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## ASH DUST CONCENTRATION IN THE VICINITY OF THE ASH DISPOSAL SITE DEPENDING ON THE SIZE OF THE POND ("WATER MIRROR")\*

*Thermal power plants Nikola Tesla "A" and "B" are large sources of ash from their ashes/slag deposit sites. Total sizes of ashes/slag depots are 600ha and 382ha, with active cassettes having dimensions ~200 ha and ~130 ha. The active cassettes of the disposal sites are covered by rather large waste ponds, the sizes of vary depending on the working condition of a sluice system and on meteorological conditions. Modeling of ash lifting was attempted using results from the dust lifting research. The relation between sizes of ponds and air dust concentration in the vicinity of ash disposal sites was analyzed. As expected, greater sizes of dried disposal site surfaces in combination with stronger winds gave greater dust emission and greater air dust concentration.*

*Key words: fly ash, dust; ash disposal sites; thermal power plants "Nikola Tesla A and B"; size of ash disposal sites ponds.*

Thermal power plants Nikola Tesla "A" and "B" (TENTA and TENTB in the following text), located in Obrenovac near Belgrade, use lignite coal with the high ash content for the power production. The use of coal with the high ash content leads to the increase of environmental problems with gaseous emissions but also with the disposal of ashes residues. The total sizes of ashes/slag depots are 600 ha and 382 ha for TENTA and TENTB respectively; active cassettes have dimensions ~200ha and ~130ha.

In Figure 1 ellipses denote positions of two ash deposits, sites TNTB and TNTA. The areas of both ash disposal sites are separated in two parts, one third is active, where fresh ash/sludge is disposed in liquid form and two thirds are partly biologically recultivated. Active cassettes of the disposal sites are covered by rather large waste ponds, the sizes of vary

depending on working condition of the sluice system and on meteorological conditions. On average, about 50% of surfaces of active waste disposal sites are covered with waste ponds. The waste ash, in liquid configuration of 10 L water per kg of ash, is transported to the disposal sites by the use of conveyor tubes. The sluice system consists of the nozzle net for damping the active parts of disposal sites, but there are situations when this system is not working for long periods of time due to technical problems or if the air is quite below freezing temperatures. The size of ponds in such situations could be quite reduced.

The aim of the present study was to develop a method for quantitative determination of dust lifting from ash disposal sites and for quantitative determination of the air dust concentration depending on the size of disposal site ponds. This algorithm could be used for managing systems of damping ash disposal sites and for maintaining the size of disposal site ponds.

### Lifting of the ash into the atmosphere and corresponding air concentrations

The first step in modelling of the concentration of ash in the air is parameterization of the lifting mechanism. Our approach was to use the parameteri-

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zation corresponding to the dust having the texture closest to ash. The starting point was the literature on dust lifting [1-4]. Several authors have pointed out saltating (sandblasting) as the most important mechanism for lifting dust aerosols to the atmosphere. The similar idea is probably valid for ashes. If surfaces of ashes and coal depots are sufficiently dry, *i.e.*, if surfaces of ashes/slag depots are not protected with the pond, a strong wind is able to roll “greater” particles (known as surface creep) or to lift some of them to the distances up to approximately 1 m downwind (saltating particles). Saltating, sand-sized particles sandblast the surface and eject fine particles which remain suspended in the air for a long period by air turbulence and which can be transported to great distances downwind. The mechanism is schematically shown in Figure 2. The most common approach in its parameterization [1] is depicted by the following equation:

$$q = A \frac{\rho}{g} \sum_{u^*} u^* (u^2 - u_{*v}^2) \tag{1}$$

where:  $q$  is instantaneous horizontal (saltation) mass flux ( $\text{g cm}^{-1}$ ),  $A$  is unit less parameter (usually assumed to be equal to 1),  $\rho$  is density of air ( $\text{g cm}^{-3}$ ),  $g$  is acceleration of gravity ( $\text{cm s}^{-2}$ ),  $u^*$  is wind shear velocity ( $\text{cm s}^{-1}$ ) and  $u_{*v}$  is threshold shear velocity ( $\text{cm s}^{-1}$ ).

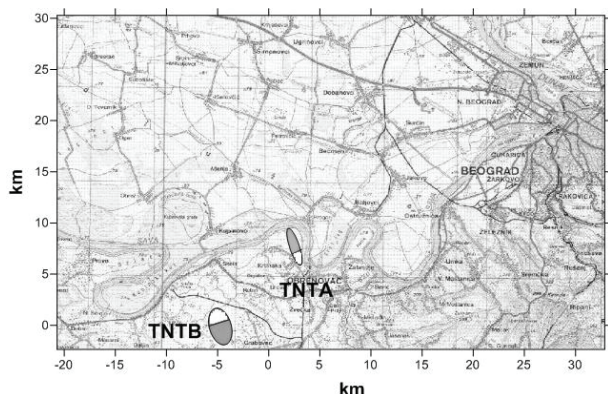


Figure 1. Calculating domain, 53.5 km x 32.5 km, and locations of TNTA and TNTB ash disposal sites (ellipses).

The wind shear velocity  $u^*$  is related to wind speed at height  $z$  under neutral condition (wind speed greater or equal to  $6\text{ms}^{-1}$ ) by:

$$U(z) = \frac{u^*}{k} \ln\left(\frac{z-D}{z_0}\right) \tag{2}$$

where:  $U(z)$  wind speed at height  $z$ ,  $k$  is von-Karman’s constant (0.4),  $z_0$  is roughness height (cm),  $D$  is displacement height (cm). The threshold shear velocity,  $u_{*v}$ , is the minimum friction wind speed assu-

med to give dust emission; it is related to soil roughness and soil characteristics.

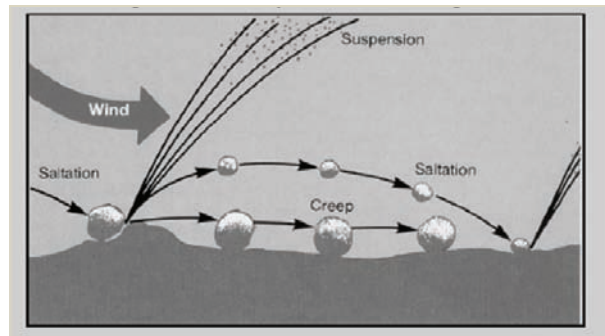


Figure 2. Saltation of dust (saltation geology from Wikipedia, the free encyclopedia [http://en.wikipedia.org/wiki/saltation\\_\(geology\)](http://en.wikipedia.org/wiki/saltation_(geology)), accessed 15 March 2010).

Because of sandblasting by saltation-sized particles, vertical dust flux,  $F$  ( $\text{g cm}^{-2} \text{s}^{-1}$ ), is linearly related to instantaneous horizontal (saltation) mass flux  $q$ , Eq. (1), by a constant  $K$  ( $\text{cm}^{-1}$ ) [1-5]:

$$F = Kq \tag{3}$$

The value of  $K$  is typically on order  $10^{-5}$ - $10^{-6}$  [5] and it is strongly dependent on depots surface texture, crusting and moisture.

**Numerical experiments**

In order to calculate the lifting of the dust from ash depots, dried surfaces of disposal sites were divided into numerous numbers of smaller cells-dust sources, characterized by its dimensions 100 m x 100 m, coordinates and surface texture (parameters  $u_{*v}^*$ ,  $z_0$ ,  $D$  and  $K$ ). In Figures 3-10 this is depicted by the grid overlaying the maps of the depots. Surface characteristics are the same in both the disposal sites. Some other characteristics of ash disposal sites, TNTA and TNTB, are presented in Table 1. The calculating domain was 53.5 km x 32.5 km with dimensions of network cells 100 m x 100 m. The values of parameters  $u_{*v}^* = 0.29 \text{ cm/s}$ ,  $z_0 = 0.3 \text{ cm}$ ,  $D = 1 \text{ mm}$  were taken from references [3-4]. From Eq. (2) and with previous values of parameters, threshold wind speed was calculated to  $U_{*v}(10) = 10.1 \text{ m/s}$ . Several sizes of dried surfaces were taken into consideration, that is, active cassettes were covered with ponds of different sizes and shapes. These variations of the size of ponds from 0% of total disposal ash sites (no presence of ponds) to 75% are given in Figures 3-10.

In the absence of the appropriate direct dust concentration and meteorological measurements at the site itself, we present the concentrations calculated using a Gaussian type model:

$$c(x, y, z) = \frac{q}{2\pi\sigma_y\sigma_z u} \exp\left(-\frac{1}{2} \frac{y^2}{\sigma_y^2}\right) \left\{ \exp\left[-\frac{1}{2} \frac{(z-H)^2}{\sigma_z^2}\right] + \exp\left[-\frac{1}{2} \frac{(z+H)^2}{\sigma_z^2}\right] \right\} \quad (4)$$

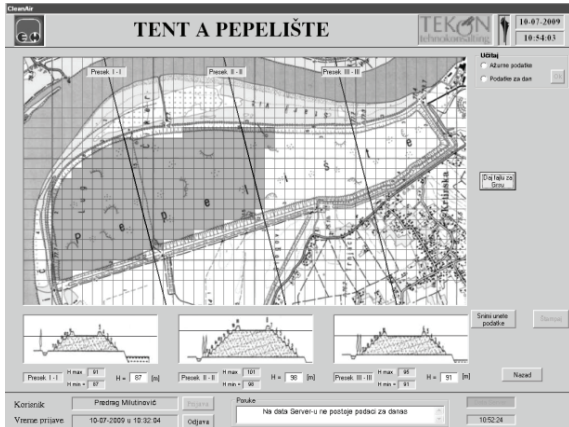


Figure 3. Ash disposal site TNTA, dry 100% of active area white painted ~130 ha.

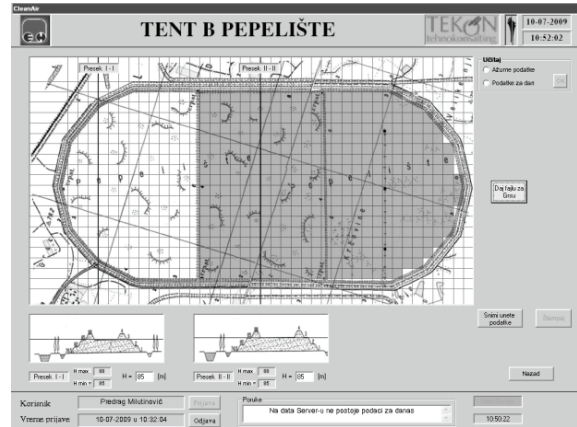


Figure 4. Ash disposal site TNTB, dry 100% of active area white painted ~200 ha.

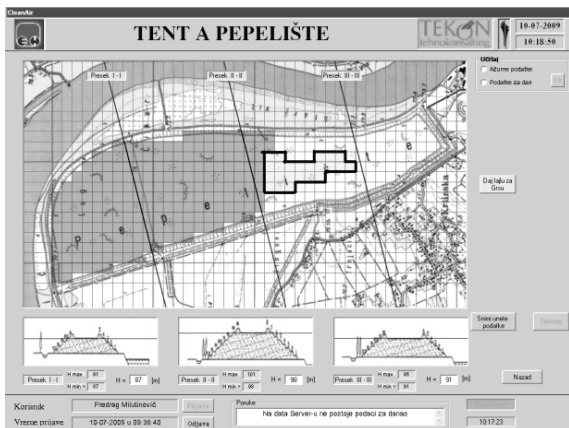


Figure 5. Ash disposal site TNTA, dry 75% of active area white painted; pond thick line edged.

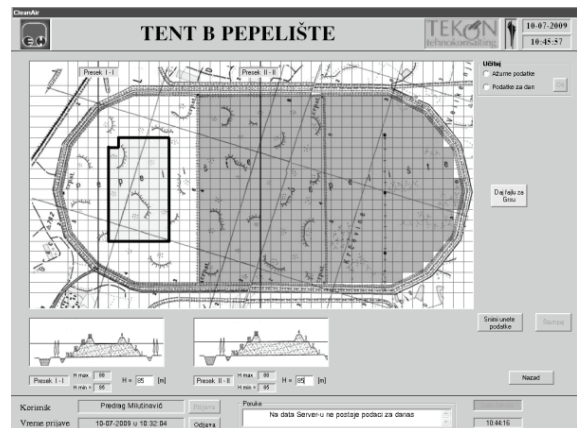


Figure 6. Ash disposal site TNTB, dry 75% of active area white painted; pond thick line edged.

where:  $c(x,y,z)$  is air pollution concentration at grid point  $(x,y,z)$  - receptor ( $\mu\text{m}^3$ ),  $y$  is lateral (crosswind) distance from the plume axis (m),  $z$  is height of the receptor above ground (m),  $Q$  is source strength (kg/h),  $H$  is effective height of source emission (m),  $\sigma_y$  and  $\sigma_z$  are diffusion coefficients in  $y$  and  $z$  directions (m), respectively, and  $u$  is average wind speed (m/s). Source strength  $Q$  is described by:

$$Q = FS \quad (5)$$

where:  $S$  is area of the source emission ( $\text{m}^2$ ). More details about the dispersion model can be found elsewhere [6-9].

The other parameter relevant for the amount of dust in the air is wind speed,  $u$ , so in Fig. 11 we present our results for different waste pond sizes and

different wind strengths. Parameter  $K$  was set to the value of  $10^{-6} \text{ cm}^{-1}$ . Figure has 12 panels, with depots size going downward while from left to right we have winds with decrease in strength (wind strengths were 20.0 and 10.1  $\text{m s}^{-1}$ ). As it can be expected, a dominant parameter in dust lifting is wind strength, due to the nonlinear nature of Eq. (1). We see the decrease in concentrations due to the decrease of the dry areas, but it is close linear as one expects.

The last group of experiments is for different value of parameter  $K$ , which presumably measures, among other factors, the wetness of the surface (Fig. 12). With the increase of its value to  $10^{-5} \text{ cm}^{-1}$ , we get a visible increase in the order of concentrations, but the qualitative conclusions from the previous value for  $K$  stay.



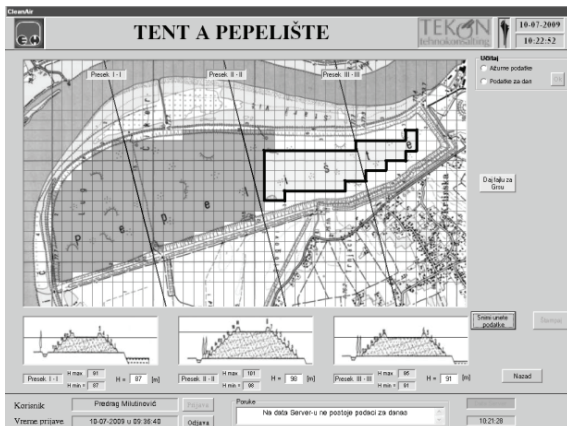


Figure 7. Ash disposal site TNTA, dry 50% of active area white painted; pond thick line edged.

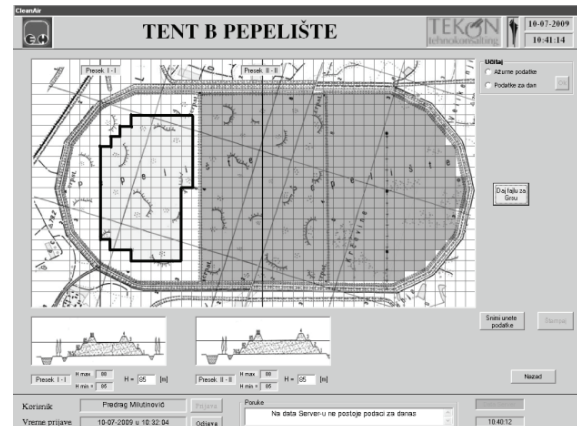


Figure 8. Ash disposal site TNTB, dry 50% of active area white painted; pond thick line edged.

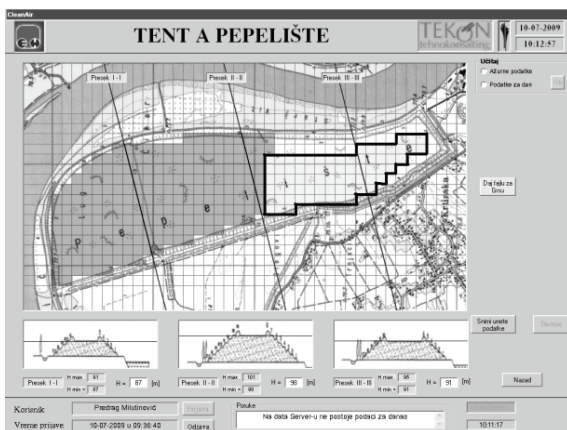


Figure 9. Ash disposal site TNTA, dry 25% of active area white painted; pond thick line edged.

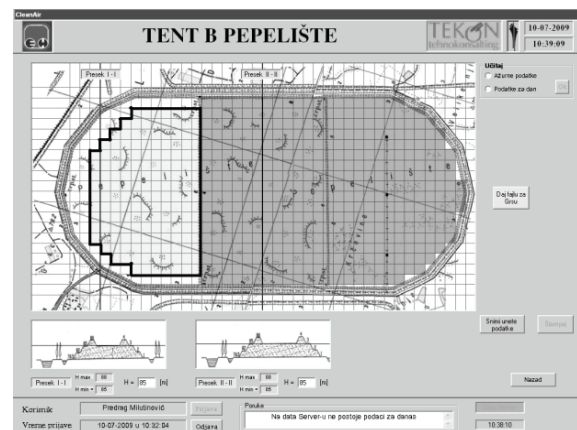


Figure 10. Ash disposal site TNTB, dry 25% of active area white painted; pond thick line edged.

Table 1. Ash/slag disposal site TENTA and TENT B

Ash disposal sites	TNTA	TNTB
Surface	~380 ha; active: ~130 ha	~600 ha; active: ~200 ha
Height	~18-25 m	~29 m

**RESULTS**

Several experiments were done for different wind speed, different sizes of source areas and finally two different values of parameter *K*. For larger values of parameter *K* ( $10^5$ ), lifted dust flux reached maximum of  $18164 \mu\text{g m}^{-2} \text{s}^{-1}$ , with the wind speed of  $20 \text{ m s}^{-1}$  and  $5668$  and  $52 \mu\text{g m}^{-2} \text{s}^{-1}$  for the wind speed of  $15$  and  $10 \text{ m s}^{-1}$  respectively. When we decreased the value for *K* ( $10^6$ ) by order of magnitude, dust flux was reduced by order of magnitude to  $1816.4$ ,  $566.8$  and  $5.2 \mu\text{g m}^{-2} \text{s}^{-1}$  for the same winds as before.

From the environmental point of view the most adverse situation is: greater value of *K* ( $10^5$ ), strong wind of  $20 \text{ m/s}$  with permanent wind direction and

with maximum dry area of the active cassette (100% dry). These conditions will give maximum daily averaged concentrations of  $33000 \mu\text{g m}^{-3}$  in the vicinity of the source TNTB while further away concentration reaches  $1500 \mu\text{g m}^{-3}$ , (30 times overestimates dust environment limit value  $50 \mu\text{g m}^{-3}$ ), see (Fig. 12a). Such large values for *K* are appropriate in the case of very fine dust, very dry and without crust that does form when wet ash dries out and it is not appropriate for real ash deposit sites.

More realistic is the situation for the lower value of *K* ( $10^6$ ), after the ash dried, with 50% of the area being dry and considered as the ash source. In that case the wind of  $20 \text{ m/s}$  (very strong wind) will generate maximum daily dust concentrations of about  $1500$

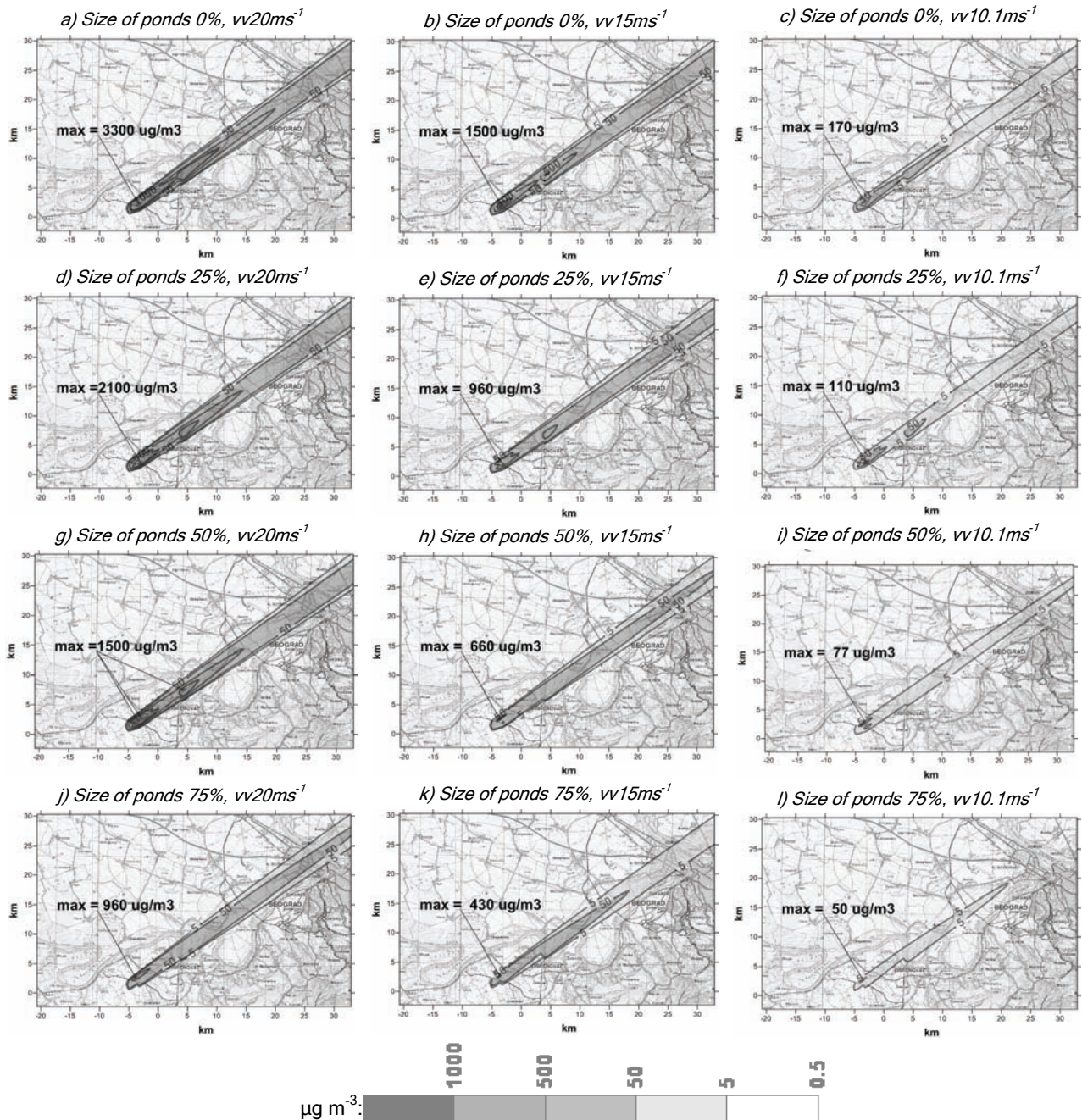


Figure 11. Air dust concentration for  $K = 10^6$  and for various wind speeds  $v_v$  (20, 15 and  $10.1\text{ m s}^{-1}$ ) and for various sizes of ash disposal site ponds (0%, 25%, 50% and 75% of a size of active cassette).

$\mu\text{g m}^{-3}$  in the vicinity of the source, while further away that concentration reaches  $150\text{ }\mu\text{g m}^{-3}$  (3 times overestimates 24-hour limit value for the protection of human health  $50\text{ }\mu\text{g m}^{-3}$ ), see (Fig. 11g). Note that concentration isolines are closed around both TNTA and TNTB power plants in both  $K$  values. This is the result of the wind but also of the size of the source areas. As we said before we did not consider the shapes of various water mirrors since they are formed in a random fashion depending on the amount of the new ash, on the present state of dryness area and on

the speed of discharge from the conveyer tubes. The wind direction was chosen as the one which is the most adverse in creating pollution over the city of Belgrade area. We have compared these results with historical data of ash concentration measurements at several sites and they agree quite well with ours for some strong values of the wind speed. Unfortunately, wind measurements were not available for those locations except qualitative statements that wind was very strong.



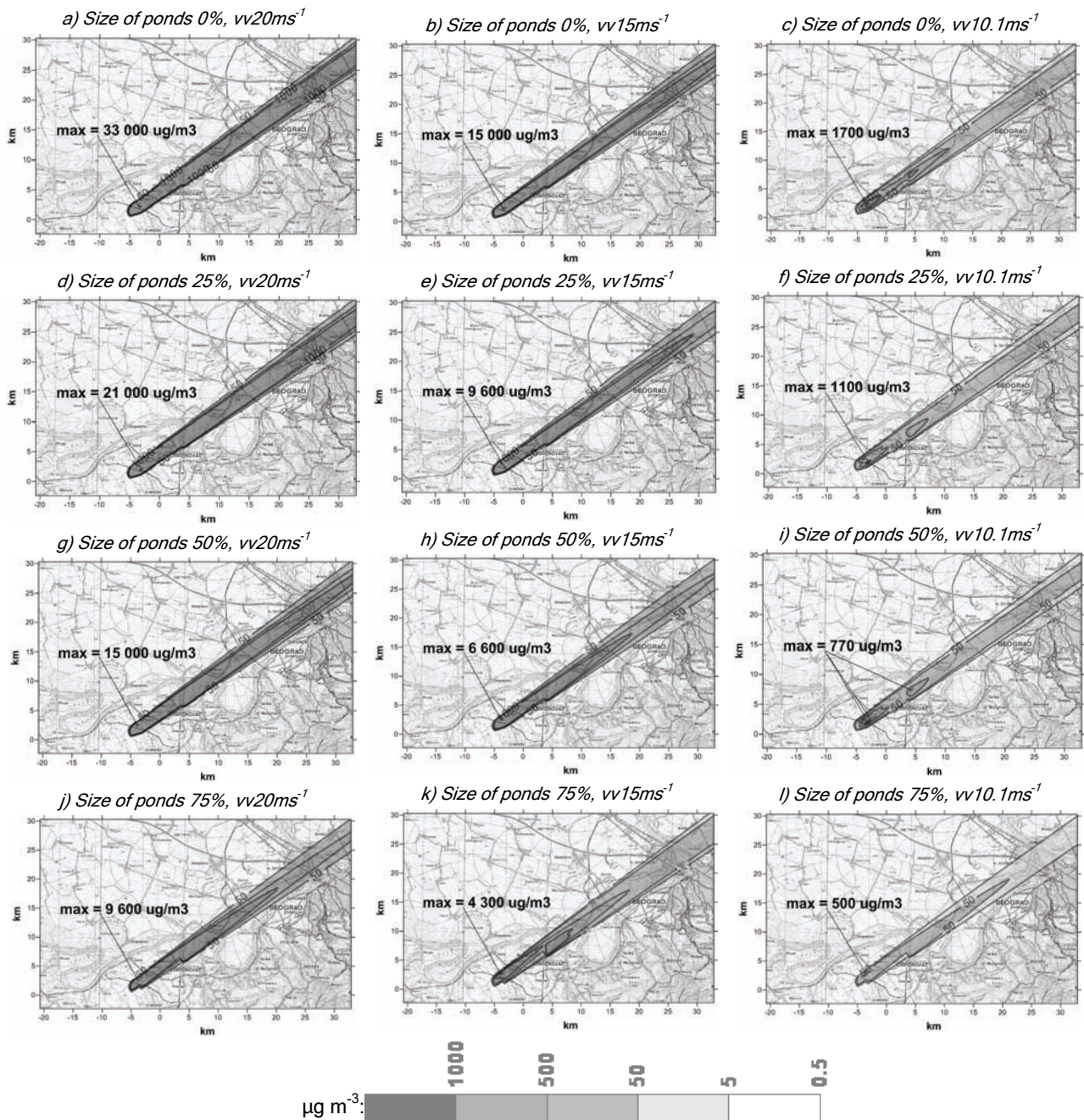


Figure 12. Air dust concentration for  $K = 10^5$  and for various wind speeds  $vv$  ( $20$ ,  $15^1$  and  $10.1 \text{ m s}^{-1}$ ) and for various sizes of ash disposal site ponds ( $0$ ,  $25$ ,  $50$  and  $75\%$  of a size of active cassette).

**CONCLUSION**

Presented results confirmed expectations that greater sizes of ash disposal site ponds restrain negative influences of ash disposal sites to their environment. The most influential factor is the wind speed if it is over threshold limit for dust lifting. For ash disposal sites of TNTA and TNTB it is necessary to investigate in details particle size distribution and surface characteristics of disposal sites like roughness, threshold shear velocity and especially their texture

because the final results depend very much on the values of parameter  $K$ . The appropriate meteorological measurements, continuous monitoring of shapes and sizes of the ponds, are necessary to better understand the importance of appropriate maintaining disposal sites ponds due to minimizing the environmental problems with ash disposal sites of TNTA and TNTB. At last, both models, dust lifting and atmospheric dust dispersion, have to be calibrated in field experiments and by using measured values of dust

concentrations in numerous points of monitoring network at representative locations of TNTA and TNTB.

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NAUČNI RAD

## KONCENTRACIJA PRAŠINE U VAZDUHU U OKOLINI DEPONIIJA PEPELA U ZAVISNOSTI OD VELIČINE VODENOG POKRIVAČA („VODENOG OGLEDALA“)

*Deponije pepela i šljake termoelektrana Nikola Tesla „A“ i „B“ u Obrenovcu, veliki su potencijalni izvori zagađivanja okoline. Ukupne površine deponija su oko 600 i 382 ha, sa površinama aktivnih kaseti ~200 ha i ~130 ha, respektivno. Aktivne kaste pepelišta pokrivene su jezerima otpadne vode, čije se dimenzije menjaju, između ostalog i u zavisnosti od rada sistema prskalica i od meteoroloških uslova. Podizanje pepela sa deponija dobijeno je matematičkim modelima, koji se zasnivaju na istraživanju podizanja prašine sa tla. U radu je analiziran odnos između veličine površine vodenih ogledala i koncentracije prašine u vazduhu u okolini posmatranih deponija. Kao što se i očekuje, veće površine suvih delova deponija u kombinaciji sa većim brzinama vetra, korespondiraju sa podizanjem većih količina pepela i većim koncentracijama prašine u njihovoj okolini.*

*Ključne reči: leteći pepeo; deponije pepela; termoelektrane „Nikola Tesla A i B“; veličina vodenog pokrivača pepelišta.*