"Environmental Engineering" 10th International Conference
Vilnius Gediminas Technical University
Lithuania, 27–28 April 2017
http://enviro.vgtu.lt

eISSN 2029-7092 / eISBN 978-609-476-044-0

Article ID: enviro.2017.228
DOI: https://doi.org/10.3846/enviro.2017.228

Analysis of Geodetic Control Points Density Depending on the Land Cover and Relief – the Opoczno District Case Study

Krzysztof Pokonieczny[1], Elzbieta Bielecka[2], Paweł Kamiński[3]

[1,2,3]Faculty of Civil Engineering and Geodesy, Military University of Technology, Warsaw, Poland
E-mails: [1]krzysztof.pokonieczny@wat.edu.pl (corresponding author);
[2]elzbieta.bielecka@wat.edu.pl; [3]pawel.kaminski@wat.edu.pl

Abstract. The main goal of this study is an analysis of statistical and spatial relationships between land cover, relief and geodetic control points' location. We aimed at proving the previous results showing that in rural areas the density of horizontal geodetic points depends at least 50% on the land cover. Moreover, two clustering methods, k-means and Kohonen self-organising maps, were used to group surveying districts according to similarity in land use, relief and geodetic control density. The research methods includes statistical methods, ie. Pearson correlation and coefficient of determination computed by Pawlowski method as well as spatial autocorrelation expressed by Moran I global index. The results show that both clustering methods give very similar results, however for the k-means the surveying districts are more spatially clustered, than for Kohonen. The coefficient of determination R^2 equals 0.652, what means that geodetic control points density in 65.2% explains by the percentage of built-up areas, forests and the standard deviation of elevation. The analysis was conducted for the 3rd order geodetic control points, for Opoczno district, located in the central part of Poland.

Keywords: cluster analysis, geodetic control, k-means, computational intelligence methods, topography.

Conference topic: Technologies of Geodesy and Cadastre.

Introduction

The number of geodetic control points and their configuration meaningfully influence the precision, reliability and geometrical strength of a control network (Baarda 1968). Hence, geodetic controls are usually established on a drawn up project and field inspection. Currently, measuring technologies, especially GNSS measurements, require also taking into account topographic criteria, namely land cover or land use and relief. Such requirements, in the form of regulations or standards, are published by National Mapping Agencies. In Australia a survey optimisation allows to adjust (increased or decreased) the density of control points until the optimal level of network precision is identified (ICSM 2007). In Canada the large numbers of monumented points are located in the more populous areas of the country (Canada Geomatics 1996), while in The United States Committee on Geodesy said that density of geodetic control is of utmost importance, especially for the use in local survey. Hence, it recommended that 3 to 10 km^2 should be covered at least by 1 control point (Committee on Geodesy 1984). Lu *et al.* (2014) stated that the density of the geodetic points should be 'different according to the different mapping scales and methods'. They recommend 3–4 geodetic points for each map sheet. However, noticed that for engineering projects this density should presumably be higher. In Poland recommendation concerning geodetic control classification, accuracy and densification are published in the Regulation of February 14, 2012 concerning geodetic, gravimetric and magnetic controls (MAiC 2012). The minimal number of geodetic controls in urban fabric and other artificial areas should be 1 to 20 hectares, while in agriculture lands and forests – greater than 1 point in 120 ha.

Analysis of location of geodetic points as well as modelling spatial relationships between geodetic control points and topography is not the subject of intense studies so far. Only selected researches (Beesley 2003; Xavier, Costa 2007; Zhang *et al.* 2008; Han, Li 2010; Han *et al.* 2012) investigate the impact of terrain elevation on the control points location measured by means of the GPS techniques. More complex studies has been conducted by the authors and published in scientific journals (Bielecka *et al.* 2014, 2015) and international conference proceedings (Pokonieczny *et al.* 2014, 2016). We have already found that the number of geodetic control points in the geodetic sections depends on the land use e.g. built-up, forest, agricultural and mixed, and is the highst in built-up areas (Bielecka *et al.* 2015; Pokonieczny *et al.* 2016). The value of the coefficient of determination (R^2) of this relationship depends on minimal mapping unit and the type of regression. For Pavlowski's method R^2 equals 0.35, while for Ordinary Last Square regression is 0.51. Moreover, using the same regression type, R^2 takes higher value for small, regular mapping units (100 m regular grid) (R^2 =0.50) than for irregular, administration units like geodetic sections or geodetic districts (R^2 =0.35). We also noticed that densification of geodetic control points is 2–3 times higher than it is required by the National Regulations (Bielecka *et al.* 2015) and that geodetic districts characterised by similar control point density do not form statistically significant spatial clusters (Pokonieczny *et al.* 2016).

This article is a continuation of the authors' previous studies. The main goal of this research is the analyses which one of the two commonly used clustering methods (k-means and Kohonen neural network) better captures differentiation of surveying districts due to various land cover, relief, and geodetic control points' densification and concentration. As well as if the delimited types of districts characterised by (high or low) density of geodetic controls form clusters or rather spatial outliers. The analysis is conducted for horizontal geodetic controls in the Opoczno district, situated in the central part of Poland.

Methods and research procedures

The main research assumption was that the results of analysis are related to the surveying districts (thereafter referred as SD) the smallest units of the surveying division of the country. In general one district corresponds to the one village in rural areas or a housing estate in urban areas. The statistical dependence between geodetic control points density (a dependent variable), land cover classes and relief (independent variables) was achieved using Pearson Coefficient Correlation (ϱ) as well as coefficient of determination (R square) computed by Pawlowski method (Pawlowski 1977). Both correlated independent variables as well as variables low correlated with geodetic control points (thereafter referred as GCPs) density ($\varrho \leq 0.15$) were excluded from further studies.

Knowing, that the distribution of horizontal geodetic control points is uneven in the country and depends mainly on land use and land development we analysed the influence of clustering method on the geodetic districts grouping. The classification of SD was done by two more often used methods: k-means clustering and Kohonen neural network. K-means algorithm belongs to the Exploratory Data Analysis and is used to group sets of objects in such a way that objects in the same group are more similar to each other than to those in other groups. Kohonen is a self-organising map type of artificial neural network. Their main task is the organisation of the multidimensional information in such a way that it can be presented and analyzed with a much smaller number of dimensions, or a map (Tadeusiewicz 1993). Both methods require number of class given a priori, so the number of classes was determined initially using the V-fold cross-validation test. The analyses were conducted according to the following procedure:

1. Data storing in PostGIS database, clipped to the boundary of the test area, and re-projected to the 34 UTM CRS according to rules established by Kadaj (2016).
2. Computation attributes for all SDs: percentage of built-up area, percentage of agriculture areas, percentage of forests, percentage of area occupied by roads (with 50 m buffer zone); slope, standard deviation of elevation, GCPs density.
3. Normalising attribute values according to the formula (1):

$$v' = \frac{v - v_{min}}{v_{max} - v_{min}}\left(new\_max - new\_min\right) + new\_min \,, \tag{1}$$

where: v – the input attribute value, v' – normalized input attribute value, $v - v_{min}$ – min, max input values, $new\_max - new\_min$ – max and min values of normalised data range [1,0].

4. Computation of statistical relationships, determination of independent variable.
5. Surveying districts grouping using k-means clustering and self-organizing map (Kohonen neural network).

Standard deviation (σ) of the elevation for each SD, computed on the basis of average 800 elevation points derived from SRTM mission, was recognized as the best parameter reflecting a fold in the hills of the study area.

Moreover, the GCPs concentration (c_{GCP}) coefficient was established and computed. It reflects the number of hectares that is covered by 1 GCP, and is calculated according to the formula (2):

$$c_{GCP} = A_{SD} \,/\, N_{GCP} \,, \tag{2}$$

where: A_{SD} – area of surveying district in hectares; N_{GCP} – number of geodetic control point within the surveying district.

The c_{GCP} concentration coefficient is an inversion of the geodetic control point density (d_{GCP}) calculated as ratio of the number of geodetic controls on the surface given in square kilometers.

Spatial autocorrelation was assessed by global Moran I index. The results are presented in tables and cartographic visualisations using choropleth or categorical maps, according to the rules established by Medynska-Gulij (2014).

Area and data used

The study area, Opoczno district, is located in the central part of Poland (see Fig. 1a). The district consists of 10 communes, including: 2 towns, 2 urban-rural communes and 6 rural communes. It is a hilly region, with the highest elevation not exceeding 300 meters above sea level, the maximum height difference is 143 m. The total number of villages and towns in the district equals 445. Its total area is 1049.19 km², and number of inhabitants is 77,457 (GUS 2014).

The district is of mainly agricultural lands take 64%, forests cover slightly over 30%, built-up areas – 5.1%, and water – 0.7%. 14% of the total territory is a protected area (LARR 2014). The road network is well developed; the district is covered by 150 km of paved roads.

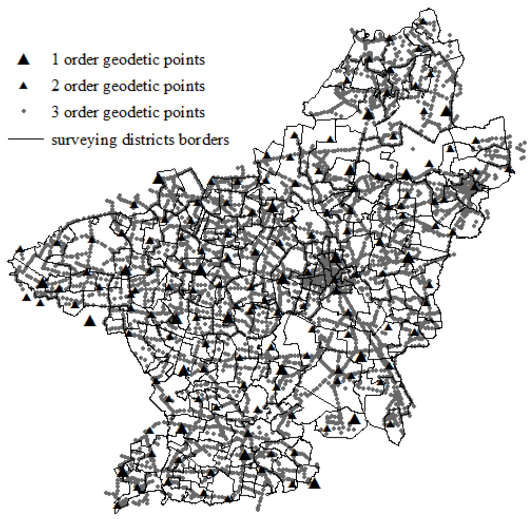

Fig. 1. Study area a) Opoczno District location, b) geodetic control points (GCPs, Source: own elaboration)

The horizontal controls data are collected by the Geodetic and Cartographic Center in Opoczno. The analyzed control consists of 5361 points, including 27 geodetic control of the 1st order, 170 points of the 2nd order and 5162 points belonging to the 3rd order of the network (i.e. detailed geodetic network). Location of GCPs is presented in Fig. 1b. The mean error of control point's location does not exceed 0.07 m.

The horizontal geodetic control networks constitute a components of the Polish Spatial Information Infrastructure. It is established and maintained on a national basis under the Head Office of Geodesy and Cartography. The number of the detailed geodetic control points in Poland equals 1,378,383 that yields the average density of 1 in 4.42 sq.km. According to the national Regulation of Ministry of Administration and Digitization of Poland of 14 February 2012 as regards geodetic control, gravimetric and magnetic networks (MAiC 2012) the density of horizontal geodetic control points should be at least 1 point in 50 sq. km. Moreover, in urban fabric areas at least 20 ha should be covered by 1geodetic control, while in arable and forest areas – 120 ha.

Borders of third administration division (commune) as well as borders of surveying districts are stored in National Register of Boundary maintained by the Central Geodetic and Cartographic Documentation Centre.

Land cover data are derived from CORINE Land Cover (CLC) 2012. It is the only exhaustive geographic land cover database covering nearly the whole Europe. The CLC nomenclature is a physical and physiognomic land cover nomenclature relevant for environment, nature and landscape protection. It distinguishes land cover classes grouped in a 3-level hierarchy. The classes of the first level are: artificial surface, agricultural areas, forests and semi-natural data, wetlands and water bodies. The nomenclature is strongly related to the process of image interpretation, the working and publishing scale and the smallest cartographic unit used in elaboration of the database (EC 1994; Luc, Bielecka 2015).

The information about paved roads network was acquired from Vector Map Level 2, provided by the Polish Military Geography Directorate. The thematic scope and the accuracy of these data roughly equivalent that of military topographic maps in the scale 1:50,000 (Kowalski *et al.* 2009) and are in line with the Military Specification MIL-V-89032 Vector Smart Map (VMap) Level 2 (NIMA 1993).

Both the CORINE Land Cover and VMap2 data have a horizontal accuracy of 50–100 m.

Data characterising relief were computed on the basis of the NASA Shuttle Radar Topographic Mission (SRTM). This data is currently distributed free of charge by USGS and is available for download from the National Map Seamless Data Distribution System. The SRTM data is available as 90 m resolution, the vertical error of the DEM's is reported to be less than 16 m (CGIAR-CSI 2017).

Results and discussion

General characteristics of horizontal geodetic controls in the Opoczno district

The density of horizontal geodetic controls in the Opoczno district yields 1 GCP in 5 sq.km, which is 10 times more then said the pertinent regulation, and 1 control point covers approximately 20.1 hectares. Built-up areas are those where densification of geodetic controls is the highest, with more than 21 point per square kilometres, the d_{GCP} takes the lowest value (3.24) for forests (see Table 1). About 40% (2063) of geodetic controls are located in the 50 m buffer around the paved roads, and 24 GCPs are situated in the close vicinity of water bodies and watercourses.

Table 1. Geodetic control points density according to land cover class (Source: own elaboration)

Land cover type	3rd order GCPsr	% of GPS	c_{GCP}	d_{GCP}
Forest	1184	23	30.8	3,24
Agriculture	2830	55	21.7	4,62
Built-up	1124	22	4.7	21,10

The research indicates unequivocally that in the Opoczno district the requirements of the Ministry Regulation are met (Table 1). In the built-up areas there are 1124 points, while in the arable and forest areas there are in total 4,134 points, i.e. 78% of all the points. It is worth to note that these numbers exceed about four times the numbers of points in the specific terrain types, required by the Regulation. The number of geodetic control points in a surveying district differs meaningfully and equals from 0 (for 1 typically arable SD) up to 124 in Opoczno, a small town of 21.8 thousand inhabitants. The average number of GCPs in the surveying districts is 22 (Table 2). The density of the GCPs also diversifies. It takes the highest values (66 GCP/sq.km) for Opoczno and the lowest for the forested districts (less than 6 GCP/ sq.km). The choropleth map shows differentiation of GCPs density (see Fig. 2), using natural break method for classifying the range of data. The global Moran I index takes value 1.25, with the z-score equals 40.94. This means that there is less than 1% likelihood that the cluster pattern forms by SDs with similar d_{GCP} are the results of random chance.

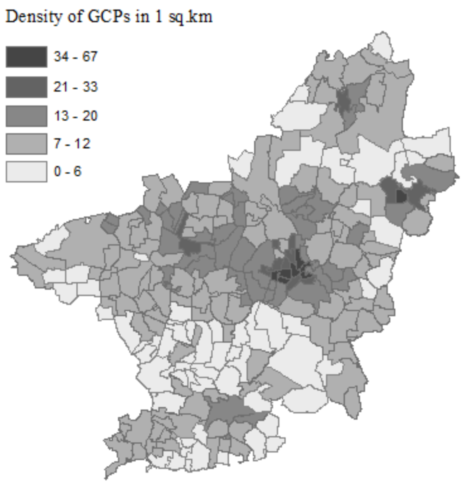

Fig. 2. Density of geodetic control points (GCPs) in the Opoczno study area (Source: own elaboration)

Table 2. Descriptive statistics of the analysed set of the detailed geodetic control points (Source: own elaboration)

Number of surveying districts	240
Minimum number of GCPs	0
Maximum number of GCPs	124
Average number of GCPs in a surveying districts	22
Median	18
Standard deviation (σ)	17
Total number of GCPs	5361
Average GCPs density d_{GCP}	5.0
Average GCP concentrations c_{GCP}	20.1

Relation between geodetic points' density, land cover and relief

Relationship between land cover (expressed by % covered by particular land cover class in a surveying district), average slope and standard deviation of elevation – the explanatory variable and geodetic control points density – the explain variable was computed using Pearson correlation coefficient (PCC). The PCC takes the highest positive values for area occupied by paved roads (with 50 m buffer zone) (0.78) and built-up areas (0.80). For elevation diversity and forest PCCs equal consequtively-0.16 and -0.32 (see Table 3), what means that the more forested and hilly area, the less geodetic control points. The correlations between slope, agriculture, water and the GCPs density are statistically insignificant. The coefficient of determination R^2, computed by Pawlowski method for the variables significantly correlated with GCPs density, equals 0.652. This means that GCPs density in 65.2% explains by the percentage of built-up areas, forests and the standard deviation of elevation.

Table 3. Pearson correlation coefficient matrix between land cover classes, relief and GCPs density (Source: own elaboration)

	Elevation σ[1]	Slope	Roads	Forest	Agriculture	Water	Built-up	GCPs density
Elevation SD[1]	1.00	0.42	–0.02	0.26	0.14	–0.18	–0.12	**–0.16**
Slope		1.00	0.02	0.15	–0.13	–0.04	–0.01	0.06
Roads			1.00	–0.31	–0.19	–0.03	**0.87**	**0.78**
Forest				1.00	–0.82	0.10	–0.31	**-0.32**
Agriculture					1.00	–0.21	–0.28	–0.15
Water						1.00	–0.04	–0.05
Built-up							1.00	**0.80**
GCPs density								1.00

[1]σ – standard deviation

Surveying districts clustering

Finally, considering the high correlation between roads and built-up areas (PCC=0.87 see Table 3) only 3 independent variables were adopted for districts clustering, namely: percentage of surveying district occupied by forest, percentage of surveying district occupied by built-up areas and standard deviation of elevation in the surveying district. The number of 4 clusters was estimated by the V-fold cross-validation test. The k-means, the hierarchical tree clustering, and the Kohonen network, distinguished the clusters of SD. For k-means 50 iteration were computed using Euclidean distance as a measure of a distance between variable values. Analysis using neural networks self-organizing map was performed using 2 by 2 grid neurons. Learning involved 1000 learning iterations, assuming that the learning coefficient is 0.1 at the beginning of the process and decreases to 0.02. The set of training data has been split into three sub-groups: a learning sample (70% of the samples) for receiving network learning, a test (15%), whereby the learning process will be controlled and validation (15%) used to verify and final selection of the best network. The samples for each set of were chosen randomly. The results show Figure 3 and Table 4.

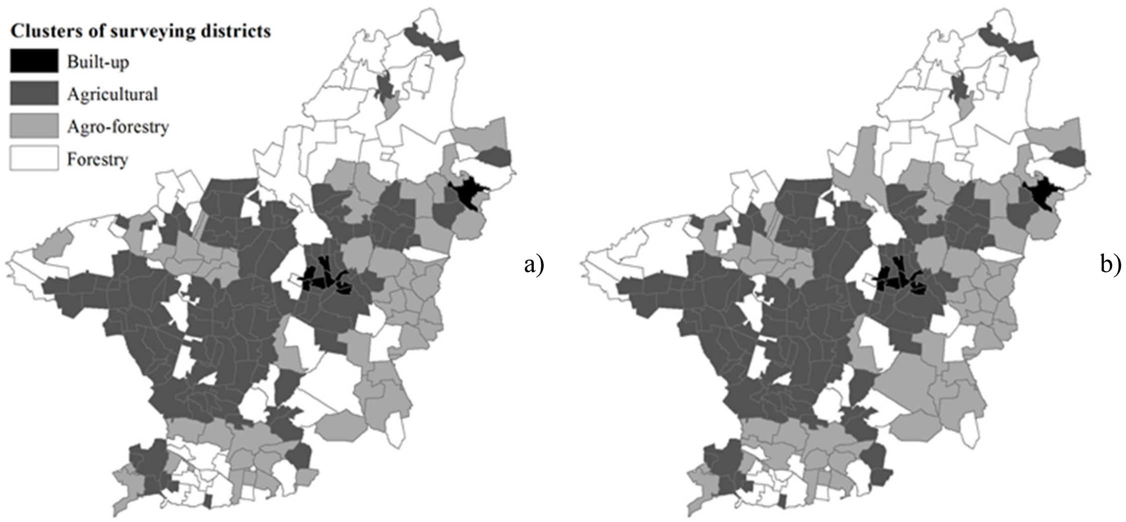

Fig. 3. Clusters of surveying districts according to land cover and relief diversity,
a) k-means algorithm, b) Kononen neural network (Source: own elaboration)

Table 4. Surveying district clusters characteristics (B-built-up, A- agriculture, A-F – agro-forestry, F – forest, SD – surveying districts; σ standard deviation, Source: own elaboration))

clus-ter	Area in km^2	SD number	Number of 3 order GCPs	3order d_{GCPs}	d_{GCPs}	Forest in km^2	Agriculture in km^2	Built-up in km^2	Paved roads in km^2	σ of elev.
k-means method										
B	12.67	9	312	24.62	25.25	0.03	0.32	0.61	6.03	5.52
A	375.38	120	2025	5.39	5.61	0.13	0.80	0.06	1.40	5.01
A-F	254.54	49	1271	4.99	5.19	0.28	0.67	0.05	1.37	11.68
F	397.36	62	1554	3.91	4.06	0.62	0.34	0.02	1.10	8.84
Kohonen neural network										
B	12.67	9	312	24.62	25.25	0.03	0.32	0.61	6.03	5.52
A	378.11	121	2036	5.38	5.60	0.13	0.80	0.06	1.40	5.02
A-F	296.49	51	1428	4.82	5.02	0.32	0.62	0.05	1.36	11.98
F	352.67	59	1386	3.93	4.07	0.62	0.34	0.02	1.07	8.25

It is clearly visible that both the k-means and Kohonen network clustering gives very similar results. The surveying districts clusters are well distinguishable. The built-up cluster comprises only 9 surveying districts, mainly occupied by urban fabric areas with the dense paved road network. The GCPs density takes here the highest value 25.25. The agriculture cluster is the biggest, 120 (or 121) districts are classified there. Both clusters are located on relatively flat areas. The agro-forestry cluster occupies hilly areas, mainly agricultural lands (62–67%) with the substantial part of forest (28–32%). The GCPs density is slightly lower than in agriculture group. Forest, shrubs and groves cover the fourth cluster – the forest – in 62%. The GCPs density takes the lowest value 3.91 points in 1 sq.km. The forest cluster contains about 25% of surveying districts.

Both methods form statistically significant spatial clusters of surveying districts characterised by similar control points density, land cover and relief. However, the global Moran I index takes higher value for k-means method (I = 0.42, and z-score = 13.48) than for Kohonen (I = 0.10 and z-score = 3.42).

Conclusions

Geodetic control provides a common reference system for establishing the coordinate positions of all geographic data; hence, its distribution should be in correspondence of land use and land development. In the study region both coefficients: density of GCPs as well as concentration of geodetic controls take the higher values then national average, theirs value are also greater then requirements of the Regulation of the Ministry. This proofs that horizontal geodetic control network in the Opoczno fits for all kinds of plan surveys and provides the spatial reference source to register all other spatial data in the district.

The geodetic control location and density mainly depends on land cover, especially built-up areas and paved road network. This dependence has positive value and fluctuates from 35 to 65% depending on land cover (percentage of built-up areas) structure and land development (density of roads). The diversification of elevation, measured by standard deviation of elevation, has slightly dissimulating impact on geodetic controls (PCC = –0.16).

The density of control points maps as well as cartographic visualisation of geodetic control concentration coefficient should be published in the form of WMS service via thematic geoportal, maintained by the Head Office of Geodesy and Cartography or local surveying authorities.

Acknowledgements

The geodetic control points' dataset used in the research was obtained from the District Geodetic and Cartographic Documentation Center (PODGiK) in Opoczno.

Funding

This work was supported by the Faculty of Civil Engineering and Geodesy, Institute of Geodesy of the Military University of Technology with the frame of statutory research [grant number PBS 933/2017].

Contribution

Krzysztof Pokonieczny: conception and design of the work, acquisition of data, analysis and interpretation of spatial data, revising critically the article.

Elzbieta Bielecka: conception and design of the work, interpretation of data, writing the article.
Paweł Kamiński: analysis and interpretation of statistical data, revising the article.

Disclosure statement

We declare that we do not have any competing financial, professional, or personal interests from other parties.

References

Baarda, W. 1968. *A testing procedure for use in geodetic networks*. Netherland, Delft. Netherlands Geodetic Commission.

Beesley, B. J. 2003. Sky viewshed modeling for GPS use in the urban environment, in *Twenty-third annual ESRI International User Conference: Proceedings: GIS serving our World*, 7–11 July 2003, San Diego, California.

Bielecka, E.; Pokonieczny, K.; Kamiński, P. 2014. Study on spatial distribution of horizontal geodetic control points in rural areas, *Acta Geod Geophys* 49: 357. https://doi.org/10.1007/s40328-014-0056-6

Bielecka, E.; Pokonieczny, K.; Kamiński, P. 2015. Description of spatial distribution of detailed horizontal geodetic control points [Charakterystyka rozmieszczenia przestrzennego punktów poziomej osnowy szczegółowej], *Annals of Geomatics* 13: 3(69): 201–208 (in Polish).

Canada Geomatics. 1996. *Accuracy Standards for Positioning Version 1.0.* September, 1996. Geodetic Survey Division, Ottawa, Ontario.

CGIAR-CSI. 2017. *SRTM 90m Digital Elevation Database v4.1* [online], [cited 08 January 2017]. Available from Internet: http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1

Committee on Geodesy. 1984. Geodesy. *A look to the future*. National Academy Press, Washington, D.C.

EC. 1994. *CORINE Land Cover Technical Guide*. Office for Official Publications of the European Commission.

GUS. 2014. *Statystyczne Vademecum Samorządowca 2016*. Statistical Office in Lodz [online], [cited 06 January 2017]. Available from Internet: http://lodz.stat.gov.pl/vademecum/vademecum_lodzkie/portrety_powiatow/powiat_OPOCZYNSKI.pdf

Han, J. Y.; Wu, Y.; Liu, R. Y. 2012. Determining the optimal site location of GNSS base stations, *Bol Ciênc Geod* 18(1): 154–169. https://doi.org/10.1590/S1982-21702012000100009

Han, J. Y.; Li, P. H. 2010. Utilizing 3-D topographical information for the quality assessment of a satellite surveying, *Appl Geomat* 2(1): 21–32. https://doi.org/10.1007/s12518-010-0016-y

ICSM. 2007. *Standards and practices for control surveys (SP1) Version 1.7.* Available on-line: http://www.icsm.gov.au/publications/sp1/sp1v1-7.pdf

Kadaj, R. 2016. The combined geodetic network adjusted on the reference ellipsoid – a comparison of three functional models for GNSS observations, *Geodesy and Cartography* 65(2): 229–257. https://doi.org/10.1515/geocart-2016-0013

Kowalski, P. J.; Olszewski, R.; Bac-Bronowicz, J. 2009. A multiresolution, reference and thematic database as the NSDI component in Poland –the concept and management systems, in Lecture *Notes in Geoinformation and Cartography*. G. Garthner, F. Ortag (Eds.). *Cartography in Central and Eastern Europe*, 443–456, 15 October 2009.

LARR. 2014. *Strategia Rozwoju Powiatu Opoczyńskiego na lata 2014–*2020 [online]. Lodz Agency of Regional Development [cited 05 January 2017]. Available from Internet: http://bip.opocznopowiat.pl/strona-734-strategia_rozwoju_powiatu_opoczyn-skiego_c.html

Lu, Z.; Qu, Y.; Qiao, S. 2014. *Geodesy. Introduction to geodetic datum and geodetic systems*. Springer.

Luc, M.; Bielecka, E. 2015. Ontology for national land use/land cover map: Poland case study, in O. Ahlgvist, D. Varanka, S. Fritz, K. Janowicz (Eds.). *Land Use and Land Cover Semantics Principles, Best Practices, and Prospects,* CRC Press, 21–40.

MAiC. 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 No. 0, entry. 352 (in Polish).

Medynska-Gulij, B. 2014. Cartographic sign as a core of multimedia map prepared by non-cartographers in free map services, *Geodesy and Cartography* 63(1): 55–64. https://doi.org/10.2478/geocart-2014-0004

NIMA. 1993. Military Specification MIL-V-89032 Vector Smart Map (VMap) Level 2. National Geospatial-Intelligence Agency (NGA).

Pawlowski, Z. 1977. Contribution to the theory of alternative predictions, *Oeconomica Polona* 3–4: 381–400.

Pokonieczny, K.; Bielecka E.; Kaminski, P. 2014. Analysis of spatial distribution of geodetic control points and land cover, in *14th SGEM GeoConference on Informatics, Geoinformatics and Remote Sensing*, 19–25 June 2014, Albena, Bulgaria, 49–56.

Pokonieczny, K.; Calka, B.; Bielecka, E.; Kaminski, P. 2016. Modeling spatial relationships between geodetic control points and land use with regards to Polish Regulation, in *2016 Baltic Geodetic Congress (Geomatics) Proceedings*, June 2–4 2016, Gdansk, Poland, 176–180. https://doi.org/10.1109/BGC.Geomatics.2016.45

Tadeusiewicz, R. 1993. *Neural networks* [Sieci neuronowe]. Akademicka Oficyna Wydawnicza RM (in Polish).

Xavier, P.; Costa, E. 2007. Simulation of the effects of different urban environments on land mobile satellite systems using digital elevation models and building databases, *IEEE Trans Vehicular Technol* 56(5–2): 2850–2858.

Zhang, K.; Liu, G. J.; Wu, F.; Densley, L.; Retscher. G. 2008. An investigation of the signal performance of the current and future GNSS in typical urban canyons in Australia using a high fidelity 3D urban model, in *Location based services and telecartography II: from sensor fusion to ubiquitous LBS*, Springer, Heidelberg, 407–420.