

CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE



Faculty of Environmental Sciences

Department of Applied Geoinformatics and Spatial Planning

Diploma Thesis

Advanced Methods of Digital Visibility Analysis

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DIPLOMA THESIS ASSIGNMENT

Bandíková Helena

Thesis title

Advanced methods of digital visibility analysis

Objectives of thesis

Providing a review of the modern visibility analysis methods. Implementing selected methods in the form of scripts executable in the ArcGIS environment.

Methodology

In the first part of the process, the available literature will be studied and reviewed. This will be followed by learning to work with the Python programming language and writing scripts for ArcGIS. Finally, the thesis will be written, giving the review of the topic and implementing selected methods in the form of Python scripts.

Schedule for processing

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End of October: Outline of the literature review + getting an idea of what to program

October - December: Learning to work with Python + writing scripts

End of December: Outline of the thesis + completed scripts

January - February: Writing the thesis

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March: Rewriting the thesis

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Chamberlain, B.C., Meitner, M.J. (2013) 'A route-based visibility analysis for landscape management', *Landscape and Urban Planning*, 111, 13-24.

Llobreda, M. (2003) 'Extending GIS-based visual analysis: the concept of visualsapes', *Int. J. Geographical Information Science*, 17(1), 25-48.

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Zandbergen, P.A. (2013) *Python scripting for ArcGIS*. ESRI Press, Redlands, CA, USA.

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Declaration

I hereby declare that the entire diploma thesis on the topic of “Advanced Methods of Digital Visibility Analysis” represents my own work, and has been completed with the use of cited literature and according to the recommendations of my supervisor. I agree that this project may be made available by the Czech University of Life Sciences to future students.

In Prague, 23rd April 2014

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ABSTRACT (EN)

The thesis deals with the topic of analysing visibility by the means of Geographical Information Systems (GIS). It presents a concise literature review of research that has been done in the area of calculating visibility, together with the possible applications of the analyses and their limitations. Three scripts for advanced computation of visibility were developed using Python programming language and were tested on real-world data, specifically on data from the Czech regions of Most, Ústí nad Labem, and Česká Lípa. These scripts calculate total viewshed, cumulative viewshed for a polygon shapefile, and visual magnitude respectively. A toolbox with a pop-up window for each script was created for a convenient use in ArcGIS.

Key words: *GIS, visibility analysis, visual magnitude, viewshed*

ABSTRAKT (CZ)

Diplomová práce se zabývá problematikou analýz viditelnosti pomocí Geografických Informačních Systémů (GIS). Předkládá učenlenou literární rešerši zahrnující přehled výzkumných prací na téma výpočetních metod viditelnosti, jejich aplikací a nedostatků. Pomocí programovacího jazyka Python byly vytvořeny tři skripta pro pokročilý výpočet viditelnosti, které byly následně testovány na skutečných datech, konkrétně na datech z oblastí okresů Most, Ústí nad Labem a Česká Lípa. Tyto skripta počítají total viewshed, cumulative viewshed pro polygonovou vrstvu a stupeň viditelnosti. Pro snadné použití v programu ArcGIS byl vytvořen nástroj pro každý z nich.

Klíčová slova: *GIS, analýzy viditelnosti, stupeň viditelnosti, viewshed*

Contents

1. INTRODUCTION	3
2. AIMS	4
3. LITERATURE REVIEW	5
3.1 Introduction to visibility analysis and viewshed	5
3.2 Applications with description of methods and results	5
3.2.1 Landscape management and assessment	5
3.2.2 Placement of wind turbines	6
3.2.3 Telecommunications planning	8
3.2.4 Urban design	9
3.2.5 Archaeological studies	11
3.2.6 Biogeographical studies	13
3.3 Limitations	14
3.3.1 Limitations of computational processes	14
3.3.1.1 <i>Data</i>	14
3.3.1.2 <i>Algorithms</i>	15
3.3.1.3 <i>3D space</i>	15
3.3.1.4 <i>Edge effect</i>	15
3.3.1.5 <i>Vegetation incorporation</i>	16
3.3.2 Physical limitations of seeing a target	16
3.3.2.1 <i>Maximum observable distance</i>	16
3.3.2.2 <i>Human vision</i>	17
3.3.2.3 <i>Environmental conditions</i>	17
3.3.2.4 <i>Properties of objects and their surroundings</i>	17
3.4 Individual perception of the landscape	18
4. METHODOLOGY	19
5. RESULTS	21
5.1 Scripts	21
5.1.1 Total viewshed	21
5.1.1.1 <i>Calculation of total viewshed</i>	22
5.1.2 Cumulative viewshed	23
5.1.2.1 <i>Calculation of cumulative viewshed</i>	24

- 5.1.3 Visual magnitude 25
 - 5.1.3.1 Calculation of visual magnitude 26
- 5.2 Toolbox 27**
- 5.3 Real-world data testing 29**
 - 5.3.1 Study area 29
 - 5.3.2 Outcomes 32
 - 5.3.2.1 Total viewshed 32
 - 5.3.2.2 Cumulative viewshed 34
 - 5.3.2.3 Visual magnitude 37
- 6. DISCUSSION 40**
- 7. CONCLUSION 43**
- References 44**
- Attachments 47**

1. INTRODUCTION

Visibility analysis has become a frequently used type of scientific processes concerning landscape evaluation and fields related to it. It has become more feasible and more advanced with the development of GIS, which offer various tools for analysing visibility and visual impact. The first part of the thesis presents case studies from various areas, including applications in both, natural and urban environments. Common limitations of visibility assessment are highlighted as well. The second part of the thesis deals with particular computation methods through development of scripts, their correct application and testing on real-world data. The outcomes of the analyses are described in detail, accompanied with maps and figures for visualization and better understanding. Finally, the interpretation of the results is discussed and presented, together with proposals of other issues that may be considered, questioned and researched in greater detail.

2. AIMS

There are two main goals of the thesis. The first one concerns other authors' research as it aims to provide a review of the modern visibility analysis methods available through the means of Geographical Information Systems, and to identify their use, strengths and weaknesses. The second one is to implement specifically selected methods in the form of Python scripts executable in the ArcGIS environment and to test their functionality on real-world data.

3. LITERATURE REVIEW

3.1 Introduction to visibility analysis and viewshed

Visibility analyses represent methods examining what places are visible from a given location, from what locations a given point is visible and also intervisibility of two points. Their main purpose is identification of significant locations in the landscape. When calculating visibility through GIS, methods based on computation of viewsheds are usually used. Viewshed can be described as the total portion of the landscape visible from an observation point. There are two basic input features required for its computation, a Digital Terrain Model (DTM) of given location, together with a layer representing observation features (typically point or polyline shapefiles). There are several limitations to calculating viewsheds in the standard way commonly used by today's GIS softwares. That is why many authors have tried to resolve these issues and suggesting new way for dealing with visibility analysis. This chapter presents a review of different studies concerned with computations of visibility, their applications and shortcomings.

3.2 Applications with description of methods and results

Visibility in the landscape plays a significant role in many branches of research. Exploring visibility has become more accessible and feasible with the growing use of Geographical Information System software. Different studies have been conducted to assess their various uses and limitations. It is very plausible that the fields of study will continue to expand in the fore coming years.

3.2.1 Landscape management and assessment

Visual evaluation of landscape is an important component of landscape assessment, planning and management (Tetlow and Sheppard 1979). Research in this area consists of various fields of interest, such as assessment of scenic beauty (Palmer 2004, Garré *et al.* 2009,

Brabyn and Mark 2011) and of change in land cover (Miller 2001), evaluation of visual properties of rural and agricultural landscapes (Sevenant and Antrop 2007, Tveit 2009, Germino *et al.* 2001), visual influence in environmental impact assessment (Wood 2000), evaluation of landscape visual impact on real-estate market (Joly *et al.* 2009), and aquaculture visual impact assessment (Falconer *et al.* 2013).

Visual evaluation of agricultural landscape can be of significant interest, as pointed out by Germino *et al.* (2001). The research focuses on evaluation of extensive agricultural landscapes in the Rocky Mountains, Wyoming, the USA, and aims to provide a satisfactory method of visibility analysis that combines planimetric and panoramic representation of the landscape. It is the vast, flat and unobstructed landscape that calls for a different methodological approach than the one usually used for viewshed calculation when a spatially smaller and more enclosed type of landscape is being evaluated. With a growing development pressure that lies on the examined region, the authors highlight the importance of view quality modelling and visual analysis incorporation into land management and suggest new ways for dealing with visual properties influencing the observer. Two kinds of viewsheds were computed: planimetric simulations for view area, depth, and relief and panoramic simulations for landcover, diversity, and edge. In addition, panoramic images taken in the field and planimetric simulations of landcover were also generated for validation and comparison. The viewsheds evaluated in the research had large areal extents, extended depth, large relief, and naturalness. The study led to a conclusion that the planimetric approach proved more suited for quantifying the dimensions of the viewsheds (areal extent, relief, and depth), while the panoramic computer simulations were more appropriate for the composition of the viewsheds (landcover, diversity, and edge).

3.2.2 Placement of wind turbines

One of the study areas, where visibility analysis has been widely used in the recent years, is evaluating visual impact of wind turbines on landscape character and on people (e.g. Johansson and Laike 2007, Molnárová *et al.* 2012, Wolsink 2000). According to the findings, there are two predominant attitudes towards wind farms. On one side, there is the desire for renewable energy resources that are more considerate towards the environment and do not add carbon to the atmosphere. On the other side, there are increasing concerns about the negative

impacts the wind turbines have on the environment and landscape, particularly from the visual impact point of view (Molnárová *et al.* 2012). Being a renewable energy source, originally welcomed as an environmental friendly option of gaining energy, wind farms have been a target of research regarding, among others, their negative aspects influencing population. This is particularly the case of inhabitants directly affected by these structures. Negative attitude is mostly caused by the aesthetic impacts of wind turbines and the noise generated by them. The aesthetic impacts can be emphasised by various characteristics, including the size and the colour of the wind turbines, as well as their distance from residential areas and the type and value of the landscape (Tsoutsos *et al.* 2009).

The paper by Molnárová *et al.* 2012 presents a comprehensive overview of the research that has been done in the area of visual preferences for wind turbines and their acceptance among the public. Additionally, it attempts to answer questions with regards to understanding the public's reaction to the visual impacts of wind turbines on the landscape. Such is achieved by using a visual preference survey to assess a series of turbine and landscape characteristics, as well as demographic variables of the respondents. Three landscape types with different aesthetic value were chosen for the study. Photographs of the landscapes were used in the survey. Wind turbines were digitally added to the photographs, with varying number of turbines (a single structure or a group of four) and distance (1.5 km, 4.5 km and 8 km). The overall results showed landscapes containing wind turbines to be perceived as less attractive (Molnárová *et al.* 2012).

Various methods have been developed to assess the visual impact of wind turbines, as it is one of the main factors influencing public acceptance of wind parks (e.g. Jallouli and Moreau 2009, Möller 2006, Ruiz *et al.* 2011, Sibille *et al.* 2009). For instance, based on historical and planning data and with the use of GIS, Möller (2006) evaluated visibility of turbines in the region of Northern Jutland in Denmark between the years 1990 to 2010, in order to assess potential visual impact of a new wind farm. This wind farm should replace 400 old turbines with 50 new ones. As suggested by the author, geographically distributed studies of visual impact of wind turbines had not been necessary in the past, mainly due to the generally positive image of wind power and the limited visibility of older turbines. In cases of planning smaller, individual projects, some kind of visualisation is usually required, however assessing the demographic and land use impact through larger and more comprehensive quantitative studies had not been common until recently. A quantitative visual impact study on a larger scale could, however, contribute to the overall goals of landscape planning

process. This is true especially since the size of wind turbines has been increasing and since more attention is paid to the influence of wind turbines not only on human but also wildlife population. Using visibility analysis with an overlay of 20 multiple viewsheds of turbines and including landscape type and population data in the analysis, the results of Möller's study conclude that there will be no increase in overall visual impact after the replacement of the old turbines. However, as the size of the new turbines varies, enlargement of the relative impact of large turbines will occur.

As pointed out by Ruiz *et al.* (2011), there is no objective methodology to evaluate the visual impact of wind farms. However, their commonly poor aesthetic integration into the landscape and resulting negative visual impact could be reduced by developing a methodology that would help with determining and evaluating the most suitable locations for new wind farm projects (Ruiz *et al.* 2011).

3.2.3 Telecommunications planning

Broadband technologies are perceived as an essential element of infrastructure that is required for effective and efficient operation of enterprises and organizations. There are many locations in the world, however, where broadband connectivity is very limited. This is the case of Canada, which is one of the most urbanized countries in the world, with more than 80% of inhabitants living in urban areas. There is a distinct division of urban and rural communities, as the urbanized population only occupies about 4% of the landmass (Sawada *et al.* 2006). This is an issue that brings a lot of problems regarding the construction of new infrastructure and maintenance of the existent one. However, providing internet access is not exclusively a matter of broadband infrastructure availability.

The focus of the research article by Sawada *et al.* (2006) is on broadband connectivity in Canada's northern communities. These communities are quite remote and isolated and the deployment of wireline broadband technology is very limited. Significant costs of installation and maintenance of the wired infrastructure are the main reasons for such limitations. A possible solution to this problem would be the use of terrestrial broadband wireless technology as it does not require the same kind of physical infrastructure. The geographic approach of the study offers the use of two kinds of specialised software for analyzing and planning of wireless technologies, focusing on spatial connections between communication

towers and dwellings. The first method is using radio propagation software, which is very precise in estimating the signal reach of a communication tower. However, this method is appropriate especially for smaller regions because of the computational limitations. The second method is applying procedures contained within GIS, which are suitable even for large study areas. Both methods can ideally be combined – the GIS methods can be used for first approximation purposes with radio propagation software then serving as a tool to site the individual towers. By employing the viewshed analysis and examining the line-of-sight from specified observation points, the authors were able to conclude that a large part of rural communities in Canada, located beyond the urban zone, have the potential to be supplied with wireless systems.

3.2.4 Urban design

Applications of visibility analysis in various areas of GIS-related research have been growing in numbers. As shown by the studies already presented, a lot of such analyses focus on the natural environment. Examination of the urban environment, however, plays an important role in obtaining new and improved methods for viewshed calculation and visibility assessment. With the ever increasing process of urbanisation and the need for towns to accommodate more and more inhabitants, examination of the urban surroundings is becoming more common. One of the reasons is the aesthetic impact of a scenic lookout that significantly influences the sale price of a home (Sandler and Manson 2007). Influence of urban landmarks can also be significant. Research in such area can include analysis of the role urban landmarks play in overall impression of the location and their role in aiding orientation (Ohsawa and Kobayashi 2005). Examination of urban trails and routes can also be of interest (Wilson *et al.* 2008), as well as the management of urban development in general (Oh 2001).

An assessment of landmarks visibility is presented by Ohsawa and Kobayashi (2005). As suggested in the study, landmarks serve as points of geographical reference in the landscape. Castles, churches, tall buildings, large hills, and tall trees all represent common orientation points. They are significant features in the landscape that create its character. Their importance relies on the size, form, colour, texture, function, symbolic meaning and on how they relate to the surroundings. Such has been demonstrated not only in geography but also in psychology. Additionally, landmarks aid travel and are a significant feature in a community or

regional landscape. The study focuses on the situation in Japan, where during the recent years, the process of urbanization allowed buildings with increasing heights to emerge in the cities. The visual impact of such buildings has often been omitted as the necessity to provide sufficient interior space has been the key priority. Consequently, construction of tall buildings and their high density in urban landscapes, has led to the decrease of visibility of already existing landmarks and blocking the views from the landmarks themselves. The model used in the research underlines how zoning regulations such as the position of zone boundaries, building height and density, and building distribution influence the landmark visibility from observation points. Results are obtained through analytical investigation of three relationships between zoning and the visibility of landmarks. The lowest visibility of the key landmark is at the zone boundaries, as shown by the first relationship. The second relationship points out that increasing of building heights affects the visibility of landmarks more than increasing of building densities. Finally, the third relationship suggests that an equal space building distribution reduces the landmarks visibility opposed to a random building distribution (Ohsawa and Kobayashi 2005).

Likewise, as pointed out by Bartie *et al.* (2010), urban landmarks are significant features not only because of their architectural attraction but also for their visual importance. They serve as useful reference points, which help building an overall impression of the location and assist in navigation and exploration. However, incorporating more complex algorithms of visibility modelling into the real world applications is currently insufficient. One of such applications is Location Based Services (LBS), which uses syntax matching and proximity as search inputs, could benefit significantly from additional input information obtained from visibility modelling. The study introduces a new method for quantifying landmark visibility and aims to provide a foundation for its possible implementation into LBS that would result in better user's experience. It does so by using visibility modelling and determining the impact of landmarks within the visual field. More precise results could, however, be achieved by incorporation of user's context, such as time of the day or current weather conditions, into the application. Visibility analysis, therefore, plays a significant role in improving the LBS application by modelling user's environment more closely, determining which features are visible and providing more meaningful assistance. An extended LOS model is used to achieve the results. The model considers the most prominent features in front of the feature of interest (FOI). It also takes into account the elevation profile of the FOI and the surrounding city, and is able to deduce if an FOI is out of sight, clearly visible, partially

obscured, or on the skyline. The final model is able to quantitatively express the degree to which FOIs is visible, or obscured from view. The authors also suggest a number of improvements to the algorithm. One of these improvements is considering partial visibility through vegetation, which is discussed in the consequent study by Bartie *et al.* (2011). Additionally, factors that influence the actual identification of FOIs in urban environment, such as their use, shape, texture, colour, materials and architectural design, could provide useful additional metrics to include in the calculation (Bartie *et al.* 2010).

3.2.5 Archaeological studies

GIS-based visibility analysis not only provides examination of today's trends, it can also offer insights into the past. Assessments of past landscapes from archaeological point of view, such as the importance of site location (Lake *et al.* 1998, Winter-Livneh *et al.* 2012), placement of cultural objects in the landscape (Ogburn 2006, Llobera 2007), location of defensive systems (Rua *et al.* 2013, Smith and Cochrane 2011), and distribution of wildlife populations (Patterson 2008), belong among these.

Using GIS as a tool to address visibility of historical objects and sites is becoming increasingly common because of the convenient way to address archaeological questions of site locations, as well as the possibility to explore cognitive issues. Evaluation of archaeological landscapes through GIS offers several advantages. Above all, it reconstructs past conditions, that are usually not existent nowadays, and simulates the views to and from selected features (Ogburn 2006).

A study considering the visibility level of cultural objects within historical landscapes was carried out by Ogburn (2006). The placement of cultural features throughout landscapes and their visibility show their importance from archaeological point of view. A case study of Inca storehouses in the Saraguro region of Ecuador is presented in the article. The storehouses were round or rectangular single-room buildings constructed to store goods and arranged on the summits in rows on terraces. Archaeologists believe these were placed in prominent locations predominantly to be visible over long distances and to impress people by proclaiming the wealth of the state. The case study is used to illustrate the application of the examined methods of visibility calculation. One of these methods is using a standard binary viewshed. The other method is implementing a target size-sensitive fuzzy viewshed to assess

the visibility of small buildings over long distances. The resulting viewsheds assess the visual clarity of past monuments while taking into account the object size and the providing possibility to interpret local environmental conditions and physical properties of the target and its settings (Ogburn 2006).

Visibility, or more precisely invisibility, plays a significant role in defence. Examination of visibility importance for the defensive sites of Remote Oceania was realized by Smith and Cochrane (2011), focusing on the analyses of historical defensive sites in the western islands of Fiji. The study is the first quantitative GIS analysis of visibility in the Pacific and examines views to and from sites and the content of those views. The methodology is divided into four steps. At first, defensive sites are grouped by elevation and slope. Secondly, views from defensive sites is identified and compared. As a third step, arable land is determined, as well as inter-visibility within viewsheds. The last step includes identification and comparison of view to defensive sites. According to the findings it was confirmed that the fortifications were purposely placed in not easily seen areas of the landscape. They also do not indicate the importance of large views from the sites and their inter-visibility.

The role that visibility played in defensive structures is also described by Rua *et al.* (2013). As suggested, being able to visually cover the surrounding landscape was a very important factor in the decision making process regarding the location of defensive structures. There are many aspects to consider, including the presence of large viewsheds, prominent observation points, access to surrounding villages, and path surveillance. Another aspect is the ability to communicate with the neighbouring sites by line-of-sight and being able to quickly and efficiently exchange information. Such aspect is examined by Rua *et al.* (2013), who propose a method for evaluating the effectiveness of defensive systems in terms of visual communication, with the case study of Lines of Torres Verdas fortification system around Lisbon, Portugal.

Two procedures are used to analyse the transmission of messages through visual devices. Firstly, intervisibility between pairs of locations is analysed with a direct line-of-sight computation, to qualitatively classify the routes messages might have followed. Secondly, a cumulative viewshed analysis is used to allow predictions for the best sites for locating visual communication devices. Based on these methods it is concluded that the communication system was efficient and robust. Additionally, a proposal is made with

regards to strengthening the system's internal ability to exchange messages with newly suggested observer locations Rua *et al.* (2013).

3.2.6 Biogeographical studies

The field of ecology and landscape conservation offers various research branches that could benefit from incorporation of GIS-based approaches and of visual analysis in particular as one of the accompanying methods for research. Some of these branches include research in the area of ground-based radiotelemetry (Etherington and Alexander 2008) and estimation of wildlife population (Maichak and Schuler 2004).

One of these applications of GIS-based visibility analysis is shown by Etherington and Alexander (2008), suggesting the use of viewsheds as a possible way to determine area sampled by ground telemetry. As pointed out in the study, recognition of the area where the radiotagged animals can be located is valuable. It can offer implications for study design, data collection, and data analysis. It can be particularly useful when considering ground-based radiotelemetry in rugged terrain, which causes radiowaves obstruction and results in reduction of the sample area. This is often solved by aerial radiotelemetry or Global Positioning System (GPS) collars, however these methods are more expensive and in many cases the researchers can only rely on ground-based telemetry. The use of GIS technology has been suggested in this study as a tool for identification of the area sampled by radiotelemetry. The viewshed function classifies the area that is visible from a specified location and therefore offers the same prerequisites as radiotelemetry – no intervening topography. A so-called “telemetry viewshed” is used to analyze a given area, which depicts the locations of grizzly bear distribution. Obtaining these results, the authors are confident that in combination with other methods, information gained through visibility analysis could improve the overall research process of ground-based radiotelemetry (Etherington and Alexander 2008).

A similar approach is encouraged by Maichak and Schuler (2004) with regards to providing a simpler and more accurate method for determining route, area and population estimate of wildlife. More traditional techniques, including road counts and nocturnal spotlight counts, rely on observers sighting animals from a travel route. Population size is then extrapolated for a given area based on number of animals counted in the area visible from the travel route. These methods often lack precision and can be under or overestimated

resulting in an inaccurate estimate, index and trend of population size and density. Visibility methods based on GIS, however, provide numerous benefits in wildlife population estimation. They can locate optimal sites for observation towers, determine the area visible from a driving route and locate population census routes, as well as provide a more accurate population estimates, indices and trends based on road counts and spotlight surveys. Viewshed calculation was used in the study to examine the distribution of bison population in Oklahoma. The results of the analysis were very successful, with 99% of observed groups contained within the viewshed derived from the driving route. The use of viewshed calculation is recommend as an excellent predictor of locating other animal species from driving routes, especially in the case of conspicuous animals that are not behaviourally affected by vehicle presence (Maichak and Schuler 2004).

3.3 Limitations

Analysing visibility through GIS brings certain limitations. Even though resolving some of the issues have been attempted by many authors (Maloy and Dean 2001, Riggs and Dean 2007, Llobera 2007, Ogburn 2006), many of the restrictions still prevail. The outcome of a visibility analysis should therefore be considered as a probable, rather than an exact real-life situation. The following chapter presents some of the most common problems encountered with when calculating visibility.

3.3.1 Limitations of computational processes

There are technical challenges that have to be overcome when attempting to accurately calculate visibility. These challenges include the often key issue of obtaining accurate data, together with limitations of existing algorithms, and the inability of current GIS to integrate additional information into the analysis, such as the use of three dimensions, incorporation of vegetation, and avoiding the edge effects.

3.3.1.1 Data

The very first assumption of any analysis to be successful is the necessity to use data accurately representing the studied situation and containing precise values. Obtaining such data is not always an easy task. In the case of visibility analysis, the predominant success therefore lies in the ability to acquire high quality landcover and elevation data to produce accurate viewsheds (Germino *et al.* 2001).

3.3.1.2 Algorithms

As described in the previous chapter, numerous methods for assessing visibility analysis exist. They all have to deal with similar limitations, particularly concerning high computational intensity required for such analyses. On one hand, it is desired to obtain results in high resolution so that they can be applied in real-life scenarios. However on the other hand, this aspiration is met with time consuming calculations that are memory demanding. It is therefore desirable to attempt and simplify the algorithms, so they can be used more efficiently, as shown by Llobera (2004).

3.3.1.3 3D space

Most of the current visibility analyses use lines of sight constructed in 2D space, as the third (z axis) is not taken into account by GIS-based visibility models. This is an significant drawback for application of the results in a real-life situation, which is particularly true when studying the visual impact of landmarks or architectural features (Paliou 2011).

3.3.1.4 Edge effect

Edge effects are worth considering especially with cumulative viewshed analysis, which is very susceptible to them. They can occur when the distribution continues outside of the study area and as a result of that, the number of cells visible from the location on the edge

can significantly be underestimated because the cells outside the boundary are not considered. One of the possible solutions to mitigate the edge effect is to select a larger area than the one to be studied. This way, the edge distortions can be minimised (Wheatley and Gillings 2002).

3.3.1.5 Vegetation incorporation

When calculating visibility, the input data for the analysis usually do not include information regarding vegetation, specifically forest cover. This is one of the main drawbacks of GIS approaches to visibility analysis, as quite often the applications are concerned with natural environment and forests tend to play a key role in overall visibility. As suggested by Llobera (2007) this fact is very likely caused by the inability of current commercial GIS to incorporate 3D information into analyses and address such shortcomings.

3.3.2 Physical limitations of seeing a target

As popular as the GIS-based assessment of visibility in the landscape has become, it can often be misleading. There are some factors which the GIS softwares do not take into account. These can, however, play a very essential role in determining the actual visibility in the landscape. The most common GIS-based analyses focus on computing binary viewsheds and lines of sight. These do not take into account whether an object of interest can be seen and recognized over distance. Omission of the limits of visibility can result in its underestimation or overestimation. In the first case, underestimation of visual impact can lead to conclusions that visibility is unimportant. On the other hand, overestimation of the visibility of objects could suggest a far greater visual impact. Among important factors, that can influence visibility, are the physical constraints on seeing a target, such as maximum observable distance, the limits of human vision, environmental limits, and the properties of objects and their surroundings (Ogburn 2006).

3.3.2.1 Maximum observable distance

Maximum observable distance is a significant factor to be considered when applying visibility analysis into the real-life situation. It can be influenced by the Earth's curvature, atmospheric refraction, and climatology, as well as by the distance to the sea, terrain elevation, land cover and soil use (Rua 2013).

3.3.2.2 Human vision

Human vision plays the most direct role in how far an object can be seen. Among other things, such as the actual quality of eyesight, the ability to detect a target of a specified size in the surroundings should be considered as well when assessing visibility in the landscape. GIS based analyses do not address the limitations of human sight but simply show what is visible within the given parameters of the model (Ogburn 2006).

3.3.2.3 Environmental conditions

Environmental conditions represent equally important factor in terms of visibility assessment. They can be very unstable and vary not only within the seasons of the year, but also within the time of the day. These include lighting conditions determined primarily by the position of the sun, which can affect the amount of light directed on and reflected from an object and its surroundings. Unfavourable weather conditions, including fog and precipitation, can completely alter the visibility in the landscape. Scattering and absorption of light along the line of sight represent other limits of environment to be considered (Ogburn 2006).

3.3.2.4 Properties of objects and their surroundings

Properties of the landmark itself and those of its immediate surroundings can affect visibility in several ways. These include the size of the object, its colour, shape and placement in the landscape, as well as the contrast between the object and the surrounding landscape.

The most relevant is the size of the landmark and the obvious linearly decreasing visibility with decreasing size of the target. Other aspects, such as creating contrast between an object and its surroundings through brightness and colour, should also not be omitted. The human eye can detect even relatively low differences in brightness and since atmospheric conditions reduce the apparent contrast in brightness, higher contrast between the object and its background enhances visibility over distance. The colour of the landmark can also influence visibility in a positive or negative way. Red objects tend to be more visible for the human eye in comparison to the green and brown colours, more commonly occurring in nature. Furthermore, placement in the landscape can have an essential effect in terms of the object's visibility, particularly if it is placed on a hilltop or ridgeline, where it is seen against the sky. Finally, the shape of the object can be considered, as within the natural landscape it can alter the landscape character and emphasise the object's visibility. This issue is often studied regarding man-made landmarks, such as windmills and skyscrapers (Ogburn 2006).

3.4 Individual perception of the landscape

Apart from the already described computational and physical limitations of current visibility analysis approaches, human perception of the landscape is also worth considering. As pointed out by Ervin and Steinitz (2003), just because the outcome of a computer analysis shows particular locations or features as visible from a specified observation point, does not in fact mean they will be seen or remembered. Furthermore, the assessment of the landscape, scenery and scenic value is not objective. Perception of wind turbines can be mentioned here as an example. What one person might find intolerable within the natural environment, the others might consider not disturbing or even perceived as a fascinating representation of technology. The outcomes of visibility analyses should therefore be considered as probable representations and not exact real-life situations.

4. METHODOLOGY

The process of the thesis composition was divided into several parts. In keeping with the aims of the thesis, the first part was devoted to the research of the available literature that studies modern methods of visibility analysis, and discusses their possible applications and limitations. This was followed by learning to work with the Python programming language with a particular emphasis on writing scripts executable in ArcGIS. In the next part, specific scripts, dealing with analysis of visibility, were designed and developed in Python. They were then tested on real-world data. Subsequently, the results were depicted in the form of maps and pictures, and possible implementations and shortcomings of the methods were considered. Finally, the thesis was written, giving a review of the visibility analysis methods, and presenting the results with the discussion.

A considerable section of the thesis is formed by the literature review, which describes the methods, applications, and limitations of current visibility analysis approaches, and is based on the preceding literature research. Even though the idea of visual impact awareness is not new, more extensive research with applications in particular fields of study has only been done in the recent years. For that reason, science journals with published articles were used as the main source of literature for this section. Most of the articles were available through the ScienceDirect (Elsevier B.V. 2014) and Web of Science (Thomson Reuters 2014) databases.

Two softwares were used for execution of the analyses in the practical part of the thesis: Esri ArcGIS for Desktop 10.1 (further referred to as ArcGIS) and Python 2.7.2. (further referred to as Python). ArcGIS was chosen as it is a widely used software within GIS and is available at the CULS. Even though it offers a variety of complicated and sophisticated operations, sometimes more efficient and robust ways to execute such operations exist. This can be achieved through development of Python scripts, which allow the user to automate tasks in ArcGIS that would otherwise be quite cumbersome and time-consuming. While Python was not actually developed by Esri, it is contained within a typical ArcGIS installation. Apart from serving as the preferred language for working with ArcGIS, there are other advantages in using Python, as it is a free and open source software and despite being relatively easy to learn, it is still a powerful programming language (Zandbergen 2013, pp.xi-xii).

Some visibility analysis tools, such as Viewshed, are available in ArcGIS. However, as the analysis, which was to be employed in the thesis, requires the use of more advanced methods, understanding of at least the basic use of the Python programming language was necessary. Therefore, learning to work with this program was an essential part of the process. This was achieved by attending a course on Python scripting in the Faculty of Environmental Sciences (FES) of the Czech University of Life Sciences (CULS) and by further self-studying using a book on general Python scripting (Summerfield 2011) and a book focused on the use of Python in ArcGIS environment (Zandbergen 2013).

Based on the knowledge obtained from the literature and on consultations with the thesis supervisor, three specific scripts analysing visibility were designed. They were then developed in Python. First two of them calculate the total viewshed for a specified area and the viewshed for a polygon shapefile. The third one calculates the visual magnitude of each cell in a given area and was developed by the thesis supervisor, as more advanced programming skills were necessary. The scripts are executable through Python, as well as in ArcGIS. A toolbox containing pop-up windows for each script was developed for convenient use in ArcGIS.

All three methods were then tested on real-world data, namely on the Most, Ústí nad Labem, and Česká Lípa regions located in the north-west part of the Czech Republic. These regions were chosen because of their varied topography that is suitable for testing visibility in the landscape. Additionally, they offer other characteristics for which analyzing visibility might be useful. Among these belong surface mining activities and subsequent land reclamation, wind power development, industrial growth, landscape conservation of protected areas connected with tourism. All of such activities influence the character of the landscape and are being considered in visibility analysis research, as shown by the examples given in the literature review chapter.

The results obtained from the analyses were then expressed through maps and pictures created in ArcGIS to show the differences for various attributes of the input features, for example cell size of the input rasters. The methods were subsequently assessed and their possible applications and limitations were considered through discussion.

Writing of the thesis was the last step in the process, attempting to provide a concise review of the visibility analysis methods and to show some of their implementations.

5. RESULTS

The initial results of the practical part of the thesis were three scripts developed in Python that analyse visibility. The first two of them deal with the calculations of total and cumulative viewsheds respectively. The cumulative viewshed calculation is set to work for a polygon shapefile as an input feature. The third script offers far more complex analysis and was created by the thesis supervisor, as higher knowledge of programming was required for its composition and successful implementation. All the scripts were executed in Python Shell and tested on real-world data.

This chapter presents the scripts for the total and cumulative viewsheds calculation, explains their specific parts, and demonstrates their use on figures obtained from applications on real-world data.

5.1 Scripts

5.1.1 Total viewshed

Total viewshed can be obtained when a viewshed from each cell of the DTM is calculated and added together, offering a simplified description of the visibility pattern within a landscape based on its topography. During the process of total viewshed analysis, each target location is compared with all other locations in the elevation matrix. This leads to X^2Y^2 number of operations for an output visibility raster calculated from an input raster of X by Y dimensions, as each individual operation requires XY calculations. Therefore, because of such high computational intensity, calculation of total viewshed at useful resolutions has proved impractical, particularly with the use of conventional algorithms (Llobera *et al.* 2004).

Despite the mentioned shortcomings, the script calculating total viewshed was created, mainly to serve as the base line for development of the cumulative viewshed script, and is presented in the following section.

5.1.1.1 Calculation of total viewshed

In the first part, all necessary modules are imported, namely *arcpy*, *os* and module *time*, which is not required, but is quite convenient, as it returns the time taken for each analysis to finish. The workspace and the ability to overwrite output are set, together with enabling the Spatial Analyst extension, which is needed for the Viewshed tool execution.

```
import time
t_start = time.time()
print "Time:", time.ctime()

import arcpy, os

workspace = arcpy.env.workspace = r"C:\..."
arcpy.env.overwriteOutput = True
arcpy.CheckOutExtension("Spatial")
```

In the next step, the layers, which are to be used, are given shorter names for simplification during the subsequent scripting. For the total viewshed calculation, only one input layer is needed, namely the digital terrain model (DTM) of the examined area. Shapefile containing the observation points is obtained through conversion of the input DTM. This is an important step, as viewsheds are calculated from single points and cannot be obtained from a raster layer. The shapefile then used to create a feature layer of the same values, which is required in the following step. At this stage, it is also necessary to set the cell size and extent for the calculation.

```
rstr = "dtm"
shp = "points.shp"
lyr = "points_fl"

arcpy.RasterToPoint_conversion(rstr, shp)

print "Raster to point converted"

arcpy.MakeFeatureLayer_management(shp, lyr)

print "Feature layer created"

cell_size = arcpy.GetRasterProperties_management(rstr, "CELLSIZEX")
extent = arcpy.Describe(rstr).extent
arcpy.env.extent = extent

print "Cell size and extent set"
```

The final part contains the actual viewshed calculation. At first, an empty raster is created, which is used at the end for adding all the individual viewsheds. It is then necessary to open the attribute table of the observation points shapefile, select every point separately and generate a viewshed for each of them. However, the points can only be selected from the attribute table of a feature layer. That is why it had been created in the preceding step. In each cycle, a viewshed is calculated for one point and added to the previously created raster. The final outcome has to be saved and all the unnecessary attributes deleted.

```

print "Calculating viewshed"

totalVshd = arcpy.sa.CreateConstantRaster(0, "INTEGER", cell_size, extent)

cursor = arcpy.da.SearchCursor(shp, ["POINTID"])

for row in cursor:
    print "Working with point: ", row[0]
    arcpy.SelectLayerByAttribute_management(lyr, "", '"POINTID" = '+str(row[0]))
    outVshd = arcpy.sa.Viewshed(rstr, lyr)
    totalVshd = totalVshd + outVshd

totalVshd.save("total_vshd")

del row, cursor, outVshd

print "Viewshed saved"
print "DONE"

print "Time:", time.ctime()
t_end = time.time()
l = t_end - t_start
print "Total time of calculation", l/60

```

5.1.2 Cumulative viewshed

Computation of cumulative viewshed provides a certain degree of location visibility. It is similar to the technique of total viewshed calculation, as it is produced by adding the number of times an area is considered visible from different viewpoints. In other words, results obtained from numerous binary viewsheds are combined to create a cumulative viewshed. This way, each cell can be compared by the number of times each location is visible from an observation point (Chamberlain and Meitner 2013). Unlike total viewshed, cumulative viewshed is not the outcome of all the cells intervisibility. Rather it shows how many times are cells within the area visible from an input feature, such as a polyline or a polygon shapefile. A script allowing cumulative viewshed computation was developed in Python and is described in the subsequent section.

5.1.2.1 Calculation of cumulative viewshed

As in the previous case, all necessary modules are imported at first, together with setting the workspace, the possibility to overwrite output, and with enabling the Spatial Analyst extension.

```
import time
t_start = time.time()
print "Time:", time.ctime()

import arcpy, os

workspace = arcpy.env.workspace = r"C:\..."
arcpy.env.overwriteOutput = True
arcpy.CheckOutExtension("Spatial")
```

Subsequently, all the layers are again given shorter names for simplification. Unlike the total viewshed analysis, two input layers are required for the cumulative viewshed calculation: the DTM of the examined area and a polygon shapefile. All the other layers are created based on the two input ones. Cell size and extent are set in this part of the analysis.

```
rstr = "dtm"
pgn = "polygon.shp"

rstr2 = "polygon_rstr"
shp = "pts.shp"
shp2 = "pts_polygon.shp"
lyr = "pts_fl"
lyr2 = "pts_pgn_fl"

cell_size = arcpy.GetRasterProperties_management(rstr, "CELLSIZEX")
extent = arcpy.Describe(rstr).extent

arcpy.env.extent = extent

arcpy.PolygonToRaster_conversion(pgn, "FID", rstr2, "", "", cell_size)

arcpy.RasterToPoint_conversion(rstr, shp)
arcpy.RasterToPoint_conversion(rstr2, shp2)

arcpy.MakeFeatureLayer_management(shp, lyr)
arcpy.MakeFeatureLayer_management(shp2, lyr2)

print "Layers created"
```

The last part, where the viewshed is computed, varies a little from the total viewshed calculation. It is because in the previous case the viewshed is generated for each single point in the examined area. In this case, the viewshed is calculated only for the points contained within the given polygon shapefile. The process of its creation is then the same, however before the final output is saved, the area of the polygon is eliminated, as it does not play an important role in the resulting viewshed output.

```

print "Calculating viewshed"

totalVshd = arcpy.sa.CreateConstantRaster(0, "INTEGER", cell_size, extent)

cursor = arcpy.da.SearchCursor(shp2, ["POINTID"])

for row in cursor:
    print "Working with point: ", row[0]
    arcpy.SelectLayerByAttribute_management(lyr2, "", '"POINTID" = '+str(row[0]))
    outVshd = arcpy.sa.Viewshed(rstr, lyr2)
    totalVshd = totalVshd + outVshd

remap = arcpy.sa.RemapRange([[0,1000,0], ["NoData",1]])
mask = arcpy.sa.Reclassify(rstr2, "VALUE", remap)
totalVshd = totalVshd * mask

totalVshd.save("vshd_polygon")

del row, cursor, outVshd

print "DONE"

print "Time:", time.ctime()
t_end = time.time()
l = t_end - t_start
print "Total time of calculation", l/60

```

5.1.3 Visual magnitude

With the use of visibility algorithms, as shown in the previous examples, it is possible to determine whether a cell is visible and from how many viewpoints it can be seen. However, such algorithms are incapable of determining to which degree a cell is visible (Chamberlain and Meitner 2013). This has probably resulted from the natural development of GIS, as it is based on geographical view of space and not on human-space interaction (Llobera 2003). For some applications, it is desired to obtain not only the frequency of how often the target is visible, but also the degree of its visibility. Computation of visual magnitude has been suggested as the means of requiring said degree of visibility. It is calculated using the slope and angle of the cells within a DTM and the distance relative to the observer.

5.1.3.1 Calculation of visual magnitude

Because of the script's extensive length, it was not convenient to include it within the text of the thesis. It can, however, be found in the attachments with included comments captioning each step of the process.

As already mentioned, visual magnitude value can be obtained by using the slope and angle of the cells within a DTM and their distance relative to the observer. The distance of the observer and the slope of the cells are easily obtained from the input data. However, the angle of the cell relative to the observer has to be calculated. Fig.1 represents the geometry of visual magnitude calculation. There are three points in the picture: point A, representing the observer, point B, representing the middle part of a cell on an inclined plane, and point C, which is the end point of the normal vector \vec{u} . The distance from point B to the observer (point A) is represented by the vector \vec{v} . The value of the angle α is the value which is necessary for the calculation and it can be obtained by calculating $\cos \alpha$. For visual magnitude calculation, the following equation is used:

$$\text{visual magnitude} = \cos \alpha * \frac{d^2}{\|\vec{v}\|}$$

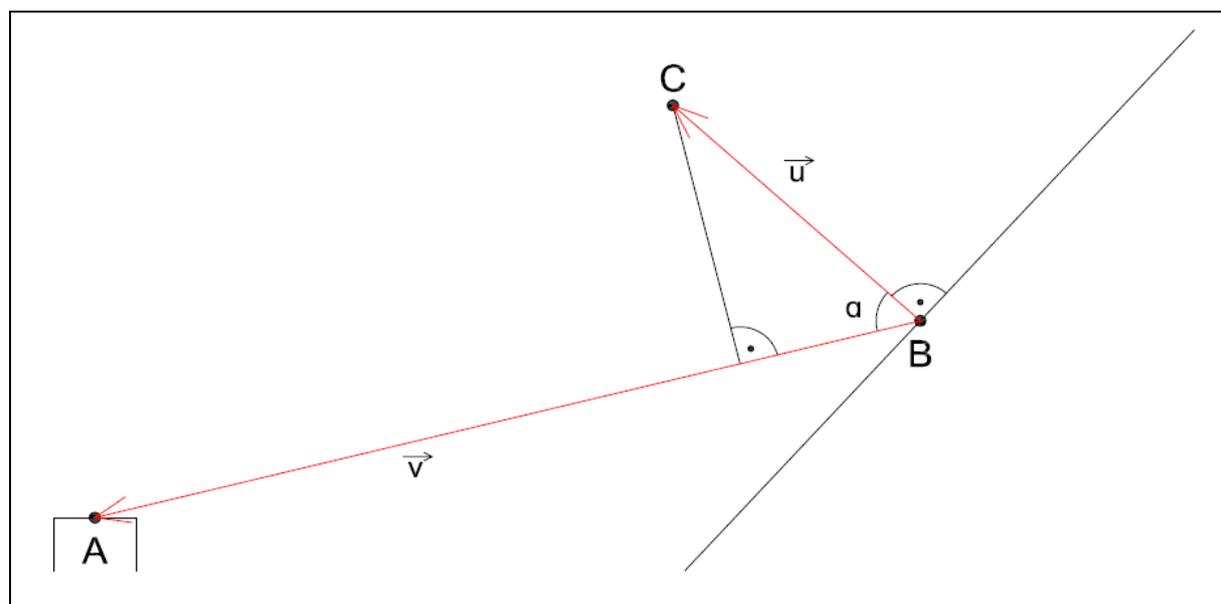


Fig.1: Geometric representation of parameters used during visual magnitude calculation.

5.2 Toolbox

There are several ways how to execute tools. Within Python, it is possible to use one of the integrated development environments (IDE), such as PythonWin, which allow the execution of a single line of Python code. It is also possible to use Integrated Development Environment (IDLE), a default Python editor provided with the standard Python installation. These applications allow the user to create scripts that can be saved on disk as a file with a .py extension (Esri 2013). Another way for tools execution is through ArcGIS, since Python serves as its preferred programming language. One option is to use the Python window, which is conveniently contained within ArcGIS (Esri 2013). Another option is using a toolbox, which contains the scripts in the form of pop-up windows. This way, the user does not deal with the actual script, but merely follows the instructions given by the window, just like when using any other tool from the ArcGIS toolbox.

As using the toolbox seems to be the most user-friendly option, each of the three scripts developed previously were also transformed to the form of a pop-up window and located into one toolbox for convenient use within ArcGIS. The toolbox was given the name *Visibility Calculation Tools* and it contains a script for total viewshed calculation, named

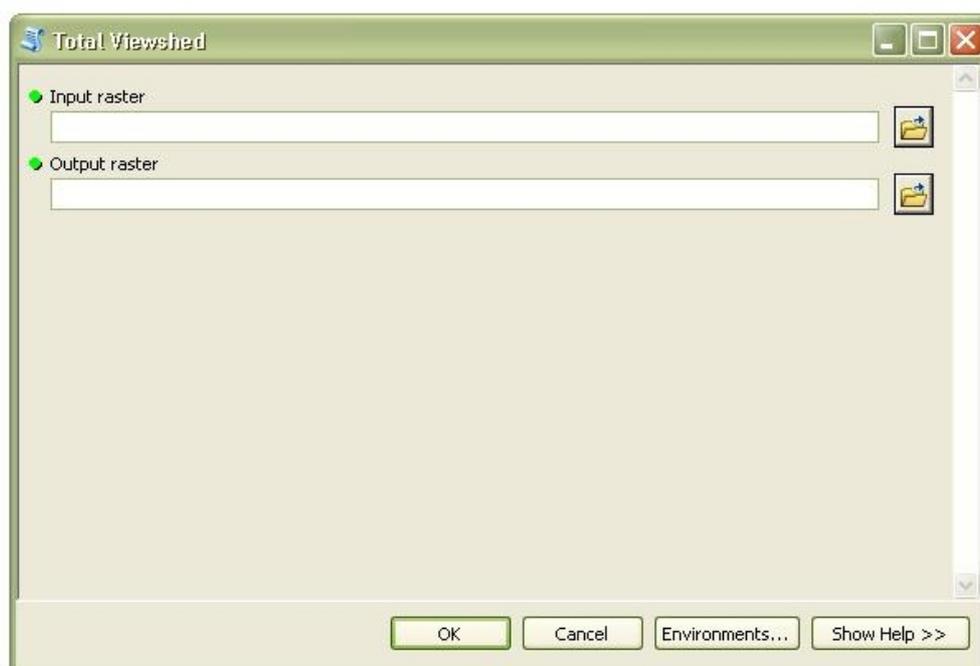


Fig.2: Pop-up window for calculation of total viewshed.

“Total Viewshed” (Fig.2), a script for cumulative viewshed calculation, named “Viewshed for polygon” (Fig.3), and a script for visual magnitude calculation, named “Visual Magnitude” (Fig.4).

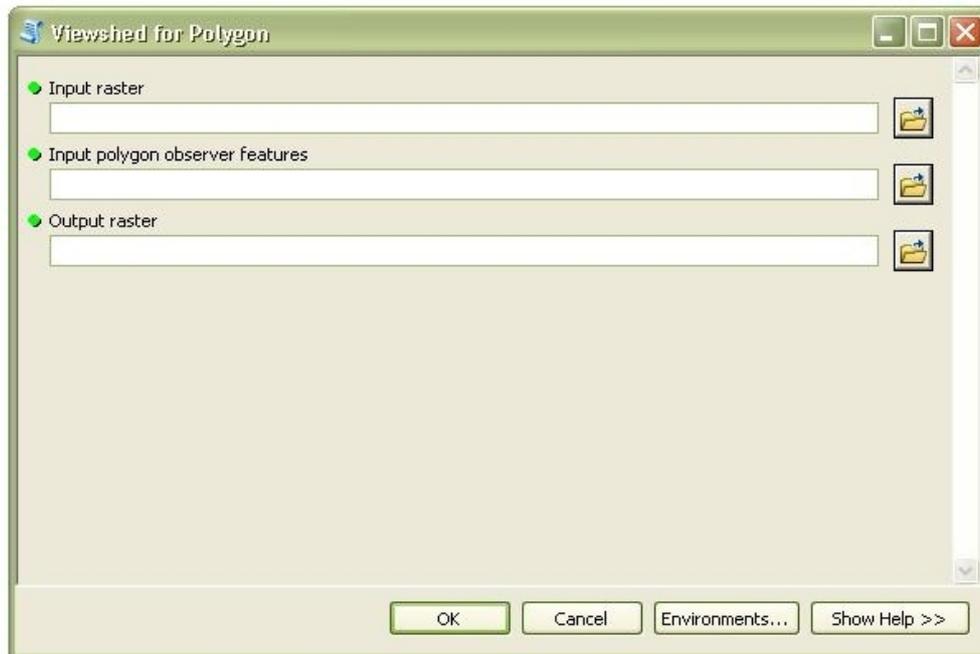


Fig.3: Pop-up window for calculating viewshed for a polygon shapefile.



Fig.4: Pop-up window for calculation of visual magnitude.

5.3 Real-world data testing

5.3.1 Study area

Three Czech regions were chosen for testing the methods, namely the region of Most, Ústí nad Labem, and Česká Lípa. They are located in the north-west part of the Czech Republic and provide certain aspects that are worth studying from the visual impact point of view. First of all, the topography is quite varied, ranging from low lying plains with lakes around 200 meters above the sea level to mountains almost as high as 1 000 meters above the sea level. Other aspects include brown coal surface mining and land reclamation connected with it, the development of wind power, expansion of industry, as well as conversion of protected areas and promotion of touristic activities. All of these elements affect the landscape, among others, from visual impact and aesthetic points of view.

The region of Most (Fig.5) is rich in non-renewable materials, brown coal in particular. The low lying areas of the region have been undergoing extensive landscape changes, as it has been influenced by surface mining activities and subsequent land reclamation. Surface mining negatively influences the environment, landscape appearance and the lives of people living in surrounding areas. As the brown coal deposits have been significantly reduced, so has been the associated mining. In the recent years, the focus has shifted to post-mining land reclamation, such as agricultural, forestry and water-associated recultivation (Český statistický úřad 2014a). Additionally, the mountainous areas of the region have been subjected to wind power development. Turbines for wind power generation have been located for instance in Nová Ves v Horách, Klíny, and Loučná (Česká společnost pro větrnou energii 2013). As shown in the literature review, studying the impact of wind turbines has been a very common application of visibility analysis.

Just as the Most region, the region of Ústí nad Labem (Fig.6) has been influenced by industrial development, predominantly by chemical industry, although heavy industry and brown coal mining has also been significant. Decrease in mining and activities related to it, has improved the quality of environment in the region, just as the on-going land reclamation projects (Český statistický úřad 2014b). One of such projects is transformation of a brown coal mine Chabařovice, which has been recultivated into a lake. The lake, called Milada, is the result of the first large water-related reclamation project in the Czech Republic. It has

become an inspiration for other, similar schemes in the north-western part of the Czech Republic, where the landscape has also been reshaped by surface mining (Wikimedia Foundation 2014a).

Unlike the two previously mentioned regions, the region of Česká Lípa (Fig.7) has not been subjected to heavy industry. Quite contrary, one third of its area is formed by natural reserves and protected landscape areas and is preserved under various legislations. Together with relatively good environmental conditions and rich cultural and historical heritage, the region attracts many visitors and is quite popular for touristic, sport and recreational sport activities (Český statistický úřad 2014c). One of the particular places, which is visited by many people each year, is the area around Máchovo jezero. The lake has long tradition of spa and wellness stays and is used mainly for recreation (Wikimedia Foundation 2014b).

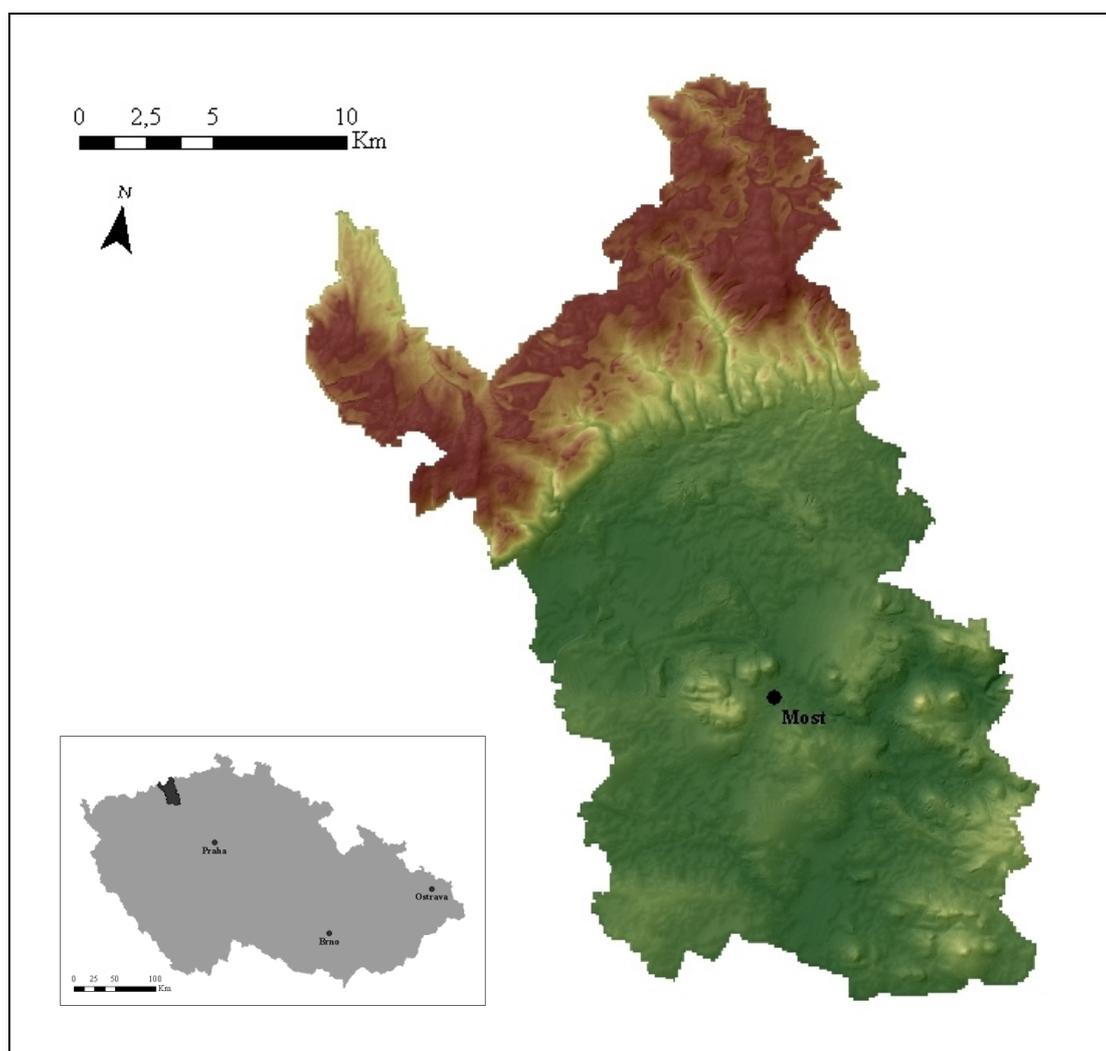


Fig.5: Overview of the study area: the Region of Most, the Czech Republic.

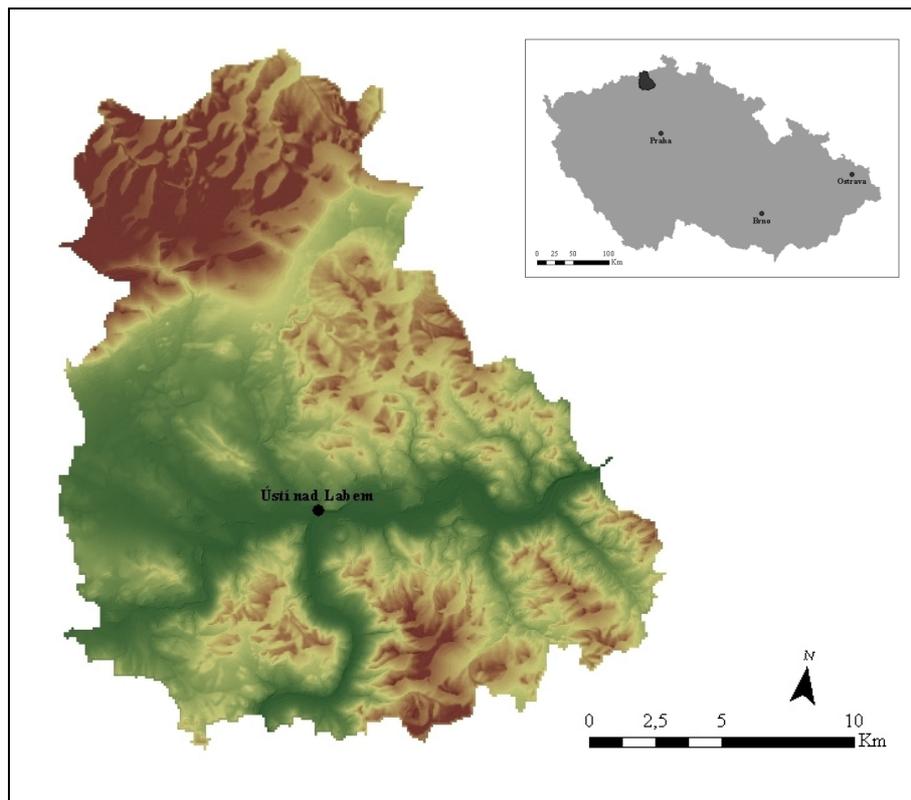


Fig.6: Overview of the study area: the Region of Ústí nad Labem, the Czech Republic.

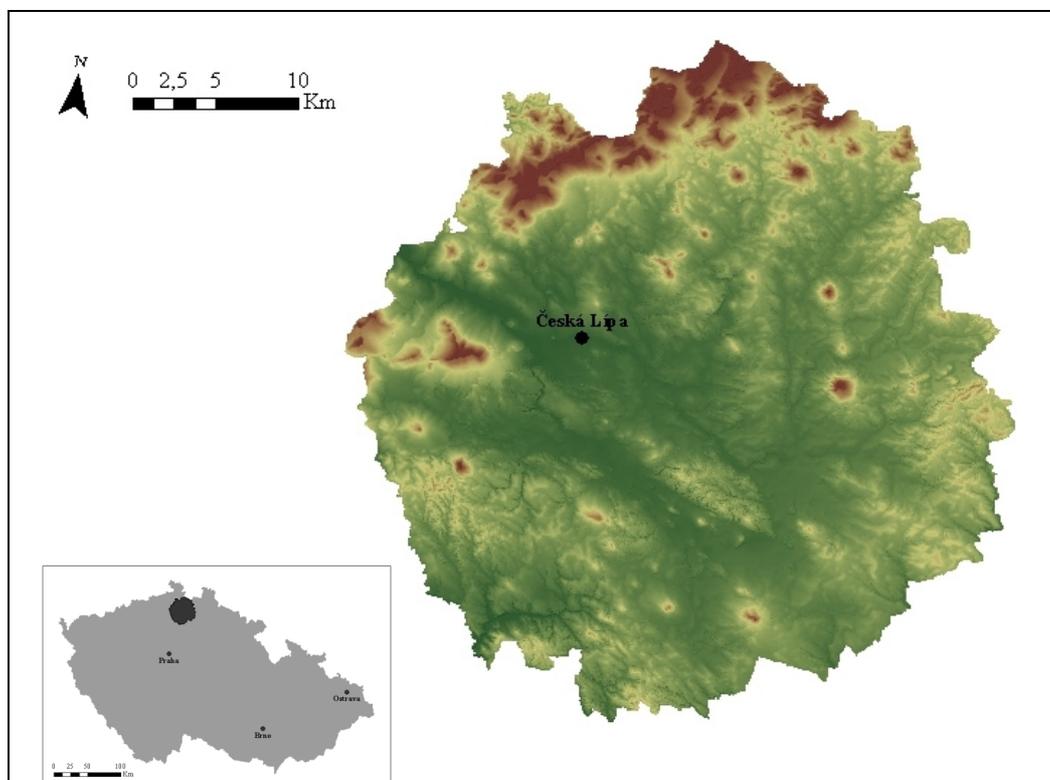


Fig.7: Overview of the study area: the Region of Česká Lípa, the Czech Republic.

5.3.2 Outcomes

Functionality of the scripts and pop-up windows was tested on the study locations presented in the previous section. All the data was obtained from the supervisor or created using images of maps and connecting them to the data through georeferencing in ArcGIS. The required input data necessary were the DTMs of the regions, together with polygon shapefiles of studied lakes. In most of the cases, input features of three different cell sizes were used for the analysis, namely 100, 50 and 10 meters, to demonstrate the difference in time of calculations and resulting quality. The default cell size of the DTMs was 100 meters. To obtain DTMs with smaller cell sizes, isolines shapefiles of the regions were transformed into rasters through Topo to Raster analysis (with the required cell size set in the Environments settings) and then reshaped with the original DTMs using Extract by Mask. As viewsheds are calculated from single points, it is also necessary to have a point shapefile for each studied location. However, there was no need for any additional input features, as all the other layers were set to be created during the analysis when running the script.

5.3.2.1 Total viewshed

The script calculating total viewshed was tested on a small DTM cut out from the DTM of the Most region. It was chosen to only test a very small area, specifically an area of 2 500 m², because of the increasing time of calculation with decreasing cell size. The first sample was composed of a 5x5 grid of cells with 100 meters in cell size. The second one of 10x10 grid with 50 meters in cell size and the last one of 50x50 grid with 10 meters in cell size. While the time of the first two analyses was only four and 16 minutes respectively, the analysis at the resolution of 10x10 meters took around 13 hours. It is because for each cell in the grid, a viewshed has to be computed and added to one another. Whereas the first two samples contain only 25 (5x5) and 100 (10x10) points, the third one includes 2 500 (50x50) points and therefore requires 2 500 viewsheds to be computed and added up. This is not only very time consuming, it also requires large operation memory. Fig.8 shows the three DTMs with corresponding viewsheds. The darker the colour of a cell in the DTM, the higher the altitude. For the viewsheds, the darker the green, the more cells are visible from a given point (or in other words, the more cells a given point is visible from).

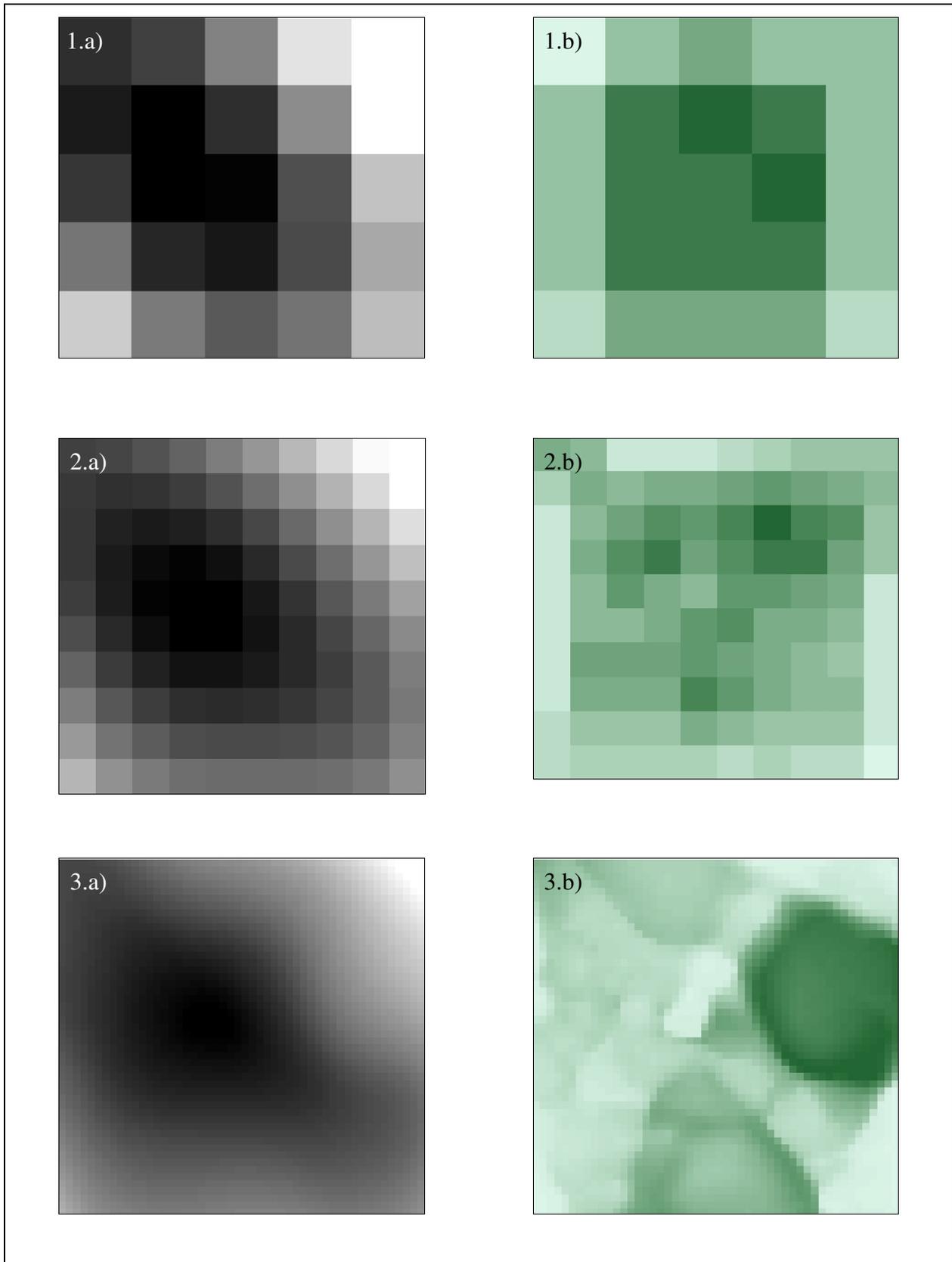


Fig.8: A small section of a DTM (part a) with computed total viewshed (part b). Cell size variation: a) 100m, b) 50m, c) 10m.

5.3.2.2 Cumulative viewshed

Unlike the total viewshed, the calculation of cumulative viewsheds is not as time consuming. It is because not all the cells of the input DTM are considered for the calculation, but only the ones contained within the input polygon shapefile. The cumulative viewshed is then obtained through adding up all the viewsheds computed from each cell of the polygon. Depending on the size of the input DTM and the polygon shapefile, even layers with larger resolutions can be used.

Fig.9 shows the visibility of Mílův rybník within the Most region. It was tested three times, each time with a different cell size (the cell size is always the same for both, the polygon and the DTM). At first, the cell size of 100 meters was used. The polygon contained only eight points, with 47 695 points in the corresponding layer of converted DTM, and the analysis took a little less than one minute. Then layers with the cell size of 50 meters were used. The DTM in this resolution was composed of 190 780 points after conversion. The polygon in this case contained 30 points and the calculation took around two minutes. Finally, the largest resolution of the input layers of 10x10 meters was used. There were 4 769 500 points contained in the converted DTM layer and 732 points in the polygon and the computation took three and a half hours.

Two other locations were then tested, namely the visibility of Máchovo jezero within the Česká Lípa region (Fig.10) and of the lake Milada within the region of Ústí nad Labem (Fig.11). Cell size of 100 meters was the same in both cases. Máchovo jezero contained 259 points and even though the DTM of Česká Lípa contained 116 190 points, the calculation took only 10 minutes. In the case of the lake Milada, the input polygon shapefile contained 243 points and the input DTM of Ústí nad Labem 41 405 points, with the analysis taking eight minutes. Table 1 summarizes all the parameters of the calculations for each study location.

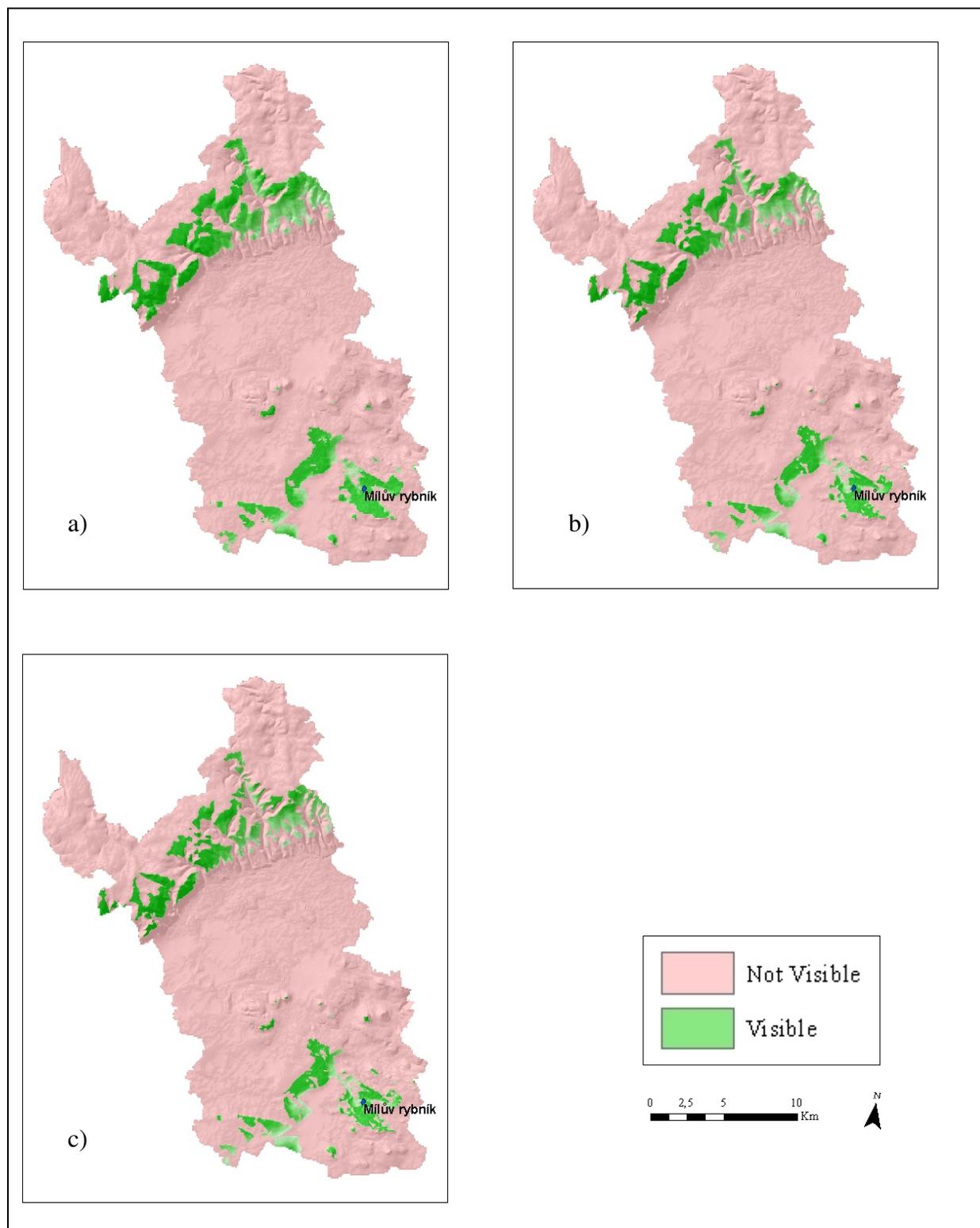


Fig.9: Cumulative viewshed for a polygon shapefile – Viewsheds of the Most region for Mílův rybník with a different cell size: a) 100m, b) 50m, c) 10m.

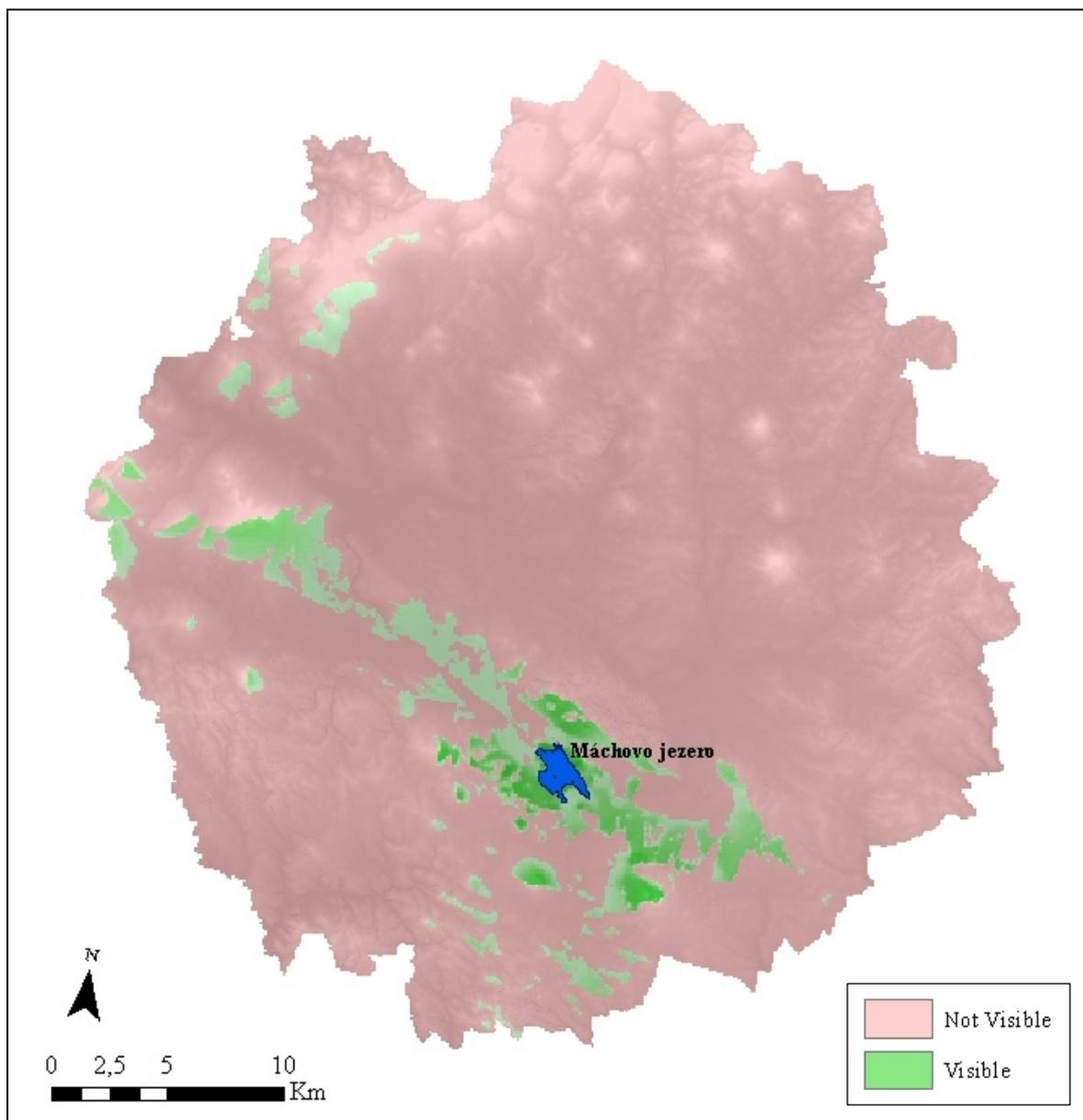


Fig.10: Cumulative viewshed for Máchovo jezero.

Name of the layer	Type of the layer	Cell size	No. of points	Time of calculation	Fig. No.
Jezero Milada	shp	100 m	243	8 min	11
Ústí nad Labem	DTM		41 405		
Máchovo jezero	shp	100 m	259	10 min	10
Česká Lípa	DTM		116 190		
Mílův rybník	shp	100 m	8	< 1 min	9 a)
Most	DTM		47 695		
Mílův rybník	shp	50 m	30	2 min	9.b)
Most	DTM		190 780		
Mílův rybník	shp	10 m	732	3h 30 min	9.c)
Most	DTM		4 769 500		

Table 1: Overview of the parameters for the tested locations.

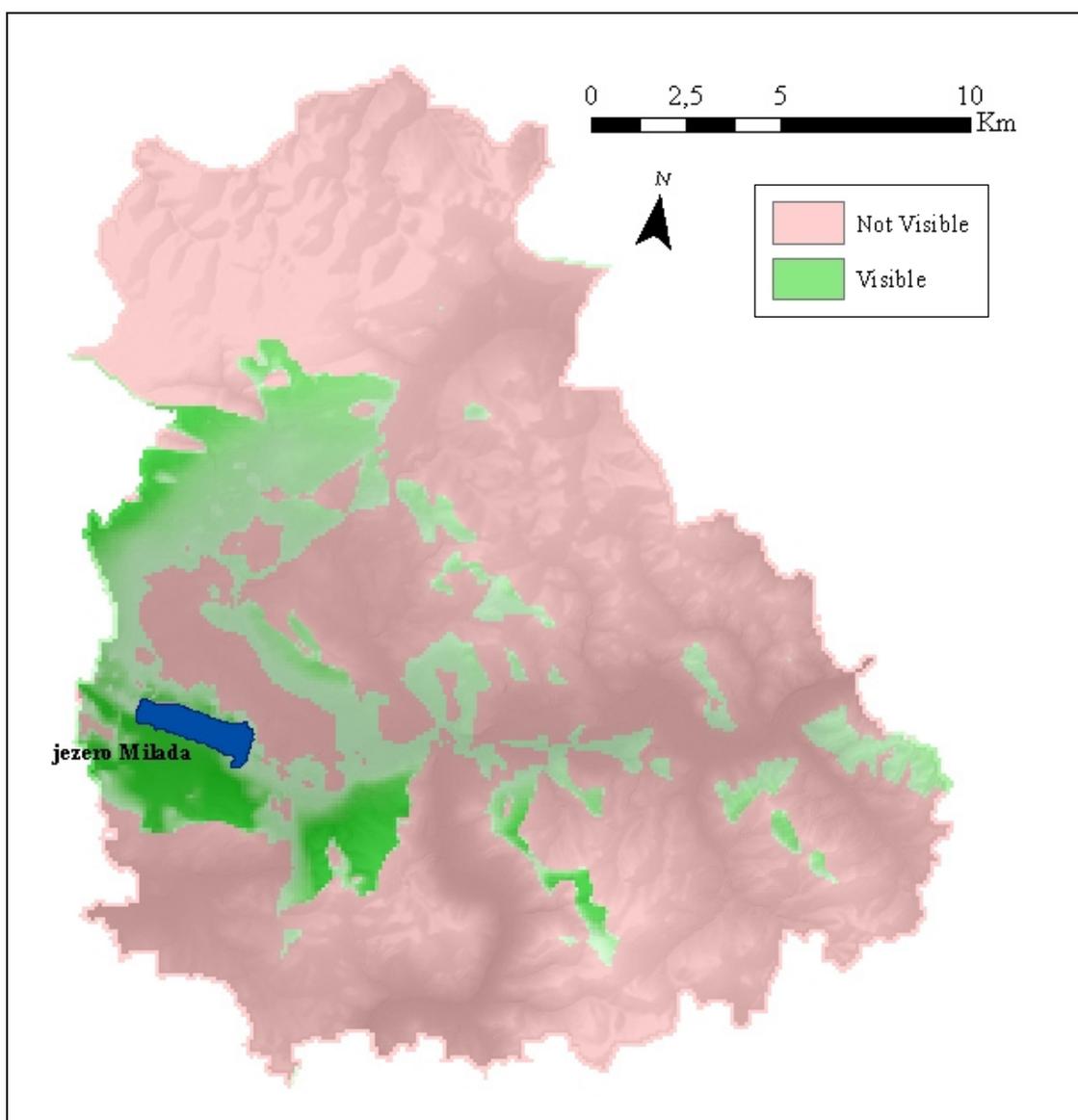


Fig.11: Cumulative viewshed for lake Milada.

5.3.2.3 Visual magnitude

Visual magnitude is calculated from a single observation point. Two of such points were chosen, namely the watchtower Hněvín and one of the wind turbines in Klíny, both located in the region of Most. This type of analysis is not very time consuming, as at the DTM cell size of 100 meters, both of the calculations took around 30 seconds. The results are shown in Fig.12 and Fig.13. Three viewsheds are shown for each observation point, one considering the distance factor, the second showing the slope factor and the last one representing the final visual magnitude.

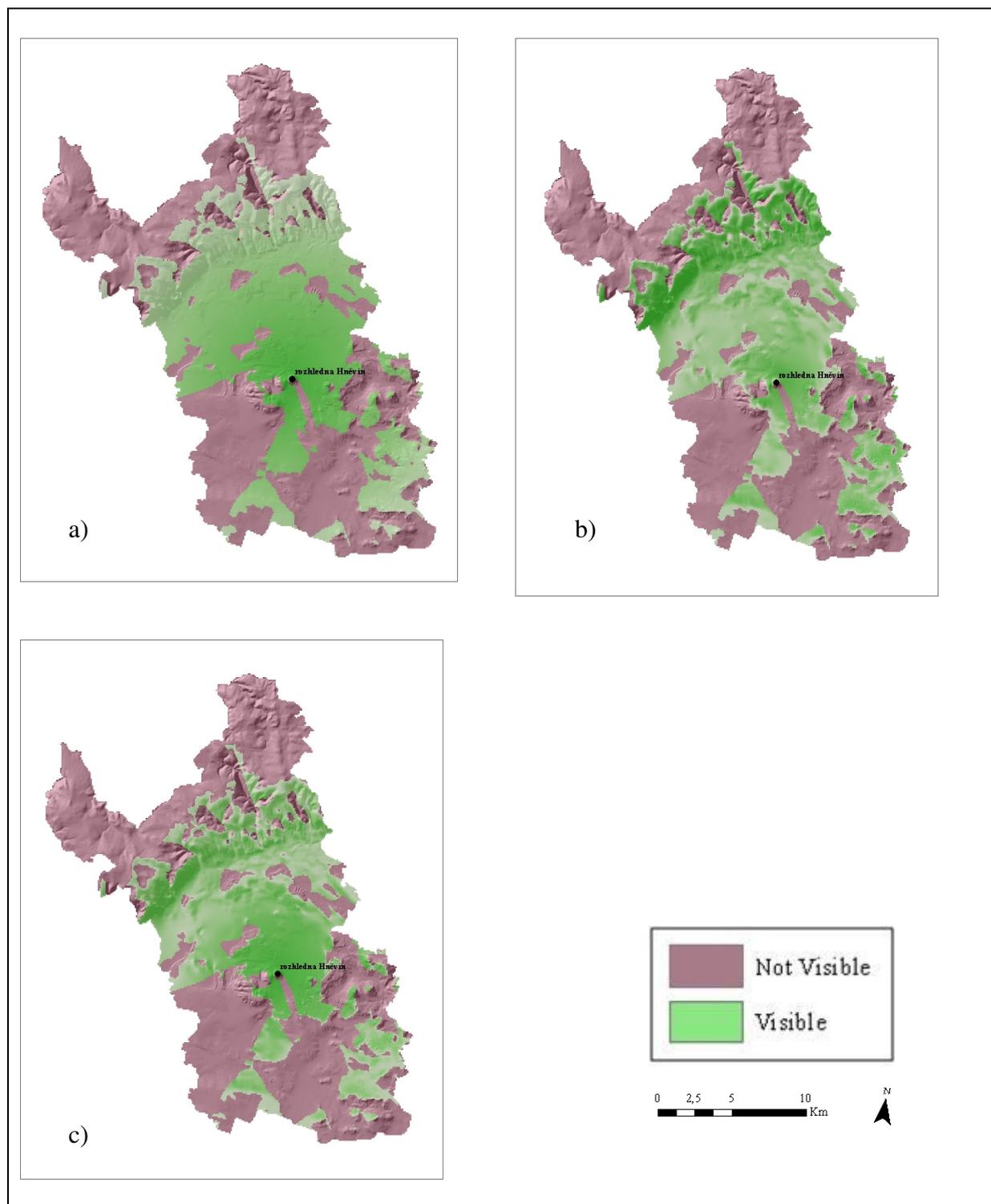


Fig.12: Visual magnitude for one observation point – Viewsheds of the Most region for watchtower Hněvín considering: a) distance factor, b) slope factor, c) resulting visual magnitude.

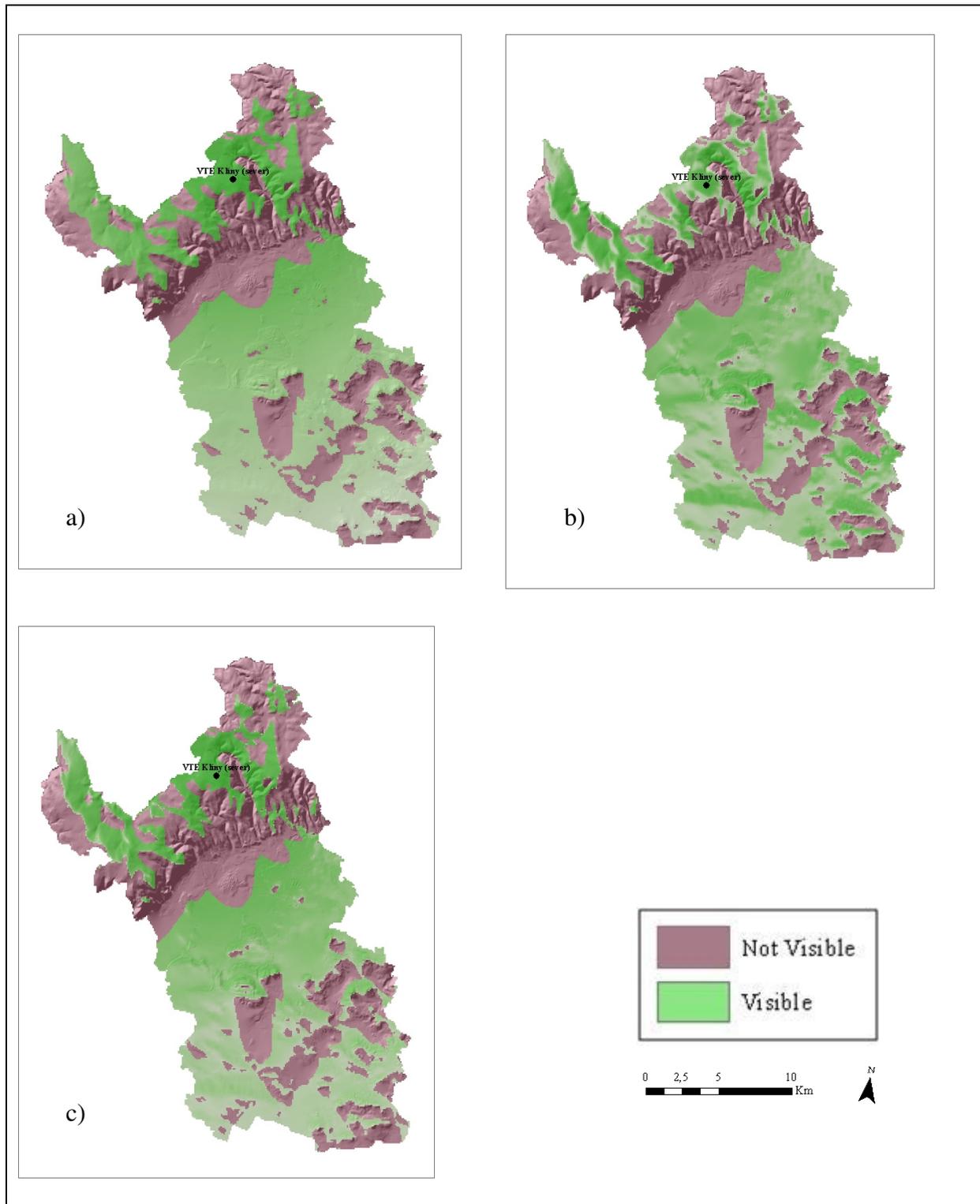


Fig.13: Visual magnitude for one observation point – Viewsheds of the Most region for the wind turbine Klíny (north) considering: a) distance factor, b) slope factor, c) resulting visual magnitude.

6. DISCUSSION

Using Python scripting for more efficient execution of ArcGIS tools can be very useful as employing only ArcGIS built-in functions can be quite tedious and time consuming at the very least. The scripts presented in this thesis calculating total viewshed, cumulative viewshed for a polygon shapefile, and visual magnitude, has proven to be functional and helpful. Total viewshed can be calculated in ArcGIS, as it is one of the tools available there, and so developing this particular script did not bring anything new. Despite this fact, its creation was necessary as it served as the core for developing the second script calculating cumulative viewshed for a polygon shapefile. Unlike the first one, this script has provided a new approach for visibility analysis. It is because the Viewshed tool in ArcGIS allows the user to input only a point or a polyline shapefile. Even more advanced analysis is achieved through the execution of the script calculating visual magnitude.

When developed correctly, any Python script can be transformed into a pop-up window, added to a toolbox and run through ArcGIS. This way, even users unfamiliar with the Python programming language can benefit from it. That is why a toolbox containing all three of the scripts was also created as part of the application and testing process. Some of the data was used to test both, the script and its corresponding tool, to try and determine, whether there is any significant difference or advantage in using one of them, such as shorter time of calculation. For the larger and higher resolution data, there was practically no difference in time taken. The smaller and lower resolution data took a little less time to complete when executed through ArcGIS, rather than through Python Shell. This is because Python Shell has to import all the given modules at the beginning of the analysis, such as `arcpy`. Therefore it can be concluded that in terms of time, there is no significant difference between the two ways of executing the analysis. One additional aspect can, however, be considered. Python Shell is less prone to crashing when compared to ArcGIS, so when working with large data, it might be safer to run the script through Python Shell or other IDE, for instance PythonWin.

Three regions of the north-west part of the Czech Republic were chosen for testing the scripts. The goal was to use various input data at different cell sizes, to get a good estimate of the most suitable approaches. Total viewshed analysis was tested at first and as this method is not new, it was decided to apply it more than once in order to assess the practicality of the

method based on cell size vs. time aspects. To be able to compare the results, it was desirable to use one input DTM and adjust its cell size before each computation. The selected cell size was 100 meters for one sample, 50 meters for the second sample and 10 meters for the last sample. The quality of the outcomes and the time of computations varied quite significantly, as presented in the previous chapter in Fig.8. The most time consuming was the sample of 10x10 meters in resolution, as the more cells there are, the more viewsheds have to be computed and added together. It is therefore quite impractical to consider total viewshed analysis for large raster datasets with large resolutions, as the process is very time consuming and also requires extensive processing memory. In spite of that, total viewsheds are still worth studying, for example as a source of deriving new information such as visual prominence, as suggested by Llobera *et al.* (2004).

The second set of calculations concerned cumulative viewsheds obtained by analysing visibility of polygon shapefiles. This script was tested the most, again with the use of data from various input features, varying in surface area size and cell size. Three regions were chosen for their characteristics, such as land reclamation (the case of Ústí nad Labem), location of wind turbines (the case of Most), as well as areas with potentially high scenic value (the case of Česká Lípa). These locations were chosen intentionally in order to demonstrate the various situations, where visibility analysis is or might be used. At first, the influence of cell size on the quality of data was examined again. In this case, the cell size does not seem to play such an important role as in the case of the total viewshed analysis. The resulting viewsheds vary only slightly, as presented in Fig.9. Viewsheds for two lakes were calculated next. Both of the lakes are similar in the surface area, so the time of computation was similar (around 10 minutes), however each of them represents a different type of research potential. Milada is a lake which has only recently been reclaimed in a post-mining location. As it lies near the Labe river, which is meandering through a large low-lying area, it can be considered quite visible, as shown in Fig.11. Máchovo jezero, on the other hand, is a lake with long history and common recreational activities, lying in between hills of volcanic origin, unevenly distributed in the landscape and obstructing its visibility, as can be seen in Fig.10.

The last script calculating visual magnitude for a single observation point was tested on two objects – a wind turbine and a watchtower. It can be thought of as considering the visual impact of the wind turbine and assessing the view from the watch tower. Both of these applications are among the common cases for which visibility or visual impact is analyzed. By adding the possibility to calculate how much from what is visible is actually visible, the

analysis gains new perspective. One of the advantages of the script is the option to extract other information related to visibility, such as the slope or distance factors. The outcomes for these factors, together with the one representing visual magnitude, can be found in Fig.12 for the Hněvín watchtower and Fig.13 for the wind turbine in Klíny. From the resulting viewsheds, influence of the distance and slope factors, can clearly be read. Distance plays a significant role in whether a location or a feature is visible and recognizable, as with growing distance from the observer, the visual impact decreases. Just as important role is played by the slope factor, for which the position of the cell and its angle towards the observer, is considered. Combination of the two factors then results in a considerably improved visibility display of the viewpoint or from it. Additionally, given that this script calculates visibility for only one point, the analysis is not time consuming and does not require such extensive computational memory, its application could be quite practical and useful.

7. CONCLUSION

The thesis gave an overview of visibility analysis methods in GIS environment, together with their applications and limitations. It presented three scripts, each concerning a method for calculating visibility. These scripts are: a script for total viewshed calculation, a script for computation of cumulative viewshed of a polygon shapefile, and a script assessing visual magnitude. They were developed with the use of Python programming language, but were also imported into ArcGIS as easily executable tools all contained within one toolbox. They were tested on real-world data, in order to check their right functioning, to be aware of the time the analysis takes at different input features resolutions, and also to present some possible applications that can be of concern for existing studies of landscape assessment and fields related to it. The outcomes were presented and accompanied with maps and pictures showing the different resulting viewsheds. Interpretations of the results were conducted and several thoughts and ideas on the matter were presented.

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Attachments

Attachment 1: Script for total viewshed

```
import time
t_start = time.time()
print "Time:", time.ctime()

import arcpy, os

workspace = arcpy.env.workspace = r"C:\..."
arcpy.env.overwriteOutput = True
arcpy.CheckOutExtension("Spatial")

rstr = "dtm"
shp = "points.shp"
lyr = "points_fl"

arcpy.RasterToPoint_conversion(rstr, shp)

print "Raster to point converted"

arcpy.MakeFeatureLayer_management(shp, lyr)

print "Feature layer created"

cell_size = arcpy.GetRasterProperties_management(rstr, "CELLSIZEX")
extent = arcpy.Describe(rstr).extent
arcpy.env.extent = extent

print "Cell size and extent set"

print "Calculating viewshed"

totalVshd = arcpy.sa.CreateConstantRaster(0, "INTEGER", cell_size, extent)

cursor = arcpy.da.SearchCursor(shp, ["POINTID"])

for row in cursor:
    print "Working with point: ", row[0]
    arcpy.SelectLayerByAttribute_management(lyr, "", "POINTID = "+str(row[0]))
    outVshd = arcpy.sa.Viewshed(rstr, lyr)
    totalVshd = totalVshd + outVshd

totalVshd.save("total_vshd")

del row, cursor, outVshd

print "Viewshed saved"
print "DONE"

print "Time:", time.ctime()
t_end = time.time()
l = t_end - t_start
print "Total time of calculation", l/60
```

Attachment 2: Script for cumulative viewshed

```

import time
t_start = time.time()
print "Time:", time.ctime()

import arcpy, os

workspace = arcpy.env.workspace = r"C:\..."
arcpy.env.overwriteOutput = True
arcpy.CheckOutExtension("Spatial")

rstr = "dtm"
pgn = "polygon.shp"

rstr2 = "polygon_rstr"
shp = "pts.shp"
shp2 = "pts_polygon.shp"
lyr = "pts_fl"
lyr2 = "pts_pgn_fl"

cell_size = arcpy.GetRasterProperties_management(rstr, "CELLSIZEX")
extent = arcpy.Describe(rstr).extent

arcpy.env.extent = extent

arcpy.PolygonToRaster_conversion(pgn, "FID", rstr2, "", "", cell_size)

arcpy.RasterToPoint_conversion(rstr, shp)
arcpy.RasterToPoint_conversion(rstr2, shp2)

arcpy.MakeFeatureLayer_management(shp, lyr)
arcpy.MakeFeatureLayer_management(shp2, lyr2)

print "Layers created"

print "Calculating viewshed"

totalVshd = arcpy.sa.CreateConstantRaster(0, "INTEGER", cell_size, extent)

cursor = arcpy.da.SearchCursor(shp2, ["POINTID"])

for row in cursor:
    print "Working with point: ", row[0]
    arcpy.SelectLayerByAttribute_management(lyr2, "", '"POINTID" = '+str(row[0]))
    outVshd = arcpy.sa.Viewshed(rstr, lyr2)
    totalVshd = totalVshd + outVshd

remap = arcpy.sa.RemapRange([[0,1000,0], ["NoData",1]])
mask = arcpy.sa.Reclassify(rstr2, "VALUE", remap)
totalVshd = totalVshd * mask

totalVshd.save("vshd_polygon")

del row, cursor, outVshd

print "DONE"

print "Time:", time.ctime()
t_end = time.time()
l = t_end - t_start
print "Total time of calculation", l/60

```

Attachment 3: Script for visual magnitude

```

import time
t_start = time.time()
arcpy.AddMessage("Importuji moduly... Time: " + time.ctime())
import arcpy, os, numpy, math

#vstupni udaje
dtm = arcpy.GetParameterAsText(0)
tower = arcpy.GetParameterAsText(1)
cos_output = arcpy.GetParameterAsText(2)
dist_output = arcpy.GetParameterAsText(3)
output = arcpy.GetParameterAsText(4)
folder = os.path.dirname(dtm)

#nastaveni prostredi
arcpy.AddMessage("Nastavuji prostredi... Time: " + time.ctime())
arcpy.env.overwriteOutput = True
cell_size = arcpy.GetRasterProperties_management(dtm, "CELLSIZEX")
extent = arcpy.Describe(dtm).extent
arcpy.env.extent = extent
arcpy.env.cellSize = float(cell_size.getOutput(0))
arcpy.CheckOutExtension("Spatial")

#Preliminary tools
arcpy.AddMessage("Pocitam viewshed, sklon a aspekt... Time: " + time.ctime())
slope = arcpy.sa.Slope(dtm, "DEGREE")
aspect = arcpy.sa.Aspect(dtm)
viewshed = arcpy.sa.Viewshed(dtm, tower)

#Souradnice bodu "observer point" (tj. tower)
arcpy.AddMessage("Extrahuji souradnice pozorovatelny... Time: " + time.ctime())
tab = arcpy.da.SearchCursor(tower, "SHAPE@XY")
row = tab.next()
tower_x = row[0][0]
tower_y = row[0][1]
offset = 20
del tab, row
name = os.path.join(os.path.dirname(dtm), "z_tower.shp")
arcpy.sa.ExtractValuesToPoints(tower, dtm, name, "INTERPOLATE")
tab = arcpy.da.SearchCursor(name, "RASTERVALU")
row = tab.next()
tower_z = row[0] + offset
del tab, row
arcpy.Delete_management(name)

#Vypocet normalovych souradnic mapovou algebrou
arcpy.AddMessage("Pocitam souradnice normalovych vektoru... Time: " + time.ctime())
convert = math.pi/180.0
sin_aspect = arcpy.sa.Sin(aspect*convert)
cos_aspect = arcpy.sa.Cos(aspect*convert)
sin_slope = arcpy.sa.Sin(slope*convert)
normal_z = arcpy.sa.Cos(slope*convert)
normal_x = sin_slope*sin_aspect
normal_y = sin_slope*cos_aspect

#Export rastru do numpy poli
arcpy.AddMessage("Exportuji rastry do NumPy matic... Time: " + time.ctime())
a_z = arcpy.RasterToNumPyArray(dtm)
anormal_x = arcpy.RasterToNumPyArray(normal_x)
anormal_y = arcpy.RasterToNumPyArray(normal_y)
anormal_z = arcpy.RasterToNumPyArray(normal_z)
h = len(a_z)
w = len(a_z[0])

```

```

#Vypocet poli s x a y souradnicemi
arcpy.AddMessage("Extrahuji souradnice bunek... Time: " + time.ctime())
d = float(cell_size.getOutput(0))
arcpy.RasterToOtherFormat_conversion(dtm, folder, "TIFF")
name = os.path.splitext(dtm)[0]
f = open(name+".tifw", "r")
lines = f.readlines()
A = float(lines[0])
D = float(lines[1])
B = float(lines[2])
E = float(lines[3])
C = float(lines[4])
F = float(lines[5])
f.close()
a_x = numpy.zeros((h,w), "float")
a_y = numpy.zeros((h,w), "float")
for i in range(h):
    x_i = C + i*B
    y_i = F + i*E
    for j in range(w):
        a_x[i,j] = x_i + j*A
        a_y[i,j] = y_i + j*D

#Vypocet visual magnitude
arcpy.AddMessage("Pocitam visual magnitude... Time: " + time.ctime())
cos = numpy.zeros((h,w), "float")
vm_dist = numpy.zeros((h,w), "float")
vm = numpy.zeros((h,w), "float")
for i in range(h):
    for j in range(w):
        if a_z[i,j] != -3.4028235e+38:
            nx = anormal_x[i,j]
            ny = anormal_y[i,j]
            nz = anormal_z[i,j]
            vx = tower_x - a_x[i,j]
            vy = tower_y - a_y[i,j]
            vz = tower_z - a_z[i,j]
            dist = math.sqrt(vx*vx + vy*vy + vz*vz)
            cos[i,j] = (nx*vx + ny*vy + nz*vz)/dist
            vm_dist[i,j] = d*d/(dist*dist)
            vm[i,j] = max(cos[i,j]*vm_dist[i,j], 0)
        else:
            vm[i,j] = -1
            cos[i,j] = -1
            vm_dist[i,j] = -1

#Vymazani neviditelnych mist
arcpy.AddMessage("Mazu neviditelna mista... Time: " + time.ctime())
view = arcpy.RasterToNumPyArray(viewshed)
for i in range(h):
    for j in range(w):
        if view[i,j] == 0:
            vm[i,j] = -1
            cos[i,j] = -1
            vm_dist[i,j] = -1
del view

#Zaverecny export do vysledneho rastru
arcpy.AddMessage("Exportuji vysledny rastr... Time: " + time.ctime())
p = arcpy.Point(extent.XMin, extent.YMin)
out_raster = arcpy.NumPyArrayToRaster(vm, p, d, d, -1)
out_cos = arcpy.NumPyArrayToRaster(cos, p, d, d, -1)
out_dist = arcpy.NumPyArrayToRaster(vm_dist, p, d, d, -1)
out_raster.save(output)
out_cos.save(cos_output)
out_dist.save(dist_output)
viewshed.save(folder+"/viewshed")

arcpy.AddMessage("Hotovo. Time: " + time.ctime())
t_end = time.time()
l = t_end - t_start
arcpy.AddMessage("Celkovy cas vypoctu: " + str(l/60))

```