THE EVALUATION OF SELECTED AIR POLLUTANTS IN KOŠICE FOR THE PERIOD 2008-2010

ANALÝZA ZNEČISŤUJÚCICH LÁTOK VO VYBRANÝCH MONITOROVACÍCH STANICIACH MESTA KOŠICE ZA OBDOBIE 2008 - 2010

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Abstract

In general, air quality is determined from the concentrations of pollutants in ambient air. Air quality criteria (limit and target values, margin of tolerances, upper and lower assessment thresholds) are based on the current legislative framework. In Slovakia, the air quality criteria are imposed by Decree No 360/2010 Coll, on air quality, of the Ministry of Environment [1]. In relation to the implemented measurements, it is necessary to choose effective tools needed for the pre-processing and post-processing of overall air quality assessment. The article aims at applying suitable GIS tools in the assessment process of air quality in the Košice agglomeration for the selected period 2008-2010. In the overall assessment of the area in question, the processing of information on emissions declared as particulate matter (PM) was considered in terms of a conservative approach to the assessment of air quality for PM_{10}. For the assessment, the yearbooks and reports on air quality in Slovakia in 2008-2010 of the Slovak Hydrometeorological Institute (SHMI) and professional publications were used.

Keywords: air quality, GIS tools, agglomeration of Košice, particulate pollutants

Abstrakt

Vo všeobecnosti kvalita ovzdušia je stanovená z obsahu znečisťujúcich látok vo vonkajšom ovzduší. Kritériá kvality ovzdušia (limitné a cieľové hodnoty, medze tolerancie, horné a dolné medze na hodnotenie) vychádzajú z platného legislatívneho rámca. V podmienkach SR kritéria kvality ovzdušia vyplývajú z vyhlášky MŽP SR č. 360/2010 Z.z. o kvalite ovzdušia [1]. V nadväznosti na realizované merania je potrebné zvoliť efektívne nástroje potrebné pre preprocesing a postprocesing procesu plošného hodnotenia kvality ovzdušia. Príspevok si kladie za cieľ aplikovať vhodné nástroje GIS do hodnotiaceho procesu kvality ovzdušia v aglomerácií Košice za vybrané obdobie rokov 2008 - 2010. Pri celkovom zhodnotení predmetnej oblasti bolo uvažované so spracovaním informácií o emisiách deklarovaných ako tuhé znečisťujúce látky (TZL) v zmysle konzervatívneho prístupu k hodnoteniu kvality ovzdušia za PM_{10}. Pre posudzovanie boli použité ročenky a správy pre kvalitu ovzdušia v SR za rok 2008 - 2010 z SHMÚ a odborné publikácie.

Keywords: kvalita ovzdušia, nástroje GIS, aglomerácia Košice, tuhé častice

1 ASSESSED TERRITORY AND INPUT INFORMATION FOR EVALUATION

Based on current legislation, Act No. 318/2012 Coll., on the atmosphere, as amended, the area of the Košice Region belongs to 1 group, i.e. among the zones and agglomerations in which the levels of one or more pollutants are higher than the limit values, or the limit values plus the margin of tolerance. The pollutant due to which the Košice Region and the town of Košice are included in the first group is PM_{10} (particulate matter in the air which passes through a size-selective inlet with a 50 % efficiency cut-off at 10 µm aerodynamic diameter) [2].

Based on further measurements, the region territory was also included in the second group, i.e. among the zones and agglomerations in which the levels of one or more pollutants are between the limit values and the limit values plus margin of tolerance. The zones and agglomerations in which the measured ozone concentration was higher than the long-term objective for ozone, but less than or equal to the target value set for ozone were also included in this group.

The pollutant due to which the area of the Košice Region and the town of Košice is classified into the group 2 is ozone.

Based on further measurements, the Košice Region was included into the group 3, i.e. the air pollution level is below the limit values, or below the limit values plus the margin of tolerance.

The pollutants due to which the Košice Region and the town of Košice is classified into the group 3 are SO_2, NO_2, Pb, CO and benzene. The overview of the inclusion of the area in question into different groups is shown in Tab. 1 [3], [4].

Tab. 1 The inclusion of the area into the zones by pollutants [5]

Group	Zone or agglomeration	The pollutant for which a given zone, or an agglomeration is included in a respective group
1	Košice Region	PM_{10}
	Košice	PM_{10}
2	Košice Region	Ozone
	Košice	Ozone
3	Košice Region	Sulphur dioxide, nitrogen dioxide, lead, carbon monoxide, benzene
	Košice	Sulphur dioxide, nitrogen dioxide, lead, carbon monoxide, benzene

*PM_{10} – *particulate matter in the air which passes through a size-selective inlet with a 50 % efficiency cut-off at 10 µm aerodynamic diameter*

1.1 Characteristics of the analysed particulate matter PM_{10}

PM_{10} and $PM_{2,5}$ (particulate matter – PM).

In general, particulate pollutants (*PM = particulate matter*) are a mixture of airborne solid and liquid fractions. Several particulate pollutants are emitted directly; others are formed in the atmosphere in reactions of other pollutants. The particulates are in a wide range of sizes. The particulates smaller than 2.5 micrometres (*µm)* in diameter ($PM_{2,5}$) are called "fine" particulate matter. They are so small that they can be captured only by electron microscopy. The particulates between 2.5 and 10 micrometres in diameter (PM_{10}) are referred to as *"coarse"*, but their size is smaller than the thickness of a human hair. The listed particulate pollutants have adverse effects on human health. They can get into the lungs, which can cause serious health problems. It is therefore necessary to monitor the presence of PM in the air [6].

Tab. 2 Geographical coordinates of monitoring stations and the list of the monitored pollutants - 2009 [7]

AGGLOMERATION/ Zone	Municipality, locality	Geographical length	Geographical width	Altitude [m]	PM_{10}	CO	Pb	Cd	Ni	As	BaP
KOŠICE	Košice, Strojárska 1)	21°15'07"	48°43'36"	202	*						
	Košice, Amurská 1)	21°17'11"	48°41'28"	201	*						
Košice Region	Veľká Ida, Letná	21°10'30"	48°35'32"	209	*	*	*	*	*	*	*

Note: 1) *Strojárska by 16 September 2009, Amurská from 5 October 2009*

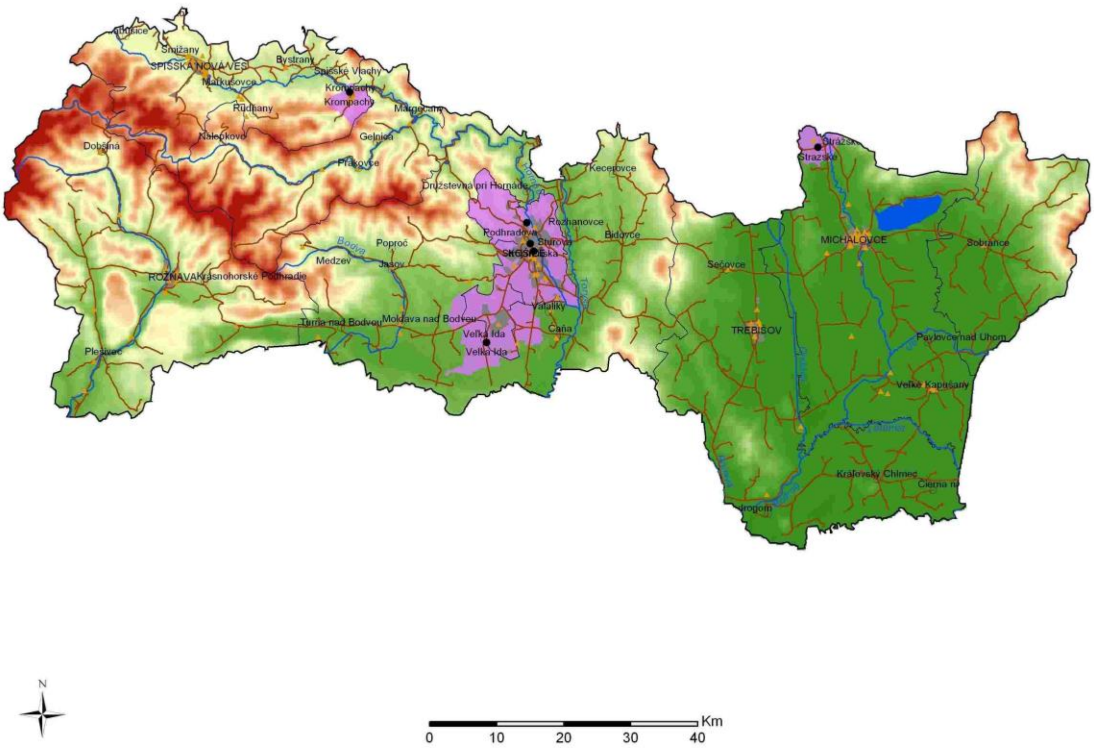

Fig. 1 The spatial localization of the area [8]

Monitoring the levels of air pollution in the territory of the Košice agglomeration is provided by the Slovak Hydrometeorological Institute (SHMI). The measurements are mainly focused on the detection of concentrations of SO_2, NO_x and particulate matter PM_{10}. The air pollution control is provided through a network of automated monitoring stations. Their number for the selected period (2008-2010) changed. In the process of addressing the issues of processing particulate matter by means of tools of the Geographic Information Systems (GIS), the following monitoring stations were used:

- Podhradová,
- Strojárenská,
- Štúrova,
- Amurská,
- Veľká Ida.

The stations were deployed to capture the situation of air pollution in Košice as well as possible. The selection of all sites was conducted in a commission way with the involvement of interested authorities, organizations and institutions. When selecting the sites, wind conditions and dominant town resources were taken into account.

The station ***Košice - Podhradová*** is located in the area of the SHMI workplace in a relatively open air space on the northern side of the Podhradová housing estate and the town itself. Since 2000, the station monitors the level of ground-level ozone pollution only.

The station ***Košice – Strojárenská*** represents the northern part of the historic town. It is located next to the Town Hall in congested urban area about 50 meters from the surrounding buildings and far from the road about 15 meters. When the southern wind flows, the site is exposed to emissions from cars in traffic in the Moyzesova Street.

The station ***Košice – Štúrova*** represents the centre of the town. It is located in an open air area in the middle of the square *Námestie osloboditeľov* between the car park and symbolic cemetery. Far from the station about15 meters north and 50 meters south there are roads of inner circle that lead in the east-west direction [9].

1.2 Climatic characteristics of the assessed area

Climatic conditions of the area in question are affected by the layout of surrounding mountains. From the south-west, the Slovak Karst affects the area, in the north there are the Slovak Ore Mountains, in the east Slanské Hills. Among the mountains, the Košická kotlina basin ranges. In the Kosice Region, several climatic zones exist. In the East Slovak Lowland (in Slovak: Východoslovenská nížina), including the Zemplin Hills (in

Slovak: Zemplínské vrchy), there is a warm area representing the area with an average of 50 or more summer days and annual daily maximum air temperature ≥ 25 °C. From a climatic point of view, also Košická kotlina basin belongs to the same area which is warm, dry, or slightly damp with cold winters. From a climatic point of view, the Slovak Ore Mountains are located in a slightly warm and cold area. In a slightly warm area, there is, on average, less than 50 summer days per year with a daily maximum air temperature ≥ 25 °C and a July average air temperature ≤ 16 °C. In a cold area, there is a July average air temperature < 16 °C with relatively high humidity. The lowest values of average annual rainfall are in southern areas of the region, such as the Eastern Lowland (in Slovak: Východoslovenská nížina) and Bodviany Hills (in Slovak: Bodvianska pahorkatina) (550-600 mm). The highest values of average annual rainfall are in highland areas of the Volov Hills (in Slovak: Volovské vrchy) in the range of 800-900 mm. It is similar with the number of days with snow cover – in southern areas it is 60 days, in highland areas 120 days. [16]

Weather conditions pose a high degree of influence on the spread of pollutants in the air. In the area in question, there is relatively small occurrence of wind calm. The highest incidence of calm is recorded in January; thereupon unfavourable conditions for dispersion of pollutants in the air arise in this month.

The north-south orientation of the basin is the most important factor in shaping the direction of flow, resulting in a significantly narrow wind rose with prevailing wind blow in the north direction and secondary wind blow in the south direction (especially in the cold half of the year). The prevailing wind from the north is characterized by relatively higher speeds, achieving on average 5.7 ms-1. The average wind speed per year in all directions is 3.6 ms-1. The southern part of the Košice basin is open and highly windy. Also, a substantial part of the town of Košice, especially, the Hornád river valley and ridges surrounding the hills are very windy. Fig. 2 below presents the wind rose from the meteorological station spatially localized in the part Košice-Airport for the period of March 2013. The abundance of wind directions is expressed in % [15].

The dispersion conditions in the area are greatly influenced by orography. The subarea of the town of Košice situated in the Hornád river valley shows limited conditions for dispersion of pollutants in the air. Airflow is of a typical north-south nature and the most unfavourable conditions for the dispersion here arise during the heating period at low south flow, or stagnant air.

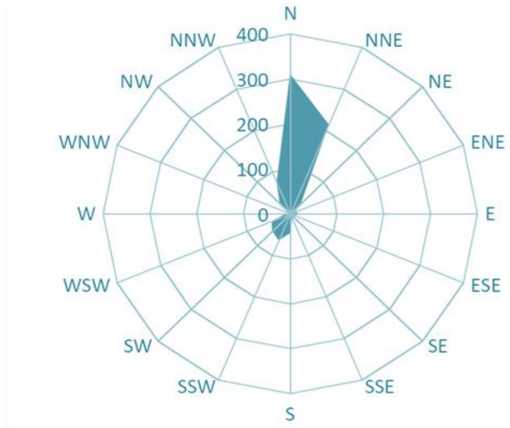

Fig. 2 Wind conditions for selected part

2 ASSESSMENT OF AIR QUALITY USING GIS

In general, the GIS represent an effective tool for the field of processing spatially localized data with versatile use. Their applications can be found in the area of the monitoring and processing of air quality. The "Reports on the state of the environment" for the selected periods were the basis for processing air pollutant values for the selected period 2008-2010 in the GIS environment. The summary reports on air quality under the conditions in the Slovak Republic are compiled by the SHMI. On the basis of available information, the air pollution levels measured at individual stations of the Observatory Network were processed for the Košice agglomeration. Available spatial information given in Tab. 3 and Tab. 4 contributed to a distinct extent to the spatial processing of air pollution. The distribution of the considered automated monitoring stations is presented in Fig. 3. In terms of the deployment of the automated monitoring stations, it is necessary to note a change in the spatial location. By 2009, the air pollution monitoring was carried out through the stations listed in Tab. 3. Since 2009, a change has occurred which necessitated the deployment of new monitoring stations. The list of the new stations which are in force to the present day is characterized in Tab. 4.

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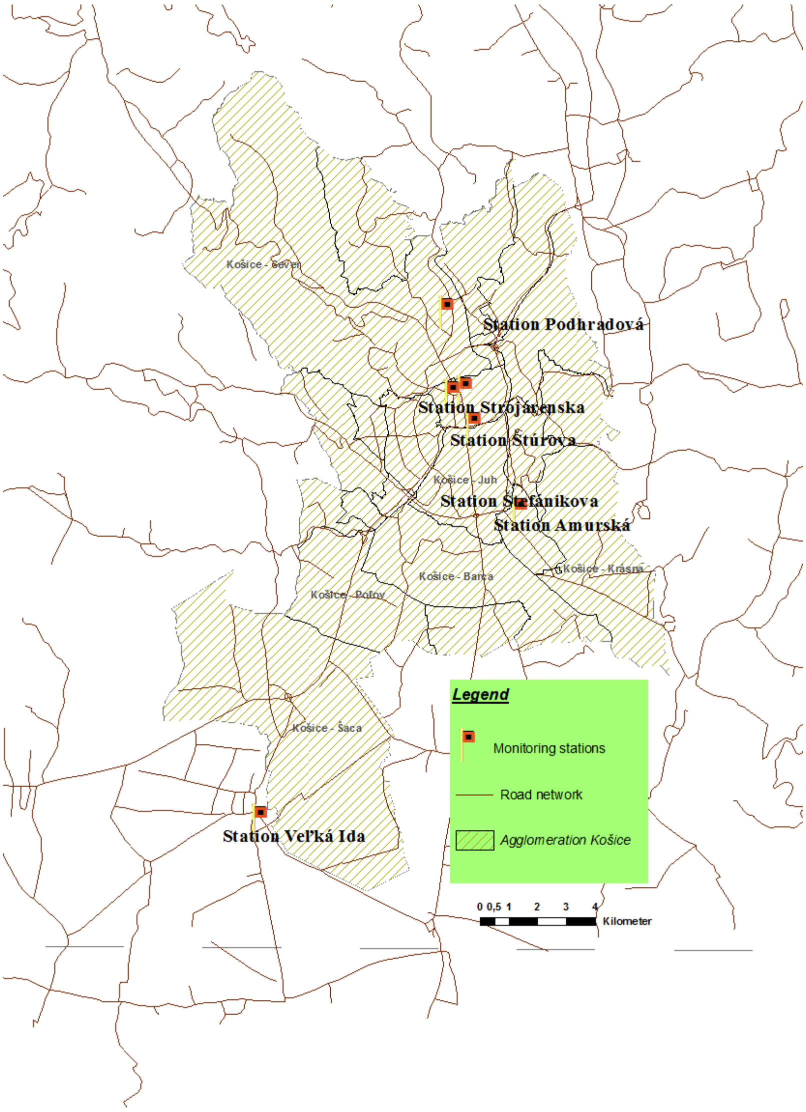


Fig. 3 Spatial distribution of monitoring stations in the agglomeration of Košice

Tab. 3 List of monitoring stations in the year 2008 [9]

Monitoring stations	Longitude	Latitude
Štúrova	E 021°15'39"	N 48°43'02"
Strojárenská	E 021°15'07"	N 48°43'36"
Veľká Ida	E 021°10'30"	N 48°35'32"

Tab. 4 List of monitoring stations since the year 2009 [7]

Monitoring stations	Longitude	Latitude
Amurská	E 021°17'11"	N 48°41'28"
Štúrova	E 021°15'39"	N 48°43'02"
Strojárenská	E 021°15'07"	N 48°43'36"
Veľká Ida	E 021°10'30"	N 48°35'32"

2.1 Processing the results of measurements of air pollution according to air pollutant limits for the period 2008-2010

In 2008, based on the results of the level of air pollution, three different monitor modes are distinguished. Fig. 4 and Tab. 5 specify requirements for the assessment of air quality for each proposed monitoring mode.

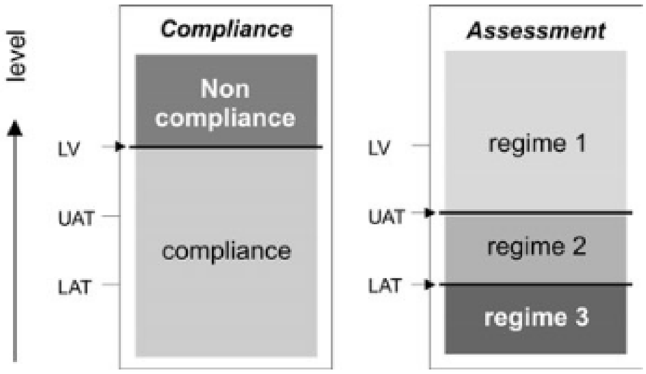


Fig. 4 Regimes of air quality assessment in relation to LV1,UAT2 and LAT3 [9], [7]

Legend: LV - limit value according to Decree No. 360/2010 Coll., on Air Quality
UAT - Upper Assessment Threshold (Decree 360/2010 Coll.)
LAT- Lower Assessment Threshold (Decree 360/2010 Coll.)

Tab. 5 Requirements for assessment in three different regimes [8]

Maximum level of pollution in agglomerations and zones	Requirements for assessment
REGIME 1 Above upper assessment threshold	High quality of measurements is obligatory. Measured data can be supplemented by further information, model computations including.
REGIME 2 Below upper assessment threshold, but above lower assessment threshold	Measurements are obligatory, however to a lesser extent, or to a lesser intensity, under the premise that the data are supplemented by other reliable sources of information.
REGIME 3 Below lower assessment threshold In agglomerations only for pollutants, for which an alert threshold has been set	At least one measurement station is required in each Agglomeration combined with the model computations, expert estimate and indicative measurements. Those are measurements based on simple methods, or operated in limited time. These are less accurate than continuous measurements, but may be used to control relatively low level of pollution and as supplementary measurements in other areas.
In all types of zones, apart from agglomeration zones, for all pollutants for which an alert threshold has been set	Model computations, expert estimates and indicative measurements are sufficient.

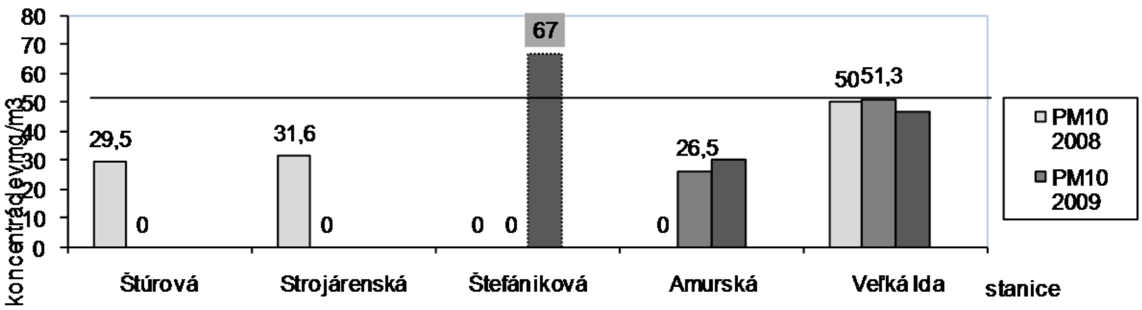
Tab. 6 Presentation of the limit values for PM 10 by [1]

Averaged period	Limit value	Threshold of tolerance
Particulate matter PM_{10}		
1 day	50 μg.m^{-3} may not be exceeded more than 35 times per calendar year	**50%**
Calendar year	40 μg.m^{-3}	**20%**

Tab. 7 Annual average concentrations of PM_{10} [μg.m^{-3}]

Monitoring stations/particulate matter	PM_{10} *2008* (24 hour)	PM_{10} *2008* (1 year)	PM_{10} *2009* (24 hour)	PM_{10} *2009* (1 year)	PM_{10} *2010* (24 hour)	PM_{10} *2010* (1 year)
Košice - Štúrova	38	**29.5**	*	*	*	*
Košice - Strojárenská	55	**31.6**	*	*	*	*
Košice - Štefániková	*	*	*	*	67	**36.2**
Košice - Amurská	*	*	15	**26.5**	30	**25.2**
Košice - Veľká Ida	157	50	166	**51.3**	132	**46.7**

According to Decree 360/2010, it was necessary to perform further processing to establish limit values for air pollution components. The set upper limits were based on Tab. 5. In accordance with relevant EU directives, the particulate matter is reported as PM_{10}. The graphic processing of the measured values of the amount of particulate matter for the selected period realized by means of a spreadsheet MS Excel is presented in Graph 1. The subject matter of the processing was to compare average annual concentrations of pollutants with corresponding air pollutant limits according to applicable SK legislation. Graph 1 shows the comparison of the average annual concentrations of the pollutant with relevant air pollutant limits. During the monitored period, the air pollutant limit values for particulate matter (PM_{10}) were exceeded at the monitoring stations Veľká Ida in 2009 and Štefániková in 2010.



Graph. 1 Graphical data processing concentrations of PM10

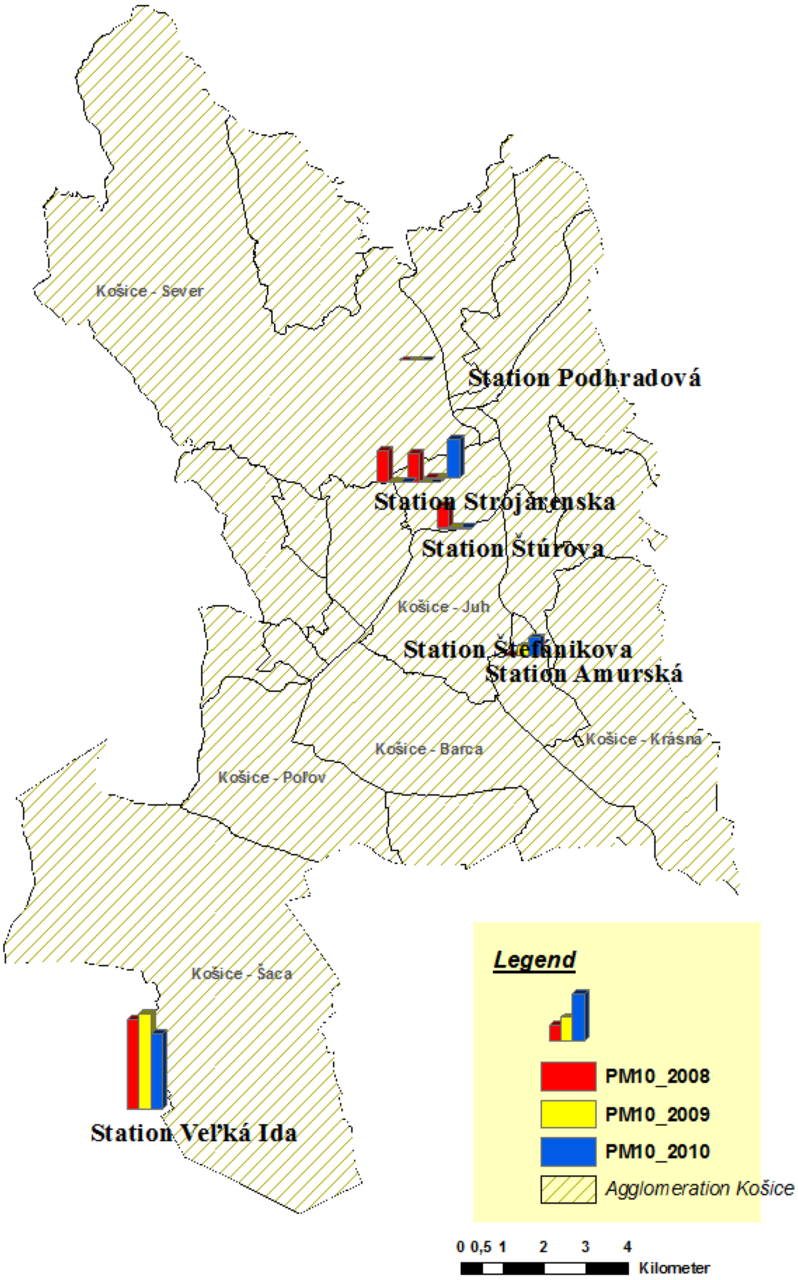


Fig. 5 Spatial processing of measured data in GIS environment

By default, also interpolation methods in addition to statistical methods are applied in processing and evaluating the measured values of concentrations of air pollutants. Together, they form a mathematical basis for the processing of data presenting the level of air pollution in general [10]. For the purpose of determining the extent of air pollution by particulate matter, it is appropriate to apply the following methods:

1. Thiessen polygon method - the nearest neighbour method,
2. Inverse distance weighted (IDW),
3. Spline interpolation
4. Bilinear interpolation,
5. Cubic interpolation. [10] , [11]

In the issues of observations of PM_{10} for a selected period of time interval of one year in the agglomeration of Košice, the IDW method was applied in the GIS environment. The IDW method represents a deterministic method, for the calculation of which the weighted linear average is used. The weight, which is used for calculation, is the reciprocal value of the distance of measurement from a local estimate with the power p. The equation of the simplest form of the IDW method according to [13] looks like this:

$$F(x,y)=\sum_{i=1}^{n} w_i Z(s_i) \qquad (1)$$

Where:

n – number of measured points,

$Z(s_i)$ – variable value in measured ith point

w_i – weight

The advantage of using the IDW method in processing the meteorological data is the fact that each cell of a raster is assigned a value according to the following mathematical equation by a weighted linear combination of the values measured at the automated monitoring stations [12]:

$$Z(s_0)=\frac{\sum_{i=1}^{n}\frac{Z(s_i)}{d_{0i}^{\beta}}}{\sum_{i=1}^{n}\frac{1}{d_{0i}^{\beta}}} \qquad (2)$$

Where:

$Z(s_0)$ – value of interpolated point

$Z(s_i)$ – value of measurement at ith point

d_{0i} – distance between interpolated point and point of measurement

β – power of weight

At a level of the modelling of spatial interpolation of concentrations of selected pollutants (e.g. PM_{10}, $PM_{2,5}$, ozone and heavy metals), this method is classified in the group of the models which are applied also in the environment of the Slovak Hydrometeorological Institute (SHMI). For the purpose of monitoring the concentrations of the substances present in the air, the IDW is a very successful used method. Under the conditions of SHMI, the interpolation method IDW-A was designed, in which the degree of influence of monitoring stations on the concentration in nodal network points is indirectly dependent on their mutual distances [7]. The interpolation model has a wide field of applicative use. Its options can also be associated for instance for the nationwide assessment of concentration levels of PM_{10}. The mentioned issue is more fully addressed also by the publication [14].

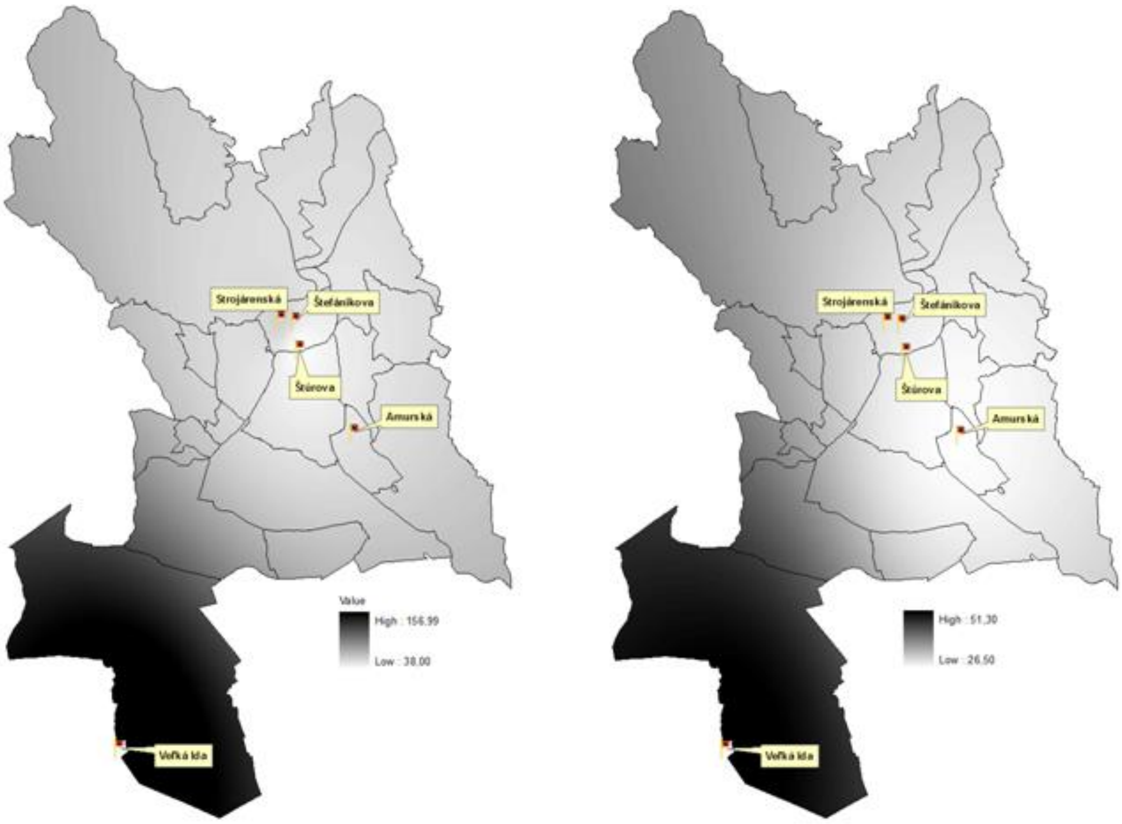
Input data for IDW

The input data should cover the following areas of resources:

- Measured or derived data from monitoring stations
- Attributes depending on an environment nature for each surveying point
  - Presence and significance of resources
  - Weights, geographic integrity
  - Size of built-up area [7]

Results and outcomes

Model calculations for the assessment of concentrations of a selected pollutant (PM_{10}) were performed by applying the above-mentioned method IDW in the GIS environment for the period 2008-2010. In the following part, the presented map outputs identify the areal layout of air pollutants for the selected area. The software support of the ArcView 9.3 interface simplified the solution process of the mentioned issues to a great extent. With the support of analytical tools, the obtained outputs offer the information at the level of air pollution carried over into a map view. The output provides an illustrative overview of the development of air pollution during the selected period 2008-2010 presented in detail in Fig. 6 and in Fig. 7.



Year 2008 **Year 2009**

Fig. 6 Spatial interpolation of PM_{10} concentrations using IDW for years 2008, 2009

Fig. 7 Spatial interpolation of PM_{10} concentrations using IDW for year 2010

3 DISCUSSION

In general, it can be stated that the main pollutants in the atmosphere are produced by the energy, automotive and transportation industries. Local air pollution of a ground layer caused by local sources is of a great significance to the human environment. Its concentration show a distinct diurnal and seasonal variations depending on the orographic and meteorological factors. In case of weak air flow or calm coupled with a significant temperature inversion, pollutant concentrations can achieve even a value far in excess of the permissible limit value.

In the area of Košice, the most emissions of main pollutants are produced in total within other regions of Slovakia on a long-term basis.

Problems of air pollution in Košice are characterized by:

- High annual amount of produced emissions of pollutants from stationary industrial sources
- Rising trend in air pollution by emissions of exhaust gases from mobile sources - automobile transport
- Air pollution emissions (from high to overlimit concentrations of NO_x and particulate matter)

The overall development of emissions from dominant sources in the area of the town of Košice in terms of air pollution by sulphur dioxide and particulate matter is auspicious. The burden on the town with the harmful substances from the end of the eighties gradually decreases.

The trend of reducing total emissions from stationary sources in Košice is the result of changes in the fuel base, progressive supplying with gas and introduction of heating systems (central heating), the implementation of technical and technological measures at the sources of air pollution.

During the selected period, the emission limit values for particulate matter (PM_{10}) were exceeded at the monitoring stations Veľká Ida in 2009 and Štefániková in 2010.

4 CONCLUSIONS

This contribution presents the analysis and evaluation of the values of particulate matter PM_{10} on the basis of measurements at selected monitoring stations with administrative determination for the area of the town of Košice. For pre-testing, analysis and visualization, a set of measured concentrations of particulate matter – PM_{10} for the period 2008-2010 has been chosen which were taken over from the reports on the state of the environment of the Slovak Hydrometeorological Institute SR. The results of processing are clearly presented through graphical outputs in a form of tables, graphs and thematic maps from the GIS environment. The selected method for the processing of spatial information – IDW is currently an active form of tracking changes in concentrations of particulate pollutants in the air. The introduced method of processing spatial data can serve as a supplement to the estimation of air pollution in the town of Košice.

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RESUMÉ

Príspevok je venovaný analýze vybraných tuhých znečisťujúcich látok, ktoré bezprostredne vplývajú na kvalitu ovzdušia vo všeobecnosti. Najväčší problém kvality ovzdušia na Slovensku, ako aj vo väčšine európskych krajín, predstavuje v súčasnosti znečistenie ovzdušia suspendovanými časticami (PM_{10}) [5]. Rozhodujúci podiel produkcií PM_{10} majú regionálne zdroje (prírodné zdroje, poľnohospodárske aktivity). Konkrétne riešenie uvedenej problematiky bolo zamerané na integráciu nástrojov GIS v oblasti posudzovania (hodnotenia) kvality ovzdušia. GIS, ako vhodný informačný systém ponúkol pre riešenú lokalitu širokú škálu analytických nástrojov a funkcií. GIS sa v súčasnosti využíva v širokospektrálnom uplatnení nevynímajúc odbor civilnej obrany preplánovanie možných krízových situácií vrátane oblasti ochrany životného prostredia. GIS na úrovni spracovania príspevku vhodnou kombináciou možnosti analytických nástrojov ponúka silný nástroj pre modelovanie priestorových javov v oblasti ochrany životného prostredia aj v budúcnosti. Komplexné spracovanie informácií týkajúcich sa kvality ovzdušia pre zvolené územie si autori príspevku bez nasadenia GIS nedokážu predstaviť. Ďalšiu neoddeliteľnú výhodu aplikácie GIS je možnosť spracovania a prezentácie dát v jednom systéme, čo ponúka možnosť komfortnej aktualizácie a integrácie aj časových radov pre ľubovoľnú monitorovaciu stanicu.

Štandardne sa v procese spracovania a vyhodnotenia meraných hodnôt koncentrácie znečisťujúcich látok v ovzduší aplikujú rôzne interpolačné metódy. Použitím interpolačnej metódy IDW boli v prostredí GIS spracované priestorové informácie monitorovacích staníc nachádzajúcich sa na území mesta Košice a jeho bezprostrednom okolí. V sledovanom období hodnoty imisných limitov pre tuhé častice (PM_{10}) boli prekročené

na monitorovacích staniciach Veľká Ida v roku 2009 a Štefániková v roku 2010. Získané výsledky spracovania koncentrácie tuhých častíc (PM_{10}) za vybrané sledované obdobie rokov 2008 - 2010 sú prezentované formou výstupných zostáv.