GIS IMPLEMENTATION FOR STUDYING NATURE DISASTER RISK IN ARDA RIVER BASIN, BULGARIA

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Applying the system and spatial approach in studying diverse aspects of nature disaster risk occurrence in Arda River Basin, Bulgaria, makes possible researching risk within its triggering sources, interactions and impacts on Social, Eco and Geosystem. Implementation of the Interpretive Structuring Method analysis techniques provides for recognizing the social, ecological and geosystem, finding out the relationships between elements of the 3 systems, categorizing and ordering elements. Revealing spatial aspects of nature disaster risk by GIS enables to map it and determine the extent of risk exposure by processing and analyzing various types of spatial and attributive geo-information.

Key Words: *system approach, spatial approach, nature disaster risk, Interpretive Structuring Method analysis, GIS*

1. INTRODUCTION

In late years, there is ever-wider implementation of GIS methods and techniques in all spheres of life where space and processes are involved. GIS always are sticking to events, activities and matters that take place in the space, and thus render them spatial appearance[1)].

The GIS constitutes of several other subsystems – the data input subsystem; the data storage and retrieval subsystem; the data manipulation and analysis subsystem and the reporting subsystem[2)].

GIS involves sophisticated operations and manipulations on data, which should be performed sequentially in order to obtain final results for the needed purpose - the data collection from various sources that are further to be input in digital format[3)].

The process of collection and pre-processing initial data is followed by their organization and storage. The successful combination of spatial data and data concerning diverse features of spatial objects renders the latter poly-dimensional functions. GIS provides tools not only for storing and spatial and attributive information, but also for analyzing, mapping etc.[4)].

Implementing GIS in broader spheres of science, technology and practice, makes "constructed inside a framework of institutional, social and cultural relationships… There is nothing magic about an information system that will resolve deep social, political and cultural differences."[5)].

Application of GIS when analyzing spatial dimensions of disaster risk events makes it possible to reveal in a better way the intensity, spatial scope and susceptivity to risk occurrence. Considering that, current research aims at finding the mutual relationships between components of social, ecological and geosystem by Interpretive

Structuring Method (ISM) in order to expose the interactions between separate elements and how disaster risk impacts society and economy. The study has also set the purpose to interpret the territorial scope of those social and economic developments that have a relation to nature disaster risk occurrence in Arda River Basin by implementation of GIS. The area of research has been selected because of its high prone to nature disaster risk events and frequent occurrence of the latter - floods, soil erosion and heavy metal pollution in particular. These impose a significant threat for daily life of people and economic activity. Economic decline and depopulation of Arda River Basin in the last 15 years of economic transition have brought significant deterioration of living standard and may also be considered as a risk for local people.

Since the dawn of mankind history, risk has always played a significant role in individual, in social life and in civilization. Contemporary society perceives and considers risk as a distinct trait of life. Risk has, however, various spatial and temporal aspects. From the point of view of GIS application when researching spatial aspects of risk, the system and the spatial-temporal approach are basic ones.

System approach to be applied is intended for the purposes of understanding the essence of the systems and their interactions with other systems; advancing the management and decision by better understanding systems; and determining all risks, hazards and uncertainties input in the system, and the variability of decision-making[6].

The spatial-temporal approach refers to combination of GIS with nature disaster risk events. The latter take place in the space and have a dynamical appearance over the time. That circumstance enables to explore nature disaster risk as any other geographic event that is bound with place, time and attributes[1].

Therefore, the aspect of regarding nature disaster risk occurrence as a geographical, time-space related phenomenon and its specificity in Arda River Basin requires applying of several GIS-related techniques – spatial analysis, overlay, geo-processing, and some mathematic operations. Spatial analysis enables to define varied surface and volume characteristics of nature disaster risk, to locate spatial objects related to the latter and to characterize the attributive features of it[2].

The overlay method is sophisticated technique for combining and fusion of different map layers where same or different spatial objects with their attributive characteristics are blended in one composite layer[3]. For the purpose of current study, both vector and raster data overlay analysis has been applied.

Geo-processing is a technique to create new data based on layers in of various layers. In most cases, the geometric properties of the features in a dataset are altered while controlling some aspects of how its attribute data is handled[7]. With the assistance of Arc View Geo Processing tool, data of different layers have been performed an intersection or unifying of 2 input layers so that the output one have the attributes of the either input themes.

2. CHARACTERISTICS OF ARDA RIVER BASIN WITH RESPECT TO NATURE DISASTER RISK

Target area comprises the Arda River Basin on Bulgarian territory with a surface of about 5200 km^2. It is located at the south rim of Bulgaria and

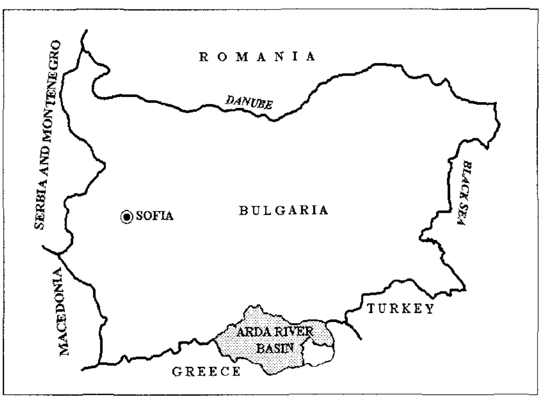

Fig. 1. Map of Bulgaria and Location of Arda River Basin (data applied from[8]).

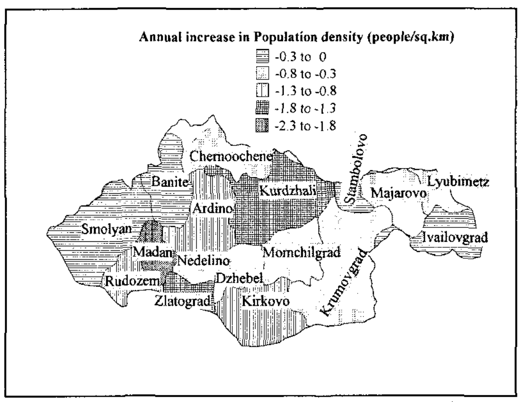

Fig. 2. Annual increase in population density for Arda River Basin (data applied from[8]).

includes territories of the Central and East Rhodopes (**Fig. 1**). This surface has a well-elevated mountainous relief (the highest peaks in the west reach about 1800-2000 m of elevation) except for the eastern part. Volcanic rocks predominately constitute the geologic background of the mountain. Climatic conditions are varied, depending on the elevation and slope exposition.

The water resources are irregularly distributed over the time. The river runoff marks extremely high values in winter, since summer shows to be a fairly dry period. Soils are very shallow, only 15-20 cm in depth, and extremely susceptible to erosion and disturbance of structure. Vegetation is varied but impacted to a high extent by the intensive human activity.

It's evident that in the target area nature has been for long time affected by hazard and risk disasters and therefore is highly susceptible to that influence. The human activity, and especially the mining industry, has significantly contributed to deterioration of environmental conditions polluting nature with heavy metals; also making excavations and taking off the soil layer that causes development of erosion.

Population status has been characterized by 2 parameters, which has been developed an overlay analysis. The first one is the population increase that reveals people's dynamics as a gross outcome of migrations and differences between birth and dead rate. It shows trends towards certain diminishment or growing the number of people that is simultaneously affected and affecting the economical processes. The population density is an indicator of social and economic potential of a given area. These 2 indices are quantitative, and the overlay has been performed by simple multiplying the values of 2 layers (**Fig. 2**). Highest decrease in that respect do not show to have municipalities where population decrease rate is high but those with higher population density like Kurdzhali and Zlatograd, since Ivailovgrad and Krumovgrad that are much suffering a population decrease prove to have the lowest rates. The process shows that dynamics in population density state is more evident, takes place in populated areas and it runs regardless of their value for population increase/decrease.

3. SYSTEM ANALYSIS PERFORMED BY ISM METHOD

System approach requires that all the elements, processes and phenomena related to nature disaster risk occurrence are set in a system in a way that their mutual relationships and way of ordering is exhibited and clearly to be explained.

In a previous research, the ISM method has been applied[9] to identify the most important components of social, eco and geosystem and their dependencies. In order to be correctly performed, the data needed have to be collected, proceed and analyzed on several stages.

1.The total number of components involved in social, ecological and geosystem is to be fixed. In that way, 15 elements have been derived and presented in the matrix below.

2.Next stage of work involves setting the elements into a matrix and assigning them binary values (either 0 or 1), depending on if there is any relationship between them.

3.The final stage involves setting up of a graph model based on the matrix above. It depicts the order of elements from input to output level, and their cause-effect relationships exhibited by a single-direction arrow. Deriving model form the

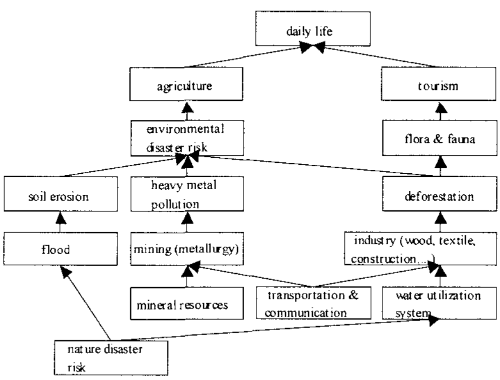

Fig. 3. ISM graph developed for recognition of systems elements and their relationships.

Table 1. Classification of the system components according to the system they belong.

Social System	Ecosystem	Geosystem
Industry (wood, textile, construction...)	Deforestation	Nature disaster risk
Soil erosion	Flora & fauna	Mineral resources
Heavy metal pollution	Environmental disaster risk	
Water utilization system		
Daily life		
Tourism		
Agriculture		
Transportation & communication		
Flood		
Mining (metallurgy)		

above matrix is performed by sophisticated rearrangements of the data in various matrices so that finally the systems elements are ordered according to their significance in cause-effect relationships.

By implementation of ISM, the graph of interactions between elements is created. It represents in a synthesized appearance the consecutivity of interactions between systems components and their ordering that depends on which event comes first and triggers the occurrence of other processes.

In the case of ISM analysis, the graph developed for the purpose of studying Arda River Basin, Bulgaria, consists of 15 components (**Table 1**) selected and ordered on 7 levels.

ISM graph (**Fig. 3**) provides the following ordering of elements and relationships:

On the 1st level, nature disaster risk is the most important input element, influences water utilization system through incurring damages to it and also triggers floods. On the 2nd level, transport and communication influences industry (transferring goods) and mining and metallurgy (carrying raw materials and products). The mineral resources provide raw materials for mining and metallurgy. And water utilization system has an input to the industry and household, delivering them water. At the 3rd level, industry causes deforestation, as logging is needed for timber material and combustibles in household; floods trigger soil erosion – the intense water flow of torrents and rivers causes washing-off the soil particles. Mining and metallurgy emits heavy metals through the wastewaters and affects heavy metal pollution. At the 4th level, deforestation has a strong impact to flora and fauna – reduces the stability and biodiversity; on the other hand, combined negative action and influence of deforestation, soil erosion and heavy metal pollution forms the environmental disaster risk. At the 5th level, environmental disaster risk negatively influences agriculture, making inferior its abilities to produce food. And flora and fauna are attractive that is main precondition for developing tourism. Tourism and agriculture (6th level) secure most of the incomes of the local people and appear to have the strongest input on daily life. Thus, the output of the system appears to be daily life that determines the wealth, quality of life and problems of the people and potential conflicts that may evolve.

3 chains of mutually dependent elements are formed: 1st starts from nature disaster risk and reveals its consequences which appear to be primarily over the agriculture; the 2nd chain depicts the effect of mining and metallurgy also concentrated over agriculture and the 3rd chain starts from industry and shows its negative impact that finally affects the tourism. Application of this graph as a final product of ISM analysis not only visualizes the interactions of components and their behavior, but also provides valuable insight of how to approach and what method to apply when studying the system related to disaster risk.

Spatial aspects of nature disaster risk occurrence, however, require that these components must be exhibited and analyzed further with the assistance of GIS. Thus, for each component a separate GIS-model has been created to reveal the spatial features, and the quantitative and qualitative attributes of it. Investigation of nature disaster risk origin and impact imposes to perform an overlay analysis on

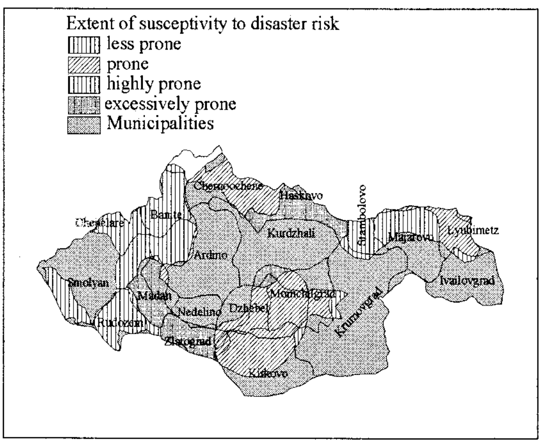

Fig. 4. Extent of Prone to Nature Disaster Risk in Arda River Basin (data applied from[8]).

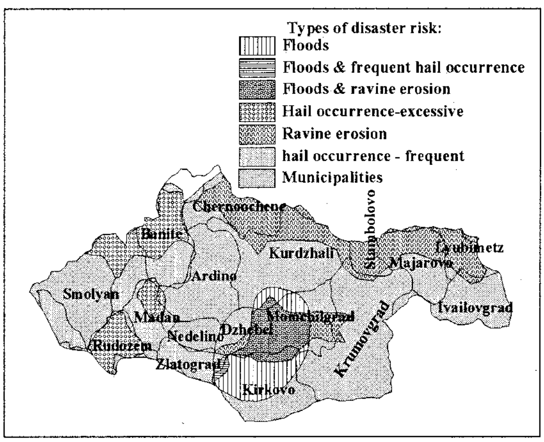

Fig. 5. Type of Nature Disaster Risk in Arda River Basin (data applied from[8]).

several data so that new composite layers have been created. These reflect sophisticated interactions between processes that are likely to trigger disaster risk events like floods, soil erosion and heavy metal pollution.

4. OVERLAY MAPS

Overlay analysis has revealed its significance in analyzing the dependencies between components. Analysis of nature disaster risk has proven that by mean of quantitative data combination, composite general indices can be derived and integrated assessment of interactions obtained.

Maps of nature hazards consist of qualitative data about the hazard type. In addition, the map of population density consisting of quantitative data has been overlaid. In that way, the exposure of population is revealed towards nature disaster risk occurrence. Usually, densely populated areas are much more exposed to risk than the population living in wider space. The input maps consist of layer about population density (people per sq km), data being represented for each municipality, and a layer about the spatial dimensions of nature disaster risk (areas affected by soil erosion, hail occurrence, and floods). Overlay has been performed on Geo-processing tool of Arc View program. The function union has been selected so that the output composite layer contains full data in its attributive table about both input layers. The output is presented in 2 patterns – the first one shows the extent the population is susceptive to nature disaster. 4 grades of prone in compliance with the 4 groups of population density have been derived. Thus, excessively prone are territories in densely populated municipalities of Kurdzhali, Madan and Zlatograd, since the extent of prone for the thinly inhabited Majarovo, Kurmovgrad and Banite municipalities is low (**Fig. 4**). The other aspect of presenting output results is to exhibit the type of disaster risk. These data are qualitative and represent the type of disaster risk. In that way, 7 categories of peril events have been derived. Some areas are evident where even more than 1 disaster risk event takes place – in the municipalities of Momchilgrad, Kirkovo and Dzhebel. Such areas of combined hazards impose a high jeopardy for the local population; therefore it's necessary to determine the extent of occurrence. (**Fig. 5**).

Another map is to exhibit how the spatial allocation of mineral resources triggers river pollution and depicts cause-effect relationships of the 2nd chain on ISM graph. The overlay has been developed by combining the maps of mineral resources and river sectors polluted by heavy metals. Usually, mining and metal-extraction plants are located close to the beds of mineral resources so that pollution sources almost coincide with mineral resources beds (**Fig. 6**).

Contamination descends mainly from mining, metallurgy and, to a smaller extent, from other branches of industry, and the main sources of pollution are located in the larger industrial cities as well as nearby the mines and ore-processing plants – Madan, Rudozem and Zlatograd. In rural areas, sources of contamination emissions are the household sewage waters. Two degrees of river water pollution have been fixed – of slight and strong pollution. Extraction of great volumes of mineral resources especially in the past 3-4 decades

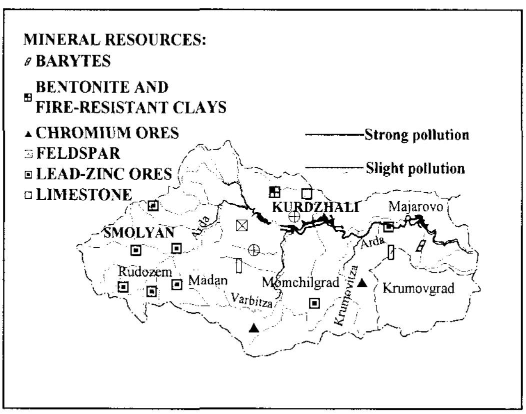

Fig.6. Mineral Resources and Heavy Metal Pollution in Arda River Basin (data applied from[8]).

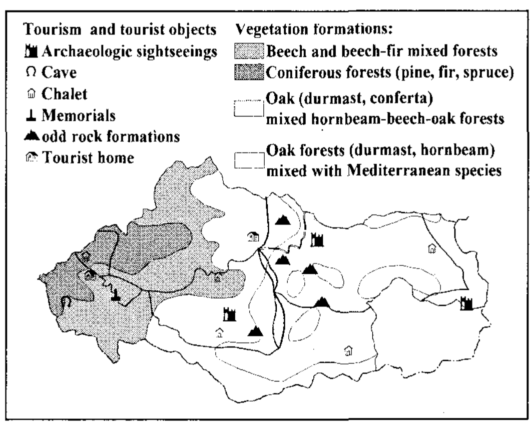

Fig. 7. Transport network, vegetation types and tourist objects in Arda River basin (data applied from[8]).

has lead to severe damages caused to ecosystems, and to deterioration of both rural and urban social environment.

Relationships existing on the 3rd chain of ISM graph have been drawn by performing a composite overlay of 3 input maps – tourist objects, transport network and vegetation formations. The complex output layer derived shows how the tourist objects are connected with roads and communications, on the one hand, and how vegetation types impact tourism (**Fig. 7**). Most of the tourist objects are concentrated in the West Rhodopes, where forests are distinguished by a great biodiversity. East Rhodopes, on the opposite, have more uniform vegetation with less species variety; however more man-made attractions are located there. Arda river basin has a multitude of nature resources for tourist development. Overnight opportunities are steadily increasing and improving. Transportation network is thinly scattered, as high mountain relief of West Rhodopes obstacles communications. River valleys here are deep, slopes very tilted, and only automobile ways haven been established. These are mainly second-category roads running down the valleys and on the slopes, often very narrow and not in a good state. Their maintenance is very expensive as well because of the harsh climatic conditions and the rapid occurrence of nature disaster risk as torrents and other escarpment processes. Vegetation is one significant premise for tourist attraction and that is one more reason for preservation of original species here. Arda river basin vegetation resources are a vulnerable system that is needed to be conserved and sustained for the future generations and local needs. As it is hardly impacted, by human activity (mining and metallurgy) and increasing necessity of timber (especially in the last years for combustibles and timber industry) though on isolated spots, the restoration of natural flora state must be set into execution.

5. CONCLUSIONS AND SUMMARY OF THE RESEARCH

1. Implementation of GIS as a tool for studying disaster risk occurrence with regard to its spatial evidence contributes to in-depth exploring the spatial distribution of risk.
2. The overlay analysis also exhibits some important peculiarities of disaster risk prone – endangered are to a high extent densely populated areas than those where population isn't so much.
3. Overlaying single-layer maps provides for developing of composite-layer maps that further can be used for purposes of assessing the social, economic potential etc.
4. Combining ISM analysis with further implementation of GIS makes it easier to investigate the aspects of risk evidence.

GIS application in nature disaster risk research exposes the territorial occurrence of risk phenomena and elucidates the spatial distribution of risk. And studying risk in terms of space, moreover, is a better way to refer to the origins of disaster, the way it runs and inflicts damages to infrastructure and society.

6. OUTLINE OF FUTURE RESEARCH ACTIVITIES

Area distribution of nature disaster risk provides valuable insights of further application of quantitative mathematic analyses. GIS provides useful means for spatial processing of varied numerical data in combination with else qualitative characteristics. Spatial analysis can also be linked to some temporal trends, which can be easily derived by data series analysis so that changes in spatial occurrence, are evident and forecasting possible. Successful combination of GIS with varied mathematical methods will reveal the best way of applying the hierarchical systems approach in nature disaster risk research.

REFERENCES

1) Longley et al. Geographic Information Systems and Science. John Wiley & Sons Publ. House, NY, p. p. 2,6, 64-65, 2001.

2) Demers, M. Fundamentals of Geographic Information Systems, 2nd Edition, John Wiley & Sons Publ. House, NY, p. p. 9, 190-192, 2000.

3) Bernhardsen, T., Geographic Information Systems. An Introduction. 2nd Edition, John Wiley & Sons Publ. House, NY, p. 151, 1999.

4) Lillesand, T., R. Kiefer. Remote Sensing and Image Interpretation, p. 38, 2000.

5) Chrisman, N., Exploring Geographic Information Systems. John Wiley & Sons Publ. House, NY, p. p. 109-117, 255-256, 1997.

6) Haimes, Y. Risk Modeling, Assessment and Management, John Wiley&Sons Publisher, p. p. 22, 93, 1998.

7) Arc View GIS 3.2. Environmental Systems Research Institute, Inc., Tutorial, 1992-1999.

8) Geographical Atlas of Bulgaria. Kartografia Publ. House, Sofia, p. p. 5, 9, 14, 16, 34, 52, 54; 2004.

9) Hagihara, Y, Hatayama, M, Sakamoto, M, Mitev, J: Environmental Disaster Risks Identification in Arda River Basin, Bulgaria, Disaster Prevention Research Institute Annuals, Vol. 48, 2005 (Under print).