THE MODELING OF SUSTAINABLE DEVELOPMENT OF ENVIRONMENTALLY HAZARDOUS AREAS IN KAZAKHSTAN IN GIS

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In this paper we propose a Geographical Information System (GIS) that provides a combination of mathematical, statistical and imitation models of economical and ecological systems. This information system allows us to estimate ecological perspective of regional development and effective large-scale measures. Thus for example with the help of mathematical models, it is possible to define an optimal allocation of water resources among the republics, regions and branches, where the interests of social and economic development, as well as playing over different scenarios of water resources use and allocation of agricultural crops have been taken into consideration.

INTRODUCTION

A sustainable development calls for an integrated and balanced approach to attaining the aims of economic grows, social equality and environmental protection to provide maximal benefits for present and wider opportunities for future generations. Man becomes a center of sustainable development of the society. These principles should occupy a highly important position in any programs and projects for development strategy. Therefore, today the question how to specify universal signs of a sustainable development is a matter of a great concern. Its answer may be obtained only on the basis of a complex scientific approach. With this aim in view, environment, economy and social development should be treated as a unified architectural ensemble with its internal communications. The interactions between population, economy, and environment often are non-deterministic character and variables that vary at different speeds. It seems to be feasible only on the basis of system analysis and inter-disciplinary approach. In the core of this view, there should be laid our knowledge about biosphere parameters limits, within which human existence is secured, regularities of biosphere development and ecological factors. On the basis of a unified system, it is easy to formulate certain target functions of optimal use of natural resources at each level and determine rational indices of a sustainable development, which reflect real links. Furthermore, on the basis of unified models there should be identified tasks to clean atmosphere, water and soil with social economic possibilities of the society taken into account [1], [2].

There has been known the following criteria of sustainability: GNP (gross national product) per capita should not exceed the same figure expected for future generations and mortality rate for future generations should be less than it is for present ones. Otherwise one may speak about unsustainable development. The Aral crisis is one of the examples, which exhibits how ignored the interconnections among economic, social, ecological factors, and therefore such a crisis might have resulted the unsustainable development Dynamics of water resources allocation in Aral Sea basin and its connection with GNP, population are shown in [2].

How to promote a sustainable development in environmental, social and economic terms is a common concern for all the countries of the region. For the Central Asia Republics, the key question is also how to balance economic and social objectives with environmental constraints and opportunities. Thereby, we have developed the ecological and economical model of some regions of Central Asia and its informational base. The problem for a creation of scientific and information base of a sustainable development in Aral Sea region and former Semipalatinsk nuclear test site is considered in the report.

1. Ecological crisis in Kazakhstan and its consequence

The vast territory and low population density of Kazakhstan well explain the irresponsible attitude of the past policy toward the natural environment. It was wrongly perceived that land and environment were infinite resources. The short-sighted military policy resulted in designation of many regions as military testing grounds. Furthermore, exploitative irrigation policy to support cotton production led to the contraction of the Aral Sea. Excessive ploughing also caused soil erosion and degradation of vast areas of Kazakhstan. Consequently, many regions now face ecological catastrophe, particular in the Aral, Caspian and Central Kazakhstan regions and in the Semipalatinsk nuclear test site.

Aral sea region

The Aral region is in a critical status, as result of the sharp decrease of water inflow from Syrdarya and Amudarya rivers. The unwise policy of water usage led to the catastrophic drying of the Aral Sea and, as consequence, to the degradation of soil, vegetation, fauna and progressive aridization and adjacent territories. Understanding the problems of the Aral Sea basin and Aral itself requires consideration of correlation between the problems of Central Asia and its geographic, natural, economic characteristics, also with regard to its social and economic development.

Nowadays, the Aral crisis has reached in a stage of culminating point. It is completely in an opposite situation against to an economic growth and ecological well being. Short-sighted policy in irrigation has pursued for creation of grandiose Central Asia cotton zones and barbarous use of natural resources, with aiming results in temporary growth of natural income. As a matter of fact, from 1960 until 1990 the national income in Central Asia Republics has increased 4.5 times on the average due to the additional increase of irrigated lands area, while the average of annual amount water inflow from two rivers Amu-Darya and Syr-Darya to Aral sea has decreased on 30 times [2]. At the same time, the development of cotton production has resulted drying up of Aral Sea, and moreover caused a big ecological crisis. As a result, a sharp decrease of water inflow has happened, the Aral Sea level has been going down by 17 m. Such a phenomenon induced its salinity increased three times, with value 40 g/l. already in 1997. The whole water reservoir was divided into two parts-Bolshoe and Maloe seas. The area of dried seabed is 34 th. sq. km. Even though the natural ecosystem has created during numerous centuries and grown up mainly by rich flora and fauna in delta of river, it has undergone degradation. About 20 species of fauna representatives disappeared. Only several hydrobionts were preserved in fauna structure. The dried up sea bed and adjacent to the sea territories became the center of birth and formation places of salty and dusty storms. Dust storms transfer and spread thousand tons of salt over vast territory. Due to such a reason, continental of climate of adjacent regions around Aral Sea is growing, the depth of deposited underground waters is changing, and moreover the process of land desertification and soil salinization is developing. As a result of these processes, the pasture productivity and crop of cultivate agricultural cereals are forced to be lowering. The dried part of Aral Sea bed, the delta of rivers Amu-Darya and Syr-Darya , and the lakes are the areas of high agricultural activity, where pollutant substances are also naturally accumulated. When the latter is drying out, pollution from these sources is dispersed over the adjacent territories, mainly in the northern, western, and northeastern directions.

The general average aerosol mass speared from all 5 sources of Kazakhstan part of the Aral Sea draying bed is evaluated as 1.175 mln. Ton. The formed ecological conditions are harmful for social sphere of population living in this region. Bad quality of drinking water, sharp deterioration of living standards, foods and working conditions of the local population have resulted in the increase of diseases rate and mortality up to the highest level registered in the CIS. The index of infant mortality in separate regions exceeds over 80 per 1000 of newborn children, and 70-80% of inhabitants are suffered from various diseases. The Aral Sea region faces a situation calling for elaborating and organizing urgent measures for saving people in the region.

At present, considerable amount of information was accumulated by the domestic and foreign scientific organizations. The results of these investigations may be used for raising efficiency of territory development management in Aral Sea basin. But the common use of the available materials is impeded as a result of departmental dissociation, different types, fragmentation and poor structural organization of information. The main problem of sustainable development as obviously shown in the above present paper is to ensure balanced development of economy, ecology, social life of society. The programs of development of economy, ecology, and social life existing today at regional and national levels are poorly correlated with each other. Thereby to arise some questions: How should be obtained a coordinated program on sustainable development at all levels: international, national, regional. It is possible to do it only on the basis of unified date base. Therefore, it is important to create geographical information system (GIS). It is necessary to define the indicators of the sustainable development and national water strategy of Central Asia Republics in Aral Sea basin.

FORMER SEMIPALATINSK NUCLEAR TEST SITE REGION

The Semipalatinsk nuclear test site was action about 40 years. During this period had been conducted 470 nuclear explosions among them 30 surface, 88 atmospheric

Nuclear explosions. Only the waste from atomic blast totals about 12 million tons, with 12.9 million Curie. Out of which 6.5 million tons are due to underground explosions and will be long deposited in the molten rock. The influence to environment will be had by this deposit very dangerous consequence. Therefore the main aim is to minimize risk and possible negative consequences of radio ecological legacy of the past. For analyzing and evaluation of radiological situation in Semipalatinsk test site and adjacent regions was carried out investigations by different

Institutions and international organizations. In result at present we have the numerous materials of radiological situation, which included:

- Gamma-spectrometric maps,
- Chronometrical list of atmospheric nuclear tests and their radiological characteristics;

- Nuclear-physical and technological characteristics underground nuclear explosions,
- Results of monitoring of population morbidity caused by radiation and food radioactive pollution,
- Geophysical monitoring and study of effect of nuclear explosions on state of terrestrial crust.

But obtained materials are not interconnected as components of a unified date base. For this reason, needs development of new information technology on the base of Geographic Information System. Because the information as a rule, is territorially distributed that is the principle bulk of data need additional characteristics – geographical coordinates, administrative, topographic and other connections. Thematically processing suggests also the usage of special models adequately reflecting spatial-temporal laws of radio nuclides migration in Semipalatinsk nuclear test site region.

2. A SIMPLE MATHEMATICAL MODEL OF ECONOMIC, ECOLOGICAL AND DEMOGRAPHIC INTERACTIONS

Consider the dynamics of growth of an economic system on base the aggregative production function [11]

$Y = TK^{\alpha_1} L^{\alpha_2}, \alpha_i \geq 0, \alpha_1 + \alpha_2 = 1.$ (2.1)

Here production depends upon capital stock-K(t), labor force-L(t) and level of technology-T. Let P is pollution stock that is accumulated over time as emissions enter the environment. The joint product relationship of pollution and production enables us to adopt the convenience of measuring pollution in the same units as those with which production is measured. From (2.1) we get

$$\frac{\dot{Y}}{Y} = \alpha_1 \frac{\dot{K}}{K} + \alpha_2 \frac{\dot{L}}{L}, \quad (2.2)$$

Let the capital stock depreciates at the positive rate a. Then the rate at which capital is growing is given

$$\frac{dK}{dt} = I - aK, \quad (2.3)$$

Where I-investment. The aggregate output Y(t) can be represented in the form

Y(t)=C(t)+I(t)+Λ(t) (2.4)

where C(t)-consumption, I(t)-investment, Λ(t)-investment for pollution control. In this case the output may be devoted not only to capital accumulation and consumption, but also to reduce the stock of pollution. Let α *and* β represent the nonnegative fractions of output expended, respectively, on consumption and pollution control, so that, for example C=αY, Λ=βY. Then the equation of the growth of the capital stock can be represented

$$\frac{dK}{dt} = sY(t) - aK \quad , \quad (2.5)$$

$where\ s = 1 - \alpha - \beta.$

The growth rate of pollution stock will be

$$\frac{dP}{dt} = (\omega - \beta d)Y(t) - bP\,, \quad (2.6)$$

where ω *is* emission factor per unit of output, b is depreciation rate of pollution naturally. An expenditure of one unit of output will reduce pollution by d units. We introduce for consideration output per capita y = Y/K and pollution stock per capita

p=$\frac{P}{K}$. Then from this we obtain

$$\dot{y} = y\frac{\dot{Y}}{Y} - y\frac{\dot{K}}{K}\,, \quad (2.7)$$

$$\dot{p} = p\frac{\dot{P}}{P} - p\frac{\dot{K}}{K}\,, \quad (2.8)$$

The supply of labor is assumed to be a function of the total population and depends on capital per inhabitants[11]

$$L = \left(\frac{K}{N}\right)^{\mu} N \quad (2.9)$$

where μ is constant. Let the concentration of toxicant in organism at time t is $\sigma p(t)$. Then the dynamics of the population are assumed given by[10]

$$\frac{dN}{dt} = \frac{N\left\lfloor r(\sigma p)N^0(r_0 + c - e) - ecN\right\rfloor}{N^0(r_0 + c - e) + eN}\,, \quad (2.10)$$

where r is the growth rate of the population

$r = r_0 - r_1\sigma p$, (2.11)

r_0 –is the intrinsic growth rate of population, r_0 –is a dose-response parameter, N^0, c, e are constants.

On substituting (2.5) in(2.7) and (2.6) in (2.8) we obtain

$$\dot{y} = -(1 - \alpha_1)(sy - a)y - \alpha_2\frac{\dot{L}}{L}\,, \quad (2.12)$$

$$\dot{p} = (\omega - \beta d - sp)y - (b - a)p. \quad (2.13)$$

From (2.9) we also get

$$\frac{\dot{L}}{L} = (1 - \mu)\frac{\dot{N}}{N} + \mu\frac{\dot{K}}{K} \quad , \quad (2.14)$$

Finally from (2.12), (2.14), (2.10) dynamic equation for y is given as:

$$\frac{\dot{y}}{y} = (-1 + \mu\alpha_2 + \alpha_1)(sy - a) + \alpha_2(1 - \mu)\frac{\left\lfloor r(\sigma p)N^0(c + r_0 - e) - ecN\right\rfloor}{N^0(c + r_0 - e) + eN}\,,$$

Finally our model of the dynamics environment-ecological system can be represented

$$\frac{dy}{dt} = y\left[(-1+\alpha_2\mu+\alpha_1)(sy-a)+\alpha_2(1-\mu)\frac{\{r(\sigma p)N^0(c+r_0-e)-ecN\}}{N^0(c+r_0-e)+eN}\right],$$

$$\frac{dN}{dt} = \frac{N\lfloor r(\sigma p)N^0(r_0+c-e)-ecN\rfloor}{N^0(r_0+c-e)+eN}, \quad (2.14)$$

$$\frac{dp}{dt} = (\omega-\beta d-sp)y-(b-a)p,$$

with initial conditions

$y(0)=y_0>0$, $N(0)=N_0>0$, $p(0)=p_0\geq 0$,

and 11 parameters, which can be grouped as follows;

population: N^0, c, r_0, r_1, e;

economy: α, a;

environment: b, σ, ω;

environment control: β, d.

Then the equilibrium solution of the system (2.14) can now be obtained as:

$$y^* = \frac{a}{s},$$

$$N^* = \frac{r(\sigma p^*)N^0(r_0+c-e)}{ec}, \quad (2.15)$$

$$p^* = \frac{(\omega-bd)a}{sb}.$$

Here all parameters are constant and $\omega \geq bd, \quad r_0+c\geq e.$

To study the stability of the equilibrium solution we introduce the following Lyapunov function[9]

$$V=\eta^2+k_1(\xi-y^*\ln(1+\frac{\xi}{y^*}))+k_2(\zeta-N^*\ln(1+\frac{\zeta}{N^*})). \quad (2.16)$$

where

$\xi = y-y^*, \quad \eta = p-p^*, \quad \zeta = N-N^*.$

Then the equations (2.14) with respect to new variables can be written as follows

$$\frac{\xi}{\xi+y^*} = (-1+\alpha_2\mu+\alpha_1)s\xi+\alpha_2(1-\mu)\frac{-cr(p^*)\zeta-r_1\sigma cN^*\eta}{(c+r(p^*))N^*+r(p^*)\zeta},$$

$$\dot{\eta} = (\omega-\beta d)\frac{(b-a)}{b}\xi-(s\xi+b)\eta, \quad (2.17)$$

$$\frac{\zeta}{\zeta+N^*} = \frac{-cr(p^*)\zeta-r_1\sigma cN^*\eta}{(c+r(p^*))N^*+r(p^*)\zeta}.$$

Using the Lyapunov function and the equations (2.17) , gives

$$\frac{dV}{dt} = -2(sy - a + b)\eta^2 + k_1(-1 + \alpha_2\mu + \alpha_1)s\xi^2 -$$
$$- k_2 \frac{cr(p^*)}{N^* + r(p^8)N}\zeta^2 + (\omega - \beta d)\frac{(b-a)}{b}\xi\eta -$$
$$- k_1\alpha_2(1-\mu)\frac{cr(p^*)\xi\zeta + r_1\sigma c N^*\eta\xi}{N^* + r(p^*)N} \le 0.$$

From this we have concluded that the equilibrium solution (2.15) is globally asymptotically stable for all parameters that are satisfying above-mentioned conditions.

3. THE EFFICIENT ALLOCATION OF WATER RESOURCES OF THE ARAL SEA BASIN

Let us consider a problem of finding optimal allocation water resources of the Syr-Darya river basin among the Republics of Central Asia, with social, economic and ecological interests of the society in consideration. Now suppose that the water basin of the river is divided into n zones (water systems), which correspond to the territories of the Republic. Then the profit maximization problem of the Republics can be written as [5]:

$$\sum_{s=1}^{n}\sum_{i=1}^{m} c_i^s \sum_{b=1}^{l} x_{ib}^s \xrightarrow[x]{} \max, \quad (3.1)$$

Where x_{ib}^s is agricultural production of sort i (cotton, rice, wheat, fodder crops,), in the region s, on the irrigated area with bonitet b, and c_i^s is the cost of the agricultural product $x_i^s = \sum_{b=1}^{l} x_{ib}^s$.

Now we formulate the resources constraints:

1. Water resources balance[4]

$$\sum_{s=1}^{k}\sum_{i=1}^{m} g_i^s \sum_{b=1}^{l} x_{ib}^s \le \sum_{s=1}^{k}(v_s^0 + \Delta v_s^0)$$
$$k = 1,2,\dots n-1, \quad (3.2)$$
$$\sum_{s=1}^{n}\sum_{i=1}^{m} g_i^s \sum_{b=1}^{l} x_{ib}^s \le \sum_{s=1}^{n}(v_s^0 + \Delta v_s^0) - w_0.$$

Here, g_i^s is the irrigation standard, v_s^0 the available volume of water resources in region s, Δv_s^0 the increasing water volume in region s, and w_0 water inflow to the Aral Sea.

2. Restriction for Land resources [7]

$$\sum_{i=1}^{m}\sum_{b=1}^{l}\frac{x_{ib}^{s}}{\delta_{ib}^{s}} \le L_s, \quad s = 1,2....,n. \ (3.3)$$

Where δ_{ib}^{s} – are the productivity of agricultural crops, and L_s – the total irrigated area in region s.

3. Restriction for production of the major types of agricultural crops in the Republic Restriction for production of the major types of agricultural crops in the Republic

$$X_i^s \le \sum_{b=1}^{l} x_{ib}^{s} \le Y_i^s \ , (3.4)$$

where X, Y are given minimum and maximum volume of agricultural products.

The problem is to find the optimal allocation of production x_i^s to each region under constraints (3.2)-(3.4). For a numerical solution of the problem (3.1)-(3.4), some data from Sar NIGMI and WARMAP project [8] can be useful.

The results of estimation of agricultural production for the vast area of Aral Sea basin are given in the paper [5]. In our calculation we used the data for 1986, 90 years. The cotton production predominates in the national economy of Uzbekistan and Turkmenistan, and their nominal incomes are higher.

According to the data base of SarNIGMI and WARMAP PROJECT, the consumption of irrigation waters in republic amounted in 1986 to 50-70% with respect to the total water usage, and to 80-90% in 1990 with no allocations for irrigation systems in any of the republics. For restrictions (3.2),(3.3), a full objective data information for a vast territory can be obtained using remote sensing methods and Geographical Information System.

Efficiency of land use was estimated as the ratio of the nominal income to the irrigation lands, and it shows that it is the most efficient in Turkmenistan, e.g., 1379,6 $/ha, while the efficiency of water usage in this republic is 6 cent/mecum. It is just the same situation as in Uzbekistan, where the irrigation areas are 3 times lager. Efficient of the irrigated lands for Kzyl Orda and Karakalpakistan are very low.

In these regions, all negative consequences of irrigation activity are connected with climatic changes, degradation of ecosystems, and decreasing of the ground water level on vast territories. For example, nominal income in Kzyl Ordaa region is 200 times less that in South Kazakhstan region, while irrigated areas do not differ considerably.

4. THE STRUCTURE OF GEOGRAPHIC INFORMATION SYSTEM "ARAL"

A specific role in solution of mentioned Aral crisis is allotted to Geographic Information Systems. The geographic information systems (GIS) are designed to input, storage, manipulation, analysis, and output of data regarding spatial location. In other words GIS means of integrating spatial data acquired at different scales and times, and in different formats [12],[6]. Geographic information systems allow for improving our understanding of the world around as and providing sustainable development of society. For example environmental managers use these systems for such applications as monitoring hazardous waste sites, measurement environment parameters, inventory disappeared species of fauna and flora, mapping and modeling. These key activities: measurement, mapping, monitoring, and modeling can be enhanced through the use of contemporary technologies, and in particular, through the use of a GIS. For this reason, needs development of new information technology on the base of GIS. This system consists of four principal blocks:

- data acquisition,
- pre-processing and storage,
- data management, manipulation and analysis,
- basic models.

DATA ACQUISITION

For analyzing and evaluation of ecological situation in Aral Sea basin and adjacent regions was carried out investigations by different institutions and international organizations. In result at present we have the numerous materials of ecological, economic and demographic states in Aral Sea region, which included:

hydro geological and hydro biological conditions,
climatologically description of the Aral sea region,
landscape-structural condition of Aral coastal region, state of soil cover,
irrigation and irrigation structures in Central Asia,
biodiversity of the Aral Sea basin,
results of aerospace monitoring of water and land resources, desertification in the Aral region,
population density, sanitary-epidemiological situation,
base and thematic maps,
statistical data of economy,
data of pollutant concentrations in water, atmosphere, soil.

PREPROCESSING

It involves extracting information from maps, space images, and printed records. statistical yearbooks, computer database and manipulating the data so that it may it is entered from various sources into GIS. This block also includes format conversion of the original data from different sources and identifying the location of data in the system.

Data-management provides consistent methods for data entry, update, deletion, and retrieval. Data-management concerns include issues of security.

MANIPULATION AND ANALYSIS

In this block of the system are analytic operators that work with the database contents to derive new information. We can to move data from our GIS to an external system where a particular mathematical model is available, and then transport the derived results back into spatial database inside the GIS.

Basic models. This block includes a several models of efficient allocation of land and water resources, economic development, population growth, optimal control of pollution. Thus created Information system allows to integrate necessary data from different sources and to decision on base of models providing sustainable development.

Product generation. These output products might include statistical reports maps, graphics.

CONCLUSION

It is necessary for future

- integrating information from different sources and to create common unified data base for GIS "ARAL'' and "Semipalatinsk",
- development of Geographic Information System" ARAL" for monitoring, diagnostics, prognosis ecological situation in Aral Sea basin and optimization of using water , land resources,
- coordination activities different countries in satellite remote sensing of territory Central Asia,
- to create common monitoring system on the base of the network of instrumental ground observations.

On base of unified data base and Geographic Information System (GIS)

- elaboration and realization of scenarios of socio-economic development of Aral region in conditions of transition to market economy and sovereignty of Central Asia Republics, distribution of manly agricultural complexes,
- the efficient allocation of surface water resources along Republics of Central Asia,

Multy-layer cartography and aerospace data as well as economic-mathematical models for analysis and forecast of human activity in the field of land use and efficient allocation water resources will be integrated in Arcinfo environment. After basing on GIS "ARAL" recommendations to modernize territorial structure of economy in Aral region will be developed.

There also hope that GIS and remote sensing constitutes a contribution for sustainable development in this region by providing the necessary information for it. The monitor changes in our surrounding in space and time. In addition, they model alternatives of action and processes operating in the environment.

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