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Determining Optimal Locations for Viewpoints Using the Open-Source Whitebox GAT Software

Abstract: The most visually exposed landscape can be determined by a rich set of GIS tools, the main limitation of which is high intensity of computation. This study aims to put forward a method of specifying optimal location for the viewpoints attractive to tourists by means of Whitebox GAT, an open-source GIS application. The study area involves the Kolbudzko-Przywidzka Upland of the southern part of the Kashubian Lakeland in Poland. The method presented herein is characterized by simplicity and low computation intensity. However, it can only be used to analyse views on a local scale, in areas whose spatial coverage does not exceed a dozen or so kilometres.

Keywords: viewpoints, absolute visibility indices, total viewshed, Whitebox GAT, GIS

1. Introduction

Analysing the degree of visibility of the area plays an important role in the process of determining the optimal location for a viewpoint since it defines the extent of the surface from which the point is exposed (Forczek-Brataniec, 2018). It facilitates choosing places with the highest field of visibility, which is useful in the planning of localisation especially in terms of radio masts (Baek and Choi, 2018), observation towers (García et al., 2010), military infrastructure, etc. (Franklin and Ray, 1994).

Methods for specifying said areas are mainly based on the analysis of *absolute visibility indices* (Rana, 2003), sometimes referred to as the *total viewshed* (Llobera, 2003). To be more specific, it is a type of visibility analysis in which the viewshed area is calculated for each raster cell in digital elevation model.

Rana (2003) and Llobera (2003, 2010) conducted meaningful studies when it comes to determining places with the highest visibility. According to their research, calculating the raster of total viewshed in useful resolution requires very high computational intensity. As such, calculation time of the total viewshed raster can be reduced in several different ways. The approach described by Rana (2003) and Kim et al. (2004) involved lowering the number of observers. As for Jakab and Petluš (2013), they used parallel calculations. Finally, Magalhaes et al. (2007), Tabik et al. (2013), and Wang et al. (2017) proposed efficient viewshed algorithms.

The aim of this study is to present and verify the method of specyfying optimal locations for viewpoints using the efficient viewshed algorithm of the open-source Whitebox GAT software (Lindsay, 2016).

When determining the position of viewpoints, the landscape is usually assessed based on views established in space. Then again, it should be noted that said procedure is mostly time-consuming. What is more, it is rarely supported by view analysis using GIS tools that help reduce the duration of all work.

2. Methods, area description and study material

The study area involved the Kolbudzko-Przywidzka Upland (Kistowski, 2018). More specifically, it is a physical-geographical microregion of 57.41 km^2 located in northern Poland, in the southern part of the Kashubian Lake District. Intersected by a longitudinally outlined edge of the upland, this structure is divided into two levels (Petelski and Staszek 2006).

The higher one, covering the western and central parts of the analysed area, is situated at an altitude of more than 160 m above sea level. It consists of a section of rolling uplands with an average height of 225 m above sea level, and its surface is diversified by kames, moraines of dead ice, and numerous erosion cuts radially escaping to the valleys surrounding this area. The highest point, i.e. 274 m above sea level, can be found at the western end of the area, between the villages of Katarynki and Klonowo Dolne.

The lower one, on the other hand, is located at an altitude of less than 160 m above sea level, east of the base of the upland's edge. It encompasses a fragment of a flat moraine upland and an outwash plain, diversified by relatively shallow river valleys and subglacial gutters. Its area of an average altitude of 135 m, falls gently to the east, reaching the lowest altitude of 60 m in the Radunia Valley.

In GIS systems, most of the search strategies for places with the highest degree of visibility consist of the following steps (Kim et al., 2004):

- location of the viewpoints within the area and calculation of the visibility range for each of them,
- summary of all visibility ranges and assignment of the total number of viewpoints from which they are visible to each place on the map,
- designation of the sites visible from the largest number of viewpoints.

In regards to the process of visibility analysis, the number of viewpoints is the key factor in the time-consuming calculations. In this analysis, each observed point on the map is at the same time an observation point and there are relations between them of visibility type n-n, i.e. many viewpoints to many points observed.

The basic strategy for establishing viewpoints is to distribute them evenly throughout the entire analysed area. Then, for each point, the level of terrain visibility is calculated. The result of such analysis is expressed by the so-called *Absolute Visibility Indices* (AVI) (Rana, 2003), sometimes referred to as the *total viewshed* (Llobera, 2003).

Usually it is presented in the form of a raster to which each cell is assigned information about the field of view, i.e. the area from which it is visible. In consequence, the AVI indicator creates a layer. The indicator both facilitates the detection of zones with increased exposure to the (much more sensitive) landscape and shows the parameter of the extent of the area viewed from a point lying anywhere on the map. The AVI indicator is characterised by a relatively small error of said visual parameter, and a substantial time-consuming calculation utilising classic methods.

In order to accelerate calculations, the number of viewpoints is often reduced by placing them on small sectors with a potentially high degree of exposure, which are also selected on the basis of intuitive and sometimes unreliable heuristics (Rana, 2003). In this regard, one of them is the conviction that the viewpoint is the same as the highest point in the area.

When it comes to the analysis of the degree of terrain visibility carried out on a limited number of viewpoints, the results are presented by the so-called *Estimated Visibility Indices* (EVI) (Rana, 2003), also known as the *cumulative viewshed* (Llobera, 2003). They are expressed as a number of viewpoints from which a given place is visible. Despite their island arrangement, the value of this indicator is assigned to each place in the study area. Therefore, on the resulting map – as well as in the case of the AVI indicator – it is easier to see the zones with a higher degree of viewpoint visibility. The accuracy of the calculation depends mainly on the correct use of heuristics, which limit the number of viewpoints as such (Franklin and Ray, 1994).

The method proposed in this article is used to determine the optimal location for a viewpoint. In addition, it is based on AVI indicator analysis, and calculated by means of the Visibility Index module of the Whitebox GAT software. The use of this program for viewshed analysis has not yet been described in the scientific literature, and as for the QGIS application, it was utilised to visualise data and simple transformations. As such, Whitebox GAT and QGIS are free of charge and open-source geoinformation programmes.

The proposed method consists of the following stages:

- generalization of the Digital Surface Model (DSM);
- calculation of the absolute visibility index (AVI) for the whole analysed area;
- exclusion of the areas of analysis not meeting the technical or legal requirements for the viewpoint location. Depending on the specific case, these may be the requirements related, for example, to accessibility of the area for pedestrians or motorists, the possibility of setting up an observation tower, access by car, and the structure of land ownership;
- determination of places with the highest AVI value, which are predisposed for the location of a viewpoint, in order to further verify them in the field.

All the view analyses were based on the Digital Surface Model (DSM) while taking into account the height of both the land itself and the elements protruding above its surface, such as plant cover, buildings, or technical infrastructure elements. For the purpose of increasing the analysis speed, the model with the source spatial resolution of 0.5 m and 1 m was generalised to 10 m. Finally, the viewshed calculation area included the DSM of 4000x4000 cells (per 10 m cell resolution) centred on the Kolbudzko-Przywidzka Upland.

Calculations of the AVI indicator were performed with the help of the Visibility Index module of Whitebox GAT version 3.4, the observer's height parameter being 1.65 m. On the resulting raster, the AVI indicator unit was by default expressed as a fraction of the total area of the analysed raster (1.0 = 100% of the area). In order to convert this unit into square kilometres, the AVI value was multiplied by the total area of the raster with the use of the QGIS *Raster Calculator* tool.

Below one can find the restrictions related to the planned viewpoint, adopted for the purposes of this article. As a matter of fact, there was a need to find a viewpoint with such an elevation that does not require constructing an observation tower for hikers, which would also interfere with the vegetation in its vicinity. Then again, establishing it on agricultural land was not out of the question. The area of at least ten kilometres of the viewshed area (AVI > 10 km^2) constituted an additional viewing criterion.

In order to exclude the areas that hinder the observer's perception of the landscape (e.g. buildings, forests) from the analysis, a normalised Digital Surface Model (nDSM) was developed. It is characterised by a height difference between the DSM and the DTM. On another note, the layers were subtracted by means of the QGIS *Raster Calculator* tool. Subsequently, with the use of the *Reclassify by Table* tool, the areas with the height of land cover not exceeding 1.5 m were converted to null value, and saved into a separate raster layer. Said layer was then multiplied in the QGIS *Raster Calculator* tool with a layer of AVI indicator, thus eliminating the areas of water, forests, bushes, and buildings from further analyses.

Furthermore, the AVI indicator calculations made with the use of the Whitebox GAT Visibility Index module were compared to the QGIS Visibility Analysis module in terms of time consumption. Due to the efficiency limitations of the QGIS programme, the DSM 20x20 km with the spatial resolution increased to 100 m was used to compare both calculations. The analysis covered 40000 observation points (200x200 px), and as for the calculation parameters, they were all the same in both programmes as well. It is also important to mention that the calculations were performed on a computer with a 64-bit system, equipped with an Intel Core i7 4600U 2.1 GHz processor, 8GB of RAM, and an SSD drive.

The main criterion for selecting the research area was the assumption that its morphological features should hinder indication of potential viewpoints based on heuristics; for instance, the conviction that the viewpoint is the same as the highest point in the area. Such features of terrain relief increase the probability of obtaining a non-obvious result of analyses, highlighting the risks associated with the use of intuitive heuristics when determining viewpoints. The research area should thus have a terrain relief that would be diversified on both the:

- local scale (occurrence of small hills that allow one to indicate potential locations of viewpoints based on simple heuristics); and
- supra-local scale (location of the area in the transition zone of a larger morphological structure, such as upland inclination, which complicates the assessment of the degree of landscape exposition in terms of local culminations in chamber works).

The complexity and dichotomy of morphology presented above was the decisive factor in choosing the Kolbudzko-Przywidzka Upland as the study area.

The Digital Surface Model (DSM) and the Digital Terrain Model (DTM) in raster format *.ASCII played a paramount role in the analyses. Both models, with a mean height error of up to 0.2 m, were based on height data from airborne laser scanning (ALS) which was carried out for the ISOK project (Computerized Information System of Country Protection from Extraordinary Hazards) in 2012 (Kurczyński and Bakuła, 2013).

The vector layer of the Kashubian Lake District's physio-geographic microregions, which was obtained from the author of the latest regionalisation (Kistowski, 2018), served as a tool to determine the boundaries of the study area. Additionally, the vector layer of roads, forests and lakes taken from the BDOT10k database of topographic objects was used as the topographic matrix, as well as the raster topographic maps in the scale 1:10 000 (1965 system), 1:50 000 (VMap L2, WGS84 system). All layers were converted in accordance with the PL-1992 coordinate reference system.

3. Results

The analyses conducted for the purposes of this paper led to creation of a raster layer of the AVI indicator (Fig. 1). The areas excluded from the location of the viewpoint were marked with a semi-transparent mask.

The area of the zone narrowed in this manner amounted to 24.13 km^2, which constituted 42.03% of the Kolbudzko-Przywidzka Upland. The range of AVI values was within 0.01–37.10 km^2, with an average of 0.82 km^2 and a stan-

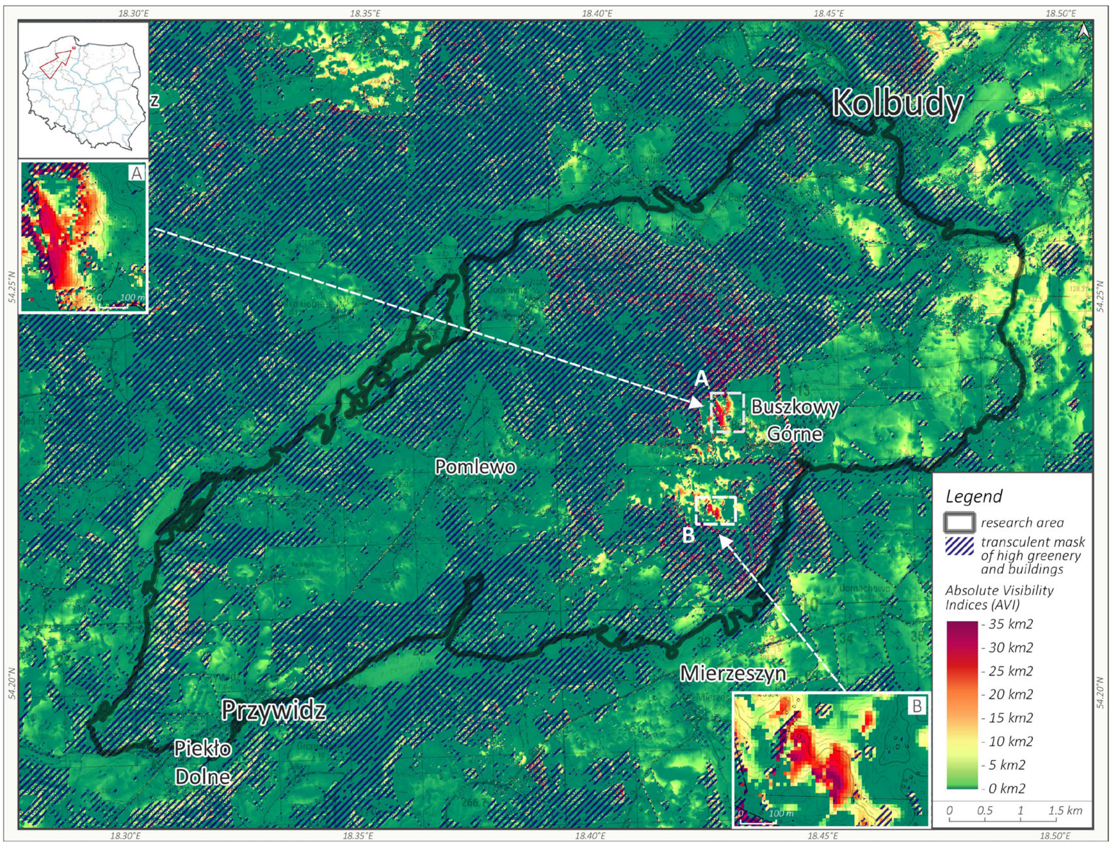

Figure 1. The value of the AVI indicator calculated in Whitebox GAT (Author's own study)

dard deviation of 2.52 km^2. The area meeting the additional viewing criteria (AVI > 10 km2) added up to only 2.35 km^2 (4.10% of the study area). It included only the sectors situated in the central and eastern part of the Kolbudzko-Przywidzka Upland. It is worth mentioning that it is in the western part of the research area that the highest elevations with the peak of 274 m above sea level are located. These, however, proved to be less landscape-exposed in relation to the areas located 50 m lower in the upland's eastern part.

The highest values of the visibility index (AVI = 37 km^2) were noted in the vicinity of Buszkowy Górne, in the zone at an altitude of about 220 m above sea level, just below the upper bend of the high elevation edge. Żuławy Wiślane can be found in the east direction from there. The sectors predisposed to being the location of viewpoints in the southern (Kozia Góra) and eastern part (Babi Dół and Pręgowo regions) of the area were characterised by a considerably lower value of this index.

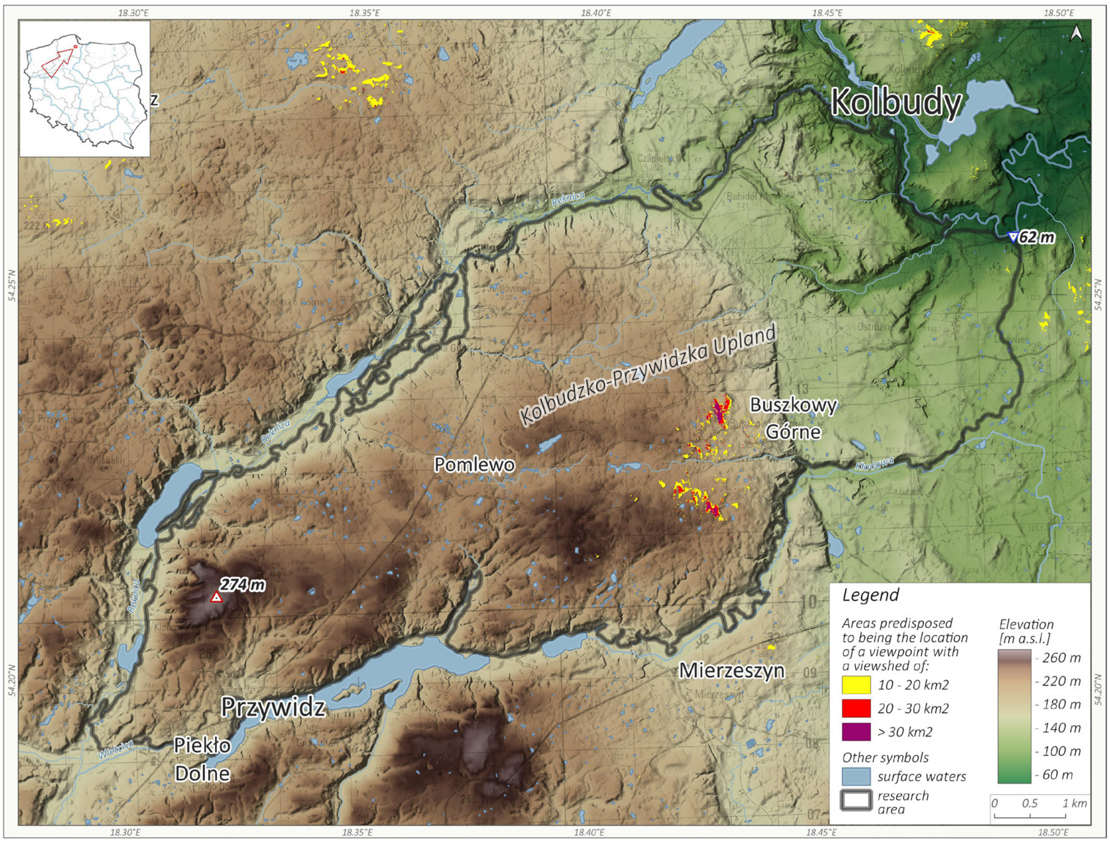

Figure 2. Areas predisposed to being the location of a viewpoint, indicated for field verification of their landscape values (Author's own study)

All the above-mentioned areas marked in Figure 2 were indicated as areas predisposed to being the location of a viewpoint. The assumption is that they require further field research aimed at specifying the location while taking into account the scenic values of the landscape.

GIS tools are excellent for calculating the surface area since – in the case of the DSM from LiDAR data – they provide results of up to 93% consistent with field observation (Klouček et al., 2015). Then again, despite their time efficiency, they can be unreliable when evaluating landscape values, especially in relation to the terrain valorisation that allow for taking the local complexity of its structure into account. In fact, this still exceeds the capabilities of computer algorithms.

The calculations made by AVI indices for DSM 40x40 km with the spatial resolution 10 m in Whitebox GAT lasted 4 days 17 hours and 31 minutes. The time consumption of the AVI indicator calculations performed with the use of the Whitebox GAT Visibility Index module and the QGIS Visibility Analysis module was compared as well. What is more, due to its limitations, the QGIS programme was juxtaposed with another low-resolution raster. The results were as follows: the calculations of the AVI indices for DSM

20x20 km with the spatial resolution 100 m in Whitebox GAT amounted to 24 seconds, while in the case of QGIS it was 765 seconds.

The proposed method of determining the location of viewpoints based on the analysis of the visibility index calculated in the Visibility Index module of Whitebox GAT showed a number of weaknesses of said algorithm after more detailed verification. Its use on a regional and national scale was not taken into consideration. The most important limitations regarding alternative solutions are:

– the inability of limiting the radius of the maximum range radius of the viewshed analysis. For the algorithm, this range is the same as the distance between the observer and the most distant edge of the raster height model; and
– omission of the Earth's curvature influence on the range of the field of view.

The imperfections of the programme mentioned above affected the analyses results mainly by overestimating the average value of the visibility index.

4. Discussion

Analysis of the AVI indicator allows for identification of areas predisposed to the location of a viewpoint, indicated for further verification in the field of their landscape values. The most astounding result of the analyses performed was the short AVI calculation time in Whitebox GAT. The calculations made by means of this application were 30 times faster than with the help of QGIS. Such a substantial reduction in time consumption originates mainly from the lower complexity of the algorithm.

Owing to the indicated limitations of Whitebox GAT, it is important to determine the maximum spatial coverage of the DSM, the calculation errors for which will not have a considerable impact on the AVI indicators of the study area. First of all, one should examine the influence of the Earth's curvature on the range of visibility. For example, under ideal weather conditions, a sailor with a sight height of 1.65 m above sea level sailing a boat towards land should theoretically be able to see the top of a 50 m cliff at a distance of about 34.2 km. The top of a 20-metre cliff would be visible from the distance of 23.6 km. That being said, the Earth's curvature affects the horizon to a large extent, and it would obscure the 50-metre high hill completely over a distance of about 34 km. These distances calculated with the formula for the so-called radar

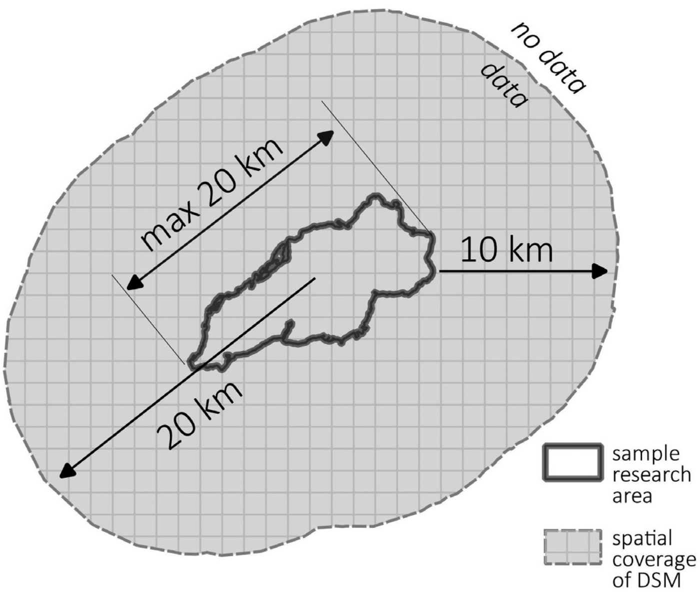

Figure 3. Proposed spatial coverage of DSM to reduce computational errors in the Visibility Index module of Whitebox GAT (Author's own study)

horizon (Gucma et al., 2010) are, in fact, much shorter. It all results from the atmospheric conditions, sharpness of the observer's blueprint, contrast of the perceived object, and the shape of the surface.

The issue regarding the maximum range of visibility under land-based conditions was investigated by, among others, Garneo and Fabrizio (2015), who analysed the visibility of high-altitude objects, paying particular attention to the impact of weather conditions on visibility. In Zachodniopomorskie voivodeship, for example, the average annual visibility in 2006–2007 was 18 and 21 km respectively, reaching its maximum in June–July and its minimum in January (Kostrzewski et al., 2008). Based on the above-mentioned studies, it can be concluded that the parameter of maximum radius length of view analyses should not exceed 20 km, with a possible exception for particularly well-exposed objects or hills of a relative height of at least 50 m.

Therefore, when using the Visibility Index module of Whitebox GAT, for which the maximum range of the calculated visibility is the same as the range of the analysed DSM, the following limitations are postulated (Fig. 3):

– spatial coverage of the research area should not exceed the length of approximately 20 km;
– spatial coverage of the DSM used in the analyses should cover the research area along with a 10 km buffer around its boundaries. The values of raster cells located outside the 10 km buffer around the area borders should be removed so that they do not influence the calculations.

The spatial coverage of the DSM determined in such manner will render the resulting AVI values directly within the research area only slightly overestimated by the viewshed of more than 20 km radius. As for the raster cells located mainly outside the area in question, the AVI value will be either under- or overestimated.

5. Conclusions

The proposed method for determining the optimal location of viewpoints based on the Visibility Index module of Whitebox GAT shows certain weaknesses of this algorithm. Said method is best suited for viewshed analyses on a local scale, in areas up to twenty kilometres long. Additionally, there is a need for further research on the possibility of using the Visibility Index module of Whitebox GAT for visibility analyses. It is also necessary to check whether this module can be modified in such a way that it will take into account the radius of visibility and the Earth's curvature when performing calculations.

The most important advantage of the discussed method is its low time consumption. It allows one to calculate the visibility index over 30 times faster than the alternative calculation method that is based on the Visibility Analysis algorithm of the QGIS programme. Such a shortened calculation time, in the face of rapidly increasing availability of spatial data, may encourage the use of GIS analyses not only for determining the location of viewpoints, but also optimising tourist routes from the landscape point of view, provided that the method is applicable in a given case.

References

Baek J., Choi Y., 2018. Comparison of Communication Viewsheds Derived from High-Resolution Digital Surface Models Using Line-of-Sight, 2D Fresnel Zone, and 3D Fresnel Zone Analysis. International Journal of Geo-Information 7, 322.

Forczek-Brataniec U., 2018. Przestrzeń widziana. Analiza widokowa w planowaniu i projektowaniu krajobrazu. Wydawnictwo Politechniki Krakowskiej, Kraków [In Polish].

Franklin W.R., Ray C., 1994. Higher isn't Necessarily Better: Visibility Algorithms and Experiments. [In:] Waugh T.C., Healey R.G. (Ed.), Advances in GIS Research: 6th International Symposium on Spatial Data Handling, Edinburgh. Taylor and Francis, London, 751-770.

García M.P., Moreno R.S., Téllez E.R., Álvarez A.P., Flores D.A., Díaz C.H., Bautista E.V., 2010. Viewshed analysis for improving the effectiveness of watchtowers in the north of Mexico. The Open Forest Science Journal 3, 17–22.

Garnero G., Fabrizo E., 2015. Visibility analysis in urban spaces: a raster-based approach and case studies. Environment and Planning B: Planning and Design 42. 688–707.

Gucma M., Chrzanowski J., Jankowski S., Juszkiewicz W., Montewka J., Przywarty M., 2010. Urządzenia radarowe w praktyce nawigacyjnej. Akademia Morska, Szczecin [In Polish].

Jakab I., Petluš P., 2013. Development of a Program Tool for the Determination of the Landscape Visual Exposure Potential. Developments in Environmental Modelling 25, 375-390.

Kim Y.H., Rana S., Wise S., 2004. Exploring multiple viewshed analysis using terrain features and optimisation techniques. Computers & Geosciences 30, 1019–1032.

Kistowski M., 2018. Propozycja delimitacji mikroregionów fizycznogeograficznych Pojezierza Kaszubskiego w świetle współczesnych źródeł i metod badawczych. Prace i Studia Geograficzne UW 63(1), 17–34 [In Polish].

Klouček T, Lagner O, Šímová P., 2015. How does data accuracy influence the reliability of digital viewshed models? A case study with wind turbines. Applied Geography 64, 46-54.

Kostrzewski A., Kolander R., Szpikowski J., 2008. Zintegrowany monitoring środowiska przyrodniczego. [In:] Landsberg-Uczciwek M. (Ed.), Raport o stanie środowiska w województwie zachodniopomorskim w latach 2006-2007. Wojewódzki Inspektorat Ochrony Środowiska w Szczecinie. Szczecin, 198-222 [In Polish].

Kurczyński Z., Bakuła K., 2013. Generowanie referencyjnego Numerycznego Modelu Terenu o zasięgu krajowym w oparciu o lotnicze skanowanie laserowe w projekcie ISOK. Archiwum Fotogrametrii, Kartografii i Teledetekcji 89(1), 59–68 [In Polish].

Lindsay J., 2016. Whitebox GAT: A case study in geomorphometric analysis. Computers & Geosciences 95, 75–84.

Llobera M., 2003. Extending GIS-based visual analysis: the concept of visualscapes. International Journal of Geographical Information Science 17 (1), 25–48.

Llobera M., Wheatley D., Steele J., Cox S., and Parchment O., 2010. Calculating the inherent visual structure of a landscape (total viewshed) using high-throughput computing. [In:] Niccolucci F. and Hermon S. (Ed), Beyond the artifact: digital interpretation of the past, CAA 04. Archaeolingua, Budapest, 146–151.

Magalhaes A.M., Magalhaes V.G.S., Andrade V.A.M., Filho L.S., 2007. An efficient algorithm to compute the viewshed on DEM terrains stored in the external memory. IX Brazilian Symposium on GeoInformatics. Campos do Jordão, Brazil, INPE, 183–194.

Petelski K., Staszek W., 2006. Objaśnienia do szczegółowej mapy geologicznej Polski 1:50 000, Arkusz Dzierżążno. Wydawnictwa Geologiczne, Warszawa [In Polish].

Rana S., 2003. Fast approximation of visibility dominance using topographic features as targets and the associated uncertainty. Photogrammetric Engineering and Remote Sensing 69, 881–888.

Tabik S., Zapata E.L., Romero L.F., 2013. Simultaneous computation of total viewshed on large high resolution grids. International Journal of Geographical Information Science 27, 804–814.

Wang W., Bo Tang B., Fan X., Mao H., Yang H., Zhu M., 2017. Efficient visibility analysis for massive observers. Procedia Computer Science 111, 120–128.