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Research Article

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Spatial pattern of ASG-EUPOS sites

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Abstract: The article presents the spatial pattern analysis of the ASG-EUPOS permanent GNSS stations in Poland. Using different methods and tools (nearest neighbour, Riplay's K-function, morphology of Thiessen polygons) we proved that the station distribution model changes within scales. At short distances up to 65 km, which are typical lengths in the network, stations are irregularly dispersed. Increasing this distance to 130 km and over could result in a clustered pattern.

The Thiessen polygon area in 72% depends on the level of urbanization, especially coverage of forested and built-up areas as well as the density of the transportation network. The smallest density of the ASG-EUPOS sites is one station over 10,000 sq. km, which is two times more than is stated in the national regulations. The mean distance from ASG-EUPOS location to the nearest station is about 41.5 km.

Keywords: ASG-EUPOS, GNSS, RTK positioning, point pattern analysis, complete spatial randomness, Thiessen polygons, Riplay's K-function, nearest neighbour analysis

1 Introduction

Spatial pattern analysis is a fundamental part of scientific research in the Earth sciences disciplines, especially in geography, geology, ecology, agriculture, urban planning, public heath, transportation, and many others. It lies in the development of quantitative geography and regional science and dates back to the early 1960s [1].

There are generally two different approaches to spatial pattern analysis. The first relies only on geometry, and strongly emphasises the point pattern analysis, quadrat analysis, and nearest neighbour methods [2–4]. This attempt describes the spatial pattern of objects by comparing observed and theoretical distribution. The theoretical pattern assumes the complete spatial randomness (CSR). The second approach is based upon second-order methods which describe the relative positioning of pairs of points [5, 6]. The multivariate K-function, formulated by Ripley [7], is mostly used for estimating relative, regardless of the scale, points' spatial distribution.

In geodesy, especially in analyzing the geographical location of geodetic control points, spatial pattern analysis is of utmost importance [8–10]. This is because the main goal of establishing a geodetic network is to determine the position of net points for positioning or monitoring the deformation of the Earth's crust [11]. Geodetic control points should cover an area relatively evenly, to enable accurate and cost-effective measurements of engineering, cadastral mapping and other purposes [8, 12]. Moreover, the geographical extent of reference stations significantly influences the number of fiducial stations and reliability of the densification results [13].

There are relatively few studies on spatial distribution of GNSS (Global Navigation Satellite System) stations as well as on the impact of certain position on determination of accuracy of station coordinates. The existing studies mainly focus on addressing the practicality of using network real-time kinematic (NRTK) especially in National continuously operated reference stations (CORS) or similar networks of permanent GPS/GNSS stations, for providing accurate positioning control. CORS stations can significantly diminish distance dependent errors (i.e. ionospheric and tropospheric refraction, broadcast orbit errors) at the user station. However, as it was noticed by Wanninger [14] the inter-station distance should range from 30 up to 100 km and any obstructions existing around user stations. Similar conclusions were drawn by Petovello et al. [15]. They found that effective distance between reference stations that enables the required precision for multi-frequency and multi-constellation receivers should not exceed 100 km. In such a network VRS and MAC corrections transmitted by networks make it possible to achieve horizontal accuracies 2 - 8 cm and 5 - 12 cm in height. Moreover, they observed that for large networks, with a distance between stations of more than 100 km, NRTK positioning is generally unreliable and inadmissible, which could be ex-

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plained by the influence of mainly ionospheric and tropospheric refraction.

The inter-station distance also plays an important role in point position determination using a post-processing technique. Eckl et al. [16] analysed the dependence between chord distance and duration of the observation session on accuracy of a 3-D relative point position determination. They focus on networks with 26 - 300 km interstation distance, as lengths typically encountered by GPS users who rely on the National CORS system for control. This research has shown that the dependence of accuracy on the chord distance between 26 and 300 km is negligibly small, but only if the following conditions are fulfilled. Firstly, the final, GPS satellite orbits and clocks delivered by IGS have to be used; secondly, the integer ambiguities have to be fixed; thirdly, the neutral-atmosphere-delay (troposphere) parameters need to be estimated appropriately, and, finally, the observing session has to last between 4 and 24 hours [16].

However, in practice, during measurement sessions the visibility of satellites could be limited by some terrestrial obstacles meaningfully decreasing the determination of coordinates [17–21]. That is why more and more researchers have analysed and studied environmental context, inter-station distances and geographical distribution of all types of stations, i.e. fiducial, permanent, and rover [16, 17, 21–25].

Many scientists draw attention to the topography and high buildings that hamper the visibility of the horizon, destroy the signal from satellites, and finally, affect the quality of rover station positioning [26–28]. The horizontal displacement of geodetic GNSS permanent stations could also be disturbed by the vicinity of water reservoirs [29] or forest canopy [17, 18, 20]. Although the homogeneous distribution of stations is highly recommended [30] some researchers noticed that it could be due to horizontal displacement [31, 32]. Firuzabardi and King, [33] said that errors in GPS measurements are the function of the full environment in which the measurements are acquired.

Following Johnson's and Wyatt's opinion [34] that the most difficult question is 'where best to locate GNSS observing sites', the EUPOS (European Position Determination System) has prepared the Guidelines for single site design [35]. The Guidelines evidently state that the quality of EUPOS service depends on the appropriate GNSS reference station site location and gives some recommendations concerning sky visibility and site stability as well as multipath and interference.

A continuously increasing role of real time kinematics (RTK) in Global Navigation Satellite System (GNSS) has substantially changed the way that surveyors, engineers, GIS/LIS professionals, and other practitioners measure points position. Networks of continuous operating reference stations even more facilitate the provision of providing centimeter-level accuracy, but only when inter-station distances are no longer those that recommended [14, 15, 36] and no environmental obstruction exists [17]. The main motivation of the presented study was testing by the means of advanced spatial pattern methods the configuration of Polish permanently operated reference stations, in term of CORS baseline lengths and geometrical distribution, as well as examining some environmental conditions in the vicinity of stations.

The aim of this study is a holistic, *ex post* analysis of the geographical distribution of the ASG-EUPOS stations. By considering varied spatial pattern analysis this approach can be used to give some advice concerning the ASG-EUPOS stations densification. Spatial analysis methods include: point pattern analysis, Thiessen polygons, proximity analysis as well as regression and descriptive statistics. The analysis provides evidence of the strengths and weaknesses of spatial distribution and the site influence on permanent GNSS stations. The locations of all ASG-EUPOS stations are publicly available from EPN (European Permanent Network) and national web pages. The remainder of the article is structured as follows. The next section describes the ASG-EUPOS system in Poland, then the methods and data used are outlined; it is followed by the results and general discussion. Finally closing remarks and conclusions are presented.

2 ASG-EUPOS

The ASG-EUPOS (Active Geodetic Network – European Position Determination System) constitutes the EPN (EUREF Permanent GNSS Network) in Poland and provides a consistent reference frame for GNSS users [30]. It was established by the Head Office of Geodesy and Cartography in 2008 according to the recommendations of the IAG subcommission for the European Reference Frame concerning densification of EUREF. In 2012 the ASG-EUPOS system became a basic control network for Poland [37]. The network consists of 103 stations located in Polish territory (February 2017) and 24 stations situated in neighbouring countries (7 stations in the Czech Republic, 7 in Germany, 4 in Lithuania, and 6 in Slovakia) [48] (www.asgeupos.pl).

The network covers the whole country so the GNSS technology theoretically has no limitations on the range of satellite measurements, which allows its broad utilization as a multifunction network, suitable for performing

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local measurements. The system provides users with both real-time positioning and post-processing services.

ASG-EUPOS stations are rather evenly distributed, the inter-stations distance does not exceed 70 km [38, 39]. Station site locations are secured over the long term so that changes of antenna location at the site are highly unlikely in the foreseeable future (no planned construction, demolition, etc. in the site vicinity). They are situated far from sources of electromagnetic interference, objects that cause reflection of satellite signals and terrain barriers above 10 degrees over the horizon. The coordinates of the ASG-EUPOS stations are determined with the highest accuracy, not worse than 0.01 m for horizontal position and 0.02 m for geodesitic height [40]. The ASG-EUPOS stations realise the ETRS89 in Poland and their coordinates are available in the Polish reference frame PL-ETRF2000 [41]. Moreover, the average density of fundamental geodetic points should be 1 point per 20,000 sq. km at most.

3 METHODS

Based on the ASG-EUPOS technical specification [40] we hypothesize that the spatial distribution of GNSS station sites is dispersed and basically regular. To prove the hypothesis the study aims to answer the following research questions:

1 Is the spatial point pattern of the ASG-EUPOS site locations really dispersed? Is this pattern scale dependent or not?
   The answer is based on testing complete spatial randomness using nearest-neighbour analysis and Ripley's K-function as well as on the morphological analysis of Thiessen polygons created from the ASG-EUPOS stations. The ASG-EUPOS smooth density surface was generated using kernel density.
2 What are land use structure and diversity of elevation in the proximity to the station site locations measured by the Thiessen polygons? Are they similar?
   The diversity of land use structure was evaluated by the statistical measures of central tendency, position and dispersion, like: mean, median and the coefficient of variation (disparity). An answer to this question allows the discovery of places where environmental obstacles are rather small or where they are relatively high and some advanced measurement and computational techniques could be recommended.
3 What is a typical distance between the nearest station site as well as the distance to water bodies, paved roads, railways and electricity lines and other geographical features that can disturb the electromagnetic signal. In other words, are the number and arrangement of the ASG-EUPOS stations suitable to minimise distance decorrelation related? And are there any stations that are exposed to environmental obstacles?

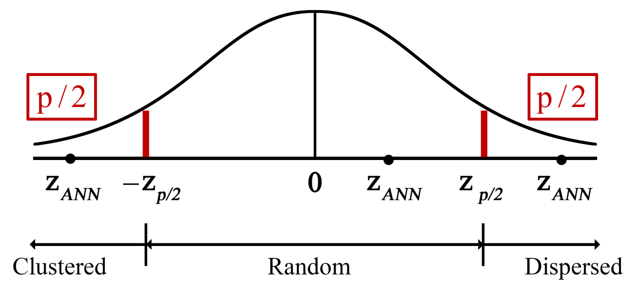

Figure 1: Two-tailed test for complete spatial randomness

Typical GIS analyses, like buffering and distance computation, were used to determine these measures.

The spatial point pattern was defined by Diggle [5] as a set of locations, irregularly distributed within a region of interest, which have been generated by random mechanisms. The analysis is generally used to measure how points are located with respect to each other over a horizontal space in a region of interest [42]. The point pattern is considered against the hypothesis of complete spatial randomness (CSR), under which the patterns are realisations of a Poisson point process.

The hypothesis of a dispersed pattern of the ASG-EUPOS sites was tested through summary characteristics of the observed pattern, such as average nearest-neighbour (ANN) and inter-point distances K-function [5, 7]. Both methods are *second-order* methods because they refer to sub-regional patterns or neighbourhood patterns within the overall distribution.

The Nearest Neighbour method aims at computing average nearest neighbour (ANN) index which compares the distances between nearest points and distances that would be expected on the basis of chance. It is one of the oldest distance statistics, developed in 1950. The null hypothesis is tested by the two-tails test of CRS. It is rejected *if and only if where:*

$$\lfloor z_{ANN} \rfloor > z_{p/2} \tag{1}$$

where: z_{ANN}–observed distribution of analysed sample of points, z_p – standard normal distribution, and p – the significance level.

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The z_{ANN} value lower than $z_{p/2}$ shows that the analysed point pattern is more clustered, while larger than $z_{p/2}$ indicates a pattern more dispersed than random.

The K-function, known as the Ripley's K-function, examines all inter-point distances instead of computing separating nearest neighbours. It illustrates how the spatial clustering or dispersion of points change when the neighbourhood size changes. For data analysis, the variance stabilized Ripley K-function called the L function is generally used (equation 2).

$$L(d) = \sqrt{\frac{A \sum_{i=1}^{n} \sum_{j=1,\, j=i}^{n} k_{i,j}}{\pi n(n-1)}} \tag{2}$$

where:
d – the distance, n – total number of points (features), A – the total area, and $k_{i,j}$ – a weight connected with edge correction function.

A comparison of the observed K-Ripley function $L(d)$ or nearest-neighbour probability $p(d)$ with functions derived from possible explanatory models, based upon the Poisson model of spatial randomness over the study area gives a statement of whether the observed occurrences are likely to have arisen from the processes underlying such models [43].

Analysis of the regularity of the ASG-EUPOS spatial pattern is based on the morphological analysis (an area and a shape of a polygon) of Thiessen polygons created from the station sites. Thiessen (called also Voronoi) polygons define individual areas of influence around each of a set of points, so any location within a Thiessen polygon is closer to its associated point than to any other point input feature [44]. This property means that Thiessen polygons are perceived as a proper construct to test the CSR hypothesis as well as the regularity of spatial distribution [45].

The diversities of the shape and area of Thiessen polygons, land use structure and elevation above sea level, were measured by the coefficient of variation v (coefficient of disparity), a dimensionless number that quantifies the degree of variability relative to the mean (equation 3).

$$v = \frac{\sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n}}}{\bar{x}} \tag{3}$$

where: n – number of categories, $\bar{x}$ – the mean value.

4 Area and data applied

The study covers the territory of Poland, a central European country, which is extended between latitudes 49° and 55° North, and longitudes 14° and 25° East. The country is situated between the Baltic Sea in the north and the Sudeten and Carpathian Mountains in the south, and lies within the European Plain. The total area of the country is 312,679 sq. km making it the 9th largest in Europe. Nearly 60% of the territory is occupied by agricultural land, forests cover approximately 30%, built-up and urbanized areas – 5%, water – about 2% [46]. More than 76% of Poland's area is situated below 200 metres above mean sea level (AMSL), 21.8% between 300-500 metres AMSL and only 3% more than 500 metres AMSL.

Figure 2: Distribution of the ASG-EUPOS system stations in Poland (www.asgeupos.pl, state on the 21 February 2017)

Coordinates of the ASG-EUPOS stations were delivered by the Central Geodetic and Cartographic Documentation Centre, in Warsaw. The geographic locations of ASG-EUPOS stations are shown in Figure 2.

Information on built-up areas, forests, water bodies, transportation networks and electricity lines is derived from the General Geographic Database (GGD). It is a national database, created by automatic generalisation 1:10,000 scale topographic data, and maintained by the Head Office of Geodesy and Cartography. Data was collected in 2013 and updated in February 2016. The GGD data is available in GML format, in 1992 National projected Coordinate Reference System (EPSG code 2180).

Data about elevation derives from the DTED2 (Digital Terrain Elevation Data) digital terrain model which has been developed according to the NATO-STANAG 3809 standard [47]. The horizontal datum of the DTED2 is WGS84 while the elevations are referred to mean sea level (MSL). The DTED2 is available in two spatial resolutions: 1" × 1" (49º – 50ºN) and 1" × 2" (50º – 55ºN). The elevation data was derived from digitization 1:50,000 military topo-

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graphic maps in '1942' geodetic datum. Relative vertical accuracy between points is about 12 m, while vertical absolute accuracy is estimated at 18 m, the horizontal accuracy is about 23 m [48]. However, in Poland the accuracy of the DTED2 is much better. Krynski et al. [49] estimate that vertical accuracy varies from 2 m in lowlands to 7 m in mountains, while its horizontal accuracy equals to 15 m.

A brief summary of the data used in this study is shown in Table 1. At the preliminary stage of the analysis all data sets were integrated in a GIS system, according to the rules given by [50, 51]. Data was transformed to WGS84 datum, stored in shp (vector data) and GRID (raster) files.

Two packages were used for data analysis: ArcGIS 10.4 for the spatial analysis and Statstica 13 - for statistical analysis.

5 Results and discussion

The null hypothesis assuming Complete Spatial Randomness (CSR) for ASG-EUPOS site locations pattern analysis was rejected, using Average Nearest Neighbour tools. The z_{ANN} score takes the value 8.63 with the level of confidence of 99 %. This means that there is less than 1% likelihood that the dispersed pattern of the ASG-EUPOS sites could be the result of random chance and that the stations are dispersed over the territory of Poland.

The Ripley's K-function confirms a statistically significant (with the level of confidence of 99%) dispersed pattern of the ASG-EUPOS sites at distances from 10 to 65 km, which are typical lengths in the network. Increasing this distance to 130 km and over could result in a clustered pattern (Fig. 3).

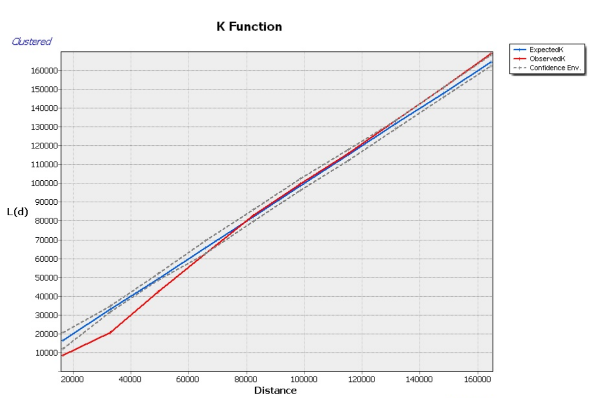
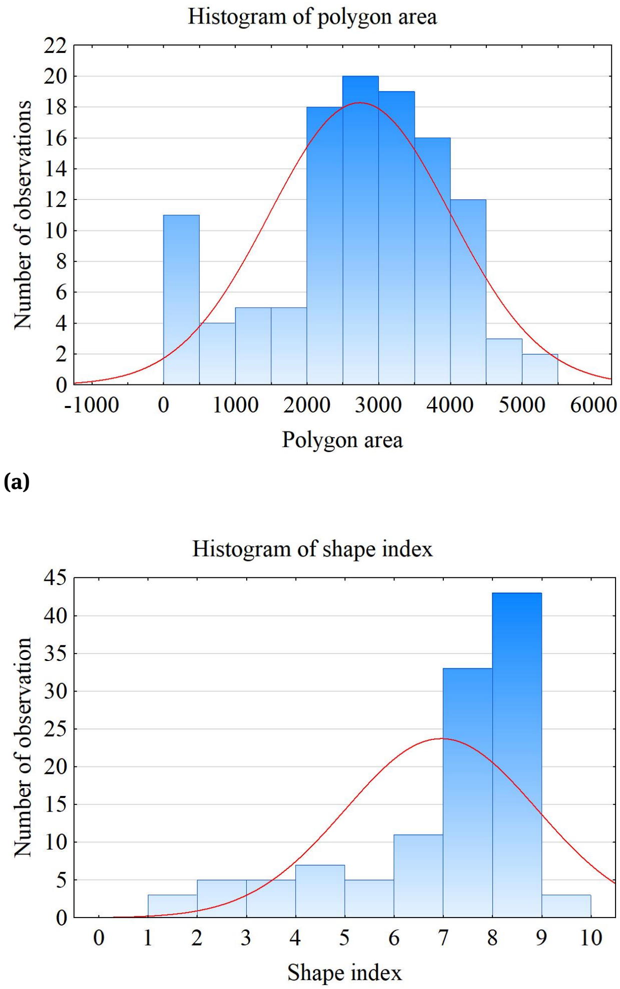


Figure 3: Measure of spatial clustering and dispersion of ASG-EUPOS stations over a range of distances (in metres)



(a)

(b)

Figure 4: Thiessen polygons histogram; (a) area of polygons; (b) shape coefficient

The analysis of morphology of the Thiessen polygons, created from ASG-EUPOS point sites, also emphasizes that the spatial pattern of the stations is dispersed. The area of 50% of the Thiessen polygons oscillates from 2,100 to 3,650 sq. km (Table 2, Fig. 4a). The shape of the polygons is rather similar (Figure 4b). The *cs* shape coefficient (calculated according to the formula $cs = 40 * \pi * \frac{A}{P^2}$, where A denotes the area and P – the perimeter) for 75% of the polygons takes a value from 6.16 to 8.21. For 50% of polygons, it equals 7.73 (median), which is very close to the value of this coefficient for a square (cv=7.85).

The coefficient of disparity (v)of the area and the shape of the Thiessen polygons takes values of 0.462 and of 0.280, respectively (Table 2). It highlights medium differentiation of the area of the Thiessen polygons and low disparity of the shapes of those polygons, and is a starting point for further analysis of the ASG-EUPOS distribution

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Table 1: General information about data used

Data set	ASG-EUPOS	General Geographic Database (GGD)	DTED2
CRS	WGS84	1992	WGS84, vertical - MLE
Location accuracy in [m]	0.01	10 – 50	15
Format	txt	GML	DTED
Updateness	2016	2016	2001
Data custodian	Head Office of Geodesy and Cartography	Head Office of Geodesy and Cartography	Polish Military Geography Directorate

Table 2: Descriptive statistics of land use structure in Thiessen polygons

	Area of Thiessen polygons [sq km]	Shape coefficient (cv) of Thiessen polygons	Forest (%)	Built-up area (%)	Transport network density [km/sq. km]	Sdt. dev of Δh [m]
Mean	2717.2	6.919	33.548	4.229	0.049	51.13
Standard deviation	1249.3	1.934	15.091	4.720	0.035	60.19
Variance	1574553.0	3.740	227.735	22.280	0.001	3622.75
Minimum	0.2	1.204	11.636	0.000	0.000	4.61
The first quartile (Q_1)	2103.7	6.160	23.196	1.772	0.032	18.78
The second quartile (Q_2) Median	2811.0	7.731	29.709	3.283	0.045	29.04
The third quartile (Q3)	3650.5	8.209	42.900	4.952	0.064	47.45
Maximum	5122.7	9. 071	91.870	35.000	0.281	282.27
Level of confidence (%)	95	95	95	95	95	95
Coefficient of disparity (v)	0.462 (medium)	0.280 (low)	0.450 (medium)	1.116 (very high)	0.714 (high)	1.177 (very high)

by the means of a smooth surface (Fig. 5). The smallest polygons (the area less than 2,000 sq. km) and the highest density of permanent GNSS stations (9 stations over 10,000 sq. km) are observed in the Warsaw metropolitan area. This is justified by the presence of high buildings that could significantly destroy satellite signals. Small polygons are also in the southern, mountainous part of Poland, near the border with the Czech Republic and Slovakia. It is due to the highly diversified elevation. The largest polygons (generated from 12 ASG-EUPOS point sites) with an area bigger than 4,500 sq. km are situated in the central part of the country, near the Baltic coast and in Masuria and Western Pomerania, where forest dominates in the land use structure. The baseline lengths there are longer than 58.5 km.

Density of the ASG-EUPOS stations does not exceed 2 stations over 10,000 sq. km. Obtained results confirm the findings of Specht and Skóra [52] concerning the dependence of the number of active GNSS stations on the level of urbanisation and further on population density.

Relative differences in elevation within the Thiessen polygons were measured by standard deviation of elevation. For the majority (75%) of the Thiessen it takes a value lower than 47 m. Only in the Sudeten and Tatra mountains this value is greater than 250 m.

The inter-station distances vary between 20-80 km, while the mean distance from the ASG-EUPOS site to the nearest station is about 41.5 km. Half of the total number of

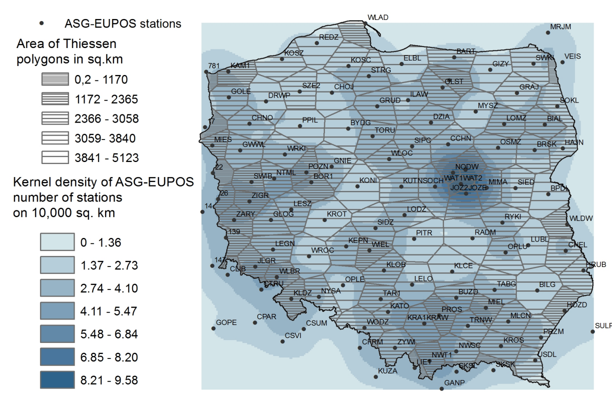

Figure 5: The density of the ASG-EUPOS stations

the ASG-EUPOS sites are located closer than 43.3 km to the nearest stations, for 92 stations (75%) the distance to the nearest station does not exceed 49.2 km. The ASG-EUPOS, Polish continuous operating reference stations, is considered to be a medium network, based on inter-station criteria given by Petovello et al. [15].

About 50% of the Thiessen polygons are 30% forested, while built-up areas cover less than 3.2 % of the polygon. The average road density is 0.05 km of each sq. km. The transportation network (including paved roads and railways) density in polygons is correlated with the built-up area; the Pearson coefficient of correlation equals 0.69. The

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diversity of land cover structure, as well as the level of urbanisation within the Thiessen polygons is very high. The polygons with the highest road density and highest percentage of built-up areas are located in the southern part of Poland because of the historical growth of the settlement network in the country [53].

As shown by the regression analysis (Table 3), the density of the ASG-EUPOS stations, measured by the Thiessen polygon area (dependent variable), is a function of urbanisation expressed by the area of the built-up land, forest and the length of the paved roads. The adjusted R square coefficient takes the value of 0.72, which means that the area of Thiessen polygons created from the ASG-EUPOS sites in 72% depends on the level of urbanisation.

All ASG-EUPOS stations are located far from paved roads and electricity power lines; the distance is generally bigger than 500 m. The GOLE station is located in the vicinity of a railway, the distance to the network is smaller than 100 m. The CHNO site is located in the vicinity of a big lake, the distance is about 50 m, while the WLAD – near the Baltic coast. Four stations (NODW, OPLU, TORU, WLOC) are situated along the Vistula river, but farther than 300 m. According to Szafranek [54] the coordinates and velocities of these stations are constantly monitored due to the possibility of signal disturbance by topographic features.

6 Summary and conclusions

Although the latest studies focus their scientific research on the impact of topography on GNSS stations positioning, they mainly handle the impact of terrain barriers on a single point. More complex research concerning the analysis of the relation between land cover and the number of geodetic points has been carried out, but only detailed horizontal geodetic networks for relatively small areas (one county, the second level of administrative division in Poland) were concerned. The impact of environmental conditions, mainly topography, urban areas and forest, is quite well recognised, explored and described in the literature. Current studies, however, relate to rather small areas and focus on applying appropriate measurements and computational techniques to obtain centimetre accuracy in positioning. This research has a broader context, and it provides some results concerning the spatial pattern of the active GNSS stations in Poland which changes within scales. The spatial dispersion of the ASG-EUPOS stations was documents by ANN analysis, one of the oldest spatial statistics. The z_{ANN} = 8.63, placed in the tail of normal distribution, makes clear evidence for dispersion. This dispersion was confirmed by the second-order spatial statistic, namely the Riplay's K- function, which shows that at the near distances from 25 up to 65 km, typical baseline lengths in the CORS, the ASG-EUPOS stations are irregularly dispersed.

This leads to the conclusion that assumed uniform distribution of reference stations over the country's territory is still not achieved. Some regions need network densification, because the inter-station distances are longer than recommended, exceeding 70 km. We estimate that at least 12 reference stations should be added to provide regular spatial distribution of the ASG-EUPOS stations. The densification of ASG-EUPOS networks over the coming years will be a huge benefit to the survey community in Poland.

The density of GNSS permanent stations is higher in the heavily urbanised areas than in the rural and forested regions,as was emphasized by the analyses of kernel density and the Thiessen polygons morphology. A small cluster of the ASG-EUPOS stations is clearly visible in the Warsaw metropolitan area, where 9 stations are in a vicinity closer than 25 km (see Fig. 5).

In Warsaw or the Silesian agglomerations, the interstation distances are smaller and the density of ASG-EOPUS is also higher, almost 20 times exceeding the density given in the Ministry Regulation.

Less than 10% of the ASG-EUPOS stations could be influenced by environmental obstacles, like huge elevation diversification (3 stations), dense built-up areas (5 stations) or tree canopy (4 stations). The most severe measurement conditions are in the Polish part of Bieszczady Mountains (USDL station), where forest covers more than 71% of the region, and at the Baltic Sea coast near Wladyslawowo (WLAD), due to inter-station distances longer than 60 km, the vicinity of a water reservoir, 44% of forest and 7.7% of built-up areas. Point position determination in these areas requires careful mission planning and use of advanced equipment (e.g. collinear antennas).

The conducted study faces the challenges in examining the configuration of Polish permanently operated reference stations, by the means of advanced spatial pattern methods. It is the first attempt to use such a methods in geodesy, especially in analysing the distribution of basic control network points. The achieved results could serve not only scientific community but also land surveyors. The spatial pattern of the ASG-EUPOS site locations could help to plan the GNSS positioning. It shows stations' accessibility in terms of baseline lengths, geometric distribution and environmental conditions in the vicinity of stations. What's more, allow national authorities to plan ASG-EUPOS modernization, by pointing places that require densification.

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Table 3: Summary table of regression analysis

R= 0.85559320; R square = 0.73203973; Adjusted R square = 0.72479756; F(3,111)=101.08 p<0,000 Std. Error of estimate: 658,27						
	b*	Std. Dev	b	Standard error of the estimation (SEE)	T (111)	p
		with b*		with b		
Constant			450.0457	144.1969	3.12105	0.002297
Built-up area	0.186356	0.067675	1.4731	0.5349	2.7537	0.006887
Forest	0.608588	0.050947	1.5729	0.1317	11.94549	0.000000
Transport network	0.313820	0.068382	4.4388	0.9672	4.58925	0.000012

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