ASPECT OF SPATIAL LOCATION OF PERNAMENT GPS ANTENNAS BY USING VISIBILITY ANALYSIS

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1. INTRODUCTION

Spatial configuration of DGPS permanent reference station elements has an effect on performance of the entire system. Arrangement of station elements, such as broadcast antenna and reference masts, requires allowance and further linking together number of technical, operational and terrain factors. Some technical and operational factors as a rule are determined by equipment manufacturer, however terrain factors are conditioned by terrain character of the future reference station site. Terrain character is a composition of its surface shape and all geographical features situated within the reference station surroundings. These factors often can cause certain difficulties during recommended elements' arrangement of the planned reference station.

This elaboration presents applications of visibility analysis in planning spatial location of reference station GPS antennas. Visibility, or viewshed, analysis is usually available in various computer programs of Geographic Information System environment. It can be performed from any point situated in three-dimensional space of elaboration range. In the case of such elements as permanent GPS antennas, application of visibility analyses solves a problem of their location with allowance of surroundings and geographical features, which can cause limitation of visibility of satellites and occurrence of multipath. By performing this kind of analyses can be determined three-dimensional position of GPS antennas, which meets such requirements as recommended horizon visibility.

2. CONFIGURATION OF DGPS REFERENCE STATION

Proper choice of place for DGPS station is an important stage during configuration of the whole system. This stage is often complicated due to many factors, which should fulfill reference station site. These factors can be divided into two elements. The first group of factors is bound up with some technical recommendations, which describe the installation of the equipment in the proposed reference station site. In the case of creation of the new station, there should be considered such factors as geographical location of proposed station place, technical aspect of location of station equipment, radiobeacon transmitting antenna or reference mast (Ketchum, Lemmon, Hoffman 1997). The second group consists of more pragmatic factors like regulation issues, property of allotment, issue of site adoption for system architecture or future site supervision.

In the case of superiority of the second factors, proper assessment of the future reference system architecture requires accurate spatial planning. A good example is placement of the GPS antennas in three-dimensional space with consideration of existing obstacles, which limits number of visible satellites. Theoretically, the best system configuration should ensure visibility of satellites around the whole sky area above the horizon due to satellite orbits geometry and signal structure. Practically, in the proposed site of reference station are situated various obstacles. Geographical features like trees, buildings, forestry, masts, chimneys and others are reason of decreasing visibility of the satellites. The second problem is related to obstacles situated in the vicinity of the reference mast, which can cause multipath, i.e. indirect signals reflected from any obstacles. Generally, the obstacles can obturate the horizon up to 10^o. Grater degree of sky obturation can cause signal loss. However, multipath decreases quality of data and finally accuracy of calculated position.

According to recommendation of Leica reference station guide (Leica Geosystems), the best antenna position should ensure visibility of sky above 10^o of its horizon. Lack of obstacles in this part of sky view should ensure high accuracy of data. The obstacles, which obturate the view above the antenna horizon, are presented in figure 1.

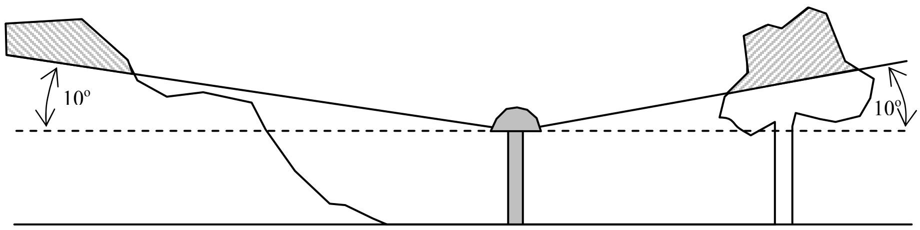

Fig. 1. Graphically example of sky obturation by various objects.

3. DGPS REFERENCE STATION IN DZIWNOW

Permanent reference station in Dziwnow is placed on the Polish coast of Baltic Sea and is used generally for maritime navigation, sounding operations, dredging works and buoys positioning (Śledzinski 2002).

Reference station site is situated in afforested area, behinds seaside dunes. It consists of two separated areas. In the first area is situated transmitting antenna whereas in the second reference mast with system equipment. Presented study is limited to GPS permanent antennas placement, thus the further consideration are related to the second part of reference station. Presently this location does not fulfill condition of effective view of the sky, what is caused by trees situated behind the station allotment. GPS antennas are situated on the roof of nautical station building at the height of about 4 m above terrain (fig. 2).

Fig. 2. View of nautical station in Dziwnow; (A) GPS antennas, (B) transmitting antenna.

Height of trees are much bigger and varies within ranges from 6.69 m to 12.40 m. Apart from this, within the borders of lot is situated one separate tree and minor building, which is about 2.5 m high. Terrain elevations changes from 4.5 to 5.0 m. Situation sketch of nautical station is presented in figure 3.

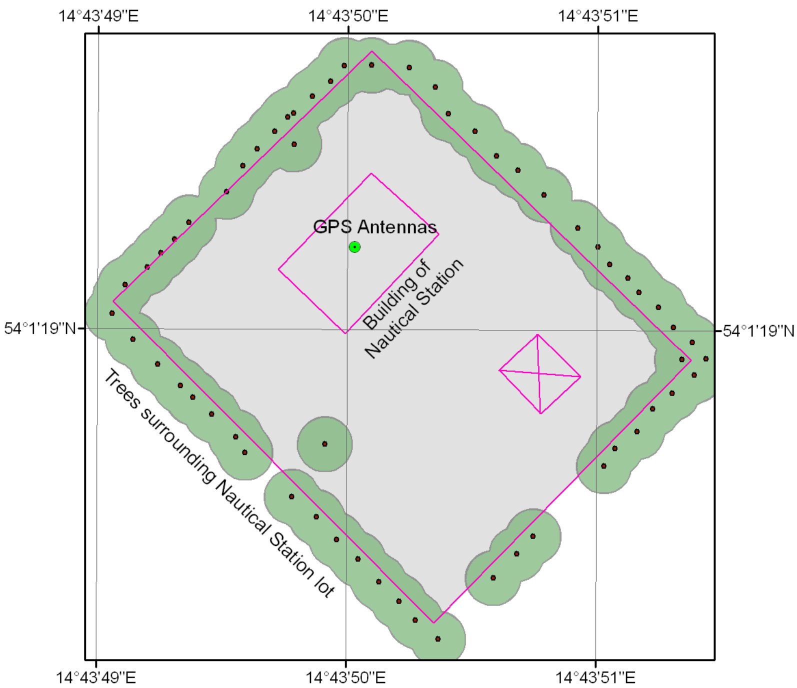

Fig. 3. Situation sketch of nautical station lot.

4. VISIBILITY (VIEWSHED) ANALYSIS

Visibility or viewshed analysis basically is performed by using raster data format of digital surface model or digital terrain model. Viewshed identifies the cells in an input raster that can be seen from observation points. Raster cells that cannot be seen from observer point or points have value of zero. When the raster cell is visible it value is set to one. Thus, the output raster identifies areas, which are visible or not visible from observer point or points by giving them values one or zeros. This feature is very useful during finding location of various observing sensors, e.g. radar sensors (Łubczonek 2008).

Viewshed analysis in ArcGis program has many parameters, which can define limited model of the field of view. Default values of viewshed analysis perform analysis in the full vertical and horizontal angle. Determination of position of GPS permanent antennas requires limitation of vertical angle of view and setting vertical offset of observation point. Vertical angle should mask visibility to 10^{o} above antenna horizon, while value of offset represents antennas height (fig. 4).

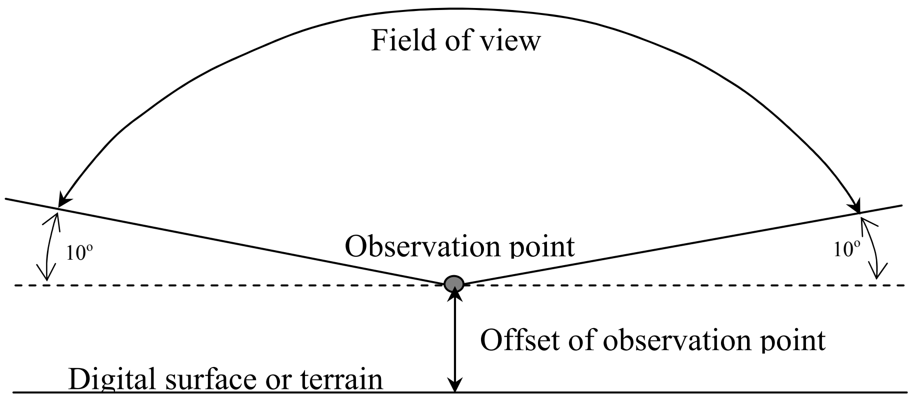

Fig. 4. Graphically presentation of parameters used in viewshed analysis.

Accuracy of viewshed analysis depends mostly on spatial accuracy of digital surface model of land cover, which consists of natural features, like trees, and artificial ones like buildings, masts and other constructions. One of the essential elements of digital surface model is a terrain shape, which can play an important role in determination of the proper observation points. For the purpose of this work a digital surface model was prepared from data of field measurement and cadastral maps. It consisted of three elements: terrain, building of nautical station and surrounding trees. Created raster model of DSM was presented on fig. 5.

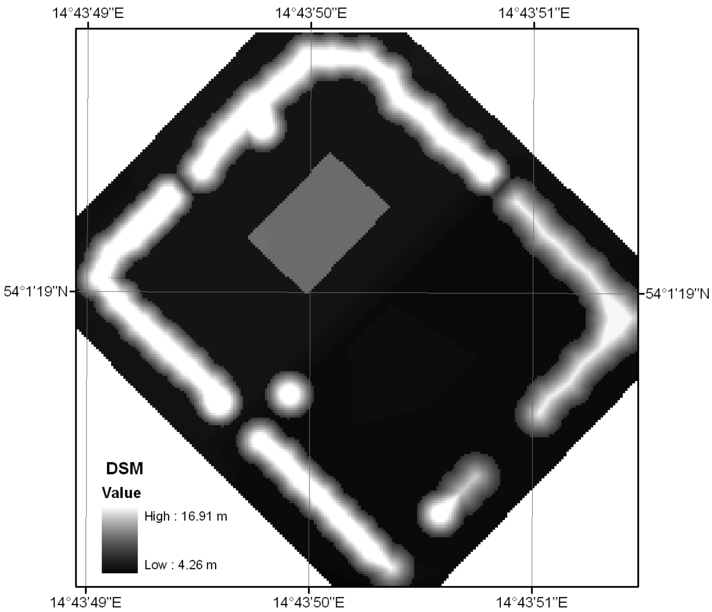

Fig. 5. Raster model of digital surface model.

5. DETERMINATION OF GPS ANTENNAS POSITION BASED ON VISIBILITY ANALYSIS

Visibility analysis is performed by using certain set of observation points or just one point. Thus, result of analysis is strictly bound up with each point coordinate. More convenient form of analysis is representation its results continuously over domain of elaboration terrain. Such form of representation enable to identify more precisely position of observation points. This advantage is essential during precise determination of 3D position of observation points within terrain of complicated spatial geometry or within border of small lots, which have usually limited space for future GPS antennas platforms.

This case of analysis concerns location of GPS antennas in Dziwnow place. Method of determination of area for GPS antennas placement and calculation of their heights was performed in following steps:

1. **creation of polygon of equally spaced points within area of reference station lot**
2. **calculation of percentage ratio of obturation for each point**
3. **creation of spatial model of percentage ratio of obturation by application of interpolation method**
4. **determination of required antenna height above sea level, which minimise obturation ratio**
5. **calculation of antenna heights above ground**

Polygon of points of the same heights, equally spaced within area of future antennas location is presented in figure 6. More points is situated in the middle part of lot, because they are apart from obstacles, e.i. trees, what makes them potential location of GPS antennas.

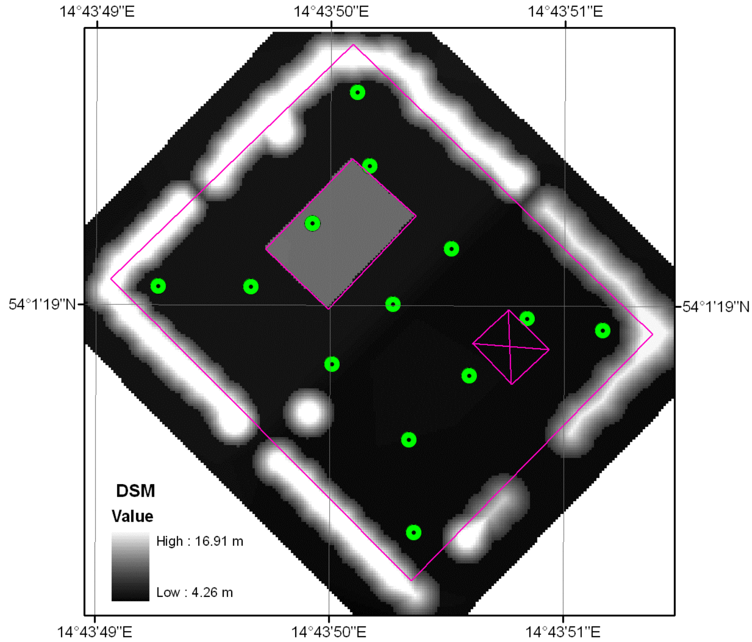

Fig. 6. Points' polygon used for calculations of sky obturation ratio.

For each point was performed viewshed analysis and it results were used for calculation of percentage ratio of obturation (*PRO*). It expresses proportion of the sky obturation causing by terrain obstacles. Percentage ratio of obturation can be expressed by the formulae:

$$PRO_i = 100 \cdot \frac{a_i}{A_n}$$

where:
PRO_i – value of percentage ratio of obturation in *i* observation point of polygon [%]
a_i – visible area of DSM, or obstacles, from *i* point [m^2]
A_n – visible area of DSM, or obstacles, from all points (*n*) [m^2]
***n* – number of observation points of the same heights**

Calculated values for each data point were used for building spatial model of *PRO* by applying kriging surface interpolation method. This is the one of the most suitable method for surface interpolation in the aspect of used data points, i.e. its spatial distribution and density (Łubczonek, Stateczny 2005). New values were interpolated according formulae:

$$\begin{array}{cccccccc}
w_1\,(h_{11}) & +\,w_2\,(h_{12}) & +\,.....\,+ & W_n\,(h_{1n}) & + & = & (h_{1p}) \\
w_1\,(h_{21}) & +\,w_2\,(h_{22}) & +\,.....\,+ & W_n\,(h_{2n}) & + & = & (h_{2p}) \\
w_1\,(h_{31}) & +\,w_3\,(h_{32}) & +\,.....\,+ & W_n\,(h_{3n}) & + & = & (h_{3p}) \\
. & . & . & . & . & & . \\
. & . & . & . & . & & . \\
w_1\,(h_{n1}) & +\,w_3\,(h_{n2}) & +\,.....\,+ & W_n\,(h_{nn}) & + & = & (h_{np}) \\
w_1 & +\,w_3 & +\,.....\,+ & w_n & +0 & = & 1
\end{array}$$

whre: (h_{ij}) – semivariance between sample data i and j; (h_{ip}) – semiwariance between polygon and interpolated point; n – number of points used in interpolation.

Finally, interpolation function *f(x,y)* can be expressed as below:

$$f(x,y) = \sum_{i=1}^{n} w_i z_i$$

By increasing antenna height was created next surface, presented in raster form with spatial resolution of 0.2 m. Each surface allow for assessment of changes in obturation ratio within the lot of reference station. The zero or near zero values of raster surface identified potential area of GPS antenna placement.

The last step was calculation of antenna heights above ground. These values are obtained by application of raster arithmetic; raster with optimal heights values of observation points above sea level was subtracted from raster of digital surface model, according the formulae:

$$C_h = C_H - C_{DSM}$$

C_h – matrix of raster cell values of minimum antenna height above ground
C_H – matrix of raster cell values of observation points' height above sea level
C_{DSM} – matrix of raster cell values of elevation of DSM above sea level

6. ANALYSIS AND RESULTS

Analysis was performed for four different antenna heights' values: 9m, 12m, 15m and 16m above sea level. Technically, GPS antennas should be mounted on very stable construction, which are resistant to deformation or sway. Thus, the new proposed construction like masts or frameworks should not be too high or enough high to ensure proper visibility of satellites.

In this study, to calculate adequate height of antenna, in the first step for each heights of observation points was performed viewshed analysis and then calculated percentage ratio of obturation in the plane XY.

First surface of visible obstacles was calculated for antenna heights of 9m and is presented in figure 7. The biggest values of *PRO* are located in the middle part of lot of nautical station, where actually are situated GPS permanent antennas.

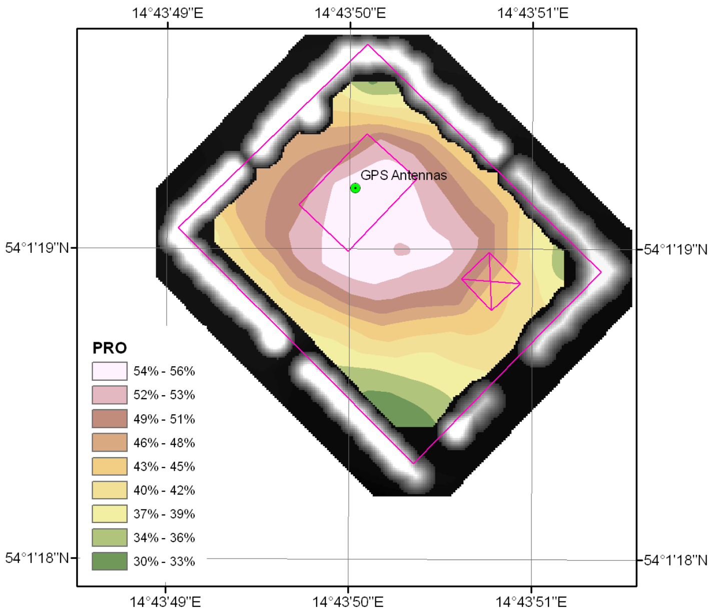

Fig. 7. *PRO* values at antenna heights of 9 m.

Next calculation was performed for height of 12 m and results were presented in figure 8. The area of *PRO* was changed. Higher elevation of antennas enlarges terrain area with smaller percentage of obturation within 0% - 5%.

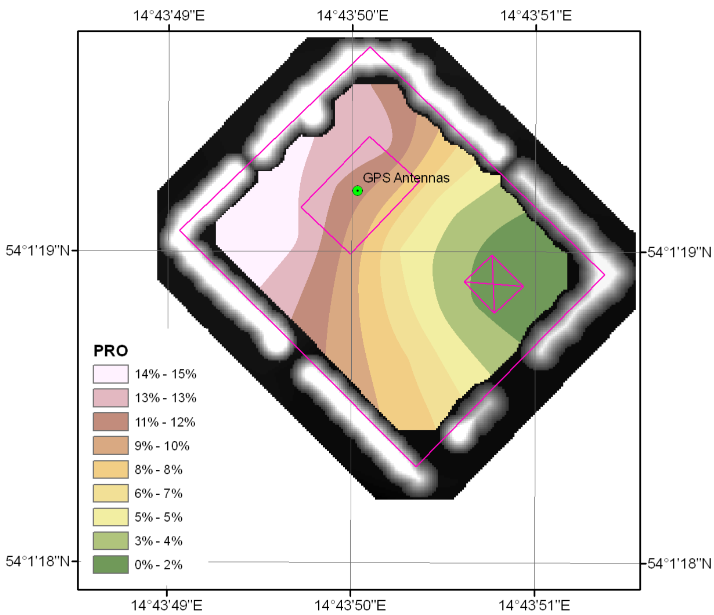

Fig. 8. *PRO* values at antenna heights of 12 m.

Results of calculation for antenna height of 15 m were presented in figure 9. At this height obstacles obturate the horizon for less than 3% in the grater part of station allotment.

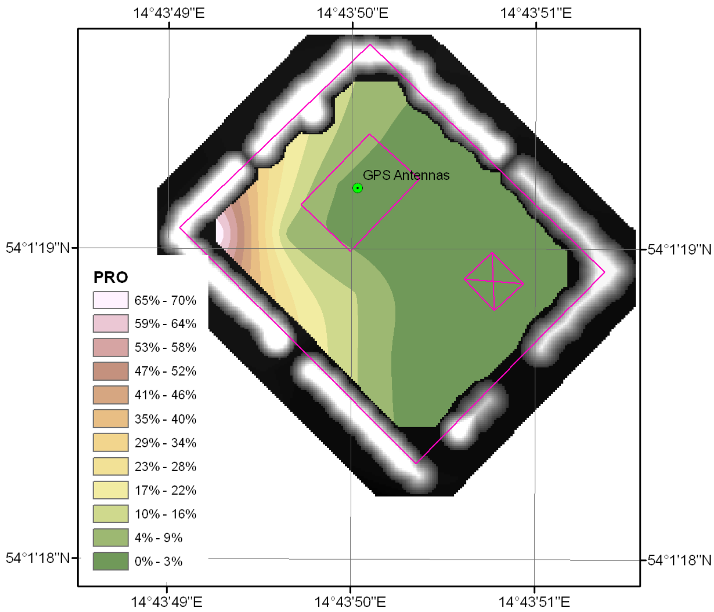

Fig. 9. Obturation ratio at antenna heights of 15 m.

When antenna height equals 16 m, no obstacles limit the view of horizon, thus this value is recommended as minimum antenna height above sea level.

The last step is calculation of antenna heights above ground with consideration of digital surface model. The antennas heights are represented also in the raster format, so by applying so-called raster arithmetic, raster of 16 m heights was subtracted from DSM. Results in the form of raster model as values of minimum heights of GPS antennas are presented in figure 10.

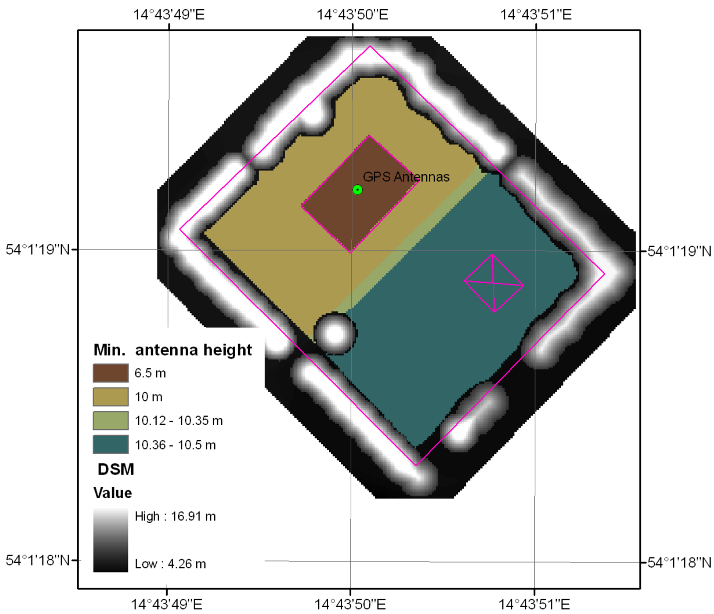

Fig. 10. Minimum antenna heights above ground.

Results of analysis can be also combined. For example we can determine area of lot with *PRO* values within range 0%- 3% at antenna height of 15 m above sea level (fig. 11).

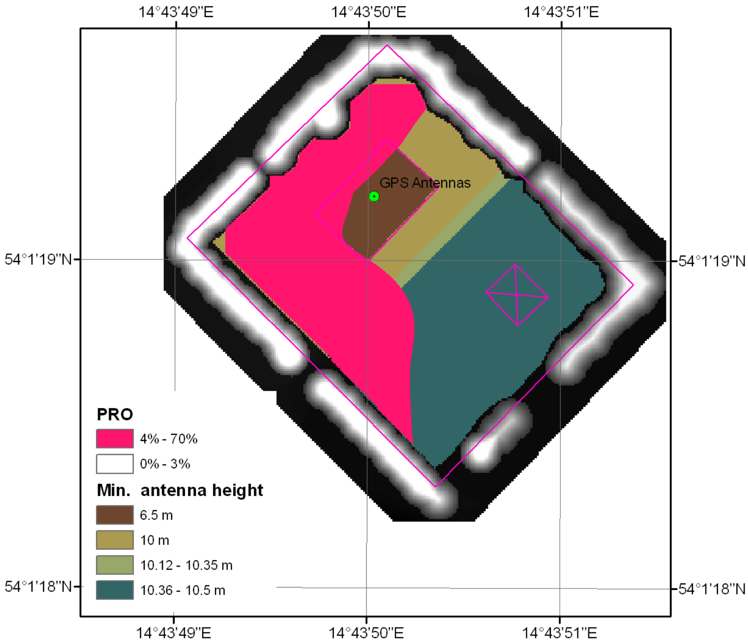

Fig. 11. Combined presentation of viewshed analysis and antennas heights above terrain; colour of *PRO* values within range 0%- 3% is transparent.

Final location of GPS antennas mast requires individual visibility analysis in the case of acceptance of some obstruction for further assessment of visible satellites.

Additional aspect of analysis is allowance of future trees heights, which requires knowledge about stand quality classification. In that case, visibility analysis should just include future heights of trees.

7. CONCLUSION

Paper presents aspects of spatial location of GPS permanent antennas by using visibility analysis. For this purpose was prepared digital surface model of examined area and was performed visibility analysis. Visibility analysis was presented as continues values in the form of two-dimensional plotting of percentage ratio of obturation. These values can be used for localization of GPS permanent antennas in the aspect of minimizing influence of obstacles on system performance. Additionally, by applying raster arithmetic can be calculated required height of antenna over terrain and potential useful buildings.

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