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ORIGINAL ARTICLE

Geoinformation modelling of the watershed area of small and medium-sized rivers for environmental audit

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Abstract

Developing and improving environmental audit methodologies is integral to natural resource management. This paper presents an innovative approach to studying and analysing anthropogenic impacts on the territories whose boundaries are limited by the watershed area of a small or medium-sized river. Using geoinformation technologies and high-resolution digital elevation models allowed us to create an accurate geospatial model of anthropogenic transformations of the Oril River watershed area within the Dnipropetrovsk region (Ukraine). The proposed approach to identifying potentially hazardous objects is based on surface slopes and their distance from the riverbed within the watershed area. Based on the modelling results, a refined watershed area of the Oril River with a total area of 11.1 thousand square kilometres was developed. Digitalisation and categorisation of anthropogenically transformed lands allocated for residential development, industrial enterprises, farms, agricultural land, roads, and railways within the Oril River watershed in the Dnipropetrovsk region (3963 km^2) were conducted. It was found in the investigation that 79% of the study area comprises anthropogenically transformed land primarily used for agricultural and industrial activities. The modelling results underscore that agricultural activity serves as the principal source of anthropogenic pressure on the ecosystems of the studied area. The proposed improvements to the environmental audit methodology can be used in developing regulations to limit the negative impact of economic activity on the environment. This will ensure the region's sustainable development and fulfil Ukraine's obligations to preserve natural resources including international standards. The conclusions of the article point to the need to further improve the tools for assessing anthropogenic impact and planning environmental protection measures.

Key words: anthropogenically transformed lands, digital elevation models, ecological audit of territories, geoinformation technologies, Oril River, watershed area

1 Introduction

Given the significant challenges associated with the conservation of natural resources and the sustainable development of natural ecosystems, a comprehensive environmental assessment of anthropogenically disturbed areas is critical. In the context of global climate change and growing anthropogenic activity, the development of a methodology that will ensure the accuracy and reliability of the boundaries of study areas is crucial for the development of scientifically sound environmental management strategies.

In this context, it is worth paying attention to an innovative approach that successfully considers previous shortcomings and, based on modelling the watershed areas of small and medium-sized rivers, provides additional opportunities to determine the spatial boundaries of territorial objects for environmental audit of land. Using high-resolution digital elevation models and advanced geoinformation technologies makes it possible to avoid systemic shortcomings in establishing territorial restrictions related to environmental risks of anthropogenic activities.

Thus, the study aims to optimise the environmental audit methodology based on modelling watershed areas of small and medium-sized rivers using high-resolution digital elevation models and geographic information technologies. It is proposed that the modelling of watershed areas based on the methodology improved by the authors be used as a basis for establishing the territorial boundaries of natural objects during environmental audits on their territories. The approach described in this paper demonstrates the stages of establishing the boundaries of a watershed area, such as the middle Oril River, considering the impact of large hydrographic objects (Dnipro River) on smaller river systems.

2 Literature review

Natural resources are an invaluable asset of every state, so their conservation and rational use should be the responsibility of every citizen of that state and the state as a whole. In this regard, each country has several laws and codes that set out the mechanisms for the use, conservation and protection of the state's natural resources (Yakymchuk et al., 2023).

Ukraine is no exception, and the use of natural resources is regulated by the Law of Ukraine "On Environmental Protection" (Protection of the Environment, 2023), according to which the environment and natural resources are subject to state protection and regulation of use on the territory of Ukraine: land, subsoil, water, air, forest and other vegetation, fauna, landscapes and other natural complexes. At the same time, local councils are responsible for the state of the environment in their territory, managing environmental protection, and controlling compliance with environmental legislation.

One of the areas of environmental management, as stated in Environmental Audit (2020), is an environmental audit – a documented systematic, independent process of assessing the object of environmental audit, including the collection and objective evaluation of evidence to establish compliance of certain activities, measures, conditions, environmental management system and information on these issues with the requirements of the legislation of Ukraine on environmental protection. However, as defined by Article 2 of Environmental Audit (2020), the objects of environmental audit may include enterprises, institutions and organisations, individual production facilities, other economic entities, and environmental management systems. This list of objects does not include environmental audits for natural environment objects that are not involved in economic use but suffer from the effects of anthropogenic human activity due to their borders with artificial objects that may have a hazardous environmental impact.

Thus, in scientific research, environmental audit of territories is considered as scientific and practical activity based on the analysis of co-adaptation between the economic and natural subsystems (Lomtatidze, 2017; Okhremenko, 2017; Xiong, 2022; Zavalniuk, 2008). In other words, an environmental audit of territories is performed based on the results of a comprehensive geo-environmental assessment and analysis of the territorial organisation of the audited object.

According to the proposed methodology for conducting an environmental audit of territories (Feketa, 2016), certain information grouped into the following blocks: cartographic information, climatic conditions, atmospheric air, land, water and bioresources, specially protected areas and recreation, complex indicators of transformation of territories, medical and demographic information, anthropogenic complex, social sphere and economic block will be analysed. According to the proposed methodology, the environmental audit involves identifying limiting characteristics (factors) and assessing the territorial component regarding potential and resilience to anthropogenic pressure. Regarding territorial restrictions in defining the object of environmental audit, the objects of both this paper and works of Okhremenko (2017) and Zavalniuk (2004) have clear geographical boundaries of the territory – island territories (Bilohrudiv Island in the Dnipro Delta) or semi-peninsular territories (Crimean Peninsula). The spatial and temporal dynamics of chlorophyll concentration, as an indicator of eutrophication, may depend on the structural features of the floodplain water network. This is a promising area for studying natural conditions and environmental audit of the Dniprovsko-Orilskyi Nature Reserve (Fedonenko et al., 2022).

It is also proposed to determine the functional classification of urban landscapes as a limiting territorial factor (Parpan and Mylenka, 2010), the regional distribution of territories by administrative boundaries (Vasenko et al., 2015), an integrated approach to studying the ecological state of a system object in accordance with the tasks of supporting environmental decision-making to regulate the safety of a natural and technogenic object (Yemelyanova, 2017), as well as the use of the basin principle to determine the impact of natural and anthropogenic factors, taking into account the landscape and geographical features of riverine (Hnativ, 2022; Rybalova and Artemiev, 2017; Sherstiuk, 2023).

In another example, to improve water quality in river basins and promote environmental management of the Songhua River Basin (Shen et al., 2017), it is proposed that quantitative assessments of environmental security be conducted by combining the watershed area and administrative boundaries of the region.

Finally, to conduct environmental observations as part of adaptive management in areas that do not have clear geographical boundaries, it is also proposed to use the watershed principle as a delineation of territorial boundaries (Vivian et al., 2023; Wu et al., 2023). It is suggested that the boundaries of watershed basins be modelled using remote sensing methods and geographic information technologies. Balakrishnan and Ilanthirayan (2017) believe that the use of geospatial tools in integrated watershed management is a worthy approach to addressing the environmental, social and economic challenges of watershed development.

Zhai et al. (2022), Tretyak and Kukhtar (2022) point out the advantages of using remote sensing technologies, with their short revisit time, extensive monitoring range, high spatial resolution of satellite images. Therefore, a prerequisite for applying remote sensing methods and analysing land surface data is carefully selecting a digital elevation model based on its properties, from resolution to the ability to reproduce natural changes at different scales accurately.

Thus, due to the specifics of the audited object, which are different from those specified in Environmental Audit (2020), there is a need to develop and refine methodological techniques for conducting environmental audits of territories.

The authors of the article propose to finalise the initial stage of the methodology of environmental audit of territories by defining clear boundaries of the territories selected for research. Based on the developed models of the watershed area, it is possible to obtain the boundaries of the territories, including the quality of environmental components, namely land, water and bioresources, protection and recreational complexes, and the impact of anthropogenic complexes that will be examined in the experiment.

A detailed configuration and defined size of a watershed area provide a basis for establishing the environmental risks of the relevant land users within the floodplain and watershed of the Oril River. This is due to a high anthropogenic load, mainly the agro-industrial complex, which releases various pollutants into the watershed with surface runoff.

Therefore, the work aims to optimise the methodology for conducting environmental audits of natural and anthropogenically transformed lands that are geographically limited to the catchment area of small or medium-sized rivers.

To achieve this goal, the following tasks were undertaken:

- the boundaries of the Oril River watershed were established, taking into account the influence of the higher hydrographic object (Dnipro River),
- digitisation of the lands of the Oril River watershed area and identification of economic entities that have a potentially hazardous impact on the river and its water protection zone,
- categorisation of anthropogenically transformed lands allocated for residential development, industrial enterprises and farms, agricultural land, roads and railways, etc,
- development of a digital map of vectorised anthropogenically transformed lands of the Oril River watershed within the administrative boundaries of the Dnipropetrovsk region to conduct an environmental audit of the lands and provide substantiated conclusions on the level of negative impact of business entities on civilian objects and natural areas bordering them.

3 Research methodology

In this paper, the study was carried out for the watershed of the Oril River, one of the largest left tributaries of the Dnipro River, the most powerful river in Ukraine. The calculation of the Oril River watershed is limited to the territory of the Dnipropetrovsk region. Taking into account the experience of previous modelling of the watershed area (Omelych et al., 2021), the study used ASTER GDEM v.3.0 DEM, which has a high resolution, a large number of sensors and comprehensive coverage, providing a reliable basis for studying river systems and developing effective water management strategies.

In the first stage, the DEM of the study area was downloaded from the open electronic resource Earthdata (2024). The digital elevation models SRTM (Shuttle Radar Topography Mission) and ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model) v.3.0 are two well-known and widely used sources of geographic data for elevation studies (Guth, 2010). Both digital elevation models can be used to build a medium-sized river watershed, but the best choice depends on the specific features of the study and accuracy requirements.

Since the study involves high requirements for accuracy and detail, ASTER GDEM v.3 is the preferred solution. It has a similar resolution to SRTM, but displays data from more sensors. ASTER GDEM v.3 can also be helpful for hydrography studies and detailed analysis of water bodies (Abrams et al., 2022; Arifian et al., 2023). The ASTER GDEM elevation map covers the earth's surface between 83°N and 83°S and was created by automated processing of 2.3 million scenes from the ASTER archive (Earthdata, 2024).

SRTM digital elevation models are also well-known and in demand in research; however, due to the low coverage of territories and a small number of sensors, errors in geospatial research may be observed in some areas (Zhang et al., 2016). Therefore, the digital elevation model ASTER GDEM v.3 was preferred to perform the tasks set in this paper.

In modelling the Oril River watershed area, the interconnection of the studied watercourse with adjacent water bodies, particularly larger rivers, was analysed, and a significant influence of a higher-order water body (Dnipro River) was identified. The presence of hydrographic objects of this type on the DEM can cause certain errors in modelling, namely, determining the accuracy of the boundaries and contours of the lower-order river watershed. Since the dynamics of water flow into a smaller water body can be significantly altered by the influence of a large river channel, such hydrological interactions can have an additional impact on the actual boundaries and direction of water flow (Ran and Lu, 2011). Therefore, to build catchment areas, it is necessary to analyse the relationships between hydrographic features of different scales carefully and consider possible deviations to achieve accuracy and reliability in defining watershed boundaries.

To avoid possible errors in constructing the Oril River watershed, the part of the digital elevation model (DEM) where the higher-order Dnipro River is located was removed using the Cut tool. This step ensured the accuracy and reliability of the results while preserving the unique characteristics of the study area. After preparing the DEM, a lower-order river basin study was conducted using the new, refined geographic framework.

The hydrological tools of the Spatial Analyst module of ArcGIS Desktop software were used to build the Oril River watershed. The modelling was carried out in several stages, which included filling in false depressions (Fill), creating a raster of the flow direction (Flow Direction), creating a raster of the snap point (Snap Pour Point), accumulating the flow (Flow Accumulation) and merging the snap points of the mouth and sources (Merging).

Using the ArcGIS Online service, a layer with the administrative boundaries of the Dnipropetrovsk region was added to the electronic map. Using the geoprocessing tool "Cut", the watershed layer was cropped along the administrative boundaries of the Dnipropetrovsk region.

These stages allowed us to build the watershed area of the Oril River, taking into account the nature of the relief and water flow directions, which will allow further analysis of the watershed area and will become the basis for conducting an environmental audit of these lands within the administrative boundaries of the Dnipropetrovsk region, depending on their intended purpose and areas of natural resource use.

Clarifying the development of the watershed area means establishing its boundaries and determining individual land areas that should correspond to the land use status and environmental conditions. For accurate area calculations, the WGS_1984_UTM_Zone_35N coordinate system was chosen, allowing obtainment of metric system results. Based on this coordinate system and a satellite image of the territory of the Dnipropetrovsk region, which was used as a background image for the study, the boundaries of settlements, roads, railways and other civil infrastructure facilities that were relevant at the time of the study were digitised and categorised using ArcGIS Online. Water management (ponds, lakes, reservoirs, etc.), forest (forest land), agricultural (farmland, pastures, hayfields, etc.), industrial (enterprises, production facilities, warehouses, petrol stations and repair shops, etc.) and urban (cemeteries, solid waste dumps, etc.) objects were also digitised and categorised.

The area of each digitised layer was calculated using ArcMap's Geometry Calculation tool in the attribute table, which provides accurate measurements of the area of each object in square kilometres.

The process of calculating the area of roads and railway tracks is worth mentioning separately. Their area can be determined using the Buffer tool, which needs to be built according to the object's width. Thus, according to the building regulations (DBN B.2.3-19-2018, 2018), the width of the main subgrade area for one main track is 7.6 m. The area of roads is calculated similarly: for trunk roads – 3.75 m, for local roads – 3 m in accordance with the construction standards for roads (DBN B.2.3-5:2018, 2018).

The implementation of this methodology for determining the boundaries of a catchment area and the individual natural and artificial objects that form it creates a clear basis for conducting an environmental audit of land.

4 Results

As a result of modelling, the watershed area of the Oril River, with a total area of 11.1 thousand km^2, was obtained. The territory of the entire watershed covers three regions – the Kharkiv region, the Poltava region, and the Dnipropetrovsk region. Using the above methodology, after trimming the watershed layer along the ad-

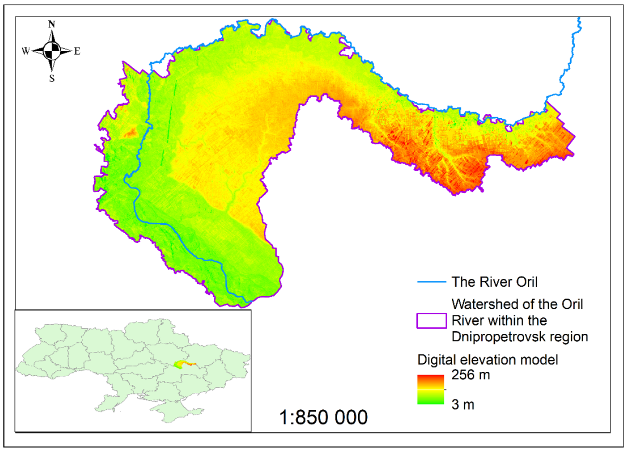

Figure 1. Boundaries of the modelled watershed of the Oril River in the territory of the Dnipropetrovsk region

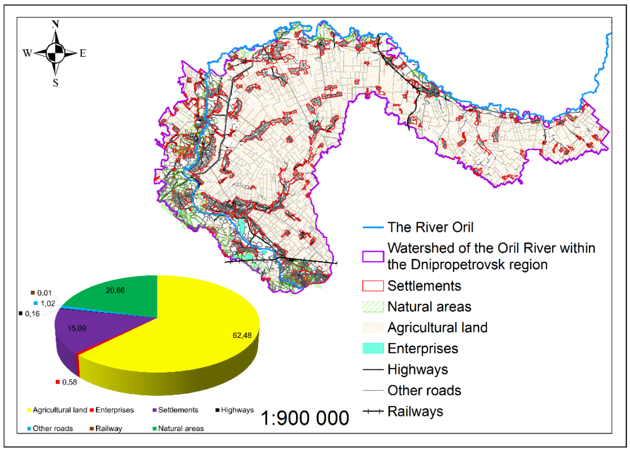

Figure 2. Digitised anthropogenically transformed lands within the modelled watershed of the Oril River in the Dnipropetrovsk region and distribution of lands in the research area

ministrative boundaries of the Dnipropetrovsk region, the area of the Oril River watershed in the Dnipropetrovsk region was calculated using the Calculate Geometry tool. The determined area is 3963 km^2, which is 12.5% of the area of the Dnipropetrovsk region and 35.7% of the total watershed area.

The watershed area of the Oril River, modelled using the above methodology, is a colour image, according to which the colour corresponds to a certain height above sea level. Thus, in Figure 1, the modelled surface corresponds to an elevation difference of 256 m (red colour scheme) to 3 m (green colour scheme) above sea level.

As can be seen from Figure 1, almost half of the Oril River watershed in the Dnipropetrovsk region has the lowest elevation of 3÷50 m above sea level due to a wide floodplain of 3–4 km and left tributaries (Orilka, Pryadivka, Zhuravka, Shyroka Kilchenka, Bahatenka and Mokra Zaplavka rivers). The eastern part of the Oril River watershed is characterised by an altitude of 80÷250 m above sea level. In the central part of the Oril River floodplain, according to the modelled watershed, areas with the lowest level were identified, indicating an uncharacteristic depression for this natural relief due to the presence of the Dnipro-Donbas artificial water channel, where a significant deepening of the bed of its channel is observed.

Data from ArcGIS Online was used to obtain the boundaries of settlements, roads and railways. By cropping the relevant layers along the boundaries of the modelled watershed area of the Oril River, it was determined that it includes 161 settlements that partially or entirely fall within the watershed. The total area of these settlements is 597.9 km^2. Considering their structure and size, roads cover an area of 6.7 km^2, and other roads – 40.4 km^2. Considering the width of the railway bed, the area of railway tracks is 0.54 km^2.

The satellite image was analysed, and industrial and agricultural facilities were digitised. According to the analysis, 150 industrial enterprises were identified, with an area ranging from 0.01 to 5 km^2, and their total area within the study area is 22.9 km^2.

The largest share of the land in the Oril River watershed, as shown in Figure 2, is occupied by agricultural land. The "Agricultural land" polygonal layer was created for their digitisation, the elements of which were digitised in large areas. Their total area is 2476 km^2, which is 62.5% of the study area.

The overall area of anthropogenically altered lands, incorporating settlements, roads, railways, industrial enterprises, and agricultural lands, constitutes a significant portion of the surveyed territory (Figure 2), namely 79%, significantly disrupting the ecological balance of the region and posing a potential anthropogenic hazard.

The digital map with vectorised anthropogenically transformed lands was obtained by decoding satellite images and digitising the watershed area of the Oril River within the Dnipropetrovsk region (Figure 2).

The digital map in Figure 2 indicates that the lands of settlements are predominantly situated in the lower reaches of the Oril River. In some instances, industrial enterprises and agricultural lands are located within the water protection zone and the coastal protective strip, with dimensions of 300 and 50 meters, respectively, from the water line (Rusina et al., 2021), presenting the most significant risk of river basin contamination.

In Figure 3, A, the farm located 273 meters from the Oril River water line is depicted. This enterprise breeds over 1,000 heads of cattle on its premises, posing potential environmental hazards to the adjacent area. The facility has a waste dump and a storage area for fuel and lubricants for agricultural machinery, the storage conditions of which do not ensure the complete prevention of water bodies and soil contamination. According to modelling results, the enterprise is situated at an altitude of 63 meters above sea level, with the surface slope directed towards the river, averaging 2.0÷4.9%, indicating a high risk of surface runoff reaching the coastal protective strip and the Oril River directly.

In another example (Figure 3, B), the slope angle magnitude (1.2÷1.6%) of the poultry farm's territory towards the Oril River is insignificant, reducing the likelihood of pollutants reaching the river through surface runoff. Considering the sufficient distance to the riverbank (577 m) and the presence of a surface runoff collection and drainage system at this facility, the environmental risk for this area has been minimised.

According to the digitisation of anthropogenic objects, it is evident that surface runoff from agricultural land poses the most significant environmental threat to the Oril River in the Dnipropetrovsk region. The application of fertilisers and pesticides to agricultural land introduces not only biogenic elements into the soil but also impurities in the form of heavy metal salts, organic compounds, and radioactive isotopes. Subsequently, these pollutants enter water bodies through surface runoff, resulting in deteriorating water quality of both groundwater and surface water, as well as the ecosystems dependent on them. This process is exacerbated by the excessive application of mineral fertilisers and their incomplete absorption by plants (Omelych et al., 2021).

Based on the calculated slope angles, it has been determined that most agricultural lands have surface runoff directed towards the Oril River. Even fields located in the right-bank southern part of the watershed and closer to the higher-order river (the Dnipro River) have slopes of 1.6÷1.8% towards the Oril River (Figure 4, A).

On average, the slope on the left bank of the Oril River ranges from 1 to 3%. For instance, one of the areas containing agricultural lands has elevation fluctuations ranging from 58 meters near the

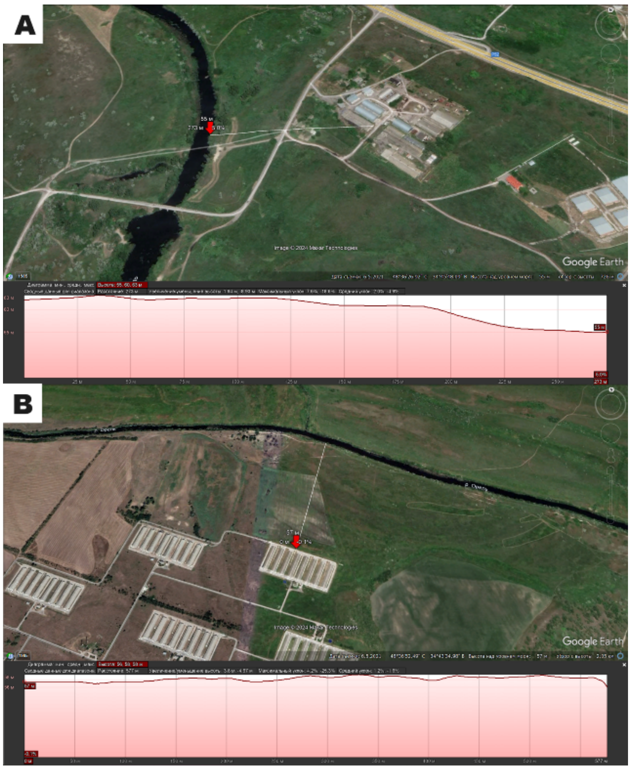

Figure 3. The map and elevation profile of the investigated area in the vicinity of: A – farmstead; B – poultry farm

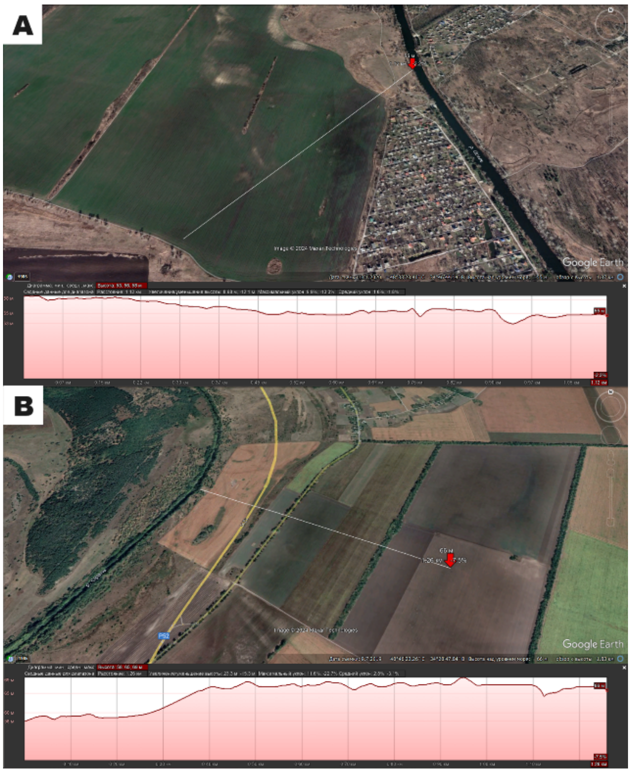

Figure 4. The map and elevation profile of the investigated areas with agricultural land use

river channel to 66 meters within the agricultural field, with a slope towards the river of 2.8÷3.1% (Figure 4, B), indicating an existing ecological threat to the river ecosystem.

5 Discussion

The proposed enhancement of the methodology for conducting land ecological audits has allowed for a more precise assessment of the degree of anthropogenic transformation within the watershed area of the Oril River within the administrative boundaries of the Dnipropetrovsk region. The constructed watershed area serves as a fundamental spatial framework, facilitating thorough analysis and categorisation of various land types and their attributes within the study area. This approach will help systematise and refine land resource usage categories, thereby reinforcing adherence to environmental norms and requirements of land and water legislation (Land Code of Ukraine, 2023; Water Code of Ukraine, 2022).

Analysing results of land digitisation within the watershed area of the Oril River in the Dnipropetrovsk region, it has been determined that agricultural activity has the most significant impact on its ecological condition, as the share of agricultural land exceeds 60% of the investigated watershed area. Agricultural lands are concentrated in the left-bank part of the Oril River floodplain (Figure 2), and based on the modelled watershed area (Figure 1), they have a slope towards the Oril River.

This categorisation of land types will not only enable a more accurate accounting and inventory of various land types but also facilitate further analysis of the impact of human activity on watershed ecosystems.

Thus, based on the modelled watershed area, it becomes possible to identify objects potentially hazardous to the environment from which surface runoff will enter the Oril River. Additionally, based on slope data and distance from the riverbed, the environmental risk level posed by each object can be determined.

The improved methodology for the initial stage of land ecological audits will ensure the accuracy and reliability of delineating the spatial boundaries of audit objects that do not have clear boundaries. The proposed optimisation of the methodology for constructing watershed areas of small and medium rivers using high-resolution digital elevation models and geoinformation technologies will help avoid systemic errors regarding the degree of anthropogenic transformation of the watershed area.

The results of modelling the watershed area and its subsequent analysis will enable reasoned conclusions regarding the level of negative impact of economic entities on adjacent territories, considering their distance from the audit object, taking into account elevation, slope, and direction.

Improving the existing methodology of environmental auditing by introducing it at the initial stages for territories not belonging to the respective landowners or users will enable justified claims to be made against economic entities for the responsibility of environmental damage inflicted on the surrounding environment. This includes pollution of surface and groundwater, soil contamination, violations of restrictions in the economic use of water protection zones and coastal protective strips, and so forth.

6 Conclusions

The conservation of natural resources and ecosystems, along with their comprehensive ecological assessment considering the increasing anthropogenic pressure amidst environmental protection resource degradation and the imperfections in the management mechanisms of compliance with environmental legislation, requires the development of innovative approaches and methods. They are a reasoned and thorough assessment of technological risks not only within the territories of economic entities.

The determination of the spatial boundaries of territorial objects for conducting environmental land audits is proposed to be carried out using advanced geoinformation technologies. They should be based on improved principles of modelling watershed areas of small and medium rivers, employing high-resolution digital elevation models, taking into account the influence of major hydrographic objects on smaller river systems.

Thus, the set goal of the study has been achieved, indicating the development of an improved methodology for conducting environmental audits of natural and anthropogenically transformed lands, which are territorially delimited by the watershed area of small or medium rivers. The boundaries of the Oril River watershed area have been established, considering the influence of the higher-order hydrographic object; digitisation and categorisation of lands within the Oril River watershed area have been carried out, and economic entities potentially posing hazardous impacts on the river and its water protection zone have been identified. Additionally, an electronic land map of the Oril River watershed area within the administrative boundaries of the Dnipropetrovsk region has been developed to address the tasks of environmental land auditing and provide well-founded conclusions regarding the level of negative impact of economic entities on adjacent civil objects and natural territories.

References

Abrams, M., Yamaguchi, Y., and Crippen, R. (2022). Aster Global DEM (GDEM) Version 3. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLIII-B4-2022:593–598, doi:10.5194/isprs-archives-xliii-b4-2022-593-2022.

Arifian, N., Denis, K. R., and Putri, S. K. (2023). Comparison of Aster GDEM images and SRTM images for river watershed and geomorphology study. *International Remote Sensing Applied Journal*, 3(2):68–73, doi:10.24036/irsaj.v3i2.38.

Balakrishnan, M. and Ilanthirayan, D. (2017). Ground water management and soil conservation of Korayar watershed through remote sensing and GIS. *6th National Conference on Innovative Practices in Construction and Waste Management*, doi:10.5281/ZENODO.579572.

DBN B.2.3-19-2018 (2018). Transport facilities. Railways track 1520 mm. Design standards. Ministry of Regional Development of Ukraine, Kyiv, Ukraine, 102 [in Ukrainian].

DBN B.2.3-5:2018 (2018). Streets and roads of settlements. Ministry of Regional Development of Ukraine, Kyiv, Ukraine, 55 [in Ukrainian].

Earthdata (2024). https://www.earthdata.nasa.gov/.

Environmental Audit (2020). Law of Ukraine No. 1862-IV, Kyiv, Ukraine. https://zakon.rada.gov.ua/laws/show/1862-15#Text.

Fedonenko, E. V., Kunakh, O. M., Chubchenko, Y. A., and Zhukov, O. V. (2022). Application of remote sensing data for monitoring eutrophication of floodplain water bodies. *Biosystems Diversity*, 30(2):179–190, doi:10.15421/012219.

Feketa, I. Y. (2016). Methodical recommendations for the course "Environmental Expertise and Audit" (for students of the specialty 7.04010401 'Geography') [in Ukrainian]. Technical report, Private Entrepreneur Breza A. E, Uzhhorod, Ukraine.

Guth, P. L. (2010). Geomorphometric comparison of aster GDEM and SRTM. In *Proceedings of the Part 4th ISPRS Archives A Special Joint Symposium of ISPRS Technical Commission IV and AutoCarto in Conjunction with ASPRS/CaGIS 2010 Fall Specialty Conference*, volume 10.

Hnativ, I. R. (2022). Assessment of technogenic impact on the hydrosphere considering the principles of watershed management [in Ukrainian]. Technical report, SumDU, Sumy, Ukraine.

Land Code of Ukraine (2023). Land Code of Ukraine [in Ukrainian]. https://zakon.rada.gov.ua/laws/show/2768-14#Text.

Lomtatidze, N. (2017). Ecological expertise, audit, control. Technical report, Batumi Shota Rustaveli State University.

Okhremenko, I. V. (2017). Theoretical and methodological aspects of environmental audit of island territories (on the example of Bilohrudiv Island) [in Ukrainian]. *Scientific Bulletin of Kherson State University. Series: Geographic Sciences*, pages 160–163.

Omelych, I., Neposhyvailenko, N., Zberovskyi, O., and Korniienko, I. (2021). Improvement of the methodology for the assessment of soil biogenic pollution through the use of geoecological approaches and the use of information technologies. *Eastern-European Journal of Enterprise Technologies*, 3(10(111)):42–53, doi:10.15587/1729-4061.2021.235845.

Parpan, V. I. and Mylenka, M. M. (2010). Methodological aspects of assessing the ecological state of urbanised and technologically altered territories [in Ukrainian]. *Biosystems Diversity*, 18(2):61–68, doi:10.15421/011027.

Protection of the Environment (2023). Law of Ukraine No. 1264-XII, Kyiv, Ukraine. https://zakon.rada.gov.ua/laws/show/1264-12#Text.

Ran, L. and Lu, X. X. (2011). Delineation of reservoirs using remote sensing and their storage estimate: An example of the Yellow River basin, China. *Hydrological Processes*, 26(8):1215–1229, doi:10.1002/hyp.8224.

Rusina, N., Lyul'chyk, V., Bida, P., Kachanovs'kyy, O., Bulakevych, S., and Petrova, O. (2021). Problems of installation water protective zones and coastal protective stripes. *Zemleustrìj, kadastr ì monìtorìng zemel'*, (3):6–6, doi:10.31548/zemleustriy2021.03.06.

Rybalova, O. and Artemiev, S. (2017). Development of a procedure for assessing the environmental risk of the surface water status deterioration. *Eastern-European Journal of Enterprise Technologies*, 5(10 (89)):67–76, doi:10.15587/1729-4061.2017.112211.

Shen, Y., Cao, H., Tang, M., and Deng, H. (2017). The human threat to river ecosystems at the watershed scale: An ecological security assessment of the Songhua River Basin, Northeast China. *Water*, 9(3):219, doi:10.3390/w9030219.

Sherstiuk, M. M. (2023). Assessment of technogenic impact on the hydrosphere considering the principles of watershed management [in Ukrainian]. Technical report, SumDU, Sumy, Ukraine.

Tretyak, K. and Kukhtar, D. (2022). Ice glacier velocity determination using Sentinel-1 data: A case study on Wiggins Glacier, West Antarctica, 2015–2017. In *International Conference of Young Professionals «GeoTerrace-2022»*, pages 1–5. European Association of Geoscientists and Engineers, doi:10.3997/2214-4609.2022590004.

Vasenko, O., Rybalova, O. V., and Artemiev (2015). *Integrated and Comprehensive Assessments of the State of the Natural Environment: Monograph [in Ukrainian]*. NUHZU, Kharkiv, Ukraine.

Vivian, A., Enweluzor, O., and Abdulwaheed, Y. (2023). Extraction of watershed characteristics in Imo state using GIS and Digital Elevation Model. Technical report.

Water Code of Ukraine (2022). Water Code of Ukraine [in Ukrainian]. https://zakon.rada.gov.ua/laws/show/213/95-ÐšÑĂ#Text.

Wu, X., Bu, X., Dong, S., Ma, Y., Ma, Y., Ma, Y., Liu, Y., Wang, H., Wang, X., and Wang, J. (2023). The impact of restoration and protection based on sustainable development goals on urban wetland health: A case of Yinchuan plain urban wetland ecosystem, Ningxia, China. *Sustainability*, 15(16):12287, doi:10.3390/su151612287.

Xiong, M. (2022). An empirical study on the moderating effect of environmental audit on the impact of economic development and ecological environment. *Frontiers in Psychology*, 13, doi:10.3389/fpsyg.2022.1047517.

Yakymchuk, A., Pavlov, K., Pavlova, O., and Golubchuk, I. (2023). Economic foundations of resource conservation in Ukraine: Foreign experience. *Herald of Khmelnytskyi National University. Economic sciences*, 318(3):163–168, doi:10.31891/2307-5740-2023-318-3-25.

Yemelyanova, D. I. (2017). Assessment of environmental safety of natural-technogenic objects based on informational and methodological support [in Ukrainian]. Technical report, V. I. Vernadsky National Library of Ukraine, Kyiv, Ukraine.

Zavalniuk, I. V. (2004). Environmental audit of territories (on the example of the Plain Crimea) [in Ukrainian]. Technical report, Taras Shevchenko National University of Kyiv, Kyiv, Ukraine.

Zavalniuk, I. V. (2008). Environmental audit of territories: Methodical implementation peculiarities [in Ukrainian]. *Geography in the Information Society*, 4:129–130.

Zhai, L., Cheng, S., Sang, H., Xie, W., Gan, L., and Wang, T. (2022). Remote sensing evaluation of ecological restoration engineering effect: A case study of the Yongding River Watershed, China. *Ecological Engineering*, 182:106724, doi:10.1016/j.ecoleng.2022.106724.

Zhang, Q., Yang, Q., and Wang, C. (2016). SRTM error distribution and its associations with landscapes across China. *Photogrammetric Engineering and Remote Sensing*, 82(2):135–148, doi:10.14358/pers.83.2.135.