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Forensic-Engineering Aspect in One Example of Long-Distance Transport of Air Pollutant

Snežana STOJIČIĆ*, Milesa SREĆKOVIĆ, Radovan RADOVANOVIĆ, Nataša PETROVIĆ, Nikola RADOVANOVIĆ, Milica STOJIČIĆ, Dragan PAMUČAR

Abstract: Forensic engineering methods might be applied in detection and identification characterisation of events according to complexity of their appearance in real environment as it covers different aspects (data, materials, chemistry, monitoring systems, technology) needed to find out the cause and predict effects. The long-distance air pollutant transport represents one challenging event for the analysis over years; specific phenomena are Saharan air masses that can transport high amounts of mineral dust particles and biological material. The dynamism of the systems in real environment, inevitably, includes time frame and spatial referencing, on location of event. However, this is directly related to providing findings and opinions when appealing to a forensic examination of an event. An example of long-distance transport of air pollutants with references to related processes in the atmosphere including time frame and spatial references is presented in the paper with discussion that is aligned with the goals of forensic engineering.

Keywords: air pollution; atmosphere processes; forensics; long distance; transport

1 INTRODUCTION

The spatial context is one of the bases for referencing an event, phenomenon or process being analysed, as well as the time frame that needs to be given with the highest possible degree of precision. However, it is not always easy to establish the relationship between time frame and spatial referencing with respect to processes in the neighbouring environment [1]. In order to confirm importance of the above mentioned components from the forensic aspect of view in the paper, it was analysed and discussed regarding one specific event caused by natural processes in the atmosphere with focus on elements chosen by authors.

Air quality depends on emissions from the biosphere, from human activities and the chemical reactions which govern the concentrations of air pollutants in the atmosphere. The rains mixed with Saharan dust, often referred to as "red rains" or "bloody rains", are relatively rare meteorological phenomena associated with long-distance transport of Saharan dust. Having in mind the different causes of these rains, as well as the fact that they appeared in the Republic of Serbia in the first quarter of 2022, data registered at air quality measurement stations was used for analysis, and results are presented in the paper.

The cause of "red rains" is most often dust, suspended in the air by desert storms, which, carried by atmospheric processes, appears in the rain. That is, raindrops are mixed with suspended dust, which causes unusual rain colours, which occur occasionally. It is also said that red rains can be caused by volcanic eruptions that emit dust and ash into the air, and according to a study conducted in India, the appearance of "red" rain is caused by the presence of a large amount of lichen-forming algae spores belonging to the genus Trentepohlia [1].

Emission, transport and deposition of sand and dust caused by wind are called Aeolian processes, after the Greek god Aeolus, the guardian of the winds. Aeolian processes occur wherever there are deposits of granular material and atmospheric winds of sufficient intensity to drive them. Hay generally occurs in deserts, beaches and other areas with sparse vegetation. Dust in the air, particles, can be transported thousands of kilometres from the region of their source [2].

There is a risk of moderate or high levels of air pollution due to Saharan dust, with open questions regarding the time of emission / transmission and the amount of dust, which correlate with the level of air pollution. Saharan dust rises from the area of West Africa and is carried north by strong winds in the direction of wind currents.

Particle transfer by wind can take place in several ways, which largely depend on particle size and wind velocity. The winds raise the dust towards the upper layers, where it can reach very high. From there, it can be transmitted in the direction of the winds in all directions, reaching distances measured in thousands of kilometres, before being covered by raindrops in the clouds, and which then fall to the ground with rain. On Earth, when water evaporates, a thin layer of dust remains on surfaces. Suspended dust particles can remain in the atmosphere for up to several weeks [2].

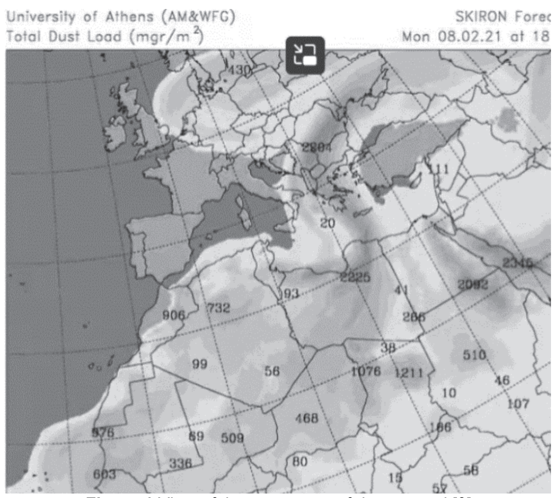


Figure 1 View of the movement of desert sand [9]

Although most people will not be affected by short-term peaks in ambient air pollution, certain categories of people, such as those with pre-existing heart or lung disease, may be affected through increased symptoms and problems.

Events characterized by red rain have been recorded all over the world, dating back to ancient times, and described as "bloody rains" [3]. Recent studies of colour rainfall according to the literature [3, 4] consider air mass trajectories, chemical analysis, and remote sensing techniques to assess source and chemical composition [2, 5, 6].

Rains of Saharan origin were registered across Europe in the first quarter of 2022 [7, 8] (Fig. 1). Due to the relative rarity of the occurrence, examples of case studies are predominantly available.

Having in mind that occurrence of the so called "red rain" on the territory of the Republic of Serbia happened occasionally, in order to analyse the phenomenon, data were taken from measuring stations that monitor hourly changes in the concentration of pollutants in the Republic of Serbia. Data were primarily taken for 10 μm (PM10) particles, as well as other available pollutant data for the same period.

Solid particles, also called aerosols or pollutants, can consist of a number of chemical compounds. Some particles are primary pollutants that come directly from chimneys, construction sites, fires or volcanoes. However, most are secondary pollutants that result from chemical reactions in the atmosphere due to emissions from power plants, factories and vehicles.

Particles are classified by size [10, 11, 16]:

- PM10 (0.01 mm) are coarse particles with a diameter of 2.5 to 10 micrometres, such as dust, dirt, pollen or mold (Fig. 2).
- PM2.5 (0.0025 mm) are fine particles with a diameter of 2.5 micrometres or less, such as soot, smoke, organic compounds or metals.

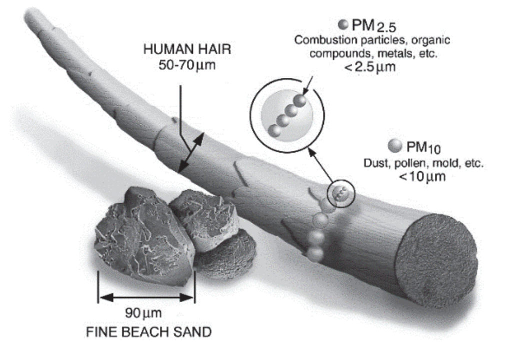


Figure 2 Show with relative particle size [10] (microns in diameter)

(a)

Component	Mass / %
SiO_2	49.5
Al_2O_3	12.1
CaO	11.5
Fe_2O_3	10
CO_2	9
Mn_3O_4	2
MgO	0.4
Organic	5.5

(b)

Figure 3 Image (a) and components of Saharan sand (b) [11]

According to the components and polluting substances, which are measured on air quality monitoring systems, for further consideration, particular matters (PM10) were selected (Fig. 3) as complex and relevant for further analysis.

The impact on air quality can also be seen through the air quality index. The Air Quality Index (AQI) of the Environmental Protection Agency (EPA) is based on measurements of six pollutants: particulate matter (PM), nitrogen dioxide (NO_2), ozone (O_3), sulphur dioxide (SO_2), lead (Pb), and carbon monoxide (CO).

Many global models simulate dust emission transport and disposal [12], with evident diversity in the approach and characteristics of the processes observed. Approach for determining the event and effects of particle transport over long distances was used in our study. Data from air quality monitoring stations in the Republic of Serbia was used for analysis, modelling and prediction. Size of particles transported over long distances does not exceed 20 to 30 μm [11] and involvement of climatic conditions is generally limited, especially considering particles with a diameter less than 10 μm [5-8, 11-14]. Having in mind limitations of the modelling processes, the limited availability of data on particles larger than 10 μm and estimates of the distance that can be reached, research is challenging. Furthermore, effect of a total sedimentation of particles on land and water might be subject of further research. A comprehensive approach is needed, as well as analysis through modelling. In that way we might be able to better understand what is the relation between processes, dynamics and transport and asses the influence on environment, air quality and human health [15] in order to be able to act proactively and reactively as needed and when needed. Following identified air pollution event through spatial and time component might significantly contribute to decision makers for timely reaction if needed. In order to confirm that, one example of long distance air pollutant transport was analysed in our study. Based on data acquired from air quality measurement stations on the territory of R. Serbia identification and movement through spatial and time spreading with short term prediction according time series was analysed.

2 EXPERIMENTAL (MATERIALS AND METHODS)

A significant increase of atmosphere air pollutant was registered on 16th March 2022, it was analysed according data collected from the automatic measurement system in The Republic of Serbia [16, 17], with respect to the reference to the spatial data as well as following up through time, in relation with source of occurrence of the red rain. In order to analyse distribution and influence on environment, estimation of influence was performed in the next short period of time.

2.1 Locations of the Measurement Stations

To determine the locations of measuring points for taking samples for measuring concentrations of pollutants, and for the purpose of assessing air quality in zones and agglomerations, the criteria given in the Regulation on conditions for monitoring and requirements for air quality are applied [16]. In particular, macro locations for fixed measurements are determined in order to protect human health, vegetation and natural ecosystems, and in the immediate vicinity of point sources, considering the density of emissions, the expected distribution of pollutants in the air and the potential exposure of the population.

The location of the measuring points is determined so that the application of standards and the best available techniques can be monitored in accordance with the regulations in the field of air pollution prevention and control. Also, the procedure of determining the locations for the measurement stations requires a preliminary analysis based on the available data in relation to the spatial data, terrain configuration, and environment. Periodically the analysis and assessment should be performed in order to confirm validity of chosen location and measurement technique by application of all predefined criteria. According to it changes might be initiated and implemented if needed [16]. From the existing locations the following referent measurement methods given in Tab. 1, are applied to data acquired for analysis.

Table 1 Referent measurement methods

Air Pollutant	Standard	Referent method
Sulphur dioxide (SO_2)	SRPS EN 14212,Ambient air quality	Ultraviolet fluorescence
Nitrogen dioxide (NO_2)	SRPS EN 14211, Ambient air quality	Chemiluminescence
Particulate matter PM_{10}	SRPS EN 12341, Air quality	Determination of the PM_{10} fraction of suspended particles, Reference method and field test procedure to demonstrate the equivalence of measurement methods
Particulate matter $PM_{2.5}$	SRPS EN 14907, Ambient air quality	Standard gravimetric method for determining the mass fraction of $PM_{2.5}$ suspended particles
Benzene(C_6H_6)	SRPS EN 14662-1, Ambient air quality	Pump sampling, thermal desorption and gas chromatography
	SRPS EN 14662-2, Ambient air quality	Pump sampling, solvent desorption and gas chromatography
	SRPS EN 14662-3, Ambient air quality	Automatic pump sampling with on-site gas chromatography
Carbon monoxide (CO)	SRPS EN 14626, Ambient air quality	Non-dispersive infrared spectroscopy
Ozone(O_3)	SRPS EN 14625, Ambient air quality	Ultraviolet photometry

2.2 Measured Parameters

Data for analysis was taken from automatic air quality measurement system, where it is measured according to air quality assessment criteria presented in Tab. 2, with qualification of categories for observed pollutant [17]. Operational monitoring, using automatic reference method, is carried out in accordance with national legislation, measured in line with air monitoring defined by the common AQI-Air Quality Index developed within European regional development support, applied in the Republic of Serbia since 2017. The air quality index, unlike air quality assessment criteria, is not covered by national legislation. The index is a mechanism based on which timely and general information about air quality can be made available to the public in simple way in real time, with the aim of raising awareness about environmental protection.

Table 2 Parameters of pollutants measured at measuring stations in Serbia

Pollutant	Period / unit	Excellent	Good	Acceptable	Polluted	Heavily polluted
SO_2	1 h/μg·m^{-3}	0 - 50	50.01 - 100	100.01 - 350	150.01 - 500	> 500.01
O_3	1 h/μg·m^{-3}	0 - 60	60.01 - 120	120.01 - 180	180.01 - 240	> 240.01
CO	1 h/mg·m^{-3}	0 - 5	5.00001 - 10	10.00001 - 25	25.00001 - 50	> 50,0001
PM2.5	1 h/μg·m^{-3}	0 - 15	15.01 - 30	30.01 - 55	55.01 - 110	> 110.01
PM10	1 h/μg·m^{-3}	0 - 25	25.01 - 50	50.01 - 90	90.01 - 180	> 180.01
NO_2	1 h/μg·m^{-3}	0 - 50	50.01 - 100	100.01 - 150	150.01 - 400	> 400.01

For presentation of findings related to observed set of data, descriptive statistical method was used to determine mean, median, standard deviation and minimum and maximum value. Also, for analysing time series was used statistical method for forecasting short period of time for all measurement stations.

3 RESULTS AND DISCUSSION

Assessment of observed parameters that was conducted in relation to the long-distance transport context, associating time and spatial scale of atmospheric processes in relation to air pollution, is shown in general in Fig. 4. General starting point in the analysis is physical processes in the atmospheric boundary layer which has a large degree of governing the relation between emission and pollution concentration in the atmosphere. There are lots of parameters through which atmospheric processes might be considered, such as pressure, temperature, mass, density, water vapour, radiation, wind velocity and turbulence [18]. It is important to note that the governing atmospheric processes take place on a broad range of temporal and spatial scales contextually shown in Fig. 4.

From that point of view, the beginning of the detection of the natural phenomenon of red rain, which happened on the territory of Serbia, was based on the use of measured data from the automated air pollution monitoring system. The data were analysed in the adjacent time period around the maximum registered value of PM10.

The maximum values of PM10 at 31 (86.1%) of 36 measuring stations were above the limit for the categorization of severe air pollution, in the period for which the data were analysed, and which include the maximum values reached on March 16, 2022, when the occurrence of red rains was registered. Descriptive data from measuring stations, including the time when the maximum values were measured are given in Tab. 3. Data from neighbour period of this specific event were taken in consideration as well as the given maximum values and information related to the time of maximum values reached.

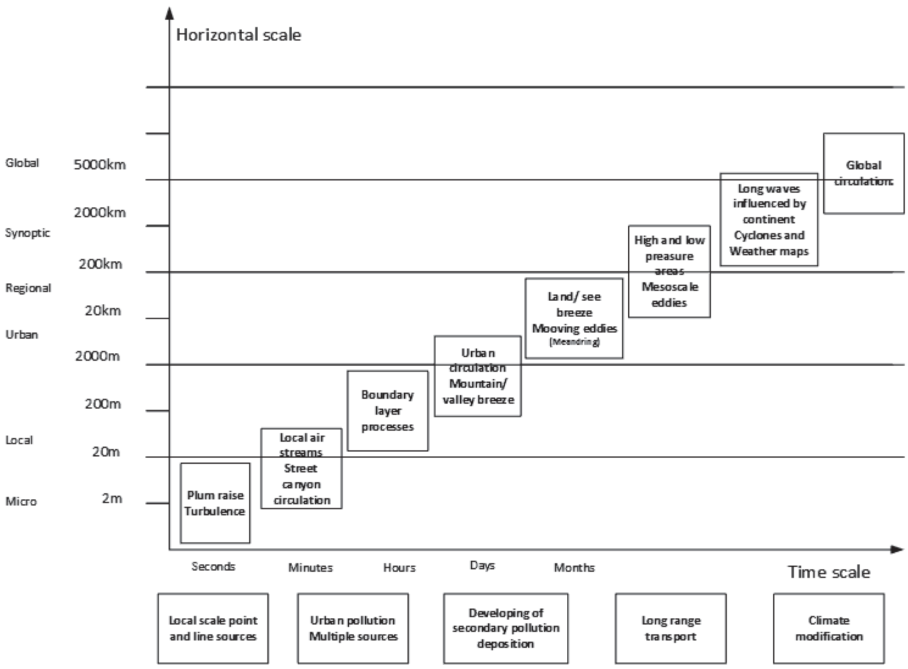
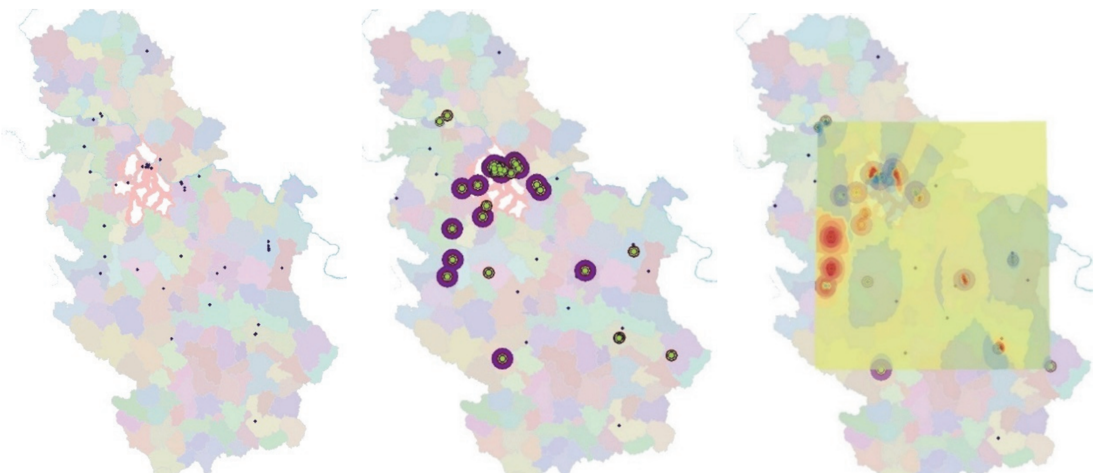


Figure 4 Time and spatial scales of atmospheric processes in relation to air pollution

Table 3 Overview of descriptive data of PM10 values for the period 23.02 - 25.03.2022. on the territory of the RS

Station name	*n*	Mean	Median	Std. Deviation	Min	Max	Max date
Beograd ObrenovacUšće	720	49.56	42.80	30.45	9.13	334.30	12/03/2022 19:00
SmederevoCenter	720	51.35	37.26	37.54	10.10	222.58	12/03/2022 19:00
PančevoStarčevo	717	58.35	43.29	51.89	4.04	428.74	12/03/2022 23:00
BeogradZemun TB	719	68.49	48.25	55.49	10.24	354.16	13/03/2022 19:00
Užice	646	99.56	69.17	90.30	0.77	604.87	14/03/2022 16:00
Čačak	719	51.21	44.16	30.12	8.46	208.71	15/03/2022 18:00
BeogradLazarevac	720	62.05	48.18	44.03	6.70	281.86	15/03/2022 22:00
BeogradDespotaStefana	719	47.34	38.48	35.15	10.90	527.45	16/03/2022 05:00
BeogradStari grad	720	48.59	39.30	35.07	9.49	339.64	16/03/2022 05:00
Beograd Novi Beograd	720	46.81	37.55	43.92	9.89	821.22	16/03/2022 06:00
BeogradOml. brigade	719	56.82	44.00	50.82	11.95	674.54	16/03/2022 06:00
BeogradTopčiderska Zvezda	720	43.93	38.13	28.69	11.16	340.98	16/03/2022 06:00
BeogradMostar	720	49.71	39.14	37.73	9.07	462.92	16/03/2022 06:00
Beograd DragišaMišović	720	41.84	37.18	24.12	10.47	239.65	16/03/2022 07:00
ObrenovacCenter	720	65.25	53.09	46.12	8.92	446.78	16/03/2022 07:00
Valjevo	719	75.35	60.39	53.60	11.07	489.62	16/03/2022 07:00
BorGradski park	720	32.30	25.60	24.27	6.62	211.78	16/03/2022 08:00
BeogradAda petlja	720	55.08	47.48	38.38	11.56	426.37	16/03/2022 08:00
BeogradBanovobrdo	720	47.69	39.94	32.41	8.93	376.75	16/03/2022 08:00
BeogradBežanijskakosa	720	50.14	39.43	36.17	10.37	407.52	16/03/2022 08:00
Beograd Vračar	720	46.65	37.40	33.14	9.82	321.46	16/03/2022 08:00
Beograd Zelenobrdo	716	39.64	34.33	21.93	9.60	217.50	16/03/2022 08:00
Popovac	720	72.75	48.34	68.07	3.68	608.01	21/03/2022 19:00
Pirot	720	54.46	46.34	33.27	7.24	312.58	22/03/2022 19:00



a) b) c)

Figure 5 Spatial analysis: a) Location of measurement stations, b) measured concentration through observed period of time, c) Spatial distribution prediction

Data from measuring stations were also analysed from the aspect of the frequency of the index for PM10, having in mind the hourly data, on the basis of which it was obtained that the air quality was excellent, i.e. the value of PM10 (μg/m^3) measured from 4.4% to 49% of cases, good from 26.2% obtained in Užice to 55.7% in Belgrade "Dragiša Mišović" and Health Center Vračar, acceptable from 10.0% in Bor-city park to 39.7% in Valjevo , polluted from 0 to 23.2% in Užice and heavily polluted from 0 to 14.9% in cases in Užice (Fig. 5).In the observed sample of PM10 values, in addition to reaching the maximum, which largely overlaps with the appearance of the red rain, it is also evident that events cannot be observed in isolation and without further study of conditions that contributed to increasing PM10 concentration in the air. A significant part of the population is still heated by fossil and other fuels (which is also a factor that is present in the observed period). Frequencies according to air quality assessment criteria for PM10 divided by above defined categories are presented in table 4. Further analysis, in addition to the sampled time series, could be performed in relation to the same time period in previous years, as well as other elements that may affect the concentration of PM10 in the air.

Table 4 Frequency of index values in the observed period by category

Pollutant	Period / unit	Excellent	Good	Acceptable	Polluted	Heavily polluted
PM10	1 h/ μg·m^{-3} , n / %	0 - 25	25.01 - 50	50.01 - 90	90.01 - 180	> 180.01
Bor Gradski park	719	342 (47.6)	278 (38.7)	72 (10.0)	28 (3.6)	1 (0.1)
Pančevo Vatrogasna stanica	720	285 (39.6)	276 (38.3)	113 (15.7)	43 (6.0)	3 (0.4)
Beograd Ada petlja	718	98 (13.6)	299 (41.6)	234 (32.6)	80 (11.1)	7 (1.0)
Beograd Banovo brdo	720	148 (20.6)	339 (47.1)	178 (24.7)	51 (7.1)	4 (0.6)
Beograd Bežanijska kosa	720	143 (19.9)	333 (46.3)	154 (21.4)	85 (11.8)	5 (0.7)
Beograd Despota Stefana	718	113 (15.7)	393 (54.7)	153 (21.3)	51 (7.1)	8 (1.1)
Beograd Dragiša Mišović	720	146 (20.3)	401 (55.7)	154 (21.4)	15 (2.1)	4 (0.6)
Beograd Lazarevac	720	85 (11.8)	288 (40.0)	212 (29.4)	115 (16.0)	20 (2.8)
Beograd Novi Beograd	720	165 (22.9)	342 (47.4)	155 (21.5)	55 (7.6)	4 (0.6)
Beograd Obrenovac Ušće	720	116 (16.1)	320 (44.4)	233 (32.4)	46 (6.4)	5 (0.7)
Beograd Oml. brigade	718	101 (14.0)	337 (46.8)	170 (23.6)	103 (14.3)	7 (1.0)
Beograd Stari grad	719	140 (19.5)	354 (49.2)	162 (22.5)	56 (7.8)	7 (1.0)
Beograd Top. Zvezda	720	140 (19.4)	388 (53.9)	164 (22.8)	23 (3.2)	5 (0.7)
Beograd Vračar HC	720	126 (17.5)	401 (55.7)	130 (18.1)	57 (7.9)	6 (0.8)
Beograd Zeleno brdo	716	172 (23.9)	390 (54.2)	134 (18.6)	18 (2.5)	2 (0.3)
Čačak	719	90 (12.5)	350 (48.6)	210 (29.2)	65 (9.0)	4 (0.6)
Obrenovac Center	720	80 (11.1)	255 (35.4)	230 (31.9)	135 (18.8)	20 (2.8)
Pirot	720	101 (14.0)	284 (39.4)	250 (34.7)	81 (11.3)	4 (0.6)
Popovac	720	109 (15.1)	261 (36.3)	174 (24.2)	122 (16.9)	54 (7.5)
Smederevo Center	720	134 (18.6)	365 (50.7)	121 (16.8)	93 (12.9)	7 (1.0)
Valjevo	719	32 (4.4)	224 (31.1)	286 (39.7)	145 (20.1)	32 (4.4)
Beograd Mostar	720	127 (17.6)	361 (50.1)	158 (21.9)	67 (9.3)	7 (1.0)
Beograd Zemun TB	719	88 (12.2)	285 (39.6)	181 (25.1)	126 (17.5)	39 (5.4)
Pančevo Starčevo	717	180 (25.1)	233 (32.5)	174 (24.3)	110 (15.3)	20 (2.8)
Užice	636	74 (11.5)	169 (26.2)	146 (22.6)	150 (23.2)	107 (14.9)

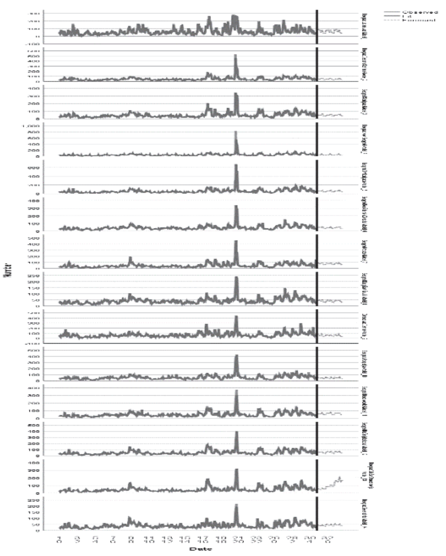


Figure 6 Presentation of time series with short prediction period for PM

In order to indicate how occasionally events might have influence through time, data was analysed, as time series with short term prediction period of time. By analysing time series in the observed sample in terms of concentration prediction, with an optionally chosen three day frame, given that the observed time period is one month, the results are shown in Fig. 5. The occurring event might be categorised as occasional without expected long time effect. As in the case of analysis of confirmed need to consider other related parameters for a certain area, so in this case it was shown that short-term deviations in concentration, although large, do not significantly affect the forecast of concentration in the coming period, which was obtained on the basis of the applied model.

Analysing information on desert dust in contemporary research confirms that such events play an important role in the climate system, as well as their impact on the environment. There are large differences in the way many global models simulate the spread of dust and the consequent impact of dust [15]. The importance of the conditions in the environment was especially identified, both from the aspect of assessing the specific situation and from the aspect of influencing the forecasts and planning possible further actions [19]. The differences under consideration may be the product of various distributions and transport of dust, and reactivity with compounds in the environment, which contribute to the occurrence of uncertainty in the assessment of performance [20-23]. Also, deposition, interactions and environmental conditions should not be neglected as well as influence and potential effect on human health [24-28]. Whether or not inhalation of PM form desert dust has adverse health effect is insufficiently investigated, there is even studies reviewed assessment of the influence of desert dust on cardiovascular diseases [29-32]. Also according to World Health Organisation (WHO) mitigation of the adverse health effects of exposure to pollutants in atmosphere has become a worldwide health concern, indicating that correlation with other research area represents challenge according to the complexity of phenomenon.

4 CONCLUSION

Identification of an event source and effect even if it is natural source represents a challenging task, needs knowing and considering all available parameters, correlating and applying different modelling techniques. Through analysing presented example of long distant transport of air pollutants it was shown how it might be followed by analysing, presented, used in decision making process, and short term prediction processes. For all consideration forensic approach might significantly contribute to assessment of effects, indicating how to come to relevant conclusion. This approach is in line with the purpose of identifying cause, source and consequence of an air pollution event with increasing values over upper limits. It might be applied in different areas, especially in cases of fire and explosion as causes of air pollution and harmless effect in relation to spatial distribution through time. Furthermore, time and space contexts represent specific part and have to be considered in analysis, allowing application of tools and techniques to assess and visualise indicative details. This allows coming to findings related to the source, composition and potential effects. Phenomenon, like the one presented, might be subject of further research from a different point of view and results might be applied in different areas.

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Contact information:

Snežana STOJIČIĆ, MSc, IT expert
(Corresponding author)
Ministry of the Interior,
Belgrade Kneza Miloša 101, Serbia
E-mail: snezana.stojicic@mup.gov.rs

Milesa SREĆKOVIĆ, PhD, Professor
Faculty of Electrical Engineering, Belgrade University,
Bulevarkralja Aleksandra 73, Serbia
E-mail: esreckov@etf.bg.ac.rs

Radovan RADOVANOVIĆ, PhD, Full Professor
University for Criminal Investigation and Police Studies,
Belgrade, Cara Dušana 196, Serbia
E-mail: radovan.radovanovic@kpu.edu.rs

Nataša PETROVIĆ, MSc, Forensic expert
Ministry of the Interior,
Belgrade Kneza Milosa 101, Serbia
E-mail: natasa.petrovic@mup.gov.rs

Nikola RADOVANOVIĆ, MSc, Construction expert
Milleninium Team d.o.o.,
Belgrade, Žanke Stošić 39, Serbia
E-mail: nikola.radovanovich@gmail.com

Milica STOJIČIĆ, MSc, medical doctor
Institute for Cardiovascular Diseases "Dedinje",
Belgrade, Heroja MihajlaTepia 1, Serbia
E-mail: stojicic.milica@gmail.com

Dragan PAMUČAR, PhD, Full Professor
Faculty of Organizational Sciences,
University of Belgrade,
Jove Ilića 154, Serbia
E-mail: dragan.pamucar@fon.bg.ac.rs