Spatial Configuration of Geodetic Points

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Key words: detailed geodetic network, surveying, geographic weighted regression, spatial pattern, choropleth map

SUMMARY

Most of the research on the configuration of a geodetic control network has focused mainly on establishing such a network of geodetic control points to ensure its high precision and reliability at the lowest possible cost. The ex-post analysis of spatial pattern of geodetic control points has not been exhaustive so far. It was mainly limited to the assessment of spatial distribution of GNSS reference stations or geodetic control points of detailed network in typically agricultural areas.

This paper discusses the distribution of horizontal, detailed geodetic control points in a broader context. Specifically, it implements geographically weighted regression (GWR) to illustrate the spatial relationships between the location of geodetic points and the type of land use, buffer analysis to distinguish geodetic control points located near roads, railways, electric lines, and watercourses, while the global Moran's I and Getis-Ord statistics represent the spatial pattern of geodetic control points. Hence, this study aims to model spatial configuration of geodetic control with respect of Polish national regulation and relationship between the number of geodetic control points and land use. The results are related to surveying units, theretofore grouped according to land use types, namely: built-up, rural, forest, and miscellaneous. The conducted study proved that geodetic control points are scattered with significantly visible groupings along roads, railways, and built-up area. It also shows that information on the land use has a vital influence on the number of geodetic control points and indicates where geodetic control needs densification.

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1. INTRODUCTION

The geodetic control network provides a reference system for determining the position of all geospatial data, defined by coordinates in the national reference frame. It plays a key role in developing all core data and users' thematic data, because it provides the spatial reference source to register all other spatial data. Furthermore, the geodetic control network is of utmost practical importance in determining the shape and size of the earth, in engineering and topographic, and cadastral surveys, assessing geospatial data quality, planning data collection as well as fit new areas of data into existing coverages. According to Baarda (1968) an optimal geodetic control network should be of high precision, reliability, and low cost. Planning a geodetic network includes determining the number of network points and their geospatial location, as well as the selection of the type, number, and weight of observations. Many studies consider these assumptions theoretically and showed results based on experimental or computational examples, using different methods of designing and densifying geodetic control network (Amiri-Simkooei et al. 2012; Wu and Chen, 2019; Novel, 2019).
The analysis of spatial patterns of geodetic control points was first publicly discussed by Bielecka et al. (2015) at the forum of national geoinformation conference and developed in their further studies on the relations between land use type and geodetic points location as well as examining the spatial disparity in their location (Calka at. al.2017; Pokonieczny et al. 2017; Bielecka et al. 2020). The presented paper is a continuation of research on the distribution of horizontal, detailed geodetic control points (referred hereinafter as GCPs) and the relationship between the density of geodetic points and the type of land use. Contrary to previous studies, geographically weighted regression was used to illustrate the spatial relationships between the location of geodetic points and the type of land use, buffer analysis to distinguish GCPs located near roads, railways, electric lines, and watercourses, while the global Moran's I and Getis-Ord statistics represent the spatial pattern of GCP. Hence, the main goal of this paper is twofold, firstly to analyze the results of modeling the relationship between the number of GCPs and the type of land use using linear regression (OLS) and geographically weighted regression (GWR), and the secondly to analyze the density of geodetic points in an agri-forest-industrial area with a very well-developed road network regarding national regulations concerning geodetic control network.

2. STUDY AREA, DATA AND METHODS,

The Radomski County is located in central Poland, in the Mazovia Province (Fig.1). It covers an area of 1,530 km², inhabited by over 151 thousand people (GUS, 2019). The land use structure is dominated by agriculture (60.1%), forests (26.8%), and artificial areas (27.7%). The road density equals 91.2 km per 100 square kilometers.

Fig.1. Radomski county location

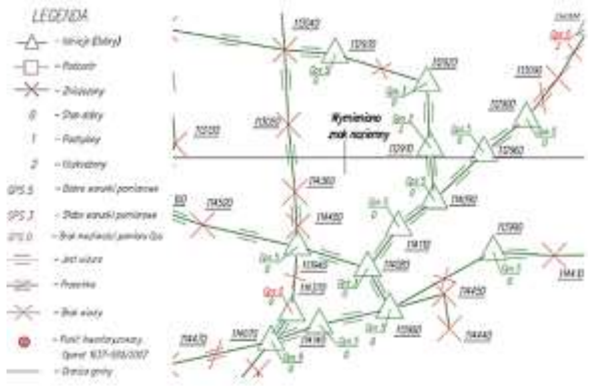

Fig.2. Detailed, horizontal geodetic network, an example

The data set of geodetic control points was obtained from the Geodetic and Cartographic Center in Radom. It comprises of 7,216 points of horizontal detailed geodetic network, sketch of the geodetic control network in the county is presented in Fig.2. The GCPs coordinate are stored in national coordinate reference system ETRS89/Poland CS2000 zone 7.

The organization, procedure and technical standards for establishing and maintaining geodetic networks are regulated by the Regulation of Ministry of Administration and Digitization (Regulation, 2012) implementing the Geodetic and Cartographic Law of the Polish Parliament. The Regulation said that the density of geodetic control points in Poland should be at least one point per 20 ha for built-up area and 120 ha on agricultural and forest areas.

The information on the land use was acquired from Database of Topographic Object provided by the Head Office of Geodesy and cartography via geoportal.gov.pl. The thematic scope and the accuracy of topographic data correspond to the 1:10,000 topographic map. The boundary of geodetic sections, the smallest enumeration geodetic unit corresponding to one village, were taken from geoportal.gov.pl maintained by the Head Office of Geodesy and Cartography.

This study aims to model spatial configuration of geodetic control with respect of Polish national regulation and relationship between the number of geodetic control points and land use. Geographically weighted regression (GWR) was used to illustrate the spatial relationships between the location of GCPs and land use type, namely built-up, rural, forest, and miscellaneous. Buffer analysis aimed to distinguish geodetic control points located near roads, railways, electric lines, and watercourses. The following buffers were set up based on literature review: roads – 50 m (Połeć, 2012), railways – 15 m (Połeć, 2012), electric lines – 100 m (Pokonieczny et al. 2016; Calka et al. 2017), and watercourses and water bodies – 100 m (Pokonieczny et al. 2016). The global Moran's I and Getis-Ord statistics represent the spatial pattern of geodetic control points throughout the study area.

3. RESULTS AND DISCUSSION

The density of geodetic control points in Radomski County is very diverse, from one point per 6.3 ha in the city of Pionki to the GCP per 63.8 ha in the Pionki rural commune, the average density of GCPs is one point per 21.3 ha. Local density of GCPs varies from 0.54 to 15.4 points over 1 km2 and shows places of higher and lower point density. A significant increase in the density of geodetic points is observed in urbanized regions (Fig. 3).

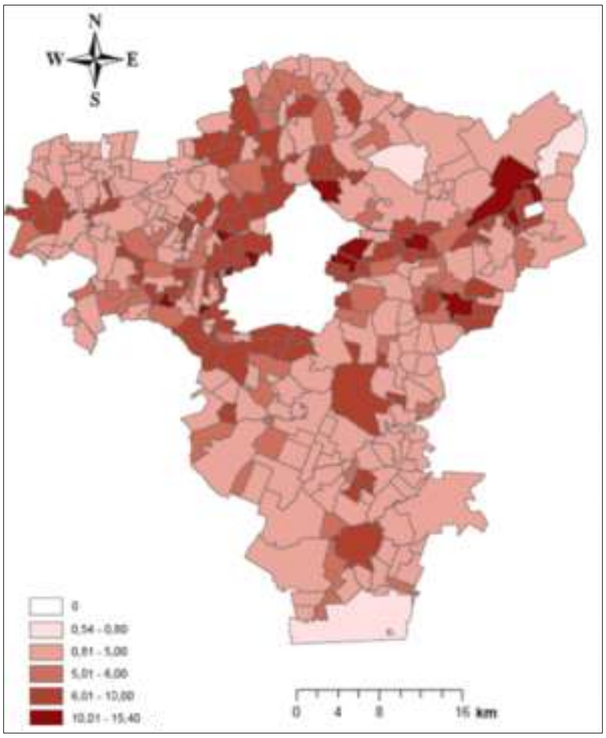

Fig. 3. Number GCPs of per 1 km^2 (Głód 2020)

The vast majority, as much as 84% of GCPs, are located less than 50 m from the road. This means good accessibility and easy access for surveyors. It should be mentioned, however, that the location of GCPs in such a short distance from the roads may lead to GCPs destruction during road renovation.

Table 1. Number of GCPs in the vicinity of roads, railways, electricity lines and water bodies (source: Głód 2020)

Buffer zones	GCPs number
50 m around paved road	6056
15 km around railways	89
100 m around electricity lines	4426
100 m around water	787

61% of the horizontal detailed geodetic control points are located in the 100 m buffer zone around power lines. It is worth to mention that measurement using GNSS technology may be difficult in this area due to electromagnetic wave disturbances. This problem was previously noted by Calka et al. (2017). About 10% of GCPs are located within 100 m from the waters, which is mainly related to the low soil stability in these areas. This could be explained by the difficulty of maintaining a point's monumentation stability in lands with high flood risk and

variable groundwater levels (Bielecka et al. 2020). Whereas there are 89 points in the close vicinity of railway lines (no more than 15 m). For details see Table 1.
The geographical points location corresponds to the main land cover type namely: built-up areas, rural, forest and miscellaneous (Table 2) with the R-square equals to 0.40. As many as 54.37% of GCPs are situated on agricultural land, 34.5% in built-up areas, and 9.9% in forest.

Table 2. Density of GCPs over land use types (source: Głód 2020)

Land use	Number of GCPs	Area [ha]	Number of GCPs per 1 ha
Rural	3816	92838.3	24.3
Built-up	2421	39465.7	16.3
Forested	693	17707.4	25.6
Miscelaneous	93	2935.3	31.6

The clustered spatial distribution of GCPs in the study region was also underlined by global Moran's I and Getis-Ord hot spot analysis. Global Moran's I statistics, based GCPs density returned negative I and z-score values of 10.459 with a 99% level of significance. This empowers rejection (with a probability greater than 1%) of the null hypothesis assuming that, density of geodetic control points is randomly distributed in study area. Therefore, the spatial distributions of geodetic control point density is clustered.
The hot spot and cold spot map (Fig. 4) show the significance of autocorrelation areas with high density of GCPs (marked in red) and low density (marked in blue).

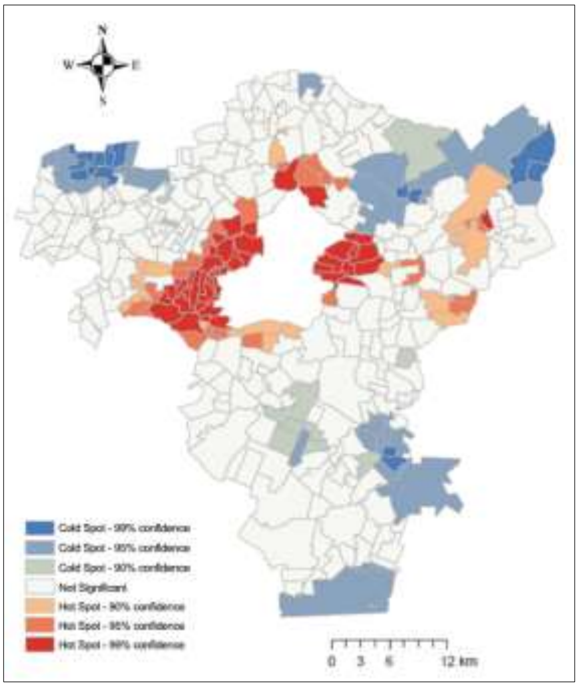

Fig. 4. Hot spot map of GCPs density (Głód, 2020)

OLS regression showed the highly corrected variables (Table 3) that were further used in Geographically Weighted Regression (GWR), namely road density and percent of built-up areas.

Table 3. Results of OLS regression (source: Głód 2020)

		coefficient	Std.	T statistics
Independent variable	GCPs density	4.85	2.59	1.88
Exploratory variables	Area	-0.01	0.02	-0.52
	Road density	0.28	0.09	3.22
	Built-up areas (%)	0.26	0.05	5.68
	Forests (%)	-0.04	0.03	-1.34
	Rural areas (%)	-0.02	0.03	-0.88
$R^2 = 0.40$ corrected $R^2 = 0.39$ Akaike AIC = 1349.73				

GWR indicated the GCPs density, independent variable, has been explained in 57% (Table 4) and is much better than using OLS linear regression (see Table 3). Better suitability of GWR is also emphasized by the lower value of the AIC criterion - 1326.12.

Table 4. GWR regression parameters.

Independent variable: GCPs density.	
Exploratory variables: % of built-up area, road density	
Sigma	1.71
Akaike AIC	1326.12
R^2	0.57
corrected R^2	0.49

In contrast to the global least squares regression (OLS) model geographically weighted regression provides better results because its local model assumes non-stationarity of the spatial process. GWR regression coefficients change with location. The greater the distance from the data location to the regression points, the smaller the weights are. A lower value of the AIC criterion indicates a greater complexity of the model.

4. CONCLUSIONS

The conducted study proved that geodetic control points are scattered with significantly visible groupings along roads, railways, and built-up area.
It also shows that information on the land use has a vital influence on the number of geodetic control points and indicates where geodetic control needs densification.

REFERENCES

Amiri-Simkooei A. R., Asgari J., Zangeneh-Nejad, Zaminpardaz, F. S. 2012. Basic Concepts of Optimization and Design of Geodetic Networks. *J. Surv. Eng.* 138, 172-183, DOI:10.1061/(ASCE)SU.1943-5428.0000081.

Baarda W. 1968. A testing procedure for use in geodetic networks. *Netherlands Geodetic Commission, Publication on Geodesy,* 2(5), pp.97.

Bielecka E., Pokonieczny K., Kamiński P. 2015. Charakterystyka rozmieszczenia przestrzennego punktów poziomej osnowy szczegółowej. *Roczniki Geomatyki [Annals of Geomatics]* 13, 3(69), 201-208.

Bielecka E., Pokonieczny K., Borkowska S. 2020. GIScience Theory Based Assessment of Spatial Disparity of Geodetic Control Points Location. *ISPRS Int. J. Geo-Inf.* 9(3), 148, DOI: https://doi.org/10.3390/ijgi9030148

Calka B., Bielecka E., Figurski M. 2017. Spatial pattern of ASG-EUPOS sites. *Open Geosciences*, 9(1), 613–621. DOI: https://doi.org/10.1515/geo-2017-0046

Głód G. 2020. Msc thesis "Analysis of the spatial distribution of points in a state geodetic network" carried out under dr Beata Calka supervision" at the Faculty of Civil Engineering and Geodesy Military University of Technology, Warsaw, Poland.

Geodetic and Cartographic Law of the Polish Parliament (Dz U. 1989 Nr 30 item 163, amended by Dz. U. 2020).

GUS. 2019. Vademecum statystyczne samorządowca. Available on-line: https://warszawa.stat.gov.pl/vademecum/vademecum_mazowieckie/portrety_powiatow/radomski.pdf (access on 27.12.2020).

Nowel, K. 2019. Squared Msplit(q) S-transformation of control network deformations. *J Geod* 93, 1025–1044. DOI: https://doi.org/10.1007/s00190-018-1221-4

Pokonieczny K., Bielecka E., Kamiński P., 2017. Analysis of geodetic control points density depending on the land cover and relief – the Opoczno district case study, "Environmental Engineering" 10th International Conference, eISSN 2029-7092 / eISBN 978-609-476-044-0, Vilnius Gediminas Technical University, Lithuania, 27–28. DOI: https://doi.org/10.3846/enviro.2017.228

Połeć T., Procedury postępowania i tworzona dokumentacja na kolejnych etapach prac prowadzonych do założenia w terenie sytuacyjnej osnowy szczegółowej III klasy, *Acta Scientifica Academiae Ostroviensis*, Ostrowiec Świętokrzyski 2012.

Pokonieczny K., Calka B, Bielecka E., Kaminski P. 2016. Modeling Spatial Relationships between Geodetic Control Points and Land Use with Regards to Polish Regulation, 2016 Baltic Geodetic Congress (BGC Geomatics), Gdansk, Poland, 2016, pp. 176-180. DOI: https://doi.org/10.1109/BGC.Geomatics.2016.39

Regulation 2012. Regulation of Ministry of Administration and Digitization of Poland of 14 February 2012 as regards geodetic control, gravimetric and magnetic networks. Dz. U. 2012 entry. 352, Poland, 2012.

Wu, Junli, Chen, Ming. 2019. Design and Service of National Geodetic Datum Modernization in China. *Geophysical Research Abstracts*, 21, 1-1.

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