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Analysis of the emission of SO_2, NO_x, and suspended particles from the thermal power plants Kostolac (Serbia)

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Abstract

Environmental situation related to the thermal power basin of Kostolac for the most part represents the result of the influence of the Thermal Power Plants of Kostolac A, Kostolac B and the open-pit lignite mine. The quality of air is monitored by continuously measuring concentrations of the overall precipitation matters and gases such as CO2, SO2, NO?, CO, and O3. Values significantly exceeding the legal limits have been found for pollutants in the surroundings of the TPPs Kostolac A and B and in the direction of dominant winds. The paper analyses the impact of different scenarios of emission of harmful matters from the blocks of TPPs Kostolac A and B on the quality of air in this part of Serbia. The Gaussian model has been used to evaluate dispersion of gas substances and suspended particulates as well as parameters related to the surroundings. Calculations have been made relating to ground-level concentrations of sulphur dioxide, nitrogen oxide, and suspended particles at varying distances from the emission source.

Keywords

Environment, the basin of Kostolac, air pollution, Gaussian model, Screen View 3.5.0

INTRODUCTION

Despite the reduced industrial and economic activity, there is a high level of air pollutants in Serbia. The underlying causes of the pollution are : out-of-date technology, lack of purification of flue gases or low efficiency of filters, irrational use of raw materials and energy, poor maintenance. The oxidized sulfur compound stake the leading position among air pollutants according to the quantitative distribution and the harmful effects on the health of residents (Kosstadinova et al, 2006). For this reason, the concentration of SO_2 in the air is taken as a reference parameter for the assessment of the quality or level of air pollution. Sources of pollution originate from refineries (Pancevo, Novi Sad), metallurgical complexes (Smederevo, Bor), power plants (Obrenovac, Lazarevac, Kostolac) (Tolmac et al, 2013). In the industry, primary emissions of SO_2 originate from the process of combustion of fossil fuels, and power plants take the special position here. In the flue gas of thermal power plants, besides sulfur dioxide, great amount of gases is released, such as CO, NO_2, O_3, tiny particles of soot and ash (powdery and suspended particles, PM).

The aim is the investigation of the air quality and the environment in the Kostolac basin. By applying the Gaussian model for assessing the dispersion of gaseous substances and suspended particles the impact of emissions from blocks of power plant Kostolac is analyzed. In the analysis SCREEN 3 model is used, which is defined by the US Agency for Environmental Protection - EPA (Environmental Protection Agency) for further comparative analysis of the impact on air quality (medium one-hour concentration) which has a single source, under different conditions of the plant's operation. The comparison was done for six classes of atmospheric stability (Pasquill - Gifford Classification atmospheric stability) and the average monthly temperature of 3.3°C in December 2008. When calculating, it is taken into account that the value of the concentration and the degree of dispersion of pollutants in ground ambient air is to varying degrees influenced by many factors, including the chimney height emitters, outlet temperature of the flue gas, exit velocity and flow of flue gas, the concentration of pollutants, meteorological and topographical characteristics of the area in the vicinity of pollutants. According to the physical and spatial characteristics of the industry, thermal power plants belong to the point source of pollution.

The results of modeling show that the power plant Kostolac represents the predominant source of atmospheric pollution. The fast coal combustion in boilers of thermal power plants, at high temperatures, large quantities of gases such as CO_2, SO_2, NO_2, CO, O_3, tiny particles of soot and ash (powdery, suspended particles PM), with traces of minerals and metals are released into the atmosphere over a period of several tens of seconds. The most common element in the flue gas is sulfur dioxide with about 97%. The emission of SO_2 in the flue gases of thermal power plants Kostolac A and Kostolac B multiply exceeds the maximum permissible values defined in the national and EU regulations. Measured values range from 5758 to 6582 mg/Nm^3. The authors have identified a large overdraft emissions of powdery substances ranging from 200-700 mg/m^3. Notwithstanding the high efficiency of electric filters they cannot absorb particles less than 10 microns which are very hazardous for the living world.

The obtained values of pollutants acknowledge validity of the general project for construction of the “desulphurization of flue gas in TPP Kostolac B” planned by the study “Ways of optimal reduction of sulfur oxides emissions from thermal power plants of Electric Power Industry of Serbia.” TPP Kostolac B was chosen as the first power plant of the planned construction of such a facility. The desulphurization of flue gas, will reduce SO_2 emissions by 94%, which will reach the exit concentration of 393 mg/m^3 at full load block and combustion of worst coal quality. The projected plant technology enables more than 50% reduction in emissions of suspended particles (Consortium, 2010).

THE IMPACT OF TPP KOSTOLAC ON THE SITUATION AND QUALITY OF ENVIRONMENT IN THE KOSTOLAC BASIN

The Kostolac basin generally belongs to the area of Greater Morava Region (Veliko Pomoravlje), covering an area of 400 square kilometres, between the Velika Morava River in the west, the mountains of Golubac in the east, the Danube in the north and the basin of Mlava River in the south. In terms of genetics and morphology, the basin is a plain, slightly wavy, the lower part of the inherited Mlava River valley which passes the gorge of Gornjak and enters the spacious bay of the Morava. In a more restricted sense, the Kostolac basin covers an area of 100 km^2 and spreads between the confluence of the Velika Morava River, the Danube, the Ram in the east and Poljana in the south, mostly in the north of Stig, with the settlement of Kostolac as its centre. The region of Kostolac coal basin is part of the southeast rim of the Pannonia basin, adjacent to the coal-rich series of the Smederevsko Podunavlje region in the west. The climate in this part of the peri-Pannonian Serbia is moderately continental with pronounced elements of steppe and continental influence of the adjacent Banat region and sub-mountain climate of the Carpathian Serbia. Weather conditions in this region, such as the temperature of air, vaporisation, cloudiness and precipitation are significantly influenced by the air currents, i.e. winds, which - both directly and indirectly - influence numerous human activities and the quality of environment. The proximity of the Djerdap Gorge contributes to the powerful impact of

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"*Kosava"* wind to the climate and quality of the environment. The most frequent wind in the Kostolac basin and Stig is this wind of south-eastern direction with the frequency of 235 ‰, the second most frequent being the eastern wind (225 ‰). Upon exiting the Djerdap Gorge these winds achieve high speed and force. Plane features of the topographic area and absence of physical obstacles allow "*Kosava"* to move unhindered, first through the lower part of the Pek River Valley, though the area known as Branicevo, then across the *Bozevacka greda* region, unabated, and through Stig. This wind is particularly problematic for the dissemination of pollutants and ashes in the surroundings because it not only disseminates ashes and covers the settlements but also leads to dehydration of plants. Notably, Stig is known as one of the windiest areas in Serbia with a very small silence frequency of only 62 ‰ (Republic Hydrometeorological Service, 2008).

The Kostolac basin comprises the open-pit mines of lignite and two thermal power plants. The reserves of coal in the Kostolac basin take the third place in Serbia, being preceded by the basins of Kolubara and Kosovo, and according to intensity of exploitation and annual production of over 9 million tonnes it comes second following the coal basin of Kolubara (Stojanovic et al, 2012; Djokovic et al, 2015). The largest portion of production of the coal mine in Kostolac is used by the thermal power plants. The power plants Kostolac A and B produce approximately 12% of the overall electricity produced in the system of "Electric Power Industry of Serbia"(EPS). TPP Kostolac A is located in the settlement of Kostolac and comprises two blocks - A_1 and A_2 - of the overall installed capacity of 281 MW (100+181 MW). TPP Kostolac B, known as Drmno, is located on the right bank of the Mlava River, in the vicinity of the village of Drmno, about 5 kilometres from the right bank of the Danube. East of the thermal power plant, at a distance of one kilometre, there is an open pit of the same name which supplies coal for the power plant. The power plant Kostolac B also consists of two blocks - B_1 and B_2 -with the capacity of 2×348.5 MW. The annual production of power in the four blocks of the power plants in Kostolac amounts to approximately 6 billion KWh (Djordjevic Miloradović et al, 2012).

The situation regarding atmosphere and the quality of environment in the Kostolac basin mainly result from the influence of industrial facilities of the Economic Association “Thermal Power Plants and Mines Kostolac” (Report, 2012). Combustion of coal in the TPP boilers, dust originating from open pits of Drmno, Cirikovac and Klenovik and deposition of slag and ashes all lead to major changes in the quality of the environment. The boilers of Kostolac TPPs burn approximately 9 million tonnes of coal per year, depositing more than 2 million tonnes of ashes, which results in the pollution of air, subterranean and surface waters and leads to soil degradation. Most changes are caused by emissions of flue gases, particulates and ash and slag production. Due to emissions of pollutants, primarily flue gases and ashes, the TPPs of Kostolac represent the dominant source of atmospheric pollution. The flue gases result from fuel, in this in case -- coal combustion and represent a mixture (sulphur-dioxide, nitrogen oxides, carbon monoxide, fluoride and chloride), the concentration of which depends on the characteristics of the fuel. Flue gases contain solid particles originating from incomplete fuel combustion, such as soot and mineral components of the fuel (ashes). The prevalent component in the flue gas is sulphur dioxide, accounting for about 97% (Consortium, 2010).

Data from Table 1 indicates that emissions of SO_2 in the flue gases from the thermal power plants of Kostolac A and Kostolac B exceed the maximum values allowed, defined in both, domestic and EU (European Union) regulations. The measured values of SO_2 range from 5758 to 6582 mg/Nm^3.

The power plant of Kostolac A emitted a quantity of particulate matters 10 times greater that allowed. In recent years there has been an improvement in the operation of the electrostatic precipitator of the TPP Kostolac A. Following the reconstruction of the boiler plant in the TPP Kostolac B, the concentration of particles emitted by this power plant is around 200 mg/m^3, but occasionally exceeds this amount, reaching as much as 700 mg/m^3. Regardless of the high efficiency of the electrostatic precipitators, they cannot absorb particles smaller than 10 microns which are very dangerous for the living organisms. It is necessary to reconstruct the existing electro filer plants in order to achieve more efficient protection and lower the concentration of particles to the level of 50 mg/m^3 as prescribed by the EU Directive.

SIMULATION MODELLING AS A METHOD FOR CALULATING CONCENTRATION AND SPREAD OF AIR POLLUTION

Mathematical modelling is the methods for calculating dispersion of gaseous substances from stationary sources. By applying the mathematical model based on the data on a stationary source, topographic, climate and urban characteristics of the studied area, it is possible to observe dispersion of gaseous matters in different scenarios. The paper analyses the influence of different emissions of harmful matters from B_1 and B_2 blocks of the TPP Kostolac B on the quality of air in the area. Ground-level concentrations of pollutants have been calculated at various distances. A Gaussian statistical model was used for estimating the ground-level dispersion of gaseous substances for certain values of gas emissions and parameters related to the environment. The model is based on the assumption that pollutants emitted continuously by a

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point source form flue-gas columns in which a symmetrical distribution of concentration of particles with respect to the column axis is observed. The principal equation of the Gaussian model combines two probability functions of normal distribution and takes the following form (Lazaridis 2011; Lokeshwari et al, 2013).

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

wherein Q stand for the mass flow (rate), C -- concentration of pollutants at the given location; $\sigma_y(x), \sigma_z(x)$ dispersions or diffusion in the direction of the relevant axes, depending on meteorological conditions and the distance covered by the particle from the source to the point with x coordinate, on assumption that the direction of the $0X$ axis coincides with the direction of wind vectors; $\bar{u}$ - the medium wind speed on the measurement level; H - effective source height (Figs. a and 2).

In the equation (1), σ_y σ_z denote the horizontal and vertical dispersion of pollutant distribution. The following relations are used for establishing these dispersions:

$$\sigma_y = Ax^a; \sigma_z = Bx^b \quad (2)$$

wherein A, a, B, b are coefficients depending on the stability of atmosphere and the shape of the surface and are experimentally established. The atmospheric stability is determined using the Paquill-Gifford system of stability classification which comprises six classes of stability, starting from A (very unstable) to F (very stable) (Table 2; Awasthi et al, 2006; Lazaridis, 2011).

When analyzing the impact of TPPs Kostolac A and Kostolac B on the quality of air (mean hourly concentration) for the purpose of this study, we used the software of the US

Envirnomental Protection Agency SCREENVIEW 3.5.0, licence number E474AA382E2AE61A. The following input values were used for calculating the concentrations of suphur oxides and particulate matters:

1) Chimney height,
2) Internal diameter of the chimney
3) Mass flow and speed of flue gas on exiting the chimney
4) Exit temperature of flue gases
5) Characteristic features of the terrain surrounding the power plants (rural and urban areas, absolute altitude, topographic features)
6) Atmospheric conditions in terms of stability and wind speed.

When designing a model for calculating the ground-level concentration or air pollution, we used data pertaining to climate changes in the 1990.--2009. period. It is known that a minimum of 10 years is necessary in monitoring climate changes in order to establish climate characteristics properly (Republic Hydrometeorological Service, 2008)[1] This is why the model used the production parameters for December 2008. (Table 3) in order to obtain a realistic relation between gas emission and atmospheric conditions at that moment.

Based on the report of the Republic Hydro-meteorological Institute, we calculated that the mean monthly temperature in the Kostolac basin in December 2008. was 3.3°C. In the same period, the prevalent classes of stability were stability class D and stability class F. For the calculation, we adopted the view that the terrain is characterized by features of a plane and a depression. The

[1] Climatic elements are processed for the period of 1999-2009.

power plants are in the lower part of the Mlava River Valley, known as Stig, which borders the Pek River Valley in the east and the 20-kilometer long valley of the Velika Morava River. The north border is the Podunavlje region further spreads against Pannonia Plain. This means that a large part of the analyzed area is characterized by flat topographic surfaces. There are no significant elevations /within the distance of more than 20 kilometres from the emission source that would stop or slow down pollutants (Miljkovic et al., 2010). Research showed that physical obstacles can lead to increased concentrations of harmful matters especially in stable atmospheric conditions (stability classes D, E and F) (Jovovic et al, 2009). It should be considered that, in this case, the obtained data were primarily predetermined by the flat terrain, which means that there was no significant influence of the terrain. We also assumed that the power plants of Kostolac are in a rural area.

The figures 3 and 4 show that the maximum SO_x output of the TPP Kostolac A1 was 85.39 μg/m³at the distance of 906 m from the emission source, for TPP A2 the maximal concentration was 467.5 μg/m³ at the distance of 1122 m, whereas for Kostolac B it was 410.2 μg/m³at the distance of 1381 m. In the case of TPP Kostolac A2, SO_x concentration exceeds permitted limit of 150 μg/m³ at the distances of 700 to 10000 m, whereas for the power plant Kostolac B it occurred at distances ranging from 600 to 7500 m. The most serious pollution resulting from emission of sulphur oxides was noted in the surroundings of TPPs Kostolac A and B at distances of 7.5 to 10 kilometres from the source in the direction of the dominant wind. The most frequent wind comes from the southeast direction, followed by second most frequent wind from the eastern direction. This means that these winds carry pollutants far into the west and northwest. In this way large cities such as Pozarevac, Smederevo and Pancevo are also threatened, even more so as they already have certain levels of pollution, especially Smederevo and Pancevo. Increased levels of pollution affect the adjacent, less densely populated towns of Kostolac, Cirikovac, Bradarac, Klenovik, and Petka. Nowadays, the VSMOKE computer model integrated with GIS tool is used for geospatial representation of the spread of gaseous substances (Jacimovski et al, 2014). Bearing in mind that VSMOKE model is primarily intended for planes and hilly areas, it is fully applicable to the Kostolac basin (Figure 5).

SO_x emissions around the power plant of Kostolac A1 do not exceed the allowed limit. Since the overall concentration of the same matter amounts to a sum of separate concentrations, it can be concluded that the SO_x concentrations are below the legal limit of 150 μg/m³ at distances larger than 35 km from the source.

As for nitrogen oxides, a similar distribution is noticeable. The maximal concentration for the power plant Kostolac A1 is 12.88 μg/m³ at a distance of 1144 m; the TPP Kostolac A2 emits the maximum concentration of 29.15 μg/m³ at distance of 1102 m, whereas Kostolac B has the maximum concentration of 33.75 μg/m³ at a distance of 1381 μg/m³. In each of the observed instances the concentrations of nitrogen oxides were below the limit of 85 μg/m³. The total concentration of nitrogen oxides was also below the allowed value.

An analysis of emissions of particulate matters and suspended particles indicated that the maximum concentration at the power plant of Kostolac A1 was 46.91 μg/m^3 at the distance of 962 m, the power plant of Kostolac A2 emitted the maximum concentration of 42.55 μg/m^3 at the distance of 1102 m, while the maximum concentration for Kostolac B was 49.69 μg/m^3 at the distance of 1381 m. The limit value for particulates (PM) is 50 μg/m^3. Individual values do not exceed this limit. The overall concentration of PM is lower than permitted at distances exceeding

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7000 m from the emission source. Higher concentrations, especially of fine particles PM-2.5 can have adverse effects on human health. The Environmental Protection Agency developed a coloured surveillance system called **Air Quality Index** for the purpose of assisting the population to grasp the degree of concentration of air pollution which may affect their health. All pollutions that are marked by brown, purple and red colours (Fig. 6) have consequences for the health of all inhabitants. Pollution represented in orange represents problems for certain populations such as children, the elderly and patients suffering from chronic heart and lungs diseases. The remaining population is probably not jeopardized by this level of pollution. Good quality of air, with allowed quantities of suspended particles, according to our calculation, encompasses an area more than 7 kilometres away from the pollution source (Figure 6).

In addition to this, comparisons were made to establish the impact of certain classes of atmospheric stability, various wind speeds and different temperatures on the quality of air.

Comparisons were made for sulphur oxides levels since they account for the largest percentage of the flue gas. In December 2008, classes D and F of atmospheric stability were most frequently present, so that comparisons were made for these classes of stability (Figs. 7-9).

Graphs in figures 7 and 8 show that increased air temperatures in the area for the same class of atmospheric stability lead to an increase in the concentration of harmful matters, as opposed to values occurring in lower temperatures. Air quality deteriorates on warm days because of a high concentration of ozone resulting from photo-chemical effect. Vertical distribution of temperature represents a measure of atmospheric stability and it is one of the most important elements that influence the spread of pollutants. Although higher speeds of wind should lead to lower

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concentrations (as indicated by equation 1), the results of the model showed an increase in concentration resulting from higher wind speed for the same class of atmospheric stability. Windy periods bring about wind erosion of the surface, uplifting and carrying tiny fractions of ash that is inadequately stored, which leads to uncontrolled secondary emissions. Measurements showed that the highest departures in values of precipitation particles occurred in the settlements of Stari Kostolac and Kostolac, which are closest to the disposal area. In case of the thermal power plant Kostolac B, the largest sources of pollution are the surface sources of overburdens, open lime, ash and gypsum landfills. Particles from the landfills mostly pollute the immediate surroundings. The graphs in figures 6 and 7 show that the concentration of harmful matters under the same conditions is higher for D class of atmospheric stability (neutral) than for class F (very stable).

Calculating the overall concentration or aerial pollution originating from different sources and multiple components is a complex problem. The overall concentration of the same substances originating from different sources is obtained by simple addition, which is shown in Table 5 for various components as C1, C2 and C3, and reduced coefficients are found for all components (Внуков, 1992):

$$K_i = C_i / ELV_i ; i = 1, 2, 3$$

wherein ELV_i represents limit values for relevant components. The resulting atmospheric pollution upon simultaneous action of multiple components is determined by means of a complex coefficient

$$P = \sqrt{\sum_{i=1}^{3} K_i^2}$$

Vnukov (Внуков, 1992) have indicated the dependence of the complex coefficient P on the number of pollution sources and pollution levels. This dependence is shown in Table 6.

In case of our study, it can be observed that pollution levels were moderate at a distance of 3 km, weak at distances of 10 to 15 km and permissible at longer distances.

CONCLUSIONS

The problem of pollution from the thermal power station Kostolac is obvious. The paper focuses on the situation from December 2008 regarding three most prevalent components of flue gas. All results of the model relating to the spread of pollutants were obtained using a screening method and using annual or monthly meteorological data characteristic of the Kostolac basin. It is obvious that the most serious pollution is that of sulphur oxides components. The overall pollution exceeds the legal limits as far as 15 km from the source in the given case. The results appear even more unfavourable when we take into account all components that lead to air pollution because precipitation matters from the Kostolac basin are present in all stages of production of coal and electricity. Dispersed dust is related to formation of overburden in open-mine pits, pulverizing and combustion of coal, emission of particles upon coal combustion and to enormous production of ash and its storage.

In this study the impact of emission of the concentration of the three most common components of harmful substances sulphur-dioxide, nitrogen oxides and suspended particles from the blocks of Thermal power plants Kostolac A and Kostolac B has been analysed. The condition of air pollution has been presented at various distances from the emitter. Gaussian static model has been applied to estimate the ground level dispersion of gaseous substances for certain values of emission of the gaseous substances and parameters related to the external environment. Software tool of the American Environmental Protection Agency SCREEN3 uses this Gaussian static model to compare the impact of one source (average one-hour concentrations) to the air quality in different working conditions.

The comparison has been done for the six classes of atmosphere stability and at the average December temperature of 3.3°C from December 2008. The distributions presented in figures 3 and 4 represent the results of modelled dispersion. The comparative analysis has been performed for the two most often stability classes F and D. The concentrations of pollutants dependant on the wind speed are presented in figures 7-9. Maximum concentrations of SO_x which exceed double values than the allowed ones, are at a distance of 1300 meters from the source and they seriously endanger the surrounding settlements Kostolac, Cirikovac, Bradarac, Klenovik and Petka. Great pollution by the emission of sulphur oxides stretches on 7.5-10 kilometers from the TPP Kostolac A and Kostolac B in the direction of the dominant wind. South-east and east winds transmit the admixtures to Pozarevac, Smederevo and Pancevo. Inhabited areas at distances more than 35 kilometers from the source have concentrations of sulphur oxides less than allowed. Simulation of spreading of nitrogen oxides for the same class of atmosphere stability shows identical results of spatial distribution. In all cases, concentration of nitrogen oxides is bellow the allowed limit value and does not endanger the health of inhabitants in the surroundings. Simulation of spreading of powder and suspended particles from the smokestacks of TPP kostolac A and Kostolac B shows values above the allowed at distances up to 7 kilometers from the source at the respective wind speeds. Additional quantities of suspended particles and floating dust occur as a result of the exploitation of ground coal pits and grinding coal. Variable pollution which is affected by winds and atmosphere stability, contribute to the deterioration of air quality at distances up to 25 kilometers from the source. The results obtained by modelling of spreading of pollutants from the TPP Kostolac A and Kostolac B show that the distribution of hourly/daily concentrations of pollutants is possible to be performed if one has detailed meteorological data (such as hourly/daily meteorological reports) and data on height relations on the terrain. The real picture related to the dispersion of pollutants is obtained by this method, which can provide a basis for estimation of the potential dangers to health of inhabitants and technical solution to protection system.

Besides Pozarevac, increased levels of pollution are noted for places such as Kostolac, Cirikovac, Bradarac, Klenovik and Petka (Figure 10). At present, emission of nitrogen oxides does not exceed legal limits. However, it should be noted that the European Union is preparing more stringent regulations which envisage permitted NO_x emission of 200 mg/Nm^3 from 1 January, 2016. Current emissions of nitrogen oxides in TPP Kostolac exceed the new limit and therefore solutions have to be sought for reducing the emission as the existing projects of desulphurisation of flue gases do not involve reducing nitrogen oxide levels.

The protective measure in the existing chimneys of the power plants of Kostolac involves built-in electrostatic precipitators for purifying flue gases from particles, but no measures for reducing the emission of sulphur oxides have been taken, as indicated by values shown in the tables, which far exceed the set limits.

Acknowledgments

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REFERENCES

<BIBL>

1. Awasthi S., Khare M., Gargava P. 2006. General plume dispersion model (GPDM) for point source emission, Environmental Modeling and Assessment 11: 267-276
2. Consortium: Faculty of Mechanical Engineering, Faculty of Mining and Geology, University of Belgrade, WorleyParsons, Energoproject --Entel. 2010. A study on the assessment of impacts to the environment - flue gas desulphurisation TPP Kostolac B, pp. 15-42, 86-114, Belgrade, Serbia
3. Djokovic N., Mitrović D., Zivotic D., Spanić D., Troskot -- Corbic T., Cvetkovic O., Stojanovic K.. 2015. Preliminary organic geochemical study of lignite from the Smederevsko Pomoravlje field (Kostolac Basin, Serbia) -- reconstruction of geological evolution and potential for rational utilization. Journal of the Serbian Chemical Society 80: 575-588.
4. Djordjevic Miloradović-J. Miloradović D. Savic N. 2012. Recultivation and greening of landfills, ash dumps and waste tips in Kostolac, pp. 72-84, RIO Kostolac, Serbia
5. Jacimovski S., S. S.Miladinovic, R. Radovanovic, Ilijazi V. 2013. Distribution of the concentration of sulphur dioxide into the atmosphere from point source, III International conference Ecology of urban areas 2013, Zrenjanin, University of Novi Sad, Technical faculty „Mihajlo Pupin" Zrenjanin, Serbia, pp. 50-58
6. Jacimovski S., Stojcic S., Miladinovic S., R. Radovanovic, V. Ilijazi. 2014. **“**The use of GIS technology to assess spreading of pollutants**”**, IV International Conference „ECOLOGY OF

URBAN AREAS“ 2014, University of Novi Sad, Technical faculty „Mihajlo Pupin” Zrenjanin, Serbia, pp. 43-55

7. Jovovic A. et al. 2009. Analysis of distribution of pollutants emission from new wet stack of TPP Kostolac B, Thermodynamics, XXXV, No. 2: 177-192
8. Kostadinova P., Dimchev D., Sokolovski E. 2006. Atmospheric pollution with sulphur and nitrogen containing gases and possibilities for protection Journal of Environmental Protection and Ecology 7, No.3: 588-593
9. Lazaridis M. 2011. First principles of Meteorology and Air Pollutant, pp. 201-232. Springer, New York, USA
10. Lokeshwari N, Srinikethan G., Hegde V. S. 2013. Management of Air Pollutants from Point Sources, International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering Vol:7, No.:12: 840-844
11. Miljkovic Lj. Stepanovic M., Miladinovic S. 2010. Physical and-geographical changes resulting from the exploitation of lignite in the open pit “Drmno” UDC 911.2 Collected papers of the Department of Geography, Tourism and Hotel Management, Novi Sad, No. 38: 20-34
12. Report of the Service for environmental management of the company of the thermal power plant Kostolac, 2012
13. Republic Hydrometeorological Service-- Meteorological station Veliko Gradiste 2008. Serbia

14. Stojanovic K., Zivotic D., Sajnovic A., Cvetkovic O., Nytoft H.P., Scheeder G. 2012. Drmno lignite field (Kostolac Basin, Serbia): origin and palaeoenvironmental implications from petrological and organic geochemical studies. Journal of the Serbian Chemical Society 77: 1109-1127.

15. Tolmac D., Prvulovic S., Dimitrijevic D., Tolmac J., Matic M 2013. Results of Automatic Air Quality Monitoring in Smederevo (Serbia) and Specific Assessment of the Situation, Journal of Environmental Protection and Ecology 14, No. 2:414-421

16. Внуков А.К. 1992. Защита атмосферы от выбросов энергообъектов: Справочник, ст. 134-138, Энергоатомиздат, Москва, Россия

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Table 1. Emissions of pollutants from the Kostolac TPPs in 2012 (The Office for EnvironmentalManagement of the Economic Association “Thermal Power Plants and Mines Kostolac”)[2]

Emissions, mass concentration, of pollutants in the air for 2011							
Organisational unit	TPP Kostolac A			TPP Kostolac B		ELV	
Block	A1		A2	B1	B2		
mg/Nm^3							
Boiler	B1	B2				ELV[1]	ELV[2]
SO_2	6.582	5.84	6.183	6.329	5.758	650	400
$NO_x(NO_2)$	407	387	381	561	511	450	500
CO	23	21	8	43	39	250	-
Particulate matters	725	102	112	600	265	50	50
	≤50*						

ELV-Emission limit value

[2]Periodic (annual) measurements lasting several days and related to specific regiments of block operation are performed by the Mining Institute of Belgrade, whereas continuous measurements are performed by the TPP Kostolac.

Table 2. Parametres for dispersion calculation (Lazaridis, 2011).

		A	a	B	b
Very unstable	A	0.527	0.865	0.28	0.90
Unstable	B	0.371	0.866	0.23	0.85
Slightly unstable	C	0.209	0.897	0.22	0.80
		A	a	B	b
Neutral	D	0.128	0.905	0.20	0.76
Stable	E	0.098	0.902	0.15	0.73
Very stable	F	0.065	0.902	0 12	0.67

 ACCEPTED MANUSCRIPT

Table 3. Parameters pertaining to production in the thermal power plant Kostolac in December 2008 (Djordjevic-Miloradovic et al.,2012)

PARAMETER	KOSTOLAC A1	KOSTOLAC A2	KOSTOLAC B
Chimney height [m]	105	110	250
Internal diameter of chimney on exit [m]	5	6.02	9.5
Temperature of fumes on exit [°C]	190	200	170
Mass flow SO_x[g/s]	24.4	403	1410.8
Mass flow NO_x[g/s]	16.6	33.1	116
Mass flow of particulate matters PM [g/s]	24.4	48.8	170.8

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Table 4. Average distribution of classes of atmospheric stability in the Kostolac basin (Jovovic et al., 2009).

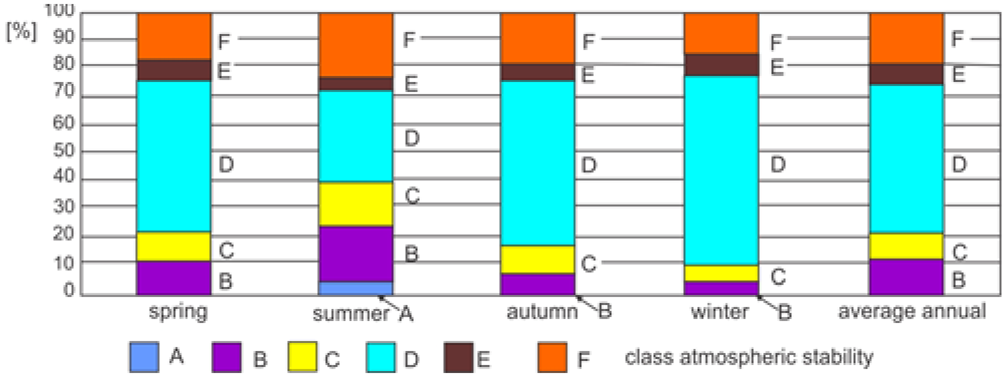

Table 5. Distribution of concentrations of various components depending on the distance from the source

Distance in km	Concentration C_1, SOx [μg/m^3]	Concentration C_2, NO_x [μg/m^3]	Concentration C_3, PM [μg/m^3]	$K_1 = C_1/ELV_1$	$K_2 = C_2/ELV_2$	$K_3 = C_3/ELV_3$	P
1	687.67	52.64	106.8	4.58	0.62	2.14	5.1
2	694.73	55.42	96.94	4.63	0.65	1.94	5.06
3	523.88	41.21	74.46	3.49	0.48	1.49	3.83
4	454.58	35.64	64.25	3.03	0.42	1.28	3.31
5	401.99	31.68	56.17	2.68	0.37	1.12	2.93
6	367.93	28.89	51.41	2.45	0.34	1.03	2.68
7	341.05	26.68	48.61	2.27	0.31	0.97	2.49
8	326.47	25.09	45.79	2.18	0.3	0.92	2.38

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9	312.29	24.27	43.41	2.08	0.28	0.87	2.27
10	295.56	23.19	41.31	1.97	0.27	0.83	2.15
15	231.68	18.67	32.78	1.54	0.22	0.66	1.69
20	193.88	15.51	26.84	1.29	0.18	0.54	1.41
25	164.75	13.28	22.9	1.1	0.16	0.46	1.2
30	150.08	12.07	20.93	1	0.14	0.42	1.09
40	133.1	11.06	18.8	0.89	0.13	0.38	0.97
50	116.87	9.9	16.62	0.78	0.12	0.33	0.86

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Table 6. Values of complex coefficient P depending on the number of pollution sources and pollution levels

Atmospheric pollution level	Number of pollutants			
	2-3	4-9	10-20	Преко 20
I permitted	2	3	4	5
II slight	2.1-4	3.1-6	4.1-8	5.1-10
III moderate	4.1-8	6.1-12	8.1-16	10.1-20
IV intense	8.1-16	12.1-24	16.1-32	20.1-40
V very intense	>16	>24	>32	>40

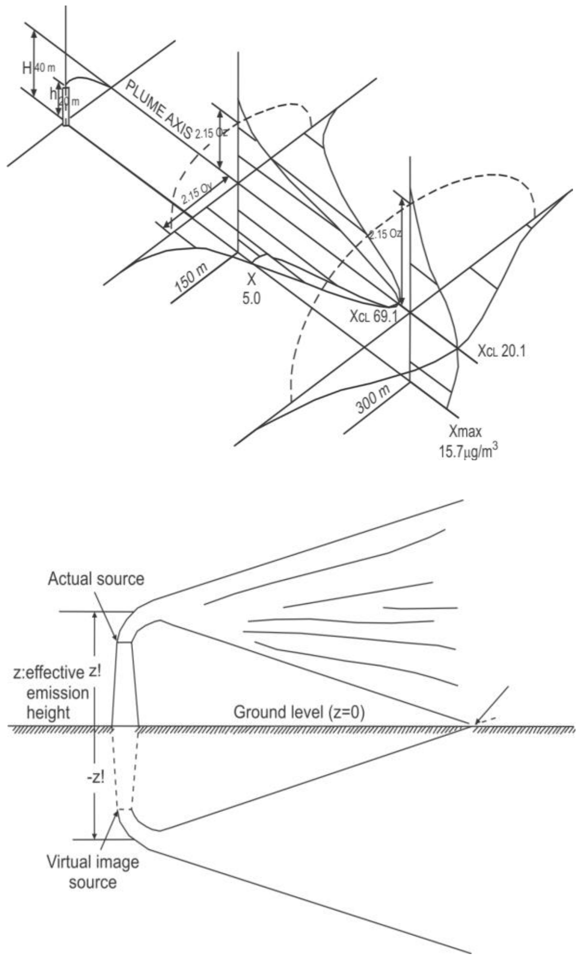

Figure 1

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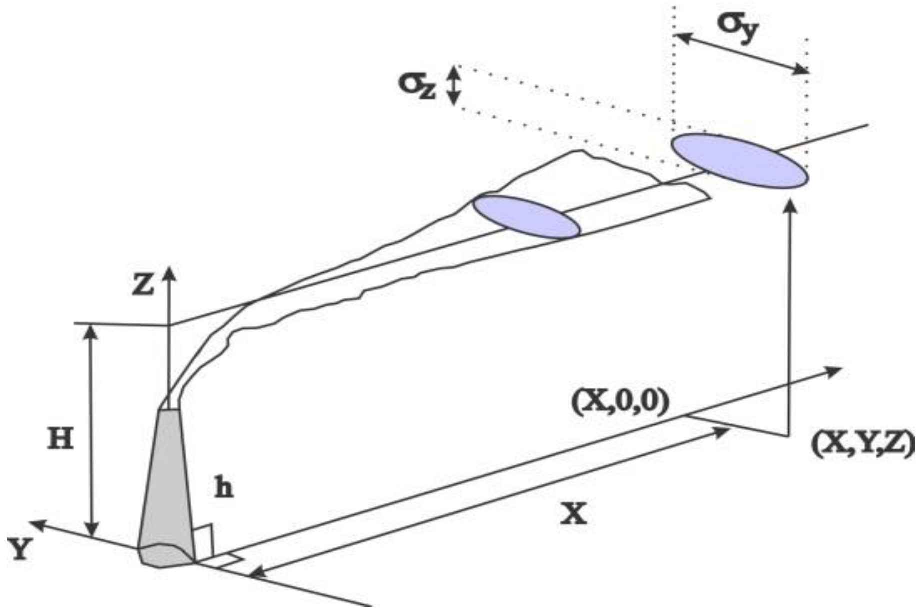
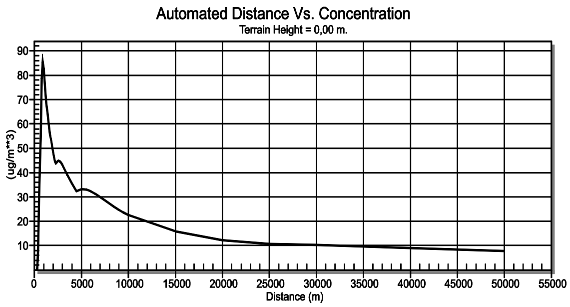
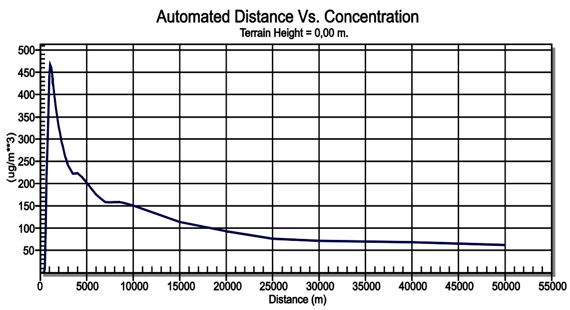


Figure 2



Automated Distance Vs. Concentration
Terrain Height = 0,00 m.
(ug/m**3)
Distance (m)



Automated Distance Vs. Concentration
Terrain Height = 0,00 m.
(ug/m**3)
Distance (m)

Figure 3

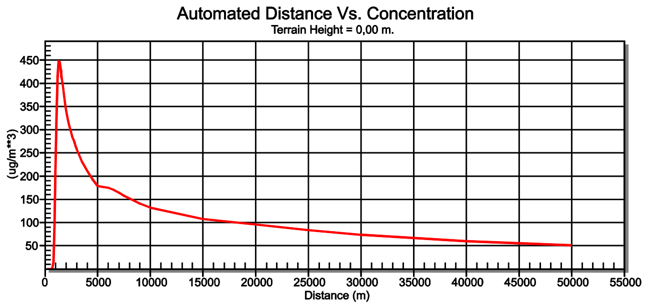

Automated Distance Vs. Concentration
Terrain Height = 0,00 m.
(ug/m**3)
450
400
350
300
250
200
150
100
50
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
55000
Distance (m)

Figure 4

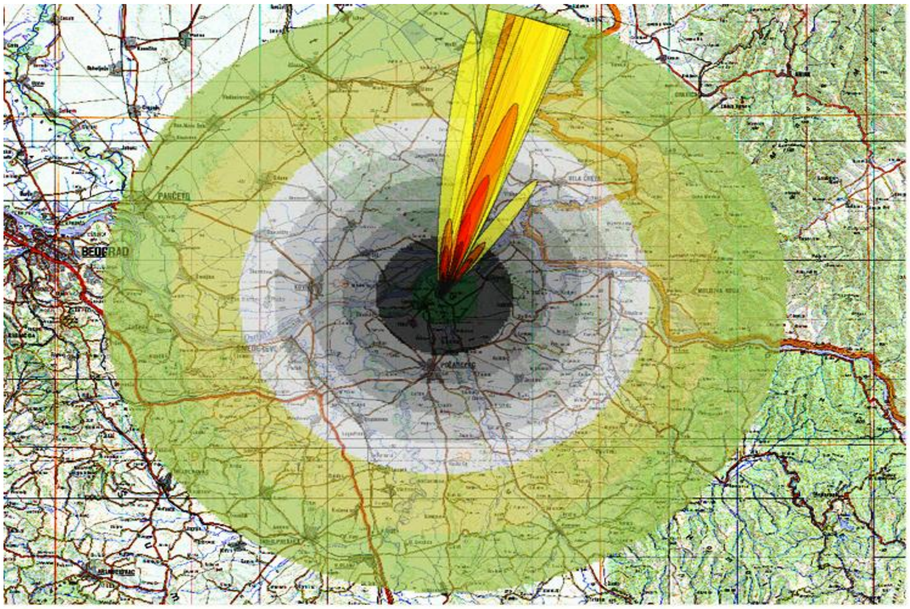


Figure 5

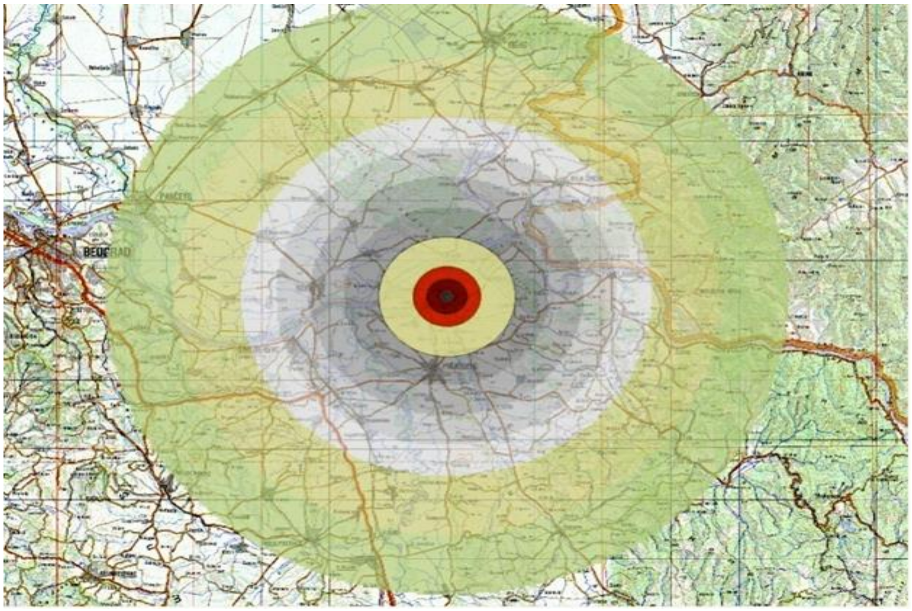


Figure 6

Human and Ecological Risk Assessment: An International Journal

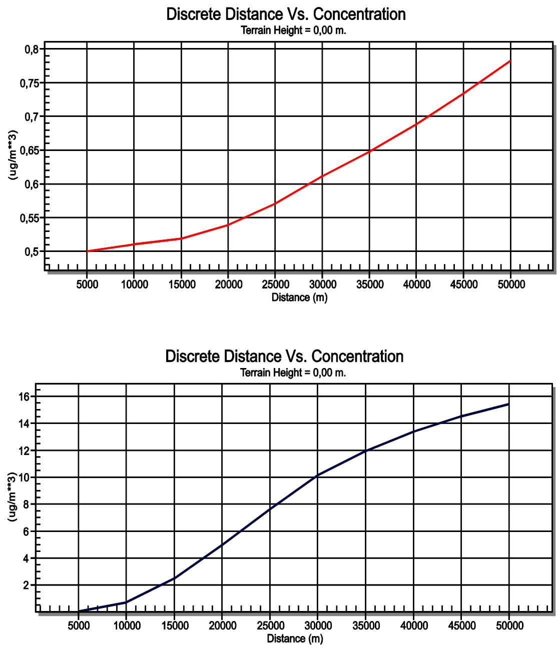
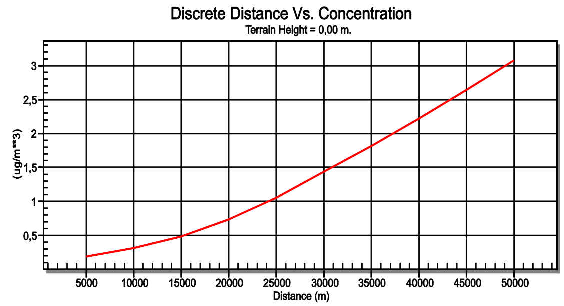

Discrete Distance Vs. Concentration
Terrain Height = 0,00 m.
(ug/m**3)
0,8
0,75
0,7
0,65
0,6
0,55
0,5
5000 10000 15000 20000 25000 30000 35000 40000 45000 50000
Distance (m)
Discrete Distance Vs. Concentration
Terrain Height = 0,00 m.
(ug/m**3)
16
14
12
10
8
6
4
2
5000 10000 15000 20000 25000 30000 35000 40000 45000 50000
Distance (m)

Figure 7


Discrete Distance Vs. Concentration
Terrain Height = 0,00 m.
(ug/m**3)
3
2,5
2
1,5
1
0,5
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Distance (m)

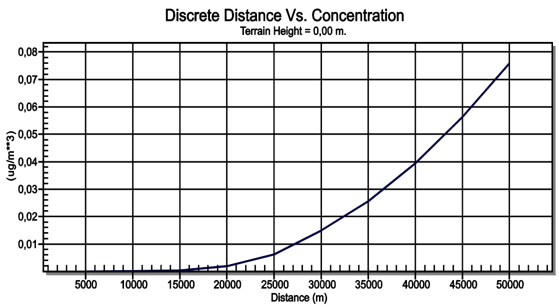
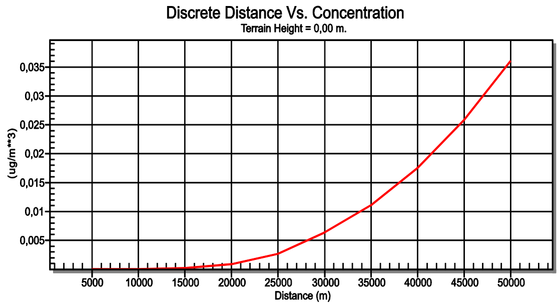

Discrete Distance Vs. Concentration
Terrain Height = 0,00 m.
(ug/m**3)
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Distance (m)

Figure 8


Discrete Distance Vs. Concentration
Terrain Height = 0,00 m.
(ug/m**3)
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0,03
0,025
0,02
0,015
0,01
0,005
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Distance (m)

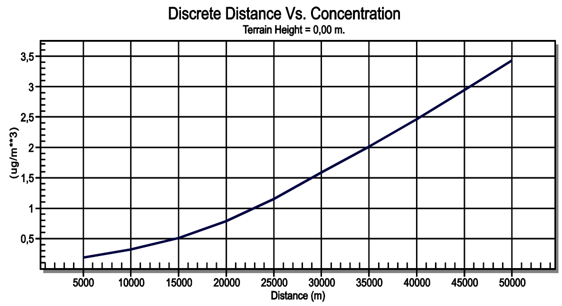
Discrete Distance Vs. Concentration
Terrain Height = 0,00 m.
(ug/m**3)
3,5
3
2,5
2
1,5
1
0,5
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Distance (m)

Figure 9

Human and Ecological Risk Assessment: An International Journal

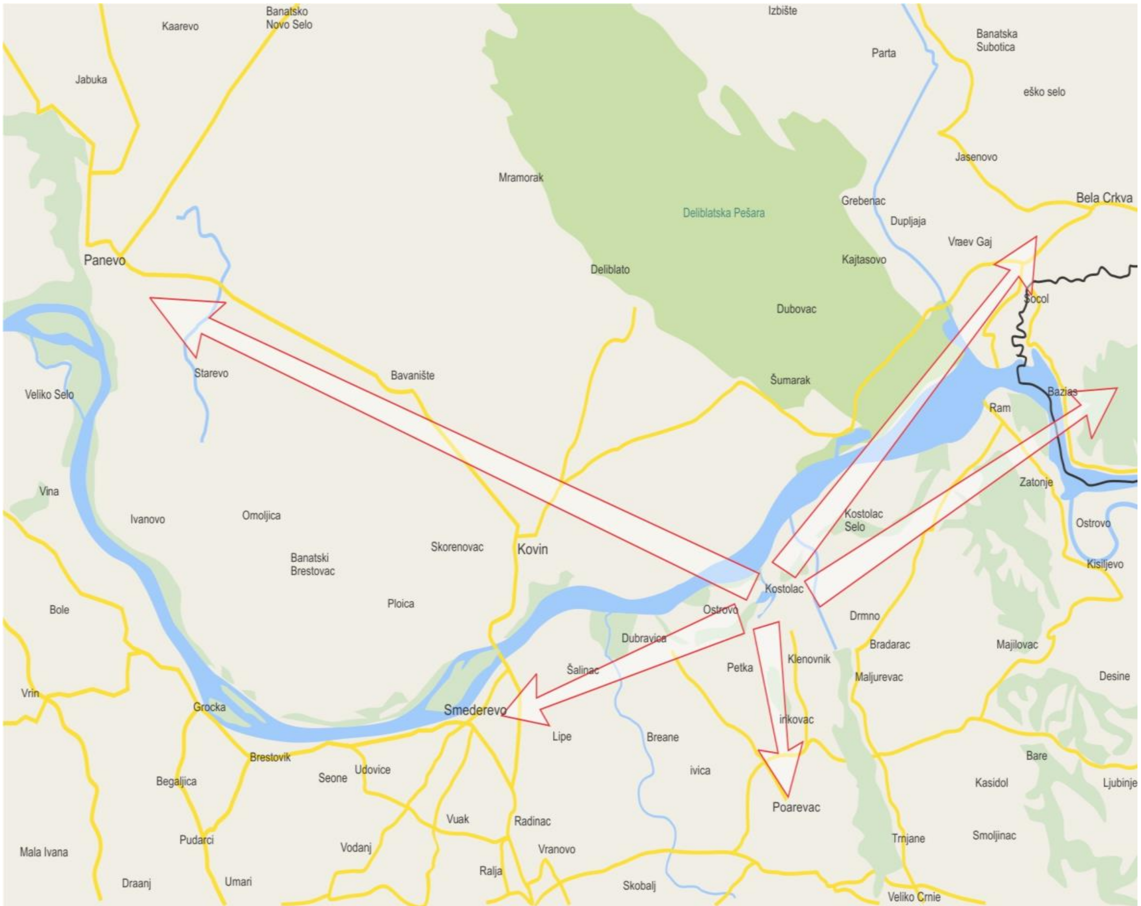

Figure 10

