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Original Research Article

STATYSTICAL ANALYSIS IN INTEGRATION OF THERMAL IMAGING AND GNSS SATELLITE MEASUREMENTS IN RELATION TO GEOLOGICAL STRUCTURE AS A METHOD TO IMPROVE THE ACCURACY OF DISPLACEMENT DETERMINATION OF ENGINEERING STRUCTURES

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A b s t r a c t

Numerous publications have confirmed the important contribution of applying GNSS satellite measurements in geologically unstable areas to the displacement measurements of engineering objects. Along with linking GNSS measurements of benchmarks considered to be stable in the long term to the nearest reference stations at appropriate measurement intervals. So, it was possible to improve the accuracy of measurements of vertical and horizontal coordinates in the area of Szczecin, ushering in coordinate errors of less than 2 and 5 mm. For objects of strategic use such as natural gas tanks located in salt formations, however, these values are too high. The displacement of salt formations is 0.5 mm per year. Therefore, I decided to review existing measurement methods in two areas with different geological structures - Szczecin and Wroclaw NW and SW Poland - as numerous spectrums of SAR methods. As a different method, I present the advantages of the radiometric method with the prospect of performing surveys in the abovementioned areas. The publication focuses on statistical analyses, and GNSS and radiometric field measurements are in progress.

Keywords: organic sediment load, organic soils, islands Szczecin, Wroclaw, GNSS, vertical, horizontal movements, deformation monitoring, radiometry

1. INTRODUCTION

Wroclaw [1] and Szczecin [2] have been covered through geodetic monitoring of displacements of engineering objects closely coordinated with the geological structure (Fig.1-3), (Tab 1). The different nature of this structure was important for the arrangement of elements of the measurement system and

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the frequency of conducting measurements. It was important in both cases to increase the accuracy of the measurement by doubling the alignment to geologically stable benchmarks and the nearest reference stations, (Tab 3). The methodology has been described in more detail in [2]. In addition, in the area of Wroclaw as well as in Szczecin in 2014-2019 measurements were performed using INSAR Satellite Radar Interferometry, as conducted by Sandwell et al 2011 (Fig.3). They are described in more detail in the review of methods. In Wroclaw, studies of the displacement of the surface layer of the Earth's crust have been conducted since the 1960s of the 20th century. In Szczecin, research has been conducted since 2017. Peats in Szczecin and sands in Wroclaw are well-hydrated formations, changing their properties under the influence of changes in the level of the water table, as well as the extrusion of water under load. The dielectric constant and the emissivity coefficient also change with the water content. Therefore, is assumed that the proposed methodology will eventually allow the creation of a neural network that permits the measurement of displacements with a very high accuracy of 0.1 mm. It will be important in the development and construction of natural gas reservoirs in the formation. Their annual displacements are very small, about 0.5 mm per year.

2. MATERIALS AND METHODS

2.1. Materials

Before the methods of satellite radar interferometry SAR and GNSS satellite measurements [3] came into widespread use, displacement analysis was carried out on the basis of analysis of changes in the height of benchmarks in the course of precise levelling of the first and in the area of Szczecin and Wroclaw. This methodology was enriched with the analysis of the geological structure of the terrain to identify geologically stable and unstable areas. The technique additionally integrated precise levelling with GNSS measurements. The following control and measurement system was proposed in Szczecin, (Tab 1).

Table.1. Characteristics of the control and measurement system for testing in space 1 D

	Segment I	**Segment II**	**Segment III**
Measurement method **Measuring instruments**	Precise levelling	Total station Precise levelling	Extensometer Gap gauge Dilatometer
Frequency of observations	1-3 years	4 months	1-50 days or permanently
Accuracy measurements	± (0.5) mm	± (0.5 – 2) mm	± (0.01 – 0.1) mm

The geological structure of the area for the monitored facility,- (i.e. the EcoGenerator Waste Utilization Plant,-) was independently analysed. The organic soil in the western part of Międzyodrze consists of peat 8.8 m thick. In the eastern part, 2.0 m thick, it is underlain with silt 7.0 m thick. The floor of the EcoGenerator Waste Treatment Plant (Fig. 1) is shown in the drawing below. The area is paved, but organic soil still causes subsidence. The speed of changes in the height of benchmarks was calculated in relation to stable benchmarks, similar to that done previously in Wroclaw (Fig.2).

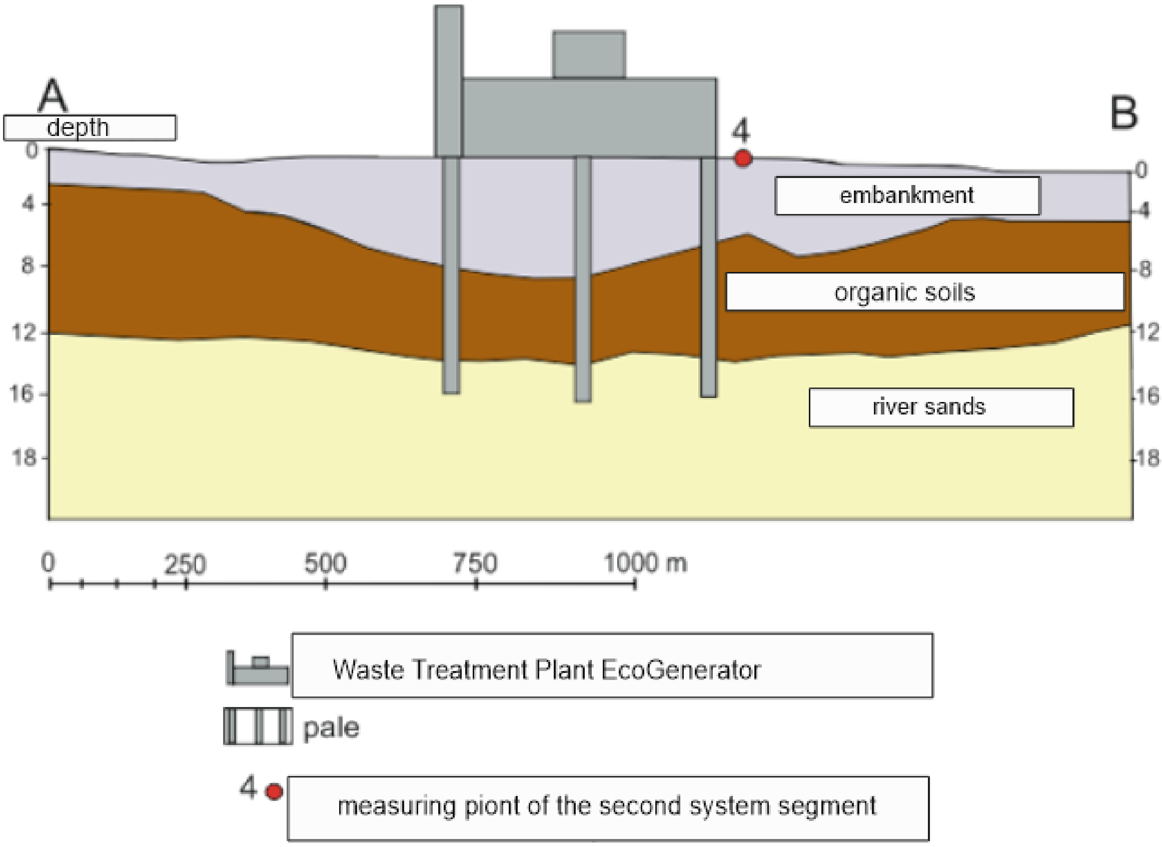

Fig. 1. Geological structure of the EcoGenerator Waste Utilization Plant based on Zygmunt (2020)

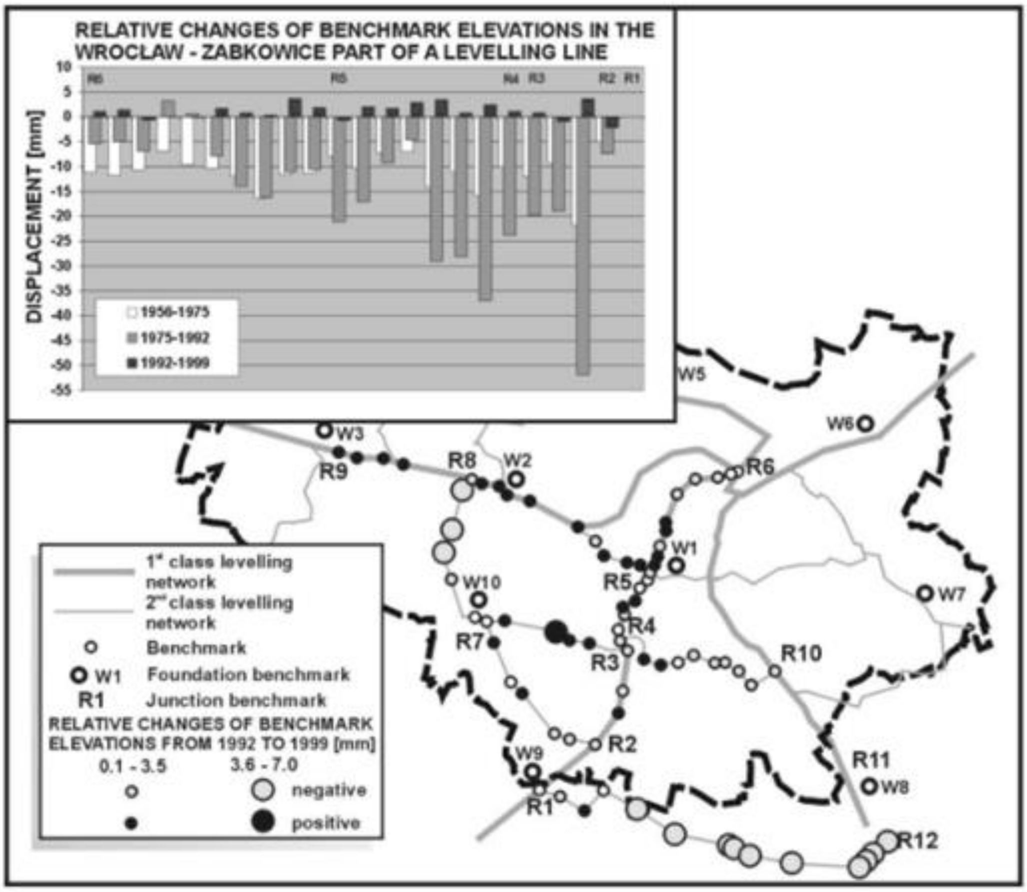

Fig. 2. Spatial network of benchmarks in Wrocław with marked reference benchmarks in geologically stable areas based on Grzempowski (2005)

The greatest subsidence in Wroclaw was observed in the north-eastern (up to -40 mm) and southern parts of the city (up to -70 mm) [2]. Satellite (Fig.3) and radiometric measurements are two independent methods of measuring soil moisture. Radiometric methods used in a small area allow researches to measure soil moisture to a certain depth. It is also possible to analyse the geological structure. A large variety of SAR methods focus on surface humidity changes largely related to plant vegetation. UAS methods can also measure surface humidity. Radiometric methods are less dependent on terrain. They are based on the phenomenon of depolarization of the aquifer.

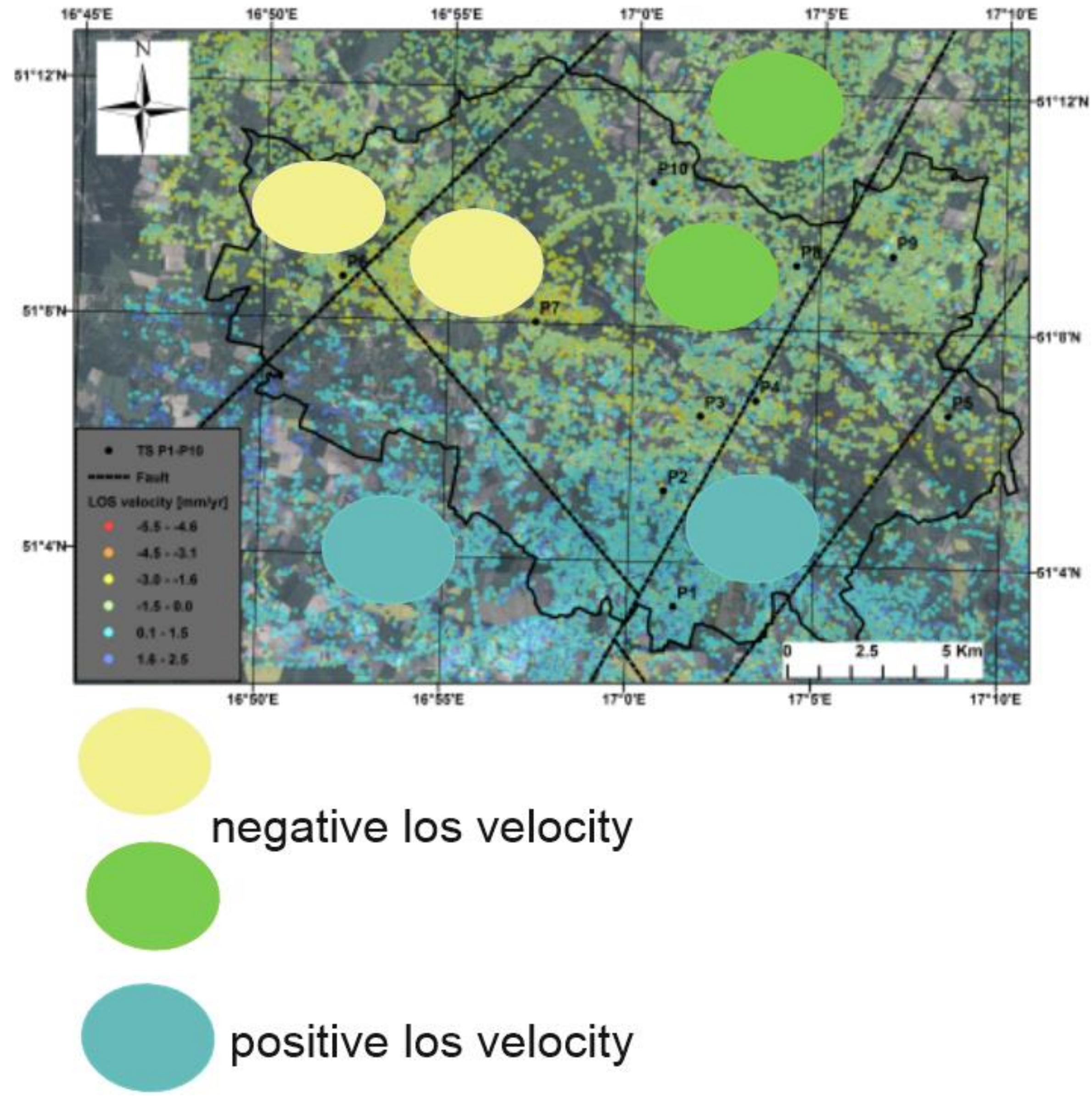

Fig. 3. Movements monitored using InSAR in Wroclaw based on Blachowski et al (2020)

Both in Szczecin and Wroclaw, measurements were carried out using InSAR Satellite Radar Interferometry, asper Sandwell et al. 2011. In Wroclaw, for all analysed sets of SAR images-,the highest density of PS points in the study area was obtained for Sentinel-1A measurements and the lowest for ERS-2 [4] (Fig. 3). Negative displacements predominated over most of the area. Positive displacements occurred in a compact subarea in the southern and central parts of the city and are scattered in the north-eastern part. Satellite SAR Radar Interferometry can also provide data from thermal imaging and, together with radiometric methods in combination with GNSS measurements, constitute the basis for the method proposed below.

2.2. Methods

Table 2 presents data regarding the measurement accuracy of 4 benchmarks in the Szczecin area. Points 1,2 and 3 are located in stable areas,- and point 4 in the immediate vicinity of the EcoGenerator [1]. In the method presented below, I assume that the accuracy of determining coordinate errors both in Szczecin and Wroclaw will increase as a result of regular GNSS observations and measurements on geologically stable and unstable points in integration with thermal measurements carried out at the same time as satellite measurements. At the points, measurements are made using a 350 to 2500nm VIS radiometer,-and a NIR field -spectroradiometer Optosky. It additionally allows for the analysis of the geological structure of underground formations. Additionally, the measurements will be enriched with photos from the Stientinel 1 [5] mission and airborne thermal measurements using the Phantom drone. The frequency of thermal and satellite GNSS measurements is 3 weeks to 3 months, carried out regularly in both areas for 2 years. Radiometric measurements will be additionally assessed at various frequencies. Soil moisture measurements using passive and active microwave techniques are considered the most accurate [6]. Drone and satellite measurements are additionally independent with a frequency comparable to radiometric ones, on the same day or more often according to [7]. The radiometer calibration will be performed according to [8].

Table 2. Coordinates aligned with ASG-EUPOS stations of 3 hour measurements (November 2020)

Position	Coordinate X (metre)	Coordinate X (error metre)	Coordinate Y (metre)	Coordinate Y (error metre)	Height H (metre)	Height H (error metre)
1	5914268,521	0,001	5481721,882	0,0011	18,615	0,0052
2	5913766,879	0,0015	5472143,054	0,0010	5,709	0,0048
3	5915137,456	0,0019	5482014,790	0,0012	14,133	0,0065
4	5921687,950	0,0011	5473141,886	0,0007	6,304	0,0042

The high dielectric constant of water causes significant differences in the signal for different water contents. A change in the dielectric constant causes a change in the signal frequency and a change in the emissivity of the ground. The type of soil, its lumpiness, and its roughness also influence the emissivity. Passive methods involve the radiometric measurement of emission intensity from the soil surface [9]. This emission is proportional to the surface temperature and surface emission, which is equal to the brightness temperature of the object. The water temperature TB can be expressed as follows:

$$T_B = t(H) * \left[rT_{sky} + (1-r)T_{soil}\right] + T_{atm} \; ; \tag{2.1}$$

where t(H) - is the atmospheric transmission for the radiometer performing measurements from a height H above the ground, r - is the reflection coefficient of the smooth ground (Fig.4), Tsoil - is the soil temperature, Tatm - is the average air temperature and Tsky - is the contribution from the reflected sky radiation [9]. Active methods provide us information about the moisture content in the medium based on the measurement of the radar backscattering coefficient (cr). Its value is influenced by two factors: backscatter from vegetation (cru) and backscatter from soil (crs), attenuated by the value of L (soil absorption) by the vegetation cover [5].

The method will also consider statistical analyses, multiple regression and the finite element method for displacements and deformations. The data set will be determined experimentally, with quantitative and qualitative factors affecting the displacements.

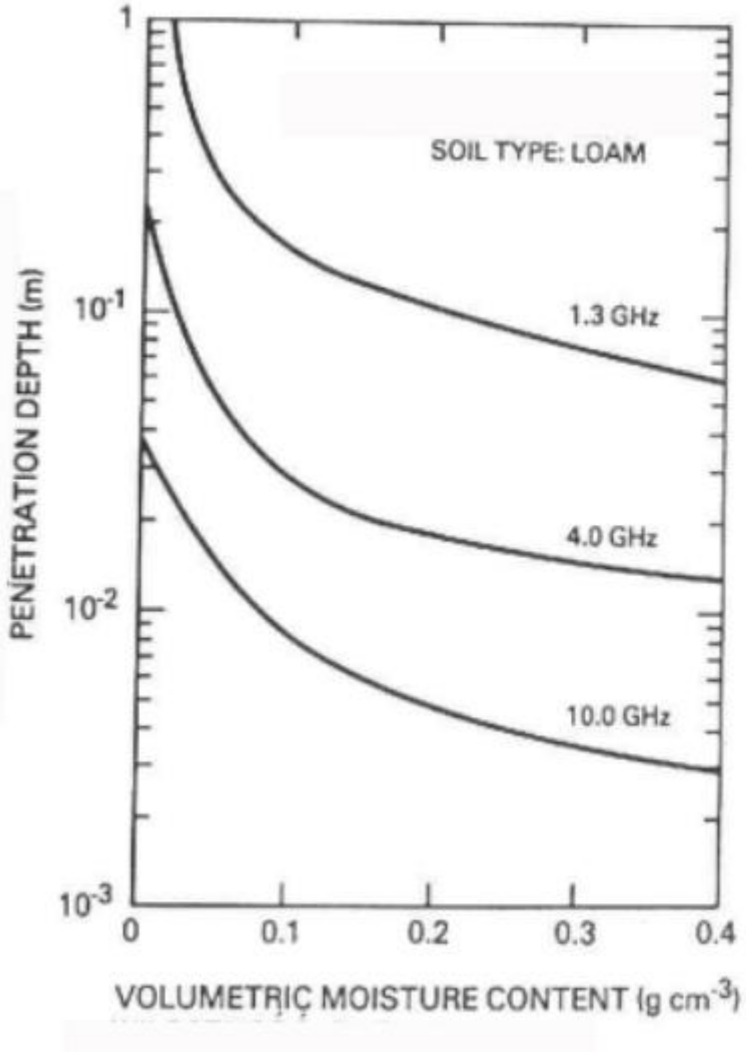

Fig. 4. Depth of microwave penetration in different soil types based on Rataj (1993)

The influence of the soil composition on the emissivity (Fig. 4) in the microwave range seems to be obvious, because the content of clay, sand, stones and other sediments determines the retention of water in the upper layers of the soil and thus determines the emissivity of the object [9]. Higher humidity is measured in clay and sandy soils. For active methods, the composition of the soil will affect the depth of wave penetration as well as the size of the signal reflected at the air-soil boundary,- (Fig. 4). Radiometric measurements will be performed in the immediate vicinity of GNSS measurement stations considered geologically stable and in geologically unstable areas. Aerial thermal measurements will cover a large part of unstable areas and the vicinity of stable benchmarks + 100 square meters, whereas satellite measurements will cover the entire research area. Fig. 5 shows the range of planned measurements in Wrocław and Szczecin. The temperature of groundwater medium is indirectly dependent on the amount of water in the ground.

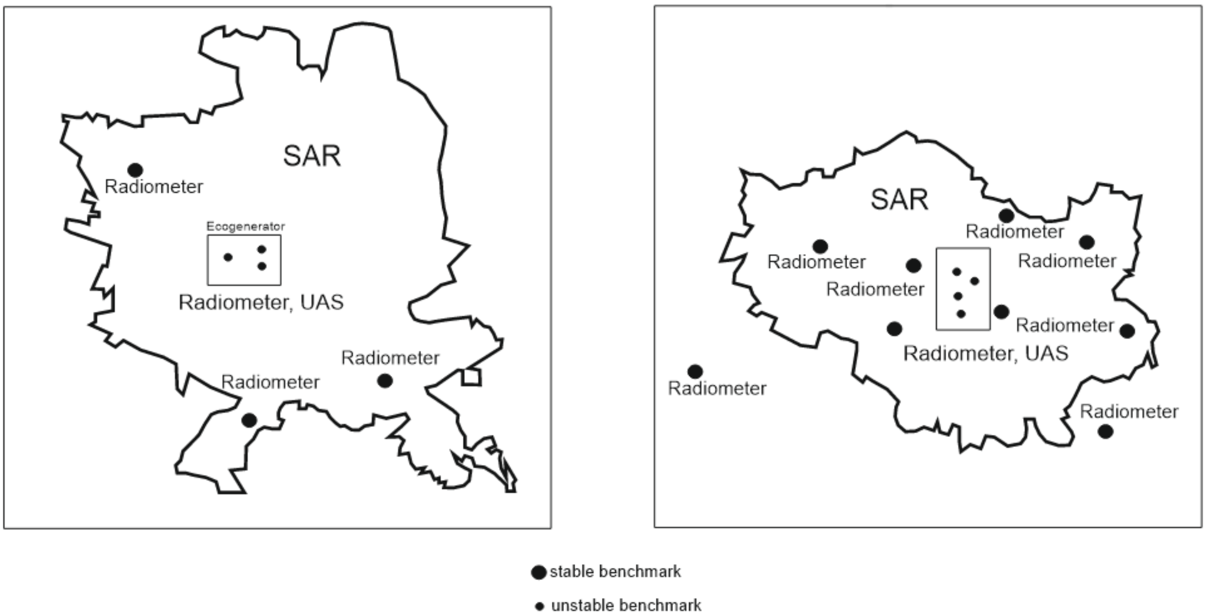

Fig. 5. Planned radiometric, UAS and SAR measurements in the immediate vicinity of geologically stable and unstable benchmarks in Wroclaw and Szczecin

The application of UAS will be as follows. At given altitudes for humidity, the predicted pixel size on the ground will be larger than the size of moist peat, (e.g., at an altitude of 100 m;), with the camera in this study each individual pixel will cover an area of 10 cm × 10 cm on the ground [10]. Within a single pixel, the radiation from any object that is smaller than 10 cm will be combined with the radiation emitted by any other object that is also within that pixel on the ground [11].

Additionally, all acquired SAR images [12] were received as Tier 0 products and then converted to Tier 1 products. Tier 1 SAR data were corrected, calibrated, and filtered in preparation for [13] soil moisture estimation.

Sigma-naught (σ°) describes the average reflectivity or scattering of a radar scene. Beta-naught (β°) interprets mean reflectance brightness estimates and separates the radiometric response from reflectance that depends on terrain properties such as local slope.

It was found that the backscatter values as β° show a better correlation with soil moisture than the backscatter values as σ° at the study site. β° is considered to provide a better estimate of soil moisture due to the low topography at the study site [11].

The microscopic properties of organic soils are very complex [14]. The relationship between loading and settlement is influenced by factors such as porosity (pore size and shape), permeability, hydraulic gradient and mineral grain arrangement (texture) of the soil [15]. Organic soils have elastic-plastic properties (Polish Building Standard PN-86/B-02480). This means they are subject to initial settlements that result from the form deformation of the soil medium saturated with water and gases (Polish Building Standard PN-86/B-03020). This is caused by an increase in pore pressure. Initial settlement occurs a short time after the application of the load. Consolidation settlement, on the other hand, results from the dissipation of excess pore pressure as a result of load application. The rate of primary consolidation depends on the volume changes and permeability characteristics of the soil [14]. The applied external load causes a change in volume and a decrease in the porosity index (e). The amount of water translates indirectly into the temperature of the groundwater medium.

The filtration coefficient also decreases [15], so that the organic soil gives up water instead of conducting it. The degree of compaction of elastic-plastic soil increases when the porosity index (e) decreases. The degree of plasticity of elastic-plastic soil then decreases. Organic soils are characterized by both porosity and elasticity. The rate of elevation change determined from the analysis of two measurement campaigns shows the rate of organic soil settlement over time (1 year). Sands are loose soils and have low elasticity. The high grain number during loading clogs the pores and makes it so that there is no clear change in the degree of compaction as in the case of organic soils. In contrast, cohesive soils – clays and loams are very elastic, but have no pore spaces. Under the influence of moisture, they swell or thaw. However, they do not give up as much water as peats without causing subsidence [16]. The porosity index (e) affects the pore pressure u and the permeability coefficient k. Also, the applied load allows you to calculate Young's modulus E. The basic equation for organic soil settlement is presented in the following equation:

$$\frac{\delta u}{\delta t} = \frac{kE\delta^2 u}{H^2 \gamma_w \delta z^2} \quad (2.2)$$

H – The thickness of the organic soil layer (peat),
γ_w- water density,
t – time,
z – vertical coordinate.

Young's modulus E is the ratio of the applied stress σ to the relative linear strain ε. In addition, the estimated thickness of organic soil H based on the geological and engineering documentation for the EcoGenerator plant site as one of the independent factors shows a correlation with the values of velocity of change of thebenchmarks height from the plant site. Organic soils in the marginal part of the plant were loaded with less anthropogenic embankments. Their thickness exceeds 7 m, and the constant loading of the plant's construction causes greater subsidence of organic soils. Is evident in the values of vertical displacements of the benchmarks located on the plant's building reaching up to 73 mm per year. The subsidence in the remaining, unencumbered part of the plant reaches 32 mm per year [17]. Within this part of the site, there is also a test site II segment of the control and measurement system labelled 4. It has subsided 19 mm in 6 months, which confirms, the slower rate of subsidence in this part of the site. These results are confirmed by statistical analyses using multiple regression, indicating the thickness of the organic soil as a factor causing the significant values of the rate of change in the height of the site's benchmarks. Significant values of vertical displacements during the year may signal the need for a third segment of the control and measurement system to conduct observations of the relative displacements of the repoints within the plant building. In the event of cracks and fissures, crack meters would be installed. Statistical analysis using the multiple regression method was also important in determining which factor has a significant effect on the vertical displacements of the benchmarks located on the EcoGenerator plant building on Ostrow Grabowski Island. This method makes it possible to study nonlinear correlations between independent variables (quantitative and qualitative factors) and the dependent variable. The values of annual vertical displacements of the benchmarks located on the EcoGnerator plant building and Wroclaw. The identification of factors that have a significant impact on the vertical displacements of the repositories helped to make a geological interpretation of the deformation results of the facility (EcoGenator Waste Treatment plant). In the construction of the model, independent variables are adopted that are strongly correlated with the dependent variable and weakly correlated with each other. The parameters of the regression function are determined by the method of least squares [18]. Prior to their determination, independent variables are verified on the basis of their mutual correlation. The value of the multiple correlation coefficient R should be evaluated. The coefficient is a measure of the relationship between the dependent variable and the independent variables. Typically, the degree to which two or more explanatory variables (independent or X) are related to the explanatory variable (dependent variable Y) is expressed by the value of the correlation coefficient R, defined as the square root of R-square. In multiple regression, R can take values between 0 and 1. To determine the direction of dependence on a particular variable, use the sign of the value of the regression coefficient (B). If B has a positive value, then the relationship is positive (as the variable X increases, the value of Y increases). Of course, if the value of B is zero, then there is no relationship between the variables. It is important to determine the significance interval α for a certain number of degrees of freedom k. F is the quantity read from Snedecor's F distribution. The regression line expresses the best prediction of the dependent variable (Y) given the independent variables (X). However, nature is rarely (if ever) perfectly predictable, and researchers usually have to deal with deviations of measurement points from the regression line (as shown in the scatter plot). The deviation of a given point on the graph from the regression line (i.e., from its predicted value) is called the residual value. When the variance of the residual values around the regression line is smaller relative to the overall variability, quality of the prediction is better. If, for example, there was no dependence at all between the variables X and Y, then the ratio of Y residual variability to the overall variability would be 1.0. If, on the other hand, X and Y were strictly (in the sense of functional dependence) dependent on each other then the residual variability would equal zero and such a ratio would be 0.0. The most commonly discussed quantity is somewhere between these extreme values, i.e. between 0 and 1. The quantity defined as 1 minus this ratio is called the R-square or coefficient of determination. It has the following interpretation. If the R-square value were 0.4 then it would be known that the variance of Y values around the regression line is 1-0.4 times the original variance of Y. In other words, 40% of the original variance of Y was explained by the regression, and 60% remained in the residual variance. In the ideal case, researchers we would want to explain as much (if not all) of the original variability as possible. The R-square value is an indicator of the quality of the model's fit to the data- (an R-square close to 1.0 indicates that almost all of the variability in the dependent variable can be explained by the independent variables included in the model). Typically, the degree to which two or more explanatory variables (independent or X) are related to the explanatory variable (dependent variable Y) is expressed by the value of the correlation coefficient R, defined as the square root of R-square. Critical values for Snedecor's F distribution for a significance level of $\alpha=0.05$. The multiple regression method showed the influence of causal variables (quantitative and qualitative) X on the effect variable Y-displacements of the benchmarks. It will be possible to assess the significance of the influence of individual factors on displacements. The frequency of measurements for each segment of the control and measurement system was determined.

3. RESULTS

3.1 Analysis using multiple regression

Analysis of the factors affecting the movements of the benchmarks on the leveling lines passing through the islands based on relation (3.1) [18]:

$$Y = a_0 + a_1 X_1 + a_2 X_2 + \ldots + a_n X_n, \qquad (3.1)$$

where:

$X_1,\ldots,X_n$ – factors causing displacement,

$a_0 \ldots a_n$ – unknown parameters.

Quantitative factors influencing the movements of the repertory included the: -
- thickness of organic sediments (X_1) - determined on the basis of the text of the explanatory notes to SMGP sheet Szczecin and on the basis of the geological and engineering documentation of the EcoGenerator site, and Wroclaw area,
- thickness of anthropogenic sediments (X_2) - determined on the basis of the text of the explanatory notes to SMGP sheet Szczecin and on the basis of the geological-engineering documentation of the EcoGenerator site and Wroclaw area,
- fluctuations in the level of the groundwater table (X_3) - determined on the basis of the geological-engineering documentation of the EcoGenerator site and Wroclaw area.

Qualitative factors include:
- type of soil within the building foundation (X_4) - geological and engineering documentation of the EcoGenerator and Wroclaw area,
- type of organic soil (X_5) - geological-engineering documentation of the EcoGenerator site and Wroclaw area.

Conclusions from the study will be able to support decision-making on the construction of engineering structures in geologically unstable areas.

First of all, the individual factors influencing vertical movements were assigned a numerical value for the expected increase in impact on displacements (Tab. 3):

Table 3. Numerical values assigned to the factors

Factor X										
Factor	**1**		**2**		**3**		**4**		**5**	
	Thickness of organic soil (m)	Number	Thickness anthropogenic soil (m)	Number	Water level fluctuations (m)	Number	Type of soil in the foundation area of the structure	Number	Type of organic soil under the foundation of the structure	Number
	0 to 1	1	0 to1	5	0 to 2	1	sand	3	silt	3
	1 to 2	2	1 to 2	4	2 to 4	2	humus sand	2	peat	2
	2 to 4	3	2 to 4	3	4 to 8	3	dusty sand	1	gythia	1
	4 to 6	4	4 to 6	2	8 to 10	4				
	6 to 10	5	6 to 10	1	10 to 12	5				

The multiple correlation coefficient R between the displacements of the 54 reps and the factors X_i was 0.51. The F statistic with k=5 and n-k-1=49 degrees of freedom was 42.4 with F_α=5.47 and α=0.05. Because F> F_α the multiple correlation coefficient was considered significant. As a result of solving the system of 54 equations, the parameters ai of the regression function were determined (Tab. 5). A model estimation error of 8.5 mm was obtained. The significance test showed insignificant parameters at the X_2 factor. The t statistic was -1.31 for it.

Table 4. Correlations and multiple regression parameters for 54 benchmarks

Factor	Correlations of factors with displacement ΔH	The parameters of the regression function a_i		The standard deviation of the parameter a_i	Statistics t
	1,10	a_0	-0,25	0,02	-9,1
X_1	0,67	a_1	1,28	0,2	6,29
X_2	0,18	a_2	-0,25	0,19	-1,31
X_3	0,56	a_3	0,92	0,1	9,11
X_4	0,44	a_4	-0,91	0,12	-7,13
X_5	0,27	a_5	-0,32	0,07	-4,35

The highest correlations of -0.67 are between the displacement of the benchmarks and the thickness of organic formations. The depth to the first groundwater level has a smaller influence on the settlement of elevation points (correlation -0.56). Significant correlations between the displacements of the benchmarks and the thickness of organic sediments are due to the phenomenon of subsidence of these geological layers. These layers are composed of peats, silts and gyttja. The parameters of the regression function for the thickness of anthropogenic layers turned out to be insignificant. Benchmarks located within the more and less thick anthropogenic layers show no displacement relative to the other benchmarks. The influence of qualitative factors also proved to be insignificant.

Smaller or constant masses of organic material over a period of more than 1 day [19], measured at weekly intervals according to Formula 2, allow for calculation of Young's modulus and thus the value of the displacement. Values calculated in this way are within the range 0.01+0.1 mm. This is confirmed by the following graphs, drawn from a linear regression of the parameters influencing the displacement values of the benchmarks from the area of Wrocław, in the vicinity of the power plant, and Szczecin, in the area of the EcoGenerator plant. The following figure show correlations between displacements and organic matter density (Fig. 6). This makes it possible to estimate changes in bulk density for very small displacement values of 0.01 to 0.1 mm. Thanks to the comprehensive system, which considers both the geological structure of the terrain and the combination of satellite measurements of displacement and thermal ground data. It is possible to monitor deformations with a very high degree of accuracy. This is of practical use in the measurement of salt movements, which are of the order of 0.5 mm per year and can have an impact on the unsealing of existing and planned natural gas reservoirs. The system is constantly being improved based on thermal images from the Sentinel 1 thermal SAR mission and thermal photogrammetric images. Displacement accuracies obtained through the system are constantly being positively verified.

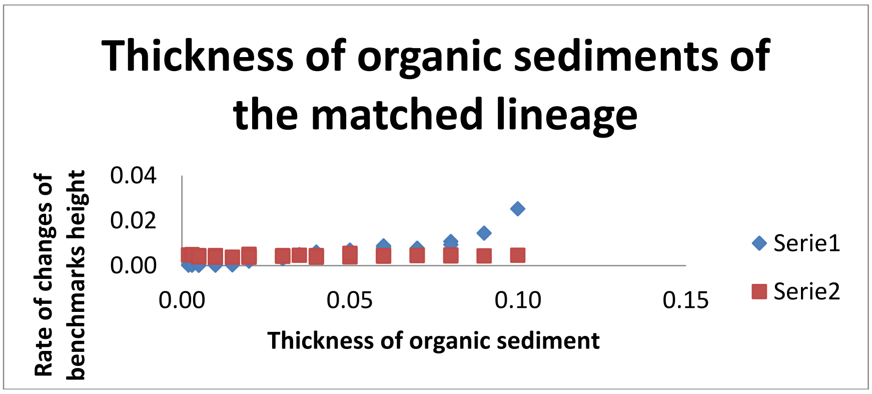

Fig. 6. Correlations between different parameters of linear regression, which influence displacements from the Wroclaw area

To achieve measurement accuracies of less than 1 mm, it is important to develop a method which integrates satellite measurements and thermal measurements using a radiometer. The existing research gap research gap between the change in the emissivity coefficient of a soil type and its displacement is an important research problem, the solution of which will improve the accuracy of such observations using GNSS. It is planned to use multiple regression to analyse the measurement data.

3.2 Genetic algorithm

The choice of the type of soil to be combined depended on certain physical characteristics of the soil, such as its compaction and whether the soil was dry or wet. The cost of each soil type was fixed at 10. If the soil was dry the price was an additional 5. If the soil was furthermore compacted the price was twice as high 2*15=30.

hard clay: 6, dry: 6, compacted: 6
soft clay: 8, dry: 10, compacted: 10
hard sand: 10, dry: 12, compacted: 12
soft gravel: 12, dry:14, compacted: 14

Because the price of dry and compacted soil is twice as high, there are twice as many people willing to buy it.

The builder has determined that each soil type (phenotype) will correspond to a specific set of characteristics (genes) that describe it. These traits including the following: soil type (4 possibilities), dry/wet-over a metre thick (2 possibilities) and compacted/loose (2 possibilities).

The traits (genes) were encoded by the digits 0 and 1. As for soils, each soil type would be described by four such digits: two describing - whether the soil is compacted-, by the following dry (1,1); or loose, wet (0,0), one digit - soil type (silt- 0, clay - 0, sand -1, gravel - 1) and one digit - hard - 1, soft -0 - over a metre of pulp. Hard clay – 01, soft clay – 00, hard sand – 11, soft gravel – 10. Dry - 1, wet - 0, loose - 0, compacted – 1 (e.g-. 1 1 0 0 – for hard sand, wet, loose).

It was necessary to formulate a fitness function to assign to each type of soil, a certain non-negative magnitude the greater the individual we are concerned with. In this case, the most natural measure of land quality is the profit from its sale – (i.e., the product of demand and price).

The elimination of weaker individuals will be determined by a ‘roulette wheel’ algorithm. In the reproduction phase, the chances of survival will be proportional to the value of the adaptation function.

It is necessary to determine how the genetic operators: mutation and crossover: work. This is a binary encoding, so mutation can be used by randomly changing the value of a single bit to the opposite (e.g., 000 to 0100).

The crossover will consist of a randomly selected pair of parents. I will then draw a crossover point -: one of three points between genes, the same for both parents. From this, a descendant will be constructed from the initial fragment of the first parent and the final part of the second. Eventually, a descendant will replace one of the parents. Parent 1- 0 0 0 1 0, Parent 2- 1 1 1 1 1, Offspring: 0 0 0 1.

So, crossover will be carried out with a probability of 50 % and a mutation of 5 % (this applies to each bit individually). The population size is 4 individuals. The initial population consists of individuals selected at random: (e.g.,0111, 1000, 1000, 0100).

In the reproduction phase, we count the value of the adaptation function of each individual. We then apply the- ‘roulette wheel algorithm’. Then we add up the function values of all individuals and divide these values by the sum obtained. In this way we obtain the percentage contribution of each individual to the total. These values are then summed cumulatively to form the distribution of Table 5 individuals.

Table 5. The fitness value of a given type of land as a function of its type

Nr	Ground	Adaptation value	% participation	Total shareholdings cumulative
1	0 1 1 1	90	23,08	23,08
2	1 0 0 0	120	30,77	53,85
3	1 0 0 0	120	30,77	84,62
4	0 1 0 0	60	15,38	100
total		390	100	

The values of the fitness function appearing in the table have been calculated on the basis of the input data, for example, land 0 1 1 has a price of 30 (it is dry and compacted) and the demand for it is 3. In the case of dry and compacted land it is divided by 2, so the profit will be 30*3=90. When selecting individuals for the next population we draw four numbers from the range [0,1] and in the last box, we check which individual they correspond to. We have drawn the numbers 0.22, 0.01, 0.15 and 0.88, and they correspond to individuals 1, 1, 1 and 4 - (we find the smallest number larger than the drawn number and select its individual). Thus the new population consists of individuals: (e.g., 0 1 1 1, 0 1 1 1, 0 1 1 1, 0 1 0 0). Thus, the best-adapted individuals have entered the next population.The next step is crossover. For each individual, we randomly draw (with a probability of 50%) that the crossover operator will be used on it. Suppose we have drawn individuals 1 and 4. We then draw which individuals they should cross with -; we have drawn that the pair for 1 will be individual 2 and that the pair for 4 will be individual 1. For the first pair, we drew that the crossover point would be the gap between the third and fourth gen.

Individual 1: 0 1 1 1 1, Individual 2: 0 1 1 1 1, Offspring: 0 1 1 1. Because individuals 1 and 2 have an identical set of genes (they describe the same type of land), crossing them does not lead to anything new. It will be different in the second case: Individual 4: 0 1 0 1 0, Individual 1: 0 1 1 1 1.

Offspring: 0 1 0 1 A new type of land has emerged in the population. It was inherited that it was wet from individual 4 and that it was dense from individual 1.

After replacing the first parents with descendants, the population consists of individuals: 0 1 1 1, 0 1 1 1, 0 1 1 1, 0 1 0 1 We move on to mutations - in our case, the probability is 5% (on average, less than 1 gene in the entire population of 16 genes will be mutated). Drawing consecutively for each bit a number in the interval [0,1], we draw a number less than 0.05-on the fifth time. Thus, the third gene of the second individual will be mutated: (e.g., 0 1 1 1, 0 1 0 1, 0 1 1 1, 0 1 0 1).

The mutation resulted in the same individual as after crossing the fourth individual with the first. Finally, after the second evolutionary cycle, the population composition is as above. The values of the adaptation function are 90, 100, 90, and 100, respectively -: on average, they were higher than the initial values. The land is evolving in the right direction.

After mutation, the algorithm will again move to the phase of reproduction, and so on. Considering Formula 2, it can be said that the most important parameter for obtaining high-accuracy measurements will be time, the soil mass, its type and moisture content related to the specyfic gravity of the water, andthe temperaturę of the soil- water medium.

4. DISCUSION AND CONCLUSIONS

Palmaka [20] uses combined statistical methods -, such as multiple regression and neural networks, to determine the best-fitting model of land subsidence after land drainage at the Belchatow Lignite Mine - in Central Poland. These are different geological conditions – such as the mine site. Other statistical factors more related to the soil compressibility modulus are considered. Settlements reach up to several cm and occur over a longer period of time. It does not use geodetic measurement methods, studying only the values of deformations caused by stresses in the ground. The presented method, supplemented with field GNSS measurements and radiometric and later satellite and UAS measurements, will further verify the high accuracy of measurements obtained through control and measurement systems coordinated with the geological structure in Wroclaw and Szczecin. An innovative genetic algorithm was used showing the selection of the right type of soil to avoid subsidence. The thickness of the organic soil is the value best suited to the recorded rates of change in the height of the benchmarks. Other factors such as changes in ground water level are closely related – such as Equation 2 with the amount of water in the ground - a radiometric measurement of temperature, settling time and soil porosity will be performed.

The proposed research method can make a significant contribution to the development of a neural network that permits measuring building deformations and estimating them with very high accuracy. The high frequency of measurements and consideration of the detailed changes in water content will allow researchers to follow the deformation process step by step. Additionally, statistical analyses and consideration of the initial stages of the subsidence curve will be important in estimating the occurrence of subsequent deformation over time and its development with much higher accuracy than in classical measurements. The estimation algorithm in thermal cameras will have additional importance when measuring, salt movements, for example both salt movements and objects located in areas built by organic and water-logged soils can be monitored very carefully and comprehensively, which will prevent the development of deformations. Assigning new heights to the benchmarks located on the building of the EcoGenerator plant in relation to the benchmarks in the Szczecin area considered stable will allow experts to improve the accuracy of determining the correlation coefficient for the organic soil mass and other qualitative and quantitative factors. The calculated rates of change in the height of these reefs during the year will be levelled both to the nearest reference stations and stable benchmarks.

Further GNSS measurements correlated with radiometric measurements will extend and complete the algorithm and create a neural network.

This is an important research problem, as thermal measurements, which are nowadays used so frequently, can contribute to improving the quality and accuracy of engineering object displacements. This concerns strategically important objects such as natural gas storage facilities located in salt formations. These formations move approximately 0.5 mm per year.

ADDITIONAL INFORMATIONS

Mark Zygmunt: Conceptualization, Data Curation, Investigation, Resources, Validation, Oryginal Draft, Methodology, Supervision.

Conflicts of interest The author declares no conflict of interest.

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