GIS Based Model of Quotas Regulation and its Impact on the Extraction of Ecosystems' Natural Resources and Social Welfare

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Abstract. Research goal of the paper is to study ecosystem using Geographical Information System (GIS) based technology to develop valid recommendations for sand extraction from water body. Our subject of research is GIS Based Model of Quotas Regulation and its Impact on the Extraction of Ecosystems' Natural Resources and Social Welfare. We used such methods as optimization methods, GIS methods, differential-equations method, marginal benefit-cost analysis. An example of mathematical model for determining of ecological equilibrium during sand extracting in the ecosystem is developed using Google Maps. The influence of economic activity due to sand extraction on fish fauna is described. The GIS based ecological-economic model is developed on the logistic model basis for establishing regional quotas for extraction of natural resources during economic activity in the southern Ukraine. Regulatory economic mechanism of natural environment is proposed. It implies such quota for sand extraction from water body, which does not lead to deterioration of the natural environment and stimulate the increase in social welfare.

Keywords: GIS technology, ecosystem, quota regulation, externality

1 Introduction

The surrounding world can be divided into three components: nature, human society and economics. Humanity provides its livelihood by developing an economy, which, in turn, functions through the consumption of tangible and intangible resources, creating negative and positive external effects. Improvement of humanity`s well-being should not occur due to excessive consumption of non-renewable natural resources, but through the creation of incentives for the population to create their needs in accordance with available natural resources, which is proclaimed the main idea of the balanced development of world society by the United Nations. There is a new function of the state – ecological, which is aimed to harmonize the interests of society and nature, ensure optimal consideration of economic and environmental interests by means of GIS. Implementation of the economic mechanism of nature management implies such a load of economic activity, which does not lead to undesirable consequences in biota and does not lead to deterioration of the quality of the environment.

It is possible to follow the changes in ecological balance, the reaction of individuals and the entire ecosystem community, expanded in time and space, with the help of mathematical research methods. Today there is a wide range of applications of mathematical modeling to solve many ecological and economic problems. Moreover, the experience of using mathematical modeling does not raise any doubts concerning the efficiency of this method in the study and forecasting the natural ecosystems state under conditions of anthropogenic influence [1].

Local minerals (sapropel, gypsum, limestone, chalk, sand, loam, sandstone) belong to non-renewable natural resources, the geological rate of formation or accumulation of which is much less than the rate of human consumption. Demand for sand is increasing in many parts of the world due to rapid economic development and subsequent growth of building activities. Sand is considered a cheap resource, because businesses need to cover only the exploitation cost (costs of equipment, labor, fuel, and transport) [2]. Lack of adequate information on the environmental impact of river sand mining is a major gap, challenging regulatory efforts in many developing countries including Ukraine. Thus, a scientific assessment is a precondition in setting management strategies in the sand mining areas. Environmental impact assessment (EIA) demonstrates that the activities associated with mining and sand processing have not only affected the health of the river ecosystems but also degraded its overbank areas to a large extent [3].

The environmental effects of indiscriminate sand mining (for example, the annual catchment areas of the Vembanad lake, southwest coast of India) are considered by Padmalal D. et al [4]. The quantitative estimation of the sand mining impacts on the rate of water level reduction in the riverbed of the catchment areas of the Vembanad lake. Also rivers on the southwest coast of India are under immense pressure due to indiscriminate extraction of construction grade sand, which is the most disastrous process. The volume of in-stream mining is about 40 times higher than the sand input estimated in the gauging stations. As a result of indiscriminate sand mining, the riverbed in the storage zone is getting lowered at a rate of 7–15 cm. This imposes severe damage to the physical and biological environments of these river systems [5]. In-stream mineral mining is strongly regulated in countries such as Portugal, Italy, and New Zealand and is prohibited in countries such as France, the Netherlands England, Germany, and Switzerland.

We proposed regulatory strategies for the overall improvement of the rivers and its biophysical environment. The policy recommendations grounded in our the paper are intended as guidance to decision makers in charge of sand mining to make more informed decisions. Physical processes and biological data were collected from {data source} to analyze optimal level of sand mining regarding damage to fish and local biota. Our task is to minimize environmental effects which mitigate negative consequences for both environment and social welfare. Present study examines the impact of sand extraction on local ecology in the study area using Google Map and Google Earth as GIS techniques. Images captured by Google Map and Google Earth during 2017 have been used for the analysis.

The **purpose** of the paper is a study of ecosystem using GIS based technology to develop valid recommendations for sand extraction from water body.

The paper is organized as follows: part 2 describes related works, part 3 demonstrates ecosystem quota model; part 4 demonstrates experimental result; the last part concludes.

2 Related works

The study by Izougarhane M. et al [6] provided a qualitative and quantitative assessment of the fishery's effectiveness at the mouth of the Sebou River (Morocco) and assessment of its environmental condition. The results of the observation since 2005 and until 2016 show reduction of qualitative and quantitative indicators of fishing. In addition, it is noted that during this period there was a change in the physical characteristics of the water body, and the quality of water in the aquatic environment is assessed as contaminated and very contaminated. The author notes that the main cause of degradation of water body biodiversity is dredging.

Sowunmi F. A. et al [7] revealed significant differences from the average silt charge of river water and quantity of fish caught by fishermen during working hours in areas with dredging and without it. Low productivity in places of dredging works is due to their negative impact on the environment. In areas where there were no sand dredging works, fishermen received more extraction per day. The authors note, the need to control the activities of sand dredges in fishing communities is to ensure the sustainability of the environment,on one hand,, and the conservation of fishing in the study area on the other

The interesting results are found in works of Adesina T. K., Adunola O. A. [8]. The expected effects of dredging activities on fishing of artisanal fishermen are considered in Lagos State, Nigeria. Results of statistical studies revealed the significant relationship between the impact of sand dredging effect on fishing activities, the relationship between monthly income and perceived effects of sand dredging on fishing activities. Scientists have suggested enhancing the artisanal fishery contribution to total Gross Domestic Product (GDP), employment generation and total increase of domestic fish production.

Akankali J. A., Idongesit A. S., Akpan P. E. [9] have assessed the physicochemical parameters of water samples collected from upstream and downstream of OkoroNsit (Nigeria) stream for sand mining activities: hydrogen index (ph), temperature, turbidity, dissolved oxygen, biological oxygen demand, sulfate, nitrate, phosphate, suspended solid, calcium, magnesium, oils and grease. It was found that river water was polluted as a production result of sand mining activities at IsoEsuk River, IkotAkpaEkpu. The results of some analyzed parameters of investigated substances were within the limits of maximum permissible values, but some physical and chemical parameters and heavy metal content were higher than the permissible water quality standards.

Wilber D. H., Clarke D. G. [10] conducted the assessment of the biological effects of increased concentrations of suspended sediment caused by human activities, such as navigation dredging, on estuarine fish and shellfish. Researchers emphasize the need for managers to determine the volume of sand extraction based on the assessment of potential consequences of production activities during dredging.

Kim C. S., Lim H. S. discovered the prevalence and accumulation of sediment in construction grade marine sand in the coastal waters of Korea on the basis of a combined approach to observations and modeling [11]. Scientists used field measurements collected during mining operations in Kyunggi Bay, Korea to develop sediment parameters and source conditions for a three-dimensional (3D) sediment transport model built on the Regional Ocean Modeling System (ROMS). The model is run with realistic forcing obtained from a 9 km meteorological model, tides, and river discharges. The resulting picture of the distribution of silt charge in depth and in space corresponds to the data of field observations and demonstrates the character of distribution in accordance with the granulometric composition of the sand.

Environmental problems occur when the rate of sand extraction, gravel and other materials exceeds the rate at which natural processes generate these materials. Sand extraction destroys the cycle of ecosystems, impacts on the biological resources including destruction of infauna, epifauna, and some benthic fishes and alteration of the available substrate. This process can also destroy riverine vegetation, cause erosion, pollute water sources and reduce fish diversity. This study aims to investigate both the positive and negative impacts of sand mining: positive in terms of financial gain or social welfare and negative in terms of environmental impacts associated with potential sand mining operations: and develop the best management practices in order to minimize the adverse environmental impacts [12].

Consequently, the results of the research of world scientists proved the necessity in development of advisory and substantiated recommendations that can be obtained by using mathematical models. It is possible with using of system analysis, computer modeling to investigate more deeply the mechanism of transformation of water objects within the framework of water management works, to make plausible scenarios of the possible development of the consequences of the impact of human economic activity on the state of water resources in accordance with the plans of economic development of the regions.

Sustainability of extraction of ecosystems’ natural resources depends on precise assessment of biomass resource, planning of cost-effective logistics and evaluation of possible environmental implications. In this context, it is important to review the role and applications of geo-spatial tool such as GIS for precise agro-residue resource assessment [13]. Although most conservation efforts address the direct, local causes of biodiversity loss, effective long-term consideration of ecosystem exploration will require complementary efforts to reduce the upstream economic pressures, such as demands for food, water and forest products, which ultimately drive these downstream losses [14].

Alternative economic approaches study the economy with a multidisciplinary view, considering paradigms of social inclusion, justice and sustainability. Geographic information science (GIScience) can be defined as a multidisciplinary and a multiparadigmatic field, where "spatial thinking" is fundamental. The study of environmental quality of life can be supported by the calculation of spatial indicators [15].

The externalities produced by extraction of natural resources are multidimensional, may strongly depend on the local context, and thus are difficult to capture through standard environmental valuation exercises [16]. We experiment a GIS approach to design a GIS based model of quotas regulation and its impact on the extraction of natural resources of the ecosystem and social welfare. The set of GIS-based variables (local context variables) prove to be significant predictors in sustainability of natural resources of the ecosystem. We can compute simulated values that combine information on social welfare of agents with opposite goals for use in policy choices such as infrastructure localization and negotiation of compensations.

Changes in natural resouves are complex, thus, managing an appropriate type of change to satisfy stakeholders with various interests is challenging. Two kinds of conflicts might occur as a result of change in an ecosystem: (1) conflicts among multiple ecosystem services i.e., internal conflicts and (2) conflicts among multiple stakeholders i.e., external conflicts [17]. In our paper we develop two change scenarios of fish recovery (net increasing and net decreasing).

Model enables decision makers to resolve internal conflicts while considering the relative values of multiple ecosystem services to show how well the model enables decision makers to resolve external conflicts in a group while taking into account the diverse goals of stakeholders. Obtaining acceptable change solutions among stakeholders with conflicting interests can lead us in moving from individual decision-making to group-based decision-making so that we can enhance sustainability in natural resource extracting.

Evaluation of analytical tools allows assessing the minimum amount of information needed to properly delineate stock units. Single technical approaches are insufficient to delineate complex fish stock structures [18]. GIS and hydro-economic models were used in order to delineate groundwater quality zones in the Central East of Punjab-Pakistan and observe the impact of groundwater quality on agricultural economics [19].

Mathematical models have been widely used to simulate all aspects of bioenergy production systems. Thus GIS-based approach is a powerful method to collect data, perform spatial analysis, combine and manage both spatial and attributes data inside a determinant region [20].

A GIS is used for locating the service areas of businesses and corresponding environmental conditions. For ecological models, the results suggest that on average there is a significant increase in efficiency of responsible decision and policy makers about extraction of natural resources when externalities are incorporated in the function of resources extraction. This suggests that businesses have internalized the effects of fishery decreasing and have adapted to the environment in which they operate. The results can simulate decision-making in public safety issues (design of model extraction, regulations of quotas).

We try to answer how to specifically estimate the ecological impact of sprawl of natural resources extraction using GIS and ecological valuation method. An ecological estimation method examines the economic losses of natural environmental.

3 Ecosystem Model of Quotas Regulation

Mechanisms responsible for the development of the natural system can be determined with consideration of the functioning of the biological or ecological system as the result of the interaction of their constituent and external factors. It is reflected in the change of the environment state in which these systems are considered. It is possible to thoroughly investigate the interaction of various factors through the use of mathematical methods and methods of mathematical modeling. These mathematical and simulation models can be used to test various scenarios and strategies in order to minimize ecological effects. We can charge specific quotas for sand exploitation using benefit-cost analysis, where benefit is a profit of businesses which extract sand; cost is a decreasing of fish population in monetary terms.

In the decision-making concerning the sand extraction, in particular sand and gravel material [21], the apparatus of game theory (GT) can be used. When studying and analyzing conflict issues and trying to predict the behavior of competitive players, GT approaches allow simulation of the self-centred attitude of the involved players with a fairly realistic manner. In that context, GT methods compared to other conventional methods of strategic analysis, such as linear programming, make better estimates of the game outcome. The role of GT is to propose a methodology about good governance of the mining sector that promotes a sustainable sharing of aggregate resource by securing environment and safekeeping revenues in mining trade market.

The simplest case of controlling the dynamics of a ecosystem's population is realized when the population's change rate is proportional to the deviation from its equilibrium state (Malthus model):

$$\frac{dN}{dt} = k \cdot (N - N_0) \tag{1}$$

Here fish population grows proportionally to their available quantity. The solution of the equation has the form: $N = N_0 + (N_1 - N_0) \cdot e^{kt}$, where N_1 is a deviation from the equilibrium state at time $t = 0$. For $k > 0$, the ecosystem will deviate from the equilibrium state N_0, whereas for $k \leq 0$ the system will return to its equilibrium state. The encroaching speed or removal speed will depend on the absolute value of the control parameter k. Linear models are aimed to maintain the system in its current state, whereas in the ecosystem it is often necessary to transfer the system from one state to another, which is more desirable according to certain criteria. Nonlinear models allow the system to be moved from one state to another.

Population dynamics can be adequately described by means of one independent variable quantities, and factors influencing the state of the system are taken into account in the form of given constants. One of the nonlinear models that allows this to be done is a logistic model that takes the form of the following equation:

$$\frac{dN^*}{dt} = aN^*\left(1 - \frac{N^*}{K^*}\right) \tag{2}$$

where $N^*(t)$ – number of population at the moment of time t, a – Malthusian parameter, $K*$ – ecological carrying capacity [22].

During the sand extraction, a temporary effect on the fish fauna is expected. It is manifested by the death of baby fish and fodder organisms, due to the increase of silt charge in surface waters from dredging. Dredgers form zones with significant quantities of silt charge. In addition, during soil removal, hydrobiota can suffocate and die. In the zone of high turbidity it is necessary to take into account the influence of silt charge both in the water column and on the bottom, which is especially important for spawning grounds and feeding places for young fish.

The reaction of fish during sand mining (response of biota to anthropogenic impact) manifests itself by the removal of adult individuals outside the zone of impact of the dredger immediately after the sensation of noise and vibration. Baby fish that are not yet capable to move by themselves, and caviar from the bottom and the water column will die in accordance with the increase in turbidity, that is, under the condition of continuous operation of the dugout for a long time. This may be in line with the condition of exceeding birth-rate mortality (negative ‘a’).

The inhibition of the fish fauna in the area of sand extraction has a local and temporary character and, after a while, there will be processes of natural reclamation of the organisms of the bottom fauna. Restoring of the feed base after the completion of the sand extraction is carried out for a certain time. Then the adult fish will return (some species of fish, even with certain indicators of turbidity), and the birth rate will eventually recover.

The equation (2) is integrated by the division of variables, and its solution determines the number of population at the moment of time t, has the form:

$$N^* = \frac{K^* N_0 e^{at}}{K^* + N_0\left(e^{at} - 1\right)} \tag{3}$$

where N_0 – initial number of fish in a water body.

The Ferkhyulst model is a generalization of Malthus model for existing restrictions on the extraction of natural resources. In this case, the management of the quotas for a sand extraction should be made in such a way as to achieve the maximum profit from the extraction of this sand, under condition that it is preserved for future use, and this extraction should not exhaust the catch of fish in the water body. Alternative management models may include sand extraction at constant speed c in the form $\frac{dN^*}{dt} = aN^*\left(1 - \frac{N^*}{K^*}\right) - c$ or quota may be determined in proportion to the available quantity of sand: $\frac{dN^*}{dt} = aN^*\left(1 - \frac{N^*}{K^*}\right) - p \cdot x$, where p is a speed of sand extraction [23]. Alternative models require daily monitoring by GIS technology, while the Ferkhyulst model allows setting a quota based on available monitoring data using GIS.

If it becomes necessary to simulate the ecosystem or its individual components under variable in time external conditions, then the problem is reduced to the consideration of a non-autonomous system. At first, an autonomous system (model) is built and studied [1].

In accordance with the methodology for calculating damage [24], which is caused to the fish industry due to soil extraction, works, damage to the caviar, larvae and baby fish by hydraulic dredger is determined by the formula:

$$N = \mathit{\Pi} VR \frac{K}{100} M \ . \tag{4}$$

where N – amount of damages, $\mathit{\Pi}$ – number of caviar, larvae and baby fish, V – volume of extracted soil, R – multiplicity of soil dilution with water, K – coefficient of industrial return from caviar, M – average weight of the adult fish.

If we need to determine the population size (caviar, larvae and baby fish), which is large enough, it is more convenient to use non-deterministic, but continuous models that have an independent variable of time. In the absence of other independent variables, it is described by ordinary differential equations.

Accepting that from equalities (3), (4), we get:

$$N = \frac{K^* N_0 e^{at}}{K^* + N_0\left(e^{at} - 1\right)} \cdot VR\frac{K}{100}M .$$

After separating independent of t values we get:

$$N\left(t\right) = K^* N_0 RM \frac{K}{100} \cdot \frac{V\left(t\right)e^{at}}{K^* + N_0\left(e^{at} - 1\right)} . \qquad (5)$$

The resulting equation (5) is a dependence that describes an autonomous system.

One of the important properties of an autonomous system (model) is that it can have stationary solutions that determine the state of equilibrium of the real ecological system. It is necessary to find points that correspond to the state of equilibrium of the autonomous system (model). In the state of equilibrium, all the indicators of the ecosystem do not change over time, so in the stationary state, all derivatives of time in the system are zero, that is $\frac{dN}{dt} = 0$:

$$\frac{dN}{dt} = K^* N_0 RM \frac{K}{100} \cdot \frac{\left(\frac{dV}{dt}e^{at} + aVe^{at}\right)\left(K^* + N_0\left(e^{at} - 1\right)\right) - Ve^{at} \cdot N_0 a e^{at}}{\left(K^* + N_0\left(e^{at} - 1\right)\right)^2} .$$

As $\frac{dN}{dt} = 0$, $K^* + N_0\left(e^{at} - 1\right) \neq 0$, then

$$\left(\frac{dV}{dt}e^{at} + aVe^{at}\right)\left(K^* + N_0 e^{at} - N_0\right) - aVN_0 e^{2at} = 0 ;$$

$$\frac{dV}{dt}e^{at}\left(K^* + N_0 e^{at} - N_0\right) + K^* aVe^{at} + aVN_0 e^{2at} - N_0 aVe^{at} - aVN_0 e^{2at} = 0 ;$$

$$\frac{dV}{dt}e^{at}\left(K^* + N_0 e^{at} - N_0\right) + K^* aVe^{at} - N_0 aVe^{at} = 0 .$$

Taking into account $e^{at} \neq 0$ for $t \in R$, we get:

$$\left(K^* + N_0 e^{at} - N_0\right)\frac{dV}{dt} + \left(K^* a - N_0 a\right)V = 0 .$$

As a result of finding the derivative (5) and equating the result to zero, we obtain the differential equation $\frac{dV}{dt}$:

$$\left(K^* - N_0 + N_0 e^{at}\right)\frac{dV}{dt} = a\left(N_0 - K^*\right)V . \qquad (6)$$

The equation (6) is integrated by the division of variables:

$$\frac{dV}{V} = a \cdot \frac{N_0 - K^*}{K^* - N_0 + N_0 e^{at}}dt , \ \ln V = a\left(N_0 - K^*\right)\int \frac{dt}{K^* - N_0 + N_0 e^{at}}$$

$$\ln V = a\left(N_0 - K^*\right)\left(\frac{t}{K^* - N_0} - \frac{1}{a\left(K^* - N_0\right)}\ln\left(K^* - N_0 + N_0 e^{at}\right)\right),$$

$$\ln V = -at + \ln\left(K^* - N_0 + N_0 e^{at}\right),$$

$$V = \left(K^* - N_0 + N_0 e^{at}\right)e^{-at}.$$

The solution of the equation, which determines the volume of extracted sand at the moment of time t, has the form:

$$V(t) = \frac{K^* + N_0\left(e^{at} - 1\right)}{e^{at}}. \tag{7}$$

4 GIS Based Approach and Quota Setting Experiment for Fish Population

4.1 GIS Based Approach

There is an acute need for regulation of production activities for the extraction of natural resources, calculation and allocation of quotas, depending on the ecological and economic situation of a particular area. Since 2016 in the Kherson region the solution of these problems requires conducting of hydrogeological survey, implementation of basin water management schemes, in particular in the Dniprovsky Basin Water Resources Management, substantiation of maximum allowable water and ecological loads, introduction of water management ecological-economic models. The data as a result of such works is extremely necessary for establishing regional quotas for extraction of natural resources while solving economic issues of southern Ukraine.

Representatives of local authorities and public organizations are concerned about the illegal sand extraction on the territory of the Kakhovka Reservoir. Thus, in the village Vesele, the Beryslav region, illegal sandwash and export of sand from the territory of the Kherson region are taking place (carts and barges go to Kamianske) as we can estimate from Google Map (fig.1).

Over the last decade or more, geographic information systems (GIS) have proved to be agile and powerful tools in academic and applied fields. The Google Maps mashup as Web application exhibits great potential to be a real live GIS. The power of GIS to analyze and illustrate suggested that public access to planning processes and research of many types would be greatly enhanced. Google Maps is a service which portends a subtle shift in GIS and what much of the world will be expecting of online geospatial business in coming years. Google Maps, the official Web service, is a quite simple tool very much similar to other online mapping services like MapQuest, Yahoo! Maps etc. This is a staple of Web-based GIS, and in Google Maps it is limited to only three choices: digital orthophotos, symbolized street maps, and a hybrid of the two [25].

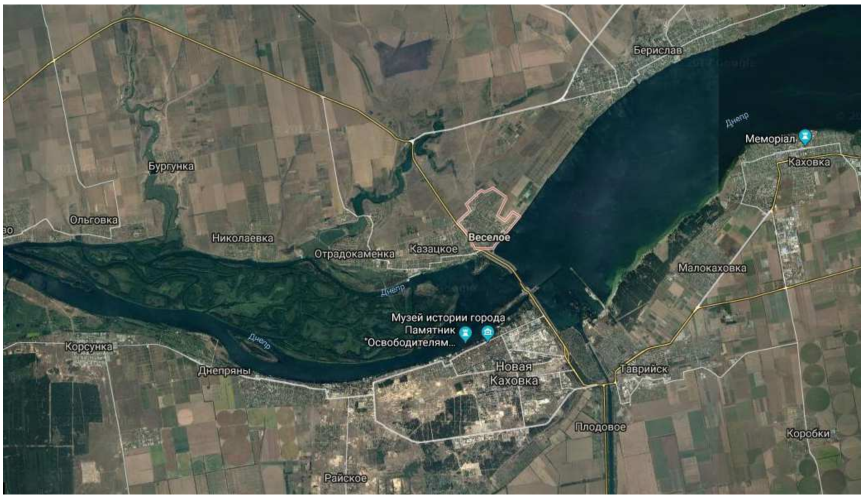

Fig. 1. Google Map based screenshot as GIS of sand extraction on the territory of the Kakhovka Reservoir

When one of results plotted on the map is clicked, a small scale is demonstrated in the bottom of this box. There is a unique and important additional component of Google Maps – its mashability. Google Maps mashups are the resultant combinations of the existing Google Maps geospatial query/display engine with geospatial data provided by non-Google users [25]. Google Maps lacks analytical power and accuracy, but it can be a platform for the addition of value by a participating public, a service to be mashed up, and the system to be possibly revised. It helps to build geospatial information resources that answer specific needs of specific industries.

It means creation of public participation geographic information system (PPGIS) that could support include necessary data to process information and make decisions of responsible persons. PPGIS applications have been extensive, ranging from community and neighborhood planning to environmental and natural resource management to mapping traditional ecological knowledge of people [26]. Example of Google Map application is demonstrated in table 1.

Table 1. Google Map applications

Year	Implementation mode	Location
2011	Google Maps	Otago Region (New Zealand)
2011	Google Maps	*Southland Region (*New Zealand*)*
2011	Google Maps	South West Victoria (Australia)
2010	Google Maps	Kangaroo Island (South Australia)
2010	Google Maps	Grand County (Colorado, U.S.)

In a recent Web-based PPGIS application authors provided an integrated Google Maps and Google Earth application interface that allowed participants the opportunity to examine and map any attribute in investigated area. We can distinguish 4 methods for collecting spatial information via PPGIS: 1) paper map and markers; 2) paper map and sticker dots; 3) flash-based Internet applications; 4) Google Maps/Earth Internet application [26]. Therefore we need to augment these applications with statistical data to make more a informative decision about resource extraction.

On the other hand authors [27] do not include popular web mapping Application Programming Interfaces (API's), such as Google Maps, Yahoo! Maps or BingMaps, Google Earth application on the list of free and open sources (fig. 2).

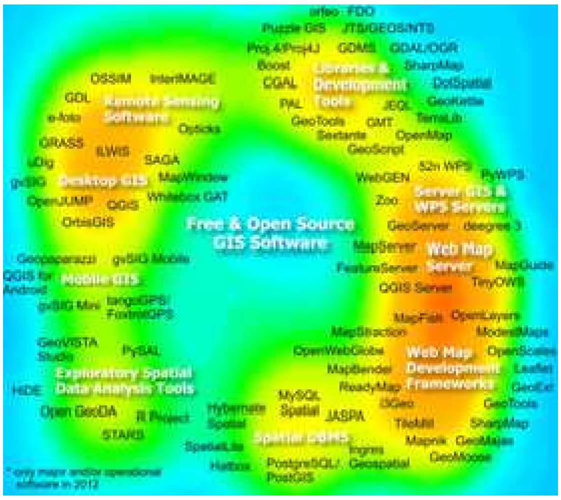

Fig. 2. Free and open source GIS Software

The reason is, that these maps are only free-of-charge in certain situations, and that their licence agreement imposes restrictions on users that limit the APIs uses to certain types of applications. For example these APIs are not free for commercial use, and private users are restricted in the daily frequency of use (number of map requests) of the services offered through these API. A recent example for a license change is the Google Maps API [27].

4.2 Quota Setting Experiment for Fish Population

Assume that a fish population at time t varies according to the following differential equation:

$$\frac{dN}{dt} = aN\left(1 - \frac{N}{K}\right) \tag{8}$$

where K – maximum capacity of fish in a water body, N – number of fish at time t, parameter $a > 0$. The solution of equation (8) is determined by the following logistic curve (fig. 3). The dynamics of the fish population is described by the logistic curve in fig. 3.

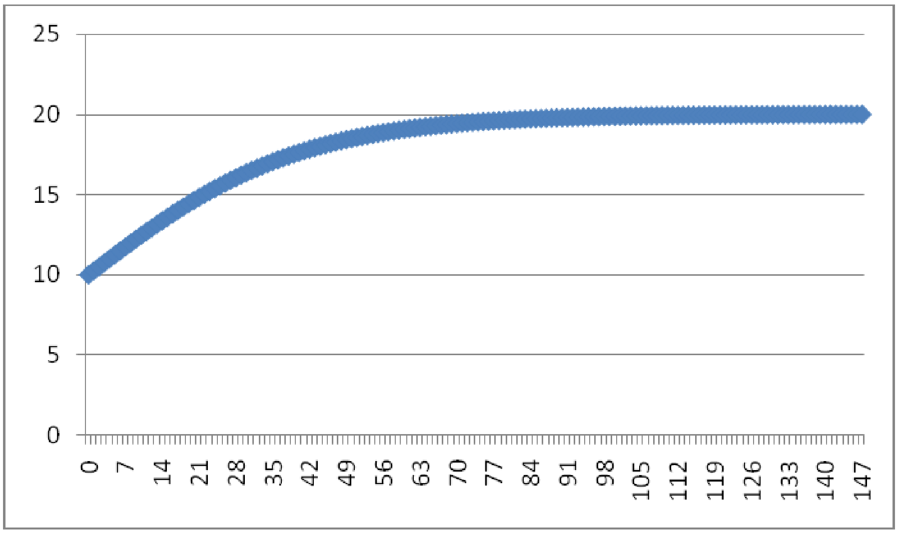

Fig. 3. The dynamics of the fish population (horizontal axis is time period in months, vertical axis is a number of fish population in tons)

In order to conduct a study, we need to choose the location of the site that is planned to be used for the sand extraction, taking into account the possible influence on the hydraulic structures that are below the current from the place of the sand extraction (Kakhovka HPS). The size of the production site, from which area sand is extracted, is determined by taking into account the relief of the water body and the coastal strip, the capacity of the sand deposits and the technical characteristics of the used equipment. Conditional unit of sand extraction taking into account the received values of quotas (20 tons), can be obtained from the area of 1 km^2 and, for example, corresponds to a strip along a coastline with a width of 0.05 km and a length of 20 km.

Let’s set the following parameters for a water body, where sand is extracted from, for example, for building on the basis of quotas established by the regulatory authorities. The net growth rate of freshwater fish is 5% per year. The volume of water and sand are determined using GIS technology: the maximum sand capacity is $V = 1000$ tons, $\max K = 20$. The losses from the sand extraction in a water body are calculated by the formula:

$$N = N^{*} V R \frac{K}{100} M \tag{9}$$

Indices of equation (9) are explained in table 2.

For the initial values of the parameters, we will determine the social welfare SW, taking into account the profit of the business Π, which extracts sand from the water body and losses from loss of fish $c \cdot N$ (negative externality) due to the sand extraction. The volume of sand extraction is determined by the formula (7).

Table 2. Initial parameters for the calculation of losses from the sand extraction

Parameters	Explanation of the parameters	Units of measurement
N	amount of fish population's loss	Kg
N^*	number of fish in a population at time t	$\frac{animal\ unit}{m^3}$
V	volume of sand extraction	m^3
R	multiplicity of soil dilution with water	-
K	coefficient of industrial return from caviar	-
M	average weight of the adult	Kg

The dynamics of extracted sand volume V (m^3) for discrete time intervals (months) is shown in Table 3. The total revenue of the sand owner is calculated by the formula $TR = P \cdot V$ (P – price per 1 m^3). The profit of a firm that extracts sand is $\Pi = TR - TC$. The population of the fish at time t is determined from the formula (9) and is presented in table 3. Amount of fish population loss N is calculated by the formula (3), and the number of fish in the population N^* is computed by the formula (2) in table 3. In the monetary equivalent, the losses from damage done to fish (negative externality) due to sand extraction equal $c \cdot N$. Social welfare (net gain or loss of society) $SW = \Pi - c \cdot N$. Quota is $Q = \frac{V}{\max V}$.

Table 3. Dynamics of ecosystem's indicators due to sand extraction

t	V	TR	TC	Π	N^*	N	$c{\cdot}N$	SW	Quota
0	20	16800	12600	4200	10	70	3150	1050	2,0%
1	19,51	16390,33	12292,75	4097,58	10,25	70,00	3150	947,58	2,0%
2	19,05	16000,63	12000,48	4000,16	10,50	70,00	3150	850,16	1,9%
3	18,61	15629,95	11722,46	3907,49	10,75	70,00	3150	757,49	1,9%
4	18,19	15277,34	11458,00	3819,33	11,00	70,00	3150	669,33	1,8%
5	17,79	14941,93	11206,44	3735,48	11,24	70,00	3150	585,48	1,8%
6	17,41	14622,87	10967,15	3655,72	11,49	70,00	3150	505,72	1,7%
7	17,05	14319,38	10739,53	3579,84	11,73	70,00	3150	429,84	1,7%
8	16,70	14030,69	10523,02	3507,67	11,97	70,00	3150	357,67	1,7%
9	16,38	13756,08	10317,06	3439,02	12,21	70,00	3150	289,02	1,6%
10	16,07	13494,86	10121,14	3373,71	12,45	70,00	3150	223,71	1,6%
11	15,77	13246,38	9934,78	3311,59	12,68	70,00	3150	161,59	1,6%
12	15,49	13010,02	9757,51	3252,50	12,91	70,00	3150	102,50	1,5%

13	15,22	12785,18	9588,89	3196,30	13,14	70,00	3150	46,30	1,5%
14	14,97	12571,32	9428,49	3142,83	13,36	70,00	3150	-7,17	1,5%
15	14,72	12367,88	9275,91	3091,97	13,58	70,00	3150	-58,03	1,5%

The task of the regulator is to determine the quota at which social welfare will remain positive. In table 3 the quota size will be 1.5%. With a given quota size, the number of periods for granting a license on the sand extraction should be no more than 14 periods (months). The dynamics of social welfare is demonstrated in fig. 4, where during transition from 14 to 15 periods (initial first period is indicated as «0»), the increase in social welfare modifies from positive to negative meaning.

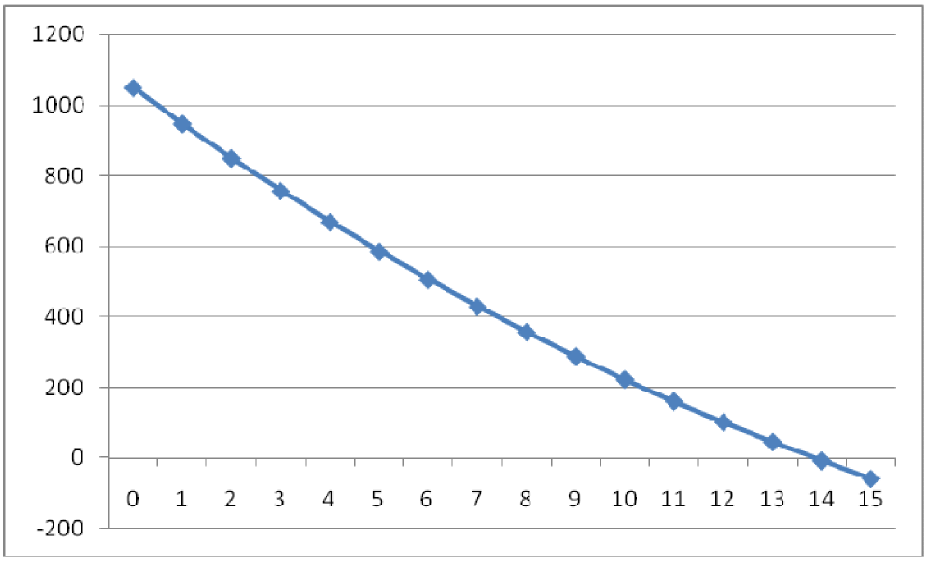

Fig. 4. Dynamics of social welfare due to sand extraction from water body (horizontal axis is time period in months, vertical axis is social welfare in monetary units)

5 Conclusions and Outlook

Instream mining can be conducted without creating adverse environmental impacts provided that the mining activities are kept within the limited optimal volume of sand mining set by the local authorities.

An example of mathematical model for determining of ecological equilibrium during sand extracting in the ecosystem is developed using Google Maps. The influence of economic activity due to sand extraction on fish fauna is described. The GIS based ecological-economic model is developed on the logistic model basis for establishing regional quotas for extraction of natural resources during economic activity in the southern Ukraine. Regulatory economic mechanism of natural environment is proposed. It implies such quota for sand extraction from water body, which does not lead to deterioration of the quality of the natural environment and stimulates the increase in social welfare.

We demonstrated that for chosen quota size, the number of periods for granting a license for the sand extraction should be no more than 14 periods (months) for our experiment in the Kherson region (Ukraine) using real data. The data of such works is extremely necessary for establishing regional quotas for extraction of natural resources in solving economic issues of southern Ukraine. This dynamic approach gives possibility to expand these results for local and national authority to determine quota size which saves exhaustible natural resources and increases social welfare for all participants using GIS based technologies.

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