Available online at www.humg.edu.vn

ESASGD 2016

GIS–IDEAS (2016)

Conference Title: International Conference on GeoInformatics for Spatial-Infrastructure Development in Earth & Allied Sciences (GIS-IDEAS)

GIMS – technology in the water quality monitoring

F.A. Mkrtchyan* and V.F. Krapivin

Institute of Radioengineering and Electronics RAS, Fryazino, 141190 Russia

---

Abstract

Results of the investigations are stated in connection with the assessment of capabilities to use the sensors of optical and microwave ranges for the diagnostics of hydrophysical and hydrochemical systems having various spatial scales. Structure of multi-functional information-modeling system (MFIMS) MFIMS consists the sensors of optical and microwave ranges and it realizes functions for the diagnostics and adaptive identification of the liquids. The system is based on the base formation of spectral standards for the liquid solutions delivered by means of multi-channel spectrophotometer or spectroellipsometer and used for adaptive recognition of spectral images.

Education process and following recognition are realized in accordance with the certain series of the methods, algorithms and procedures for accumulation, analysis, sorting and processing observation data. Assembly of all tools forms the information-modeling system oriented on the operative diagnostics of the state of the water objects when multi-channel information is delivered by the on-site and remote sensors and high-performance information technologies are used for the solution of the tasks related to the classification and identification of the water objects.

A solution of operative multi-pronged task of the water quality control and state of hydrochemical systems when their spatial heterogeneity is taken into consideration and series of physical, chemical and biological factors exist to be as influencing on them is realized by means of the collection of computer algorithms and models that are the hydrochemical monitoring system. This collection gives a possibility to parameterize typical water balance on restricted territory that reflects an interaction between hydrological cycle components. Under this, the system has adaptation function to the real hydrophysical object or process. The MFIMS can used under the water media or other liquids quality control under the expedition conditions when chemical laboratory no exist.
Kywords: spectroellipsometer, spectral image, cluster analysis, identification, liquid solution, algorithm, model, recfognition

1.Introduction

Numerous problems of the environmental monitoring are solved by means of the ecoinformatics technologies. Global information systems (GIS) are the most developed elements of natural monitoring. GIS-technology has severe success and brings perceptible economic effects. GIS-technology is positioned in the interface of computer cartography, databases and remote-sensing. The GIS elements are computer net, database, data transmission net and a system for the reflection of real situation by means of computer display. Numerous GIS show that GIS-technology guarantees convenient tool for the masses use to control the monitoring object and is efficient mechanism for the integration of multi-factor information. However, GIS-technology has serious restrictions when complex environmental task are solved and when synthesis of dynamic image of the environment is needed on the database that is episodic at the time and fragmentary in the space. Basic GIS imperfection consists in that it does not orient on multi-plane prognosis of the monitoring object evolution.
In particular, the microwave remote-sensing systems that are widely used to equip the flying laboratories and the natural-resources satellites supply the data sets that are geographically distributed. Reconstruction of the

* Corresponding author. Tel.: +74965652558; fax: +74965652407.
E-mail address: ferd47@mail.ru.

information obtained is possible only by employing methods of spatial-temporal interpolation for the development of which several techniques and algorithms of simulation modeling have been used in the past by Krapivin et. al., 2014, Krapivin and Shutko, 2012. For example, the spatial modeling has been widely used for the interpretation of the data obtained by environmental instruments, which monitor the lithosphere, cryosphere, hydrosphere, vegetation interfaces and urban environments.

For the accomplishment of the complex task of the environmental diagnostics, it is necessary to built up a system that incorporates such functions, as well as data collection (by means of remote sensing and in-situ methods), their analysis and processing. A system of this type is capable to conduct systematic observations and assessments of the environmental state, to predetermine forecasting diagnostics of changes of the environmental elements (due to anthropogenic impacts) and to analyze the evolution of environmental processes, taking into account the anthropogenic scenarios. One of the system functions is to provide warnings about undesirable changes in the environment. Attainment of such functions for environmental monitoring is feasible with the use of simulation methods allowing the development of a model for the investigation of the natural subsystem.

The GIS tool guarantees the geographical data processing, the relation with existing databases and the topological representation for studied territories. With the help of technology modeling, the GIS can be extended to global information-modeling system (GIMS), modifying some functions of the user interface for computer cartographic systems, including forecasting assessments of conditions for environmental system functioning within predefined scenarios. Furthermore, these parametric changes can be used both for the evaluation of model coefficients and for the prognostic assessment of environmental dynamics based on the evolutionary modeling.

2.New ecoinformatics tool

Important step in the GIS-technology development was made in the papers Krapivin et al., 2014, Krapivin and Varotsos, 2008, Mkrtchyan and Krapivin, 2014, krapivin at al., 2015, where new technology of the GIMS synthesis was proposed. This technology eliminates many GIS imperfections and gives a possibility to synthesize the monitoring systems having prognosis function. Generally, principal GIMS-technology conception is represented in Fig. 1. Remote determination of highly possible of number of parameters for the model of controlled geo-ecosystem is key element of the GIMS-technology. Just, that sort of combination of empirical and theoretical functions of the GIMS-technology allows the operative assessment of current and prediction changes in the environment.

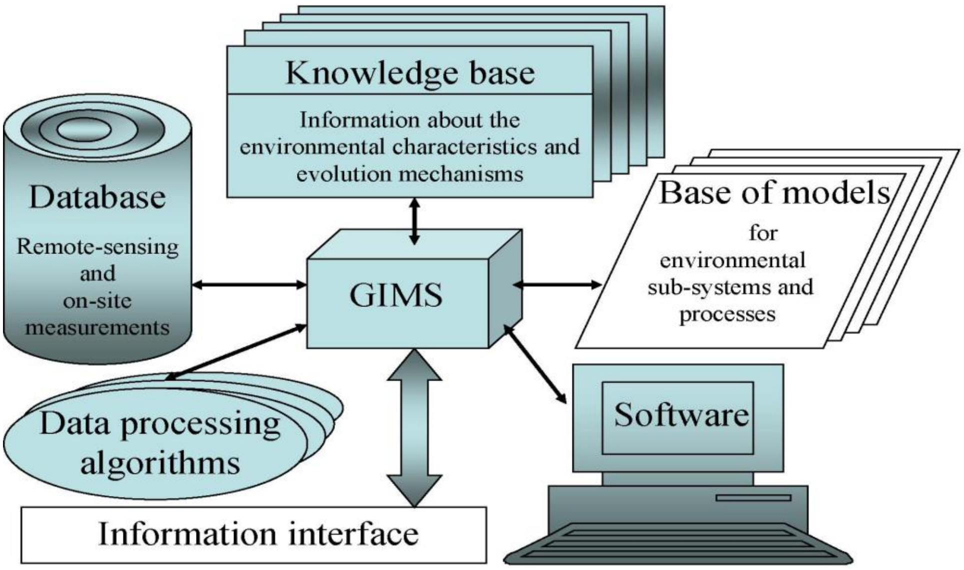

Fig. 1. Conceptual diagram showing the definition of the GIMS-technology architecture.

The hierarchical structure of environmental monitoring systems optimizes the use of financial resources with high quality of final results. This is the basic argument for the creation of geoinformation monitoring systems using the technology of hierarchical synthesis. Fig. 2 shows an organizational structure of the GIMS-technology functioning and its position within the monitoring procedure. The GIMS-technology optimizes multi-channel informational structure of monitoring system and forms a current database that is the most keeping with solved environmental task.

The GIMC-technology is based on a joint use of the following structural constituents:

- remotely sensed microwave and optical data;
- *in situ* measurements;
- GIS and other available data banks information; and
- mathematical modeling of spatial-temporal variations in physical and chemical parameters of the

environment.

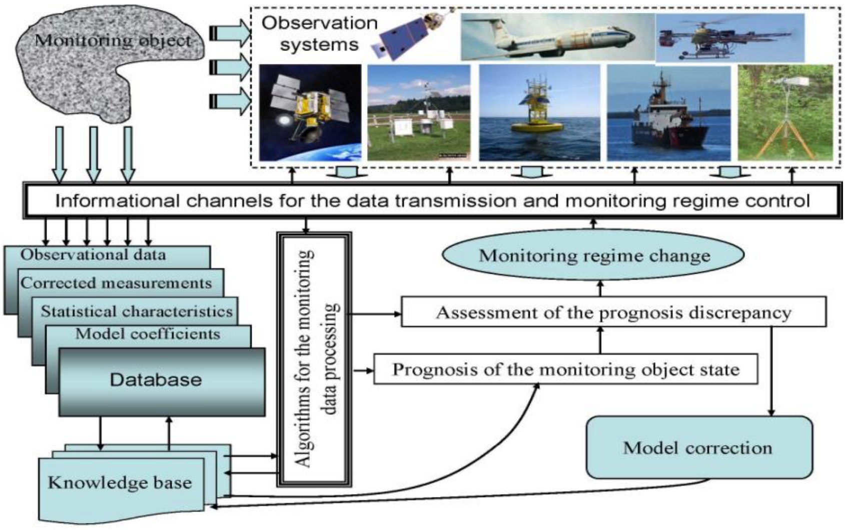

Fig. 2. Functional structure of global information-modeling system (GIMS). Principal scheme of the GIMS functioning in the regime of adaptive correction of the parametrical space and monitoring mode of operation.

3.The GIMS-technology functions

State of any geo-ecosystem is characterized by large variety of parameters determining a dynamics of its functioning taking into account of the interaction with bordering territories. Some of these parameters characterize the soil and vegetation types, water regime of the territory, saline mixture of the soil-ground, position level of the subsoil waters, dislocation structure of the anthropogenic objects and many others. In principle, information needed about above parameters can be received with different reliability from in-situ and remote observations as well as from the GIS databases where *a-priory* information exists being accumulated during past years . Problem arising before decision making person consists in the obtaining of answers on the following questions:

- What kind of instruments are to be used for conducting the so-called ground-truth and remote measurements?
- What is the cost to be paid for the contact and remote information?
- What kind of balance between the information content of contact and remote observations and the cost of these types of observations is to be taken under consideration?
- What kind of mathematical models may be used both for the interpolation of data and the extrapolation of them in terms of time and space with the goals to reduce the frequency and thus the cost of observations and to increase the reliability of forecasting the environmental behavior of observed objects.

The GIMS-technology gives a possibility to answer on these questions using adaptation procedure to the prehistory of the monitoring object functioning. The GIMS structure includes series of blocks that realize the following functions:

- data collection (current information about the soil-canopy system: soil moisture, depth to a shallow water table, soil salinity, biomass of vegetation, rainfall rate, etc.);
- data preprocessing, sorting, and storing in the data bank;
- modeling (simulation) of different kinds of ecological, hydrological, agricultural, climatological processes in different geophysical and environmental systems (these blocks contain a variety of models of crop productivity, the functioning of irrigation systems, geo-ecology, and the epidemiology of certain vector-borne diseases, etc.);
- estimation of the current state of a specific geophysical system;
- forecasting the state of this system at a future time;
- feedback support, information deficit assessment, information optimization; and
- realization of specific operations to data processing in framework of the user needs (evaluation and prognosis of the object state when anthropogenic scenario is realized, etc.).

4.GIMS - technology for the diagnostic of liquid solutions

During last time, optical devices are intensively used for the investigation of characteristics of liquid and solid mediums. It allows the operative diagnostic practically in real time mode. Spectroellipsometry is the peak of polarization optics. The creation of multichannel polarization optical instrumentation and use of spectroellipsometric technology are very important for the real-time ecological monitoring of the aquatic environment. Spectroellipsometric devices give us high precision of measurements. Spectroellipsometric and their multichannel measurements in an aquatic environment provide the basis for the application of modern algorithms for the recognition and identification of pollutants. Present multi-channel spectrophotometers and spectroellipsometers deliver spectral images of controlled objects with high speed and precision. Use different algorithms and models for the processing spectral images allows the adaptive identifier synthesize that has principal difference from traditional approaches to the liquid solution control.

Combined application of instrumental tools and software for operative monitoring of the water medium on the Earth developed insufficiently on account of complexity of complex monitoring system synthesize. Tasks of the adaptation of algorithms and models to the specific monitoring system are complexity and sometimes contradictory. Krapivin et al., 2014, Mkrtchyan at al., 2013, Mkrtchyan and Krapivin, 2013, Mkrtchyan at al., 2015, proposed new universal technology for solution these tasks. This technology based on the precision compact polarimeters and the education algorithms for recognition of spectral images. Under this, a solution effectiveness of multi-parametrical tasks is mainly determined by the sensitivity and precision of sensors, their universality, and by using wide spectral bands.

Spectral measurements of the water medium deliver information for the using the proper algorithms and models of identification and recognition of pollutants. This is the first time the combined use of real-time spectroellipsometry measurements and data processing methods have been realized as different versions of an Adaptive Identifier (AI) (Fig.3). Use of an acromatic compensator on the basis of Fresnel rhomb made of fused quartz that enhances the precision of measurements.

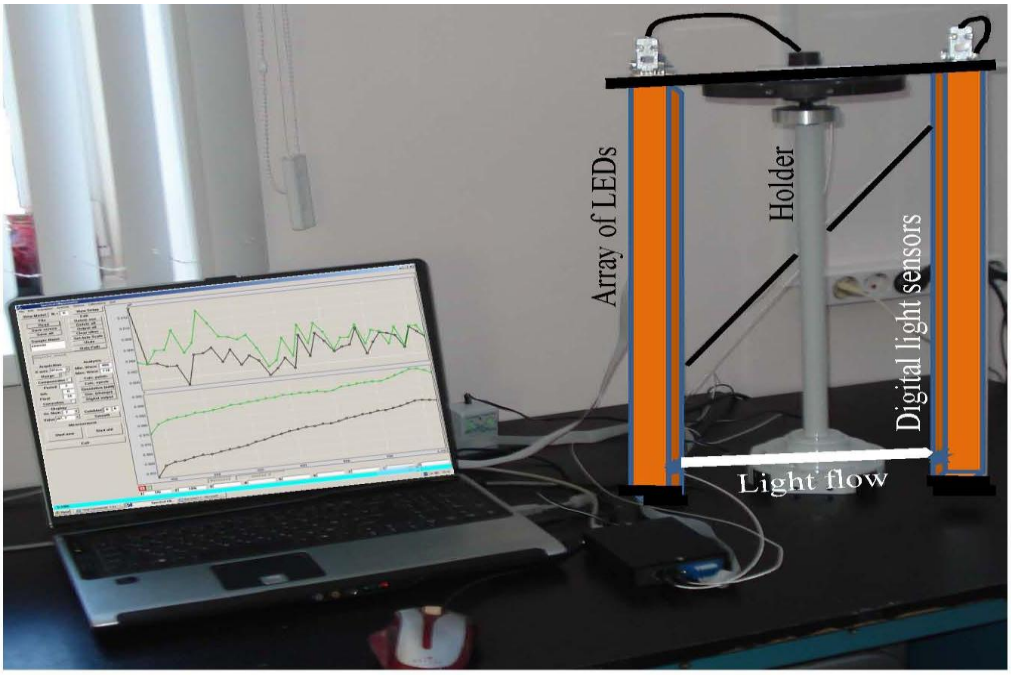

Fig. 3. Adaptive Identifier. LEDs is light-emitting diodes.

Spectroellipsometric measurements deliver spectrums that are considered as spectral images of water solutions. Space of spectral images is formed during the learning procedure realized in laboratory conditions when spectral images and chemical analysis are performed at the same time.

Table 1. Structure of standard spectral image of water solution. Notation: A_1 is the square occupied by spectral curve, A_2 is the maximal value of spectral curve, A_3 is the minimal value of spectral curve, A_4 is the distance between wavelengths with minimal and maximal values of spectral curve, respectively; A_5 is the maximal derivative of spectral curve; A_6 is the maximal value of second derivative of spectral curve; A_7 is the number of spectral curve maximums; A_8 is the average value of spectral curve; A_9 is the wavelength corresponded to average value of spectral curve; B is the chemical element concentration.

Et. Num.	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	B
1	A_{11}	A_{21}	A_{31}	A_{41}	A_{51}	A_{61}	A_{71}	A_{81}	A_{91}	B_1
… …										
n	A_{1n}	A_{2n}	A_{3n}	A_{4n}	A_{5n}	A_{6n}	A_{7n}	A_{8n}	A_{9n}	B_n

An identification of spectral image for unknown water solution is realized by means of comparison his vector – identifier with elements of the EDB. Depending from used optical device spectral image of water solution can be represented by one or two vector-identifiers calculated with the use of rule described in Table 1. Final identification is realized by means of search in the EDB of vector – identifiers which are minimal distance from considered vector-identifier $Q=\{X_1,\ldots, X_n\}$ of given water solution. Distance between vector-identifiers is calculated with the use of the following formula:

$$\delta = \min_n \rho(Q - Q_n) = \frac{1}{2n}\min_i\left[\sum_{j=1}^{n}\left|X_j - A_j^i\right| + \sqrt{\sum_{j=1}^{n}\left(X_j - A_j^i\right)^2}\right] \tag{1}$$

Use of (1) gives better result in comparison with the application of other known criteria of closeness between spectral curves. That is why in this case there is minimal risk to miss the situation with dangerous pollution of water reservoir. In common case, usually the following methods are used:

- *Cluster analysis.* In this case two types of clusters are formed for CosΔ and TanΨ where Δ and Ψ are ellipsometric angles corresponding to complex amplitude reflection coefficients for two different polarizations. Decision is made by weighted values (1) or independently for each polarization.
- *Algorithm of discrepancy between spectra.* It is assessed average distance between the ordinates for both spectra and spectrum of studied case and decision is made taking into account minimal value of this distance.
- A*lgorithm of discrepancy between etalon vectors.* In this case, decision is made taking into consideration of minimal δ.
- *Inverse task solution.* This algorithm is based on linear dependence of optical spectrum on the concentration of chemical elements in water solution. In this case, sub-definite system of linear algebraic equations is solved.

Last algorithm allows the obtainment of concentrations for chemical elements $\{y_s,\ s=1,\ldots,k\}$ in aquatic environment. Its meaning is in the following procedure. As a result of the MCS functioning, at moment t_i at the output of each channel λ_j ($j=1,\ldots,n$) values Z_{ijp} ($i=1,\ldots,m$; $p=1,2$) are fixed, so that $Z_{ij1}=Cos\Delta_j+\xi_{ij}$ and $Z_{ij2}=\mathrm{Tan}\Psi_j+\zeta_{ij}$, where Δ_j and Ψ_j spectroellipsometric polarization angles, and ξ_{ij} and ζ_{ij} are a random values (noises) with zero mean and dispersion σ_j^2. It is supposed that concentration of chemical elements linearly forms each spectrum:

$$\sum_{s=1}^{k} a_{js} y_s = Z_j^1 \quad \text{and} \quad \sum_{s=1}^{k} b_{js} y_s = Z_j^2, \tag{2}$$

where $Z_j^p = \frac{1}{M}\sum_{i=1}^{M} Z_{ijp}$ ($p=1,2$), M is number of spectrums averaged, empirical coefficients a and b are determined when studied aquatic environment has known parameters $\{y_s,\ s=1,\ldots,k\}$.

Practically $s<n$. In this case equations (2) are undetermined and their solution can be realized with the use of many methods. Mkrtchyan and Krapivin, 2013 proposed analytical method based on solution dispersion minimization. This method is realized in the STW item.

The MFIMS was used in different laboratory and in-situ conditions. Table 2 gives experimental results which give possibility to compare above mention algorithms. Dependence of risk assessment as function of solution concentration is represented in Fig. 4. As it follows from these results risk to have high error under the solution identification is reduced when algorithm of Table 1 is used. We see that risk to have high error is growth with increase of chemical element concentration. It is caused that discrepancy between spectra is decreased with increase of chemicals concentration. In this case it is necessary to extend the database of spectral etalons.

Table 2. A precision of the MFAIMS.Comparatively assessment of algorithms for recognition of spectral images of water solutions.

Object for study	Identification algorithm and its error (%)			
	Cluster analysis	Discrepancy between spectra	Discrepancy between vector-etalons with the use equation (1)	Inverse task solution
$CuSO_4$	15	12	8	7
NaCl	17	11	7	5
$NaHCO_3$	16	10	5	5
NH_4OH	21	13	9	6
$ZnSO_4$	22	12	8	6
Potassium iodite	13	10	6	4
Na+Cu+Zn+Mn+glucose	18	9	9	8
Furaciline	23	11	5	5
Bifidbacterium	14	10	4	4

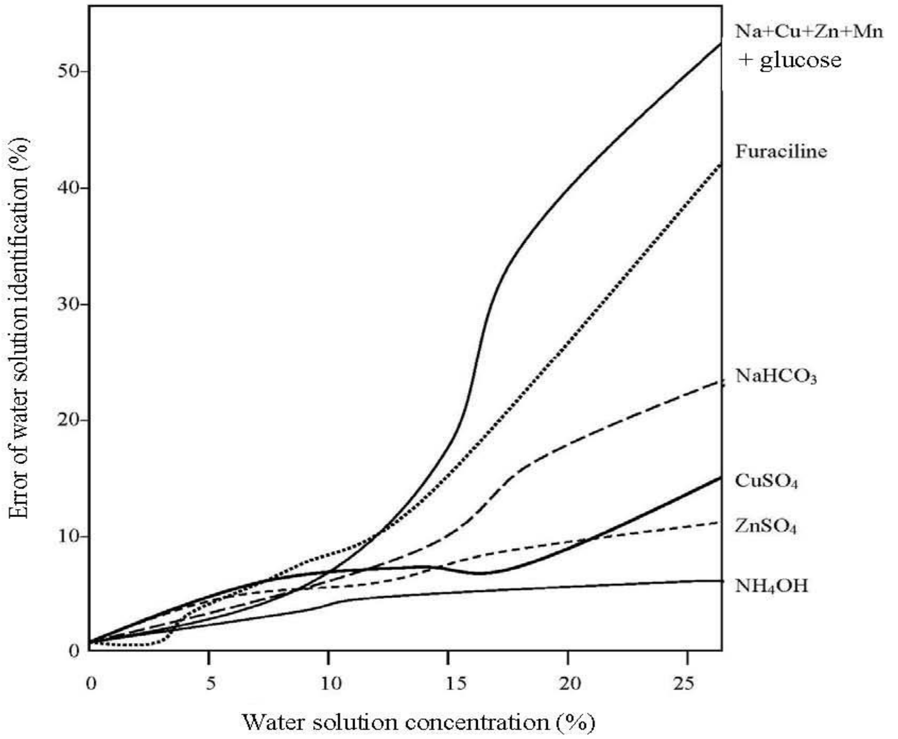

Fig.4. Dependence of spectral image identification on the solution concentration.

5.Conclusion

The questions discussed in this paper are some of part of numerous global ecodynamics problems a solution of which is barest necessity of today under rational management of natural systems. Basic defect of elaborated and used geo-ecological monitoring technologies consists in the efforts to do the integrating reasoning for the environmental system state on the base of study of separate systems. Therefore, many monitoring systems are not enough effective and non-informative. Set of the GIMS-technology authors focusing on this their attention [4-6] note it's the more universal character under the use of data and knowledge and a possibility to provide the most economical acquisition of new knowledge and data. This is achieved by means of adaptive package of technical and algorithmic tools harmonized by information content.

Thus, the GIMS provides remote sensing, on-ground (*on-site*) samplings, using GIS-information and mathematical modeling of physics-chemical processes in selected areas. GIMS-technology can effectively be applied for solving many agricultural, hydrological, environmental and many other Earth related problems.

Acknowledgements

"The reported study was partially supported by RFBR, research project No.16-01-00213-a".

References

Krapivin V.F., Nitu C., Mkrtchyan F.A., 2014. "Algorithms for the solution of spectroellipsometry inverse task". The Scientific Bulletin of Electrical Engineering Faculty, V. 2, No.26, pp. 3-8.

Krapivin V.F., Shutko A.M.,2012. "Information technologies for remote monitoring of the environment". Springer/Praxis, Chichester U.K., p.498.

Krapivin V.F., Varotsos C.A., 2008. "Biogeochemical cycles in globalization and sustainable development". Chichester, U.K.: Springer/PRAXIS. P. 562 .

Mkrtchyan F.A., Krapivin V.F., 2014. Assessing The Quality Of Water Solutions Using An Adaptive Multichannel Spectroellipsometer. Proceedings of the 2014 IEEE 27th International Symposium on Computer-Based Medical Systems (CBMS 2014), 27-29 May, New York, pp 521-522.

Krapivin V.F., Varotsos C.A., Soldatov V.Yu., 2015. New Ecoinformatics Tools in Environmental Science: Applications and Decision-making. Springer, London, U.K., p. 903.

Mkrtchyan F.A., Krapivin V.F., Klimov V.V., Kovalev V.I., 2013. Hardware-software system of the water environment monitoring with use of microwave radiometry and spectroellipsometry means. Proceedings of the 28-th International Symposium on Okhotsk Sea & Sea Ice. 17-21 Fedruary 2013.Mombetsu, Hokkaido, Japan. The Okhotsk Sea & Cold Ocean Research Association, Mombetsu, Hokkaido, Japan. pp. 104-109.

Mkrtchyan F.A., Krapivin V.F. "An adaptive monitoring system for identify of the spots of pollutants on the water surface". *World Environment*, 2013, **3**(5), pp. 165-169.

Krapivin V.F., Mkrtchyan F.,A., 2014. Multichannel Spectroellipsometric Technology for Aguatic Environment Diagnostic. Environment and Ecology Research. Vol.2, No.2, pp.91-96.

Mkrtchyan F.A., Krapivin V.F., Klimov V.V. An Adaptive Spectroellipsometric Technology for the Diagnosis of Water Ecosystems. PIERS 2015 in Prague, Progress In Electromagnetics Research Symposium, July 6-9, 2015, Proceedings, Prague, pp. 199-202