Title: Aplication of IDW and RBF methods to develop models of temperature distribution within a spoil tip located in Wojkowice, Poland

Author: Adrian Zarychta, Roksana Zarychta

Citation style: Zarychta Adrian, Zarychta Roksana. (2018). Aplication of IDW and RBF methods to develop models of temperature distribution within a spoil tip located in Wojkowice, Poland. "Environmental and Socio-Economic Studies" (Vol. 6, iss. 1 (2018), s. 38-45), doi 10.2478/environ-2018-0005

DE GRUYTER OPEN

Environmental & Socio-economic Studies

DOI: 10.2478/environ-2018-0005

Environ. Socio.-econ. Stud., **2018, 6, 1: 38-45**

Original article

Aplication of IDW and RBF methods to develop models of temperature distribution within a spoil tip located in Wojkowice, Poland

Adrian Zarychta[1], Roksana Zarychta[2*]

[1]Department of Botany and Nature Protection, Faculty of Biology and Environmental Protection, University of Silesia, Jagiellońska Str. 28, 40-032 Katowice, Poland
[2]Department of Geoinformation and Geoenvironmental Research, Institute of Geography, Faculty of Geography and Biology, Pedagogical University of Cracow, Podchorążych Str. 2, 30-084 Kraków, Poland
*E–mail address (*corresponding author): roksana.zarychta@up.krakow.pl*

ABSTRACT

This article describes two methods of showing the distribution of temperature on the surface and inside a spoil tip (coal mine waste dump) located in Wojkowice (in the Silesian Voivodeship). Two deterministic estimation methods were tested, i.e., Inverse Distance Weighting (IDW) and Radial Basis Functions (RBF). According to isotherm maps the highest temperature on the surface of the "Wojkowice" spoil tip was in the NE area, while inside the heap the highest temperature noted was in the SW area. Better results were obtained from the application of the RBF method. A three-dimensional model (3D model) was generated by the method, which visualized the temperature distribution within the "Wojkowice" spoil tip. According to the 3D model of the temperature distribution the greatest heat centre inside the heap in Wojkowice was located in the SW part with a temperature of around 300°C. As a result, it can be concluded that the material of the "Wojkowice" spoil tip is burning out in a NW direction. On the basis of the model obtained it is possible to determine the location of potentially dangerous places which are exposed to possible deformations caused by the material burning under the surface. The results of the research presented make it possible to assess the thermal state of the spoil heap located in Wojkowice, Poland.

KEY WORDS: spoil tip, spoil dump, extractive waste, spontaneous combustion, Inverse Distance Weighting, Radial Basis Functions

ARTICLE HISTORY: received 21 October 2017; received in revised form 8 December 2017; accepted 10 December 2017

1. Introduction

Exploitation of mineral resources, in the case of both underground and open pit mines, contributes to significant changes in the natural environment. As a result of coal mining, surface deformations or land subsidence occur and therefore the level of groundwater is changed (KASZOWSKA, 2007). Exploitation of the raw material also results in a large amount of post-mining waste. Therefore, post-mining heaps of different shapes, surfaces and volumes (KORBAN, 2011) are formed. According to DRENDA ET AL. (2007) such anthropogenic objects are called spoil tips (hałda) in Upper Silesia. Improper methods of dumping the waste, as well as the presence of a high volume of combustible material in them, usually contribute to the activation of thermal processes.

Numerous publications on post-mining spoil tips have been published. They include works on: the occurrence of vegetation on spoil tips (e.g. ROSTAŃSKI, 2006; CIESIELCZUK ET AL., 2011; ALDAY ET AL., 2012; CIESIELCZUK ET AL., 2015a), their mineralogy and geochemistry (e.g. CIESIELCZUK ET AL., 2014; CIESIELCZUK ET AL., 2015b; RIBEIRO ET AL., 2016), their thermal state (e.g. WASILEWSKI & CHOROBA, 2011; KOTRYBA ET AL., 2012; NÁDUDVARI, 2014; WASILEWSKI & SKOTNICZY, 2015), fire hazards and the use of preventive technologies (e.g. DRENDA ET AL., 2007; CEBULAK ET AL., 2010; DULEWSKI ET AL., 2010; ŁĄCZNY ET AL., 2011; GOGOLA ET AL., 2012; SÝKOROVÁ ET AL., 2016).

So far, there has been little interest in the ways of presenting the temperature distribution on the surface and inside burning heaps, especially by application of deterministic estimation methods. Therefore, this article presents models showing temperature distribution on the surface and inside a poorly investigated spoil tip located in Wojkowice. The main aim of the study was to estimate sites on the surface and inside the examined heap where the highest temperatures were recorded using the Inverse Distance Weighting (IDW) and the Radial Basis Functions (RBF) methods. The estimation methods used to generate the visualizations were evaluated. This article was based on a poster prepared for the 1st Interdisciplinary Scientific Conference "Current Problems of Environmental Protection" held on May 19th, 2017 at the Faculty of Biology and Environmental Protection, University of Silesia in Katowice (Zarychta A. & Zarychta R., 2017).

2. Materials and research methods

A network of measurement points was determined within the "Wojkowice" spoil tip by means of a GNSS receiver (MobileMapper 120) (the study was conducted in February 2017). At each point, the temperature was measured by means of a pyrometer (DT-8858, with a temperature range from -50 to 1300°C). On the surface of the investigated heap, the temperature was measured at 109 points, while in its interior, 27 points were used (with a maximum depth of 1 m due to potential health and life hazards e.g. burns). The total number of points measured in the field was 136. Additionally, the ground temperature was measured in a place where thermal phenomena did not occur. The temperature there was equal to -17.2°C. After that, the collected data were used to generate models of temperature distribution (isothermal maps) on the surface and within the investigated anthropogenic object. To do that, two deterministic interpolation methods were used: Inverse Distance Weighting (IDW) and Radial Basis Function (RBF). Using these methods it was possible to extrapolate temperatures down to the depth of 6.5 m. The maximum temperature measured to the depth of 1 m was set as the highest (however, the occurrence of higher temperature values inside the spoil tip cannot be excluded) (Table 1). Statistical analyses were carried out to calculate the Mean Error (ME) and the correlation coefficient (r for p=0.05), which enabled the selection of the best of the applied methods. Finally, a 3D model was created to visualise the temperature distribution within the examined heap (to a depth of 6.5 m) based on the chosen estimation method). Statistica 13 software was used to carry out statistical analyses, while isotherm maps were drawn by means of the programme called Surfer 12.

3. Geographical location and characteristics of the spoil tip

The investigated post-mining spoil tip is located in the Silesian Voivodeship, in a town called Wojkowice which, according to the physico-geographical regionalization of Poland by Kondracki (2000), is located in the northern part of the Katowice Upland (belonging to the Silesian Upland). The spoil tip is situated within the boundaries of the post-excavation site of the former "Saturn" Cement Plant, 297 m a.s.l. It covers an area of about 0.55 ha, while its height is about 20 m (Figs 1 and 2).

Quite intensive thermal processes can currently be observed within the investigated spoil tip, which can be caused by gas emission, higher ground and air temperature, snow melting, the decay of plants, mineralization and other similar phenomena. These processes are the result of improper dumping of material (by gravitational pouring) which has caused loosening of the material and finally the formation of voids and fissures. The lack of any preventive measures during the dumping of waste on the spoil tip, and after completion of the process, especially the lack of waste compaction and an insulation layer, enables penetration of the spoil tip by precipitation and atmospheric oxygen, which is also facilitated by strong winds. Atmospheric oxygen can oxidise organic matter and pyrite contained in the waste. These processes are exothermic reactions which cause self-heating of the spoil tip and formation of fire centres. Consequently, carbon dioxide CO_2, carbon monoxide CO, sulphur dioxide SO_2, hydrogen sulphide H_2S, ammonia NH_3, chlorine Cl_2 and water vapour H_2O, and also many organic compounds are released to the atmosphere (Drenda et al., 2007). The places where combustion gases escape to the atmosphere are rapidly cooled down, which may cause re-sublimation of their components. Hence, such materials as sal ammoniac NH_4Cl, native sulphur and others, which are formed as a result of volcanic exhalation in natural conditions, can crystallise on the surface of the spoil tip (Nowak, 2014) (Fig. 3).

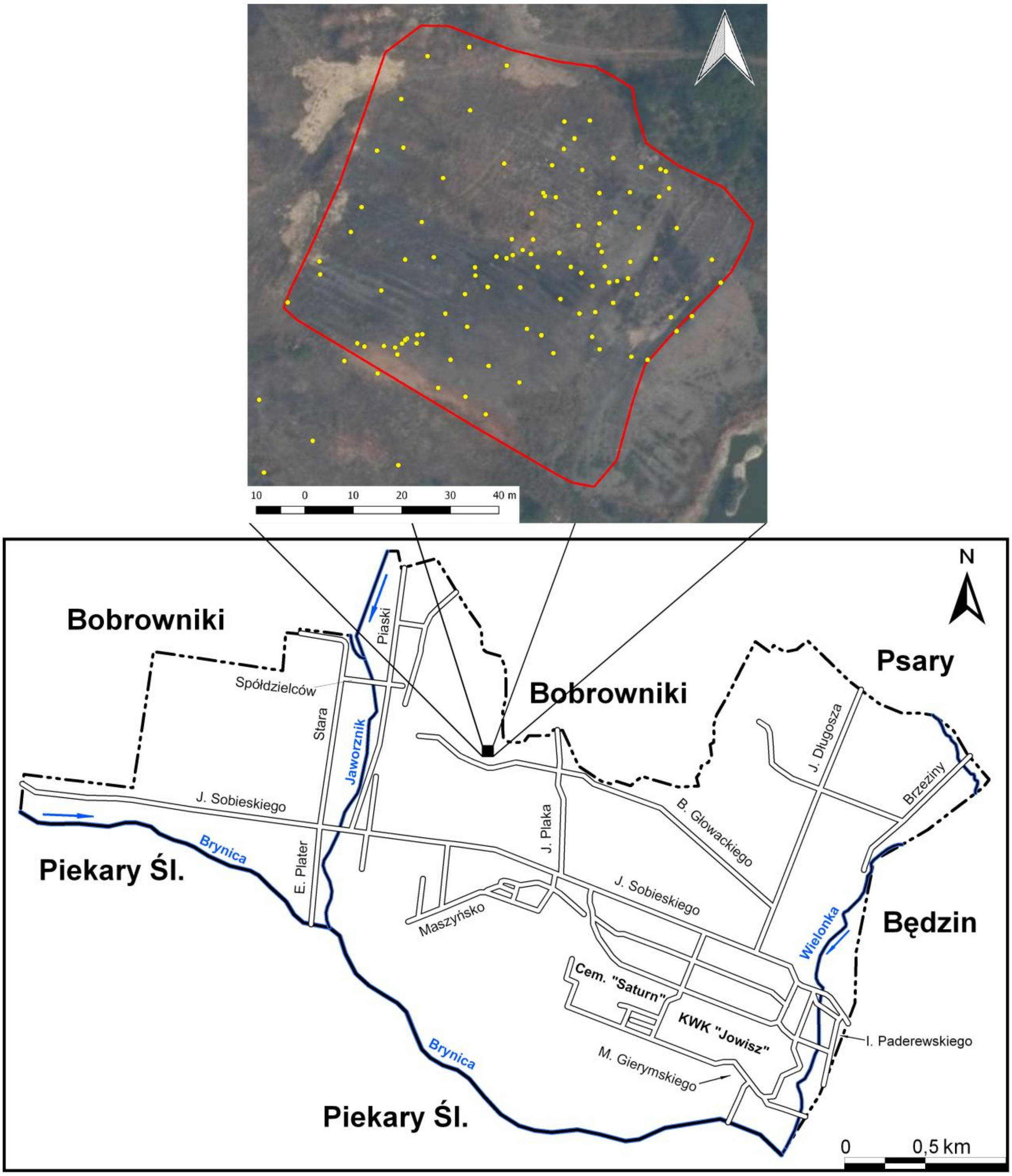

Fig. 1. Location of the "Wojkowice" spoil tip with sampling points (Zarychta R., Zarychta A. 2012, changed)

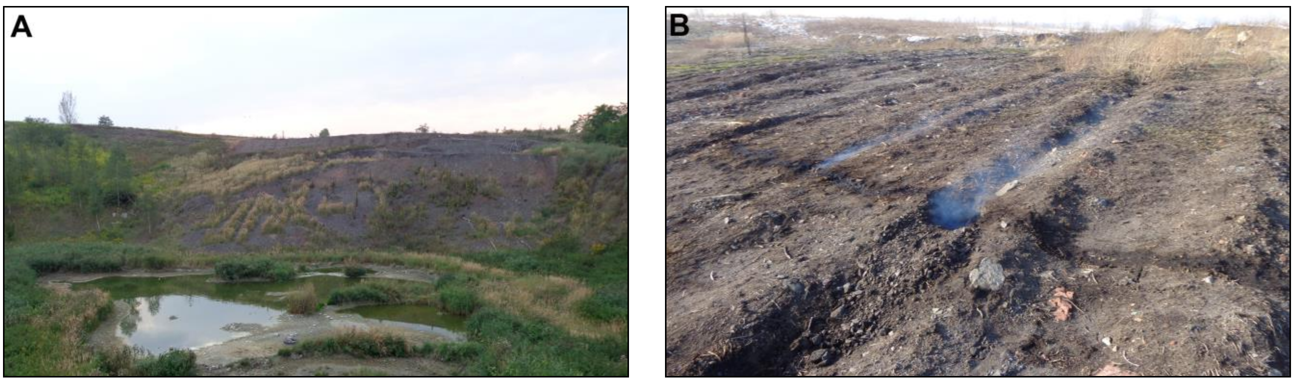

Fig. 2. A view of the "Wojkowice" spoil tip: A – August 2017; B – February 2017 (*A. Zarychta*)

Fig. 3. Sulphur efflorescence on the surface of the "Wojkowice" spoil tip, January 2017 (*A. Zarychta*)

4. Research results and discussion

Based on the data obtained from the field investigation (the total number of points measured on the surface and inside the heap was 136), models showing temperature (isotherm maps) on the surface and below the surface of the investigated spoil tip were generated. The models were based on two deterministic estimation methods, i.e. the Inverse Distance Weighting (IDW) and the Radial Basis Function (RBF) (Tables 1, 2 and 3; Fig. 4; the values of parameters in Tables 2 and 3 have been chosen in a particular way to obtain the lowest values of the Mean Error – ME).

There are varied temperature values on each map that result from the fact that a different type of estimator was used each time. The hottest spots stretched from NE to SW, with the highest temperature on the heap surface noted in the NE area, while inside the heap, the highest temperature was recorded in the SW area (Fig. 4).

Hence the question arises; which of the above maps showing the temperature distribution on and below the surface of the heap is the closest to the real situation?

The Mean Error and the correlation coefficient (r) were calculated to evaluate, and thus to select, the appropriate interpolation method to be used at the later stage to generate a three-dimensional model of the heap interior which would visualise the temperature distribution to a depth of 6.5 m.

Table 1. Basic parameters of the statistics (A – the spoil tip surface, B – interior of the spoil tip)

Temperature	A	B
	°C	
Average	12.1	25.8
Maximum	142.1	295.5
Minimum	-18.7	0

Table 2. Parameters used for the inverse distance weighting (A – the heap surface, B – interior of the heap)

Parameters		IDW	
		A	B
Power		2	2
Smoothing		2	2
Anisotropy	Ratio	1	1
	Angle	0	0

Table 3. Parameters used for the radial basis function (A – the heap surface, B – interior of the heap)

Parametres		RBF	
		A	B
Basis Function		multiquadratic	multiquadratic
R2 Parameter		0	0.35
Anisotropy	Ratio	1	1
	Angle	0	0

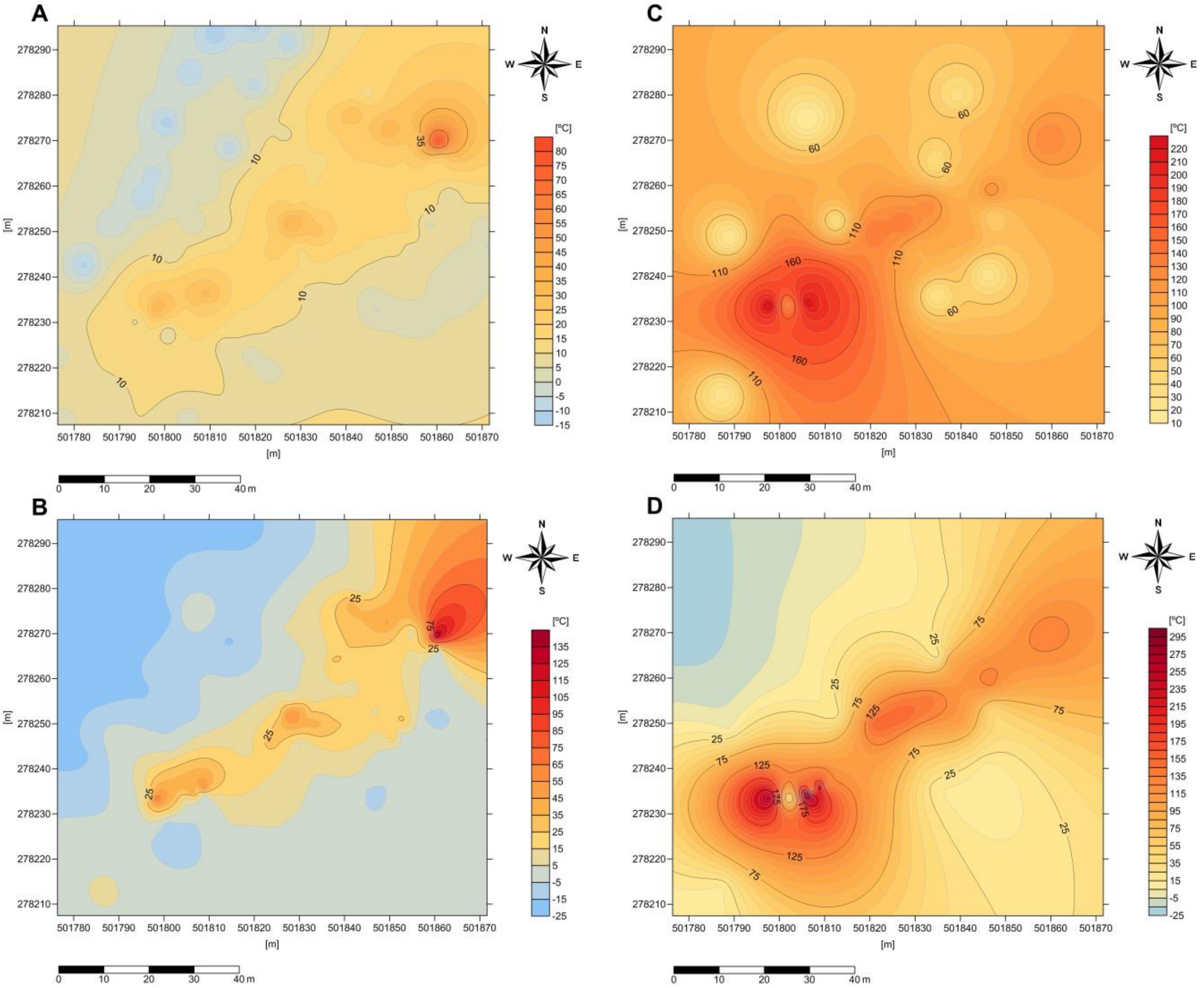

Fig. 4. Isotherm maps, referring to the temperature measured on the surface and inside the "Wojkowice" spoil tip, generated by means of IDW and RBF ETRS89/Poland CS92: A – temperature distribution on the heap surface obtained by the use of IDW; B – temperature distribution on the heap surface obtained by the use of RBF; C – temperature distribution inside the heap obtained by the use of IDW; D – temperature distribution inside the heap obtained by means of RBF

At the first stage, the Mean Error was calculated for the models obtained. The error was well distributed for the surface models of both methods, which was due to a relatively large number of measurement points. The situation was different in the case of the internal models, as the number of drilled holes was not so high, higher deviations of the estimated values from the real ones were observed. The lowest ME values were recorded in the case of RBF (Table 4). Only slight differences were proven between the temperature values measured on the surface and those inside the heap compared with the estimated ones (see: ZARYCHTA, 2013; Zarychta R. & Zarychta A., 2013).

The next step was the calculation of the correlation coefficient (r) for the real data and the estimated ones for the surface and below the surface of the heap by means of IDW and RBF methods. A positive correlation was recorded in all cases. The correlation coefficient of the data collected on the heap surface and the estimated ones obtained by means of the Inverse Distance Weighting was 0.984, and when the Radial Basis Function was used it was equal to 0.993. When considering the correlation coefficient of the temperature data collected inside the heap and the temperature estimated by means of the Inverse Distance Weighting, it was 0.973, while in the case of the Radial Basis Function it was 0.997. All the results obtained showed a moderate correlation of the data (Fig. 5).

Table 4. Values of the Mean Error, referring to the maps of isotherms of the "Wojkowice" spoil tip generated by means of IDW and RBF (A – the surface the heap, B – inside the heap)

Error	IDW		RBF	
	A	B	A	B
ME [°C]	3.776	18.711	1.369	7.683

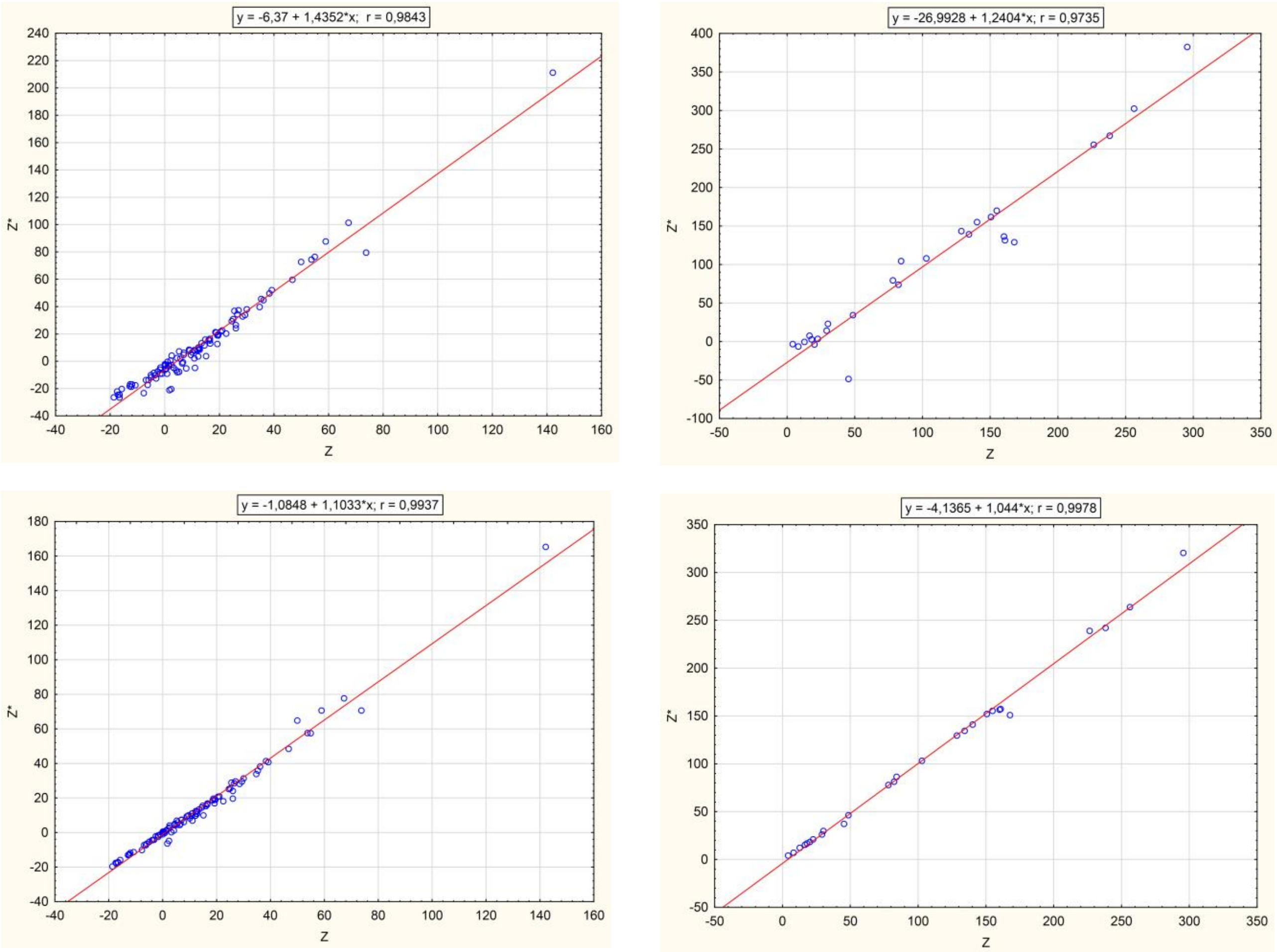

Fig. 5. A dispersion diagram of the real (Z) and estimated (Z*) values obtained by means of IDW and RBF within the "Wojkowice" spoil tip: A – for points located on the surface of the heap, application of IDW; B – for points located on the surface of the heap, application of RBF; C – for points located inside the heap, application of IDW; D – for points located inside the heap, application of RBF

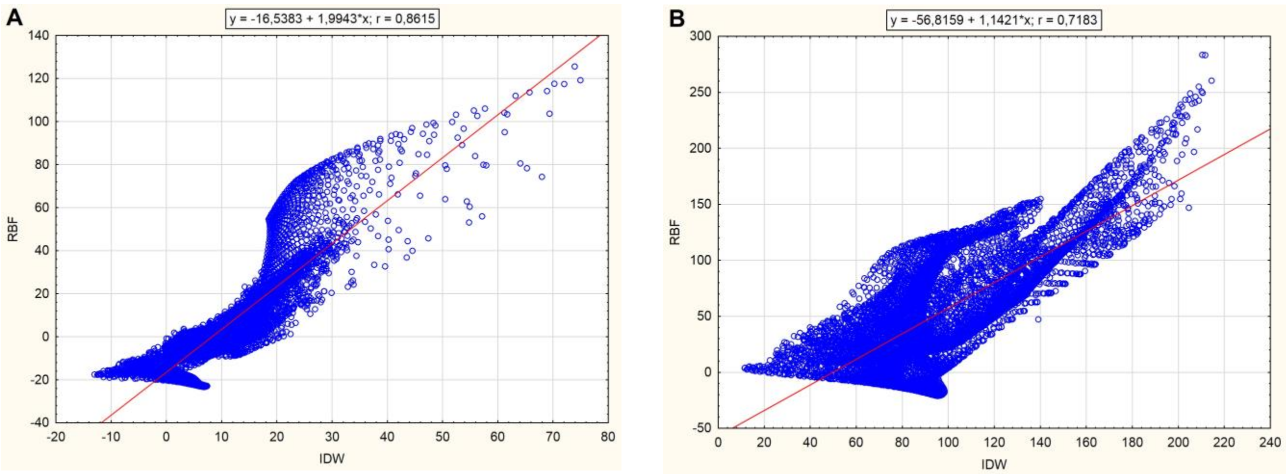

Fig. 6. Diagrams of dispersion between the models of the temperature distribution obtained by means of the two different estimation methods within the "Wojkowice" spoil tip: A – a correlation between the models showing the temperature on the heap surface; B – a correlation between the models showing the temperature inside the heap

Additionally, the models of temperature distribution obtained by using the two different estimation methods were checked to see if there was any correlation between them and a positive correlation was reported. The correlation coefficient for the surface models obtained by means of IDW and RBF was 0.861, while for modelling the temperature distribution inside the heap, it was 0.718. Hence, a relatively strong correlation between the maps of isotherms was shown (Fig. 6).

When analysing the results obtained, the following question arose: why were the estimated temperature values inside the heaps statistically worse than those estimated on the surface of the spoil heap studied? The answer to the question may not be possible until other estimation methods based on geostatistics are tested, particularly those methods which use more variables for the analysis, for example cokriging.

Basing on the information provided in this article, the Inverse Distance Weighting method contributes to an underestimation of the high and low values. This is due to the application of a smoothing factor that has a decisive effect on the final result, despite the fact that the method is based on a precise interpolator. When smoothing is relinquished, clear concentric circles appear on the map around the sampling points. In the Radial Basis Function method, there is no overestimation or underestimation of values in the points of the interpolation grid. As a result, the measured values are the same as the values measured in the field. However, isotherm maps based on the RBF method show points with negative temperatures. This is due to the lack of measurement points at those locations and the fact that the distance between the defined interpolation points and the measurement points was too big, on the basis of which the estimation was performed.

Considering the above facts, the optimum method of interpolation was chosen. The Radial Basis Function method (RBF) showed better isotherms and better statistics.

After choosing the estimating method, the temperature data were gauged to the depth of 6.5 m inside the Wojkowice spoil tip. As a result, a three-dimensional model, showing the temperature distribution inside the spoil tip was generated. As the depth increased, the heap temperature changed. In the SW part of the spoil tip, the greatest heat centre was found at a depth of about 1.5 m where the temperature was around 300°C. The occurrence of new "heat cells" in the central part of the heap and in the NE allowed the assumption that the material in the heap was burning in that direction (Fig. 7).

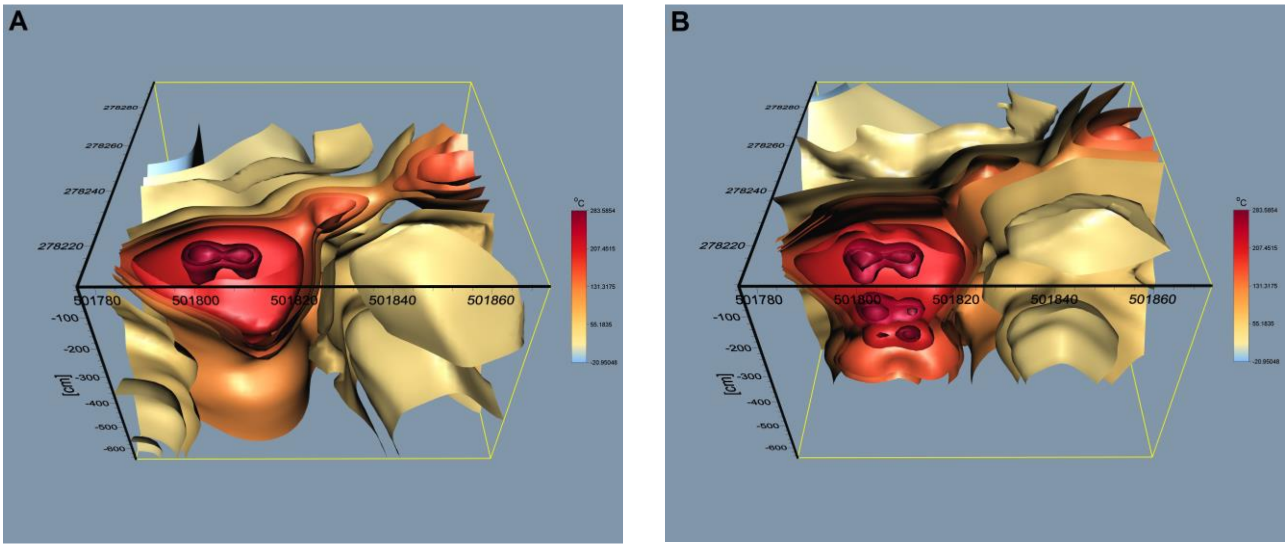

Fig. 7. 3D model, visualizing the temperature distribution inside the "Wojkowice" spoil tip; ETRS89/Poland CS92: A – coordinates on the Z axis; B – coordinates on the Y axis)

Conclusions

The two estimation methods, i.e., Inverse Distance Weighting (IDW) and Radial Basis Function (RBF) which have been presented in this article gave similar results. However, the RBF proved to be better, not only because of the maps obtained, but also because of the calculated statistics. Application of the method allowed the creation of a 3D visualization, which presented the probable temperature distribution within the spoil tip located in Wojkowice.

The results of the research are applicable to an assessment of the thermal state of a particular anthropogenic object. As a result, it is possible, for example, to specify the direction in which the material within the heap might burn or to predict those places most vulnerable to spontaneous combustion (see ZARYCHTA A. & ZARYCHTA R., 2017). Such information will certainly be useful at a given spoil tip when adopting more efficient extinguishing actions and fire protection measures.

References

Alday J.G., Marrs R.H., Martínez-Ruiz C. 2012. Soil and vegetation development during early succession on restored coal wastes: a six-year permanent plot study. *Plant and Soil*, 353(1-2): 305–320.

Cebulak S., Gardocki M., Miczajka M., Szlosarek M., Tabor A. 2010. Wstępna ocena możliwości stosowania proszków gaśniczych w prewencji endogenicznych pożarów w obiektach zagospodarowania odpadów z wydobycia węgla kamiennego. *Górnictwo i Geologia*, 5(4): 77–90.

Ciesielczuk J., Czylok A., Cebulak S. 2011. Sukcesja roślinna oraz gigantyzm obserwowane na palącej się hałdzie w Katowicach-Wełnowcu, Polska. *Documenta Geonica*, 1: 51–54.

Ciesielczuk J., Czylok A., Fabiańska M. J., Misz-Kennan M. 2015a. Plant occurrence on burning coal waste – a case study from the Katowice-Wełnowiec dump, Poland. *Environmental and Socio-Economic Studies*, 3(2): 1–10.

Ciesielczuk J., Kruszewski Ł., Majka J. 2015b. Comparative mineralogical study of thermally-altered coal-dump waste, natural rocks and the products of laboratory heating experiments. *International Journal of Coal Geology*, 139: 114–141.

Ciesielczuk J., Misz-Kennan M., Hower J.C., Fabiańska M.J. 2014. Mineralogy and geochemistry of coal wastes from the Starzykowiec coal-waste dump (Upper Silesia, Poland). *International Journal of Coal Geology*, 127: 42–55.

Drenda J, Różański Z, Słota K, Wrona P. 2007. Zagrożenie pożarowe na zwałowiskach odpadów powęglowych. *Górnictwo i Geoinżynieria*, 31(3/1): 149–157.

Dulewski J., Madej B., Uzarowicz R. 2010. Zagrożenie procesami termicznymi obiektów zagospodarowania odpadów z górnictwa węgla kamiennego. *Gospodarka Surowcami M*ineralnymi, 26(3): 125–142.

Gogola K., Bajerski A., Smoliński A. 2012. Modyfikacja metody oceny zagrożenia pożarowego na terenach lokowania odpadów powęglowych. *Prace Naukowe GIG, Górnictwo i Środowisko*, 2: 13–32.

Kaszowska O. 2007. Wpływ podziemnej eksploatacji górniczej na powierzchnię terenu. *Problemy Ekologii*, 11(1): 52–57.

Kondracki J. 2000. *Geografia regionalna Polski*. Państwowe Wydawnictwo Naukowe, Warszawa.

Korban Z. 2011. Problem odpadów wydobywczych i oddziaływania ich na środowisko, na przykładzie zwałowiska nr 5A/W-1 KWK „X". *Górnictwo i Geologia*, 6(1): 109–120.

Kotryba A., Grądziel M., Gogola K. 2012. Zastosowanie metody elektrooporowej w badaniach stanu termicznego zwałowisk odpadów powęglowych. *Przegląd Górniczy*, 68(4): 53–61.

Łączny M.J., Olszewski P., Gogola K., Bajerski A. 2011. Czynniki wpływające na wybór technologii prewencyjnych, profilaktycznych i gaśniczych stosowanych na obiektach uformowanych z odpadów powęglowych. *Prace Naukowe GIG, Górnictwo i Środowisko*, 4: 87–102.

Nádudvari Á. 2014. Thermal mapping of self-heating zones on coal waste dumps in Upper Silesia (Poland) – A case study. *International Journal of Coal Geology*, 128–129: 47–54.

Nowak J. 2014. Wpływ stopnia termicznego przeobrażenia odpadów powęglowych na ich skład mineralny i petrograficzny. *Gospodarka Surowcami Mineralnymi*, 30(1): 143–160.

Ribeiro J., Suárez-Ruiz I., Ward C.R., Flores D. 2016. Petrography and mineralogy of self-burning coal wastes from anthracite mining in the El Bierzo Coalfield (NW Spain). *International Journal of Coal Geology*, 154–155: 92–106.

Rostański A. 2006. *Spontaniczne kształtowanie się pokrywy roślinnej na zwałowiskach po górnictwie węgla kamiennego na Górnym Śląsku*. Wydawnictwo Uniwersytetu Śląskiego, Katowice.

Sýkorová I., Kříbek B., Havelcová M., Machovič V., Špaldoňová A., Lapčák L., Knésl I., Blažek J. 2016. Radiation- and self-ignition induced alterations of Permian uraniferous coal from the abandoned Novátor mine waste dump (Czech Republic). *International Journal of Coal Geology*, 168: 162–178.

Wasilewski S., Choroba T. 2011. Zdalne pomiary temperatury w ocenie aktywności termicznej składowisk odpadów węglowych. *Górnictwo i Geoinżynieria*, 35(1): 93–106.

Wasilewski S., Skotniczny P. 2015. Mining waste dumps – modern monitoring of thermal and gas activities. *Gospodarka Surowcami Mineralnymi*, 31(1): 155–182.

Zarychta A., Zarychta R. 2017. Wykorzystanie IDW przy wizualizacji rozkładu temperatury wewnątrz zwałowiska położonego w Wojkowicach. [In]: E. Sierka, A. Nadgórska-Socha [eds.] *Aktualne problemy ochrony środowiska. Ocena stanu, zagrożenia zasobów i stosowane technologie*. Uniwersytet Śląski, Wydział Biologii i Ochrony Środowiska, Katowice: 62.

Zarychta R, Zarychta A. 2012. Walory hydrologiczne gminy Wojkowice. *Kształtowanie środowiska geograficznego i ochrona przyrody na obszarach uprzemysłowionych i zurbanizowanych*, 44: 71–83.

Zarychta R. 2013. The validity of cross-validation usage in generating digital relief model of an anthropogenically transformed area. *Environmental and Socio-economic Studies*, 1(4): 1–11.

Zarychta R., Zarychta A. 2013. Zastosowanie krigingu zwyczajnego do rekonstrukcji i wizualizacji reliefu w miejscach odkrywkowej eksploatacji piasku. [In]: Z. Kurczyński [ed.] *Geodezyjne Technologie Pomiarowe*. Wydanie specjalne Archiwum Fotogrametrii, Kartografii i Teledetekcji, Warszawa, pp. 133–146.