**REPUBLIC OF AZERBAIJAN**

*On the rights of the manuscript*

# APPLICATION OF MATHEMATICAL AND AEROCOSMIC METHODS TO THE PROBLEMS OF OPTICAL MONITORING OF URBAN AIR

Speciality: 3324.07- Remote aerospace research

Field of science: technology

Applicant: **Zakir Jumshud oglu Zabidov**

## ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

**Baku – 2022**

The work was performed at the department of "Non-harmonic analysis" Institute of Mathematics and Mechanics Azerbaijan National Academy of Science

Scientific supervisor: Corr. member of ANAS,

dr. of ph. and math. sci., prof.

**Bilal Telman oglu Bilalov**

Official opponents: Doctor of technical sciences, professor

**Tofig Ibrahim oglu Suleymanov**

Candidate of technical science

**Ismail Mukhtar oglu Zeynalov**

Doctor of Philosophy in Technology

**Amil Tofig oglu Agayev**

One-time dissertation council BFD 2.01 of the National Aviation Academy, Presidential Higher Attestation Commitee of the Republic of Azerbaijan

Chairman of the Dissertation council: Dr. of ph. and math. sci.,

Academician

**Arif Mir Jalal oglu Pashayev**

Scientific secretary of the Dissertation council: Dr. of geogr. sci. ,

Assec. prof.

**Surkhay Hasan oglu Safarov**

Chairman of the scientific seminar: Dr. of ph. and math. sci., prof.

**Latif Khalil oglu Talybly**

# GENERAL CHARACTERISTICS OF WORK

**The actuality of the subject.** The rapid growth of cities and the intensification of the urbanization process leads to a sharp increase in anthropogenic loads on the atmosphere, an increase in environmental tensions in cities and industrial centers (increased levels of environmental pollution). In cities, this process is determined by a complex set of natural-climatic and intensive anthropogenic factors. The organization and conduct of urban air monitoring in order to develop a control mechanism for the emission of pollutants into the air and to assess the spatial distribution of pollutants has become a modern requirement. As a result of monitoring, a large amount of information characterizing pollutants is collected. However, the issues of how to process data, mathematically model and obtain certain results remain open. In such cases, remote sensing and mathematical methods can be used. There are specific methods of obtaining, collecting, initial processing and analysis of information in the monitoring system. The organization and conduct of monitoring is regulated by state standards approved by the relevant government agencies. The information collected on pollutants in the urban air by optical methods is distinguished by its efficiency and informativeness.

In modern times, a large number of scientific and practical research on optical monitoring of urban air is carried out by various international and local organizations. As an example of theoretical research, one can see the research of such authors as K.Ya. Kandratiev, V.E. Zuev, M.E. Berlyand, L.S. Gandin, L.S. Ivlev, Yu.M. Timofeev, P. Rayst, Yu.V. Israel, as well as other authors.

Nowadays, there is a need to study the urban climate, taking into account regional natural and climatic conditions. The level of air pollution with harmful substances depends not only on the amount of primary pollutants, but also on the release of pollutants into the environment under certain weather conditions. At the same time, the second process of pollution occurs in cities. As a result, the concentration of pollutants increases under certain weather conditions and can reach critical level. The level of background air pollution in the city is related to the circulation of matter in the "atmosphere - surface" system, the mechanisms of interaction of aerosol-gas compounds, regional conditions.

It should be noted that the creation of an urban air monitoring network is based on the correct solution of the problem of rational planning and placement of this network. Rational planning of the observation network is characterized by the fact that the network is economically viable on the one hand, and highly informative on the other. Rational planning of the observation network allows monitoring-level research. The effective location of the observation network in these areas is one of the key issues that needs to be addressed, and to some extent depends on the purpose for which the information obtained from the observation posts is used. There are many scientific approaches to the correct solution of the effective deployment of the observation network. A group of researchers divides the city into zones of the same nature. In this case, subjectivity is allowed in the selection of zones. The methodology proposed by O.A. Drozdov and A.A. Shepelovsky has a special significance. O.A. Drozdov and A.A. Shepelovsky developed a methodology for determining the maximum possible distance between observation posts. In this regard, the operative and systematic study of the current environmental situation of the city air, continuous monitoring, efficient placement of observation posts and management of the operating mode has become one of the most pressing problems of our time.

**The object of research** is an optical monitoring system of urban air pollution.

**The subject of research** is mathematical models and algorithms of optical data processing, mathematical and aerospace methods.

**The goal and objectives of the study.** The purpose of the dissertation is to organize and conduct optical monitoring, which is an integral part of a comprehensive environmental monitoring system, the processing of optical monitoring data by mathematical methods, the analysis of trends in the formation and change of polluted air in the urban environment. The purpose of the study is to study the features of the initial processing of objective observation materials, objective and statistical analysis, characterizing the urban air basin, taking into account regional meteorological conditions.

The dissertation envisages the development of application schemes of mathematical methods (three sigma rules, main components and wavelet analysis methods) and the principles of efficient placement and management of the urban air observation network.

**General technique of studies.** The following theories and methods were used to solve the problems posed in the dissertation: statistical and objective data analysis theories, digital signal processing theory, information and information systems theory, mathematical modeling of system analysis, interpolation and optimization theories, mathematical adjustment methods (decision theory), wavelet analysis theory.

**Main provisions of dissertation.**

- Preliminary processing algorithm of optical monitoring data (collection and initial processing of optical data with appropriate measuring devices);
- Algorithm for calculating various statistical indicators and optical parameters of observation data;
- Carrying out mathematical calculations to create a physical-mathematical model describing the optical monitoring of polluted air:
    - Application of three sigma rules;
    - Analysis of observation data by the main components method;
    - Analysis of optical data over time;
    - Application of wavelet analysis methods;
- Mathematical indicators of informative data of different directions of polluted air basin in the city territory for rational placement of city air observation network;

– Method of application of mathematical adjustment methods for efficient placement of observation points and management of work regime.

**Scientific novelty.** In the work the following scientific novelties are obtained:

- ✓ There is a weak correlation between the fluctuations of the optical thickness of the air basin in different directions over Baku;
- ✓ Fluctuations in the optical thickness of the air over Baku over time in three directions of the city (west, north and south-east) are shown;
- ✓ A methodology for assessing the informativeness of the optical condition of the city air between different directions of observation was given and an appropriate calculation scheme was developed;
- ✓ An appropriate calculation scheme was developed for the efficient placement of observation points of optical monitoring of Baku city air and the efficiency of optimal three-point (center of an equilateral triangle) optimal interpolation was shown in determining the density of the observation network;
- ✓ The method of effective organization and management of the ground observation network of remote monitoring of urban air with the application of the method of mathematical regulation was given, the calculation scheme determining the order of importance of the effective operation mode of the observation point was developed.

**Theoretical and practical value of the study.**

The dissertation is mainly devoted to environmental monitoring in regional meteorological conditions. The obtained results are theoretically substantiated and have scientific and practical significance. The results obtained in the dissertation can be used in the relevant departments of the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, in the institutions of the Azerbaijan National Academy of Sciences, as well as in urban planning. The results of the dissertation can be used for the organization of optical monitoring of the airspace over the city (efficient deployment of ground surveillance network and operation mode management). In the dissertation, the following assessments and calculations were made to create a physical-mathematical model describing the optical monitoring of the airspace:

- Remote monitoring of the air layer was comprehensively associated with the study of the structure of the atmosphere, the dynamics of microphysical and optical parameters of aerosol-gas compounds in the atmosphere, optical thickness was calculated, approximation of observed data was given and approximation error was estimated;
- Application schemes of mathematical methods (main components, wavelet analysis and three sigma rule) have been developed to create a qualitative structure of the observed data;
- Values of wavelet coefficients and entropy function were calculated, histograms of measurement data and wavelet coefficients were constructed; The regression dependence of optical measurement data was estimated (for Baku);
- A methodology for assessing the informativeness of the optical condition of the city air between different directions of observation was given and an appropriate calculation scheme was developed;
- An appropriate calculation scheme has been developed for the effective placement of observation points for optical monitoring for optical monitoring of Baku city air;
- The method of effective organization and management of the ground observation network of remote monitoring of urban air with the application of the method of mathematical regulation was given, the calculation scheme determining the order of importance of the effective operation mode of

the observation point was developed.

**Approbation and application.** The main results of the dissertation were discussed at the Joint Scientific and Technical Council of the National Aerospace Agency, at scientific seminars of the Institute of Ecology, at scientific seminars of the Department of Non-harmonic Analysis of the Institute of Mathematics and Mechanics of ANAS. Also, the main provisions of the dissertation were reported at scientific conferences: III International Conference "Problems of Cybernetics and Informatics" (Baku, September 6-8, 2010); IV International Conference "Problems of Cybernetics and Informatics" (Baku, 12-14, 2012); at the Second Caspian International Conference on Water Technologies (Baku, April 11, 2014); at the International Conference "Theoretical Mathematics and Its Applications" (Ufa, September 2015); at the International Conference "Actual Problems of Mathematics and Mechanics" dedicated to the 55th anniversary of the Institute of Mathematics and Mechanics (Baku, May 15-16, 2014); at the I Republican Scientific and Practical Conference "Multidisciplinary Problems of Electronic Medicine" (Baku, May 24, 2016); at the International Conference "Non-harmonic Analysis and Differential Operators" (Baku, May 25-27, 2016); at the III Republican scientific conference "Mathematical problems of application and new information technologies" (Sumgait, December 15-16, 2016); at the 2nd International Conference "Mathematical Modeling in Applied Sciences" (Belgrade, August 20-24, 2019); at the X International Conference of the Georgian Mathematical Union (Batumi, September 2-6, 2019).

The results of the dissertation can be used for the organization of optical monitoring of the airspace over the city (efficient deployment of ground surveillance network and operation mode management).

**Publications of the author.** 16 scientific works on the topic of the dissertation were published, including 9 works in the republic and 7 works abroad. 7 of the published scientific works are conference materials, 5 of them were international conferences. Published works cover the issues raised in the dissertation and meet the requirements set by the Supreme Attestation Commission under the President of the Republic of Azerbaijan. The main content of the dissertation is reflected in published scientific articles.

**The name of the institution where the dissertation was completed**. The work was performed at the department of Non-harmonic analysis of the Institute of Mathematics and Mechanics of National Academy of Sciences of Azerbaijan.

**Volume and structure of the dissertation** (in signs, indicating the volume of each structural unit separately). The dissertation title page (348 characters), table of contents (3394 characters), introduction (11270 characters), three chapters (53921 characters, 49470 characters, 42046 characters), result (1555 characters), list of abbreviations and symbols (516 characters) and consists of a list of used literature (13607 characters). The volume of the dissertation is 162520 characters. The dissertation contains 29 tables, 15 graphs and 14 figures.

## THE CONTENT OF THE DISSERTATION

The introduction substantiates the relevance of the research topic, indicates the goal, objectives, scientific novelty, and the practical significance of the work.

The first chapter is entitled "Environmental monitoring system, systematic analysis of optical monitoring of urban air" and is devoted to the organization and conduct of optical monitoring, which is part of a comprehensive environmental monitoring system. The essence of optical monitoring is explained here. The first chapter of the dissertation shows the need to develop a scientific and practical basis for optical monitoring of polluted urban air in Azerbaijan and explains the existing problems. Environmental legislation in our country is based on international agreements. Environmental monitoring in the Republic of Azerbaijan is carried out by the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan. Environmental monitoring is a system of observation, assessment and forecasting of changes in the natural environment as a result of anthropogenic impacts. The monitoring system is an integral part of the national information infrastructure.

The block diagram of the monitoring system subsystems adopted in the science centers is shown in Figure 1[1].

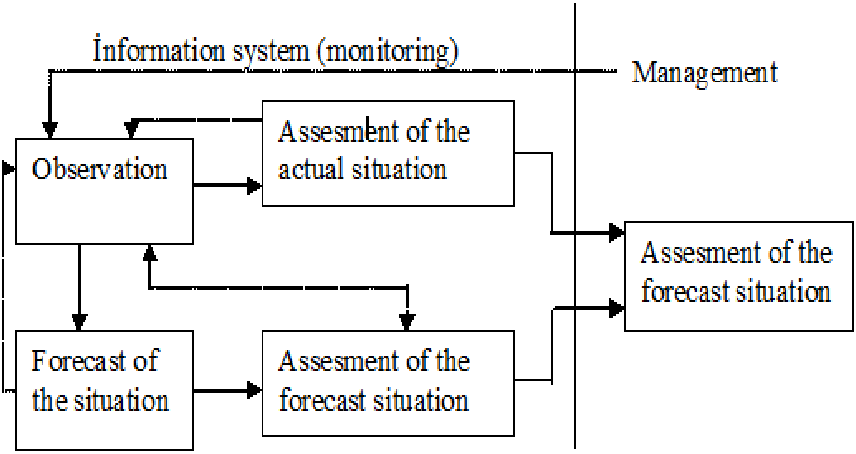


Figure1. The block diagram of monitoring system

The first chapter also provides information on the explanation of the main physical quantities, units of measurement and calculation rules used in the optical monitoring of the urban air basin. Remote monitoring of the air layer is comprehensively linked to the study of the structure of the atmosphere, the dynamics of microphysical and optical parameters of aerosol-gas compounds in the atmosphere. The Earth's atmosphere is heterogeneous in space and time. Layer characteristics in the vertical direction of the Earth's atmosphere have been studied. The properties of stratification in the vertical direction of the atmospheric structure show themselves more clearly and precisely in the nature of changes in air temperature with altitude.

[1] Pashkevich, M.A., Environmental monitoring / M.A. Pashkevich, V.F. Shuisky, - St. Petersburg. Gidrometeoizdat, - 2002.- 89 p.

The stratification properties of the structure of the Earth's atmosphere have been investigated [2]. It is shown that in the vertical direction of the atmosphere the air temperature changes depending on the stratification more clearly and accurately. The stratification properties of the structure of the atmosphere also shows itself in its heterogeneity of chemical composition along the height [3].This chapter examines the laws of distribution according to the microphysical characteristics and size of aerosol particles in the atmosphere. One of the main characteristics of an aerosol is its size distribution function. It is often described by a logarithmic-normal distribution function for particle size.

This chapter discusses the chemical composition of the scattering agents that cause light to scatter in the atmosphere and their complex refractive index. The overall attenuation of the incident light set is different from the absorption and scattering processes that depend on the chemical composition of the substance.[4] The problem of the transfer of light rays in the atmosphere is, first of all, the problem of multiple scattering of light in an aerosol medium. As a result of the scattering and reflection effects of the sun's rays, a visible atmospheric radiation background is formed in the "atmospheric-surface" system, which changes continuously depending on changes in the height of the Sun and meteorological conditions. This chapter focuses on the transformation of light rays in the Atmosphere-Earth system.

This chapter explains optical observation methods and shows the division of remote sensing methods into ground and aerospace methods. Optical observation methods are divided into passive and active methods. The passive method is based on actinophotometric measurements, which focus on the measurement of the components

---

[2] Timofeev, Yu.M. Theoretical bases of atmospheric optics / Yu.M. Тимофеев, A.B. Vasiliev, - St. Petersburg. Science, - 2007. - 152 p

[3] Райст, П. Аэрозоли. Введение в теорию / П.Райст – Москва. "Мир", – 1987.– 241 с.

[4] Zuev, V.E., Atmospheric aerosol optics / V.E. Zuev, M.V. Kabanov, Leningrad. Gidrometeoizdat, - 1987. - 255 p.c.

of sunlight (direct and diffuse radiation). The optical parameters of the air layer are determined by active and passive sounding methods. In both passive and active sounding methods, information on contaminants is based on the spectral (wavelength) dependence of the optical parameters[5]. Optical mass and optical thickness were calculated based on the measured radiation characteristics of the atmosphere, and fluctuations in optical thickness were investigated. It is shown that the database (DB) is widely used for the storage of information in computers. It is shown that the database (DB) is widely used for the storage of information in computers. The data structure should be chosen to ensure efficient use of the data. Today, most DBs are tabular, that is, they have a relational structure. The table is the main and most important object of DB, as the data is stored in these tables. In the ecological monitoring system, the measurement dates and time values of the components of solar radiation are placed in the tables of the DB of the air basin.

In the second chapter, it is shown that for the study of air pollution processes and operational control of pollution processes, appropriate measuring instruments, as well as mathematical methods of data processing, are needed. Obviously, data processing is closely related to the solution of such problems as mathematical modeling, optimization, operations research, systematic analysis, etc. It is proposed here, during the initial processing of the measuring material, to carry out the operations of data centering and scaling. It is proposed to use a number of standard parametric (Exponential; Fourier; Sum of Sin Functions; Gaussian; Weibull; Power) and nonparametric (Interpolant; Smoothing Spline) mathematical models during the initial processing of the measuring material. After approximating the data by the model, to assess the quality of the approximation, it is proposed to use such criteria for the suitability of the approximation as - Sum of squares due to error; R-square; Adjusted R-square; Root mean Squared Error.

---

[5] Kondratyev, K.Ya., Atmospheric aerosol / K.Ya. Kondratyev, N.I. Moskalenko, D.V. Pozdnyakov, -Leningrad. Hydrometeoizdat, 1983.– 224 p.

In section 2.2 of the thesis, the initial data are considered as random variables. Since the probability of random variables receiving very high values is too small, in practical calculations, usually, instead of the $\pm\infty$ limiting values of random variables, its any reasonable value is taken. The solution to this problem is based on a rule, the so-called criterion 3σ

$$\left| f_i^j - \overline{f}^j \right| \geq 3\delta . \qquad (1)$$

Here $\overline{f^j}$ is the mathematical expectation of random variables $f$, and σ is the standard deviation at this point.

In section 2.3 of the dissertation, the initial data are examined in statistical terms. Statistical processing of data requires their proper acquisition and storage. Statistical data processing is a necessary step in the creation and development of practical guidelines for the sustainable management of ecosystems. Environmental research involves the analysis of many variables. During research, there is a need to evaluate, analyze and describe this information. The organization of observation is related to the collection of initial data and is the first stage in the study of the problem. Each problem has its own characteristics and they differ in their observations. It is known that the results of measurements form statistical sets. In solving some practical problems, it is advisable to use some quantitative indicators, but not all of the values of a random quantity. In section 2.3 of the dissertation work, various statistical indicators of the studied quantity (mathematical expectation, variance, standard deviation, etc.) were calculated and appropriate tables were compiled. As a result of the research, the differences in the correlation dependence of the optical thickness of the atmosphere in three different directions in Baku were shown[6]. These directions are

[6] Ismailov, F.I., Abdurahmanov, Ç.Ə., Zabidov, Z.C. On the rational placing of land remote sensing network of urban air Baku // IV International Conference "Problems of Cybernetics and Informatics" ( PCI ' 2012). Section #7, Control and Optimization,– Baku , – September 12-14, – 2012,– v.IV, pp.14-17.

west, north and south-east. The fluctuations of the weather are very variable in the west, relatively stable in the south-east and moderately variable in the north[7]. These dependencies are determined by the regional physical conditions of the presence of aerosol particles in the atmosphere. These particles mainly cause the transformation of light in the atmospheric air. The difference in the correlation dependence of the optical thickness of the atmosphere is visually shown on the map-scheme of Absheron in Figure 2.

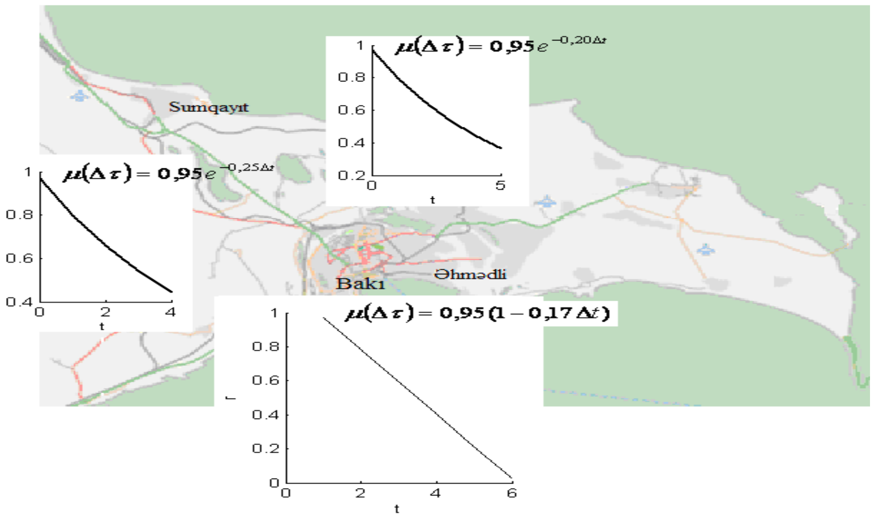


Figure 2. Different correlation of optical thickness

In the 2.4th section of the thesis, it was proposed to use the principal component analysis (PCA) in order to reduce the dimension of the original data, while losing the least amount of information. The essence of the choice of key elements is to calculate functions that are a linear combination of the original variables. Suppose that

[7] Bilalov B.T., Zabidov Z. J. Creation and analysis of data bank for the variability of optical thickness of urban air in Baku // News of Science and Education NR 24 (24), 2014, pp.23-28.

the initial input data $X$ of the quantity are given in linear space $L^k$. The introduction of PCA allows you to go into linear space $L^m$ $(m<k)$. Since most of the data variation will be concentrated in the first coordinates, which allows you to move to a space of lower dimensions. In other words, the PCA implementation allows describing the main variability of the initial data $X$ by the first $m$ components, and the rest $(k-m)$ components are not considered, since they have little effect on the data variability[8]. A covariance matrix of total radiation for specific measurements is built here. The calculated specific numbers and the percentage of the effect of the main elements on the variability of the total radiation are also given.

Section 2.5 introduces the concept of wavelets and describes their use in practical calculations. Analysis and processing of non-stationary (in time) or non-uniform (in space) signals of different types represent the main field of wavelet analysis applications. The classical Fourier transform (continuous or discrete) is a very important mathematical tool for analyzing and synthesizing signals, but it is not effective enough for analyzing complex signals. Often, spectral analysis of real signals must be performed in both frequency and time[9;10] . To analyze such signals, it is important to select some of the basic functions that allow them to characterize the signals, both in frequency and in time. In other words, the basic functions must have localization characteristics in frequency as well as in time. The signal has a finite energy: $f \in L_2(-\infty,+\infty)$. Therefore, basic functions called wavelets should also be included in the $L_2$.

In the analysis of information in practice, for many reasons, in contrast to the continuous case, discrete wavelet transforms are

[8] Zuev V.E., Optical models of the atmosphere / V.E. Zuev, G.M. Krekov - Leningrad. Gidrometeoizdat, - 1986. - 256 p.
[9] Burnaev, E.V. Application of wavelet transform for signal analysis / E.V. Burnvev. - Moscow. MIPT, - 2007 .-- 138 p.
[10] Daubechies, I. Ten lectures on wavelets / I. Dobishi, - Moscow. Research Center “Regular and Chaotic Dynamics”, - 2004.- 464

used. In this case, the transformation parameters "a" and "b" are given a discrete value and the appropriate transform is called a discrete wavelet transform. The basis of discrete wavelet transformation is the scale function and the wavelet function. The construction of the Wavelet conversion base is the principle of scale conversion and sliding. By changing the scale, the wavelets allow to detect the diversity of characteristics at different scales and the properties of the signal at different points in the interval under consideration by sliding.

Each signal can be characterized by its prices at certain intervals ("trends") and fluctuations around these prices. The oscillations around the averages will be called fluctuations. During signal processing, the values of fluctuations at different scales are important because they can be used to study the causes of fluctuations. In this case, averages are performed at different intervals. In the analysis of signals in the dissertation the statistical aspect of wavelet conversion coefficients was carried out. As an example, the work describes a histogram of the measured values of total radiation, histograms of detail coefficients at different levels, a graph of the wavelet spectrogram, and a wavelet separation coefficient corresponding to the selected value of the scale.

Any measurement data is distorted to one degree or another. For example, measurement data displays unwanted noise signals in addition to the wanted signal. In model calculations, signals are usually taken as[11] $S(t) = f(t) + e(t)$. Here $f(t)$ is an indicator of the useful signal content, $e(t)$ is the noise content. By using wavelet separation, it is possible to remove noise from the signal and show its useful content. During wavelet analysis, the signal is divided into approximation and detail coefficients. In the dissertation the method of noise cleaning of signals with wavelet separation is described. In the work as an example the values of total radiation measured on a

[11] Smolentsev, N.K., Fundamentals of the theory of wavelets. Wavelets in MATLAB / NK Smolentsev, - Moscow. Publishing house DMK, - 2005. - 304 p.

specific date and the description of the signal cleaned from noise are given.

In the tasks of environmental monitoring, when processing the measurement results, the main objects of education are not functions set on the entire time axis, but time series, the length of which is always finite. We will assume that the time series is set by the values of the function following each other with a constant step $\Delta t$:[12]

$$S_k(t) = S(t_k),\ t_k = \Delta t \cdot k\ ,\ k=0,1,2,\ \ldots,\ N-1\ . \qquad (2)$$

Here N is the number of measuring points.

In the process of analyzing the signal using wavelet ratios, it is often not known in advance which wavelet will be used. It is chosen depending on the issue to be resolved. Improper selection of Wavelet sometimes leads to unresolved issues. Some methods are known for the selection of Wavelet. The entropy of the signal is used to optimize the wavelet separation of the signal with a certain accuracy. Four entropy criteria are usually used in signal processing (‘shannon’, ‘norm’, ‘log energy’, ‘threshold’). For this purpose, in the analysis of experimental data, the wavelet coefficients of the signals given for different days and the values of the entropy function were calculated, and histograms of the measurement data and wavelet coefficients were constructed.[13]

Section 2.6 of the dissertation develops a scheme for the application of wavelet separation and decay methods of signals to assess the regression dependence of measurement data.

The third chapter shows that the problem of identifying air pollution in urban and industrial centers depends on the effectiveness of the automatic air basin monitoring network. This dependence is primarily determined by the information content and density of observation points. The information content of observations is

---

[12] Vityazev, V.V. Wavelet analysis of time series / V.V. Vityazev. - Leningrad. Publishing house of the St. Petersburg State University, - 2001.– 60 p.

[13] Bilalov B.T. and Zabidov Z.J. Exploring Urban Air by the Technologies of Statistical and Wavelet Analysis Math.Aeterna, Vol.5 no. 2, 2015, pp.327 – 335.

characterized by the accuracy, volume, and regularity of the experimental material. It is noted here that the visibility range is one of the main indicators of the optical state of the air. The definition of the visibility range is based on Koshmider's law and the following dependencies were used to determine the visibility range[14]

$$L_m = 3{,}9\tau^{-1}. \qquad (3)$$

In the dissertation, in order to assess the air pollution situation, a gradation of the visibility range was carried out in relation to weather conditions. The optical state of the atmosphere depends on the microphysical parameters of aerosol particles (density, size, scattering and absorption coefficients). It is indicated that the density of aerosol particles based on optical measurements can be estimated using the following parametric dependence[15]

$$m = 2.2 \cdot 10^{-10}\sigma_{(0.55mkm)}. \qquad (4)$$

In this chapter, a corresponding table has been compiled to assess the state of air pollution in relation to optical visibility.

In section 3.2 of the dissertation, the solution of the effective placement of support observation posts was discussed. The optical thickness and brightness function, which are the optical parameters of the polluted air basin, was used in order to correct the efficient placement of the observation network. It should be noted that the restoration of the radiation field at all points of the air layer on the basis of statistical data is carried out by the interpolation method. Here, a quantitative approach to the selection of a remote sensing coordinate network of urban air using multiple actinometric measurement data in and around Baku is considered. Perennial

---

[14] Zuev V.E. Optics of atmospheric aerosol / V.E. Zuev, M.V. Kabanov, - Leningrad. Gidrometeoizdat, - 1987. - 255 p.

[15] National Aerospace Agency, Report of the Institute of Ecology: Development of scientific and practical bases of optical monitoring of urban air, –2010 and 2011, - p.24.

actinometric measurements were made in July-August during the most polluted periods of urban air[16].

The approximation of the observed data is expressed by the following equation[17]

$$\widehat{f}(r_0) = \sum_{i=1}^{n} a_i \widetilde{f}(r_i)\,. \qquad (5)$$

Here $\hat{f}(r_0)$ is the result of the approximation, $\widetilde{f}(r_i) = f(r_i) + \delta_f(r_i)$ is the observation data; $f(r_i)$ is the actual value of the data and $\delta_f(r_i)$ is the measurement error; $a_i$ are interpolation coefficients.

The accuracy of the approximation is determined by the standard deviation of the interpolation

$$E^2 = \overline{[\sum_{i=1}^{n} a_i \widehat{f}(r_i) - f(r_0)]^2}. \qquad (6)$$

The normalized accuracy of the optimal approximation at the point $r_0$ is given by the following expression

$$\varepsilon^2 = E_0^2 / \sigma_0^2\,. \qquad (7)$$

The accuracy of the optimal interpolation is found from the minimum condition

$$\frac{d\varepsilon^2}{da_i} = 0\,,\ (i = 1,2,3,\ldots,), \qquad (8)$$

It is assumed that the optical thickness at any point in urban air is calculated using the optical thickness values at discrete points that are experimentally determined. In this case, the interpolation of the optical thickness is carried out by the following formula

---

[16] Ismailov, F.I., Abdurahmanov, Ç.Ə., Zabidov, Z.C. On the rational placing of land remote sensing network of urban air Baku // IV International Conference “Problems of Cybernetics and Informatics” ( PCI ' 2012)– Baku , – September 12-14, – 2012,– v.IV, pp.14-17.

[17] Gandin, L.S. Statistical methods of interpretation of meteorological data / L.S. Gandin, R.A. Kagan, Leningrad. Hydrometeorology, - 1978. - 360 p.

$$\tau(t_0) = \sum_{i=1}^{n} a_i \tau(t_i), \qquad (9)$$

here $\tau(t_i)$ is the optical thickness $i$ at a point at time $t$. $a_i$ is a weighting factor and satisfies the following condition

$$\sum_{i=1}^{n} a_i = 1. \qquad (10)$$

In order to meet the requirements for the effective placement of optical observation points in the city, it is proposed to use the following condition[18]

$$\varepsilon_m \sim \eta, \qquad (11)$$

here $\varepsilon_m$ is the maximum possible value of the interpolation error, η is the scale of the measurement error and usually characterizes the measuring device.

Using the above condition allows you to determine the maximum possible distance between observation points based on the calculated value of the interpolation error. The calculation of the maximum possible distances must comply with the requirement to estimate the density of the observation network. Note that we (together with a group of aerosols of the Institute of Ecology) calculated the range of changes in the interpolation errors $\varepsilon_i$ and weight coefficients $\alpha_i$ relative to different parts of the city of Baku. At this time, multi-point (segment center, right triangle center, square center) optimal interpolation types were used. $\rho_0$ is the maximum distance between the observed points of the celestial sphere.

When evaluating for all directions of the celestial sphere, the value of μ (0) was taken equal to 0,75. In calculations for the western direction of the celestial sphere, the value of $\rho_0$ was taken equal to 0,85. Also, in the calculations for the northern direction of the celestial sphere, the value of $\rho_0$ was taken equal to 0,85 and for the

[18] Gandin, L.S. Objective analysis of meteorological fields /L.S. Gandin, - Leningrad, Hydrometeorologist, - 1963.– 287 p.

southern and eastern directions of the celestial sphere, the value of $\rho_0$ was taken equal to 1,37.

Here, depending on the dimensionless parameter $\rho/\rho_0$ the weight coefficients $\alpha_i$ and the corresponding interpolation errors $\varepsilon_i$ were taken. The calculation results are shown in Table 1. Shown here are the values of the areas S defined as the intersection of the set of interpolation error values $\varepsilon_i$ and the set of measurement error values η of the measuring device.

Table 1.

The values of the dimensionless parameter $\rho/\rho_0$ and the values of the areas S for different directions of the city of Baku with different types of interpolation

| directions of the sky spheres | Calculated parameters | on two points | on three points | on four points |
|---|---|---|---|---|
| Western direction $\mu(\rho) = \mu(0)(1-\rho/\rho_0)\exp(-\rho/\rho_0)$ | $\rho/\rho_0$ | 0,109-0,207 | 0,113-0,235 | 0,121-0,217 |
| | $S$ | $1{,}659\cdot10^{-3}$ | $1{,}854\cdot10^{-3}$ | $1{,}681\cdot10^{-3}$ |
| Southern direction $\mu(\rho) = \mu(0)(1-\rho/\rho_0)$ | $\rho/\rho_0$ | 0,294-0,562 | 0,355-0,643 | 0,329-0,598 |
| | $S$ | $5{,}537\cdot10^{-3}$ | $5{,}784\cdot10^{-3}$ | $5{,}481\cdot10^{-3}$ |
| Northern and eastern directions $\mu(\rho) = \mu(0)\exp(-\rho/\rho_0)$ | $\rho/\rho_0$ | 0,352-0,682 | 0,422-0,756 | 0,388-0,705 |
| | $S$ | $2{,}87\cdot10^{-3}$ | $4{,}829\cdot10^{-3}$ | $4{,}512\cdot10^{-3}$ |

The results show that increasing the number of interpolation points decreases the variation in area S In three- and four-point interpolations, the difference in areas is minimal. Hence it follows that three-point interpolation is more appropriate in the case of optimal interpolation when determining the density of the observation network.

In the 3.3th section of the thesis, mathematical methods of ranking were applied to assess the optical state of urban air. The information content of the optical state of urban air (between different optical intervals and different directions of observation) is investigated. Mathematical methods used in decision-making technologies are applied. The main essence of these methods is to determine the order of preference among the elements of a set of specific properties. According to these rules, the essence of determining the order of preference is as follows:[19]

1. $X = \{x_1, x_2, ..., x_n\}$ - a set of certain properties is defined;

2. To determine the degree of preference,

$F_i(x) : X \to \{1,2,...,n\}, i = \overline{1,m}$ -functionals are determined;

3. Using the numerical values functionals $F_i(x)$ at each

point of $x \in X$ -$\{F_i(x)\}, i = \overline{1,m}$ the order of preference among the elements of the set $X$ is determined.

In order to assess the optical state of urban air and obtain representative information on the spatio-temporal change in air pollution, first of all, serial measurements are carried out using mobile devices (pyranometer, actinometer, photosensor, etc.). The results obtained form a set of basic statistics. It is known that the use of entropy indicators is a general approach to assessing information content in many areas of research. The process of obtaining any information can be explained as a result of changes in uncertainty in the process of signaling. If any manifestation moves from a situation (for example, A) to another situation (for example, B), then transient

[19] Kozin, IV Rules of adoption of decisions on the basis of relations of parnodominance / IV Kozin // Bulletin of the Zaporizhia National University, - Zaporozhye.– 2008. №1, - p. 97-104

information is understood as the difference between uncertainties in these situations[20].

$$\dot{I}(A,B) = H(A) - H(B), \quad (12)$$

here $H(A)$ and $H(B)$ are the values of entropy corresponding to states A and B.

The assessment of the informativeness of the optical condition of the city air was carried out using the measurement data on the basis of the following methodology proposed by us:

1. A series of data has been created in different directions of the city's celestial sphere by means of measuring devices on different dates;
2. Measurement data were cleaned of noise by wavelet analysis method;
3. Entropy values of measurement data are calculated;
4. Information values characterizing the variability of the optical position of the celestial sphere were calculated for each direction;
5. Based on the values of entropy and information, a matrix of relations of different directions of the celestial sphere is constructed;
6. The order of informativeness of the optical situation between the application of mathematical methods of adjustment and the multiplicity of directions of the celestial sphere has been determined.

As an example, the informativeness of the optical weather in Sumgayit was assessed. Monochromatic images were used to measure the brightness of the sky as measurement data. The Conderse method was used to determine the order of optical state informatization.[21]

---

[20] Chernyshov, VN, Theory of system and system analysis / VNChernyshov, AVChernyshov– Tambov. Tamb Publishing House. гос. techn. un-ta, - 2008. - 96 s.s.

[21] Bilalov B.T., Zabidov Z.C. Assessment of informatization of optical condition of city air for different directions and different optical intervals // Azerbaijan Oil Economy Journal, Baku, 2017, № 01, p.40-43.

In section 3.4 of the dissertation the informativeness of the optical condition of the city air was assessed by the Schulz method, one of the methods of mathematical regulation. For this purpose, the entropy values of the measurement data collected in different observation directions of the optical air condition were first calculated. Using entropy values, a table of correlations of informativeness of measurement realizations was constructed. At the next stage, an important road graph was constructed and the values of the power matrix of the roads were calculated[22]. By comparing the strengths of these roads, the importance structure of the information between the directions was determined. As an example, the informativeness of the optical condition of different directions of Sumgayit city air was assessed and the order of importance of informatization between the directions was determined.

In the 3.5th section of the dissertation, it was proposed to apply mathematical methods of ranking for the effective organization and management of the mode of operation of observation points for remote monitoring of urban air[23]. As an example, the issue of monitoring the operating mode of the observation point, which was carried out by actinometric measurements, was considered. The values of the total radiation, which were obtained using the "Peleng SF-06" pyranometer, were used as the initial data. Actinometric measurements were carried out in the city of Baku. Measurements were made at intervals of $\Delta t = 2$ seconds. Measurements were made on different dates and at different time intervals of the day. For this purpose, the entropy values of the first collected measurement data

---

[22] Bilalov BT, Zabidov ZC, Assessment of informatization of optical condition of city air for different directions by Schulch method // Sumgayit State University, Scientific News, Sumgayit, 2016, volume 16, № 4, p.22-26..

[23] Zabidov Zakir J., Gasymov Telman B. The application of Condorcet, Bordo, Kopland and Simpson rules to rational organization and control of the ground observation the network of remote sensing of urban air // Ecological Bulletin of Research Centers of the Black Sea Economic Cooperation, 2017, No. 1, p. 83-87.

were calculated. The calculations used the 'shannon' entropy. Shannon entropy (‘shannon’) is defined by the following formula[24]

$$E(S) = -\sum_i S_i^2 \log(S_i^2) \quad . \qquad (13)$$

Using entropy values, a table of correlations of informativeness of measurement realizations was constructed. At the next stage, the rules of Condorcet, Borda, Kopland, Simpson were applied[25], and the mode of operation of the support observation post was determined according to the informativeness of the time intervals.

In conclusion, the author expresses his deep gratitude to the scientific adviser, corresponding member of ANAS, dr. of ph. and math. sci., professor Bilal Bilalov for his scientific advice and constant attention to work in the implementation of mathematical model computational algorithms.

## CONCLUSIONS

- Remote monitoring of the air layer is associated with the study of the structure of the atmosphere, the dynamics of microphysical and optical parameters of aerosol-gas compounds in the atmosphere,optical thickness was calculated, approximation of observed data was given and approximation error was estimated;
- Application schemes of mathematical methods (Main components, wavelet analysis and three sigma rules) have been developed to create a qualitative structure of the observed data;
- There is a weak correlation between the fluctuations of the optical thickness of the air basin in different directions over Baku;

[24] Smolentsev, N.K., Fundamentals of the theory of wavelets. Wavelets in MATLAB / NK Smolentsev, - Moscow. Publishing house DMK, - 2005. - 304 p.

[25] Kichmarenko, O.D., Decision-making theory / O.D. Kichmarenko, A.P. Ogulenko, - Odessa. Odessa National University named after I. I. Mechnikov, - 2012.– 52 p.

- Fluctuations in the optical thickness of the air over Baku over time in three directions of the city (west, north and south-east) are shown;
- Graduation of urban air distance and pollution status according to weather conditions was carried out;
- A methodology for assessing the informativeness of the optical condition of the city air between different directions of observation was given and an appropriate calculation scheme was developed;
- An appropriate calculation scheme was developed for the efficient placement of observation points of optical monitoring of Baku city air and the efficiency of optimal three-point (center of an equilateral triangle) optimal interpolation was shown in determining the density of the observation network;
- The method of effective organization and management of the ground observation network of remote monitoring of urban air with the application of the method of mathematical regulation was given, the calculation scheme determining the order of importance of the effective operation mode of the observation point was developed.

**The main clauses of the dissertation work were published in the following scientific works:**


1. Ismailov, F.I., Abdurahmanov, Ch.A., Zabidov, Z.C. On the rational placing of land remote sensing network of urban air Baku // IV International Conference “Problems of Cybernetics and Informatics” (PCI '2012). Section # 7, Control and Optimization, - Baku, - September 12-14, - 2012, - v.IV, pp.14-17.
2. Забидов З. J. Research of own vectors and own values of ecological condition of atmospheric air in Baku / Actual

problems of Mathematics and Mechanics Proceedings of the International Conference dedicated to the 55th anniversary of the Institute of Mathematics and Mechanics, Baku, Azerbaijan, May 15-16, 2014, 167.

3. Bilalov B.T., Zabidov Z. J. Creation and analysis of data bank for the variability of optical thickness of urban air in Baku // News of Science and Education NR 24 (24), 2014, pp.23-28.
4. Bilalov B.T. and Zabidov Z.J. Exploring Urban Air by the Technologies of Statistical and Wavelet Analysis // Math.Aeterna, Vol.5 no. 2, 2015, pp.327 - 335.
5. Bilalov BT, Zabidov ZD The use of the wavelet apparatus for the study of ecological conditions in the urban atmosphere / Collection of theses VIII International School-Conference for students, graduate students and young students "Fundamental Mathematics and its applications, 2015 -7".
6. Bilalov BT, Zabidov ZC, Assessment of informativeness of the optical condition of the city air for different directions by the Schulch method // Sumgayit State University, Scientific News, Sumgayit, 2016, volume 16, № 4, p.22-26.
7. Zabidov Z.C., Mammadov F.X., Zabidli Sh.Z., Hasanova S.B. Evaluation of informatics in determining the optical condition of urban air for different directions on the board // News of the Azerbaijan National Aerospace Agency, Physical and technical problems of remote sensing of the Earth, Baku, 2016, volume 19, № 3 (19), p.41-45.
8. Zabidov Z.C., Zabidli Ş.Z. Application of the rules of collective decision-making in the effective organization and management of the surface observation network of remote monitoring of city air / Materials of the III Republican scientific conference "Mathematical application issues and

new information technologies", Sumgayit, December 15-16, 2016, p.51-52 .

9. Zabidov Z.C., Abbasova A.S. Analysis of proximity measure between urban air pollution and background pollution at different days / International Workshop on Non-Harmonic Analysis and Differential Operators / Baku- Azerbaijan, May 25-27, 2016, p.105-106.
10. Bilalov B.T., Zabidov Z.C. Assessment of the informativeness of the optical condition of the city air for different directions and different optical intervals // Azerbaijan Journal of Oil Economy, Baku, 2017, № 01, p.40-43.
11. Zabidov Zakir J., Gasymov Telman B. Application of Condorcet, Bordeaux, Kopland and Simpson rules to rational organization and control ground observation set network of remote sensing of urban air // Asian Journal of Mathematics and COMPUTER Research, 2017, Vol 16 Issue 2, pp. 129-133, http: // www. ikpress.org/issue/886
12. Zabidov Zakir J., Gasymov Telman B. The application of Condorcet, Bordo, Kopland and Simpson rules to rational organization and control of the ground observation the network of remote sensing of urban air // Ecological Bulletin of Research Centers of the Black Sea Economic Cooperation, 2017, No. 1, p. 83-87.
13. Zabidov Z.C. Application of valet and statistical methods to the assessment of informativeness of optical observation data // Ecology and water economy, Scientific-technical and Production magazine, Baku, 2019, № 4, p.81-83
14. Zabidov Z.C. Mathematical Aproaches to Ground Objects Classification According to Satellite Data // Caspian Journal

of Applied Mathematics, Ecology and Economics V. 7, № 1, 2019, pp. 3-11.

15. Zabidov Z.C., Atabey M.Guliyev Application of mathematical regulation methods of assessing the optical state of urban air / 2-nd International Conference on Mathematical Modeling in Applied Sciences / Belgorod-Russia, August 20-24, 2019, pp. 227-228.
16. Atabey Guliyev, Zakir Zabidov Application of mathematical regulation methods of assess the optical state of urban air / X International Conference of the Georgian Mathematical Union / Batumi, September 2-6, 2019, p. 105.

**Personal service of the author in scientific works published together with co-authors:**

[2,13,14] - works freely prepared by the author.

[3,4,6,10] -collection of measurement data, initial processing, algorithm development, explanation of the obtained results.

[1, 5, 7,8, .9, 11, 12, 15,16] - research, analysis and modeling, processing of results.

The defense will be held on 08 April 2022 at $14^{00}$ at the meeting of the Dissertation council BFD 2.01 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at the National Aviation Academy.

Address: Azerbaijan National Aviation Academy, AZ1045,
Baku, Mardakan road, 30

Dissertation is accessible at the National Aviation Academy Library

Electronic versions of dissertation and its abstract are available on the official website of the National Aviation Academy.

Abstract was sent to the required addresses on 07 March 2022.

Signed for print:  24.02. 2022
Paper format: 60x84 1/16
Volume: 38133
Number of hard copies: 20