part of the factor side of the analysis. The visibility analysis plug-in conducts a visual analysis over a raster DEM, by assessing the connectivity between two points positioned on the DEM. The plug-in analysis determines whether it is possible to view one point from the position of another point.

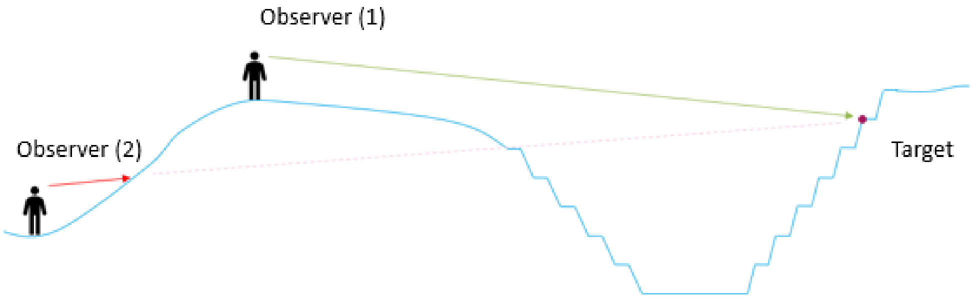


FIGURE 4.4: CONCEPT INTERVISIBILITY

There are a few requirements set by the visibility plug-in in order for the plug-in to work. Furthermore, a few requirements will be set by this method to guarantee the guiding principles. There are two elements needed in order to properly conduct the analysis. These elements are:

- A Raster DEM of the target landscape,
- Location points which represent;
    - The observerpoint: The point at which the observer is viewing the *target*.
    - The targetpoint: The point which is being viewed by the *observer*.

These two elements have some requirements set by the plug-in and by the standards of the tool developed in this thesis. Hard requirements are requirements which must be met in order for the tool to function. Soft requirements are requirements which are not necessary for the tool to function but are necessary for the tool to have a comparable result. These requirements are outlined next:

Hard requirements:

- Both elements need to be projected into the same projection system which must correspond with the site area on the globe in which the surface operation will occur.
- The DEM must be in raster form. A raster or grid of squares digital elevation model is known as a heightmap represented in squares with a distinct resolution.
- The DEM must be a DTM, a digital terrain model, which models the terrain only and leaves out buildings and vegetation. The visibility analysis is a "worst case scenario" analysis which focusses solely on the effect of the terrain on visibility. It is possible to later add elements to the DTM model to represent relevant buildings and vegetation.
- The view- and targetpoints must be singular (point) objects.

Soft requirements:

- The DEM can be acquired through several methods including photogrammetry, lidar (light detection and ranging of laser image detection and ranging), IfSAR (low frequency synthetic aperture radar) or land surveying. The VIA professional is free to decide which method is used to obtain the base data; however, the quality and resolution requirements must be achieved regardless of which data acquisition is utilized. However, when two scenarios are being compared with one another, the method of data acquisition must be the same for each scenario.
- The resolution of the observerpoints must have a minimum of 20 by 20 meter. This standard is set to ensure that the results of two different analyses can be compared against one another accurately. However, a larger or smaller resolution can be chosen by the VIA professional if this is applicable to his scenario. Ideally, the observerpoints have the same resolution as the underlying DEM. Due to time and hardware restriction the resolution is limited and the recommended resolution is 10 by 10 meter.

If some of these soft requirements cannot be met due to any reason, the tool can still be executed. However, it is impossible to compare two different scenarios with one another if any of these soft requirements differ from one another. Furthermore, it must be explicitly stated if the analysis deviates from any of the requirements in the report produced for the analysis.

This raster DEM can be generated by the VIA professional and must encompass a reasonable area around the operation. This extent can be discussed with the licensing and permitting expert in order to meet the demands set by the (local) government. There are no strict guidelines as to which area must be covered by the analysis as every operation has a different effect on the surroundings. However, in order to effectively compare the results between different scenarios, the full affected area (found in the ZTV analysis) must be encompassed in the analysis. Or, the tool recommends a minimum of 4-kilometer radius in the shape of a square around the center of the pit as the minimum and standard extent used in the tool (extent is made into a square for ease of use purposes). This 4-kilometer radius in the shape of a square is used as the minimum distance as human-scale objects are resolvable as extended objects from a distance of just under 3 kilometer (Wolchover, 2012). The distance of 4 kilometers is used to ensure full visibility.

In order to compare scenarios where a different extent is used, it is possible to normalize the result to the standard extent. This can be done by taking the deviating surface area of the scenarios and normalizing these to the surface area of the standard extent (64 km^2) and then comparing the results.

4.7.1 Observer- and Targetpoints

An important aspect of correctly executing this tool is the generation and placement of the observer- and targetpoints. This tool develops a systematic approach to generating and placing the observer- and targetpoints in order to uphold the guiding principles set out at the start of this document. The QGIS plug-in Visibility Analysis has a function in which it can determine whether there is intervisibility between an observerpoint and a targetpoint. The intervisibility analysis gives a binary response to the question of visibility, yes or no.

These observer- and targetpoints need to be generated and placed onto the DEM. To accurately do this there are several requirements for each set of points. These will be set out in the following paragraph.

Observerpoints:

The goal of the observerpoints is to represent the viewpoints across the landscape from which the observer can view the operation in the landscape. This tool values a systematic approach to selecting these viewpoints. The observerpoints are placed in a grid over the landscape, across the extent of the impacted area, which was assessed in the ZTV analysis. The resolution of the grid must be a minimum of 20 by 20 meters, with a recommended resolution of 10 by 10 meters. Furthermore, to better represent the real-life situation the observerpoints are placed 1.6 meters above the DEM's surface to mimic an average height person's eye height.

Targetpoints:

Targetpoints are placed onto the object that are wished to be viewed. In the case of this analysis, that is the surface mining operation. Unfortunately, the operation is not going to be a single point at a single coordinate. Thus, the points need to be strategically placed in order to represent the operation and so severity can be measured from all the observerpoints.

It is impossible to place points across the entire surface of the operation, as explained before. The processing time and complexity of having a near infinite number of points removes this as a viable option. A balance must be found between a number and location of points which accurately represent the operation and limiting the amount of points to reduce processing time and complexity. Depending on which visibility angle is being researched, a different pattern is needed to represent the operation accurately. Firstly, a closer look will be taken at the pattern that is designed for the vertical visibility angle.

4.7.2 Vertical Visibility Angle

In the vertical visibility angle, the goal is to find the largest visible vertical length of the operation to find the vertical visibility angle. When an observer is viewing the operation, how much of the operation is visible vertically? If we were to place targetpoints on each of the edges of the benches, from crest to toe of the pit, how many of these points are visible from the observerpoint? This line of points created by placing targetpoints in a line on the benches will be called an arm from now on. In this scenario, the observer would be able to view 4 out of 6 points on the arm.

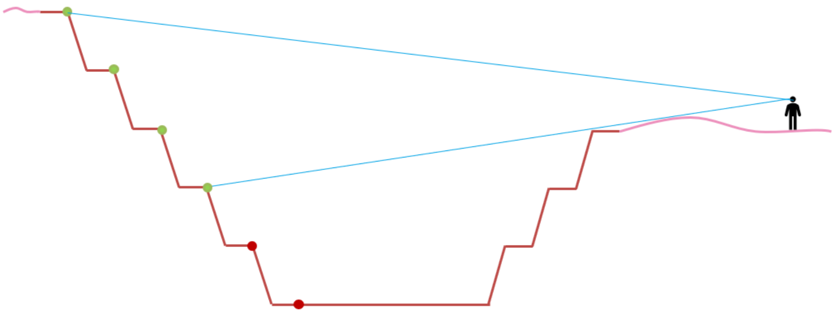


FIGURE 4.5: VERTICAL VISIBILITY ANGLE

After placing the points on the benches using software like AutoCAD, these targetpoints are exported into QGIS for further processing. In QGIS it is possible to display the targetpoints onto the DEM, showing how the targetpoints are placed on the benches. In the image, dark black is lower elevation, light grey is higher elevation. The image is taken from QGIS example Pit 1.

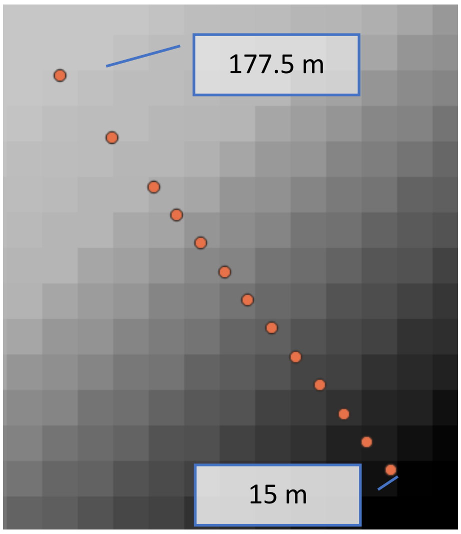


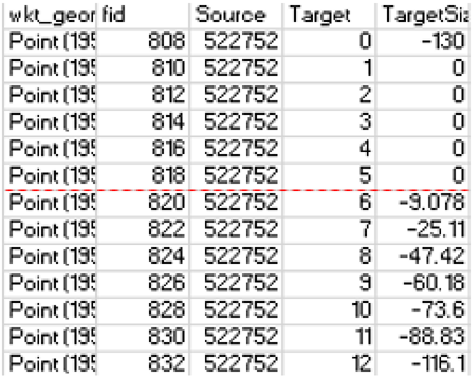
FIGURE 4.6: TARGETPOINTS ON THE BENCHES (ONE ARM)

With the targetpoints placed on the DEM and the observerpoints in the landscape, the intervisibility network can be constructed. The intervisibility network is part of a free, open source plugin called the Visibility Analysis plugin. This plugin can be installed using the QGIS interface. The QGIS visibility analysis plug-in shows the results in table form. The table will give binary information about the intervisibility between the observer and the targetpoint.

- Column one, **wkt_geom**, represents the point coordinates in the QGIS projection system.
- Column two**, fid**, represents the id number of the row.
- Column three, **Source**, represents the id number of the observerpoint.
- Column four, **Target**, represents the id number of the targetpoint.
- Column five, **TargetSize**, represents the intervisibility between the two points. When the TargetSize is negative, there is no intervisibility (n), when the TargetSize is zero, there is intervisibility (y).

The results are shown in table form with the rows sorted based on the Source number, following the target number. It is therefore possible for every observerpoint to define which point is the lowest visible point in the arm. Target zero is the center point of the pit and thus also the lowest point. The final targetpoint with a zero for TargetSize is the last visible point. This point and the crest point (Target number 1) form the largest visible vertical length of the operation.

TABLE 4.1: INTERVISIBILITY NETWORK ANALYSIS RESULT EXAMPLE



wkt_geor	fid	Source	Target	TargetSiz
Point (19	808	522752	0	-130
Point (19	810	522752	1	0
Point (19	812	522752	2	0
Point (19	814	522752	3	0
Point (19	816	522752	4	0
Point (19	818	522752	5	0
Point (19	820	522752	6	-9.078
Point (19	822	522752	7	-25.11
Point (19	824	522752	8	-47.42
Point (19	826	522752	9	-60.18
Point (19	828	522752	10	-73.6
Point (19	830	522752	11	-88.83
Point (19	832	522752	12	-116.1

Using the intervisibility network analysis, the intervisibility between the observer and the targetpoints is now known. Furthermore, the highest (crest targetpoint) and lowest (last visible targetpoint) is now known. However, the vertical visibility angle is still unknown. QGIS has a function to calculate the distance between several points (function: extractive specific vertices).

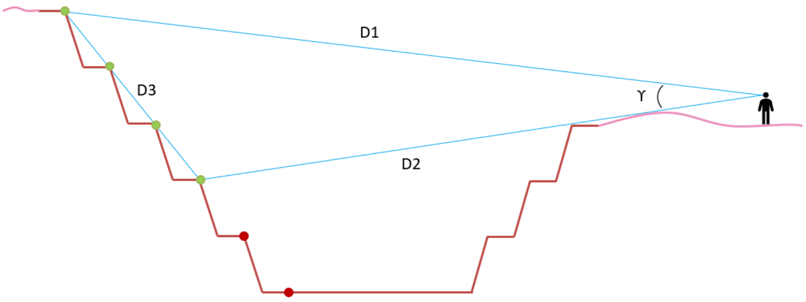


FIGURE 4.7: DISTANCE ANALYSIS

By using the extractive specific vertices analysis tool on the intervisibility network, it is possible to extract the distance between the observerpoint and the targetpoints and the targetpoints to one another. Additionally, the elevation data of the target and observerpoints must be known as the extract specific vertices function does not locate the points in accordance with the DEM. This data can then be exported to excel where through further filtering and if-statements, it is possible to calculate the distance between each of the points and then calculate the vertical visibility angle with simple geometric functions.

The law of cosines can be used to calculate the sought after angle:

$$D_1^2 = D_3^2 + D_2^2 - 2 * (D_3) * (D_2) * \cos(\gamma)$$

$$\cos(\gamma) = \frac{D_1^2 - D_3^2 - D_2^2}{-2 * (D_3) * (D_2)}$$

$$\gamma = \cos^{-1}(\frac{D_1^2 - D_3^2 - D_2^2}{-2 * (D_3) * (D_2)})$$

This calculation would give the angle subtended by the maximum vertical visible length of the operation and thus fits the requirements for the vertical visibility angle. However, this would only work with an observerpoint which is directly in line with the arm. If the arm is oriented diagonally from the observerpoint, the angle subtended by this arm will also be diagonal. This phenomenon will be described using the term osculation from now on.

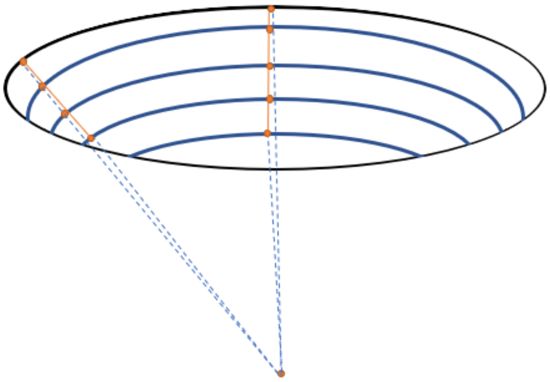


FIGURE 4.8: OSCULATION EFFECT

When looking directly at the center of the operation, the arms further away from the center line of the operation will have more osculation effect than the arms closer to the center line, with the arm directly on the center line having zero osculation.

The result of this osculation is an erroneous vertical visibility angle result, as the angle will not be purely vertical, but diagonal. The further away from the center line, the worse this diagonality is. The ideal situation would be zero osculation for each observerpoint; however, this would mean that there would have to be thousands of arms encircling the center point of the operation. As mentioned before, a very large number of points is not a possibility in digital modelling. A reasonable range of osculation must thus be accepted in order to create a practical working method. A decision must be made regarding the number of arms originating from the geometric center point of the pit. An example layout of the lay-out of the arms is shown below.

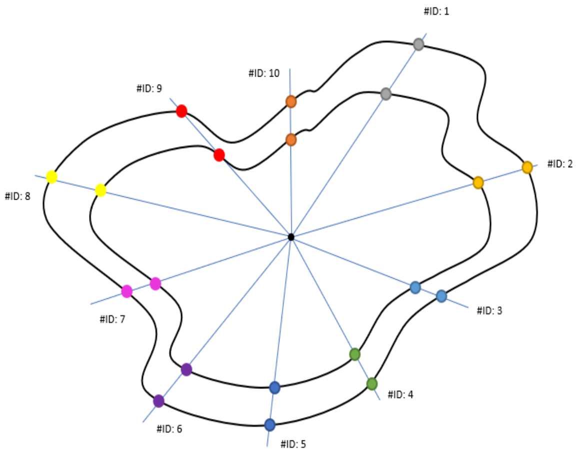


FIGURE 4.9: EXAMPLE LAY-OUT OF THE ARMS

As was determined in the osculation effect calculations, it is important to optimize the angle range in which observerpoints are still accurate when determining the vertical visibility angle through an arm. A balance must be found between accurately model reality and reducing processing time. It is impossible to use, for example, 100 arms as this would have an impossible long process time. In the appendix a calculation can be found which shows the osculation for a few example arm separation degrees. For this tool, the decision is made to go for 36 arms, with an angle range of 10 degrees for the observerpoints. All observerpoints which fall outside of this 10-degree range (subtended from the arm) are discarded.

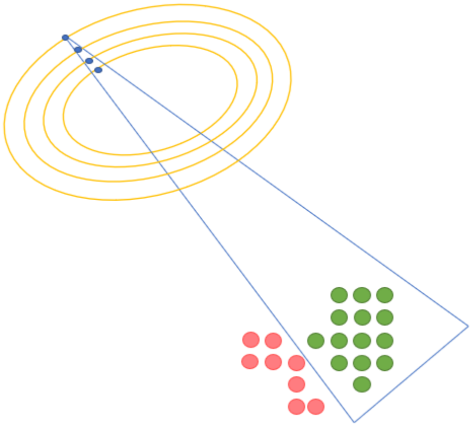


FIGURE 4.10: OBSERVERPOINT FILTERING

The recommended number of arms to complete the analysis is 36 arms to gain the most reasonably accurate results, it is possible to do the analysis with more, or less, arms. The decision to use 36 arms is explained in the appendix. When conducting an analysis using this tool, the number of arms used must always be mentioned in the report.

Furthermore, when comparing two different scenarios the number of arms must be equal. When an unequal number of arms is used, it is impossible to normalize the results and impossible to compare the two results. With less arms used the resulting visual impact value will be higher than with more arms.

Utilizing the method of 36 arms in the intervisibility analysis, the vertical visibility angle for each of the observerpoints can be found. The result is a heat map in which on the DEM, every 10-by-10-meter pixel shows the vertical visibility angle in the form of a colour.

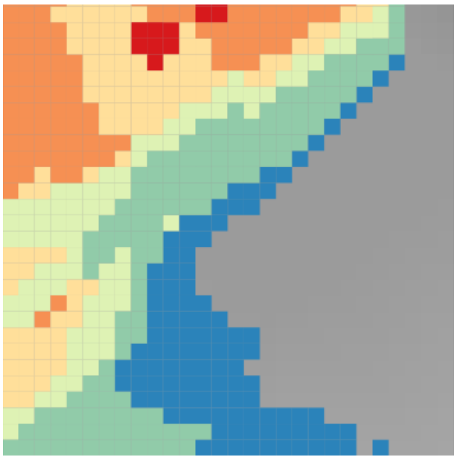


FIGURE 4.11: VERTICAL VISIBILITY HEAT MAP

4.7.3 Horizontal Visibility Angle

In the horizontal visibility angle, the importance shifts to the maximum visible horizontal length of the operation. When an observer is viewing the operation, how much of the operation is visible horizontally. Similarly, as with the vertical visibility angle, the targetpoints need to be place strategically in order to best represent the operation.

If we were to place targetpoints along the crest of the pit, how many of these points would be visible to the observer? In the image below, the observer can view 4 of the 8 targetpoints on the crest of the pit. Once initial intervisibility is determined. It is possible to determine intervisibility between multiple targetpoints to establish the largest visible horizontal length.

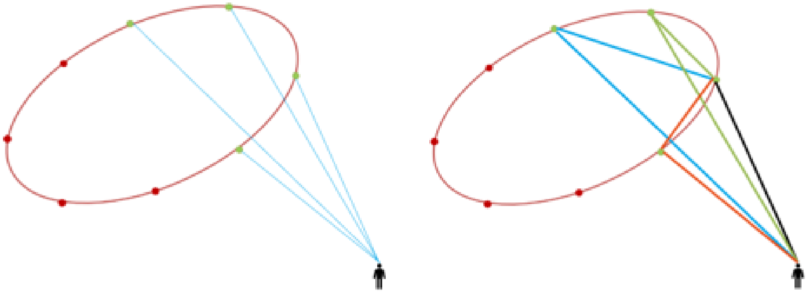


FIGURE 4.12: HORIZONTAL VISIBILITY ANGLE

Similarly, with the vertical visibility angle, QGIS can determine the distance between multiple points. By assessing all point visible against one another and the distance between these points, the visible horizontal length from which the largest visible horizontal angle is subtended can be found. From this information, the horizontal visibility angle can be found with simple trigonometric formulas.

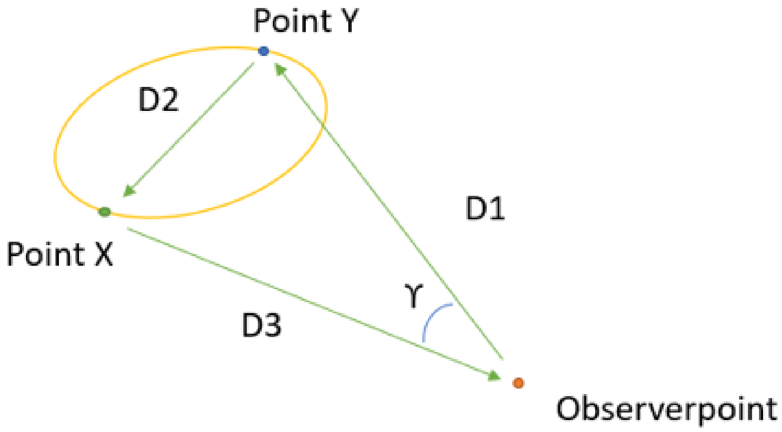


FIGURE 4.13: DISTANCE ANALYSIS AND ANGLE CALCULATIONS

In the case of the horizontal visibility angle there is no problem of osculation. However, to guarantee accuracy of the results, the number of targetpoints placed on the crest must be assessed. The assumption is made that when 100 points are placed on the crest, and a ZTV analysis is made for these 100 points, the area which is visually impacted by the 100 points is the maximum (and thus reality) area visually affected by the operation. In order to find the optimal number of targetpoints, a balance must be found between an accurate representation of the operation and a limitation on the number of points used in the model.

By trial and error, the number of targetpoints can be found. A minimum number of points of 12 on the crest is recommended to start from. Starting with 12 points, the area visually affected by these 12 points is assessed in a ZTV analysis. If the area is equal to 85% or more of the maximum area visually impacted by the operation, the number and position of points is accepted. If the 85% limit of the affected area is not met, a point is added to the crest and the analysis is done again. If the 85% is met, the amount and location of points is accepted. If the 85% is not met again, a point is added until the 85% limit is reached.

To meet the requirement for **objectivity**, the targetpoints are placed on the crest using the path array function in AutoCAD. An initial point is placed at 0 degrees on the crest of the quarry, which is then expanded in an array through the path array function. The distance between the points on the crest will be even (on the line of the crest). There will be no subjective choice in placing the targetpoints by utilizing the path array tool. It is possible to use a different array tool in this method, however, in order to compare different scenarios, the same array function must be used in all scenarios.

The results of this analysis are again a heat map on the DEM, where every 10-by-10-meter pixel shows the horizontal visibility angle in the form of a colour.

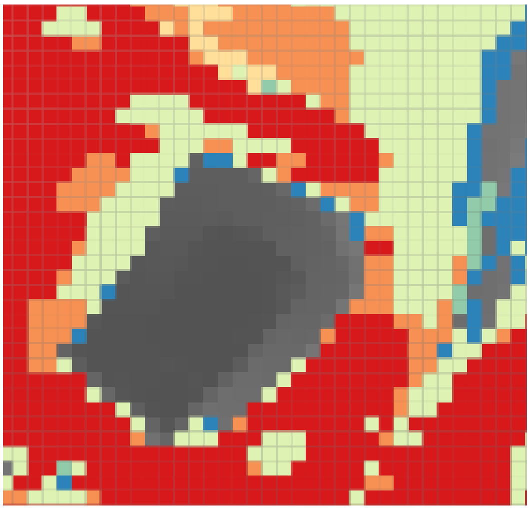


FIGURE 4.14: HORIZONTAL VISIBILITY HEAT MAP

4.7.4 Severity Ranges

The vertical and horizontal visibility angle are translated into a severity range to enable a better visualisation of the results and in order to compute with the data in a simpler way. The visibility ranges can be mapped in a colour heat map in order to efficiently show the visual impact that the surface mine will have on the landscape. The severity ranges will be set in this chapter.

4.7.5 Vertical Visibility Angle Range

The vertical visibility angle range is based on previous research conducted by SLR (2018), a landscape expert company, on a quarry owned by Lhoist. The vertical visibility angle ranges used in this study are:

TABLE 4.2: VERTICAL SEVERITY RANGES (SLR, 2018)

Severity Range	Vertical Visibility Angle (degrees)	Description
1	0.00-0.25	Very Low Vertical Impact
2	0.25-1.00	Low Vertical Impact
3	1.00-3.00	Medium Vertical Impact
4	3.00+	High Vertical Impact

By separating the vertical visibility angle into 4 severity ranges it is possible to create a heat map with no, little, medium and high impacted areas in the landscape.

This distribution was decided on by SLR and will be accepted in this thesis for further reference. Severity range 1 is defined as the very low vertical impact, due to potential rounding or measurement errors this visibility can be discarded, however, in this thesis the range will be shown in the results to show the maximum zone of visual influence. Vertical severity range 2 and 3 are chosen to represent low to medium impact on the landscape. This visibility is used to describe features which are clearly visible in the landscape, but not overpowering. The 4th vertical visibility range describes features which are extremely visible in the landscape and can be described as very invasive in the landscape.

4.7.6 Horizontal Visibility Angle Range

The horizontal visibility angle range is based on the human field of vision. The horizontal visibility angle ranges used in this study are:

TABLE 4.3: HORIZONTAL SEVERITY RANGES

Severity Range	Vertical Visibility Angle (degrees)	Description	Vision
1	0.0-5.0	Very Low Horizontal Impact	Central Vision
2	5.0-10.0	Low Horizontal Impact	Paracentral Vision
3	10.0-20.0	Medium Horizontal Impact	Focus Vision
4	20.0-50.0	High Horizontal Impact	Field of Vision
5	50.0+	Very High Horizontal Impact	Peripheral Vision

The horizontal visibility angle was not used in the study conducted by SLR. Therefore, these horizontal severity ranges were defined in this thesis. The horizontal severity ranges are based on the visual boundaries of human eyesight. The human field of view is defined into five different zones. The five zones are: Central vision, paracentral vision, focus vision, clear field of vision, and peripheral vision.

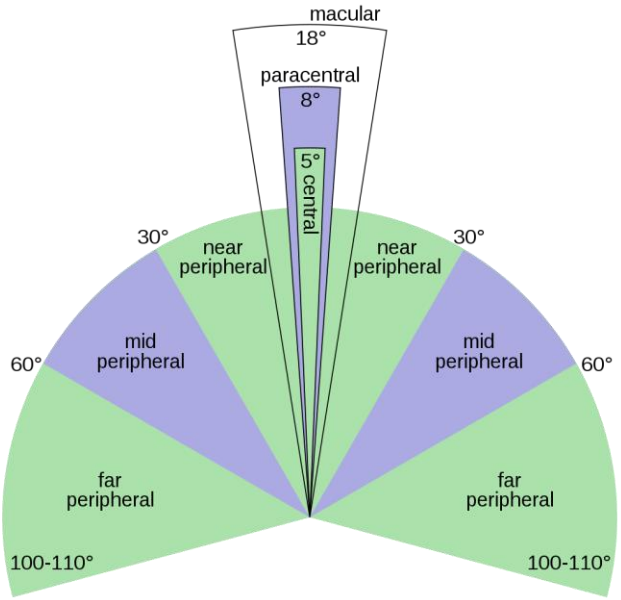


FIGURE 4.15: HORIZONTAL VISUAL BOUNDARIES IN HUMAN FIELD OF VISION (WIKIMEDIA COMMONS, 2014)

All ranges are chosen so that the range falls fully within the field of vision to which it is linked. The ranges are further simplified to be more easy to read and understandable for any members of the local population that might want to look at the results. This contributes to **universality**.

By separating the visibility angles into severity ranges it is possible to visually represent the visual impact of surface mining operations in a heat map. In the heat map, the visual severity ranges are given colours to represent the severity from low to high. By doing so, the most impacted areas can be shown visually. Furthermore, it is also possible to visual show which areas are not visually impacted by the surface mining operation. The severity ranges give a simplified numerical value to the visual impact which allows for calculations to be computed on the horizontal and vertical visibility angle value.

4.7.7 Combined Visibility Factor

As was described before, the combined visibility factor is the transformation of the 1-dimensional visibility angle to a 2-dimensional visibility factor. By multiplying the horizontal and vertical severity range with one another, the combined visibility factor is found.

With this combined visibility factor, the visual impact of the surface mine is determined for all observerpoints in the landscape. With this, the spatial factor value of the surface mine is known for every 10-by-10-meter square on the DEM and thus the landscape. Similarly, as with the vertical and horizontal visibility angle, a heat map of visual impact can be created for the entire landscape around the surface mine.

4.8 Chromatic Difference

As was explained before, half of the perceived visual impact of surface mines is determined by the chromatic difference between the ore and overburden and the surrounding landscape. In order to determine the chromatic difference, this study will utilize the Euclidean distance between two colours in a chosen colourspace.

The chosen colourspace in this study is the CIELAB colourspace. The CIELAB colourspace is widely used in industrial settings to estimate the perceived chromatic difference between two colours (Bishop, 1997). CIELAB was defined by the international commission of illumination (CIE) to serve as a tool which can approximate human vision in terms of colour. CIELAB expresses colour using three values (Hoffmann, 2003):

TABLE 4.4: CIELAB VALUES

Value	Characteristic	Value	
L*	Lightness	0 (black)	100 (white)
a*		- (green)	+ (red)
b*		- (blue)	+ (yellow)

The colourspace was defined with the following principle in mind:

"The same amount of numerical change in these values corresponds to roughly the same amount of visually perceived change."

CIELAB is a suitable tool for the purpose of this study as the tool is copyrighted but fully licence-free. This contributes to the universally availability of the tool. It is possible to determine the chromatic difference between two colours in the CIELAB colourspace by taking the Euclidean Distance between the two colours plotted in the colourspace.

Jain and Anil (1989) explain that the relative perceptual difference between any two colours in L*a*b* space can be approximated by treating each colour as a point in a three-dimensional space and taking the Euclidean Distance between them.

Meaning, if two colours are known, namely the colour of the overburden and ore and the colour of the surrounding landscape, the chromatic difference can be determined. Thus, the colour of the overburden, ore and landscape must be determined in order to define the chromatic difference.

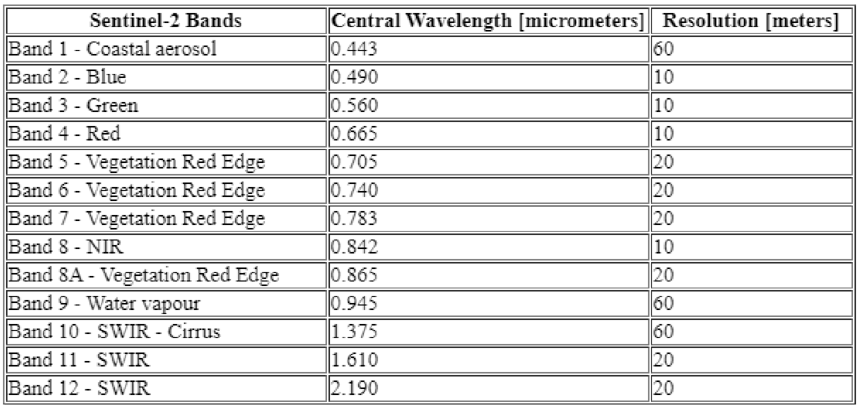
This tool allows for several methods of acquiring the colour values of the landscape. In this study it is advised to use satellite images to extract the colour value. Satellite images are extracted as RGB bands and can very easily be translated into the CIELAB colour model. It is also possible to take images on site with a photo camera. If the overburden or ore colour is not available to be extracted, it is possible to look at mines with similar ore and overburden compositions in order to extract the correct colour value.

The satellite image must always contain less than 10% cloud cover. This must be done to ensure sufficient visibility of the landscape. The satellite image must have been taken in the summer months to represent the maximum contrast scenario. March until and including August for the northern hemisphere and September until and including February for the southern hemisphere. The image must be cut to a suitable size.

Depending on the location of the surface quarry, a different source of satellite image must be chosen. In Europe, the satellite images recommended are sentinel-2 satellite images. Sentinel-2 images are acquired by multispectral satellites developed by the European Space Agency (ESA) for the Copernicus land monitoring services (Congedo, 2016). The accuracy of the images is important, the higher the accuracy, the more accurate the results will be. Sentinel-2 images have RGB-bands with a resolution of 10 meters. Sentinel-2 provides the best resolution free satellite images available. This enables users to access the data for free, which ensures the tool remains an easily accessible and **universal** tool.

If satellite images with a better resolution can be acquired elsewhere in the world, then those images are also suitable for the tool. However, when two results are compared against one another, the datasets must be the same. This ensures **comparability** of the results.

TABLE 4.5: SENTINEL-2 BANDS WAVELENGTH AND RESOLUTION (ESA, 2015)



Sentinel-2 Bands	Central Wavelength [micrometers]	Resolution [meters]
Band 1 - Coastal aerosol	0.443	60
Band 2 - Blue	0.490	10
Band 3 - Green	0.560	10
Band 4 - Red	0.665	10
Band 5 - Vegetation Red Edge	0.705	20
Band 6 - Vegetation Red Edge	0.740	20
Band 7 - Vegetation Red Edge	0.783	20
Band 8 - NIR	0.842	10
Band 8A - Vegetation Red Edge	0.865	20
Band 9 - Water vapour	0.945	60
Band 10 - SWIR - Cirrus	1.375	60
Band 11 - SWIR	1.610	20
Band 12 - SWIR	2.190	20

Images from summer or spring are used as spring and summer are deemed worst-case scenario situations. With vegetation in bloom, the surrounding landscape will have a larger chromatic difference with the ore and overburden than in autumn and winter, when soil is exposed. If the analysis is made for an surface mine operation which is located in countries with long periods of snowfall, this could be added to the analysis. The report should always mention the date of acquisition of the images. It is possible to use images from spring or summer due to the availability of satellite images. In the case of photographs, the VIA professional would have to wait until the right season to be able to take images.

It is possible to use different methods of acquiring the initial information from the RGB bands. However, in order to be able to compare the different scenarios, the acquiring method should be the same. It should always be mentioned in the report which acquiring method is used.

Some satellite images can be acquired for free in QGIS using the semi-automatic classification plugin. After acquiring the most recent satellite image, the colour value for the overburden and ore and the surrounding landscape must be extracted. A random selection of 10 points must be taken in QGIS (random point tool) in the ore and overburden zone and the surrounding landscape. From these points, the RGB band values can be extracted.

Using the RGB band values for each set of ten points, the average RGB value can be found for both the overburden and ore and the landscape. Once the average RGB band value are known they can be converted to CIELAB colour model using an online translator or with CIELAB matrix calculations. With the L*, a* and b* values are known, it is possible to calculate the Euclidean distance between the two colours (Hoffmann, 2003).

The Euclidean distance in the CIELAB colourspace can be calculated with the following formula (McLaren, 2008):

$$\Delta E_{ab}^{*} = \sqrt{(L_2^{*} - L_1^{*})^2 + (a_2^{*} - a_1^{*})^2 + (b_2^{*} - b_1^{*})^2}$$

The answer of the equation is a value between 0 (for two colours which are the same) and 375 (for two colours that are exactly opposite). A Euclidean distance of 2.3 corresponds to a JND (Just noticeable difference). A just noticeable difference is the minimum amount by which stimulus intensity must be changed in order to produce a noticeable variation in sensory experience (USD Internet Sensation & Perception Laboratory, 2020). In order to achieve the total result of the analysis, the visibility factor, and the chromatic difference must be multiplied with one another.

First, the chromatic difference value is adjusted to human perception. As a Euclidean distance of 2.3 equates to a just noticeable distance, the total Euclidean distance is divided by the JND.

$$Chromatic\ Factor\ Value = \Delta E_{ab}^{*} \ / \ 2.3$$

With the chromatic factor value known, the total physical factor score can be determined. As Dentoni and Massacci (2008) had determined, the chromatic difference and the visual spatial difference of the operation are equal parts as impactful for the visual impact on the receptor.

For every 10-by-10-meter pixel the chromatic difference and the visual spatial difference is multiplied against one another. The following formula is used:

$$Physical\ Factor\ Value = Spatial\ Factor\ Value * Chromatic\ Factor\ Value$$

With this value, the physical change impact in the landscape is known for every 10-by-10-meter pixel on the landscape.

4.9 Perception

With the steps taken in the previous subchapter, the physical aspect of the visual impact has been determined. This covers the factor aspect of the quantification of the visual impact. A closer look will now be taken at the perception side of the quantification of the visual impact, the filters.

Filters are defined as the subjective perception of the physical aspect of the visual impact. The filters are meant to give additional weight to the factors by multiplying the physical factors with a value which represents the way people perceive the factors.

The filters are based on the setting in which the observer is viewing the surface mine. Any location at which humans are present is a setting in which the observer is viewing the operation. The study will outline two methods which can be used to acquire the filters. Similarly, as with the physical factors, both methods can be used, however, to compare scenarios the same method must be used.

In both methods, the basic principle is the same. The filter serves as a multiplication component of the physical factors. Areas must be identified in which the receptors are viewing the surface mine for a longer duration or on a constant basis. The two methods will now be described.

4.9.1 Image Classification Method

One of the methods is based on image classification of remote sensing images. Using techniques and technologies developed in the remote sensing science, it is possible to use satellite images to classify the class of land use of the landscape.

GISGeography (2020) describes classification in remote sensing as the process of assigning land cover classes to pixels. For example, classes include water, urban, forest, agriculture and grassland. The goal of the filter analysis is to identify areas which will be occupied by human beings, like roads, buildings and other population centres. Classification in remote sensing will be utilized to identify pixels in satellite images in which the land use class is urban.

There are three classification styles currently available in remote sensing:

- Unsupervised image classification
- Supervised image classification
- Object-based image classification

Unsupervised image classification generates pixel clusters based on similar spectral signatures in the image inserted into the classification tool. These clusters are generated by the tool itself without any input from the user. These clusters are then classified into the different landcover macro classes automatically, without input from the user (Olaode, et al., 2014).

Supervised image classification requires the user to first select training samples, manually selected pixel clusters based on known areas of built-up, vegetation or any of the other landcover classes. These training samples are manually classified into the landcover macro classes. The algorithm then generates pixel clusters based on similar spectral signatures, and links these to the manually classified macro classes (Olaode, et al., 2014).

Object-based image classification utilizes an algorithm to segment pixels into distinct objects GISGeography (2020). The image imported into the classification tool must be high resolution and quality for the analysis to work.

In this study, the supervised image classification method was utilized to classify land use, however it is possible to use either of these three methods. If another method or tool is used in the analysis, it must be stated in the report. It is only possible to compare different scenarios if they have been classified using the same classification method.

The unsupervised classification method seems it would be most suitable for this thesis, as it is unsupervised and therefore relies solely on the numerical information in the data. This would serve the **objectivity** requirement well. However, supervised classification is regarded as far more accurate than unsupervised classification, especially when poor quality (free) satellite images are used.

Supervised image classification is chosen as it is possible for the user to collect that data with which the computer algorithm trains its classification to classify the image. This allows the user to change the input data if the previous input data was not sufficient enough to reach the desired level of accuracy. The unsupervised image classification method does not give this option. The supervised classification method is more accurate because the user is able to guide the algorithm in the correct direction. However, the accuracy of the supervised classification method is highly dependent on the user's skill and the quality of the image. To ensure the accuracy of the results, an accuracy test is conducted at the end of the analysis. This accuracy requirement allows for the classification method to meet the **objectivity**, **repeatability** and **comparability** requirement.

Object-based image classification works by segmenting the image into distinct objects or features and subsequently classifying these objects and features. However, this method does not work well in low resolution images like the free, open-source satellite images which are used in this thesis. Therefore, object based image classification is not used.

The chosen method, supervised image classification, has three steps. The process steps are:

1. Create training set
2. Develop signature file
3. Classify image

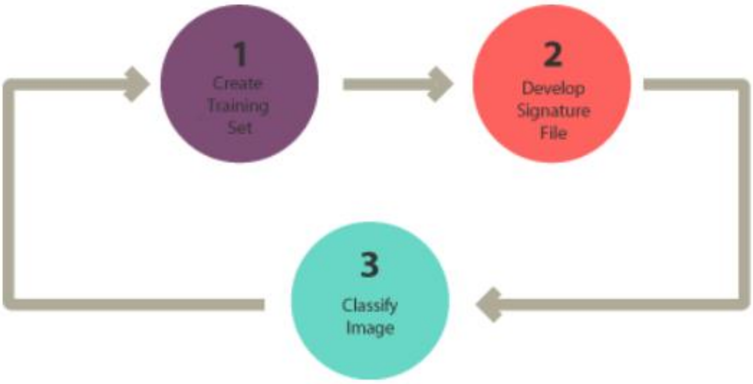


FIGURE 4.16: THE THREE STEPS OF SUPERVISED IMAGE CLASSIFICATION (GISGEOGRAPHY, 2020)

In supervised image classification, pixels are selected as training samples in a satellite image, this training sample is then manually assigned and marked with a class. The spectral signature of these pixels is recorded as the manually assigned class. This process must be repeated for every class, with multiple clusters per class. These training samples are saved into a training file. The training file stores all the spectral signatures and the assigned classes in one file. This training file will then be used to run a classification. The classification can be run with several different classification algorithms, for example:

- Maximum Likelihood
- Minimum distance
- Principal components
- Support Vector Machine
- Iso cluster

The classification process will use the training file containing the training samples in order to determine the land use class for each pixel in the satellite image. It is possible to use either of these classification algorithms, however, the classification algorithm used must be documented in the report. If two scenarios are compared against one another, the same classification algorithm must be used for an accurate result.

In this study, the classification analysis is made with the Semi-Automatic Classification Plugin (SAC plugin) on QGIS (Congedo, 2016). The SAC plugin is a free to use, open source software in QGIS which can be used to classify land use in satellite imaging. The plugin is universally accessible and enables the user to download up-to-date satellite images of the entire globe, therefore it is possible to use this plugin on any location in the world. The semi-automatic classification plugin has a built-in function with which it is possible to download sentinel-2 satellite images. The sentinel-2 images are downloaded, cut to the canvas size used in the analysis and represented in QGIS as a *true-colour image*. This is done by sorting the bands in the order of 432. This image is used to create the training samples, step one of the classification process. The SAC plugin using manual selection to create training samples, or ROIs (regions of interest) and assignment of class of these ROIs. The user selects multiple sets of pixels which are then manually classified as a *macro class*. The macro classes can for example be:

- Water
- Urban
- Vegetation
- Quarries and mines

The training samples will record the spectral signature of these pixels and record the manually assigned class to the pixel. These training samples will then be grouped and saved into a training file, which is then used to conduct the classification process. In this study, it was found that the maximum likelihood classification algorithm achieved the best results for the analysis. Therefore, the Maximum likelihood algorithm will be explained in this study.

The maximum likelihood algorithm calculates the probability distributions for the classes. The algorithm estimates the probability of spectral signature of a pixel belonging to one of the previously assigned land cover classes (Congedo, 2016).

The SAC plugin uses the discriminate function, described by Richard and Jia (2012), to calculate the probability of a spectral signature to belong to a class with the following function:

$$g_k(x) = \ln p(C_k) - \frac{1}{2} ln|\Sigma_k| - \frac{1}{2}(x - y_k)^t * \Sigma_k^{-1} * (x - y_k)$$

$C_k = land\ cover\ class\ \boldsymbol{k}$
$x = spectral\ signature\ vector\ of\ an\ image\ pixel$
$p(C_k) = probability\ that\ the\ correct\ class\ is\ C_k$
$|\Sigma_{\boldsymbol{k}}| = determinant\ of\ the\ covariance\ matrix\ of\ the\ data\ in\ class\ C_k$
$\Sigma_k^{-1} = invserse\ of\ the\ covariance\ matrix$
$y_k = spectral\ signature\ vector\ of\ class\ k$

Therefore:

$$x \in C_k \Leftrightarrow g_k(x) > g_j(x) \forall k \neq j$$

With this formula, the class can be determined for each pixel. The class probability function with the highest value at the spectral signature vector of an image pixel is determined to be the class assigned to the pixel.

In the following image this process is shown. The two values, X1 and X2, are determined to be inside the $g_a(x)$ and $g_b(x)$ spectral signature respectively.

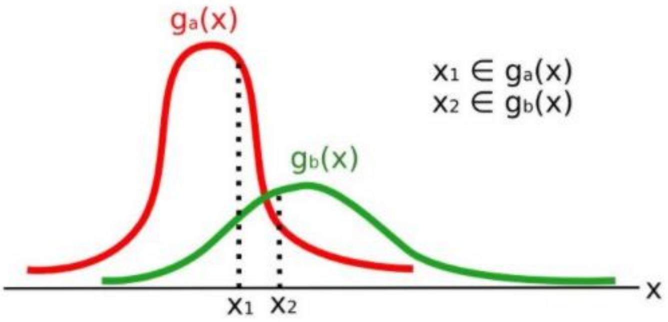


FIGURE 4.17: MAXIMUM LIKELIHOOD PROBABILITY FUNCTION OF THE CLASSES (CONGEDO, 2016)

The algorithm determines, for every separate pixel, the spectral signature value. This value is shown on the x-axis and described with the value “x1” and “x2”. Each pixel (x1 and x2) will be assigned a classification. The classification is assigned based on the $g_k(x)$ formula. This formula describes the probability of a spectral signature falling into the class associated with the $g_k(x)$ formula. In the example above, x1 falls into the $g_a(x)$ classification, as the probability of “a” is larger than the probability of “b” at the spectral signature of “x1”. The computer algorithm will classify the appropriate class for each distinct pixel on the canvas.

In order to guarantee accuracy of the results, an accuracy assessment must be conducted. The SAC plugin recommends a method to assign accuracy to the results. This method will be described in this study. It is possible to use other accuracy assessment methods, however, in order to be able to compare two scenarios, the accuracy method assessment must be the same for both scenarios.

The accuracy assessment consists of four steps. The process steps are:

1. Determine the number of pixels per class necessary for the accuracy analysis.
2. Randomly select the number of pixels in the canvas.
3. Manually assess the class of the selected pixels.
4. Calculate the accuracy result.

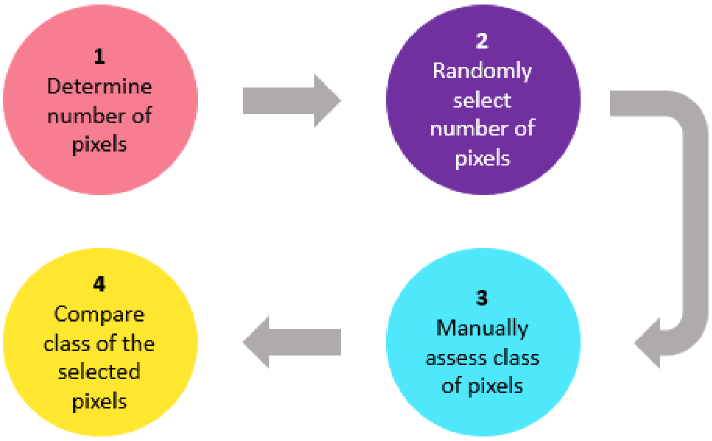


FIGURE 4.18: THE FOUR STEPS OF THE ACCURACY ASSESSMENT

The analysis works by selecting a specific amount of randomly chosen pixels per class. Thereafter manually checking the real-life class of the pixels. The assigned class of the pixel must then be compared to the manually checked real-life class. From the total number of pixels, the overall accuracy can be assessed.

In order to find the necessary number of pixels per class to be selected, the SAC plugin recommends using the formula of Olofsson et al (2014).

The formula developed by Olofsson et al (2014) was developed as a step of a “good practice” recommendation for assessing the accuracy of land change. This good practice recommends three components, namely, sampling design, response design and analysis. The formula is part of the sampling design step of the good practice guidance developed by Olofsson et al. (source).

Olofsson et al have established a protocol for selecting the subset of special units that will form the basis of the accuracy assessment. The formula to determine the number of samples necessary to assess the accuracy of landcover classification is described as:

$$N = (\Sigma_{i=1}(Wi * Si)/So)^2$$

$Wi = mapped\ area\ proportion\ of\ macro\ class\ i$
$Si = standard\ deviation\ of\ macro\ class\ i$
$So = expected\ standard\ deviation\ of\ overall\ accuracy$
$c = total\ number\ of\ classes$

Si and So are being assumed. Olofsson et al (2014) set a target standard error for overall accuracy of 0.01, therefore S_o is assumed to be 0.01. From past studies it is was possible to determine the error of the specific macro class (Olofsson et al, 2011). The errors of the specific macro classes are shown in a table below:

TABLE 4.6: STANDARD DEVIATION OF STRATUM CLASSES

Macro class Name	**Class ID**	**S_i (standard deviation)**
Water	1	0.5
Vegetation	2	0.2
Built-up	3	0.45
Soil	4	0.4

Once the total number of pixels is calculated, the number of pixels per class can be determined. The number of pixels per class can be determined by using the mean of the equal distribution and weighted distribution of the landcover class.

The weighted distribution is calculated by taking the percentage of assigned landcover class on the canvas times the total number of sample pixels to be selected. The equal distribution is merely the total number of sample pixels divided by the total classes present.

Following this selection, the required number of pixels and pixel class must be selected from the canvas. These sample pixels are then manually checked for the real-life landcover class.

Following this analysis, a comparison is made between the assigned class by the algorithm, and the manually checked class. Following this analysis, the error matrix shows which classes are being confused in the classifications.

The total accuracy, of all pixels, must be more than 85% for the classification to be accepted for this study. The accuracy of the Urban class must be at least 80% for the classification to be accepted. If the analysis is not accepted, it must be done again.

When the classification is accepted, the land cover raster is transformed into a vector file in QGIS. Every class except for the urban class is removed from the canvas. As we are only interested in the urban areas in which humans can perceive the surface mine. The pixels which are classified as urban, are given a value of 10 and are multiplied with the physical factor score.

TABLE 4.7: CLASSIFICATION URBAN PERCEPTION FILTER VALUE

Element	Description	Value
Urban	Urban area, roads, buildings, population centres	10

This results in a value for each 10-by-10-meter pixel, the pixel will have a physical factor value, which will then be multiplied with the perception filter value. Resulting in a total pixel value.

$$Pixel\ Value = Physical\ Factor\ Value * Perception\ Filter\ Value$$

4.9.2 Cadastre analysis

While the landcover classification method is widely used in remote sensing and is regarded as a very accurate method of assessing where urban areas are located, this study also looks at a second method to find the filter component. The second method relies on online, freely accessible cadastre data, supplied by most governments of developed countries. Most governments in developed countries offer digital data on the locations of buildings and roads. If this data is available, it should be used instead of the landcover classification method. However, if the goal is to compare scenarios and only one scenario has cadastre data available and only the landcover classification can be used. Depending on how detailed the data available is, a specific value can be added to the data files. An example can be:

TABLE 4.8: EXAMPLE OF CADASTRE VALUES

Element	Description	Value
Minor Roads	Local, destination roads and foot and cycling paths	2
Major Roads	Regional, main roads	5
Buildings	Homes, offices, shops and other urban infrastructure	10

Every 10-by-10-meter pixel on the landscape which contains one or more of these cadastre elements will have its physical factor multiplied with the perception filter value.

4.10 Landscape and Visual Analysis Value

In this chapter, all the necessary steps and processes to determine the quantifying data to assess the visual impact of surface mines has been described. To achieve a total value, with which different scenarios can be compared, these values must be combined. Firstly, a summary of the known data will be given:

TABLE 4.9: QUANTIFYING DATA ANALYSIS RESULTS

Physical Quantifying Component	**Value (min – max)**	**Description**
Vertical Visibility Angle	0 – 3+ degrees	Vertical angle taken up in the visual field of the observer
Horizontal Visibility Angle	0 – 50+ degrees	Horizontal angle taken up in the visual field of the observer
Vertical Visibility Severity	1 – 4	Vertical severity determined from the vertical visibility angle
Horizontal Visibility Severity	1 – 5	Horizontal severity determined from the horizontal visibility angle
Visibility Combined	0 – 20	Two-dimensional combined visibility factor determined from the one-dimensional visibility angles
Chromatic difference	0 – 375	The Euclidean distance between the average colour of the landscape and the ore and overburden visible in the surface mine
Perception Quantifying Component (Option 1 or 2)	**Value**	**Description**
(1) Classification in remote sensing	1 – 10	Multiplication value of 10-by-10-meter pixels
(2) Cadastre identification	1 – 10	Multiplication value of 10-by-10-meter pixels

The above shown components are, after the analysis, known for each 10-by-10-meter pixel on the canvas. In this chapter, the formula for combining these factors and filters together will lead to a total visual impact value for each 10-by-10-meter pixel. The physical quantifying components must be combined first in order to calculate the visual impact value. The combined physical quantifying components was determined for every 10-by-10-meter pixel with the following formula:

$$Combined\ Physical\ Quantifying\ Components = \left((VVS * HVS) * CD\right)$$

$VVS = Vertical\ Visibility\ Severity$
$HVS = Horizontal\ Visibility\ Severity$
$CD = Chromatic\ Difference$

With the physical factor known, the visual impact value for every 10-by-10-meter pixel can be calculated with the following formula:

$$Visual\ Impact\ Value = Physical\ Factor * Perception\ Filter$$

$Physical\ Factor = Combined\ Physical\ Quantifying\ Components$
$Perception\ Factor = Perception\ Quantifying\ Component$

With this calculation, the visual impact value of every pixel on the canvas was determined. As a result the value of every 10-by-10-meter pixel is known for the entire canvas of the study, these values can be added together to combine into the Total Visual Impact Value. The total visual impact value describes the total visual impact which the surface mine has on the entire canvas or chosen analysis area. With this total visual impact value, different scenarios can be compared to one another.

As was described earlier in this chapter, in order to compare different scenarios to one another, there are two requirements which need to be met. The first requirement is the canvas size requirement. This study sets two options to meet the criteria for the canvas size requirement. The two options for the canvas size requirements are the following:

(1) A minimum of a 4-kilometre radius, squared into a rectangle, around the centre point of the surface mine.
(2) The total area visually affected by the surface mine, determined in the ZTV analysis.

In order to compare two different scenarios to one another, the canvas size of both scenarios should fall into one of the following categories:

TABLE 4.10: CANVAS SIZE AND ZTV REQUIREMENTS

Canvas 1		Canvas 2		Accepted (Y/N)
Requirement met	Size	Requirement met	Size	
Total ZTV-analysis		Total ZTV-Analysis		Y
Total ZTV-analysis	< 4-kilometer radius	4-kilometer radius		Y
Total ZTV-analysis	> 4-kilometer radius	4-kilometer radius		N
4-kilometer radius	Same size	4-kilometer radius	Same size	Y
4-kilometer radius	Smaller	4-kilometer radius	Larger	N

In the case of the third row, with canvas 1 meeting the requirement of the total ZTV-analysis and being larger than the 4-kilometer radius squared, and canvas 2 meeting the requirement of the 4-kilometer radius squared but not the ZTV-analysis requirement. The analysis cannot be accepted because of the canvas size requirement. It is impossible to normalize the canvas extent to meet the canvas size requirement. In this case, canvas number 2 must be adjusted to encompass the total ZTV area.

In the case of the fifth row, with canvas 1 and 2 both not meeting the ZTV-analysis requirement and being of different size, the analysis cannot be accepted because of the canvas size requirement. It is, however, possible to normalize the results to meet the canvas requirement. The canvas size of both options will be normalized to the 4-kilometer radius squared size. This size is 8 * 8 kilometre: 64 km^2.

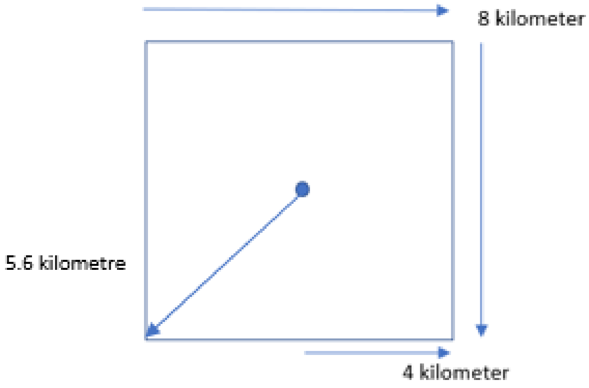


FIGURE 4.19: STANDARD CANVAS SIZE

The diagonal length of the square from the centre to the corner is 5.6 kilometres. By normalizing the area of the two canvas sizes to the standard canvas size, it is possible to compare the two canvas scenarios. The normalization formula for each canvas is:

$$Visual\ Impact\ Value = normalized\ Total\ Visual\ Impact\ Value * (100\ /\ (\frac{Scenario\ Canvas\ Size}{Standard\ Canvas\ Size})$$

By normalizing both canvases, the Visual Impact Value can be compared.

The second requirement to be met is in relation to the accuracy of the analysis. Each scenario has a different accuracy rating due to the number of points used. The accuracy of the scenario has already been calculated in the horizontal visibility angle analysis and is expressed in the form of a percentage figure. This percentage figure can be used to normalize the visual impact value.

$$Normalized\ accuracy\ Impact\ Value = Visual\ Impact\ Value * (100\ /\ Accuracy)$$

By normalizing the results for the canvas size and the accuracy of the scenario, the total visual impact value is found. However, are mining companies and the general public interested in the total visual impact value? This study makes a distinction between two different visual impact values.

TABLE 4.11: VISUAL IMPACT VALUE CATEGORIES

Visual Impact Values Categories	**Description**
Total Visual Impact Value	Complete value for the entire canvas
Roads and Buildings Visual Impact Value	A value only for the pixels containing infrastructure in which observers often spend time
Normalized Total Visual Impact Value	Normalized complete value for the entire canvas
Normalized Roads and Buildings Visual Impact Value	Normalized value only for the pixels containing infrastructure in which observers often spend time

The Normalized Roads and Buildings Visual Impact Value will mainly be used to compare different surface mine scenario between one another. With this value, it will be clear which surface mine scenario has the largest visual impact on the areas in which humans are mostly found.

With the Normalized Roads and Buildings Visual Impact Value, it is possible to compare the impact between two scenarios. This value will now be called the **v**isual **i**mpact **s**core. The result will be shown in a percentage value which shows how much less impactful one scenario is compared to the other.

$$Impact\ Difference\ (\%) = 100 - (\left(\frac{Lowest\ Visual\ Impact\ Score}{Highest\ Visual\ Impact\ Score}\right) * 100)$$

With the impact difference, a quantified, objectively found value is found which describes the visual impact value between two scenarios.

4.11 Economic impact

With the difference in visual impact known, a better understanding of the visual impact of the scenarios exists. This information is vital for mining companies and the general public to ensure a balance between increasing profitability of surface mines and reducing the visual impact on local communities. In order to establish this balance, the economic impact of the scenarios must also be assessed. While a very low visual impact increases the chances of acquiring permitting and licenses, the profitability of the scenario might not suit the needs of the company and vice versa.

4.12 Additional Options

This study utilizes a digital terrain model as the digital elevation model. Digital terrain models only model the terrain and do not incorporate buildings, infrastructure and vegetation. This means that the analysis is a worst-case scenario analysis. It is possible that infrastructure and vegetation forms a natural barrier between the open cast mine and the observer. In order to increase the accuracy of the assessment, it is possible to model large areas of trees on the landscape in the digital elevation model, by inserting shapes in modelling software like SURPAC and DATAMINE.

It is also possible to analyse strategically placed mitigation, to form an artificial barrier between the observer and the surface mine. The mitigation berms or treelines can be modelled in modelling software like SURPAC and DATAMINE in order to assess the changes in visual impact when artificial mitigation is installed.

5 Case Study

The tool developed in this study is used to assess and compare the visual impact of four pitshell scenarios for the company Lhoist. Lhoist is planning to increase reserves at the Wartet quarry at Marche-les-Dames. The quarry currently at operation at Marche-les-Dames has around 20 years of life of mine left. During this time, the plan is to acquire the required permitting, plan and design the extension and start the ramp-up phase to ensure continued operations at Marche-les-Dames.

Wartet quarry extracts dolomitic limestone for kiln firing at 3 million tons a year. The limestone is not used for aggregates, but for the steel industry, glass production, the chemical industry, agricultural applications and more. The quarry has been in operation since 1937 at varying levels of extraction. The quarry moves ore by waterway to processing plants in the surrounding areas. The quarry is located in Walloon, Belgium, with many villages in the surrounding area. The villages all have a population of less than 1,000 inhabitants, expect for Andenne, which lies 7.6 kilometers in easterly direction, which has 24,055 inhabitants.

One of the main problems which were identified by the Lhoist mine development team is the visual impact which the quarry will have on the surrounding landscape. The local population has shown hostility and apprehension towards expanding the mining operations in the area due to the visual impact which the expansion will have. In order to find a balance between the economic gain and the visual impact of the mining operations, the tool developed during this study will be conducted on this case study at Marches-les-Dames. An initial study has been conducted by the mine development team at Lhoist. This study was based on the zoning plan at the site and any visually interesting zoning areas.

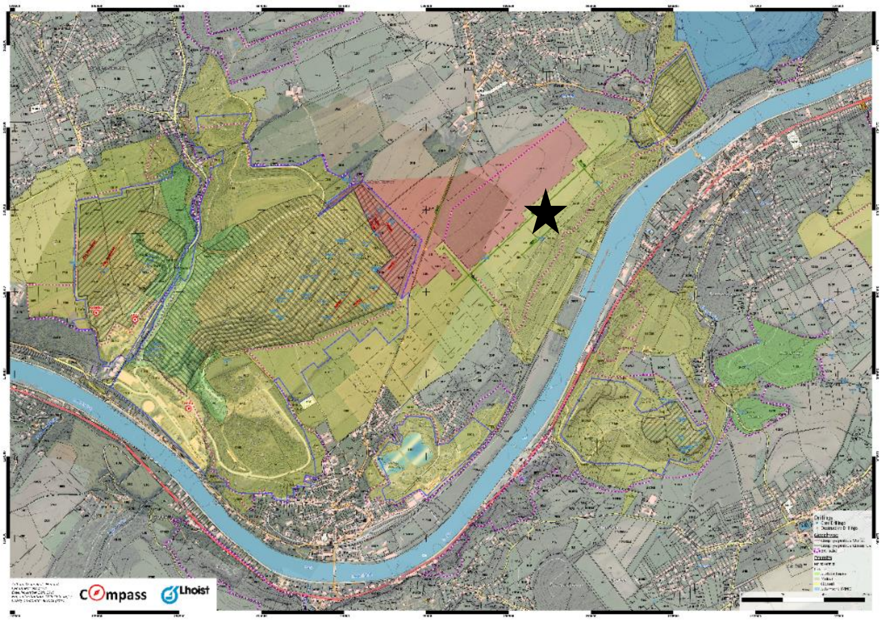


FIGURE 5.1: ZONING PLAN AT MARCHE-LES-DAMES

The red-white dashed lines denotes the land designated for extraction. The land marked with a black star is called Gevrinne. The red shade denotes land which is owned by a local farmer and will cost Lhoist an additional amount of money to extract. The diagonal lines show land already quarried by Lhoist.

From this study, two possibilities of increase mineral reserves are determined, these are:

1. Expanding the quarry currently in operation at Wartet.
2. Extending the existing quarry into a Greenfield at Gevrinne.

In order to fairly compare the possibilities, the expansion and the Greenfield option will have similar economic value. The pit design is conducted with the aim to create two pits with equal amount of mineral reserve. This economic value will be based on the reserve increase. From the analysis of the zoning plan and visually interesting zones, three planning boundaries are designed for three pitshell scenarios.

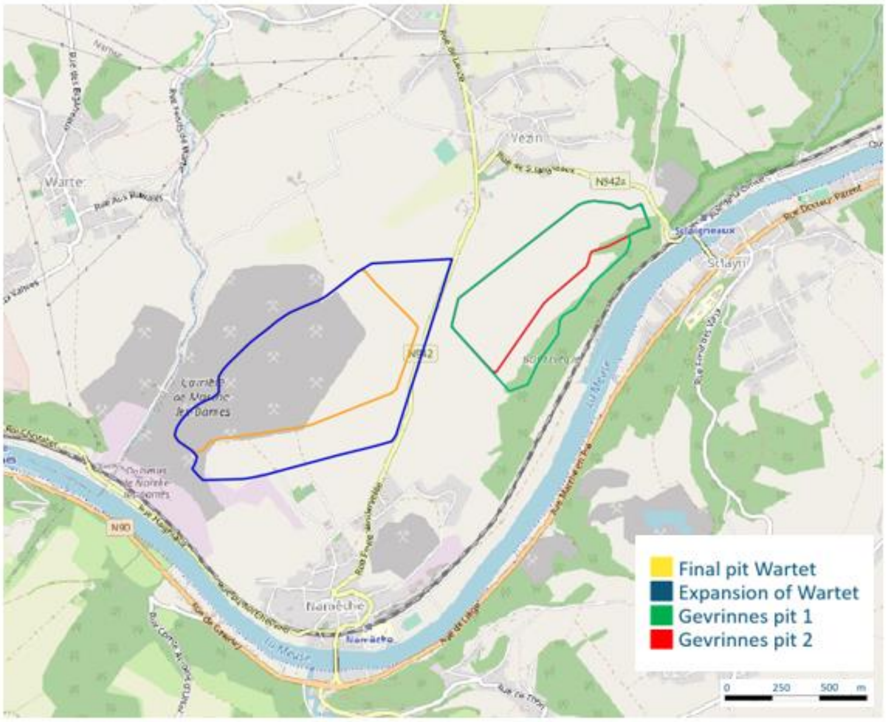


FIGURE 5.2: PLANNING BOUNDARIES

As is shown in the image, there is one planning boundary scenario (blue) which functions as an expansion of the quarry currently in operation at Wartet. The quarry will extend beyond the current planning boundary on the northern, eastern and southern side. The expansion extends on the faces which are currently still being worked on, with the western face of the quarry being used as waste material tip.

A mirror scenario is planned at the greenfield site of Gevrinne. This mirror scenario contains the same amount of chemical ore as the expansion scenario at Wartet. Making it possible to compare the visual impact between an equal reserve increase either as an expansion of the current operations or a greenfield operation.

A second pitshell scenario is designed at Gevrinne with a decreased amount of chemical ore reserves. This option will be compared to the first pitshell scenario at Gevrinne to compare the visual impact between a larger and a smaller quarry.

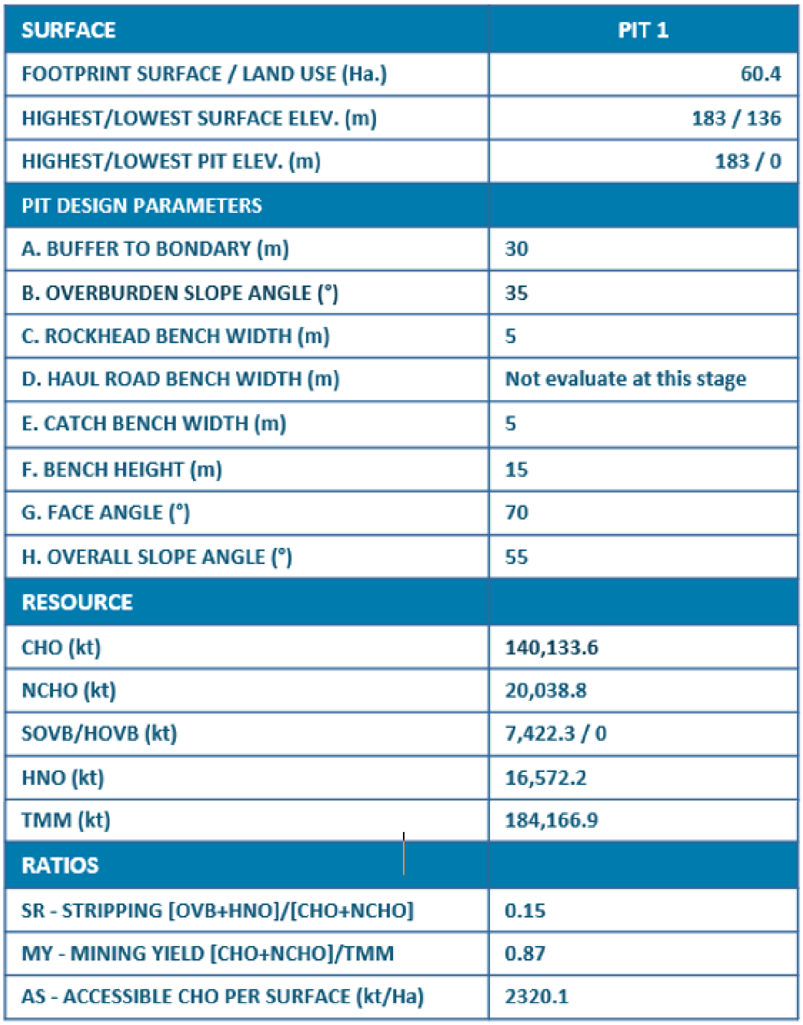
The pitshells were designed during this study and will serve as a case study to test the effectiveness of the tool developed in this study. As this case study example is in the pre-feasibility phase of development, the pitshells were designed with few details like ramp-infrastructure and sequencing.

The pitshell designs were based on geotechnical research done on site by the Lhoist mine planning and geology team.

5.1 Pitshell description

The pitshell scenarios are designed based on the geotechnical study conducted by the Lhoist mine planning and geology team and the previously assigned outer boundary lines. The following tables and figures show the properties of the pitshell scenarios.

TABLE 5.1: PITSHELL SCENARIO 1 (GEVRINNE 1)



SURFACE	PIT 1
FOOTPRINT SURFACE / LAND USE (Ha.)	60.4
HIGHEST/LOWEST SURFACE ELEV. (m)	183 / 136
HIGHEST/LOWEST PIT ELEV. (m)	183 / 0
PIT DESIGN PARAMETERS	
A. BUFFER TO BONDARY (m)	30
B. OVERBURDEN SLOPE ANGLE (°)	35
C. ROCKHEAD BENCH WIDTH (m)	5
D. HAUL ROAD BENCH WIDTH (m)	Not evaluate at this stage
E. CATCH BENCH WIDTH (m)	5
F. BENCH HEIGHT (m)	15
G. FACE ANGLE (°)	70
H. OVERALL SLOPE ANGLE (°)	55
RESOURCE	
CHO (kt)	140,133.6
NCHO (kt)	20,038.8
SOVB/HOVB (kt)	7,422.3 / 0
HNO (kt)	16,572.2
TMM (kt)	184,166.9
RATIOS	
SR - STRIPPING [OVB+HNO]/[CHO+NCHO]	0.15
MY - MINING YIELD [CHO+NCHO]/TMM	0.87
AS - ACCESSIBLE CHO PER SURFACE (kt/Ha)	2320.1

The resource tab describes the classification of the material inside the designed pitshell scenario. The resource classifications are separated into different categories. All categories are reported on in kilotons. The first resource classification is chemical ore (CHO) and is defined as limestone ore which can be processed in a limekiln. This is the high value and main ore type that Lhoist wants to extract. The second class of resource is non-chemical ore (NCHO). This is limestone which cannot be profitably processed in a limekiln, but can be sold as aggregate. This is a by-product that Lhoist would prefer not to extract, but can sell if necessary.

The third class is overburden and is considered waste which must be removed to reach the ore. The class is divided into soft overburden (SOVB) and hard overburden (HOVB). The forth class is additional waste found in-situ. The class is hard non-ore (HNO) and sterilises some CHO at lower datum.

The fifth class is the total material moved (TMM) in the entire designed pitshell. This includes all ore, non-ore and waste.

The Ratios tab of the table gives information about the ore to non-ore ratio and other various ratios relating to the designed pitshell. The stripping ratio (SR) describes the relation between the overburden and the chemical and non-chemical ore which can be extracted after removing said overburden. The lower the stripping ratio, the better accessible the ore is.

The mining yield (MY) calculation describes the yield of ore compared to the total mass moved in the designed pitshell. The higher this number, the more ore can be extracted compared to the total material inside the pitshell.

The last ratio is the accessible ore per surface area (AS). The total kt of ore is divided by the total hectares that the pitshell covers on the surface. The higher this number, the more ore can be accessed per hectare and thus have a smaller footprint on the surface.

Pitshell scenario 1 at Gevrinne consists of 60.4 hectares of land use in order to mine 140 Mt of Chemical Ore. The pitshell is designed based on a surface boundary outline, which was based on the zoning plan in which approval for mineral extraction has already been granted.

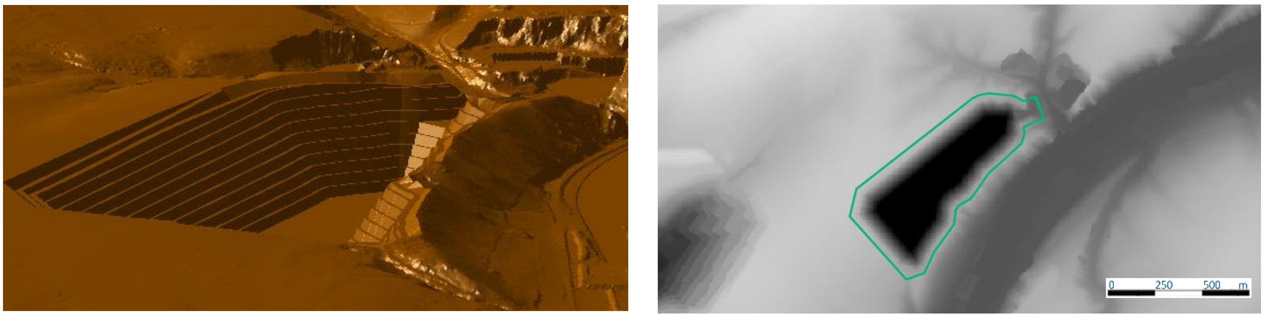


FIGURE 5.3: DTM PITSHELL SCENARIO 1 AT GEVRINNE

Pitshell scenario 1 is regarded as the largest possible pit which can be created at Gevrinne due to the available planning permission and mineral rights in the area. However, as this pitshell is the largest possible option, the visual impact on the surrounding landscape caused by this pitshell is assumed to be the most significant as well.

The south western boundary of the pitshell is located on a slope dipping down to the river Meuse, this area has been identified by the Lhoist mine development team as being potentially problematic in terms of visual impact. Therefore, a second pitshell scenario was designed with the aim to reduce this potentially problematic impact.

Pitshell scenario 2 is located at Gevrinne, with the north western boundary corresponding to scenario 1. The south eastern boundary is moved up the slope, limiting the surface area of scenario 2 to 45 hectares.

TABLE 5.2: PITSHELL SCENARIO 2 (GEVRINNE 2)

SURFACE	PIT 2
FOOTPRINT SURFACE / LAND USE (Ha.)	44.9
HIGHEST/LOWEST SURFACE ELEV. (m)	183 / 136
HIGHEST/LOWEST PIT ELEV. (m)	183 / 0
PIT DESIGN PARAMETERS	
A. BUFFER TO BONDARY (m)	30
B. OVERBURDEN SLOPE ANGLE (°)	35
C. ROCKHEAD BENCH WIDTH (m)	5
D. HAUL ROAD BENCH WIDTH (m)	Not evaluate at this stage
E. CATCH BENCH WIDTH (m)	5
F. BENCH HEIGHT (m)	15
G. FACE ANGLE (°)	70
H. OVERALL SLOPE ANGLE (°)	55
RESOURCE	
CHO (kt)	79,732.0
NCHO (kt)	5,947.1
SOVB/HOVB (kt)	5,575.1 / 0
HNO (kt)	16,572
IPW (kt)	0
TMM (kt)	92,688.9
RATIOS	
SR - STRIPPING [OVB+HNO]/[CHO+NCHO]	0.08
MY - MINING YIELD [CHO+NCHO]/TMM	0.92
AS - ACCESSIBLE CHO PER SURFACE (kt/Ha)	1775.8

As can be seen in the table, the surface area is reduced by 15.5 hectares compared to pit 1. The pitshell scenario yields a chemical ore reserve of 80 Mt.

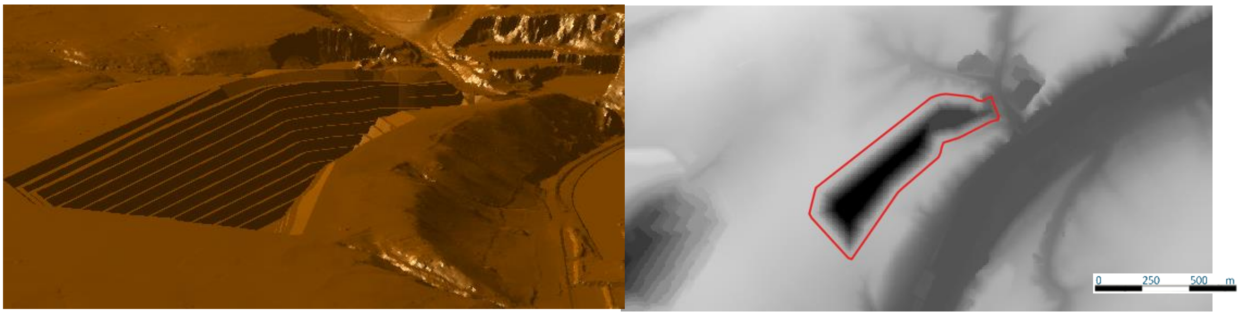


FIGURE 5.4: DTM PITSHELL SCENARIO 2 AT GEVRINNE

The last pitshell scenario developed during this study is the expansion pitshell scenario. The expansion pitshell scenario has the same amount of chemical ore as pitshell scenario 1, in order to effectively compare the expansion to Greenfield scenario. The expansion extends from the final pit of the current operations at Wartet on the northern, eastern and southern side. This expansion falls outside of the zoning plan areas which have mineral extraction rights granted.

Table 5.3: Pitshell scenario 3 (Expansion at Wartet)

SURFACE	PIT 4
FOOTPRINT SURFACE / LAND USE (Ha.)	47.5
HIGHEST/LOWEST SURFACE ELEV. (m)	190 / 35
HIGHEST/LOWEST PIT ELEV. (m)	190 / 0
PIT DESIGN PARAMETERS	
A. BUFFER TO BONDARY (m)	30
B. OVERBURDEN SLOPE ANGLE (°)	35
C. ROCKHEAD BENCH WIDTH (m)	5
D. HAUL ROAD BENCH WIDTH (m)	Not evaluate at this stage
E. CATCH BENCH WIDTH (m)	5
F. BENCH HEIGHT (m)	16
G. FACE ANGLE (°)	70
H. OVERALL SLOPE ANGLE (°)	55
RESOURCE	
CHO (kt)	141,167.8
NCHO (kt)	58,377.5
SOVB/HOVB (kt)	6,421.2 / 0
HNO (kt)	47,691.2
IPW (kt)	0
TMM (kt)	253,658.4
RATIOS	
SR - STRIPPING [OVB+HNO]/[CHO+NCHO]	0.27
MY - MINING YIELD [CHO+NCHO]/TMM	0.79
AS - ACCESSIBLE CHO PER SURFACE (kt/Ha)	2972.0

The expansion has a similar reserve increase as scenario 1, 140 Mt. However, the expansion has a much smaller footprint on the surface, at only 47.5 hectares. This means that the accessible chemical ore per surface area is much larger in scenario 3.

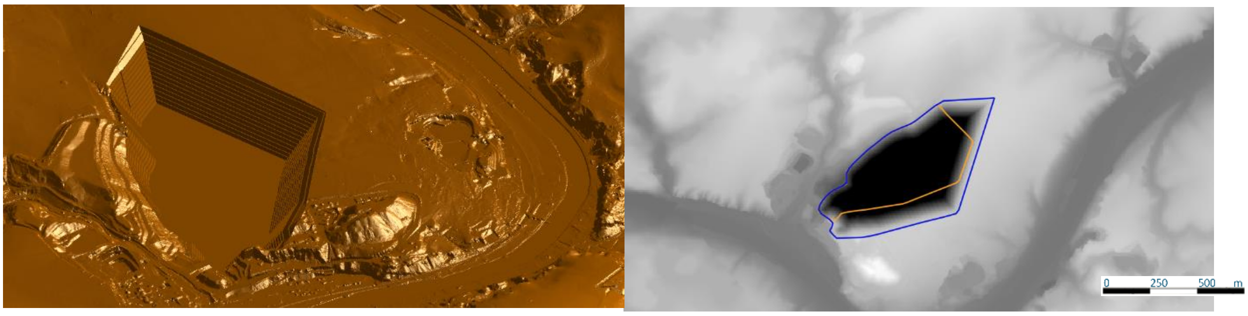


Figure 5.5: DTM pitshell scenario 3 (Expansion at Wartet)

In addition to these pitshell scenario analyses, a fourth analysis was also conducted for pitshell scenario 2 with a mitigation berm and treeline designed during the pit-design stage. The mitigation scenario will use the same pitshell as pitshell scenario 2, except with a 5-meter high berm on the north-western side and a 15-meter high treeline on the south-eastern side.

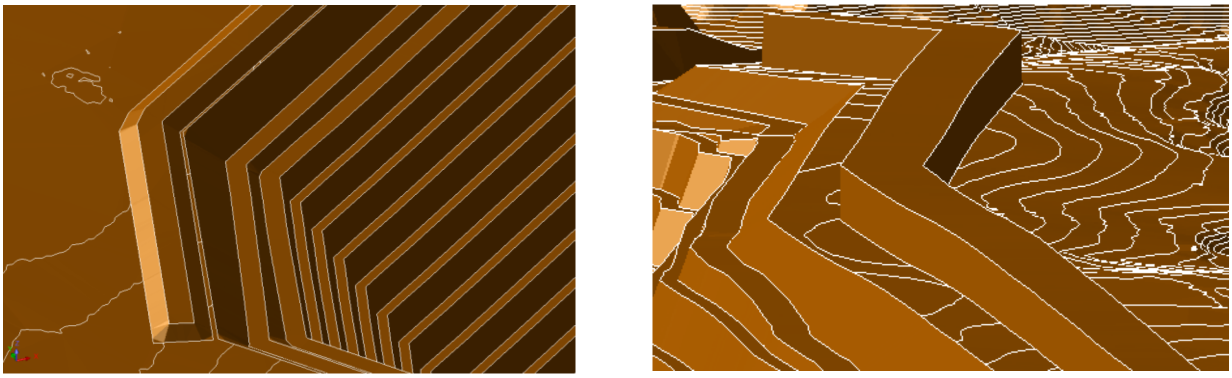


FIGURE 5.6: DTM PITSHELL 2 WITH MITIGATION (GEVRINNE 2)

While the economic and volume information are known, the visual impact of these pitshells is not. In order to find the visual impact of the different pitshells and to be able to compare the different pitshell scenarios in terms of visual impact, the tool which is developed in this study will be executed on this case study. In this chapter, the base data is described in accordance with the necessary information needed in order to complete a visual impact report based on this visual impact tool.

5.2 Base data used in the Analysis

In order to conduct the visibility angle analysis, a few digital data items need to be created. In this chapter, the data which is needed for the analysis is described. In following table shows all data necessary for each pit scenario in a simple format. With the base data known, the analysis can be conducted.

TABLE 5.4: DATA NEEDED FOR TOOL ANALYSIS

Data Name	**Description**	**Data type**	**Created through**
Digital Elevation Model	Digital Terrain Model of the surrounding landscape	.asc	Satellite image & leapfrog
Satellite image	RGB Satellite image of the surrounding landscape	Sentinel-2	SAC-plugin
Cadastre information	Cadastre from the Belgian government	.shp	Belgian government
Pit 1 - Data Name	**Description**	**Data type**	**Created through**
Digital Elevation Model	DTM of the surrounding landscape with the pitshell inserted	.asc	Satellite image, SURPAC & leapfrog
Pitshell String Files	Stringfile of the bench crest to place targetpoints	.dxf	SURPAC
Vertical Targetpoints	Targetpoints on the benches of the pitshell	.dxf	AutoCAD
Horizontal Targetpoints	Targetpoints on the crest of the pitshell	.dxf	AutoCAD
Pit 2 - Data Name	**Description**	**Data type**	**Created through**
Digital Elevation Model	DTM of the surrounding landscape with the pitshell inserted	.asc	Satellite image, SURPAC & leapfrog
Pitshell String Files	Stringfile of the bench crest to place targetpoints	.dxf	SURPAC
Vertical Targetpoints	Targetpoints on the benches of the pitshell	.dxf	AutoCAD

Horizontal Targetpoints	Targetpoints on the crest of the pitshell	.dxf	AutoCAD
Pit 4 - Data Name	**Description**	**Data type**	**Created through**
Digital Elevation Model	DTM of the surrounding landscape with the pitshell inserted	.asc	Satellite image, SURPAC & leapfrog
Pitshell String Files	Stringfile of the bench crest to place targetpoints	.dxf	SURPAC
Vertical Targetpoints	Targetpoints on the benches of the pitshell	.dxf	AutoCAD
Horizontal Targetpoints	Targetpoints on the crest of the pitshell	.dxf	AutoCAD
Pit 2 Mitigated - Data Name	**Description**	**Data type**	**Created through**
Digital Elevation Model	DTM of the surrounding landscape with the pitshell inserted	.asc	Satellite image, SURPAC & leapfrog
Pitshell String Files	Stringfile of the bench crest to place targetpoints	.dxf	SURPAC
Vertical Targetpoints	Targetpoints on the benches of the pitshell	.dxf	AutoCAD
Horizontal Targetpoints	Targetpoints on the crest of the pitshell	.dxf	AutoCAD

While this is the base data required in order to complete the analysis, more details about this data will be needed before the analysis can be conducted. As was described in the previous chapter, there are some hard and soft requirements for each dataset which must be designated and described.

For example, the canvas extent of the digital elevation model in this analysis meets the “larger than 4-kilometer squared radius requirement. The entire area on the landscape which is visually affected by the operation is not reported on, however, the minimum required extent is met. In the following table all requirements will be touched on.

Another example of a data characteristic is the resolution of the digital elevation model. In the previous chapter, it was described that the digital elevation model must have a minimum of 20-by-20-meter pixel resolution. In the case of this case study, the digital elevation model has a resolution of 10-by-10-meter pixels.

TABLE 5.5: HARD AND SOFT REQUIREMENTS

Data Name	**Requirement**	**Description**		
DEM	Canvas extent	10.1 kilometer x 8.56 kilometer = 86,456,000 m^2		
	Resolution	10-by-10-meter pixels		
	Projection	EPSG: 31370		
Intervisibility points	Targetpoints Horizontal	**Pitshell scenario**	**Number of Targetpoints**	**Accuracy**
		Gevrinne 1	12	89.93%
		Gevrinne 2	12	93.05%
		Gevrinne 2 mitigated	12	87.05%
		Expansion 4	12	89.62%
	Targetpoints Vertical	Number of arms	36 – 10-degree osculation	

With the required base data known, the analysis can be conducted. In the following chapter, the results for each step of the analysis will be described for every pit scenario.

5.3 Vertical Visibility Analysis

The vertical visibility angle is determined for each pitshell scenario. The result will be shown in the form of a *heat map*, where every 10-by-10-meter pixel shows the vertical visibility angle for the observerpoint.

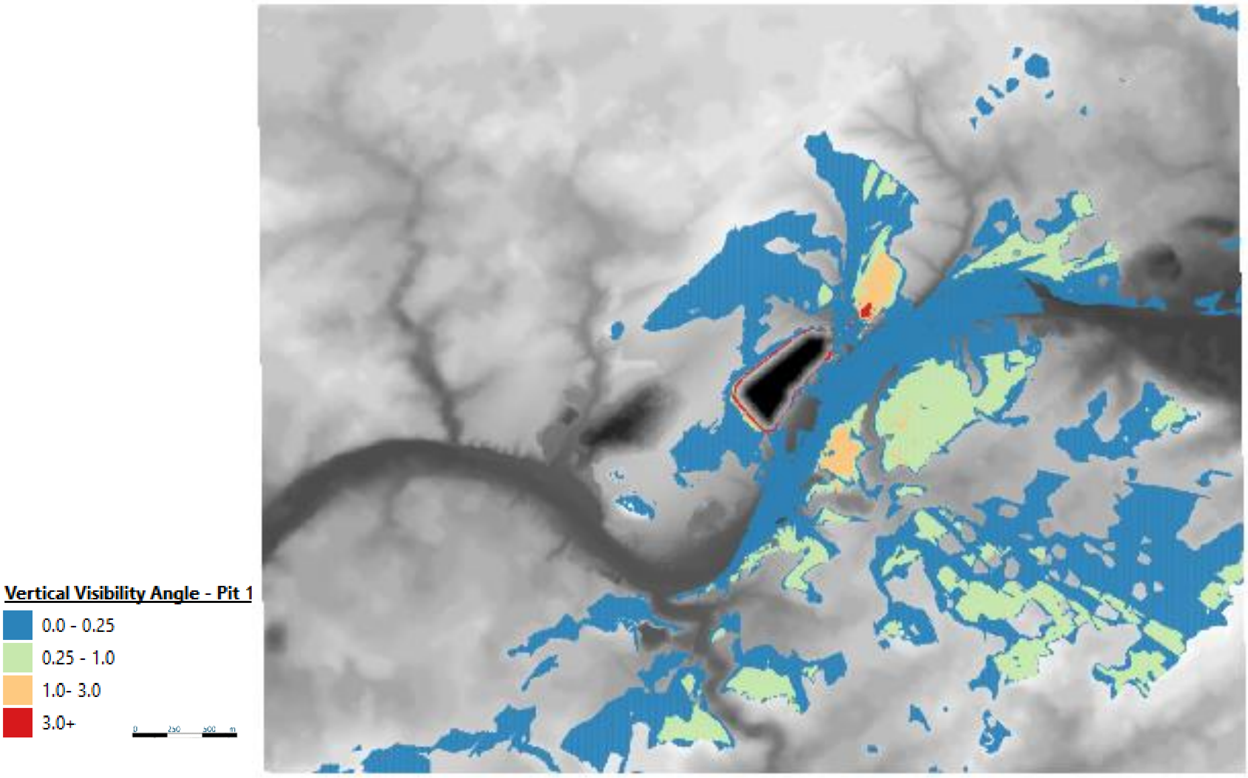
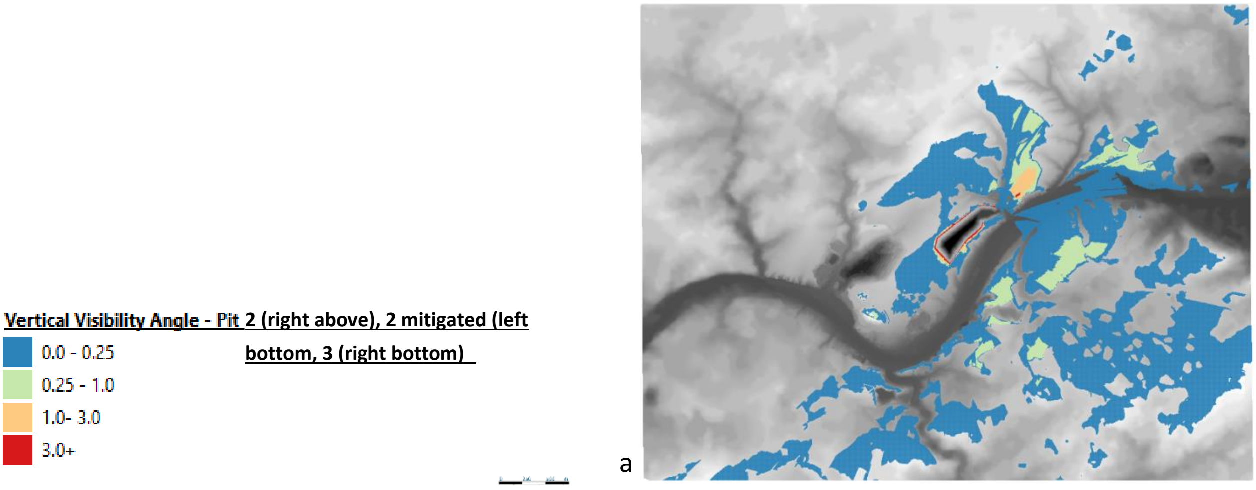


FIGURE 5.7: HEAT MAP VERTICAL VISIBILITY ANGLE HEAT MAP SCENARIO 1

The clearer heat map results of the vertical visibility angle for pitshell scenario 2, 2 mitigated and 3 are to be found in the appendix.



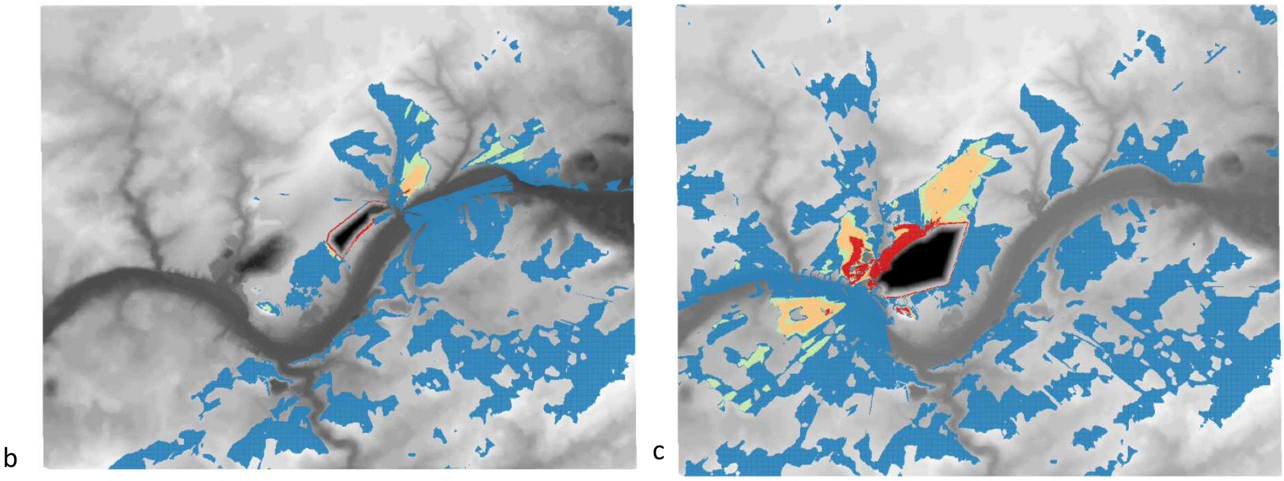


Figure 5.8: Heat map Vertical Visibility Pitshell scenario 2 (a), 2 mitigated (b) and 3 (c)

The heat maps show the visual impact on the surrounding landscape by the pitshell scenarios visually. The greyscale background of the heat map shows the pitshell elevation and the elevation of the surrounding landscape. If the greyscale background is visible, there is no visual impact on that section of the surrounding landscape. The heat map itself shows, for the vertical heat map, four colours. The colours represent the vertical visibility angle for each pitshell.

Table 5.5: Vertical Visibility Angle Colour Code for Heat map

Colour	**Vertical Visibility Angle**
Blue	0 - 0.25 degrees
Green	0.25 - 1.0 degrees
Orange	1.0 - 3.0 degrees
Red	3.0+ degrees

If the heat map shows blue, green, orange or red is shown over a section of the elevation data, that area has the respective vertical visibility on the pitshell scenario. The difference in heat map vertical visibility is clear between scenario 1, 2 and 2 mitigated. With the heat map showing more blue, and less green and orange with the smaller quarry and with mitigation added. To be able to properly compare these results, the severity value is calculated for each scenario.

Table 5.6: Vertical Visibility Severity

Pitshell Scenario	**Vertical Severity**	**Accuracy**	**Normalized Vertical Severity**
Scenario 1	233929	89.93%	260123
Scenario 2	195154	93.05%	209730
Scenario 2 Mitigated	157912	87.05%	181404
Scenario 3	853282	89.62%	360644

Table 5.6 shows the results of the vertical visibility severity for each scenario as portrayed in the heat map for each scenario. The vertical severity column shows the non-normalized vertical visibility severity. This is the value that comes out of the analysis when it is not adjusted for the accuracy of each scenario. This value cannot be compared with the value of other scenarios for that reason. It is therefore not entirely accurate to compare the heat maps visually, however, it gives a good impression of which areas, villages and cities are mainly affected by each scenario. Furthermore, it

gives a good impression of which areas are affected more in different scenarios than others. In order to properly compare the different scenarios, the vertical visibility severity value must be normalized to the accuracy of each scenario. With this normalization, it is possible to compare the values for each scenario. The comparison is made between pitshell 1 and each other pitshell.

TABLE 5.7: VERTICAL VISIBILITY SEVERITY DIFFERENCE

Severity Difference Vertical	**Pit scenario 1**	**Pit scenario 2**	**Pit scenario 2 mitigated**	**Pit scenario 3**
Percentage (%)	0%	-19.37%	-30.26%	+38.64%

What can be seen in the heat map, is also represented in the vertical visibility severity value. Scenario 1 has a higher vertical visibility severity than scenario 2 and scenario 2 mitigated. The vertical visibility severity affects similar areas for pitshell scenario 1, 2 and 2 mitigated. However, pitshell scenario 3 affects different areas than the greenfield scenarios. This makes it more difficult to accurately compare the scenarios. Pitshell scenario 1, 2 and 2 mitigated are situation in a very similar geographic location and differ only in size. Therefore, the ZTV of these pitshell scenarios will encompass a similar area, for the most part only dissimilar in size, not shape. The 3^rd^ pitshell scenario is located in a different geographical location and is dissimilar is size and shape. Therefore, the shape, size and location of the ZTV is divergent from the ZTV of the first three pitshell scenarios. This complicates the comparison of the different pitshell scenarios to one another. As for example, certain villages will be affected visually by the third pitshell scenario which are not affected in any of the greenfield pitshell scenarios. This will be examined more in the final analysis of the results.

5.4 Horizontal Visibility Analysis

The horizontal visibility angle is determined for each pitshell scenario. The result will be shown in the form of a heat map, where every 10-by-10-meter pixel shows the horizontal visibility angle for the observerpoints.

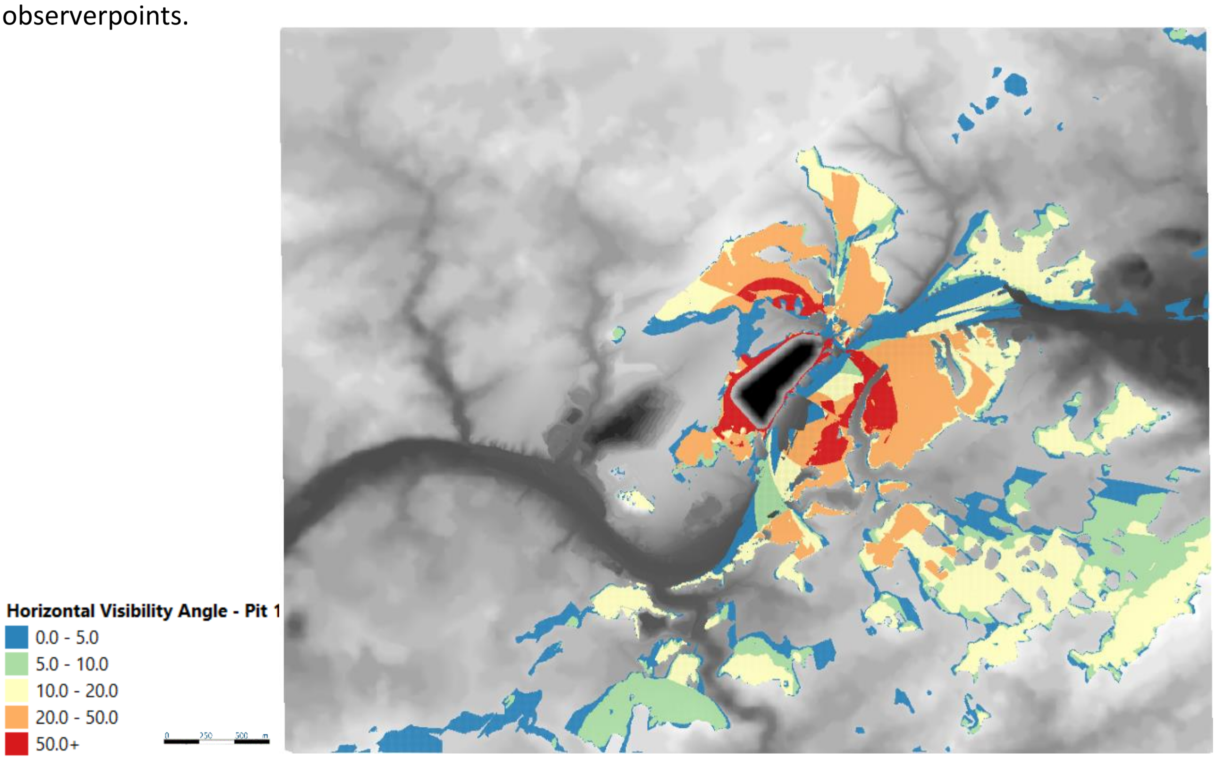


FIGURE 5.9: HEAT MAP HORIZONTAL VISIBILITY ANGLE SCENARIO 1

Clearer heat map results of pitshell scenario 2, 2 mitigated and 3 can be found in the appendix. The horizontal severity of all scenarios shows more red, orange and yellow than the vertical visibility severity. This means, that in these scenarios and in this landscape, the horizontal visibility is more impactful for the total visual impact than the vertical visibility.

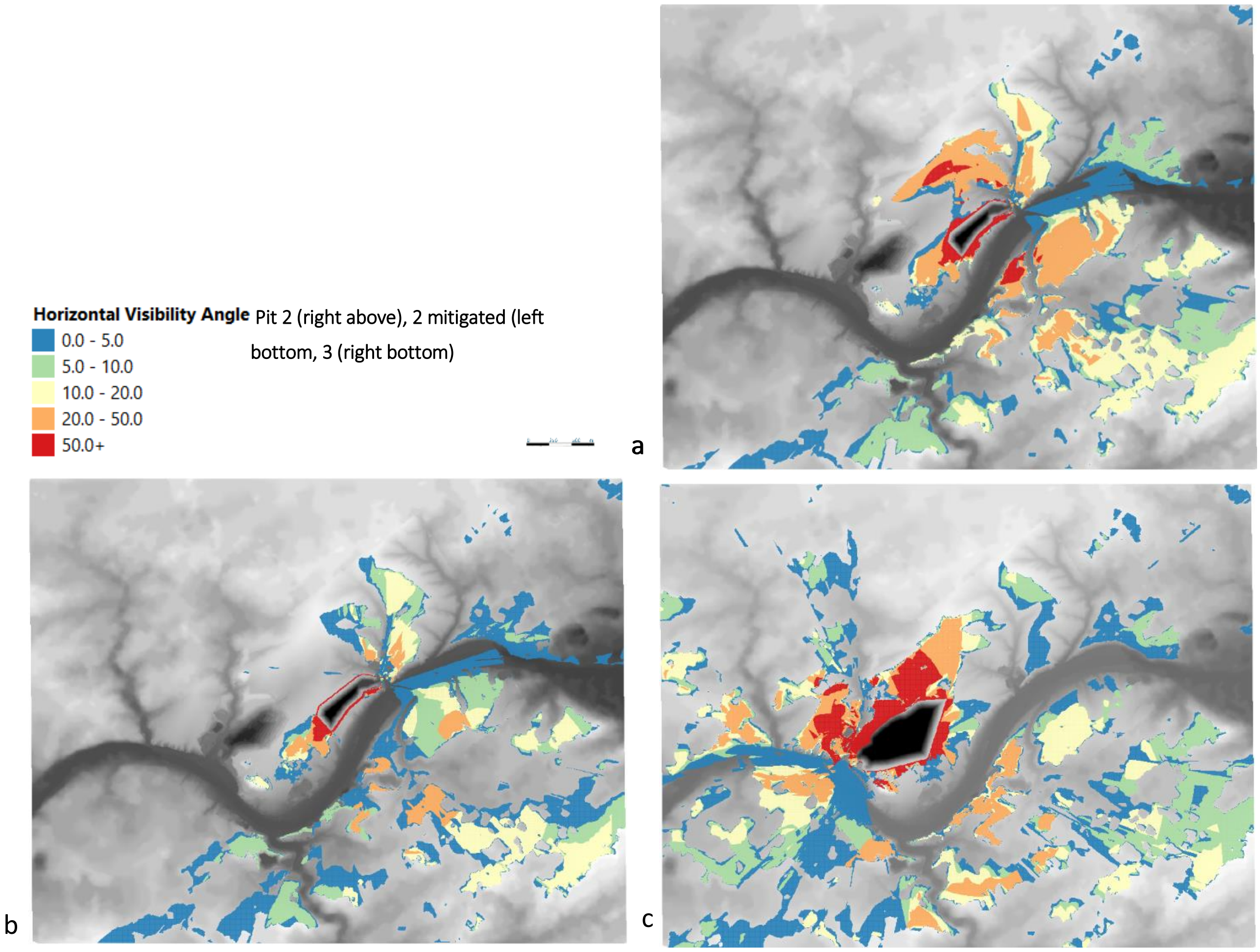


FIGURE 5.10: HEAT MAP HORIZONTAL VISIBILITY PITSHELL SCENARIO 2 (A), 2 MITIGATED (B) AND 3 (C)

The heat maps show the visual impact on the surrounding landscape by the pitshell scenarios visually. The greyscale background of the heat map shows the pitshell elevation and the elevation of the surrounding landscape. If the greyscale background is visible, there is no visual impact on that section of the surrounding landscape. The heat map itself shows the horizontal visibility angle impact on the surrounding landscape using colours to represent the angles. The colours in this heat map are defined as below.

TABLE 5.5: HORIZONTAL VISIBILITY ANGLE COLOUR CODE FOR HEAT MAP

Colour	Horizontal Visibility Angle
Blue	0.0 – 5.0 degrees
Green	5.0 – 10.0 degrees
Yellow	10.0 – 20.0 degrees
Orange	20.0 – 50.0 degrees
Red	50.0+ degrees

The difference in heat map horizontal visibility is clear between scenario 1, 2 and 2 mitigated. With the heat map showing more blue and green and less yellow, orange and red with the smaller pitshell scenario and with mitigation added. To be able to properly compare these results, the severity value is calculated for each scenario.

TABLE 5.8: HORIZONTAL VISIBILITY SEVERITY

Pitshell Scenario	Horizontal Severity	Accuracy	Normalized Horizontal Severity
Scenario 1	482309	89.93%	536316
Scenario 2	441943	93.05%	474952
Scenario 2 Mitigated	288116	87.05%	330978
Scenario 3	663772	89.62%	668683

The table shows the results of the horizontal visibility severity for each scenario as portrayed in the heat map for each scenario. The horizontal severity column shows the non-normalized horizontal visibility severity. This is the value that comes out of the analysis when it is not adjusted for the accuracy of each scenario. This value cannot be compared with the value of other scenarios for that reason. It is therefore not entirely accurate to compare the heat maps visually, however, it gives a good impression of which areas, villages and cities are mainly affected by each scenario. Furthermore, it gives a good impression of which areas are affected more in different scenarios than others.

In order to properly compare the different scenarios, the horizontal visibility severity value must be normalized to the accuracy of each scenario. With this normalization, it is possible to compare the values for each scenario. The comparison is made between pitshell 1 and each other pitshell.

TABLE 5.9: HORIZONTAL VISIBILITY SEVERITY DIFFERENCE

Severity Difference Horizontal	Pit scenario 1	Pit scenario 2	Pit scenario 2 mitigated	Pit scenario 3
Percentage (%)	0%	-11.44%	-38.29%	+24.68%

What can be seen in the heat map, is also represented in the horizontal visibility severity value. Scenario 1 has a higher horizontal visibility severity than scenario 2 and scenario 2 mitigated. The horizontal visibility severity affects similar areas for pitshell scenario 1, scenario 2 and scenario 2 mitigated. Furthermore, while the scenarios affect similar areas, the smaller pitshell and the smaller pitshell with mitigation impact less total area than scenario 1.

Pitshell scenario 3 affects different areas than the Greenfield scenarios. This makes it more difficult to accurately compare the scenarios, as the comparison is no longer like to like. This will be examined more in the final analysis of the results.

5.5 Combined Visibility Analysis

With the vertical and horizontal visibility severity known for each scenario, these two severities need to be combined. The vertical and horizontal visibility severity are both one-dimensional severity values. In order to better represent reality, these two one-dimensional values are multiplied against one another to describe a two-dimensional value.

For each 10-by-10-meter pixel, the vertical visibility severity and the horizontal visibility severity are multiplied against one another.

TABLE 5.10: COMBINED VISIBILITY FACTOR

	1 (0-5 degrees)	2 (5-10 degrees)	3 (10-20 degrees)	4 (20-50 degrees)	5 (50+ degrees)
1 (0-0.25 degrees)	**1**	**2**	**3**	**4**	**5**
2 (0.25-1 degrees)	**2**	**4**	**6**	**8**	**10**
3 (1-3 degrees)	**3**	**6**	**9**	**12**	**15**
4 (3+ degrees)	**4**	**8**	**12**	**16**	**20**

With this calculation, a better impression of the total area which the pitshell scenario takes up in the observer's field of vision is known. The results of the combined visibility analysis are shown in a heat map in which every 10-by-10-meter pixel shows the combined visibility severity.

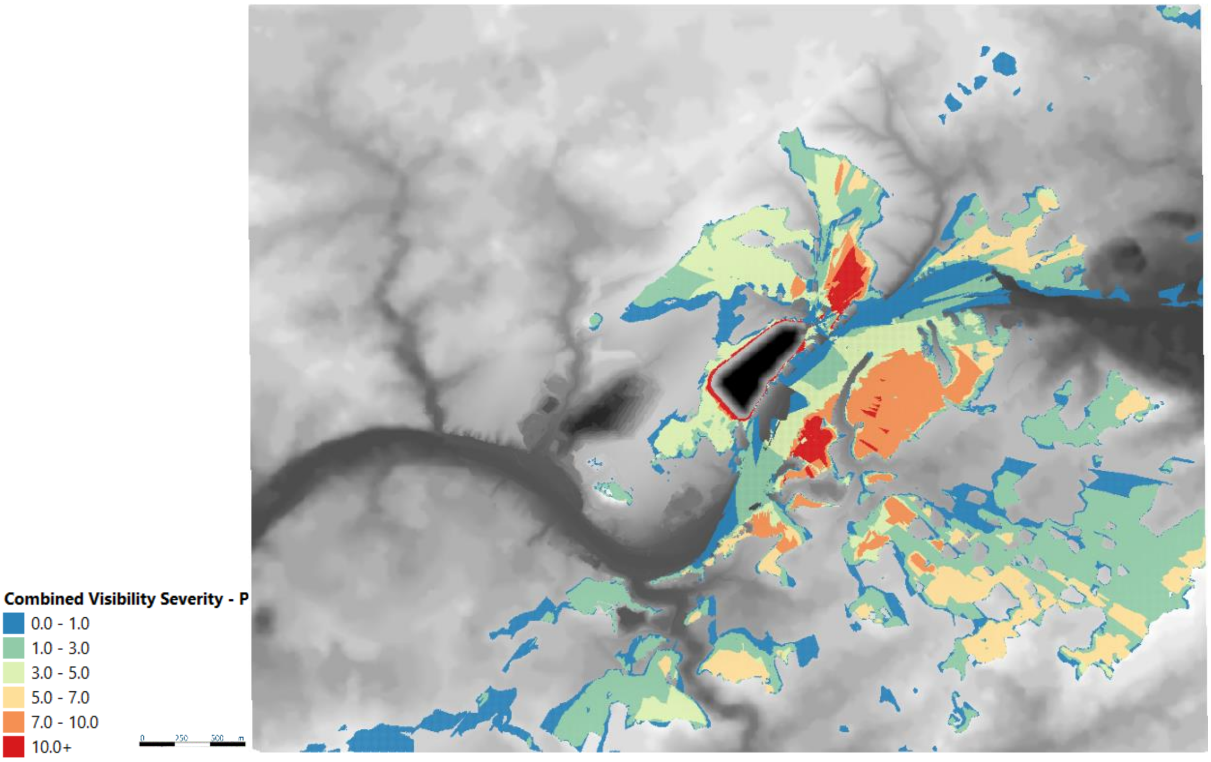


FIGURE 5.11: HEAT MAP COMBINED VISIBILITY SEVERITY SCENARIO 1

Clearer heat map results of pitshell scenarios 2, 2 mitigated and 3 can be found in the appendix. A similar phenomenon as in the vertical and horizontal visibility angle can be seen. This is logical, as the combined visibility severity is deduced from these two values. Pitshell scenario 1, 2 and 2 mitigated affect the same areas, with pitshell scenario 2 and pitshell scenario 2 mitigated having a reduced impact.

Pitshell scenario 3 has zones of extreme red areas, mainly close to the pitshell itself. Pitshell scenario 3 affects different areas than pitshell scenario 1, 2 and 2 mitigated.

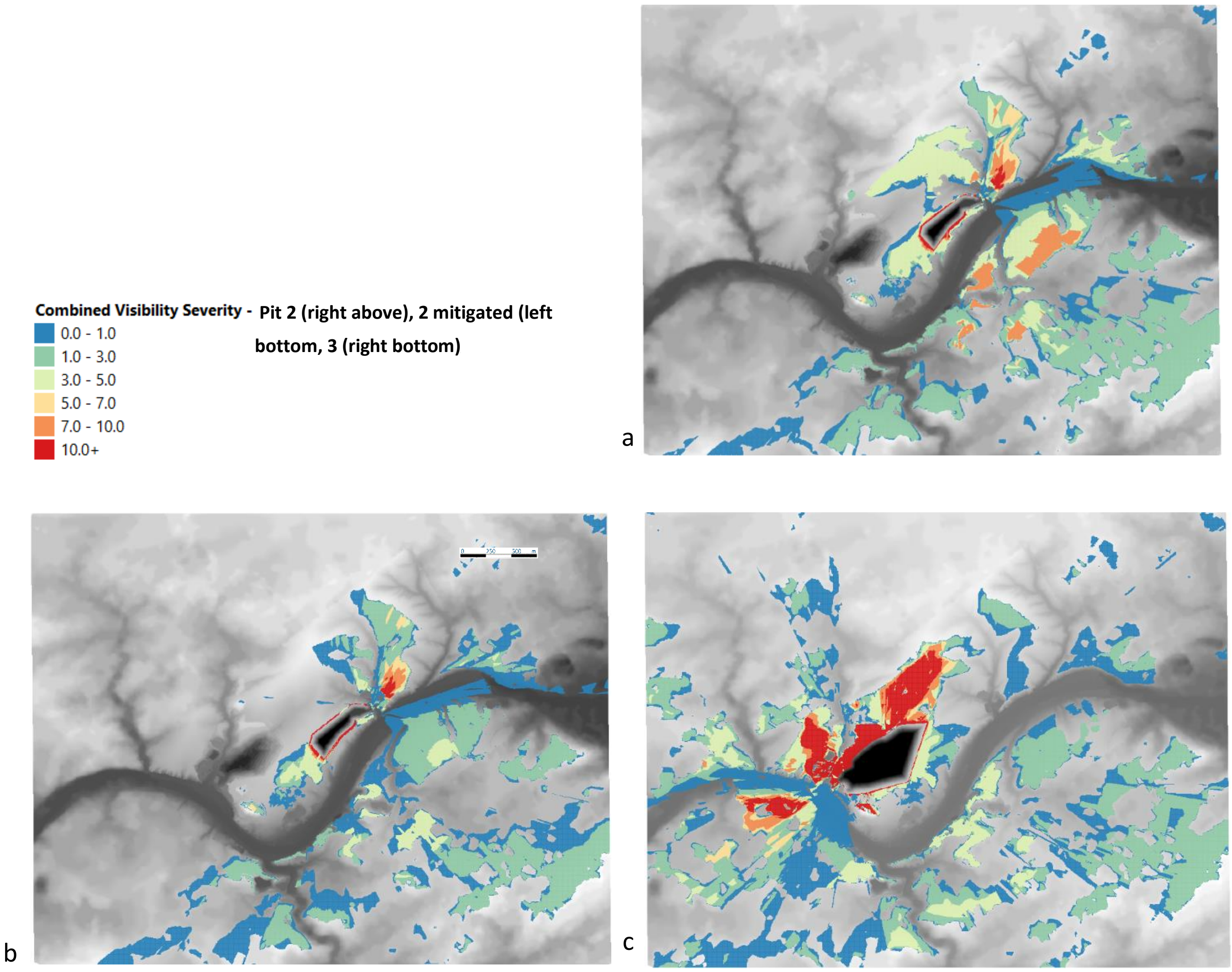


FIGURE 5.12: HEAT MAP COMBINED VISIBILITY PITSHELL SCENARIO 2 (A), 2 MITIGATED (B) AND 3 (C)

The heat maps show the visual impact on the surrounding landscape by the pitshell scenarios visually. The greyscale background of the heat map shows the pitshell elevation and the elevation of the surrounding landscape. If the greyscale background is visible, there is no visual impact on that section of the surrounding landscape. The heat map itself shows the combined visibility impact on the surrounding landscape using colours to represent the severity. The colours in this heat map are defined as below.

TABLE 5.5: COMBINED VISIBILITY ANGLE COLOUR CODE FOR HEAT MAP

Colour	Combined Visibility Severity
Blue	0.0 – 1.0
Dark Green	1.0 – 3.0
Light Green	3.0 – 5.0
Yellow	5.0 – 7.0
Orange	7.0 – 10.0
Red	10.0+

The following table shows the results in the form of a number value which can be compared against one another. The combined severity value is calculated for each scenario.

TABLE 5.11: COMBINED VISIBILITY SEVERITY

Pitshell Scenario	Combined Severity	Accuracy	Normalized Combined Severity
Scenario 1	663772	89.93%	738099
Scenario 2	515501	93.05%	554004
Scenario 2 Mitigated	318428	87.05%	365799
Scenario 3	853282	89.62%	952111

The table shows the results of the combined visibility severity for each scenario as portrayed in the heat map for each scenario. The combined severity column shows the non-normalized combined visibility severity. This is the value that comes out of the analysis when it is not adjusted for the accuracy of each scenario. This value cannot be compared with the value of other scenarios for that reason. It is therefore not entirely accurate to compare the heat maps visually, however, it gives a good impression of which areas, villages and cities are mainly affected by each scenario. Furthermore, it gives a good impression of which areas are affected more in different scenarios than others.

In order to properly compare the different scenarios, the combined visibility severity value must be normalized to the accuracy of each scenario. With this normalization, it is possible to compare the values for each scenario. The comparison is made between pitshell 1 and each other pitshell.

TABLE 5.12: COMBINED VISIBILITY SEVERITY DIFFERENCE

Severity Difference Horizontal	Pit scenario 1	Pit scenario 2	Pit scenario 2 mitigated	Pit scenario 3
Percentage (%)	0%	-24.94%	-50.44%	+29.00%

What can be seen in the heat map, is also represented in the combined visibility severity value. Scenario 1 has a higher combined visibility severity than scenario 2 and scenario 2 mitigated. The combined visibility severity affects similar areas for pitshell scenario 1, 2 and 2 mitigated. Furthermore, while the scenarios affect similar areas, the smaller pitshell and the smaller pitshell with mitigation impact less total area than scenario 1.

Again, as in the vertical angle impact, pitshell scenario 3 affects different areas than the greenfield scenarios. This makes it more difficult to accurately compare the scenarios. This will be examined more in the final analysis of the results.

With the combined visibility severity known, the second physical factor aspect must be assessed. The combined visibility severity makes up half of the physical factor, the other half consists of the chromatic difference. In the following chapter, the chromatic difference will be assessed.

5.6 Chromatic Difference

The chromatic difference shows the perceived colour difference between two colours. In quarrying operations, the surrounding landscape and the exposed rock and overburden most commonly have a different colour. Using the Euclidean distance, the perceived colour difference is calculated for this case study.

The assumption is made that for each scenario, the colour of the landscape and the exposed ore and overburden are the same. Furthermore, as this project is situated right next to a currently operation mine of Lhoist (Wartet) containing the same mineral, the open quarry at Wartet is used to approximate the colour of the exposed ore and overburden. The quarry will be used to extract the 10 RGB-values. The surrounding landscape in an area of 500-meter around the proposed Greenfield site and the already existing quarry will be used to extract the colour of the landscape.

The colour samples are taken from the target area. The target area contains the bare rock exposed by the quarry and a small selection of the landscape around the proposed pitshell location. This small section of the landscape represents the "background" colour when looking at the operation.

FIGURE 5.13: SATELLITE IMAGE OF THE TARGET AREA

The satellite images are sentinel-2 images, downloaded using the free, open access service from Copernicus. The semi-automatic classification plugin has a built-in option to download sentinel-2 images. The sentinel-2 images for this case study acquired are taken on the 25th of April 2020. The file used is named: L2A_T31UFR_A016379_20200425T104615_2020-04-25, acquired from *scihub* Copernicus, downloaded through the semi-automatic classification plugin. The bands are processed for atmospheric corrections using DOS1 correction in the semi-automatic classification plugin.

Using a random point creation tool (in QGIS), 10 random points are created in the target areas in both the surrounding landscape and ore and overburden class. The RGB-value at each of these 10 points is extracted from the satellite image.

TABLE 5.13: RGB-VALUE OF TARGET ZONES

Ore and Overburden	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
R	210	189	254	212	233	222	170	240	251	233
G	190	167	251	217	235	195	137	221	245	216
B	167	190	245	208	226	196	149	227	222	168
Surrounding Landscape	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
R	112	239	47	131	174	37	100	36	75	129
G	155	231	77	152	169	99	140	90	135	169
B	130	204	56	50	148	65	116	53	114	150

With the RGB-values known for all 10 randomly selected points, the average RGB value for the ore and overburden and the surrounding landscape can be calculated. The average is simply calculated for each R, G, and B band separately with the following formula:

$$Average\ value = \frac{R1 + R2 + R3 + \cdots + R10}{10}$$

$$Average\ value = \frac{G1 + G2 + G3 + \cdots + G10}{10}$$

$$Average\ value = \frac{B1 + B2 + B3 + \cdots + B10}{10}$$

This formula gives an average value for the R-, G- and B-bands. Using this average value for each colour band, an artificial average colour for each target area is created. This average colour value is representative of each target area.

Table 5.14: Average RGB-value

RGB-value	Ore and Overburden	Surrounding Landscape
R	221	108
G	207	142
B	200	109
Colour	⬜	🟩

The RGB-value of each of these colours is then translated into the CIELAB colourspace. By translating the average RGB colour value of each colour class, it becomes possible to compare these two colours and calculate the Euclidean distance.

Table 5.15: CIELAB colour value

CIELAB-value	Ore and Overburden	Surrounding Landscape
L*	84.05	55.72
a*	3.66	-18.78
b*	5.21	13.8
Colour	⬜	🟩

The chromatic difference can be calculated using the Euclidean distance between two colours in the CIELAB colourspace. The formula used for this Euclidean distance is:

$$\Delta E_{ab}^{*} = \sqrt{(L_2^{*} - L_1^{*})^2 + (a_2^{*} - a_1^{*})^2 + (b_2^{*} - b_1^{*})^2}$$

$$\Delta E_{ab}^{*} = \sqrt{(84.05 - 55.72)^2 + \left(3.66 - (-18.78)\right)^2 + (5.21 - 13.8)^2}$$

$$\Delta E_{ab}^{*} = 37.15$$

A Euclidean distance of 2.3 corresponds to a “Just Noticeable Difference” (JND). To determine the chromatic factor value, the Euclidean distance is divided by the JND.

$$Chromatic\ Factor\ Value = \Delta E_{ab}^{*} / 2.3$$

$$Chromatic\ Factor\ Value = 37.15 / 2.3$$

$$Chromatic\ Factor\ Value = 16.2$$

The chromatic factor value is multiplied with the spatial factor value of all 10-by-10-meter pixels. This combines the two factors of the analysis into the physical factor value of each pitshell scenario.

TABLE 5.16: PHYSICAL FACTOR SEVERITY

Pitshell Scenario	Spatial Factor Value	Chromatic Difference	Physical Factor Value
Scenario 1	738,099	37.15	11,957,196
Scenario 2	554,004	37.15	8,974,870
Scenario 2 Mitigated	365,799	37.15	5,925,943
Scenario 3	952,111	37.15	15,424,200

The physical factor value is normalized to the accuracy of the analysis and will be compared against one another. As the chromatic difference is the same for each scenario, the severity difference is the same.

TABLE 5.17: COMBINED VISIBILITY SEVERITY DIFFERENCE

Severity Difference Horizontal	Pit scenario 1	Pit scenario 2	Pit scenario 2 mitigated	Pit scenario 3
Percentage (%)	0%	-24.94%	-50.44%	+29.00%

As the difference in severity stays the same for each scenario, the chromatic difference doesn’t have to be taken up in this case study. However, if there were to be a situation in which this case study needs to be compared to another scenario, at a different location, in which another ore is mined, another overburden material is present or a lack of vegetation around the operation, the chromatic difference must be included in the analysis.

5.7 Perception filter value

With the physical factor value known, the human perception needs to be incorporated in this case study. The human perception filter value is a value which is multiplied with the physical factor in order to give the physical factor that is given a humanly perceived weight.

As was described in the method chapter, there are two methods to assess the perception filter value. In this case study, it is possible to conduct the analysis using cadastre information provided by the Belgian government. This method should be the first choice and should always be accepted as the preferred method. However, both methods will be shown in this case study. If the scenarios in this case study were to be compared against other scenarios, the method of acquiring the perception filter value should be the same. The remote sensing classification will be assessed first.

5.7.1 Remote sensing classification method

The semi-automatic classification plugin was used in this analysis to assess the urban areas in this case study. The satellite image used is the same image as used in the chromatic difference analysis. The file used is named: L2A_T31UFR_A016379_20200425T104615_2020-04-25, acquired from scihub Copernicus, downloaded through the semi-automatic classification plugin. The bands are processed for atmospheric corrections using DOS1 correction in the semi-automatic classification plugin.

The bands are described in table 4.5 in chapter 4. Band 2 (Blue), band 3 (Green) and band 4 (Red) are used in the analysis. These bands are needed to represent the true-colour image.

Table 5.18: Sentinel-2 Bands Wavelength and resolution (ESA, 2015)

Sentinel-2 bands	Central wavelength (micrometers)	Resolution
Band 2 – Blue	0.490	10
Band 3 – Green	0.560	10
Band 4 – Red	0.665	10

The bands are ordered 4-3-2 to portray a true-colour image in QGIS. This image is used to conduct the semi-automatic classification plugin process. Five classes are defined in this study which will be classified in the process. The classes are:

1. Trees
2. Water
3. Fields
4. Built-up
5. Quarry

In order to classify each pixel with one of these classes, three steps have to be executed. The first step is to create the region of interest zones and record the spectral signature for each regional of interest (ROI). 50 regions of interest are selected on the satellite image and classified manually into one of the 5 classes. With 10 regions of interest for each class. Step 2 includes binding the regions of interest into a ROI file which contains all the spectral signatures. This file is saved and stored.

In step 3, the semi-automatic classification plugin calculates the expected class for each pixel according to its spectral signature. In this analysis, the maximum likelihood algorithm is used. The result is shown in a classification pixel map and in a results table.

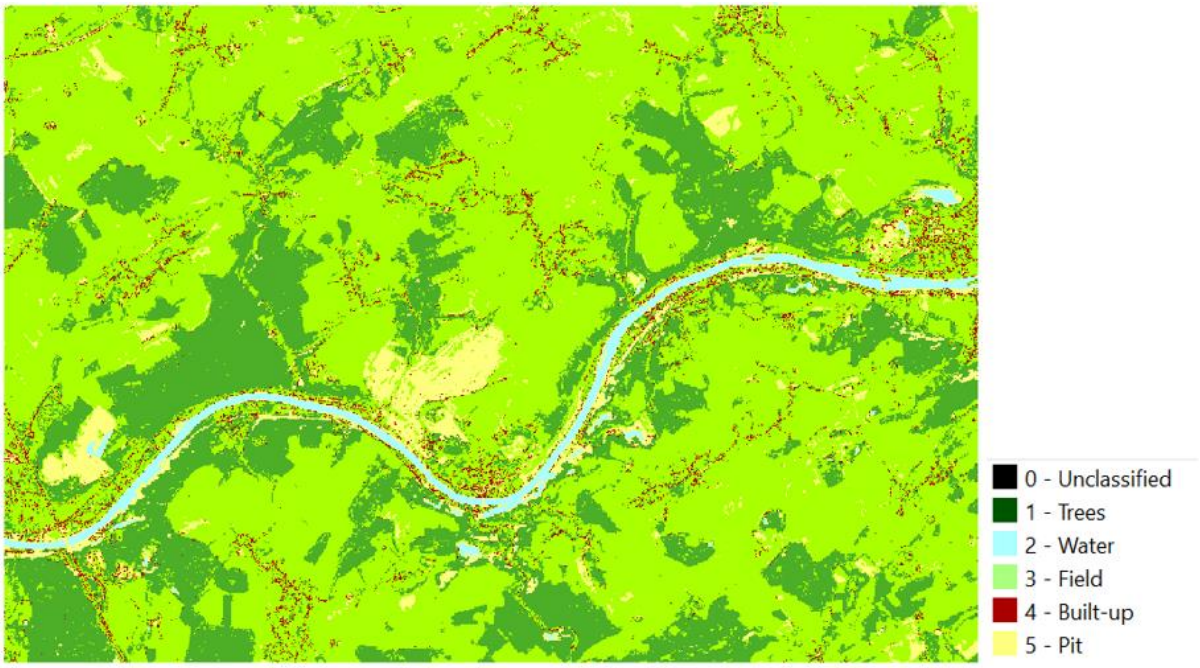
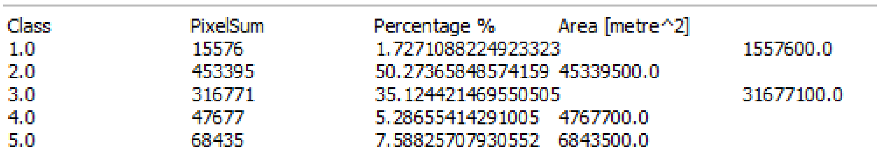


Figure 5.14: Classification pixel map result

The classification pixel map result shows a clear visual conformity with reality. Villages are classified as built-up clusters; however, roads and other transport infrastructure is less well defined. The results are also shown in a classification report.

TABLE 5.19: CLASSIFICATION REPORT



```
Class       PixelSum    Percentage %         Area [metre^2]
1.0         15576       1.7271088224923323                   1557600.0
2.0         453395      50.27365848574159  45339500.0
3.0         316771      35.124421469550505                   31677100.0
4.0         47677       5.28655414291005   4767700.0
5.0         68435       7.58825707930552   6843500.0
```

The classification shows the number of pixels in each class, the percentage of each class and the area in square meters of each class. With this analysis, it is determined that 5.29% or 47,677 pixels of the canvas are classified as the built-up class. Meaning, 47,677 pixels will be given the value of 10 in terms of perception filter value. All other pixels will be given a value of 1.

In order to access accuracy of the results, an accuracy analysis is conducted. The accuracy assessment was set up in order to ensure the results are accurate enough. In the accuracy analysis, the first step is to assess the number of samples needed for each class to conduct the analysis.

$$N = (\Sigma_{i=1}(Wi * Si)/So)^2$$

$$Wi = mapped\ area\ proportion\ of\ class\ i$$
$$Si = standard\ deviation\ of\ stratum\ i$$
$$So = expected\ standard\ deviation\ of\ overall\ accuracy$$
$$c = total\ number\ of\ classes$$

TABLE 5.20 : NUMBER OF SAMPLES NEEDED

Land cover class	**Area**	**%**	**W_i**	**S_i**	**$W_i * S_i$**	**S_o**
1 – Water	1,557,600	1.73	0.0173	0.5	0.00865	0.01
2 – Fields	45,339,500	50.27	0.5027	0.2	0.10054	0.01
3 – Trees	31,677,100	35.12	0.3512	0.3	0.10536	0.01
4 – Quarry	4,767,700	5.29	0.0529	0.4	0.02116	0.01
5 – Built-up	6,843,500	7.59	0.0759	0.45	0.034155	0.01
Total	93,185,400				0.269865	

S_i and S_o are assumed. The S_i assumption is based on the user accuracy, determined previously in a study (Olofsson et al., 2011), where classes with larger areas are assumed to be more accurately assessed than classes with lower areas. S_o is assumed to be 0.01 based on former studies (Oloffson et al., 2014).

With the table and inserting the values into the formula, the result is:

$$N = (0.269865\ /\ 0.01)^2$$

$$N = 728\ samples$$

With the number of samples known, the number of samples per class needs to be known. This is done by taking the mean of the equal distribution and weighted distribution of the landcover classes.

TABLE 5.21: NUMBER OF SAMPLE PER CLASS

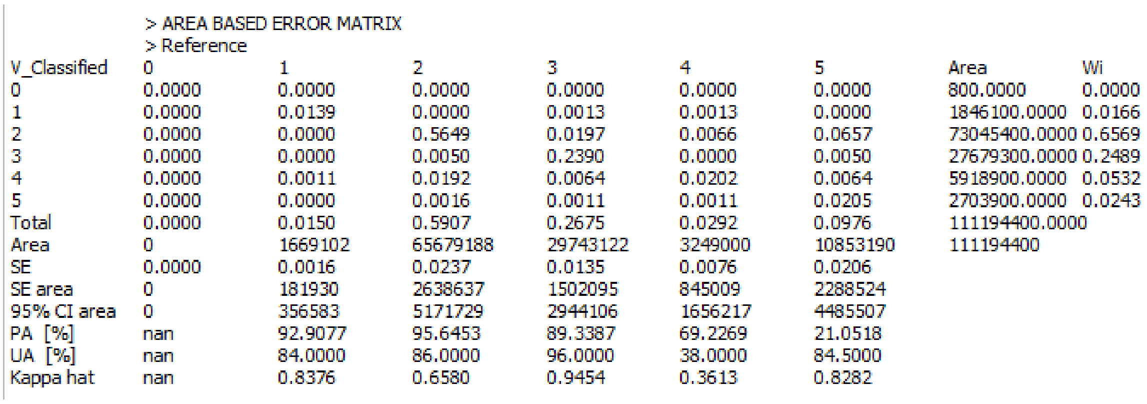
Land Cover Class	**Weighted**	**Equal**	**Mean**
1 – Water	13	146	80
2 – Fields	366	146	256
3 – Trees	256	146	201
4 – Quarry	39	146	93
5 – Built-up	55	146	101
Total			731

The weighted distribution of landcover classes is taken by multiplying the 728 samples with the area percentage taken up by each landcover class. The mean is the simple weighted mean between the weighted distribution and the equal distribution.

The semi-automatic classification plugin has an automatic process in which the plugin selects the required number of randomly located pixels, in the determined desired landcover classes. With the required number of pixels selected by the plugin, these pixels must be manually checked on accuracy.

This manual accuracy check is executed in a simple way. The plugin has an up-to-date free, open source landcover map available. This map is used as an underlay of the pixel layer and is used to check the landcover use of the pixel in real life. For example, a pixel is shown which is classified as the water landcover class. The map is brought up to determine the landcover class of the pixel in question. The real landcover class is recorded in the plugin. If the map does not give sufficient information, satellite images can be used instead. This process is repeated for all pixels.

The plugin will then compare the determined pixel landcover class by the algorithm and the manually determined landcover class to one another. This comparison is made for every pixel in the accuracy assessment. The results are shown in an error matrix.



```
                > AREA BASED ERROR MATRIX
                > Reference
V_Classified    0           1           2           3           4           5           Area            Wi
0               0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      800.0000        0.0000
1               0.0000      0.0139      0.0000      0.0013      0.0013      0.0000      1846100.0000    0.0166
2               0.0000      0.0000      0.5649      0.0197      0.0066      0.0657      73045400.0000 0.6569
3               0.0000      0.0000      0.0050      0.2390      0.0000      0.0050      27679300.0000 0.2489
4               0.0000      0.0011      0.0192      0.0064      0.0202      0.0064      5918900.0000    0.0532
5               0.0000      0.0000      0.0016      0.0011      0.0011      0.0205      2703900.0000    0.0243
Total           0.0000      0.0150      0.5907      0.2675      0.0292      0.0976      111194400.0000
Area            0           1669102     65679188    29743122    3249000     10853190    111194400
SE              0.0000      0.0016      0.0237      0.0135      0.0076      0.0206
SE area         0           181930      2638637     1502095     845009      2288524
95% CI area     0           356583      5171729     2944106     1656217     4485507
PA  [%]         nan         92.9077     95.6453     89.3387     69.2269     21.0518
UA  [%]         nan         84.0000     86.0000     96.0000     38.0000     84.5000
Kappa hat       nan         0.8376      0.6580      0.9454      0.3613      0.8282
```

FIGURE 5.15: ERROR MATRIX ACCURACY RESULTS

With the error matrix, the accuracy results are shown. In row 3-10 the pixel area of the accuracy assessment is determined. Additionally, it shows the calculated W_i for each landcover class. In order for the accuracy to be accepted, the W_i must fall into similar ranges as the W_i in the results of the algorithm. In a previous chapter the allowed accuracy range was described. This range is 85% for the overall accuracy and 80& for the built-up class.

TABLE 5.22: MAPPED AREA PROPORTION

Landcover Class	Algorithm W_i	Accuracy W_i
1 – Water	0.0173	0.0166
2 – Fields	0.5027	0.6569
3 – Trees	0.3512	0.2489
4 – Quarry	0.0529	0.0532
5 – Built-up	0.0759	0.0243

At first glance, the numbers seem to be in similar ranges. The error matrix, however, also gives an accuracy for each landcover class in terms of the W_i value. This percentage value shows the accuracy of the algorithm in predicting each landcover class and the overall accuracy of the algorithm.

TABLE 5.23: ACCURACY PERCENTAGE OF LANDCOVER CLASSES

Landcover Class	Percentage Accuracy	Landcover area	Overall Accuracy
1 – Water	84%	0.0173	0.014532
2 – Fields	86%	0.5027	0.432322
3 – Trees	96%	0.3512	0.337152
4 – Quarry	38%	0.0529	0.020102
5 – Built-up	84.5%	0.0759	0.064136
SUM			86.8244%

The accuracy of each landcover class is calculated separately and summed up to show the accuracy of the complete analysis. As can be seen in the table above, the accuracy for each landcover class is relatively high. Only the landcover class of quarry is exceptionally low at 38%. After analysis of the results, it is determined that this is due to the fact that the spectral signature of the pixels located in the quarry and the pixels of the field class are fairly similar.

While it is not ideal to have a class with such low accuracy, the overall accuracy is determined to be 86.8244%. In the previous chapter, two requirements were set for the acceptance of the classification analysis. The two requirements are:

- The overall accuracy of the analysis must be at least 85%.
- The accuracy of the built-up class must be at least 80%.

With the overall accuracy being determined to be 86.82%, the first requirement for the classification to be accepted, is met. The second requirement is also met, with the built-up accuracy being 84.5%. As both requirements are met, the classification analysis is accepted and can be used in the landscape and visual impact assessment. However, as there is cadastre data available for this location, the cadastre information will be used in the comparison assessment instead.

5.7.2 Cadastre method

While the classification method is accepted for the landscape and visual impact analysis, using available cadastre information is more accurate. Therefore, if cadastre information is available, this data should be used. Cadastre information is different for each country and region of the world, thus, in order to properly compare different scenarios, a close look must be taken at the characteristics of the cadastre information.

The cadastre information available in Belgium is provided by the Belgian government for free, to be downloaded from the "Federale Overheidsdienst Financiën" (FEDERALE OVERHEIDSDIENST FINANCIËN, 2021) or the Geoportal of Wallonia (Government of Belgium, 2021). The data is accessible to individuals and businesses and can be used however the user deems necessary. The FOD financiën or the Geoportal of Wallonia must be mentioned as the owner of the data.

As every country provides a different format for each cadastre data set, the characteristics of the formatting of the available dataset must be examined carefully. The analyser is allowed to make decisions based on the data available at hand, however in order to compare different scenarios which use different cadastre datasets, the characteristic of the formatting used in the analysis must be the same. In the case of the Belgian data, the following datasets will be used in the analysis:

- Bpn_CaBu (FOD Financiën)
- VOIRIE_AXE (Geoportal of Wallonia)

The Bpn_CaBu data consists of shapefile polygons which represent the buildings in the area. Each polygon shows the geographical location of each building and its footprint.

The VOIRIE_AXE data consist of shapefile lines which represent the roads and footpaths in the area. Each line shows the geographical location of each road and path. Both datasets most be able to be manipulated in QGIS. The data will be described in the table below.

TABLE 5.24: DESCRIPTION DATASETS

Characteristic	**Dataset FOD Financiën**	**Dataset Geoportal of Wallonia**	
Dataset format	Shapefile (.shp)	Shapefile (.shp)	
	Polygon	Line	
Dataset area	Municipality	Province	
Dataset Subdivision	N/A	VCO	Communal roads
		CHA	Paths
		NTL	National roads

The FOD Financiën dataset is downloaded per municipality, thus multiple datasets need to be downloaded. These datasets are then merged and cut to the size of the canvas. The Geoportal of Wallonia dataset spans the entire province and thus only one dataset has to be downloaded and cut. With the data downloaded and inserted into QGIS, the data can then be grouped and manipulated to represent filter values.

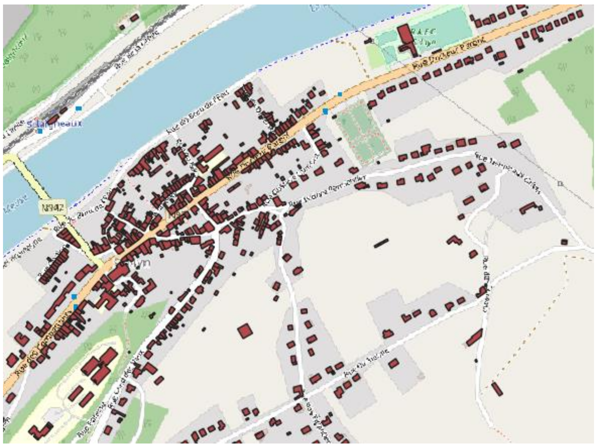


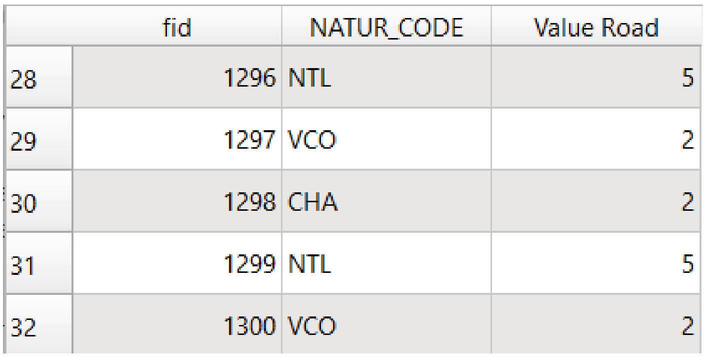
FIGURE 5.16: BPN_CABU IN QGIS

With the data cut to the canvas size, containing all data necessary for the analysis, the data can be assigned a value for the filter value. This is done at the liberty of the analyser and is specific to each case study. As the datasets used are all the same for each scenario and thus the designation of the filter value can be the same for each scenario.

TABLE 5.25: CADASTRE FILTER VALUES

Element	Description	Value
VOIRE_AXE_CHA	Footpaths and cycling paths	2
VOIRE_AXE_VCO	Local, destination roads	2
VOIRE_AXE_NTL	Regional, main roads	5
Bpn_CaBu	Homes, offices, shops and other urban infrastructure	10

Each element in the dataset is assigned a value associated with the classification in the table above.



	fid	NATUR_CODE	Value Road
28	1296	NTL	5
29	1297	VCO	2
30	1298	CHA	2
31	1299	NTL	5
32	1300	VCO	2

FIGURE 5.17: FILTER VALUE ASSIGNED TO EACH ELEMENT

The location and specifics of the cadastre elements is known. To input the cadastre data in the QGIS model, it must be determined if each 10-by-10-meter pixel, representing a 10-by-10-meter stretch of land in reality, contains one or multiple of these cadastre elements. The cadastre data is overlaid with the pixels. If a pixels overlaps with the cadastre data, the cadastre value is automatically input in the pixel. This cadastre value is then multiplied with the physical factor value to achieve the full visual impact value for each 10-by-10-meter pixel.

In the case of multiple cadastre elements being present in one pixel, the physical factor value is multiplied by all filter values.

$$Visual\ Impact\ Value = Physical\ Factor * Perception\ Filter$$

$$Visual\ Impact\ Value = Physical\ Factor * Bpb\_CaBu\ *\ VOIRE\_AXE\_(CHA/VCO/NTL)$$

This multiplication is done for every 10-by-10-meter pixel. By doing so, the severity of the pixel is recorded in a heat map and in a table. The heat map shows the severity for each pixel with a colour scale. The table shows the location and the ID of the pixel and the numerical visual impact value as the result.

5.8 Visual Impact Value

This multiplication of the physical factor and the perception filter are done for each scenario in the case study. By doing so, the total visual impact value of all scenarios is known in full, and thus can be compared for the final comparison. Firstly, the scenarios are compared in a heat map.

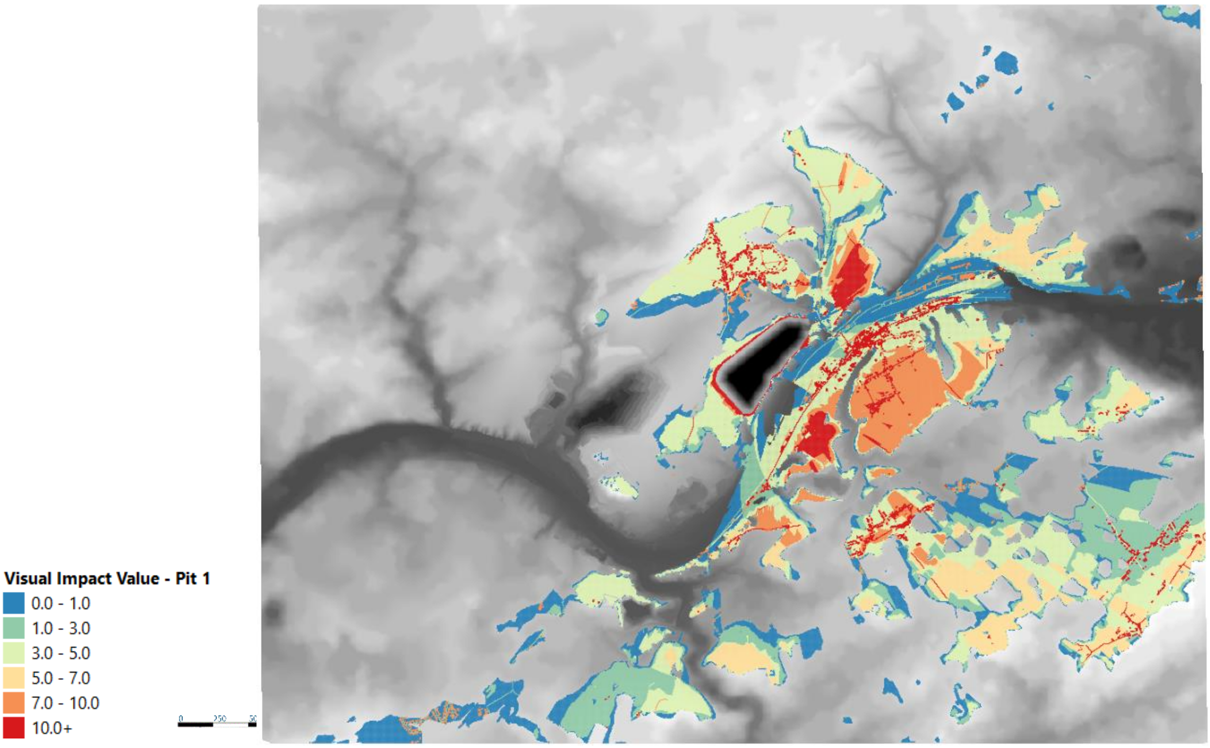
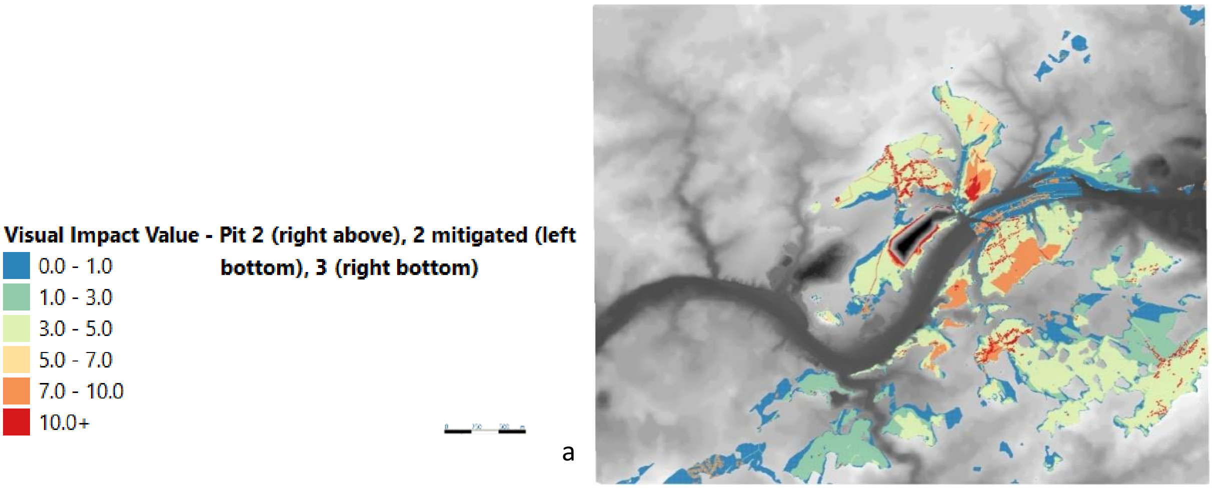


FIGURE 5.18: HEAT MAP VISUAL IMPACT VALUE SCENARIO 1

Clearer heat maps of scenario 2, scenario 2 mitigated and scenario 3 are to be found in the appendix. As can be seen in the heat map, the number of pixels which are classified as 10.0+ in visual impact value has increased greatly compared to the combined visibility severity.



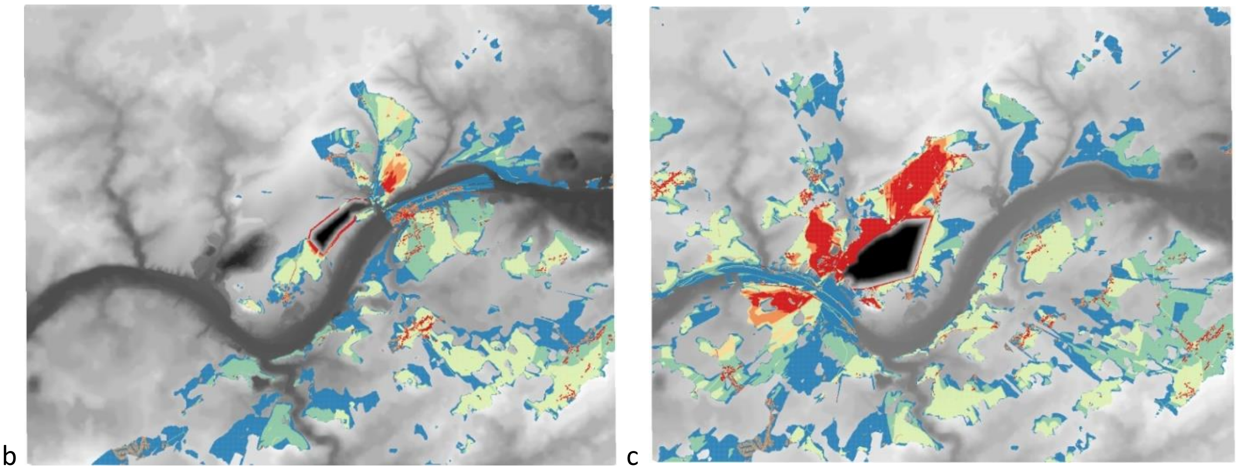


FIGURE 5.19: HEAT MAP VISUAL IMPACT VALUE SCENARIO 2 (A), 2 MITIGATED (B) AND 3 (C)

The heat maps show the visual impact on the surrounding landscape by the pitshell scenarios visually. The greyscale background of the heat map shows the pitshell elevation and the elevation of the surrounding landscape. If the greyscale background is visible, there is no visual impact on that section of the surrounding landscape. The heat map itself shows the total visual impact on the surrounding landscape using colours to represent the severity. The colours in this heat map are defined as below.

TABLE 5.5: COMBINED VISIBILITY ANGLE COLOUR CODE FOR HEAT MAP

Colour	Combined Visibility Severity
Blue	0.0 – 1.0
Dark Green	1.0 – 3.0
Light Green	3.0 – 5.0
Yellow	5.0 – 7.0
Orange	7.0 – 10.0
Red	10.0+

The heat map shows clearly the areas of built-up which are affected visually by the proposed pitshells.

The difference in heat maps for each scenario is clear to see. With pit scenario 2 being less impactful than pit scenario 1, and pit scenario 2 mitigated less impactful than pit scenario 2. Pit scenario 3 is impacting other areas than pit scenario 1, 2 and 2 mitigated, with a large area severely impacted on the northern and western side of the pitshell. Now to be able to properly compare the results, the scenarios are described in a numerical visual impact value.

TABLE 5.25: VISUAL IMPACT VALUE

Pitshell Scenario	Visual Impact Value	Accuracy	Normalized Visual Impact Value
Scenario 1	1,372,915	89.93%	1,526,589
Scenario 2	970,762	93.05%	1,043,290
Scenario 2 Mitigated	497,928	87.05%	571,996
Scenario 3	1,278,971	89.62%	1,427,105

The table shows the results of the visual impact value for each scenario as portrayed in the heat map for each scenario. The visual impact value column shows the non-normalized visual impact value. This is the value that comes out of the analysis when it is not adjusted for the accuracy of each scenario. This value cannot be compared with the value of other scenarios for that reason. It is therefore not entirely accurate to compare the heat maps visually, however, it gives a good impression of which areas, villages and cities are mainly affected by each scenario. Furthermore, it gives a good impression of which areas are affected more in different scenarios than others.

In order to properly compare the different scenarios, the visual impact value must be normalized to the accuracy of each scenario. With this normalization, it is possible to compare the values for each scenario. The comparison is made between pitshell 1 and each other pitshell.

TABLE 5.26: VISUAL IMPACT VALUE DIFFERENCE

Severity Difference Visual Impact Value	**Pit scenario 1**	**Pit scenario 2**	**Pit scenario 2 mitigated**	**Pit scenario 3**
Percentage (%)	0%	-31.7%	-62.5%	-6.5%

The comparison shows that the difference in visual impact of pit scenario 1 to pit scenario 2 and 2 mitigated has only increased. This is to be expected from the heat map, as can be seen on there that many villages fall outside of the zone of impact of pit scenario 2 and 2 mitigated compared to pit scenario 1.

Pit scenario 3 however, went from being more impactful than pit scenario 1 in the combined visibility angle, to 6.5% less impactful in the visual impact value. This is due to the fact that the zone of impact of pit scenario 3 envelops much less villages than pit scenario 1. Therefore, the visual impact is lowered compared to pit scenario 1.

In this case study, Lhoist is mainly concerned about the visual impact on the villages, roads and footpaths in the area. The impact on the fields is less interesting, as the local population will develop less opposition when areas where fewer humans affected. In order to understand this, a visual impact value of only the areas containing roads, footpaths and buildings (villages) was created.

In this case study, only the pixels containing either roads, footpaths, buildings or both are counted for the visual impact value. The filtering is done in excel, using the result table from the analysis in QGIS. After filtering, the filtered visual impact value is summed up and presented in a table.

TABLE 5.27: FILTERED VISUAL IMPACT VALUE FOR ROADS, PATHS AND BUILDINGS

Pitshell Scenario	**Accuracy**	**Normalized Filtered Visual Impact Value**	**Percentage of Visual Impact Value**
Scenario 1	89.93%	846,142	55.4%
Scenario 2	93.05%	528,990	50.7%
Scenario 2 Mitigated	87.05%	229,240	40.1%
Scenario 3	89.62%	533,034	37.4%

In the column of normalized filtered visual impact value, the visual impact value of only the pixels containing roads, paths and buildings is shown. In the column of the percentage of visual impact, the percentage of visual impact which comes from the pixels which contain roads, paths and buildings is shown compared to the total visual impact value of the entire scenario.

It shows that for pit scenario 1, more than half of the visual impact value comes from pixels that contain roads, paths and buildings. This percentage decreases for pit scenario 2 and scenario 2 mitigated, as well as pit scenario 3. This explains why the filtered visual impact value for pit scenario 3 is lower than for pit scenario 1.

With the normalization of the filtered visual impact value, the pit scenarios can be compared in terms of visual impact for areas containing roads, paths and buildings.

TABLE 5.28: FILTERED VISUAL IMPACT VALUE DIFFERENCE

Severity Difference Filtered Visual Impact Value	Pit scenario 1	Pit scenario 2	Pit scenario 2 mitigated	Pit scenario 3
Percentage (%)	0%	-37.5%	-72.9%	-37.0%

With the visual impact of the different pit scenarios known, the next and final step of the analysis can be executed. The economic impact of each pit scenario and comparison of the different scenarios.

5.9 Economic Impact

Lhoist is using the total content of chemical ore in kilo tons in the pitshells to determine the economic impact of the pit scenarios. The chemical ore content of the pitshells has been determined using volume calculations in SURPAC. The data was acquired from previously execute borehole analysis conducted for Lhoist. In addition to chemical ore, which is the main product being extracted by Lhoist, the pitshells also contain non-chemical ore which can be used for aggregates. As this is not the primary product sold by Lhoist, but can still be sold, it is used in the calculation of the total mass moved, the stripping ratio and the mining yield.

The formulas used to calculate these figures are shown below.

$$Stripping\ Ratio = (OVB + HNO)/\ (CHO + NCHO)$$

$$Mining\ Yield = (CHO + NCHO)\ /\ Total\ Mass\ Moved$$

$$Accessible\ CHO\ per\ Surface = (CHO\ /\ Ha)$$

$OVB = Overburden$
$HNO = Hard\ non\ Ore$
$CHO = Chemical\ Ore$
$NCHO = Non\ Chemical\ Ore$

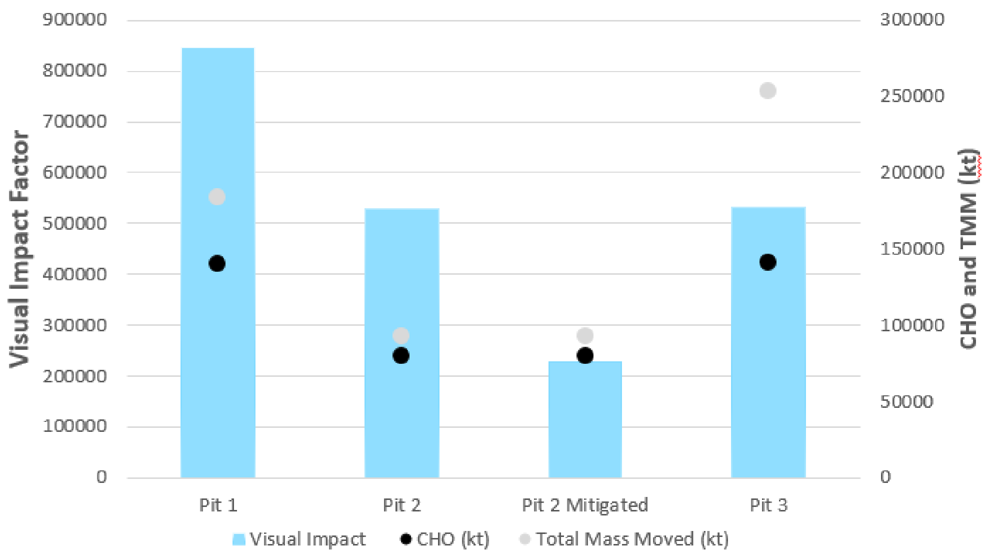
The results of this analysis are shown in the table below.

TABLE 5.29: FILTERED VISUAL IMPACT VALUE DIFFERENCE

Economic Impact	Pit scenario 1	Pit scenario 2	Pit scenario 2 mitigated	Pit scenario 3
CHO (kt)	140,133.6	79,732.0	79,732.0	141,167.8
Total Mass Moved	184,166.9	92,688.9	92,688.9	253,658.3
Stripping Ratio	0.15	0.08	0.08	0.27
Mining Yield	0.87	0.92	0.92	0.92

As can be seen in the table, pit scenario 1 and pit scenario 3 contain similar amount of chemical ore, this is to accurately compare the scenario of starting a greenfield quarry or to expand the current quarry. Pit scenario 2 has a little more than half of the content of pit scenario 1. In the following graph the figures are shown visually.

GRAPH 5.1: ECONOMIC IMPACT AND VISUAL IMPACT COMPARISON



The light blue bars represent the visual impact value of the different pit scenarios. The number is linked to the left y-axis, with the higher the impact. The higher the visual impact, the bigger the light blue bar. The dark blue dot represents the chemical ore content of the pitshell scenario. The chemical ore content is linked to the right y-axis. The higher the dark blue dot, the higher the CHO content. The light grey dot represents the total mass moved; this includes all materials present in the pit shell. The right y-axis is linked to the total mass moved. The higher the grey dot, the more total mass moved.

The decision-making process of the trade-off between economical gain, visual impact and many other aspects that are associated with the selection of different pitshell scenarios, are at the discretion of the company. The landscape and visual impact study serves merely as a determination of the visual impact of the different pit scenarios. The weight that is given to this analysis when comparing economic gain against visual impact is up to the discretion of the company.

6 Discussion

As was set out at the start of this thesis, the tool developed in this study must meet the four demands set out on the basis of the literature study. By meeting these four requirements, the tool can be used to assess and compare different pitshell scenarios in terms of landscape and visual impact across the world. The requirements set out in the beginning of this study were:

- Repeatability
- Objectivity
- Comparability
- Universality
- Pre-feasibility

In order to conclude this study as being successful, these five requirements set out must be met by the tool which was described and tested in this thesis. Now the tool must be evaluated against these requirements. This is done by assessing the definition of all four requirements and comparing these to the tool. The description of the four requirements is shown below:

TABLE 6.1: DESCRIPTION OF THE FOUR REQUIREMENTS

Repeatability	The evaluation and result of an assessment of the visual impact of an surface mine operation must be able to be reproduced when the same data is used.
Objectivity	The evaluation and result of an assessment of the visual impact of an surface mine operation must be reached by taking exclusively objective decisions.
Comparability	Two distinct evaluations and results of an assessment of the visual impact of an surface mine operation must be comparable between one another.
Universality	The evaluation and result of an assessment of the visual impact of an surface mining operation must be universally accessible and usable globally.

Now for each factor of the requirements, the tool will be set out and compared to assess whether the tool meets the requirements. All the steps in the tool will be analysed for each of the four requirements.

6.1 Repeatability

Firstly, repeatability is compared against the tool. In order for the tool to be deemed reliable, the tool must give the same result or a result within acceptable range when you repeat the entire analysis. This is guaranteed by the fact that most steps of the analysis require no interpretation of the data. The steps follow from one another from the moment the data is inserted in the analysis.

The data evolves from step to step without any input form the VIA professional. The steps in the analysis are performed merely by inserting the data into an algorithm in QGIS, which returns the result. In the following table, each step of the tool is described and compared to the repeatability requirement.

TABLE 6.2: REQUIREMENT REPEATABILITY – TOOL STEPS

Tool Step	Description of Repeatability	Repeatability	
Vertical visibility angle	Automatically placed targetpoints on the benches, QGIS algorithm calculates the distance and angle.	Full	V
Horizontal visibility angle	Semi-manually placed targetpoints on the crest, QGIS algorithm calculates the distance and angle. By requiring an 85% accuracy limit, repeatability is met.	Accuracy requirement + Full if using AutoCAD	V
Combined visibility value	Multiplying the vertical and horizontal visibility range for each 10-by-10-meter pixel provides the same result when the visibility angle information is not changed.	Full	V
Chromatic difference	Chromatic difference uses a randomized algorithm to select 10 different pixels to represent the colour of the landscape or the ore/overburden. By taking 10 pixels, the repeatability and accuracy is ensured. It is possible to use more pixels, however 10 is chosen as the minimum requirement.	Full	V
Classification algorithm	The classification algorithm contains manually selecting and classifying pixels in order to train the algorithm, this creates repeatability issues. By setting an 85% and 80% accuracy limit, repeatability can be kept up within acceptable ranges.	Accuracy requirement	V
Cadastre information	Cadastre information is provided by the government of the country in which the analysis takes place, repeatability of results is guaranteed by the nature of the data used in this step.	Full	V
Total visibility value	The multiplication of the steps and combining of all data known in the analysis is done using a set, non-interpretable formula and will allow for the same result to occur when repeating this step.	Full	V

In the case of the classification algorithm and the horizontal visibility angle analysis, where the VIA professional must select either ROIs or horizontal targetpoints manually, the 85% accuracy requirement ensures that the result of the analysis falls within acceptable bounds of repeatability. In order to further proof the repeatability of the tool, the analysis of the pit scenarios in the case study must be repeated in the tool to see if the results are the same or within 85% bounds of repeatability.

6.2 Objectivity

In order for the tool to be deemed objective, the tool must have no subjective choices or decisions to be made. With solely objective choices, the analysis can be made by any VIA professional and will achieve the same result. To ensure objectivity, all steps in the process must only include objective decision-making parameters and should leave no space for the VIA professional to make a decision based on his own opinion. The table below shows each step of the tool and whether the steps fall within the objectivity requirement of this analysis.

TABLE 6.3: REQUIREMENTS OBJECTIVITY – TOOL STEPS

Tool Step	Description of Objectivity	Objectivity	
Vertical visibility angle	Automatically placed targetpoints on the benches, there is no human input on the selection of the observer- and targetpoints. This ensures objectivity.	Full	V
Horizontal visibility angle	Semi-manually placed targetpoints on the crest. By requiring an 85% accuracy limit, objectivity is met. Furthermore, by using the path array tool of placing horizontal targetpoints in AutoCAD, there is no manual placement. This ensures or ensures by accuracy the objectivity.	Accuracy requirement + Full if using AutoCAD	V
Combined visibility value	Multiplying the vertical and horizontal visibility range for each 10-by-10-meter pixel is done with a multiplication formula which is set in stone. This ensures objectivity.	Full	V
Chromatic difference	Chromatic difference uses a randomized algorithm to select 10 different pixels to represent the colour of the landscape or the ore/overburden. The formula with which the chromatic difference is calculated is set in stone and these two facts ensure objectivity.	Full	V
Classification algorithm	The classification algorithm contains manually selecting and classifying pixels in order to train the algorithm, this creates objectivity issues. By setting an 85% and 80% accuracy limit, objectivity can be kept up within acceptable ranges.	Accuracy requirement	V
Cadastre information	Cadastre information is provided by the government of the country in which the analysis takes place, objectivity of results is guaranteed by the nature of the data used in this step.	Full	V
Total visibility value	The multiplication of the steps and combining of all data known in the analysis is done using a set, non-interpretable formula and will guarantee the objectivity of the results.	Full	V

All steps in the process are objective, where one step follows from another without any input from the VIA professional. In the case of the classification algorithm and the horizontal visibility angle analysis, where the VIA professional must manually select either ROIs or horizontal targetpoints, the 85% accuracy requirement ensures that the objectivity level is met.

6.3 Comparability

To meet the comparability requirement, the results of the analysis of different pitshell scenarios must be able to be compared to one another. By doing this comparison, a percentage value must be given which represents the difference between the two pitshell scenarios in terms of visual impact. In order to compare the results, the base data of the results and the method used in order to reach the results must be the same. The basic requirements of objectivity and repeatability already assist in the meeting of the requirement of comparability. In the different tool steps, safety features and rules are built in to ensure comparability for the whole tool.

In each tool step, the base data used to conduct the tool step must be the same for each pitshell scenario used in the analysis. If the base data is not the same, this must be mentioned in the analysis and any comparison cannot be accepted by the tool. For each tool step, the base data used must be recorded in the report and the specifics of the data must be shown for each data set. By comparing the base data used in each scenario to one another and ensuring that the base data is the same for each scenario, comparability can be guaranteed in this tool.

6.4 Universality

To ensure universality in this tool, the tool must be usable for all people interested in the landscape and visual impact analysis across the world. The results must be simple enough to be understood by the local population viewing the results, and the data used in the analysis must be accessible all over the world in order to guarantee comparability of the scenarios. The table below shows a more detailed description of the universality of the data needed in the analysis.

TABLE 6.4: REQUIREMENTS UNIVERSALITY – TOOL STEPS

Tool Step	**Description of Universality**	**Universality**
Vertical visibility angle	The base data used for the vertical visibility angle is a digital elevation model, which can be downloaded and manipulated using free sources and software. Furthermore, the way the results are presented (as visibility angles) makes it easy for the results to be read by any reader of the report. This ensures universality.	V
Horizontal visibility angle	The base data used for the horizontal visibility angle is a digital elevation model, which can be downloaded and manipulated using free sources and software. Furthermore, the way the results are presented (as visibility angles) makes it easy for the results to be read by any reader of the report. This ensures universality.	V
Combined visibility value	The combined visibility value is achieved by manipulating the data with simple formulas and operations in QGIS, a free, open source software accessible by all. This guarantees universality.	V
Chromatic difference	The data needed to calculate the chromatic difference is available for free download from several open source satellite image agencies, furthermore the Semi-Automatic Classification Plug-in (SACP) in QGIS, a free, open source plugin, enables everyone to easily download and manipulate the data for free.	V
Classification algorithm	The classification method uses data from free, open-source satellite images. The classification method uses a free, open-source plug in called the SACP to execute the analysis. This ensures universality.	V
Cadastre information	Cadastre information is by definition free, open-source data provided by a government agency. Therefore, if the data are available in the region in which the VIA professional operates, universality is guaranteed. If the data are not available, there remains the classification method which ensures universality.	V
Total visibility value	The final multiplication and summation operations use a simple formula which can be used universally.	V

By determining that the five guiding principles are met, either fully or by partial accuracy assessment explained in previous chapters, the tool developed in this thesis can be accepted. The tool can be used as a guideline to assess and compare the visual impact of different pitshell scenarios. The five research questions have been answered in a positive way and thus, the hypothesis can be accepted. The result of this thesis is therefore that:

“It is possible to assess the visual impact of surface mining pitshells in the pre-feasibility phase of development.”

6.5 Further discussion

As the tool is based on a modelled approximation of reality, there will be errors due to the nature of the data used. This chapter will discuss any issues or opportunity discovered during the process of this study.

The tool models reality and is only as accurate as the data that is put into it. Therefore, the results of the analysis must not be taken as full fact. The results of the analysis can be used as an estimation.

It is impossible to validate the tool on accuracy until the pitshell scenarios analysed in this study are fully developed. This means that it is impossible to assess the accuracy of the results of this tool until the far future. Therefore, the results must not be taken as fact yet, but further research is necessary to further confirm accuracy.

As the analysis is done during the pre-feasibility phase, the data used in the analysis is limited in detail and accuracy. Once a pitshell scenario is chosen it is beneficial to redo the analysis again when more data is known about the pitshell. Furthermore, the analysis is done on the final pitshell scenario, the most impactful. Thus, when scheduling scenarios are known the analysis can be done again for significant scheduling stages.

The tool utilizes a digital terrain model, this means that the model used represents only the terrain at ground level and does not include the buildings, trees and vegetation that are present in the landscape. This is due to the fact that, if a DSM model was used, the observerpoints would be placed on top of the trees and buildings, instead of inside of them or at the ground level. Therefore, in areas with dense forest or other vegetation or villages, the visibility might be obstructed, but this obstruction is not shown in the analysis. In the appendix, an image is shown which shows this phenomenon in the case study.

7 Conclusion

With the methodology and case study finished, the tool developed in this study must now be validated in order to accept the hypothesis set out in the beginning of this study. The hypothesis is:

“It is possible to assess the visual impact of surface mining pitshells in the pre-feasibility phase of development.”

In order to validate the hypothesis, the research questions set up at the start of this study will be answered. Furthermore, the guiding principles will be compared against the developed tool to assess if the tool adheres to the GAP analysis following from the literature study.

7.1 Research questions

In order to validate the tool and accept the hypothesis, the research questions are repeated and answered. The following research questions were asked at the start of this study:

- Is it possible to eliminate the use of subjectively chosen viewpoints in the visual impact assessment of surface mining operations in the pre-feasibility phase?

It is possible to eliminate the subjectively chosen viewpoints in the visual impact assessment. By inserting observerpoints (viewpoints) which are placed by an algorithm in a regular grid across the landscape, the viewpoints are no longer selected by a (subjective) VIA professional.

- Is it possible to determine the physical change of the landscape before this physical change has occurred?

It is possible to determine the physical change of the landscape before this physical change has occurred. The physical change in the landscape is divided into two categories: extent of the visible alteration and the chromatic change between the landscape and the exposed ore and overburden.

The extent of the visible alteration can be determined with digital terrain models and the assessment of the visual impact angle subtended by the modelled change in the landscape. The model can be developed without breaking ground. The chromatic change in the landscape can be assessed using currently available data (of overburden and ore colour) as well as current landscape colour. The expected ore or overburden colour can be assessed using satellite images of (nearby) similar quarries or mines. The colour extraction can be conducted without uncovering the ore or overburden.

- Is it possible to define perception, a subjective element, as an objective element in the visual impact analysis of surface mining operations?

It is possible to define perception as an objective element. The perception can be described as the duration at which a person is viewing the operation and the setting in which the person is viewing the operation. This can be translated into a numerical value and used in concrete, objective calculations.

- How are the physical changes in the landscape, cause by the surface mining operation, described in relation to the visual impact on humans?

In order to translate the extent of the physical change in appearance, the change is described in a visual angle. This visual angle is graded in severity based on the human field of vision, this makes the reader of the study able to translate the figures into a relatable view or feeling. The chromatic difference, using the CIE Lab colour model, is based on the way humans perceived colour and colour difference. Furthermore, the chromatic difference factor is described in a factor of change barely visible by humans.

By translating these objective elements into elements which are related to the human scale, the physical change in the landscape can be described in the relation to the visual impact on humans.

- Is it possible to compare visual impacts of different surface mining operations?

By creating a purely numerical value of visual impact for each scenario, it is possible to compare different visual impacts of different surface mining operations. The way of acquiring these numerical values must be identical and objective in order to be able to compare the values.

8 Recommendations

The tool can be refined and improved upon to better suit every scenario. The following recommendations should be taken into account:

- The visible impact analysis is not the only aspect which is researched before a pitshell is chosen. The VIA professional and the mine planner must assign a weighted value to the analysis. This weighted value shows the importance of the analysis in the decision-making process. The VIA professional should also assign a confidence factor to the analysis. If the analysis was based on low quality data, a lower weighted value can be assigned.
- As was said in the discussion, areas that show high visibility in the analysis have the potential of being blocked by trees or other vegetation which does not show up on the DTM. In further research, it would be possible to model areas of significant visibility blockage in the original DTM, as is done with the mitigation modelling in scenario 2 mitigated. Areas of dense forests can be modelled in the DTM to represent reality. The current analysis results is a worst-case scenario when it comes to obstruction of view of the operation by the landscape.
- The analysis tool is currently fully manual, there are no steps in the process which are automated. In order to increase the speed at which an analysis can be executed, it would be beneficial to automate all or some steps of the process.
- The optimal number of observer- and targetpoints should be researched to optimize processing time.
- This thesis and tool focusses on surface mining operations only. However, the tool could also be useful for underground mines. This is due to the fact that underground mining operations generate waste which must be stored somewhere. This waste can have a visual impact on the landscape and on the surrounding communities. The tool can be adjusted to also work for tips, tailings and other mining features.

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Appendix

A.1 Osculation effect

The osculation effect comes from the nature of the analysis. As we are working with a model of reality, the results will never be entirely accurate, unless we model thousands of arms and thousands of targetpoints. To determine the optimal (or acceptable) balance between the amount of data and the accuracy a calculation is done.

The calculation is done on a point on the edge of the crest of the pit to test the “worst-case” scenario. The osculation will always be less than in the example shown below.

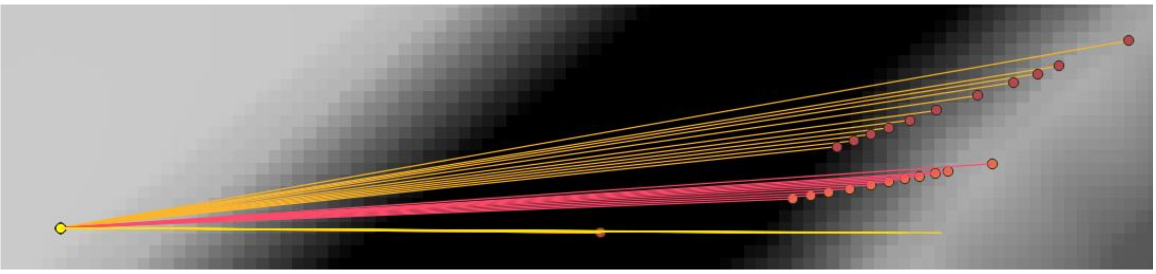

FIGURE A.1: OSCULATION CALCULATIONS

The vertical angle calculations are conducted for an observerpoint at 0 degrees, 10 degrees and 20 degrees removed from the centre line. By comparing the difference between the results, the osculation can be determined.

TABLE A.1: OSCULATION CALCULATIONS DIFFERENCE

Degree separation	Vertical visibility angle	Difference
0	2.133436873	0%
10	2.83820769	+28.83%
20	3.840941224	+44.46%

As can be seen in the results, while the 20-degree angle would greatly reduce the amount of processing time, it has a very inaccurate result. The perfect result would obviously be the 0-degree angle; however this would generate too much data and processing time. While the 10-degree gives a 28.83% accuracy error, the 10-degree armshed has shown to be on the limit of the capabilities of the current process time and hardware abilities. Therefore, the 10-degree angle is accepted for this analysis. In further research, the range can be determined even closer to the optimal.

A.2 Vertical Visibility Angle

Vertical visibility angle results

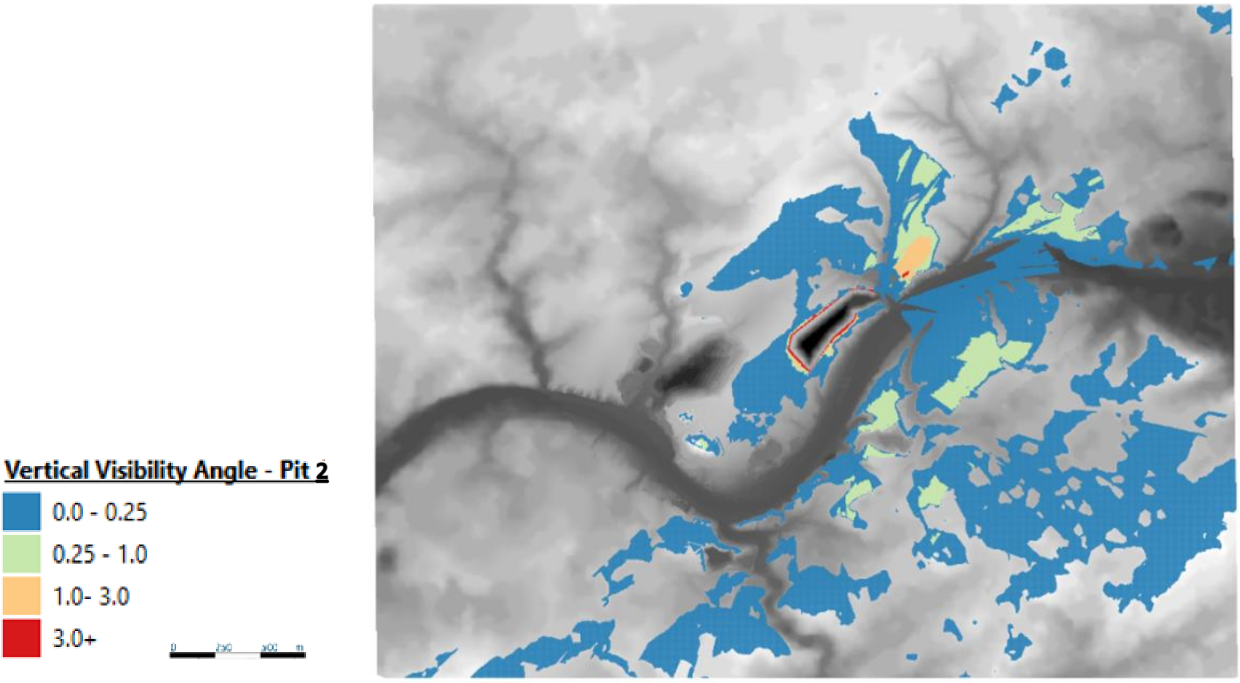

FIGURE A.2: HEAT MAP VERTICAL VISUAL ANGLE VALUE SCENARIO 2

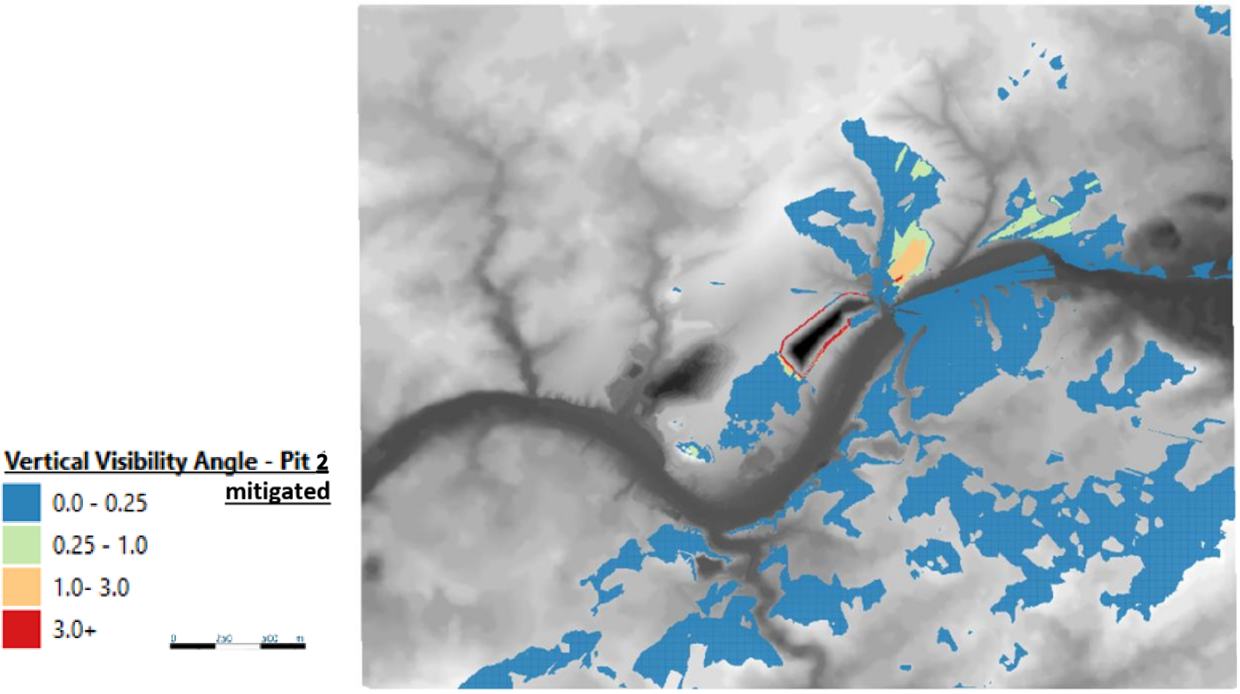

FIGURE A.3: HEAT MAP VISUAL IMPACT VALUE SCENARIO 2 MITIGATED

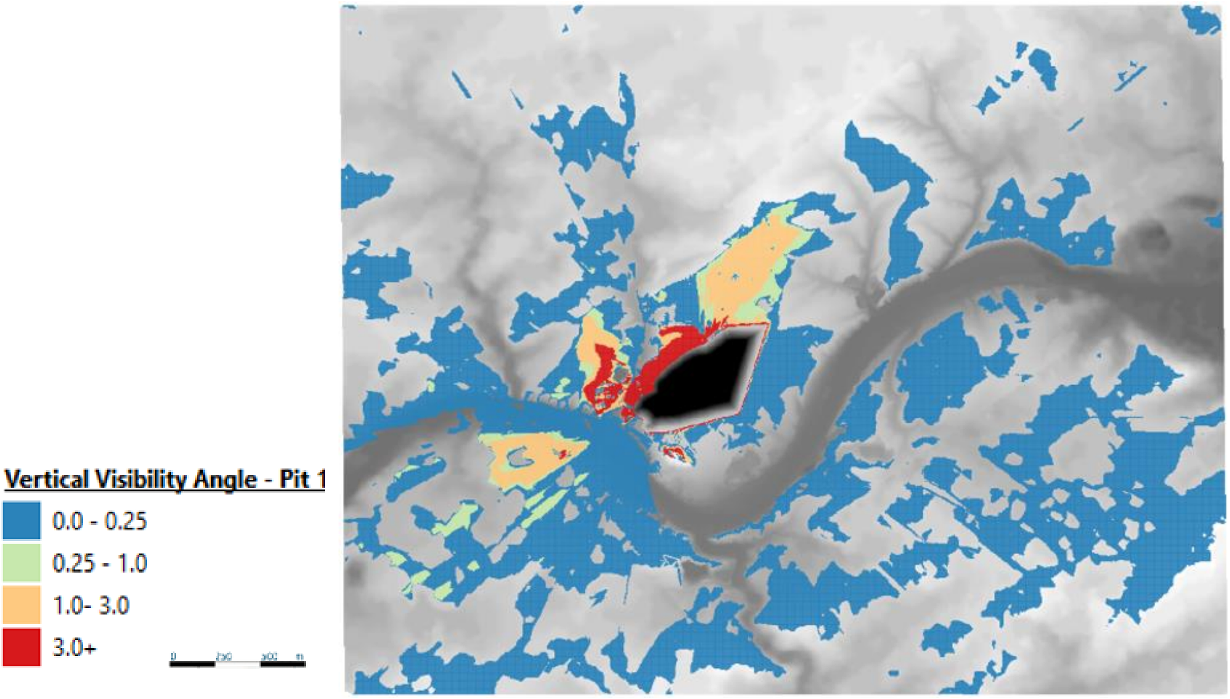

FIGURE A.4: HEAT MAP VISUAL IMPACT VALUE SCENARIO 3

A.3 Horizontal Visibility Angle

Horizontal visibility angle results

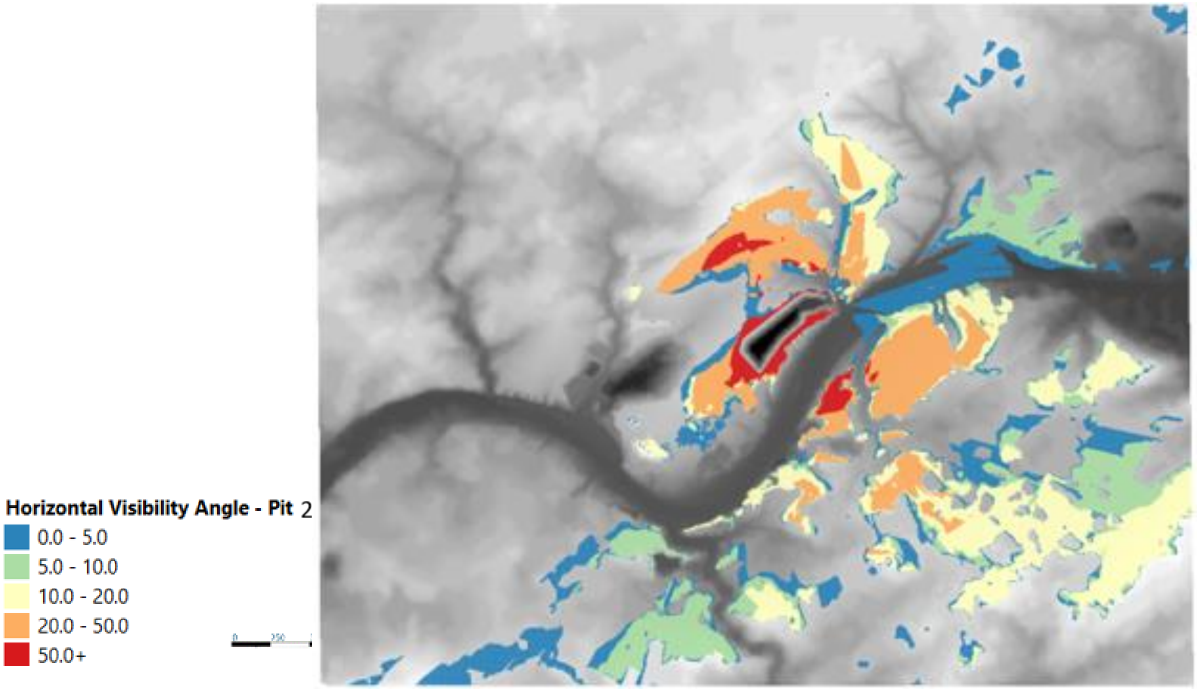

FIGURE A.5: HEAT MAP HORIZONTAL VISUAL IMPACT VALUE SCENARIO 2

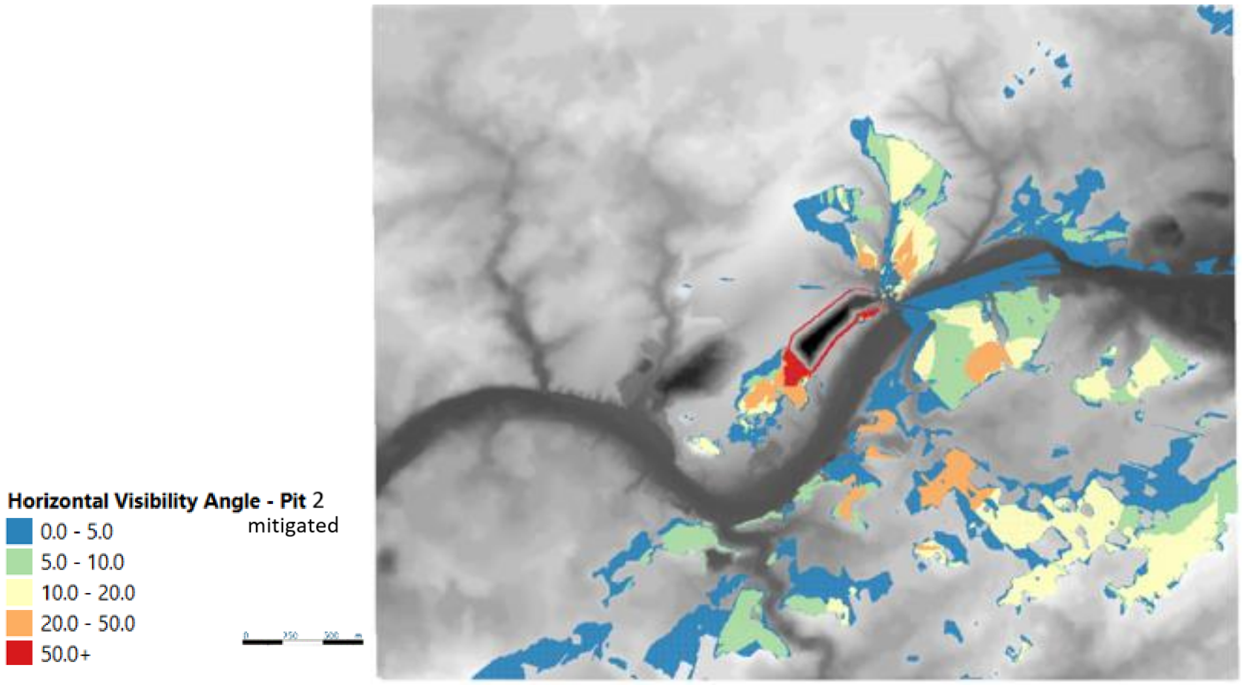

FIGURE A.6: HEAT MAP HORIZONTAL VISUAL IMPACT VALUE SCENARIO 2 MITIGATED

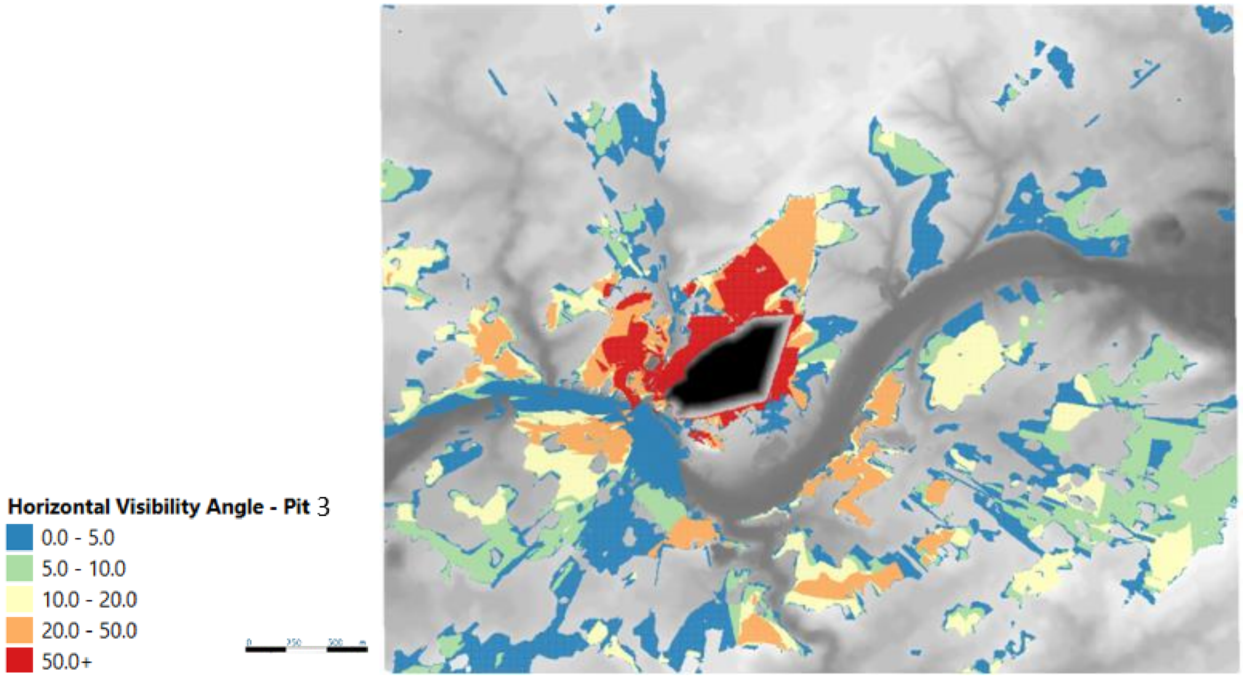

FIGURE A.7: HEAT MAP HORIZONTAL VISUAL IMPACT VALUE SCENARIO 3

A.4 Combined visibility angle

Combined visibility angle results

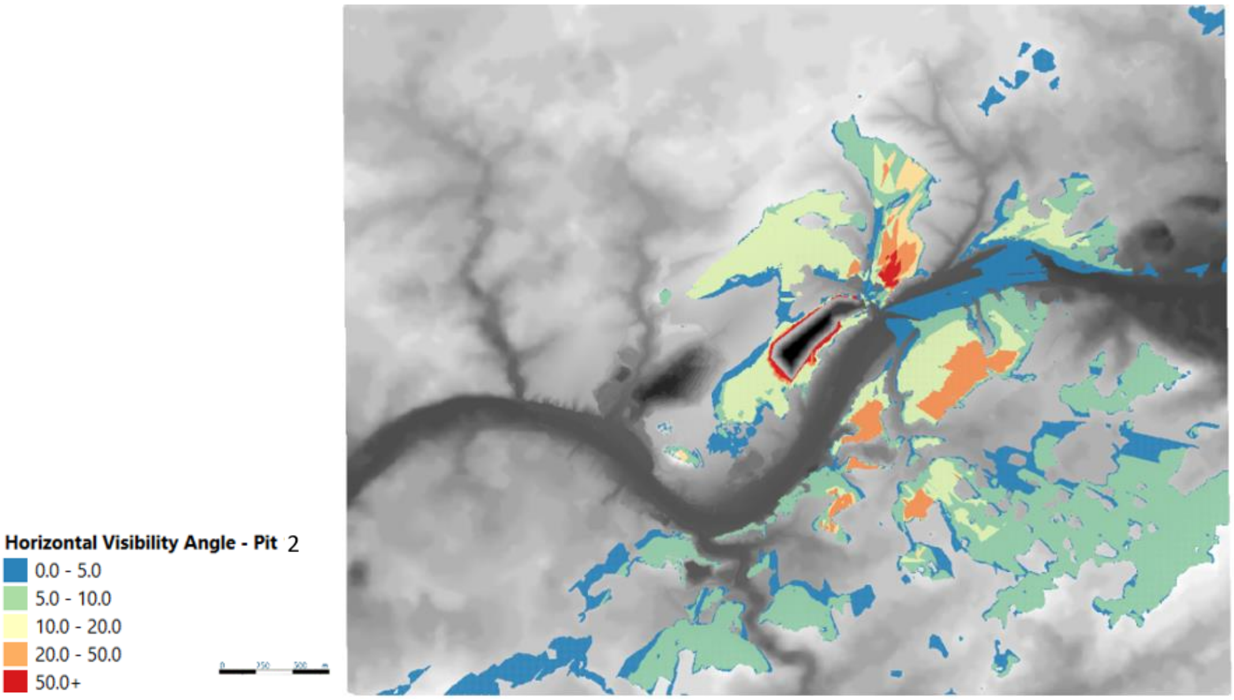

FIGURE A.8: HEAT MAP COMBINED VISUAL IMPACT VALUE SCENARIO 2

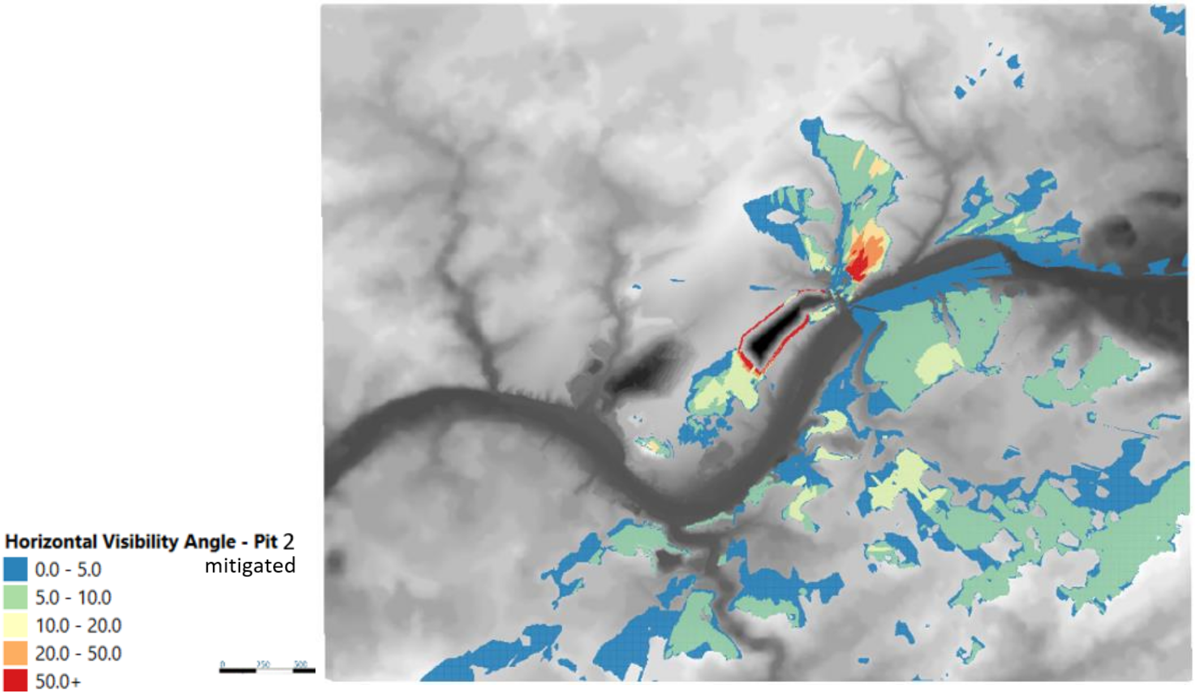

FIGURE A.9: HEAT MAP COMBINED VISUAL IMPACT VALUE SCENARIO 2 MITIGATED

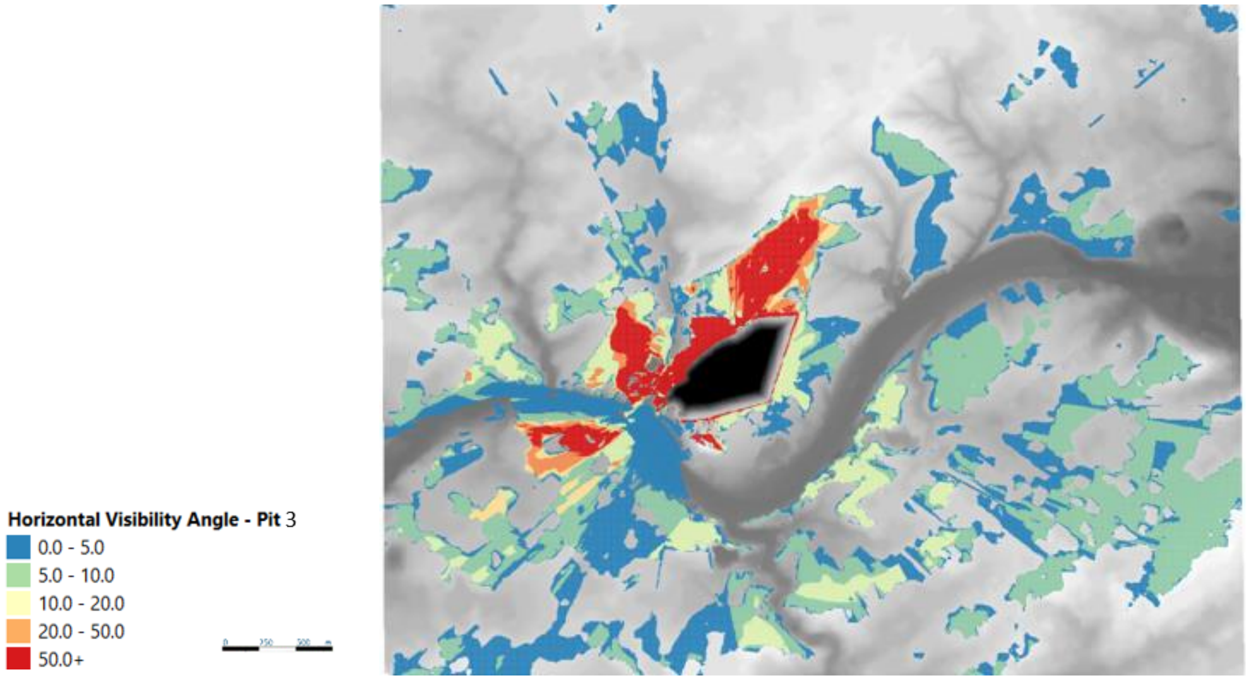

FIGURE A.10: HEAT MAP COMBINED VISUAL IMPACT VALUE SCENARIO 3

A.5 Visual impact value

Visual impact value results

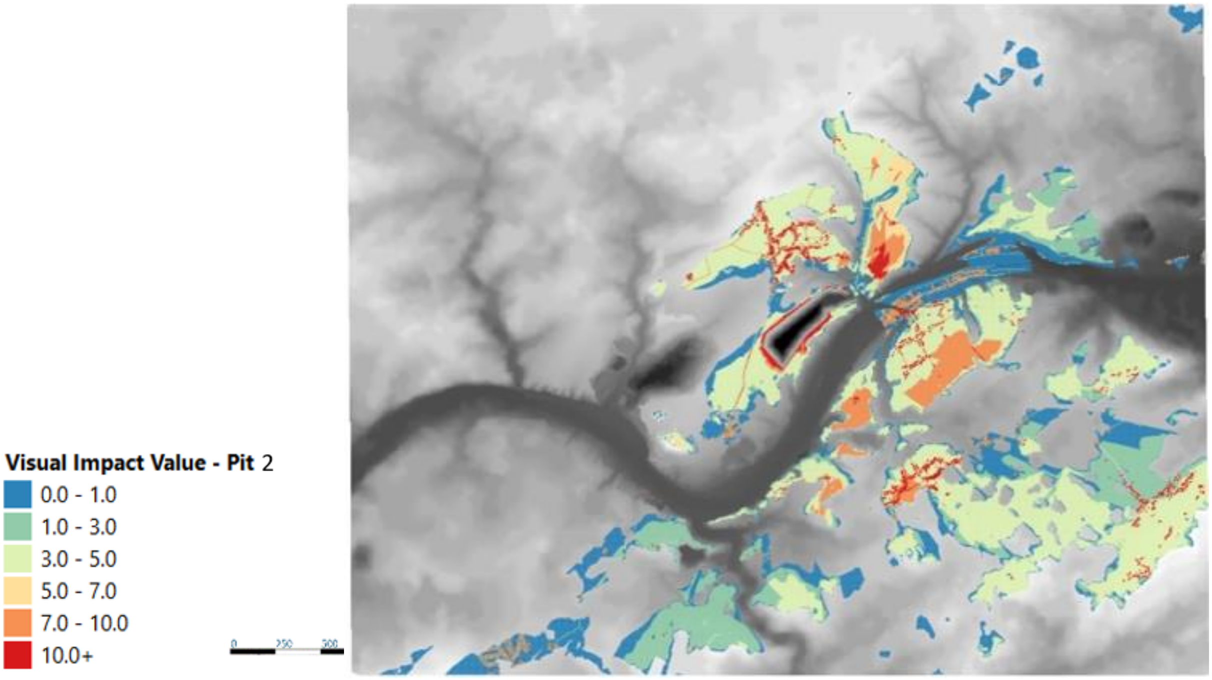

FIGURE A.11: HEAT MAP VISUAL IMPACT VALUE SCENARIO 2

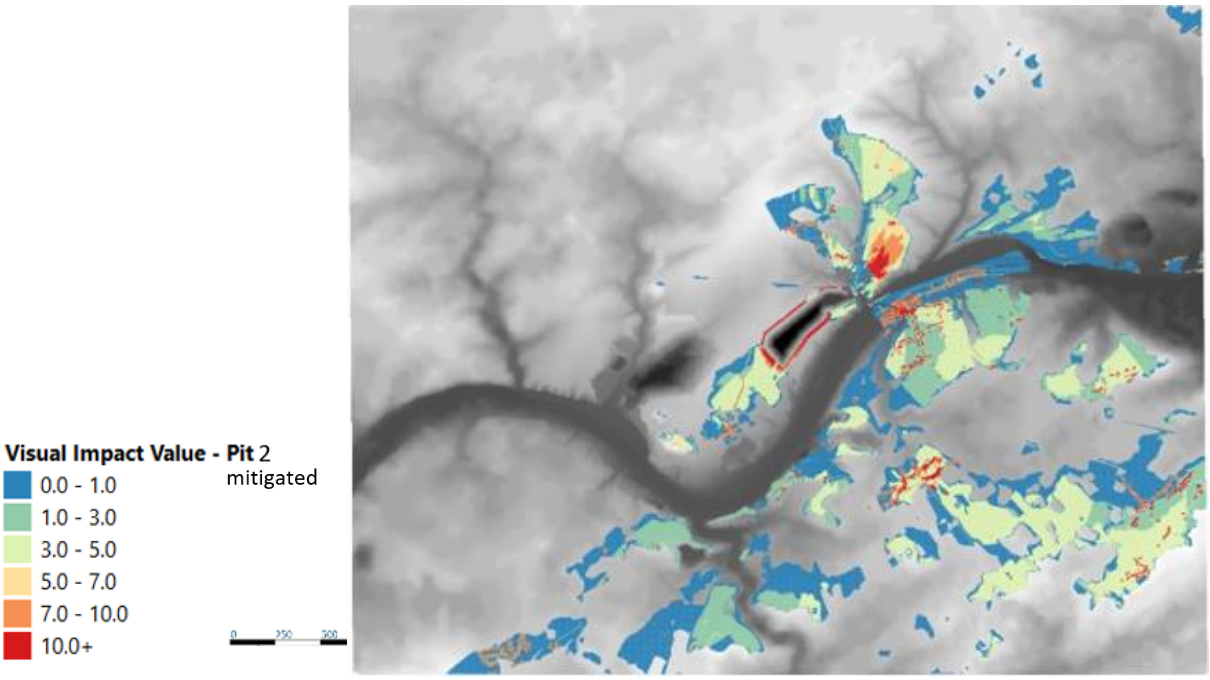

FIGURE A.12: HEAT MAP VISUAL IMPACT VALUE SCENARIO 2 MITIGATED

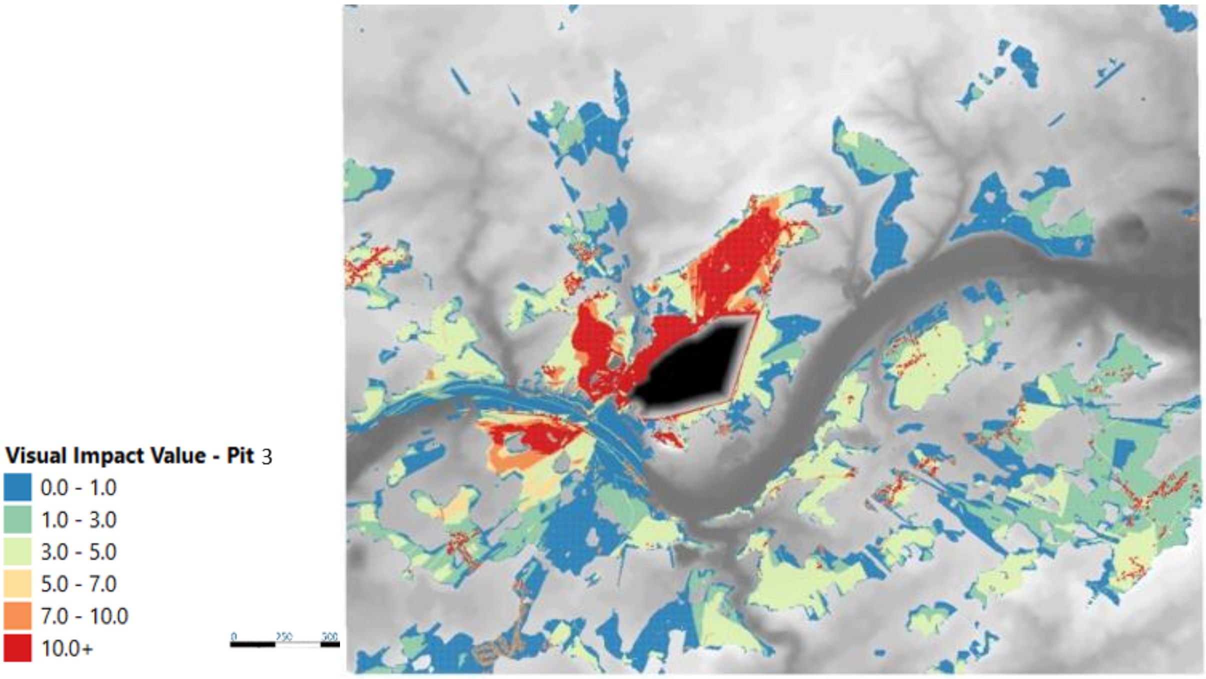

FIGURE A.13: HEAT MAP VISUAL IMPACT VALUE SCENARIO 3

A.6 Discussion – DTM and vegetation mitigation

The images are taken on site of certain viewpoints in which there is at least some visibility of the proposed pitshell. As can be seen in the photographs, the view of the proposed pitshell is either fully or partially blocked by vegetation.

FIGURE A.14: DTM – VEGETATION MITIGATION

Step by Step Method Explanation

This method generates a lot of data and results. In order to keep the data nicely organized, folders must be created for each data type and must be sorted by order of use. The folder order is shown below the document. After creating data, ensure that it has the correct name and is inserted in the right folder to ensure correct results and clarity for any other user.

[…] = folder name and location

<…> = File name

Surpac – Base data creation

Any software program can be used which can create digital elevation models (.dtm) and string files (.str) which can be exported into AutoCAD files (.dxf). Surpac is used in this case study as this is the standard program used to conduct pit design.

Needed data:

- DTM of the local landscape for the extent of the canvas.

Method steps:

1. Design the desired pitshell in SURPAC.
2. Create a DTM of the pitshell.
3. Export the outermost string of the pitshell as a cutting string.
4. Cut the Stringfile of the local landscape with the cutting string and delete the inside.
5. Place the Stringfile of the pitshell into the stringfile of the local landscape.
6. Create a DTM of the total landscape with pitshell inserted.
7. Export the DTM. [01_SURPAC/02_Landscape_DTM] <YYMMDD_Landscape>
8. Delete all “toe” strings of the pitshell Stringfile (leave all “crest” strings and the final toe string)
9. Export the “crest” Stringfile as a .dxf file. [01_SURPAC/01_Pit_Stringfile] <YYMMDD_Stringfile>

Leapfrog – ASC creation

Leapfrog is used as Surpac does not have the ability to create .asc files (which are needed for the QGIS plugin used in the analysis).

Needed data:

- DTM of the total landscape created in Surpac

Method steps:

1. Import the DTM into leapfrog.
2. Export the DTM as elevation grid.
3. Choose the X-Y size of the cells of the grid (in this case: 10-by-10-meter)
4. Export the .asc file. [02_Leapfrog] <YYMMDD_Topography_Scenario_1>

AutoCAD –Targetpoint creation

AutoCAD is used to create and place the targetpoints of the intervisibility analysis. A distinction will be made between the vertical visibility angle and the horizontal visibility angle. Furthermore, AutoCAD is used to create the "arms" and subsequent armsheds which filter the intervisibility analysis to reduce process time and to create correct results.

Needed data:

- Pitshell "crest" string file

Method steps:

AutoCAD – Vertical Visibility Angle

1. Add pitshell "crest" stringfile to new AutoCAD file.
2. Find geometric center point of the lowest elevation string.
3. Export geometric center as .dxf file. [03_AutoCAD/01_Infrastructure] <YYMMDD_Geometric center_Scenario_1>
4. Create a line from the center point at 90-degree orientation, intersecting the highest elevation string.
5. Conduct polar array to create 36 lines at 10-degree intervals.
6. Draw one point on the geometric center of the pitshell.
7. Draw points on each intersection between the arm and the string lines starting from the upper-bound string down to the lower-bound string. Finish each arm (from highest elevation line to lowest elevation line) before moving onto the next arm.
8. Export the geometric center point and all points of one arm to a new AutoCAD file.
9. Save .dxf point files for each arm. [03_AutoCAD/02_Vertical_Arm] <YYMMDD_Vertical_Entitypoints_Arm_1>
10. Create filter for observer-point selection for each arm (armshed).
11. Cone of interest is 10 degrees wide with 5 on each side of the line of the arm, starting from the center point of the arm spiral.
12. Length of the lines must be more than half of the length of the canvas at least.
13. Export the center point and the 2 armshed points for each cone as a separate .dxf file in the same folder as the arm points. [03_AutoCAD/03_Vertical_Armshed] <YYMMDD_Vertical_Armshed_Arm_1>
14. Repeat these steps for each arm.

AutoCAD – Horizontal Visibility Angle

- Load "crest" string files, center point (from vertical analysis) and 90-degree center-point line to new AutoCAD file.
- Conduct polar array to create 18 lines at 20-degree intervals. These much stretch to the end of the canvas.
- Draw a cone of interest for each armshed according to the guiding lines.
- Export two external (at the end of the guidance lines) points and the center point at a time into a .dxf file. These points should make up one armshed at a time. [03_AutoCAD/04_Horizontal_Armshed] <YYMMDD_Horizontal_Armshed_Arm_1>
- Delete all lines but the crest stringfile line and reload the 90- degree center-point line.
- Create a point on the intersection of the 90-degree line and the crest stringfile line.
- Conduct path array of the point start at 12 points.

- Draw over the 12 points and export them as .dxf file. [03_AutoCAD/05_Horizontal_Arm] <YYMMDD_Horizontal_Entitypoints_12_Points>
- Conduct path array of the point for 100 points.
- Draw over the 100 points and export them as .dxf file. [03_AutoCAD/06_Accuracy] <YYMMDD_Accuracy_Assessment_100_Points>

QGIS – Horizontal targetpoints amount assessment

The amount of horizontal targetpoints need to be assessed. They must meet the 85% accuracy requirement. This is conducted in QGIS by comparing the 12-point file against the 100-point file. If the 12-point file does not meet the 85% accuracy requirement, then the analysis must be done again for 13 points etc.

Data needed:

- Horizontal entity points .dxf (12 points) <YYMMDD_Horizontal_Entitypoints_12_Points>
- Total accuracy targetpoints .dxf (100 points) <YYMMDD_AccuracyAssessment_100_Points>
- .ASC topography file

Method steps:

1. Insert the .dxf file into QGIS <YYMMDD_Horizontal_Entitypoints_12_Points>.
2. Add the .ASC file to QGIS <YYMMDD_Topography_Scenario_1>.
3. Place .ASC and .dxf points into the proposed project coordinate reference system (in this case: EPSG: 31370).

4. Conduct viewshed analysis of the visibility plugin for the 12 points:
5. Create viewpoints:
    a. Observer location: .dxf points <YYMMDD_Horizontal_Entitypoints_12_Points>.
    b. Digital elevation model: .ASC file <YYMMDD_Topography_Scenario_1>.
    c. Observer ids: [leave blank]
    d. Radius of analysis: should be more than maximum distance from points to end of canvas (in this case: 10000).
    e. Field value for analysis: [leave blank]
    f. Observer height: 0.1
    g. Field value for observer height: [leave blank]
    h. Target height: 1.6
    i. Field value for target height: [leave blank]
    j. RUN <YYMMDD_Viewshed_Viewpoints_12_Points>
    k. FOLDER: [04_Accuracy/01_12_Points]
6. Conduct viewshed:
    a. Analysis type: Binary viewshed
    b. Observer location(s): <YYMMDD_Viewshed_Viewpoints_12_Points>
    c. Digital elevation model: .ASC file <YYMMDD_Topography_Scenario_1>.
    d. TICK: Take into account Earth curvature
    e. Atmospheric refraction: 0.130000
    f. Combining multiple outputs: maximum
    g. RUN <YYMMDD_Viewshed_Accuracy_12_points>
    h. FOLDER: [04_Accuracy/01_12_Points]

7. Conduct viewshed analysis of the visibility plugin for the 100 points.
8. Create viewpoints:
    a. Insert 100 points file in QGIS <YYMMDD_AccuracyAssessment_100_Points>.
    b. Observer location: .dxf points <YYMMDD_AccuracyAssessment_100_Points>.
    c. Digital elevation model: .ASC file <YYMMDD_Topography_Scenario_1 >.
    d. Observer ids: [leave blank]
    e. Radius of analysis: should be more than maximum distance from points to end of canvas (in this case: 10000).
    f. Field value for analysis: [leave blank]
    g. Observer height: 0.1
    h. Field value for observer height: [leave blank]
    i. Target height: 1.6
    j. Field value for target height: [leave blank]
    k. RUN <YYMMDD_Viewshed_Viewpoints_100>
    l. FOLDER: [04_Accruacy/02_100_Points]
9. Conduct viewshed:
    a. Analysis type: Binary viewshed
    b. Observer location(s): <YYMMDD_Viewshed_Viewpoints_100_Points>
    c. Digital elevation model: .ASC file <YYMMDD_Topography_Scenario_1>.
    d. TICK: Take into account Earth curvature
    e. Atmospheric refraction: 0.130000
    f. Combining multiple outputs: maximum
    g. RUN <YYMMDD_Viewshed_Accuracy_100_points>
    h. FOLDER: [04_Accuracy/02_100_Points]

10. Polygonise both files <YYMMDD_Viewshed_Accuracy_100_points> & <YYMMDD_Viewshed_Accuracy_12_points>: [04_Accuracy/01_12_Points] <YYMMDD_Polygonized_Viewshed_Accuracy_12_Points> & [04_Accuracy/02_100_Points] <YYMMDD_Polygonized_Viewshed_Accuracy_100_points>
11. Delete all zero values in both polygonised files.
12. Add the $Area for every polygon in both polygon files.
13. Calculate the total area for each polygonised file and calculate the % of area difference. [04_Accuracy/03_Excel] <YYMMDD_Accuracy>
14. If the 85% requirement is met, use the 12-point file. If not, repeat for the 13-point file.

QGIS – Vertical visibility angle

With the data available now, it is possible to set up the visibility and distance calculation in QGIS. The is done using several plugins. The method steps consider one arm at a time, to optimize process time it is better to do every step for every arm first, before moving to the next step.

Needed data:

- Vertical arm files, 36 .dxf files <YYMMDD_Vertical_Entitypoints_Arm_1>.
- Topography file .ASC <YYMMDD_Topography_Scenario_1>
- Vertical armshed file <YYMMDD_Vertical_Armshed_Arm_1>
- Geometric center .dxf file

Method steps:

Set-up for QGIS manipulations:

- Load .asc topography into new QGIS project <YYMMDD_Topography_Scenario_1>
- Load midpoint of the pitshell into QGIS project <YYMMDD_Geometric center_Scenario_1>
- Create rectangle around midpoint of the pit at 10.000 x 8.000 meters (Rectangle, Ovals, Diamonds (fixed)) (or desired size of canvas)
- Clip topography raster with polygon (clip raster with polygon).
- Create regular points on canvas extent [05_Vertical_Angle/01_Infrastructure] <YYMMDD_Regular_Points>.

Repetition for each arm:

1. Insert each arm into the QGIS project. <YYMMDD_Vertical_Entitypoints_Arm_1>.
2. Sort arm target-points with MMQGIS on EntityHandle. [05_Vertical_Angle/02_MMQGIS] <YYMMDD_MMQGIS_Arm_1>
3. Remove unnecessary columns.

4. Create viewpoints for viewshed analysis on points in the arm.
    a. Observer location: observerpoints <YYMMDD_Vertical_Points_1>.
    b. Digital elevation model: ASC file <YYMMDD_Topography_Scenario_1>.
    c. Observer ids: [leave blank]
    d. Radius of analysis: should be more than maximum distance from points to end of canvas (in this case: 10000).
    e. Field value for analysis: [leave blank]
    f. Observer height: 0.1
    g. Field value for observer height: [leave blank]
    h. Target height: 1.6
    i. Field value for target height: [leave blank]
    j. RUN <YYMMDD_Viewshed_Vertical_Observerpoints_Arm_1>
    k. FOLDER: [05_Vertical_Angle/03_Accuracy_Viewshed_Observerpoints]
5. Conduct viewshed:
    a. Analysis type: Binary viewshed
    b. Observer location(s): < YYMMDD_Viewshed_Vertical_Targetpoints_Arm_1>
    c. Digital elevation model: .ASC file <YYMMDD_Topography_Scenario_1>.
    d. TICK: Take into account Earth curvature
    e. Atmospheric refraction: 0.130000
    f. Combining multiple outputs: maximum
    g. RUN <YYMMDD_Viewshed_Vertical_Observerpointspoints_Arm_1>
    h. FOLDER: [05_Vertical_Angle/04_Accuracy_Viewshed]
6. Transform viewshed analysis into polygon (vectorize). [05_Vertical_Angle/05_Accuracy_Viewshed_Polygonised] <YYMMDD_Polygonized_Viewshed_Vertical_Observerpoints_Arm_1
7. Remove all zero values in the polygon.

8. Clip regular points <YYMMDD_Regular_Points> with viewshed polygon (clip points with polygon). [05_Vertical_Angle/06_Clipped_Points] <YYMMDD_Clipped_Regular_Points_Arm_1>

9. Create lines from the Vertical armshed <YYMMDD_Vertical_Armshed_Arm_1> (Path from points). [05_Vertical_Angle/07_Path] <YYMMDD_Vertical_Armshed_Path_Arm_1>
10. Create polygon from path <YYMMDD_Vertical_Path_Arm_1> (Path to polygon). [05_Vertical_Angle/08_Polygon] <YYMMDD_Vertical_Armshed_Polygon_Arm_1>

11. Clip viewshed points <YYMMDD_Vertical_Clipped_Regular_Points_Arm_1> with armshed polygon (clip points with polygon). [05_Vertical_Angle/09_Clipped_Points_2] <YYMMDD_Vertical_Clipped_Points_2_Arm_1>

12. Create observerpoints from the clipped_2 points.
    a. Observer location: s < YYMMDD_Vertical_Clipped_Points_2_Arm_1>.
    b. Digital elevation model: ASC file <YYMMDD_Topography_Scenario_1>.
    c. Observer ids: [leave blank]
    d. Radius of analysis: should be more than maximum distance from points to end of canvas (in this case: 10000).
    e. Field value for analysis: [leave blank]
    f. Observer height: 1.6
    g. Field value for observer height: [leave blank]
    h. Target height: 0.1
    i. Field value for target height: [leave blank]
    j. RUN <YYMMDD _Vertical_Observerpoints_Arm_1>
    k. FOLDER: [05_Vertical_Angle/10_Observerpoints]

13. Create viewpoint targetpoints from <YYMMDD_MMQGIS_Arm_1>
    a. Observer location: observerpoints <YYMMDD_MMQGIS_Arm_1>.
    b. Digital elevation model: ASC file <YYMMDD_Topography_Scenario_1>.
    c. Observer ids: [leave blank]
    d. Radius of analysis: should be more than maximum distance from points to end of canvas (in this case: 10000).
    e. Field value for analysis: [leave blank]
    f. Observer height: 1.6
    g. Field value for observer height: [leave blank]
    h. Target height: 0.1
    i. Field value for target height: [leave blank]
    j. RUN <YYMMDD _Vertical_Targetpoints_Arm_1>
    k. FOLDER: [05_Vertical_Angle/11_Targetpoints]

14. Run intervisiblity analysis between the targetpoints <YYMMDD _Vertical_Targetpoints_Arm_1> and observer-points <YYMMDD_Vertical_Observerpoints_Arm_1>.
    a. Observerpoints: <YYMMDD_Vertical_Observerpoints_Arm_1>.
    b. Targetpoints: <YYMMDD _Vertical_Targetpoints_Arm_1>
    c. Digital elevation model: <YYMMDD_Topography_Scenario_1>
    d. TICK: Save negative links
    e. TICK: Take in account Earth curvature
    f. Atmospheric refraction: 0.130000

    g. Output layer: <YYMMDD_Vertical_Intervisibility_Arm_1>
    h. FOLDER: [05_Vertical_Angle/12_Intervisibility]

15. Create viewpoint for target to target analysis:
    a. Observer location: observerpoints <YYMMDD_MMQGIS_Arm_1>.
    b. Digital elevation model: ASC file <YYMMDD_Topography_Scenario_1>.
    c. Observer ids: [leave blank]
    d. Radius of analysis: should be more than maximum distance from points to end of canvas (in this case: 10000).
    e. Field value for analysis: [leave blank]
    f. Observer height: 0.1
    g. Field value for observer height: [leave blank]
    h. Target height: 0.1
    i. Field value for target height: [leave blank]
    j. RUN <YYMMDD_ Vertical_TargettoTarget_points_Arm_1>
    k. FOLDER: [05_Vertical_Angle/13_Viewpoints_XtoX]
16. Conduct intervisibility analysis for target to target:
    a. Observerpoints: <YYMMDD_ Vertical_TargettoTarget_points_Arm_1>.
    b. Targetpoints: <YYMMDD _ Vertical_TargettoTarget_points_Arm_1>
    c. Digital elevation model: <YYMMDD_Topography_Scenario_1>
    d. TICK: Save negative links
    e. TICK: Take in account Earth curvature
    f. Atmospheric refraction: 0.130000
    g. Output layer: <YYMMDD_Vertical_Intervisibility_TargettoTarget_Arm_1>
    h. FOLDER: [05_Vertical_Angle/14_Intervisibility_XtoX]

17. Run Extract Specific Vertices for target to target intervisibility analysis:
    a. Input layer: <YYMMDD_Vertical_Intervisibility_TargettoTarget_Arm_1>
    b. Vertex indices: 0, -1
    c. Vertices: <YYMMDD_Vertical_Vertices_TargettoTarget_Arm_1>
    d. FOLDER: [05_Vertical_Angle/15_Vertices_XtoX]
18. Run Extract Specific Vertices for intervisibility analysis:
    a. Input layer: < YYMMDD_Vertical_Intervisibility_Arm_1>
    b. Vertex indices: 0, -1
    c. Vertices: <YYMMDD_Vertical_Vertices_ Arm_1>
    d. FOLDER: [05_Vertical_Angle/16_Vertices]
19. "Clean" The vertices results <YYMMDD_Vertical_Vertices_ Arm_1>
    a. Remove all columns except for: fid, Source, Target, TargetSize, distance, angle
20. "Clean" The target to target vertices result <YYMMDD_Vertical_Vertices_TargettoTarget_Arm_1>:
    a. Remove all columns except for: fid, Source, Target, distance

Elevation data calculation:

The extract specific vertices method only calculates the distance on the X-plane, thus, the distance on the Y-Plane must also be calculated. This is done using the point sampling tool (plugin) in QGIS.

1. Export all arms and the center point from AutoCAD in a .dxf file <YYMMDD_Total_Arms>
2. Insert total arms file in QGIS <YYMMDD_Total_Arms> and place in right coordinate system

3. Create viewpoints for viewshed analysis:
    a. Observer location: <YYMMDD_Total_Arms>.
    b. Digital elevation model: <YYMMDD_Topography_Scenario_1>.
    c. Observer ids: [leave blank]
    d. Radius of analysis: should be more than maximum distance from points to end of canvas (in this case: 10000).
    e. Field value for analysis: [leave blank]
    f. Observer height: 0.1
    g. Field value for observer height: [leave blank]
    h. Target height: 1.6
    i. Field value for target height: [leave blank]
    j. RUN <YYMMDD_Viewshed_Viewpoints_Total_Arms>
    k. FOLDER: [06_Elevation]
4. Conduct viewshed:
    a. Analysis type: Binary viewshed
    b. Observer location(s): <YYMMDD_Viewshed_Total_Arms>
    c. Digital elevation model: <YYMMDD_Topography_Scenario_1>.
    d. TICK: Take into account Earth curvature
    e. Atmospheric refraction: 0.130000
    f. Combining multiple outputs: maximum
    g. RUN <YYMMDD_Viewshed_Total_Arms>
    h. FOLDER: [06_Elevation]
5. Polygonize the viewshed <YYMMDD_Polygonized_Viewshed_Total_Arms> [06_Elevation]
6. Delete all zero values in the polygonised viewshed
7. Clip the regular points with the polygonised viewshed <YYMMDD_Clipped_Total_Arms> [06_Elevation]

8. Open the point sampling tool and insert:
    a. Layer containing sampling points: <YYMMDD_Clipped_Total_Arms>
    b. Layers with fields/bands to get values from: <YYMMDD_Topography_Scenario_1>
    c. Output point vector layer: <YYMMDD_Elevation_Observerpoints>
    d. FOLDER: [06_Elevation]

Repeat for each arm

1. Open the point sampling tool and insert:
    a. Layer containing sampling points: <YYMMDD_Vertical_Entitypoints_Arm_1>
    b. Layers with fields/bands to get values from: <YYMMDD_Topography_Scenario_1>
    c. Output point vector layer: <YYMMDD_Elevation_Targetpoints>
    d. FOLDER: [06_Elevation/01_Targetpoints_Elevation]

QGIS – Horizontal Visibility Angle

Data needed:

- Regular points: <YYMMDD_Regular_Points>.
- Topography: <YYMMDD_Topography_Scenario_1>
- Horizontal armshed file: <YYMMDD_Horizontal_Armshed_Arm_1>
- Horizontal targetpoint files: <YYMMDD_Horizontal_Entitypoints_12_Points>

- Polygonized viewshed 12 points (made sure zero values are deleted) <YYMMDD_Polygonized_Viewshed_Accuracy_12_Points>

Method steps:

Setting up steps:

1. Import the topography file into QGIS <YYMMDD_Topography_Scenario_1>
2. Import the Horizontal targetpoint files <YYMMDD_Horizontal_Entitypoints_12_Points>
3. Import polygonised viewshed of previous accuracy assessment <YYMMDD_Polygonized_Viewshed_Accuracy_12_Points>
4. Import regular points <YYMMDD_Regular_Points>
5. Clip regular points with the polygonised viewshed (clip points with polygon) [07_Horizontal_Angle/01_Clipped_Points] <YYMMDD_Horizontal_Clipped_Regular_Points>

Repetition for every horizontal armshed:

1. Create lines from the horizontal armshed <YYMMDD_Horizontal_Armshed_Arm_1> (Path from points). [07_Horizontal_Angle/02_Path] <YYMMDD_Horizontal_Armshed_Path_Arm_1>
2. Create polygon from path <YYMMDD_Horizontal_Path_Arm_1> (Path to polygon). [03_Polygon] <YYMMDD_Horizontal_Armshed_Polygon_Arm_1>
3. Clip viewshed points <YYMMDD_Horizontal_Clipped_Regular_Points> with armshed polygon (clip points with polygon). [07_Horizontal_Angle/04_Clipped_Points_2] <YYMMDD_Horizontal_Points_Arms_1> ***We still call it arm here but it is not an arm..**

4. Create targetpoints for intervisibility analysis:
   a. Observer location: .dxf points <YYMMDD_Horizontal_Entitypoints_12_Points>.
   b. Digital elevation model: .ASC file <YYMMDD_Topography_Scenario_1>.
   c. Observer ids: [leave blank]
   d. Radius of analysis: should be more than maximum distance from points to end of canvas (in this case: 10000).
   e. Field value for analysis: [leave blank]
   f. Observer height: 1.6
   g. Field value for observer height: [leave blank]
   h. Target height: 0.1
   i. Field value for target height: [leave blank]
   j. RUN <YYMMDD_Horizontal_Targetpoints_12_Points>
   k. FOLDER: [07_Hoirzontal_Angle/05_Targtepoints]

5. Create observerpoints for intervisibility analysis:
   a. Observer location: <YYMMDD_Horizontal_Points_Arm_1>.
   b. Digital elevation model: .ASC file <YYMMDD_Topography_Scenario_1>.
   c. Observer ids: [leave blank]
   d. Radius of analysis: should be more than maximum distance from points to end of canvas (in this case: 10000).
   e. Field value for analysis: [leave blank]
   f. Observer height: 1.6
   g. Field value for observer height: [leave blank]
   h. Target height: 0.1
   i. Field value for target height: [leave blank]

   j. RUN <YYMMDD_Horizontal_Observerpoints_Arm_1>
   k. FOLDER: [07_Horizontal_Angle/06_Observerpoints]

6. Run intervisibility analysis:
   a. Observerpoints: <YYMMDD_Horizontal_Observerpoints_Arm_1>.
   b. Targetpoints: <YYMMDD _Horizontal_Targetpoints_Arm_1>
   c. Digital elevation model: <YYMMDD_Topography_Scenario_1>
   d. TICK: Save negative links
   e. TICK: Take in account Earth curvature
   f. Atmospheric refraction: 0.130000
   g. Output layer: <YYMMDD_Horizontal_Intervisibility_Arm_1>
   h. FOLDER: [07_Horizontal_Angle/07_Intervisibility]

7. Create observerpoints for target to target intervisibility analysis:
   a. Observer location: observerpoints <YYMMDD_Horizontal_Entitypoints_12_Points>.
   b. Digital elevation model: ASC file <YYMMDD_Topography_Scenario_1>.
   c. Observer ids: [leave blank]
   d. Radius of analysis: should be more than maximum distance from points to end of canvas (in this case: 10000).
   e. Field value for analysis: [leave blank]
   f. Observer height: 0.1
   g. Field value for observer height: [leave blank]
   h. Target height: 0.1
   i. Field value for target height: [leave blank]
   j. RUN <YYMMDD_Horizontal_TargettoTarget_Points>
   k. [07_Horizontal_Angle/08_Viewpoints_XtoX]

8. Conduct intervisibility analysis for target to target:
   a. Observerpoints: <YYMMDD_Horizontal_TargettoTarget_Points>.
   b. Targetpoints: <YYMMDD_Horizontal_TargettoTarget_Points>
   c. Digital elevation model: <YYMMDD_Topography_Scenario_1>
   d. TICK: Save negative links
   e. TICK: Take in account Earth curvature
   f. Atmospheric refraction: 0.130000
   g. Output layer: <YYMMDD_Horizontal_Intervisibility_TargettoTarget>
   h. FOLDER: [07_Horizontal_Angle/09_Intervisibility_XtoX]

9. Run Extract Specific Vertices for target to target intervisibility analysis:
   a. Input layer: <YYMMDD_Horizontal_Intervisibility_TargettoTarget>
   b. Vertex indices: 0, -1
   c. Vertices: <YYMMDD_Horizontal_Vertices_TargettoTarget>
   d. Folder: [07_Horizontal_Angle/10_Vertices_XtoX]
10. Run Extract Specific Vertices for intervisibility analysis:
    a. Input layer: < YYMMDD_Horizontal_Intervisibility_Arm_1>
    b. Vertex indices: 0, -1
    c. Vertices: <YYMMDD_Horizontal_Vertices_ Arm_1>
    d. FOLDER: [07_Horizontal_Angle/11_Vertices]
11. “Clean” The vertices results <YYMMDD_Horizontal_Vertices_ Arm_1>

    a. Remove all columns except for: fid, Source, Target, TargetSize, distance, angle

12. “Clean” The target to target vertices result <YYMMDD_Horizontal_Vertices_TargettoTarget_Arm_1>:
    a. Remove all columns except for: fid, Source, Target, distance

Excel – Vertical Visibility Angle

Excel is used to compute the data gathered in QGIS into something we can read and use for the results. The vertical visibility angle is calculated for every raster pixel.

Set up vertical angle template

1. Open vertical angle template
2. Open Elevation data observerpoints <YYMMDD_Elevation_Observerpoints> in Excel
3. Copy wkt_geom and elevation column into column AB + AC of the template
4. Save template for further use.
5. FOLDER: [05_Vertical_Angle/17_Excel]

Repeat for every arm

1. Copy Vertices <YYMMDD_Vertical_Vertices_ Arm_1> with distance > 0 into Excel
2. Copy Vertices <YYMMDD_Vertical_Vertices_ Arm_1> with distance = 0 into Excel
3. Swap column wkt_geom from distance = 0 to the distance > 0 column
4. Delete columns of distance = 0
5. Insert remaining data from vertices <YYMMDD_Vertical_Vertices_ Arm_1> into column B-H.
6. Rewrite angle filter with the required angle filter for that arm. **Not necessary, just make sure is 1**
7. Copy Vertices <YYMMDD_Horizontal_Vertices_TargettoTarget_Arm_1> with distance > 0 into Excel
8. Copy Target + Distance column into column Y + Z
9. Copy data for target elevation <YYMMDD_Elevation_Targetpoints> into Excel
10. Copy fid and elevation column into column AE + AF
11. Extend column I up to column W to the end of the document
12. Extract Angle ϒ, wkt_geom and ID into separate Excel file. (Column B+D+W)
13. Select all data and removed all zero rows (γ-angle = zero)
14. Save file as CSV <YYMMDD_Vertical_Angle_Arm_1>
15. FOLDER: [05_Vertical_Angle/18_CSV]

Excel – Horizontal Visibility Angle

Excel is used to compute the data gathered in QGIS into something we can read and use for the results. The horizontal visibility angle is calculated for every raster pixel.

Set up vertical angle template

1. Open horizontal angle template
2. Insert vertices target to target <YYMMDD_Horizontal_Vertices_TargettoTarget_Arm_1> into separate excel sheet.
3. Add the target to target (0 to 0, 1 to 1, 2 to 2 etc) into the table with all columns zero.
4. Copy column: source, target, targetsize, distance into column A to D
5. Extend true distance column to the full limit.
6. Save template for further use.
7. FOLDER: [07_Horizontal_Angle/12_Excel]

Repeat for every "arm"

1. Copy Vertices <YYMMDD_Horizontal_Vertices_ Arm_1> with distance > 0 to a separate excel sheet.
2. Copy Vertices <YYMMDD_Horizontal_Vertices_ Arm_1> with distance = 0 to the same excel sheet.
3. Swap the wkt_geom column of distance = 0 into the wkt_geom with distance > 0 column.
4. Delete the table with distance = 0.
5. Copy the remaining columns: wkt_geom, source, target, targetsize, distance to the excel template in column H until L.
6. Extend column M to AA to the limit of the document.
7. Copy column N (True distance) to column AO.
8. Insert the following formula into cell AC3: OFFSET(AO3,COLUMNS($AO3:AO3)-1+(ROWS($3:3)-1)*12,0)
9. Extend cell AC3 right until cell AN3.
10. Create a list of number from cell AB3 down, 1 until the last number of the source (for example 1, 2, 3,…, 6394 if there are 6394 observerpoints in the armshed).
11. Copy this list 12 times underneath eachother
12. **I am sure this can be done simpler, but I am not sure how.**
13. Extend cell AC3 until cell AN3 down until the end of the document.
14. Select from cell AB3 until AN3 down until the end of the document and select sort smallest to largest.
15. Keep the selection and select: select blanks.
16. After processing: insert =(the cell above)AC3 and press ctrl+enter.
17. Select AB3 until BD3 and extend until the end of the document.
18. Select column H, I, BD (wkt_geom, source and y) copy and paste in new excel document.
19. Select all data in new document and filter all zero values out.
20. Save file as CSV <YYMMDD_Horizontal_Angle_Arm_1>
21. FOLDER: [07_Horizontal_Angle/13_CSV]

QGIS – Processing of the results

With the results of the analysis in the CSV files, we must now process these CSV files in QGIS to create a readable result file. This is done for both the vertical and horizontal visibility angle.

Vertical visibility angle

1. Add all CSV files into a fresh QGIS project. <YYMMDD_Vertical_Angle_Arm_1>
2. Put the CSV files in the correct projection coordinate system.
3. Merge all CSV files with merge vector layers <YYMMDD_Vertical_Angle>
4. Load style for the vertical visibility angle <20200623_Style_Vertical>
5. Export image as vertical result.
6. FOLDER: [05_Vertical_Angle/19_Results]

Horizontal visibility angle

1. Add all CSV files into a fresh QGIS project. <YYMMDD_Horizontal_Angle_Arm_1>
2. Put the CSV files in the correct projection coordinate system.
3. Merge all CSV files with merge vector layers <YYMMDD_Horizontal_Angle>
4. Load style for the horizontal visibility angle <20200623_Style_Horizontal>
5. Export image as horizontal result
6. FOLDER: [07_Horizontal_Angle/14_Results]

Severity Ranges visibility angle

In order to do calculations with the results, the angles must be translated into severity ranges. This is done using the QGIS open field calculator.

1. Use join attribute by location to merge the vertical and horizontal angle in the same file <YYMMDD_Combined_visibility_Angle>
    a. Input layer: <YYMMDD_Horizontal_Angle>
    b. Join layer: <YYMMDD_Vertical_Angle>
    c. Geometric predicate: intersects
    d. Fields to add: Vertical Angle
    e. Join type: one-to-one
    f. Joined layer: <YYMMDD_Combined_Visibility_Angle>
2. Update the vertical angle column with the following formula to fill in NULL fields

```
IF (“Vertical Angle” is NULL, 0, “Vertical Angle”)
```

3. Use the field calculator to translate the angles into severity ranges.
4. Add new column: Vertical Range:

```
CASE
        WHEN “Vertical Angle” > 0 THEN 1
        WHEN “Vertical Angle” > 0.25 THEN 2
        WHEN “Vertical Angle” > 1 THEN 3
        WHEN “Vertical Angle” > 3 THEN 4
END
```

5. Add new column: Horizontal Range:

```
CASE
        WHEN “Horizontal Angle” > 0 THEN 1
        WHEN “Horizontal Angle” > 5 THEN 2
        WHEN “Horizontal Angle” > 10 THEN 3
        WHEN “Horizontal Angle” > 20 THEN 4
        WHEN “Horizontal Angle” > 50 THEN 5
END
```

6. With the severity ranges known, the combined visual impact can be assessed.
7. Create a new column: “combined visual impact” with the following formula:

```
“Vertical Range” * “Horizontal Range”
```

8. Create a grid: Vector> Research tools > create grid
    a. Grid type: rectangle
    b. Grid extent: use layer extent
    c. Horizontal spacing: 10
    d. Vertical spacing: 10
    e. Horizontal overlay: 0
    f. Vertical overlay: 0
    g. Grid <YYMMDD_Grid>
    h. FOLDER: [08_Results]
9. Join attributes by location:
    a. Input layer: <YYMMDD_Grid>

    b. Join layer: <YYMMDD_Combined_Visibility_Angle>
    c. Geometric predicate: intersects
    d. Fields to add: combined visual impact
    e. Join type: one-to-one
    f. Joined layer: <YYMMDD_Grid_Combined_Visibility_Angle>
    g. FOLDER: [08_Results]

With the combined visual impact known, the cadastre information must be added to the file. The cadastre information was set up earlier in the following way:

1. Download cadastre information (Buildings)
2. Give each row in the cadastre information a new column “Building Value” with value 10.
3. Clip the layer with the canvas extent polygon. <YYMMDD_Cadastre_Building>
4. FOLDER: [09_Cadastre]

5. Download cadastre information (Roads)
6. Give all rows a new column “Road Value” with a value related to the name of the row
    a. VCO: 2
    b. CHA: 2
    c. NTL: 5
7. Clip the layer with the canvas extent polygon. <YYMMDD_Cadastre_Road>
8. This designation of the values can be adjusted according to Lhoist’s needs.

Now the cadastre and combined visual impact must be combined.

1. Join attributes by location:
    a. Input layer: <YYMMDD_Grid_Combined_Visibility_Angle>
    b. Join layer: <YYMMDD_Cadastre_Building>
    c. Geometric predicate: intersects
    d. Fields to add: Building Value
    e. Join type: one-to-one
    f. Joined layer: <YYMMDD_Grid_Combined_Visibility_Angle_Buildings>
    g. [08_Results]
2. Join attributes by location:
    a. Input layer: <YYMMDD_Grid_Combined_Visibility_Angle_Buildings>
    b. Join layer: <YYMMDD_Cadastre_Road>
    c. Geometric predicate: intersects
    d. Fields to add: Road Value
    e. Join type: one-to-one
    f. Joined layer: <YYMMDD_Total_Visibility_Angle>
    g. FOLDER: [08_Results]
3. Update the Road Value column with the following formula to fill in NULL fields

IF (“Road Value” is NULL, 1, “Road Value”)

4. Update the Building Value column with the following formula to fill in NULL fields

IF (“Building Value” is NULL, 1, “Building Value”)

5. Finally, the total visibility value is calculated, add a new column “Visibility Impact” with the following formula:

*Combined visual impact” * “Building Value” * “Road Value”

6. Load the style: <20200623_Style_Final>
7. Export the table into Excel
8. Create new column in Excel “Total Visual Value”
9. SUM the visibility Impact column in this new column
10. Normalize the visibility value using: Visibility value SUM * (100/accuracy %)
11. Filter the results in a second column “YESorNO”
    a. IF(OR(“Road Value > 1, “Building Value” > 1),1,0)
12. And a third column “Road/Building”
    a. IF(“YESorNO = 1, “Visibility Impact”,0)
13. Create a new column in excel called “Total Road/Building Value”
14. SUM the “Road/Building” column
15. Normalize the road/building value using: Road/Building SUM * (100/accuracy %)
16. Save file as result
17. FOLDER: [08_Results]

Folder distribution

01_SURPAC	01_Pit_Stringfiles
	02_Landscape_DTM
02_Leapfrog	
03_AutoCAD	01_Infrastructure
	02_Vertical_Arm
	03_Vertical_Armshed
	04_Horizontal Armshed
	05_Horizontal_Arm
	06_Accuracy
04_Accuracy	01_12_Points
	02_100_Points
	03_Excel
05_Vertical_Angle	01_Infrastructure
	02_MMQGIS
	03_Accuracy_Viewshed_Observerpoints
	04_Accuracy_Viewshed
	05_Accuracy_Viewshed_Polygonised
	06_Clipped_Points
	07_Path
	08_Polygon
	09_Clipped_Points_2
	10_Observerpoints
	11_Targetpoints
	12_Intervisibility
	13_Viewpoints_XtoX
	14_Intervisibility_XtoX
	15_Vertices_XtoX
	16_Vertices
	17_Excel
	18_CSV
	19_Results
06_Elevation	01_Targetpoints_Elevation
07_Horizontal_Angle	01_Clipped_Points
	02_Path
	03_Polygon
	04_Clipped_Points_2
	05_Targetpoints
	06_Observerpoints
	07_Intervisibility
	08_Viewpoints_XtoX
	09_Intervisibility_XtoX
	10_Vertices_XtoX
	11_Vertices
	12_Excel
	13_CSV
	14_Results
08_Results	
09_Cadastre	