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PRINCIPLES OF SOFTWARE AND INFORMATION FOR MODELING HYDROLOGICAL RIVER BASINS OF THE UKRAINIAN CARPATHIANS

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Abstract. This study addresses the information and software tools used for modeling hydrological basins in the Ukrainian Carpathians, a region distinguished by its complex terrain and diverse ecosystems. The research focuses on a variety of hydrological modeling software, including HEC-HMS, SWAT, and GIS applications, which facilitate the analysis of hydrological processes and the assessment of river runoff dynamics. Furthermore, the integration of meteorological data and land use information is discussed to enhance the accuracy of hydrological models. The results highlight the significance of using advanced software for understanding the impacts of climate change, land use changes, and human activities on water resources in the region. This research aims to provide a framework for sustainable water resource management and contribute to the conservation of aquatic ecosystems in the Ukrainian Carpathians.

Keywords: Hydrological modeling, Ukrainian Carpathians, HEC-HMS, SWAT, GIS, river basins.

Introduction

Modeling the hydrological basins of rivers in the Ukrainian Carpathians is important for water management, flood prevention, and environmental safety.

A catchment basin is the surface from which a river system, sea or lake collects water. Suppose forests in the catchment area are not managed sustainably. In that case, there is a sharp unevenness in water flow, increased erosion, and solid runoff entering the water body, which can lead to eutrophication of water bodies, siltation, or intoxication of the aquatic environment. A water body and its catchment area form a single ecosystem and need to be protected in areas of intensive use.

Relevance of the topic: Modelling of hydrological river basins in the Ukrainian Carpathians is an important aspect of water resources research, especially in the context of climate change and increasing anthropogenic activities that affect the region's ecosystems.

The main objective of the study is to comprehensively model hydrological processes in the river basins of the Ukrainian Carpathians and elementary basins.

The subject of the study is a comprehensive analysis and modeling of hydrological processes occurring in the river basins of this region. This study aims to understand how various natural and anthropogenic factors affect the water regime of rivers, their flow, water quality, and ecosystems.

The object of the study is a complex system that encompasses physical, chemical, biological, and socio-economic aspects of the hydrological basins of the Ukrainian Carpathians. The study of these objects allows us to focus on understanding their interrelationships, behavior, and responses to various internal and external factors.

Problem Statement

Modeling hydrological river basins in the Ukrainian Carpathians is an essential and relevant area of research, as the region faces numerous environmental, social, and economic challenges. These are the key aspects that characterize the state of the problem: climate change, economic activity, insufficient data, methodological challenges, including difficulties in modeling. The article is dedicated to the modeling problem itself.

The study of modeling the hydrological basins of the Ukrainian Carpathian rivers is of great importance for sustainable water management, mitigation of climate change, preservation of ecological balance, and prevention of the adverse effects of natural disasters. The processes studied can help make informed decisions in the field of ecology, water use, and region development.

A review of the literature on this topic highlights the relevance of research related to hydrological processes, climate change, and their impact on water resources. The study of specialized literature provides insight into modeling methods, previous research results, and problems and challenges.

The main applications for the modeling of hydrological basins are those that use digital terrain models. The main ones are:

1. SWAT (Soil and Water Assessment Tool) is a watershed-scale model developed by the USDA's Agricultural Research Service. It simulates the cycling of water, sediment, and nutrients in large catchments. Key features: Integrated modeling for hydrology and land use. Ability to model the impact of land management practices on water quality and quantity. Customizable interface through interfaces such as ArcSWAT (integration with ArcGIS).

2. HEC-HMS (Hydrological Engineering Centre Hydrological Modelling System) Developed by the US Army Corps of Engineers, HEC-HMS is used to model precipitation and runoff processes in watersheds. It provides a comprehensive framework for modeling various hydrological processes and supports different types of precipitation and runoff modeling techniques.

3. MODFLOW is a groundwater modeling software developed by the US Geological Survey. Although it focuses on groundwater, it can be integrated with surface water models to simulate fully coupled hydrological systems. The main features are 3D groundwater flow modeling and flexible structure to incorporate different water management scenarios. It is possible to combine it with surface water models for integrated basin analysis.

4. MIKE SHE is a comprehensive modeling system developed by DHI for modeling the entire water cycle, including surface and groundwater flows and environmental impacts. Its main features are an integrated approach to modeling hydrology, hydraulics, and water quality; support for a wide range of applications from small catchments to large river basins; and a user-friendly interface with a graphical modeling environment.

5. SAGA GIS (System for Automated Geoscientific Analysis). Being primarily a GIS software, SAGA includes a variety of geospatial analysis tools that can be used for hydrological modeling. The main features are extensive hydrological analysis capabilities, such as DEM analysis, watershed delineation, and runoff accumulation, and the ability to integrate with other models and tools to improve hydrological analysis.

6. QGIS with processing plug-ins (e.g., GRASS GIS, TauDEM). QGIS is an open-source GIS platform that, combined with processing plug-ins, can perform various hydrological analyses. Key features are: plug-in-based architecture provides flexibility in modeling methods; tools for catchment, flow direction, and storage analysis; visualization and integration of spatial data.

7. The Watershed Modelling System (WMS) is a specialized catchment modeling software that integrates hydrological and hydraulic modeling systems. The main features are a user-friendly interface for modeling runoff and water quality and support for several modeling mechanisms, including HEC-HMS and SWMM.

8. EnviroFlows is a tool designed for environmental assessment of river and basin flows. It combines hydrological modeling and environmental data analysis. The main features are that the program allows the estimation of water flow requirements for maintaining ecological health and easily integrates with hydrological models to assess the impact of flow changes.

9. EPA SWMM (Stormwater Management Model) Developed by the Environmental Protection Agency, SWMM is primarily used to model the quantity and quality of stormwater runoff from urban areas. The main characteristics of the program are that it is ideal for modeling stormwater management practices in urban catchments and includes hydrological and hydraulic analysis capabilities [3,7].

Main Material Presentation

In selecting river basin modeling software, it is essential to consider several factors, including the specific modeling requirements, ease of use, data availability, and scale of analysis. The integration of hydrological models with land use and climate data is of paramount importance for the accurate assessment of data and the development of effective management strategies.

In the context of river basin modeling, the availability of comprehensive information and data is of paramount importance for the accuracy of the modeling and assessment process. The following section presents a detailed breakdown of the critical information and data required for effective river basin modeling.

1. Digital Elevation Model (DEM) – represents the elevation of the land surface and is crucial for defining catchment boundaries, flow paths, and catchment characteristics. Potential sources include the Shuttle Radar Topography Mission (SRTM), the National Elevation Dataset (NED), and local or regional LiDAR data.

Precipitation data are of importance for the estimation of river flows and flows. Both historical and forecast precipitation data are of value. Potential sources include national meteorological services, remote sensing data (e.g., TRMM, GPM), and local weather stations.

Thirdly, temperature data is a significant factor influencing evaporation rates, which in turn affects runoff and water quality within the basin.

4. Land use/land cover data that provide insight into the utilization of the land are crucial for modeling infiltration rates, runoff, and pollutant loading.

5. The soil characteristics, including texture and type, influence infiltration rates, water retention, and drainage. Sources of data include the geographical soil survey database (SSURGO) and national cooperative soil survey data.

6. Hydrological runoff data are of vital importance for the calibration of models and the comprehension of the hydrological dynamics of the basin. Local hydrological surveys constitute an excellent source of data.

7. Water quality data collection is essential for assessing the impact of land use and management practices on the basin. Furthermore, the collation of historical water quality data is invaluable for the determination of model parameters [6,8].

Accurate river basin modeling requires a combination of spatial data, hydrological data, and information on human activities. The collection of reliable data is vital for successful model calibration and validation, which ultimately contributes to effective water management, flood risk assessment, and environmental protection.

Methods of modeling hydrological processes are based on the use of hydrological models.

Hydrological models: Characterised by the development of models such as HEC-HMS and SWAT, which are used to simulate flow and analyze hydrological cycles. Works such as those described in Stepanenko (2015) [5] and Galasyuk and Lunkov (2019) [2] emphasize the importance of choosing a model for specific conditions.

Geographic information systems (GIS): The integration of GIS in hydrological modeling is an important topic, as it allows for visualizing spatial data and modeling various scenarios, as shown by Alanchuk and Kish (2020) [1].

The current context of environmental change and the need for sustainable water management indicates the need for further research in this area. Many authors, such as Obodzinsky (2017) [4], emphasize the importance of an integrated approach to studying hydrological processes.

The literature review shows that the study of river basin modeling in the Ukrainian Carpathians covers several key aspects, including methods, climate change impact analysis, anthropogenic factors, and environmental impacts. This material provides a basis for further research that can help develop recommendations for sustainable water management in the region.

For successful modeling, it is important to use high-quality data, such as:

- Hydrological observations (river flow and precipitation studies).
- Meteorological data (temperature, humidity, weather conditions).
- Geographical characteristics of the basins (area, landscape).

QGIS is a powerful and flexible hydrological modeling tool that provides users with the ability to actively analyze and model water resources.

QGIS has many plug-ins that extend its capabilities, particularly for hydrological modeling and water resources analysis. The GRASS GIS plug-in was used to model elementary river catchments in the Ukrainian Carpathians.

A watershed can be defined using various software tools that use spatial information based on a digital elevation model. One of these is the free GRASS image processing software.

Basin delineation in GRASS GIS is an important part of hydrological modeling, which allows you to define catchment boundaries for runoff analysis.

Based on digital elevation models and hydrological network maps, elementary basins were created for the rivers of the Ukrainian Carpathians. The digital elevation model used was the CGIAR SRTM model with a spatial resolution of 90 m and further reduced to 30 m (Fig. 1).

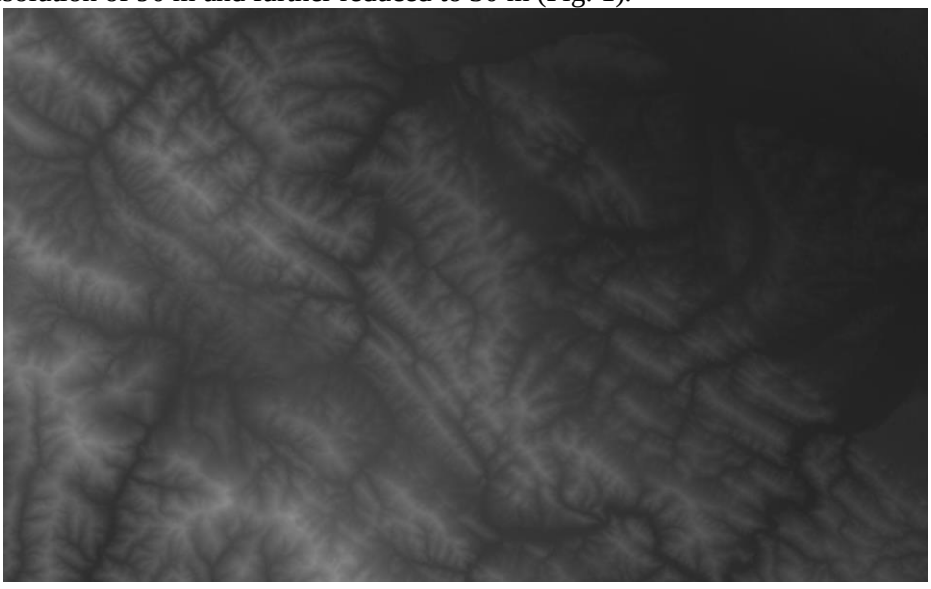

Fig. 1. A fragment of a digital terrain model for the Ukrainian Carpathians.

This modeling was carried out using the GRASS software, an integral part of the QGIS software. The r.watershed module was used to build watersheds using GRASS. This module can be used to create maps showing runoff accumulation, drainage direction, location of streams and river basins, and LS and S coefficients for the Revised Universal Soil Loss Equation (RUSLE).

The geographical area of the study area is the Ukrainian part of the Carpathian Ecoregion. The study area was separated from the general raster of the Digital Elevation Model, and the resulting raster was used to calculate further. For such calculations, an additional threshold parameter was also used, which indicates

the minimum value of the outer catchment basin. The resulting raster image was vectorized and converted to shapefile format. The vector image was further processed in the ARC/GIS environment, and watersheds with an area of up to 4 hectares were aggregated.

The resulting vector map of the Ukrainian Carpathian ecoregion was combined with a map of rivers for a separate analysis of each river (Fig. 2).

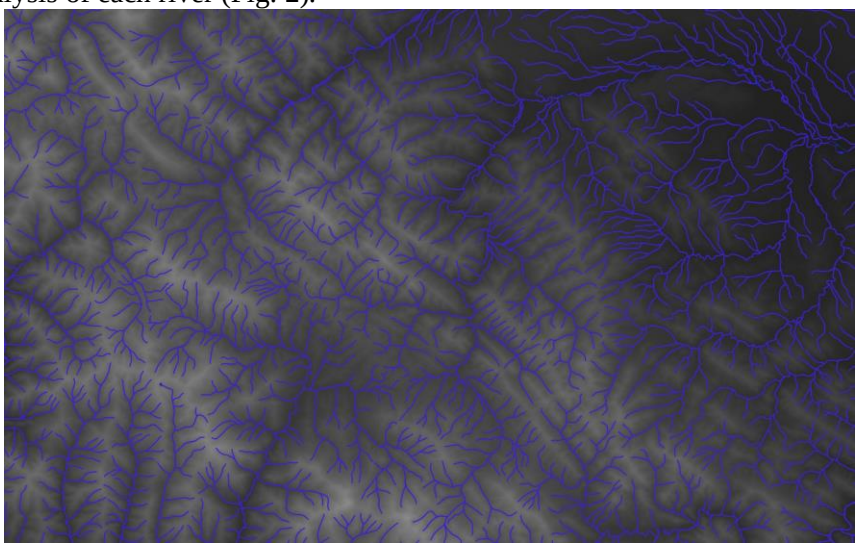

Fig. 2. Digital terrain model combined with river network

Figure 3 illustrates an example of modeling elementary catchments for the Prut River.

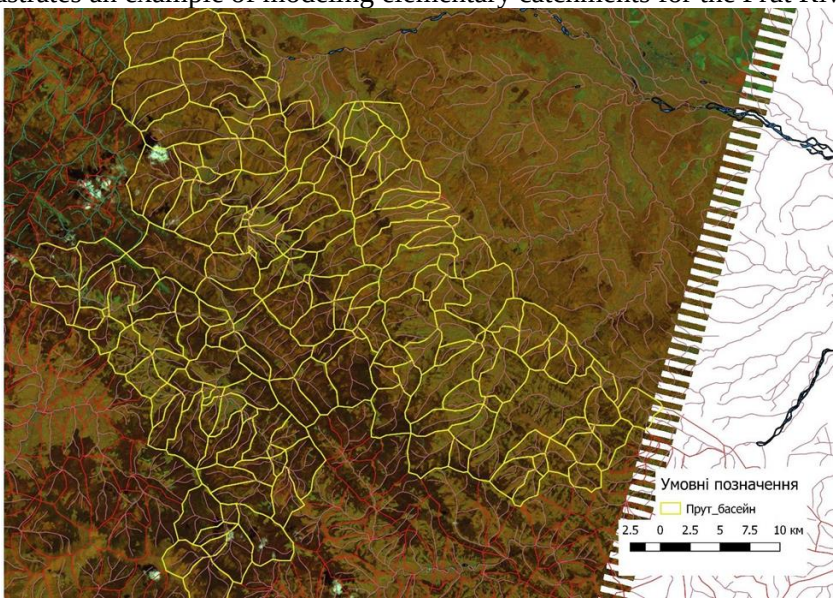

Fig. 3. A model of elementary catchments for the Prut River (background - Landsat-7 satellite image).

Conclusions

Such elementary basins are the basis for spatial planning and management decisions. An important conclusion is the use of geographic information systems for hydrological modeling.

The integration of GIS into the modeling process allows for the visualization of spatial data, which significantly improves the accuracy and visibility of the results. GIS helps to identify the main features of catchment areas, which is important for further analysis and management of water resources.

References

[1] Alanchuk, V. M., & Kish, L. B. (2020). Hydrological features of the rivers of the Ukrainian Carpathians. Journal of Hydrology, 2(3), 45-56.

[2] Galasyuk, L. V., Lunkov, A. M. (2019). Modeling the water regime of rivers under climate change. Ecological Safety: Theory and Practice, 10(1), 19-25.

[3] Zozulya, I. O., & Kostyuk, T. I. (2018). The impact of anthropogenic activity on the hydrological regime of the rivers of the Carpathians. Scientific Bulletin of the Ukrainian Geographical Society, 14(2), 23-30.

[4] Obodzynskyi, V. I. (2017). Hydrology of Ukraine: Textbook. Kyiv: Slovo.

[5] Stepanenko, I. S. (2015). Hydrological models for watersheds. Kyiv: Naukova Dumka.

[6] Petrov, O. A. (2021). The impact of climate change on the hydrological regime of rivers in the western region of Ukraine: dissertation abstract. Lviv: Lviv National University.

[7] Chin, D. A. (2019). Water Resources Engineering. New York: Pearson.

[8] Bowles, D. S. (2016). Hydrology and Water Resource Management. New York: Wiley.

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ПРИНЦИПИ ПРОГРАМНО-ІНФОРМАЦІЙНОГО МОДЕЛЮВАННЯ ГІДРОЛОГІЧНИХ РІЧКОВИХ БАСЕЙНІВ УКРАЇНСЬКИХ КАРПАТ

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Анотація. У статті розглядаються інформаційні та програмні засоби, що використовуються для моделювання гідрологічних басейнів в Українських Карпатах, регіоні, який вирізняється складним рельєфом та різноманітними екосистемами. Дослідження зосереджено на різноманітному програмному забезпеченні гідрологічного моделювання, включаючи додатки HEC-HMS, SWAT та GIS, які полегшують аналіз гідрологічних процесів та оцінку динаміки річкового стоку. Крім того, обговорюється інтеграція метеорологічних даних та інформації про землекористування для підвищення точності гідрологічних моделей. Результати підкреслюють важливість використання передового програмного забезпечення для розуміння впливу зміни клімату, змін у землекористуванні та людської діяльності на водні ресурси в регіоні. Це дослідження має на меті створити основу для сталого управління водними ресурсами та сприяти збереженню водних екосистем в Українських Карпатах.

Ключові слова: Гідрологічне моделювання, Українські Карпати, HEC-HMS, SWAT, GIS, річкові басейни.