International Institute for
Applied Systems Analysis
IIASA www.iiasa.ac.at

Environmental Monitoring and Information Systems

Sazonov, B.

IIASA Working Paper

WP-75-125

1975

ENVIRONMENTAL MONITORING AND INFORMATION SYSTEMS

B. Sazonov

October 1975 WP-75-125

Environmental Monitoring and Information Systems

1. Pollution problems
2. Levels of pollution
3. Design of the regional monitoring system
4. Unsolved monitoring problems

I. PROBLEMS OF POLLUTION

In last decades pollution problems have become more a regional and more a global problem than a local problem. Pollution now influences not only hundreds or thousands of people, who are working in the polluted atmosphere of plants or factories, but millions of people who are living in industrial regions. Many factors now play a role in increasing pollution on a regional or global scale. The first of these is increasing population (1-2% per year); of equal or even greater importance is the increasing production of energy, material, fertilizers, etc., (2-6% per year). In many countries there are now very large industrial areas, growing in sites where living areas, industrial areas, areas for waste disposal and transportation routes interact and influence each other. About 90% of the population in the developed countries is living in such industrialized areas and is exposed to pollution.

Important pollution abatement techniques are to avoid events where high concentrations of pollutant can happen in some localities. Some technical innovations (as a tall smoke chimney) move pollution problems from local areas to regional and global areas. Some pollutants are carried by air under this condition to a distance of 50-80 km from the sources, by water to a distance of 300-500 km. Sometimes solid wastes are transported to distances up to 100m from industrial areas to the place of disposal. Now, in spite of some regional differences in the structures of industries, it is possible to talk about universal regional pollution problems which have resulted from the development of power stations, transportation techniques, and urbanization. Differences in climatic and geographical conditions sometimes create more important peculiarities in regional pollution conditions than differences in the structure of industries of different regions.

Distribution of pollutants in time and space domains creates some specific problems. Now, most dangerous conditions can be found not in proximity of the sources of pollutants and not at the moment of emission, but at a later time and at a distance.

II. LEVELS OF POLLUTION

All kinds of most dangerous pollutants which create problems on a regional and global scale, e.g. sulphur dioxide, particulates, hydrocarbon, carbon oxide, nitrogen dioxide, were well known to plants and animals of the earth before industrialization. Toxic heavy metals and big organic molecules create local pollution problems and sometimes can be easier collected at the source. Eruption of volcanos, large forest and swamp fires created, without a doubt, in the previous history of the earth, some regional and global levels of pollution. We have no information about the frequency and strength of such events in previous history of the earth. But we can be sure that: (a) such events constantly created some level of global pollution to which plants and animals adapted themselves during the process of evolution; (b) the level of global pollution which we can recognize is now practically the same as that which existed during the history of man's evolution. Except for carbon oxide, industry still does not create more pollutants on a global scale than natural processes.

On a regional basis, man-made pollution can overcome global level by hundreds of times and can be easily recognized. This situation has served to create two monitoring systems to look after global and regional pollution levels. These two levels of pollution serve to give different information for decision makers.

1) A Global information (monitoring) system gives us an idea firstly of the geophysical processes (such as climate) and the well-being of the biosphere as a whole. This system includes not only pollution data but data about geophysical and geochemical processes and observations on processes, and in the biosphere as well. Global monitoring will help man to prevent any disaster which can happen on the earth as a result of man's increasing activity on the earth. The level of natural pollution for some pollutants is so low and the dynamics of it is so badly investigated that great international efforts are needed to understand and to find a global pollution situation. For this purpose, 15-20 monitoring stations are under creation now in different unpopulated areas of the world.

2) Regional monitoring systems are created to serve problems which occur in highly populated and highly industrialized areas of the earth. These areas occupy not more than 5% of the earth's surface. Regional monitoring systems serve primarily for public health and sanitary purposes. Air and water pollution and solid wastes are the most pressing regional environmental problems requiring the development of environmental monitoring and informational system. Regional monitoring systems should have a response time appropriate for providing periodic and complete

information on pollutants, which approach biologically unacceptable levels.

Devices in regional monitoring systems in general need not be so accurate and expensive as in global monitoring systems but they should provide all information to prevent public health problems of people in industrialized regions.

Thus we can consider two levels of pollution:

(1) background level of pollution, i.e., natural pollution level, and

(2) regional level of pollution, which reflects mainly the level of industrialization, geographical conditions and technology in the investigated region.

III. DESIGN OF THE REGIONAL MONITORING SYSTEM

We are going to discuss in this paragraph problems which occur when one would like to design a regional monitoring system. It is possible to recognize at least four situations:

(1) Nothing is known about any pollution in the chosen geographical region.

(2) There are only a few unsystematic data of pollution and good meteorological information.

(3) There is good information about pollution but only in a few points of the region, and it is consequently necessary to chose more points for stations.

(4) There is a well-developed regional monitoring system. Is it necessary or not to improve this network of stations for the collection of pollution data?

The first situation, when nothing is known about pollution, looks very strange for industrialized regions of developed countries, but it still exists in newly developed areas, especially in developing countries. Sometimes it is not clear whether it is desirable to organize in this region some observation or there are no problem with pollution in the chosen region. In this situation, the best way to solve the problem is the creation of some rough surveys of the situation in industry, and also the geography of the region. Previous experience can be used to evaluate regional situations with pollution, and some points, where pollution can reach extremely high level can be chosen. If there is a need to find annual level of pollution at specific points, some vegetation, animals, materials, samples of water or soil can be subjected to chemical analysis to find traces of pollutants. Analyses of snow and ice in regions have given especially good results. From such type of survey, we can get the idea of the pollution situation in the regions.

In many cases it is not enough to obtain only an idea of regional pollution, but it is necessary to obtain the annual value of some pollutants at different points in the region. In this case, the best way to obtain information in an area is random sampling methods. For example, in the case of the more common air pollutants, 15-20 measurements per year based on random sampling at one measurement location are enough in order to obtain the annual pollution level at a chosen point. Comparisons have shown that random samples and continuous measurement give practically the same annual values of pollution if 15 random measurements are taken in simple geographical region (or 20 in mountainous areas). The points for random measurement should be chosen from preliminary survey.

The second situation, when only few unsystematic data of pollution exist in the region, can be also investigated by random sampling method. But it should be taken into consideration that this method is quite costly if one would like to receive detailed information on the distribution of pollutants in the entire region. A more reliable approach to regional pollution problem in these circumstances lies in construction of models of distribution of pollutants in the region. From the collection of data about industry in the region, it is possible to find out main sources of pollution in the area. Using meteorological and hydrological data, it is possible to create some models that can give an idea of the distribution of pollution. The limited information about pollution available for the region can be used for checking and for calibrating the models.

Preparations of models is hundreds and thousands times cheaper than even rough survey of the area by random sampling method. In any circumstance, if available allow data it is worthwhile to prepare diffusion pollution models of the region to appreciate distributions of pollutants. Model can help make decisions in many circumstances in the distribution of industrial and outside area, in development of a network of stations and so on.

The third situation with development of regional pollution monitoring system can be considered as the most complicated one. Most of the highly industrialized regions in the world are in this or in the fourth situation. In these areas there is good information about pollution in a few points of region there is meteorological information for area, there are some models of annual distribution of pollutant, and existing mobile stations can provide survey in area, where the density of monitoring stations is not sufficient. In this situation many factors begin to play a role to stimulate the development of regional monitoring system (economical, biological, political, ecological, technical, etc.).

From one side, in time and in space observations should not be interrelated each other--it reduces the usefulness of information. From the other side, information should be complete enough to avoid the situation when in some points pollution could be underestimated. Areas where levels of pollution surpass the biologically accepted level should be defined closely by observations of regional monitoring system. From another point of view, regional monitoring system calls to protect people and the more observation should be taken in area the high density of polution existed. In all cases, the cost of regional monitoring systems should be minimized. Sometimes availability of prepared personnel, future urban and industrial development of region, the needs to receive data on daily and weekly variations of pollutions, cost of devices and other reasons, play the primary role in development of regional monitoring system.

To help the designer of monitoring systems, some rules have been produced by scientists to find the number of observations which necessary to have in the point, where variability and mean value of pollution, density of population and other information are taken into consideration. If number of observations in one place higher than number of observations which necessary to make in other place, it means that first place is more preferable for installation of stationary environmental station than second one.

We can give one example of such rules.

Let us take C_m (mg/m^3) as an observed value of pollution in industrial area X (km^2),

C_s (mg/m^3) as ambient air quality standard in area Y (km^2), which is located normally next ot industrial area,

and

C_b (mg/m^3) as background level of pollution, natural or global level of pollution in area A (km^2), which is far from industrial region.

$(C_m > C_s > C_b)$

We can calculate the total number of samplers, N in the chosen area, if from models we can obtain the value of pollution C_m, C_s, and C_b and corresponding surface of area X, Y, and Z.

$$N = N_x + N_y + N_z \quad ;$$

The number observations in subareas are described as follows:

$$N_x = 0.0965 \frac{C_m - C_s}{C_s} X \quad ,$$

$$N_y = 0.0096 \frac{C_s - C_b}{C_s} X \quad ,$$

and

$$N_z = 0.0004Z \quad .$$

This method gives good results in the United States for particulate and SO_2 pollution. Note that concentration values used in the equations are annual averages.

If you take samples of pollution at some point every K-th day, and you wish to know the percentage M of deviation from the true mean annual value, you can use the relationship

$$M \approx 0{,}6 \, .K \quad ,$$

It means that, taking samples every 10th day, you can be sure that percentage of deviation from the true annual mean should not be more than 6%. On these steps regional monitoring water and wastes become also important.

Normally the more run-off water in the region, and the higher the velocity of water in the stream region, and the lower the temperature of the water, the lesser the problem in the region with water pollution.

The same approach as for air pollution monitoring can be applied to the creation of water regional monitoring system. It should be taken into consideration that water quality problem is a relatively old one; physical and chemical analysis of water stream was introduced on main river twenty to thirty years ago. The rate of flow and the strength of both domestic sewage and industrial wastes vary throughout the day and the week, and these cyclical changes are reflected in the treated effluents and correspondingly in the rivers.

Biological oxygen demand (BOD) is without a doubt the main indicator of river pollution. In unpolluted rivers, BOD $<$ 3 mg/l, in rivers of doubtful quality BOD $\approx$ 5-7 mg/l, in rivers of poor water quality BOD $\approx$ 8-11 mg/l, and in grossly polluted rivers, BOD $>$ 12 mg/l.

Normally for inland rivers, regular cyclic variations with periods of one day, one week, and one year may occur at sampling points. In high density population areas, these cyclic variations sometimes play an important role and should be monitored. If daily and weekly variation in water quality is not important, the total number of samples should, at least initially, be not less than six or seven. We should make the same samples per week to investigate weekly variation and the same sample needed per day to investigate daily variation. There exist many more complicated methods for the calculation of the number of observations in which estimation of standard deviation of level of water pollution serves as a key for decision maker.

A multiple purpose regional water monitoring program includes (a) point source monitoring, (b) periodic river basin surveys of ambient water quality and nonpoint sources, and (c) a set of continuing case studies, including water quality models.

The most important requirements of all are to define the objectives of the programs very precisely and then to evaluate fully the resources and devices needed to achieve those objectives.

If air pollution problem practically similar in all kind of heavy industrialized area, river pollution problem provide in new river new pollution problems. For conservative substances, monitoring and mass balance modelling can be constructed over relatively coarse intervals of time and space for the river basin as a whole. For nonconservative substances, monitoring and modelling do not necessarily need to be executed simultaneously over the entire river basin system.

Cost of environmental control, environment protection cannot be evaluated quantitatively and would not be possible to measure ultimate societal goals.

Three aspects are generally important, and their discussion jointly by the planners and by analytical experts will ususlly be beneficial.

(1) Many substances can exist in water in a variety of different chemical and physical forms. For example, phosphorous may be present as ortho-phosphate, condensed inorgnaic phosphates and organic phosphorous compounds; soluble and insoluble forms may also be presented. Metals, carbon, nitrogen often may exist in many forms. The response of an analytical method often depends on the form of the substance in the sample.

(2) Some quality parameters of water are often representing a class of compounds. For example, phenolic compounds, pesticides, organic matter and so on. For such parameters, it is desirable to specify the individual compounds of interest so that, again, appropriate analytical methods can be selected.

(3) Such indexes as color, turbidity, taste and odor are important overall properties of water samples.

Besides that there are two distinct phenomena that occur in the field during critical periods that have significant implications for monitoring and modelling of river basin systems. The first has been assumed traditionally as a steady state process, the second is an unsteady phenomenon. Between storm events, variation in water quality over space can be described by a steady state model. It has been shown that in urban-industrial regions, runoffs during the storms can suppress oxygen levels below the low levels already existing in the stream. Thus, monitoring over both dry weather and storm weather is necessary. From the point of view pollution problems is vitally important, especially if it is desirable to improve system of regional water quality monitoring.

Problems of waste (or sewage sludge) monitoring are somewhat easier in comparison to problems of air and water pollution in the industrial region. Agricultural wastes are the biggest among others not create acute problem as do industrial and municipal wastes. Agricultural wastes are dispersed in the country area and are partly utilized in the farms. Such wastes pollute air, water, soil, provide food for rats and other pests and degrade the landscape. A system of waste monitoring should provide information on (1) waste generation rates in the sources, (2) composition of regional wastes, and (3) availability of wild area for waste disposal.

Some survey of the main sources and sinks of wastes should be done, usually monthly or seasonally. Normally in big industrial areas, daily information on waste production in main industrial sources is collected as a basis for a model, in which transportation problems and proper technological treatment of regional wastes are considered as well as problems of waste generation and waste disposal. Prediction of waste situations in the future is sometimes very important for planning regional development.

At least once in ten years a detailed survey should be done in highly industrialized regions on the waste problem.

(4) When sampling periods of air quality measurements have to be shorter than 24 hours approximately (such needs come in extremely highly industrialized areas where high density of pollution sources and high density of population exists) it often becomes necessary to automate the measurements and create computerized environmental information system (CEIS). Automation of data processing is also necessary because of the large amounts of data collected. The shorter the sampling period, the more automation is necessary. Often telemetric transmission to a central computer is useful.

This period we can consider as a fourth stage of development of regional monitoring system. Air quality monitoring and operational system is the task for this period.

New models must be created as a part of CEIS in this period to provide mathematical relationships between air pollution emission sources, meteorological patterns and the resulting level of air quality. Averaging time of prediction in such models is not more than a few hours. Meteorological information (very elaborate) is generally assumed to remain unchanged over forecasting interval. The key to successful prediction, is, therefore, a detailed inventory of emissions projected by automatic monitoring systems, including traffic, domestic and other sources of pollution for specific seasons, specific days of the week, and specific hours.

It was proposed that a computerized system for the collection, storage, processing and distribution of relevant environmental data should be planned and designed in many regions of the world. One basic principle is that, to every possible extent, the output data should be presented in the format that the user demands.

CEIS has two main tasks: (1) to create awareness in industry about the pollution and (2) to provide the authorities with a possible means of checking that the pollution is within the prescribed limits.

It is considered desirable that periodically, three to four times a year, a more detailed control of pollution by physical-chemical measurement and evaluation by specialists would be performed.

If automatic regional monitoring systems are available as well as transmission lines to the central laboratory, the next step is the preparation and calibration of mathematical models for pollution control. In many cases, needs for data of the dynamics of emissions of the largest industrial plants appear immediately and some station should be installed near the biggest sources of pollution. It is also apparent that an emergency network based only on permanent automatic stations is not a proper solution. The basic task of an emergency station is to immediately deliver information on emergency episodes concerning maximum concentrations observed at a given moment. The occurence of the maximum concentration value, however, may change quickly, depending on meteorological conditions, transport situations, and other reasons. A system of movable sampling stations, which could carry out the measurements at those places, where, at a given moment, the maximum concentrations might be expected according to model prediction or other reasons would be the ideal solution. Such measurements, appropriately programmed, performed with the use of cars equipped with fully automized instrumentation, that transmit the data by radio to a central dispatcher's office, can deliver more information than the same number of stationary stations. In some regions, where weather, transportation and pollution production situations are extremely changeable and rather complicated in patterns, such monitoring systems based partly on a portable monitoring station appear to be a more economical solution. Practically for any region it seems reasonable to have moveable and permanent stations in certain balance. Regional monitoring based only on permanent automatic stations or only on portable stations seems to be either very expensive or insufficient.

Because traffic shows heavy peaks, often of short duration (one - three hours) the sampling time also should be short.

Since many stations give data concerning 24 hour concentrations of air pollution and since continuously working apparatus give data that can easily be reduced to 24 hour concentrations, which can be used instead of annual mean concentrations it is possible to calculate monthly and yearly mean values from daily data. However, experience shows that in the region where CEIS is organized, all scientific investigation is much better done with daily mean values.

In well developed CEIS, not more than one mathematical model for control and prediction pollution situation can be used. It is possible to create and use models for calculation of damages from pollution, models for traffic changes in the region to prevent pollution, models for changing fuel, raw material or technology in industry, models for analysis of alarming pollution situations, and other models. For monitoring of water and waste, computerized environmental informational systems are considered undesirable. Simpler systems work satisfactorily.

IV. REGIONAL ENVIRONMENTAL MANAGEMENT AND PLANNING

The task of regional environmental management is to prevent (a) high degree of air pollution (b) high degree of pollution of the surface of the soil, (c) shortage of fresh drinking water in the region, (d) increase of human diseases in the region, (e) high degree of excessive noise, odor, vibration and so on.

Proper environmental management prevents any disasterous interactions between man's activity and the nature. A developed regional monitoring system is the cornerstone of decisions to prevent such types of events in the region. The relative cost of the creation of monitoring systems in a very rough way can be considered as the following:

(1) preliminary survey (first step according to our classification); relative cost = 1.

(2) creation of diffusion model and installation of first station (second step); cost $\approx$ 100.

(3) development monitoring system in the region, cost $\approx$ 1000.

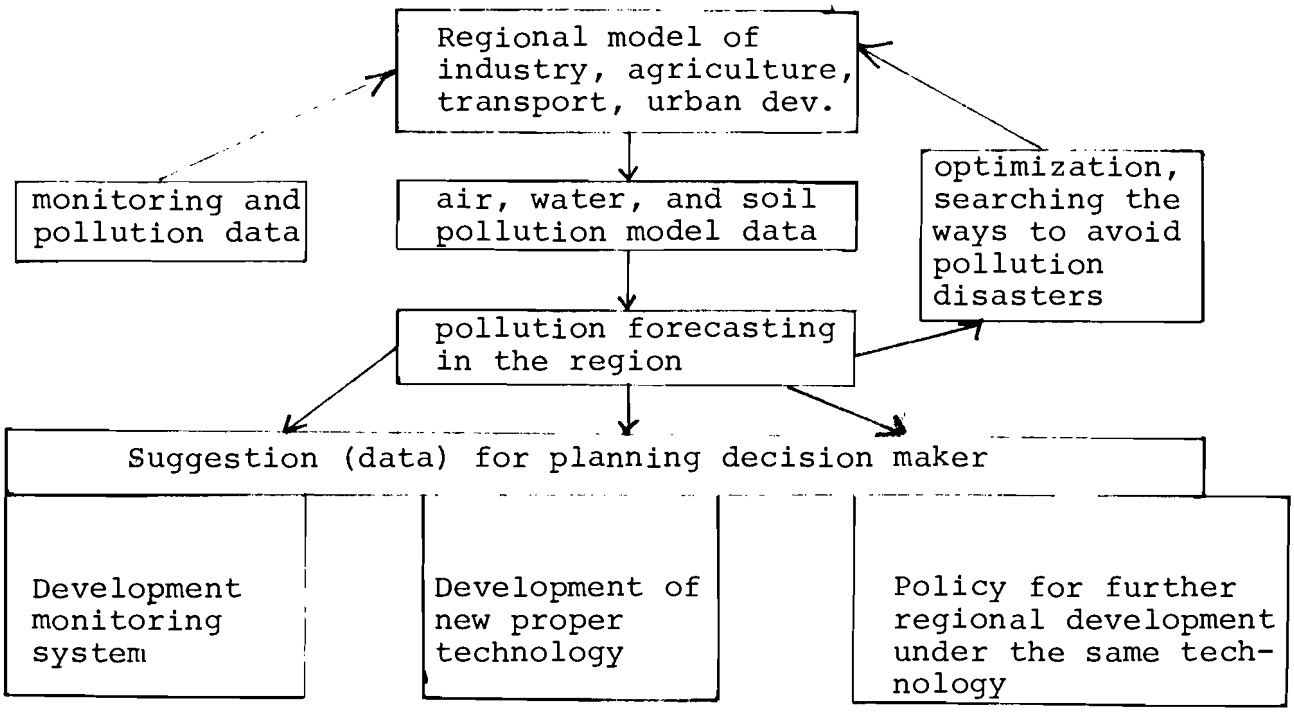
(4) development computerized environmental information system (CEIS), cost = 10000.

Regional environmental management has a twofold aspect: (a) current control and immediate action and (b) strategy of planning on a basis of proper prediction of regional environmental situation.

The best way to fulfil first objective is to make decisions on a basis of CEIS information. We have nothing to add to what was said in III on creation and operation CEIS.

To fulfil the second objective some iterative process should be established between decision making,implementation and scientific analysis of environmental situation, to give the basis for new decisions. The best way to predict future regional environmental situations is the preparation of proper mathematical models for regional development of industry, urbanization, transportational ways with their connections to pollution problems. Methodology of preparation of such regional models for prediction of regional development is still not properly developed. Nevertheless, a lot of regional models exist or are in preparation.

Let us imagine that good regional model capable of predicting regional development of industry, agriculture, transport, urban area is available. With the help of such a model, the future environmental conditions can be predicted to provide important information for a decision maker concerned with long range planning. It is easier to show how it can be done by the following figure:



From the point of view of environmental management for a long-range time horizons, the most important things which should be known ahead are:

(1) the desirable policy (strategy) of regional planning to avoid the possible pollution problems in future if technology utilizing

mineral and environmental resources in the region will not be changed. (2) To predict future technology for planners and decision makers, it is usually more important to know what kind of regional pollution from definite sources will create future critical situations in the region. It means that technological changes will be extremely desirable to make for these specific sources of pollution. At present, the more common way of avoiding pollution problems in future is by changing in technological treatment of raw material and wastes. (3) Action for development of an environmental monitoring system should be made parallel with action for development industrialized region itself. It means that planner and decision maker should have also suggestions concerning adequate development of regional monitoring system. Using models of regional industrial development, on the one hand and models of distribution of pollution in the region, in which future sources of pollution will be included as well as existing sources, one can get an idea of the needs of future environmental monitoring system. Long range environmental management for air and water areas can be made with the help of models, which step by step can be improved or renewed as far as new monitoring data will be available and pressure from some further industry developing in the region can be recognized.

To find strategy for long-range wastes management in the region is not so easy. Collection, transportation, utilization wastes in future cannot be properly predicted without proper prediction of industrial development, urbanization, development agriculture, urban growth, future land use policy and future transportational means in the region. Composition of future wastes and technology of treatment is practically unpredictable. Sometimes it is easier to predict only costs of collection, transportation, disposal and utilization of the regional wastes in future.

V. UNSOLVED MONITORING PROBLEM

At the conclusion of this paper we can mention some problems, the solution of which we consider as very important for global and regional monitoring and modelling.

First of all we would like to mention the unsolved interactions environment problem in different time and space domains. We have very little information on how decisions which are taken today influence future environmental conditions or how actions which happened in some areas influence global conditions. The answer for these are questions especially important to know when we consider action in the area of man's industrial activity and its consequences in the health of man and biosphere.

Still not clear is the meaning of the words "healthful human environment". How far can the meaning of "environment" be extended? Are social and economical conditions in which people exist part of the "environment" or do only physical and biological and chemical processes create the "environment."

The cumulative effect of many pollutants on many living creatures is unfortunately not investigated, but this question becomes more and more important as time passes. In industrialized regions with developed environmental monitoring and information systems, authorities have succeeded in removing situations when concentration of some pollutant can reach extremely high levels. Normally, many pollutants in industrialized regions are in the area somewhere near biologically acceptable levels, but the number of such pollutants continue increases in industrialized areas. Very soon scientists should give some recommendation on the number of pollutants and their composition which can be acceptable from the biological point of view in industrialized areas. We can stress that uncertainties in calculation of pollution impact on biosphere are the weakest point of all environmental monitoring and management systems.

Some difficulties exist in appreciation of pollution effect on plant growing. More easy to recognize this effect on forest and on trees but more difficult on grasses. Calculation pollution effect on food production -- one of the important pollution problems.

Still scientists do not pay adequate attention to esthetic and physiological (psychological??) aspects of the pollution problem. Only public reaction to the radiation problems which accompany the untilization of atomic energy have been investigated. Meanwhile the impact of these factors on the economy seems to be quite recognizable.

Stability (resilience) of renewable natural resources (climate, water, soil, biosphere) under the influence of different pollutants is a way of the investigation. The scale of investigation in this area cannot be considered as adequate to the importance of the problem.