DOI: https://doi.org/10.66118/MMP.2025.084

INFRASTRUCTURE PROJECTS: ASSESSMENT OF ANTHROPOGENIC IMPACT ON RIVER ECOSYSTEMS

Danshyna S., Podorozhko K.

The aim of the study is to improve the accuracy of assessing anthropogenic impacts on rivers by developing an integrated approach that combines functional modeling and satellite monitoring. The methodological foundations for assessing anthropogenic pressure on river ecosystems within infrastructure projects are considered. Using the IDEF0 methodology, a functional model of the assessment process is proposed, which structures the sequence of actions, input and output data for monitoring and analyzing anthropogenic impacts on rivers. Particular attention is paid to the processing of data on anthropogenic factors, in particular hydrological, morphological, and Earth remote sensing data.

Introduction

Infrastructure projects (e.g., construction of water supply, sewage, transport, and energy facilities, residential and social buildings, etc.) which implement strategic efforts to achieve social, economic, and environmental sustainability goals aimed at solving long-term problems, become a means of creating and realizing values with long-term consequences for the environment and society. Such projects are expensive, controversial, and complex to manage, requiring mandatory assessment of their impact on natural resources, ecosystem services, and social services to prevent overspending, social conflicts, and reputational losses, ensuring project sustainability [1, 2]. Therefore, a comprehensive approach to assessing the environmental impact of infrastructure projects is needed, combining traditional assessments of cost, time, and quality [1].

Intensive infrastructure development – transport, energy, water supply, housing construction – is increasingly affecting the state of water ecosystems, particularly rivers, which are sensitive to anthropogenic changes. The construction of facilities within river basins is accompanied by [3]:

1. Changes in riverbed processes, as construction affects water flow velocity, sediment transport, and riverbed erosion, which in turn leads to a decrease in the regenerative capacity of riverbeds.

2. Pollution of rivers, as the discharge of industrial waste, agricultural chemicals, and urban wastewater significantly deteriorates water quality. Water pollution with heavy metals, pesticides, and nitrates leads to the degradation of ecosystems and the deterioration of living conditions for many aquatic species.

3. Changes in the hydrological regime, in particular due to agricultural land reclamation, the use of water resources for industrial needs, and the straightening of river channels.

In this regard, there is a growing need for reliable tools that allow for a scientifically sound assessment of the impact of infrastructure projects on the aquatic environment at the planning and decision-making stages [4].

Functional model of the assessment process for anthropogenic impact on rivers

When developing infrastructure projects, it has become common practice to consider the various consequences of decisions, which are characterized not only by direct profits but also by non-monetary aspects. In particular, environmental, health, and safety issues are receiving increasing attention to prevent both short-term and long-term damage [5]. The anthropogenic impact on rivers is a multifaceted problem, the theoretical, methodological, and methodological aspects of which are addressed in scientific works by geographers, hydrochemists, hydromeliorators, and ecologists Vyshnevsky P.F., Kirilyuk O.V., Levkivsky S.S., Likho O.A., Myskovets I.Ya., Morokova V.V., Rybalova O.V., Solovey T.V., Tymchenko Z.V., Khilchevsky V.K., Tsvetova O.V., Yasenchuk T.O., Yatsyk A.V., and others. Various methods have been developed that can be used to identify weaknesses in infrastructure projects that require technical measures or to compare different options for prioritizing resource investments. However, their scope of application varies between methods. For example, infrastructure project risk assessment focuses on random problems that may arise in river systems, while life cycle assessment (LCA) identifies long-term and sustainable impacts on river basins. Ideally, several assessment methods should be used to take into account the impact on different areas when making decisions [1, 5]. However, in practice, project managers face difficulties:

– when collecting the necessary data for the implementation of non-traditional approaches to project assessment, such as LCA;

– when combining assessment results obtained using different methods during decision-making;

– when systematizing tools, data, and measures at different stages of the project life cycle.

Therefore, scientists increasingly turn to Earth remote sensing (ERS) methods in the study and assessment of anthropogenic impacts of infrastructure projects. For example, the use of satellite data and aerial photography allows assessing the scale and dynamics of changes in river systems under the influence of human activity. In scientific publications on this topic, ERS data are used for [2–4]:

1. Monitoring changes in river channels using multi-year series of satellite images, which allows identifying changes within the channel, displacement of channel forms, and changes in coastlines.

2. Assessing the impact of the construction of hydraulic structures (dams, weirs, canals), when ERS data make it possible to clearly track the effects of sediment retention upstream, bank erosion in the lower reaches of rivers, and artificial changes in the hydrodynamics of river systems, as well as to identify the consequences of flooding or erosion of banks, etc.

3. Determination of changes in river systems and degradation of natural river landscapes due to agricultural development, changes in drainage, and/or land reclamation. Here, satellite images are used to track changes in the area of irrigated land, the expansion of agricultural land, the drainage of coastal areas, and the increase in water abstraction from rivers.

4. Investigation of erosion processes and sedimentation over large areas, where high-resolution images are used to analyze coastal erosion, identify areas most susceptible to sedimentation processes, track changes in channel dynamics, etc.

The combination of modern geographic information systems (GIS) and ERS data creates new approaches for assessing the impact of infrastructure projects on the aquatic environment. However, in practice, there is often no comprehensive solution that would allow not only to record changes, but also to proactively mitigate the effects of impact, taking into account spatial, temporal, and regulatory parameters. That is why, at the planning, assessment, and implementation stages of an infrastructure project, it is important to have a tool that allows [4]:

– model scenarios of impact on the aquatic environment,

– assess the level of risk from human activities,

– visualize the spatial location of critical areas (pollution, riverbed degradation, etc.),

– make management decisions based on data rather than intuition or «average estimates».

In recent years, such decision support systems have become increasingly important. This trend will continue in the future, but most likely on a much larger scale. Although until recently the focus was on individual software tools and services, their integration into engineering workflows is becoming a new and complex area of research and development [6], requiring a systematic approach that takes into account the interrelationships between natural, technical, social, and managerial components.

The key point here is to accurately define the necessary data and information, tools, and modeling mechanisms at different stages of evaluation and to present the entire process in the form of a business model.

An effective tool for developing a decision support system is the IDEF0 functional modeling methodology. It presents the system as a business model of comprehensive information analysis [5–7], which is commonly used in several infrastructure project evaluation methods, with a particular focus on the environmental assessment of its life cycle and the assessment of risks during project implementation (Fig. 1).

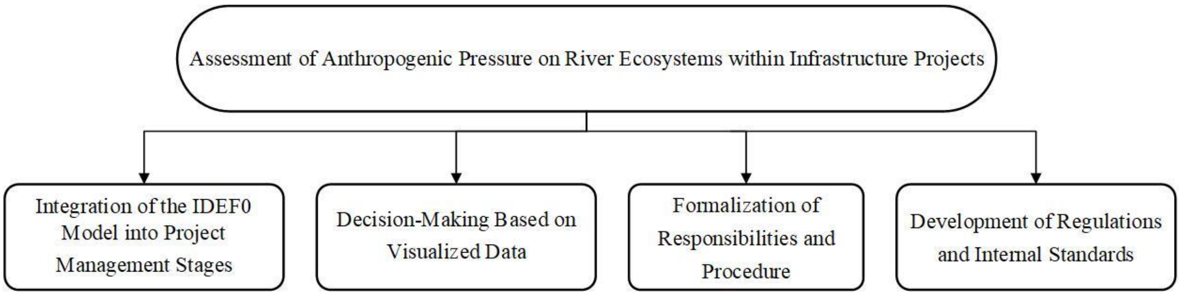

Fig. 1. Stages of assessment of the anthropogenic impact on river ecosystems within infrastructure projects

Thus, in the functional model, environmental, health, and safety aspects are considered as new project evaluation criteria alongside traditional economic and technical indicators. This approach allows linking the logic of environmental monitoring processes with project implementation processes, visualizing information and functional links between decision-making stages, and identifying points of influence where environmental risks can be minimized [7].

Fig. 2 shows the IDEF0 model of the process of assessing the anthropogenic impact of infrastructure projects on rivers. In accordance with the provisions of the functional modeling methodology, this model defines the structure of information technology for assessing the anthropogenic impact on the state of rivers. It provides a systematic and transparent description of the project assessment stages, when the manager must take into account various types of requirements for the conservation of water and biological resources and the maintenance of the ecological status of river ecosystems, the availability of relevant design constraints and resources at different stages of design, etc.

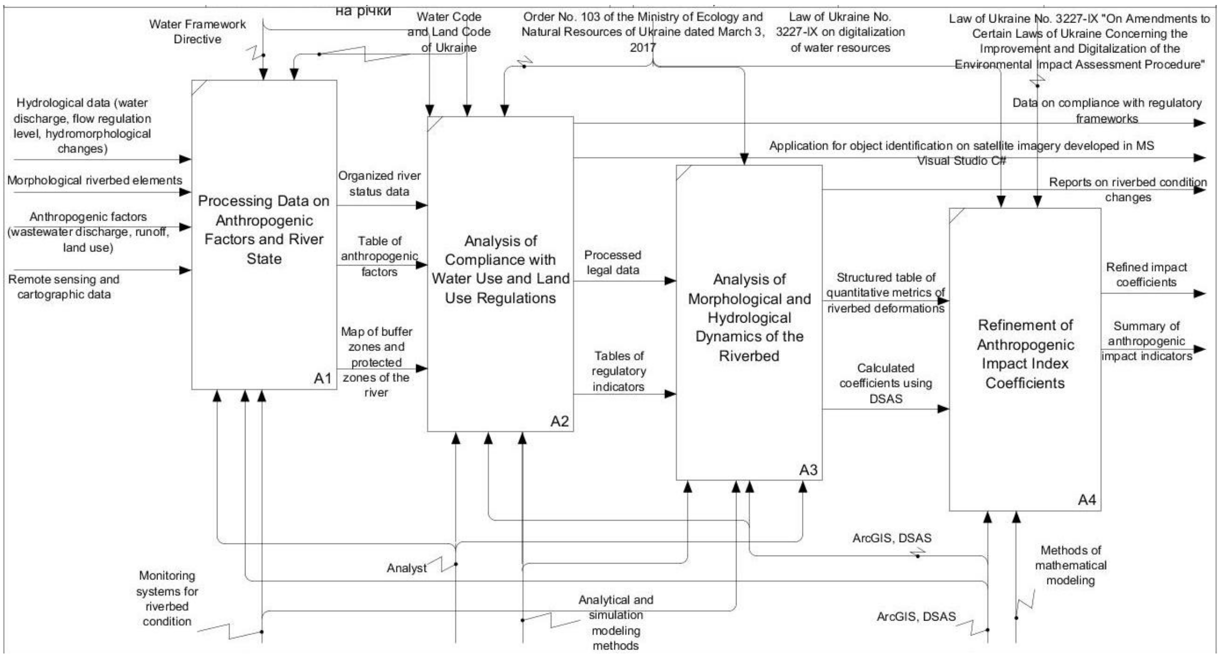

Fig. 2. IDEF0 model as a structure of information technology for assessment of anthropogenic impact on river ecosystems within infrastructure projects

The proposed IDEF0 model visualizes the procedure for obtaining assessments of anthropogenic impact on rivers, taking into account various aspects of data acquisition at the stages of the infrastructure project life cycle (Table 1). It provides an understanding of the characteristics and volumes of data required for the formation of assessments [6, 8] and enables the creation of regulations and internal project standards. For example, based on the IDEF0 model, it is possible to develop:

– regulations for environmental support of the project (when and which process blocks are involved at the stage of assessment formation);

– checklists for project managers (what data is needed to obtain assessments, when they should be analyzed);

– algorithms for decision-making and developing alternatives (for example, in cases of exceeding the impact level).

Such a system contributes to increasing the transparency of decisions, timely identification of environmental risks, and optimization of control procedures. Thanks to its integration into the planning, implementation, and monitoring stages, the IDEF0 model helps reduce uncertainty in management decision-making, which in turn improves project management efficiency and reduces the anthropogenic load on river ecosystems [7, 8].

Table 1

Using the IDEF0 model in project management stages

Project life cycle stage	Use of the IDEF0 model
Initiation	– provision of basic environmental data on the river basin area; – risk analysis at the site selection stage.
Planning	– modeling of the impact of alternative project solutions; – development of environmental protocols.
Implementation	– assessment of the actual impact on the river ecosystem; – monitoring of project deviations; – development of corrective measures.
Completion	– generation of a final project report; – assessment of the residual load on river ecosystems; – recommendations for the future.

In the changing conditions of infrastructure project implementation, uncertainty in the distribution of functions among project participants, the absence of clearly defined procedures for action in critical environmental situations, and insufficient integration between technical and environmental solutions can lead to irreversible damage to water ecosystems. Formalization based on the proposed IDEF0 model allows establishing transparent links between functional management blocks and specific performers, regulatory constraints, and documentation. This ensures not only the effectiveness of management decisions but also their compliance with environmental legislation and international standards [8, 9]. In conditions of environmental instability and growing demands for sustainable development, effective management of environmental projects requires a clear understanding of who makes decisions, when, and on the basis of what data [9, 10]. Each block of the IDEF0 model can be linked to specific departments of organizations or institutions (State Water Agency, design institutes, environmental departments, etc.), documents (technical specifications, water body passport, etc.), regulatory restrictions (water protection zones, maximum permissible concentrations, etc.).

The IDEF0 model also provides elements for visualizing the obtained assessments using GIS tools. Traditional approaches based solely on text documents are insufficient in complex interdisciplinary tasks where spatial, temporal, and risk-oriented indicators must be taken into account [8–10]. Visualization of data through GIS maps, dynamic forecasting models, or analytical dashboards makes it possible to increase the transparency and soundness of decisions, simplify communication between participants, and minimize the influence of the human factor.

Thus, the proposed IDEF0 model can be viewed as an «interaction architecture» between data, processes, and decisions. Its use allows environmental issues to be integrated into the actual process of infrastructure project management –

from analytics to practical environmental risk management in the context of anthropogenic pressure on rivers.

Processing data on anthropogenic impact factors on the state of river ecosystems

According to Fig. 2, at the first stage of assessing anthropogenic impact, data of various types relating to the state of rivers should be processed. This stage is based on the integration of information from various information resources, among which hydrological, morphological indicators, and cartographic data play a key role.

Hydrological indicators include [11]: water consumption, the level of flow regulation, and changes in the hydromorphological state of the riverbed. Morphological data characterize the configuration and structural parameters of riverbed forms and allow the identification of areas of intense erosion or sediment accumulation [12, 13]. Anthropogenic factors of human activity, such as the degree of coastal land cultivation, urbanization, and military operations, are considered separately [14].

An important source of information is Earth remote sensing (ERS) data obtained from high-resolution satellite images and aerial photography. The use of multispectral images, in particular those obtained from Landsat satellites (Table 2) and radar images, makes it possible to detect changes in the water surface, determine the degree of siltation and fragmentation of aquatic ecosystems, and perform automated classification of objects using GIS, in particular

ArcGIS and specialized processing software (in particular, using algorithms in MS Visual Studio C#) [11, 12, 14].

At the processing stage, the input ERS data undergoes preliminary cleaning, georeferencing, and integration into a single information and analytical database [10, 11].

The results obtained are used to construct buffer zones for hydrological stations, form tables of hydrological observations, and create maps of the spatial distribution of anthropogenic loads. This enables further analysis in the subsequent stages of assessment – verification of compliance with regulatory requirements, modeling of riverbed morphodynamics, and refinement of anthropogenic impact indices [14].

Table 2

Information about Landsat 8, 7, 5 satellite channels [10, 11]

Description of channel ranges	Landsat 8		Landsat 7		Landsat 5	
	Channel number	Wavelength, μm	Channel number	Wavelength, μm	Channel number	Wavelength, μm
Ultraviolet (UV)	1	0,433 –0,453	–	–	–	–
Blue	2	0,450 – 0,515	1	0,450 – 0,515	1	0,450 – 0,515
Green	3	0,525 – 0,600	2	0,525 – 0,605	2	0,525 – 0,605
Red	4	0,630 – 0,680	3	0,630 – 0,690	3	0,630 – 0,690
Near IR (NIR)	5	0,845 – 0,885	4	0,750 – 0,900	4	0,750 – 0,900
Shortwave IR 2 (SWIR 2)	6	1,560 – 1,660	5	1,550 – 1,750	5	1,550 – 1,750
Shortwave IR 3 (SWIR 3)	7	2,100 – 2,300	7	2,090 – 2,350	7	2,090 – 2,350
Panchromatic (PAN)	8	0,500 – 0,680	8	0,520 – 0,900	–	–
Shortwave IR (SWIR)	9	1,360 – 1,390	–	–	–	–
Far IR (FIR 1)	10	10,30 – 11,30	6-1	10,30 – 11,30	6	10,40 – 12,5
Far IR 2 (FIR 2)	11	11,50 – 12,50	6-2	10,30 – 11,30	–	–

Thus, the use of spatial analysis methods and ERS data at the early stages of an infrastructure project's life cycle ensures a more informed assessment of the environmental status of river systems, which in turn improves planning quality, minimizes risks, and optimizes management decisions. This approach contributes to more effective project implementation and enables the achievement of sustainable development goals in the field of water ecosystems.

Conclusions

To improve the accuracy of assessing anthropogenic impacts on river ecosystems within infrastructure projects, a functional model of the process has been developed that combines system modeling using the IDEF0 methodology and modern Earth remote sensing data processing tools. The functional model clearly structures the assessment process, defining the relationships between input data, analysis tools, and expected results.

The proposed approach involves the integration of various types of data, including hydrological, morphological, and cartographic data with multispectral satellite images, ensuring improved spatial and temporal accuracy and relevance of assessments. The use of GIS and specialized software allows automating the detection of changes in riverbed conditions, assessing the degree of anthropogenic load, and timely identifying critical areas.

The practical significance of the results obtained lies in the possibility of applying the developed model to improve water resource management, plan environmental protection measures, and minimize the negative impacts of infrastructure projects on river ecosystems. There is potential for scaling up to other basin systems and integration into national and international environmental monitoring systems. Issues of environmental support for infrastructure projects, the development of regulatory and methodological documents, and the formation of effective environmental policy in the water sector are being addressed.

The work was carried out with the support of the Ministry of Education and Science of Ukraine (state registration numbers of projects 0125U000573, 0125U001680).

Reference

1. Danshyna S., Podorozhko K. Spatial assessment of infrastructure projects. *Decision Support Systems in Project and Program Management* : collective monograph / ed. by I. Linde. Riga : European University Press, ISMA University of Applied Sciences, 2024. P. 41 – 52. DOI: 10.30837/MMP.2024.041
2. Impacts of Infrastructure Developments on Ecosystem Services / E. Y. Menteşe, T. Kaya, A. Erol, M. F. Türker. *Frontiers in Environmental Science*. 2021. Vol. 9. Article 614752. DOI: 10.3389/fenvs.2021.614752
3. Assessing anthropogenic impacts on reverie ecosystems using PLS regression and GIS: A case study in the Ave River basin (Portugal) / A. R. L. Ferreira, J. P. Nunes, N. Abrantes, F. Gonçalves. *Science of the Total Environment*. 2017. Vol. 579. P. 1094 – 1104. DOI: 10.1016/j.scitotenv.2016.11.144
4. Rousseau A. N., Mailhot A., Turcotte R. Integration of hydrological modelling and GIS for watershed management. *Journal of Hydrologic Engineering*. 2000. Vol. 5, issue 2. P. 174 – 182. DOI: 10.1061/(ASCE)1084-0699(2000)5:2(174)
5. Analysis and Modeling of Information Required for Process Assessment on Environment, Health, and Safety by IDEF0 and UML / Y. Kikuchi et al. *Computer Aided Chemical Engineering*. 2012. Vol. 31. P. 1392 – 1396. DOI: 10.1016/B978-0-444-59506-5.50109-7
6. Schneider R. A., Marquardt W. Information technology support in the chemical process design life cycle. *Chemical Engineering Science*. 2002. Vol. 57, issue 10. P. 1763 – 1792. DOI: 10.1016/S0009-2509(02)00075-1
7. IDEF0 activity modeling for integrated process design considering environmental, health and safety (EHS) aspects / M. Hirao, H. Sugiyama, U. Fischer, K. Hungerbühler. *Computer Aided Chemical Engineering*. 2008. Vol. 25. P. 1065 – 1070. DOI: 10.1016/S1570-7946(08)80184-8

8. Too E. G., Weaver P. The management of project management: A conceptual framework for project governance. *International Journal of Project Management*. 2014. Vol. 32, issue 8. P. 1382 – 1394. DOI: 10.1016/j.ijproman.2013.07.006
9. Project Management Institute. *A Guide to the Project Management Body of Knowledge (PMBOK® Guide).* Project Management Institute, Inc., 2021. 478 p.
10. Kumar G., Bali R., Agarwal A. K. GIS integration of remote sensing and electrical data for hydrological exploration: a case study of Bhakar watershed, India. *Hydrological Sciences Journal*. 2009. Vol. 54, issue 5. P. 949 – 960. DOI: 10.1623/hysj.54.5.949
11. Remote Sensing Satellite. *Sentinel-2 Series*. Available at: https://ecoruspace.me/Sentinel+2.html (accessed 22 March 2025).
12. Unraveling the Impacts of River Network Connectivity on Ecological Quality Dynamics at a Basin Scale / X. Li et al. *Remote Sensing*. 2024. Vol. 16, issue 13. Article 2370. DOI: 10.3390/rs16132370
13. Herzog A., Hellwig J., Stahl K. An investigation of anthropogenic influences on hydrologic connectivity using model stress tests. *Hydrology and Earth System Sciences*. 2024. Vol. 28, P. 4065 – 4083. DOI: 10.5194/hess-28-4065-2024
14. Danshina S. Yu., Podorozhko K. D. Method of spatial analysis of riverbed deformation based on combined data. *Restoration of ecosystems damaged by military operations: Ukrainian and European challenges: abstracts of reports from the International Scientific and Practical Conference REDMO-2024*, Kyiv, November 6, 2024. K., 2024. P. 20–25.