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Air Protection in Theory and Practice

Preliminary comparative assessment of PM_{10} hourly measurement results from new monitoring stations type using stochastic and exploratory methodology and models

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Abstract. The paper presents selected preliminary stage key issues proposed extended equivalence measurement results assessment for new portable devices - the comparability PM_{10} concentration results hourly series with reference station measurement results with statistical methods. In article presented new portable meters technical aspects. The emphasis was placed on the comparability the results using the stochastic and exploratory methods methodology concept. The concept is based on notice that results series simple comparability in the time domain is insufficient. The comparison of regularity should be done in three complementary fields of statistical modeling: time, frequency and space. The proposal is based on model's results of five annual series measurement results new mobile devices and WIOS (Provincial Environmental Protection Inspectorate) reference station located in Nowy Sacz city. The obtained results indicate both the comparison methodology completeness and the high correspondence obtained new measurements results devices with reference.

1. Introduction

The direction in which follow modern society is the development and growing importance of urban industry-agglomerations – smart cities. It is essential that process proceeded in a way that ensures balances economic development as a consequence of providing a high quality of life for residents. In classical terms, the model concept of "smart city" the environment is one of six main elements [12].

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Automatic air pollutants monitoring (APM) systems are a key part of the "nervous" smart city [12]. The functions it must ensure, among others, such as reporting on the state of the air, weather warnings or ultimately control the emission determine the adopted solutions. Such system must provide above all the credibility of measurements results. Obtained data allow to use them in key models: impact air pollution on health [1, 3]. It is indispensable in the statistical methodology [4].

The use of quantitative methods, including stochastic and exploratory techniques in environmental studies does not seem to be sufficient in practical aspects. There is no comprehensive analytical system dedicated to this issue, as well as research regarding this subject.

Automatic air monitoring systems in the agglomerations are built on the basis of reference devices (WIOŚ, ARMAAG). Currently, they provide the highest credibility of measurement results, and thus – mathematical modeling, environmental assessments including health impacts and forecasts. The disadvantages are the high cost of purchasing equipment and their maintenance over a long period of time, to ensure the highest quality of measurement results. This is a barrier to the development of monitoring networks even for large industrial urban areas. The purchase of reference equipment is sometimes costing several hundred thousand dollars, depending on the equipment and measured impurities.

This is one of the reasons why there is a need for cheaper measuring devices. Such devices, apart from significantly lower purchase and maintenance costs, have a number of other advantages, including:

- allow making measurements in places not yet available for large and expensive stations such as public transport, inaccessible hilly and marine areas,
- the network of such stations, through their large number, allows for more accurate modeling and forecasting, as errors are eliminated. with mathematical spatial interpolation necessary for reference point measurements,
- allow making measurements in the immediate vicinity of the impact of pollutants on humans so that a precise assessment of the impact of pollutants on health is possible.

These three examples show how many potential changes in air pollution measuring can introduce new devices.

In addition to the advantages, these measures, however, have a major drawback, namely the risk of erroneous quality of measured results. The quality of the measurement itself determines the further use of the acquired data.

In this case, the term "quality" does not mean rating the quality of measured data and the cause of its origin [1]. In the first stage of work on new methods of balancing differences of measurement results, it is necessary to evaluate the conformity with the reference measurement standard - this is a problem of equivalence of measurement results. In the case of PM_{10}, the gravimetric method (manual weighting) [2] is used as the reference method according to PN-EN 12341: 2014 which results in daily results (24 hours). For continuous measurements, it is necessary to average the hourly data.

Particulate matter in one of the major air pollutants. It is a complex mixture of particles of different chemical composition and size that strongly interacts with human health [3, 4, 5]. It can be found both from natural sources (marine aerosol, rock erosion) as well as anthropogenic (transport emissions, municipal and other emissions). It is considered as derivative pollution [6, 7] due to on the complexity of processes that shape the number of particles of a certain size at a given location.

The European Union has set the requirements for permissible concentrations of atmospheric dusts [8] and obliges Member States to take effective action in the event of exceeding the limit values. The Polish legal system is obliged to carry out annual assessments of air quality. Quality assessment is prepared by the Provincial Inspector for

Environmental Protection, which is the result of the obligation imposed by Art. 89 and 90 of the Environmental Protection Law [9].

2. Materials and methods

2.1 Construction of new portable devices

The prototype air quality measurement device was constructed by scientists from the Warsaw University of Technology. The devices consist of microcontroller, temperature, humidity, particular matter sensors and communication modules.

Optical dust sensors are used in the devices. In order to select a suitable sensor, several models were tested. The DFRobots particular matter sensor in the preliminary tests showed the best correlation with the DustTrak portable device, so it was chosen as the primary particular matter sensor for further testing.

According to the producer, the sensor detects three types of particular matters: PM_{10}, $PM_{2.5}$ and PM_1 ranging from 0 μm/m^3 to 1000 μm/m^3 and has a response time of less than 10 seconds. It allows continuous measurements.

The devices were also equipped with temperature and humidity sensors, a modem and additional components to provide the correct voltage specifications for each component. The central part of the device is based on the Arduino Mega microcontroller. Communication with the particulate matter sensor and modem is via serial ports. The temperature and humidity sensors communicate via a digital interface. The devices operate 24 hours a day. They send measurements to the server with the database [10, 11].

2.2 Data source

The preliminary analysis of the comparability of PM_{10}measurements was based on the results of continuous measurements from five mobile stations u1 to u5 compared to the reference station PL0550A (Fig. 1.) in Nowy Sacz for an annual period from 27.09.2016 to

Fig. 1. Measurement units localization in Nowy Sacz city
Source: Author's own work based on research

30.09.2017.

Table 1 shows average concentrations of PM_{10} and average values of temperatures and relative humidity in the analyzed months at all stations.

Designed measuring devices have been used to build a measuring network operating under real conditions. As their location was chosen the area of the Nowy Sacz. Nowy Sacz is a city of over 80 thousand inhabitants, it covers area of 57 km^2 and is located in the Malopolska province. The city is characterized by diverse terrain – the lowest point of the city is situated at 272 m AMSL, while the highest – 475 m AMSL. In the city there are typically urban areas with town houses, parks and green areas and single-family housing. Some areas are powered by district heating (therefore, theoretically low emissions should be there reduced), while others, especially single-family housing, have their own fireplaces, which, as may be supposed, can be a source of low emissions. There is one air quality monitoring station owned by polish General Inspectorate of Environmental Protection. The closest measurement station is located in Tarnow (about 45 km in straight line).

Table 1 Monthly averaged values of PM_{10} dust concentration on five mobile (u) stations and reference (Ref), temperature, relative humidity, where Ref – reference station, u1 to u5 measuring devices.

month	**PM_{10} [µg/m^3]**						**Temp [ºC]**	**Humidity [%]**
	Ref	**u1**	**u2**	**u3**	**u4**	**u5**		
1	113.21	97.93	156.74	108.72	121.42	20.17	-2.49	94.99
2	75.05	78.63	138.64	98.25	100.17	70.93	4.13	94.33
3	46.53	44.38	68.56	50.50	62.94	41.31	9.74	89.74
4	28.11	26.33	34.52	27.62	33.93	16.34	11.59	83.48
5	22.86	24.97	25.00	20.60	24.51	5.62	19.12	73.57
6	18.68	13.54	12.10	9.74	14.04	8.02	24.76	58.78
7	16.85	10.15	12.00	9.53	17.23	9.09	25.44	64.42
8	22.91	18.14	17.32	13.84	23.35	19.56	25.48	71.13
9	20.30	20.12	21.34	17.17	28.42	18.39	18.06	80.78
10	26.78	33.08	44.67	35.95	42.43	2.37	11.42	83.42
11	50.88	52.01	72.09	61.29	65.92	6.23	6.85	95.30
12	79.49	67.24	112.47	72.49	83.03	13.89	2.45	98.07

Source: Author's own work based on research

Under the agreement between the Nowy Sacz, Faculty of Building Services, Hydro and Environmental Engineering in Warsaw University of Technology and Gdynia Maritime Academy, the first prototype devices were installed in September in 2016 and started operating in five locations in Nowy Sacz. The location, areas and method of assembly were determined by the employees of the Environmental Protection Department of the Nowy Sacz. The data from the individual devices are available to the residents at: http://www.nowysacz.pl/pomiary-powietrza, so that it is possible to check the current air quality from individual measuring devices.

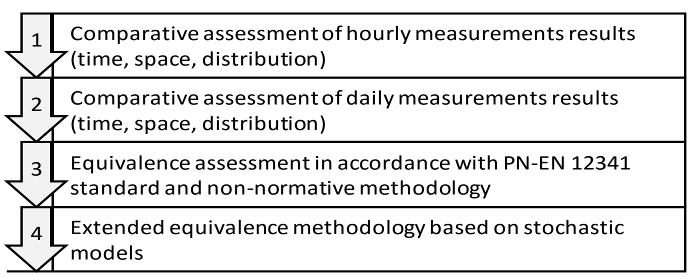

Fig. 2. Proposed measurement results equivalence methodology based on stochastic models
Source: Author's own work based on research

3. Methodology

The present equivalence methods have been described in detail in [3, 4]. These methods allow for the correction of measurement results of various types of new measuring devices based on correction factors and models of linear and orthogonal regression. The main objective of the study is to propose a new, extended methodology of equivalence based on statistical functions and models, including nonlinear models, to improve the quality of the measurement results from new equipment, ie. to reduce the difference in measurement results to reference devices. New correction models are designed to operate in real time, ie. the correction mechanisms will be built directly into devices. The proposed methodology (Fig. 2.) comprises four stages, the first of which is the subject of this study.

The first two steps aim is to identifying the differences in the statistical properties of measurement results comparable sets of new portable devices in relation to reference device in three domains of construction stochastic and exploratory models (time, frequency and space). A comparison of the correctness in the internal structure of the measurement results allows us to identify potential causes for differences, which, according to as the Jenkins Box models [1], will allow to build more accurate correction models in the final stage. Phase three includes the equivalence models currently in use.

The last stage of the extended equivalence methodology includes proposals for correcting the measurement results based on the identified differences in earlier stages.

3.1 Idea

The essence of the first stage of the proposed stochastic correction models is a detailed comparison of internal correctness in the results of measurements, presented on the example of PM_{10} concentrations.

The alignment of the series of measurement results of the examined devices and reference devices is not sufficient. It only allows the final assessment of the differences and the extent to which the measurement results differ from the reference.

The comparison of the causes of these differences, ie. the accuracy of the results of the measurements, allows, on the one hand, for accurate and reliable comparative assessment, and on the second hand, in case of strong differences, to propose correction models based on the causes of differences and not on the results alone (Fig. 3.).

In the time domain, aside from the results of measurements, the key comparisons of correctness are, among others:

- process constancy measured by the basic function of the total autocorrelation and partial autocorrelation, in the form of:

$$r_\tau^* = \frac{\sum_{t=\tau+1}^{n} X_t^* X_{t-\tau}^*}{\sum_{t=\tau+1}^{n} (X_{t-\tau}^*)^2} \tag{1}$$

where: τ - *lag in hours*, X_t – time serie, μ - average, n – total size

- homoscedasticity, the estimation of which is the variability of the process variance over time,

- the stability of mutual relations in selected, previously identified, statistically significant periodic periods for a given concentration.

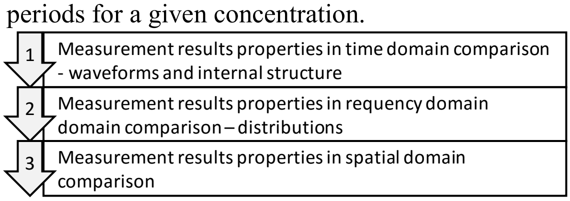

Fig. 3. Proposed measurement results comparison methodology
Source: Author's own work based on research

In the frequency domain, it is crucial to compare the spectral models (Fourier) with the results of periodograms and the form of distributions.

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Comparison of the spatial domain is not obligatory - it is required in the case where the measuring devices are located, for independent reasons, in different spatial locations. In this case, the probable causes of the differences should be recognized.

In the final phase, this stage must be eliminated. Monitoring devices should be located in the immediate vicinity of the reference device to minimize the impact of additional interference factors on the measurement differences (eg. meteorological factors, additional emission sources).

This is not always possible in practice, as in this example, for reasons independent of researchers. It is therefore necessary to take this into account.

The property comparison in the results of hourly and continuous measurements averaged daily must lead to common conclusions. If this is not the case, or the deviations in the regularities are very strong, this may indicate instability in the measurements and consequently the impossibility of building a stable correction model for the measuring device.

4. Results

Before comparing, PCA (Principal Component Analysis) model was used to analyze the relationships between mobile station measurements and differences in relation to reference results (Fig. 4.).

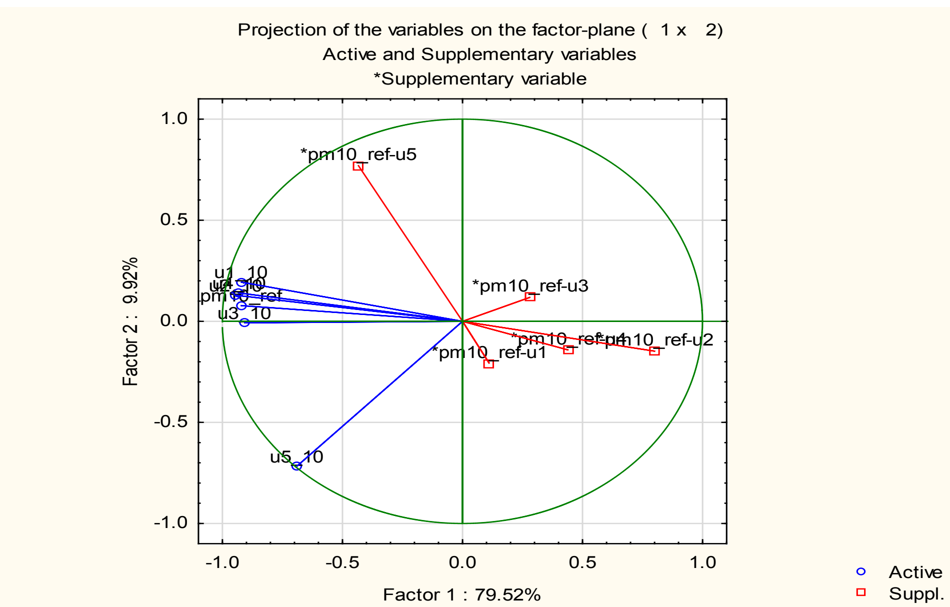

Fig. 4. PM_{10} concentrations results projection and differences from reference results on the two-dimensional plane of the factors in the PCA model.
Source: Author's own work based on research

The obtained results show strong spatial similarities between PM_{10} measurements at stations u1 to u4. Station u5 deviates from the rest due to the location in which there is no impact of traffic and municipal traffic.

A slightly different situation occurs in the case of differences in the results of measurements in relation to reference device. In addition to the PM_{10} measurements at station u5, u3 is also characterized by greater variation. The differences are related to location and confirm the need to build different correction models for each station in the future.

Fig. 5 shows the time series of 1 hour PM_{10} measurements of all analyzed mobile stations (marked as “u”) and reference station.

The waveforms indicate a higher variation in the measurement results in the first half of the year, with a high degree of compliance with the reference results. Confirmation is the R2 determination coefficients of linear regression models of mobile stations performance with reference device in the daily cycle (Fig. 6).

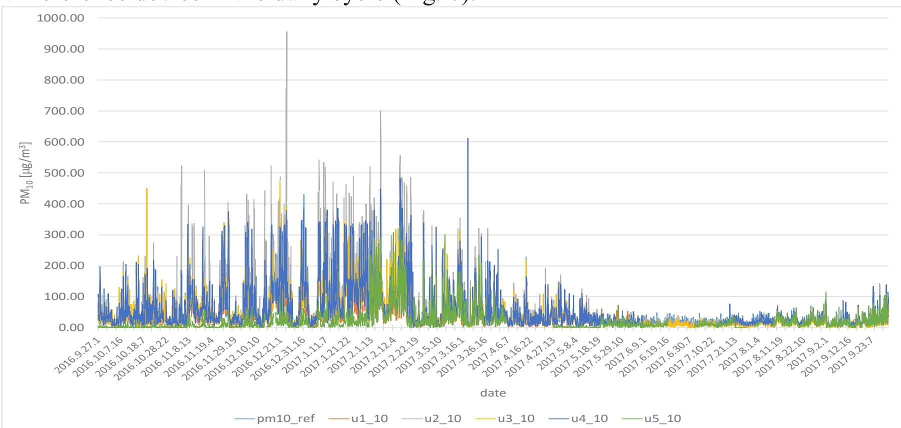

Fig. 5. PM_{10} 1-hourly concentrations results time series; 27.09.2016 to 30.09.2017 in Nowy Sacz.
Source: Author’s own work based on research

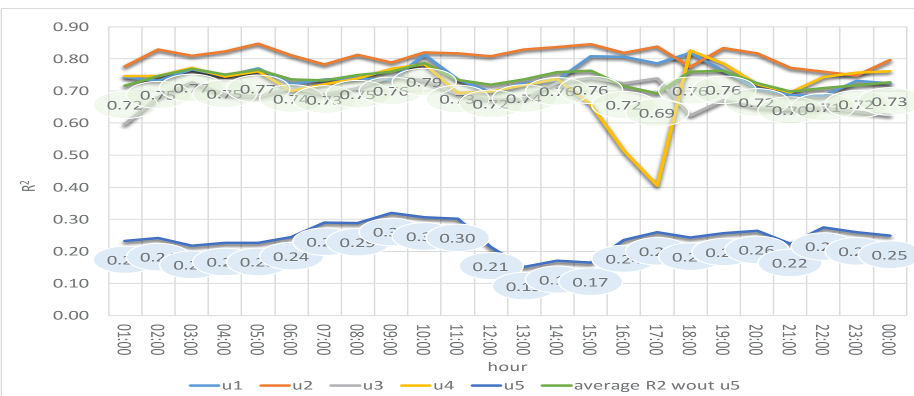

Fig. 6. Determinations coefficients R2 PM_{10} regression models of reference measurements with test stations (u) for each hour in daily cycle.
Source: Author’s own work based on research.

Fitting of linear regression models for each station, except u5, is high (average from 0.69 to 0.79), which makes it possible to assert that the introduction of a more accurate correction function can significantly improve the quality of measurement results obtained with new meters.

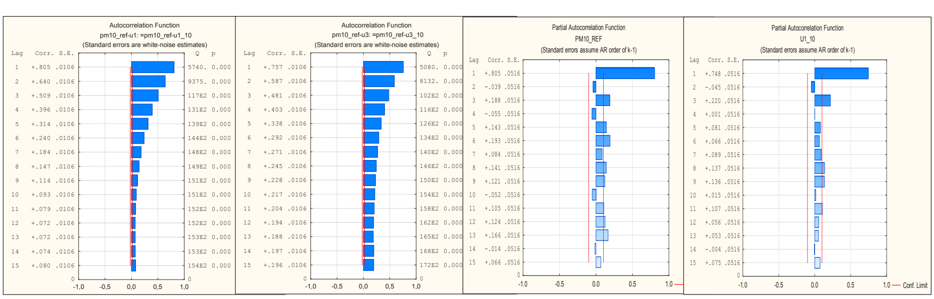

Fig. 7. Selected differences PM_{10} autocorrelation function (a, b) and partial autocorrelation functions of selected PM_{10} results (c, d).
Source: Author's own work based on research.

Comparison of the total and partial autocorrelation of measurement differences from mobile devices to reference device and PM_{10} measurements indicates a high degree of similarity between the PM_{10} measurements of new stations and reference station. This observation leads to the conclusion that the probability of obtaining effective corrections with new correction models using the stochastic methodology is high.

5. Conclusions

Due to the limited volume of the paper, all research results for one hour data, including Fourier models, time correlation coefficients and detailed regression models of PM_{10} measurement results with PM_{10} reference results, are not presented. A separate study presents conclusions for daily averaged data and is therefore directly used for estimation of equivalence.

All obtained results, including these which are not presented, confirm the high compatibility of PM_{10} measurements from new mobile stations with the reference station. Lower differences in the results were observed for the warm season, higher for the cooler. Regression models are also highly adjustable regardless of the time.

A key synthetic conclusion is the high probability of proposing new effective models and correction functions, based on identified regularities, for continuous and daily PM_{10} measurements of new measurement devices. It will also be possible to implement them as the measurement device software, so that the correction will be done in real time.

References

1. P. O. Czechowski, A. Badyda, G. Majewski, Arch. of Environ. Protect., **39**, 4 (2013)
2. J. Gębicki, K. Szymańska, Atmos. Environ. **54** (2012)
3. G. Majewski, W. Rogula-Kozłowska, P. O. Czechowski, A. Badyda, A. Brandyk, ISSN 2073-4433, Atmosphere, **6** 2015
4. A. Badyda, J. Grellier, P. Dąbrowiecki, Adv. in Exper. Med. and Biol., **44** (2016)
5. A. Badyda, P. Dąbrowiecki, P. O. Czechowski, G. Majewski, Resp. Phys. & Neur., **209** (2014)
6. J. Gębicki, K. Szymańska, W. Wardencki, Inst. Inż. Ochr. Środ. Poli. Wroc. (2012)
7. J. Gębicki, K. Szymańska, Pol. J. Environ. Sci. **20**, 6 (2011)
8. Directive of the European Parliament and of the Council 2008/50 / EC, 21 may (2008)
9. Official Gazette Republic of Poland **25**, 15 (2008)
10. M. Rogulski, B. Dziadak, Appl. Manag. (2017)
11. M. Rogulski, **128**, Energy Proc. (2017)
12. BSI Standards Publication, ISBN 978 0 580 84320 4, (2014)