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AUTOMATED CONSTRUCTION

METHOD OF DRAINAGE BASIN OF RIVERS OF NAKHCHIVAN REPUBLIC BASED ON DIGITAL ELEVATION MODEL

MÉTODO AUTOMATIZADO DE CONSTRUCCIÓN DE CUENCA DE DRENAJE DE RÍOS DE LA REPÚBLICA DE NAKHCHIVAN BASADO EN EL MODELO DIGITAL DE ELEVACIÓN

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ABSTRACT

Currently, geoinformation technologies are widely used in hydrology for operational calculations and assessment of water resources. The use of aerospace technologies, in particular, digital three-dimensional relief models, makes it possible to quickly carry out automated complex analysis and interpretation of materials from the hydrological analysis of river networks. This article provides a detailed description of the stages of building a model of the river drainage basin on the territory of the Nakhchivan Autonomous Republic of Azerbaijan (NAR) based on a digital elevation model and the use of hydrological analysis tools in a geographic information system. As a result of the study, the morphometric characteristics of the relief were generalized into operational-territorial units of analysis - river basins. For each river basin, average, minimum, and maximum heights, range of heights, average values of slope steepness, exposure, erosion potential of the relief, and other statistical parameters are determined. A number of hydrological maps have been compiled. A feature of the constructed model for the Nakhchivan Autonomous Republic, presented in this article, is the ability to extend it to the creation of a drainage basin of any territory in an automated mode, changing only the initial data.

Keywords: Hydrology, River basins, Digital elevation model.

RESUMEN

Actualmente, las tecnologías de geo información se utilizan ampliamente en hidrología para cálculos operativos y evaluación de recursos hídricos. El uso de tecnologías aeroespaciales, en particular, modelos digitales de relieve tridimensionales, permite realizar rápidamente análisis e interpretación complejos y automatizados de materiales del análisis hidrológico de las redes fluviales. Este artículo proporciona una descripción detallada de las etapas de construcción de un modelo de cuenca de drenaje fluvial en el territorio de la República Autónoma de Azerbaiyán de Nakhchivan (NAR) basado en un modelo de elevación digital y el uso de herramientas de análisis hidrológico en un sistema de información geográfica. Como resultado del estudio, las características morfométricas del relieve se generalizaron en unidades de análisis operativo-territoriales: las cuencas fluviales. Para cada cuenca se determinan alturas promedio, mínima y máxima, rango de alturas, valores promedio de pendiente de pendiente, exposición, potencial de erosión del relieve y otros parámetros estadísticos. Se han compilado varios mapas hidrológicos. Una característica del modelo construido para la República Autónoma de Nakhchivan, presentado en este artículo, es la posibilidad de extenderlo a la creación de una cuenca de drenaje de cualquier territorio de forma automatizada, cambiando solo los datos iniciales.

Palabras clave: Hidrología, Cuencas hidrográficas, Modelo digital de elevación.

INTRODUCTION

Geographic Information Systems (GIS) are a comprehensive framework for collecting, managing, and analyzing data, deeply rooted in geographical science. These systems integrate various data types and analyze spatial locations, organizing information layers for visualization through maps and/or 3D scenes (Lü et al., 2019). This unique capability allows GIS to uncover hidden insights within data, such as patterns, relationships, and situations, thereby aiding users in making informed decisions. GIS technology benefits numerous disciplines and specializations. Professionals in fields like cartography, geography, and surveying often manage these systems, leveraging their expertise to visualize data on maps and relate various geographic phenomena (Aguilar-Moreno & Granell-Canut, 2013). GIS can depict a wide range of information, from road maps to agricultural plot identification and population density. Furthermore, GIS allows for the querying and representation of results in web environments and mobile devices in a dynamic and intuitive manner, effectively solving planning and geographic management problems. Thus, GIS are very common in disciplines such as cartography, geography, surveying, urban planning, architecture, municipal management, route information, and transportation systems for the visualization, analysis, and management of geographic data (Dean et al., 2017).

On the other hand, a drainage basin, also known as a watershed, is a land area where all surface water converges into a single natural drainage system, such as a river flowing into the sea or an endorheic lake. These basins are delineated by ridgelines, or drainage divides (Hilgendorf et al., 2020; Jones et al., 2022). Studying drainage basins is essential for understanding water flow and management in a specific area, allowing for the characterization and description of the watershed's shape and condition. This understanding how water flows within a drainage basin helps manage water resources sustainably, predict and mitigate floods, regulate ecosystems, and plan infrastructure like roads and bridges (Batista et al., 2019). Therefore, studying drainage basins is vital for effective water management, environmental protection, and community safety.

Since its introduction The Digital Elevation Model (DEM) has been crucial for watershed management as it enables geomorphological analysis, morphometric parameter calculation, and runoff estimation, significantly enhancing the understanding and management of water flow. DEMs, integrated with Geographic Information Systems (GIS), automate the extraction of morphometric parameters and use satellite images to create distributed runoff coefficient maps (Martz & Garbrecht, 1992; Yin & Wang, 1999). Digital elevation models (DEM) play an essential role in hydrological and geomorphological analysis. One of the main DEM applications, which has made it possible to massively simplify the analysis of a river-drainage system, is the automated construction of watersheds and the calculation of their morphometric characteristics (Jafarova, 2017; Mamedov et al., 2003; Tabunshchik et al., 2023). Thus, modern aerospace and geo-informational technologies have become an intrinsic part of geoecological research, as the source material is fairly available. Besides, objective quantitative calculation methods are provided, and it is possible to cover large areas simultaneously.

During the calculation of the geomorphometric parameters of the relief, the integration of digital elevation models and geoinformation technologies allows for the development of a set of geoecological maps. Each of these maps allows characterization of the territory in terms of assessing the spatial position and quantitative characteristics of erosion and accumulation processes, illustrating the zones of demolition, transit, and accumulation of sedimentary material, moisture, and dissection (Berland, 2002; Mamedov, 2017a; Mehdiev et al., 2015; Safronova & Kilchenko, 2014). Considering the above, in the article were selected parameters for constructing the drainage basin of rivers on the territory of the Nakhchivan Autonomous Republic of Azerbaijan (NAR) using maps based on a digital terrain model. Such maps most fully reflect the geomorphometric parameters of the relief. They include geometric (surface slope angle, slope exposure, and curvature) and hydrological (total and specific water catchment areas of rivers in the research area) parameters. Since the compiling and editing of the listed maps is a rather complicated process, requiring both time resources and the fulfillment of the calculation process conditions. These conditions resulted in the appeal to geoinformation technologies for compiling a geomodel of the entire process of creating the drainage basin of the rivers of the Nakhchivan Autonomous Republic using the ModelBuilder tools.

We consider the basin approach as the most convenient for the spatial assessment of land areas, which is characterised by a dense river network. Thus, the purpose of this study was to compile an electronic map of the basins of small and large rivers in the catchment area of the rivers of the Nakhchivan Autonomous Republic to form a specialised geoinformation system - "Drainage basins of the rivers of Azerbaijan" within the framework of the thematic work of the Institute of Geography. The compiled maps can serve as a basis for establishing the dependences of the formation and functioning of small river systems and their watersheds on the landscape and geographical conditions of the territory, mapping the patterns of river flow, and solving several other problems.

MATERIALS AND METHODS

The process of creating a cartographic model of basins as an electronic vector layer of basin boundaries can be divided into the following main stages: 1) selection of initial data; 2) preparation of a relief model; and 3) construction of basin boundaries in an automatic mode based on the prepared relief model. When developing a model of the orders of watercourses, the classical Strahler–Filosofov system was used. The primary data for compiling geomorphological maps and building the drainage basin of the study area included the following:

1. Digital elevation model (DEM).
2. Scale topographic maps 1:50000.
3. Satellite data (Google Earth).

In the research, the method of building a process model using the Model Builder tool in ArcGIS was applied to compile maps for conducting a hydrological analysis of the catchment area of the rivers. The Model Builder module is used to create, modify, and manage geoprocessing models, which automates the work with these tools. Modules are operating processes, connected in a series of geoprocessing tools, passing the output of one tool to another tool as input.

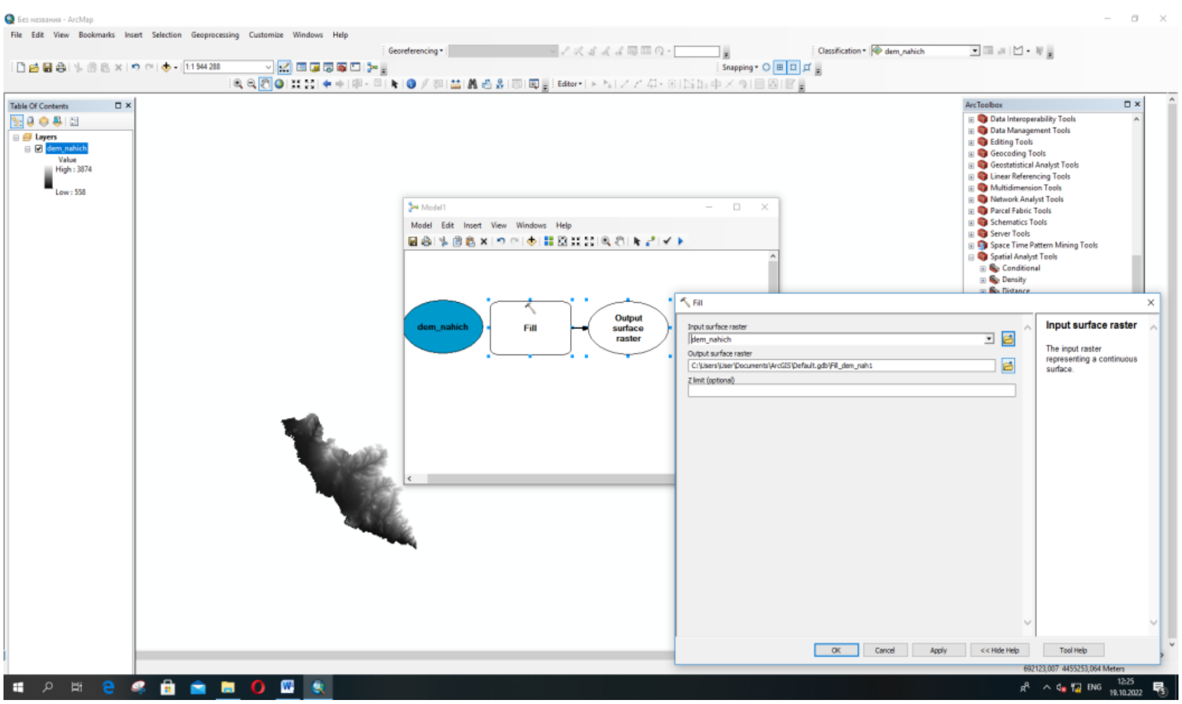
Model Builder can also be considered a visual programming language for developing workflows. To develop a geoprocessing model in Model Builder, one should add tools and data to the model and then make connections among them, together with setting the model execution order.

Model building order:

In the GIS ArcGIS 10.4.1, the Model Builder window is brought out (Figure 1), and the source DEM model file (indicated in blue outline in Figure 1) is added to its working window. The next step is to add the launch window to start the Fill procedure.

One should use the link operation to link the initial information (DEM model) with the Fill procedure. Figure 1 shows this procedure as a pop-up window when one right-clicks on the Fill procedure window. The file with which the following procedure should be linked is indicated in the pop-up dialog box (in Figure 1, Fill is connected with the DEM model). All subsequent steps are processed similarly; each subsequent one is associated with one or more previous results. The Fill procedure is needed to correct errors in forming a DEM model. All following procedures are carried out based on the result of the Fill operation, that is, with the resulting Fill-surface. The next steps are shown in Figure 2 (Mamedov, 2017a; Yermolayev et al., 2018).

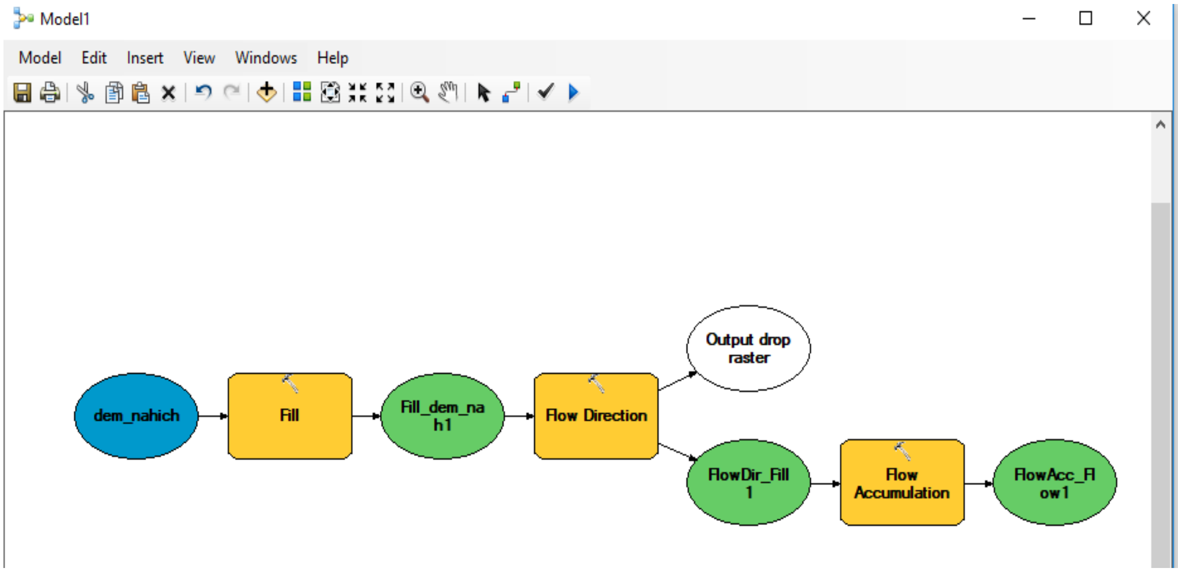
Fig 1. Model Builder window in ArcGIS 10.4.1 environment (DEM model and Fill procedure launch window added).



Source: own elaboration.

Based on the Fill-surface, we obtain the surface of the Flow Direction. Next, based on the Flow Direction surface, we develop the Flow accumulation surface.

Fig 2. Sequence of steps: building a Fill-surface, Flow Direction, and Flow accumulation.



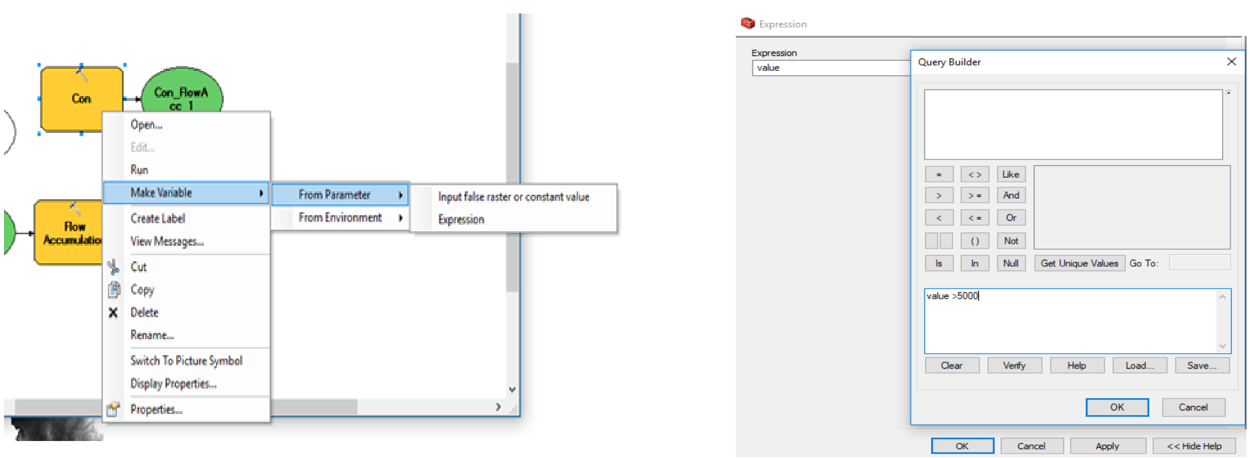
Source: own elaboration.

In each cell, the Flow Direction raster shows the direction of the maximum slope of the terrain. It is necessary for building watersheds and other hydrological and morphometric analysis tasks. The Flow accumulation raster in each cell stores the number of cells drained up the slope. In fact, this number shows the catchment area for each cell. According to the digital elevation model, the catchment area is necessary for the automatic selection of watercourses (valley-lines) (Berland, 2002; Mehdiev et al., 2015; Safronova & Kilchenko, 2014; Tabunshchik et al., 2023).

Continuation of building the model indicating the condition that only rivers, with a level in which the current accumulation value is greater than the specified value, are displayed on the map

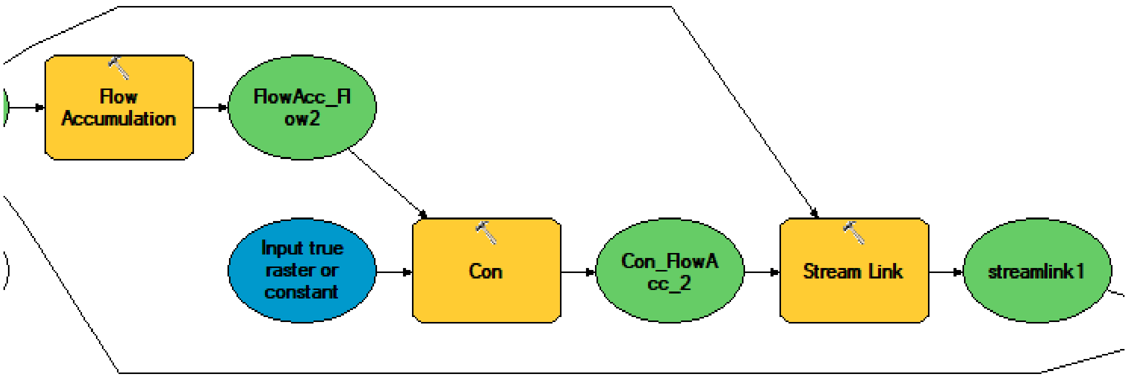
Figure 3 shows the entry of the condition - "watercourses belong to those pixels in which the current accumulation value is greater than the specified value. The rest of the pixels should be blank". To implement this query, one should use the Spatial Analyst > Conditional > CON tool with the parameter: value > 5000 (Figures 3 and 4).

Fig 3. Continuation of building the model.



Source: own elaboration.

Fig 4. A fragment of the model, where the surface of watercourses is built.



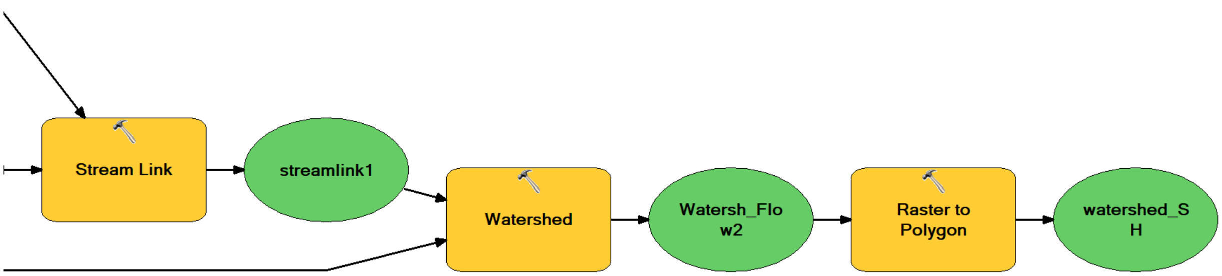
Source: own elaboration.

A fragment of the model, where the surface of watercourses is built, with the current accumulation value greater than the specified value (surface ConFlowAcc2) and the surface Streamlink1

Figure 4 shows a fragment of the model with the development of the ConFlowAcc2 surface, and the Streamlink1 surface is built based on it (the Spatial Analyst Tools > Hydrology > Stream Link tool is applied here). Based on the results of applying this tool, all streams in which the current accumulation value is more than 5000 will be selected on the surface of ConFlowAcc2 and Stream Link (Mamedov, 2017b; Yermolayev et al., 2018). This fragment of the model is for the automatic selection of a model with a different value of the "value" parameter, which allows a user to build a river network of different density.

The watershed vector file is based on the Watershed_Flow2 surface. Here we use the Raster to Polygon tool from the ConversionTools group (Figure 5). As a result, we receive a polygonal vector file for the drainage basin of the rivers of the Nakhchivan Autonomous Republic.

Fig 5. Including the development of a raster of the Watershed surface.



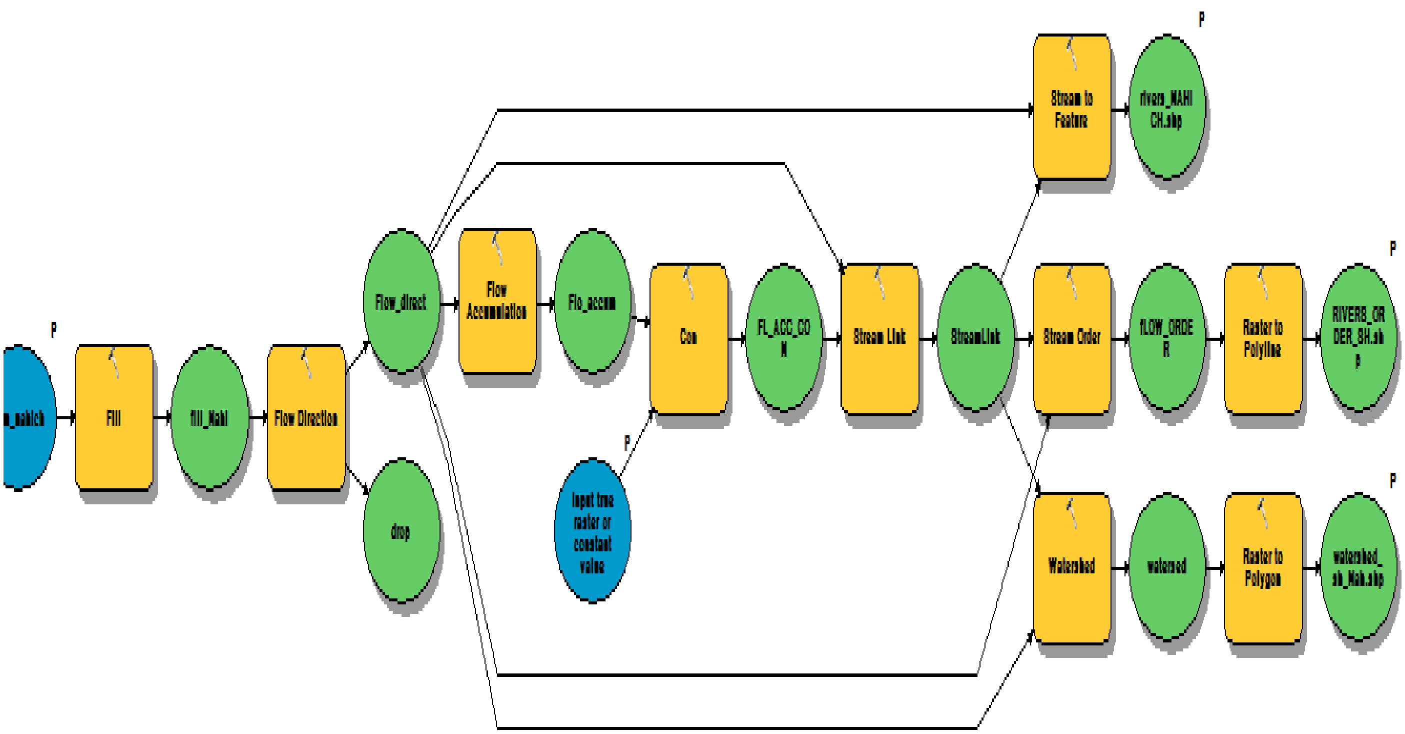
Source: own elaboration.

Figure 5, including the development of a raster of the Watershed surface in the procedure model provided value>5000 and the development of a vector file of the drainage basin

The Stream to Feature (Spatial Analyst Tools > Hydrology > Stream to Feature) tool is used to get a linear vector file of rivers. As a result of this operation, we obtain a vector file of the rivers of the Nakhchivan Autonomous Republic (Figure 6). At the same time, based on the Streamlink1 surface, the StreamOrder surface is developed, being used to create a vector file of large and small rivers of different orders (Figure 6). A river with an order number of 1 indicates that this river has no tributaries, while the rest have 2, 3, or 4 tributaries. For example, if we run the procedure with a value > 1000, the river network will be denser, and there will be more tributaries.

Based on the resulting surfaces, vector line layers Rivers and Riverboarder are created, respectively, using the Raster to Polyline tool from the Conversion Tools group. Consequently, we complete the construction of the model (Figure 6) and launch its verification. Figure 6 presents a complete model for developing the drainage basin of rivers, including the vector layers of rivers and the order of small and large rivers of the Nakhchivan Autonomous Republic of Azerbaijan. The given model was developed using a digital elevation model and compiled using the ModelBuilder tool.

Fig 6. Complete model for developing vector layers of rivers and the drainage basin of the rivers of the Nakhchivan Autonomous Republic.



Source: own elaboration.

RESULTS AND DISCUSSION

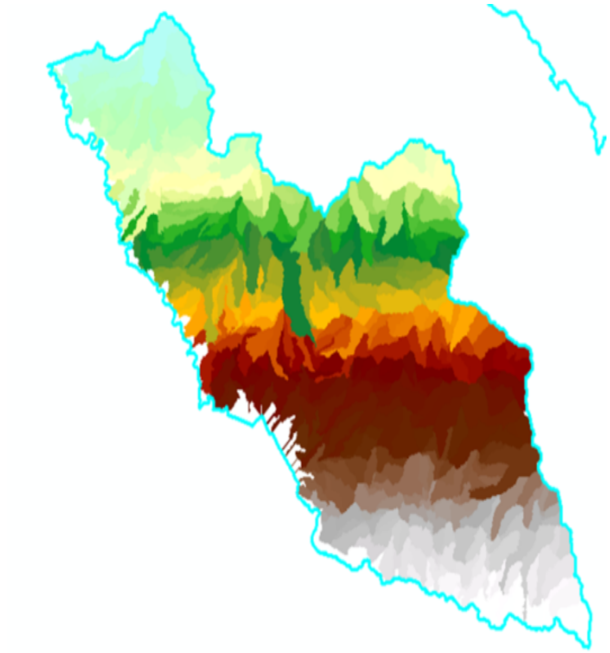
As a result of developing a complete model (Figure 6), the scheme for building surfaces for creating a drainage basin of rivers and a vector layer of rivers, as well as a layer of the order of large and small rivers, was significantly accelerated and simplified. The entire development procedure took a total of thirty minutes, in contrast to the traditional step-by-step development of surfaces based on the scheme (which usually takes from one to two days, taking into account various corrections for the value). In this case, the model was compiled in 30 minutes; the model verification lasted 10 minutes, while the model's launch to obtain results lasted 3 minutes.

Figures 7, 8, 9, 10, 11, and 12 show the results of running the model and its operation, where the original DEM model was corrected using the Fill (Hydrology) procedure. Figure 8 shows the DEM model in layered colour. Figure 9 presents the contours of the watershed of the rivers (based on the watershed shape file). Figure 10 shows the watershed in colour. Figure 11 shows the lines of the rivers obtained under the condition value > 5000.

Fig 7. Initial DEM model of the Nakhchivan Autonomous Republic (NAR).

Source: own elaboration.

Fig 8. DEM-model in layered colouring.

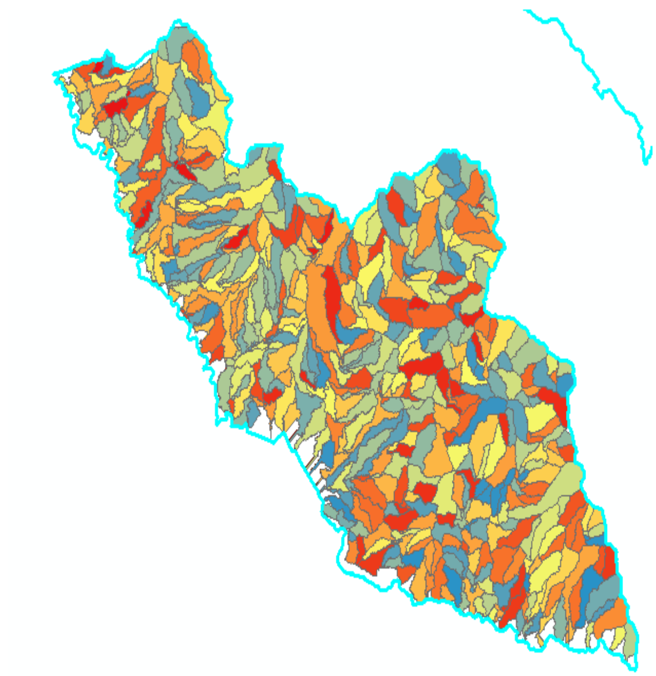


Source: own elaboration.

Fig 9. Drainage basins of rivers of NAR.

Source: own elaboration.

Fig 10. River drainage basins in colour.

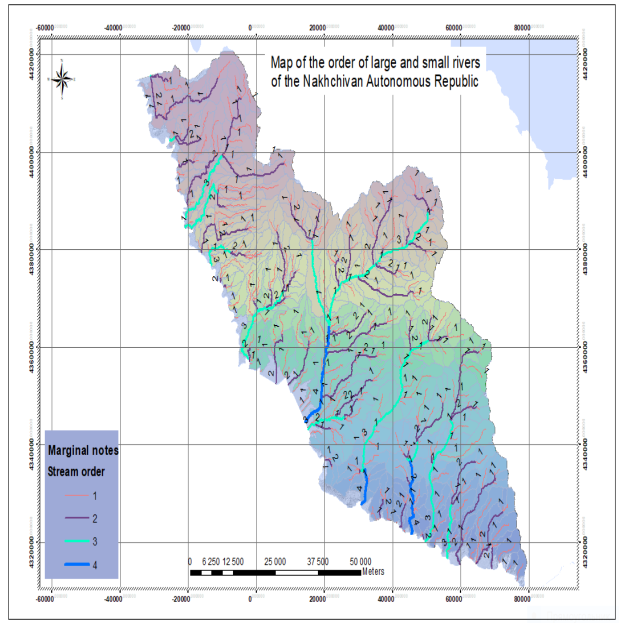


Source: own elaboration.

Fig 11. Rivers feature layer.

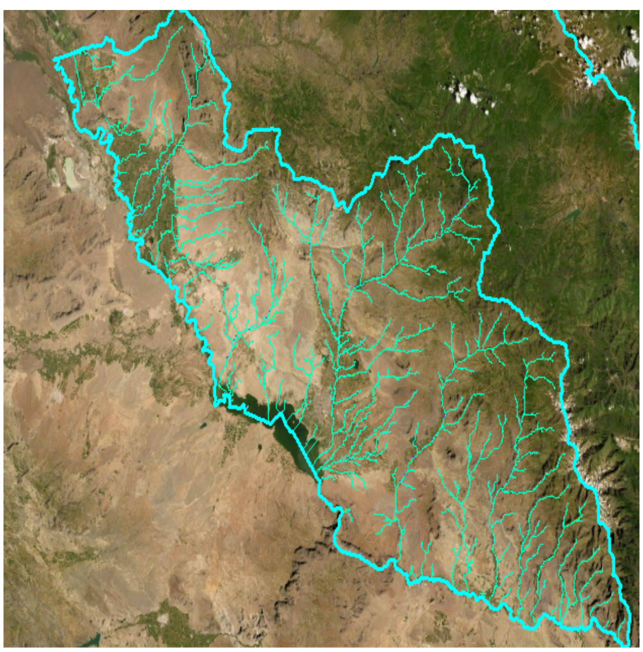
Source: own elaboration.

Fig 12. Vector layer map of the order of large and small rivers.



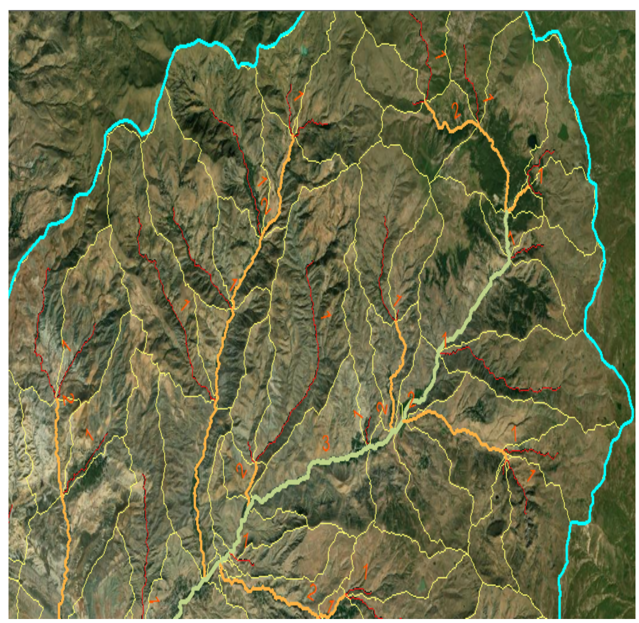
Source: own elaboration

Fig 13. Vector layer of rivers applied on a satellite image.



Source: own elaboration.

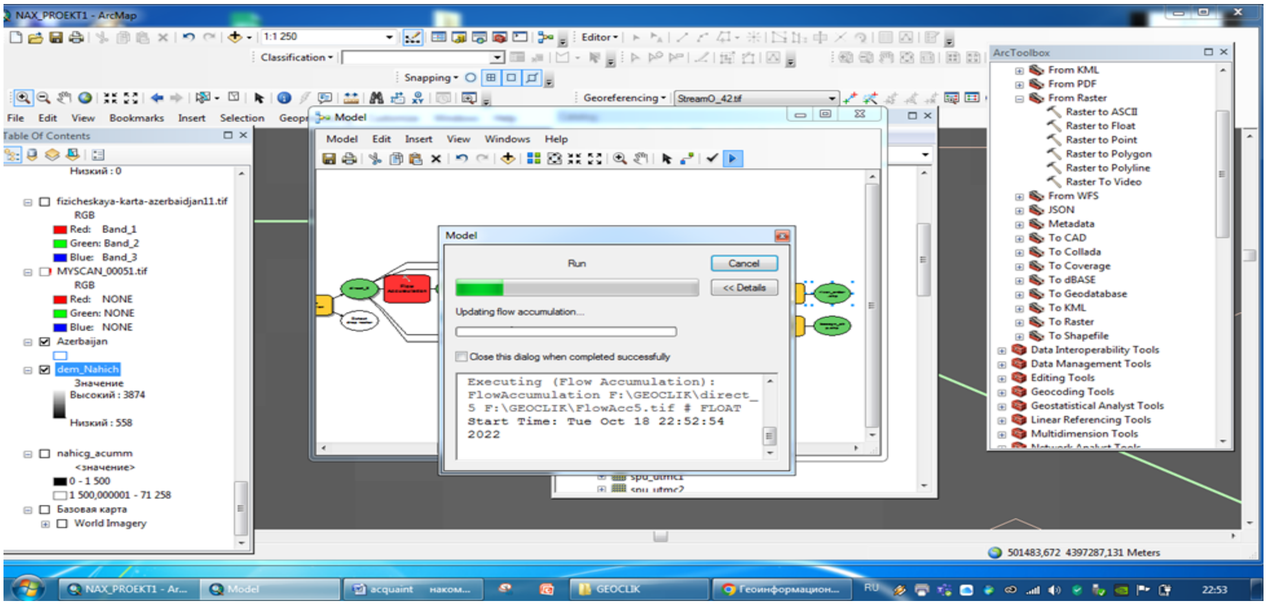
Fig 14. Enlarged fragment layer of rivers and satellite image.



Source: own elaboration.

Figure 12 presents a map of the order of large and small rivers. In Figures 13 and 14, the obtained layers of the rivers applied on the satellite image coincide entirely with the lines of the rivers in the image, which proves the accuracy of the constructed model. Figure 15 shows the launch of the constructed model.

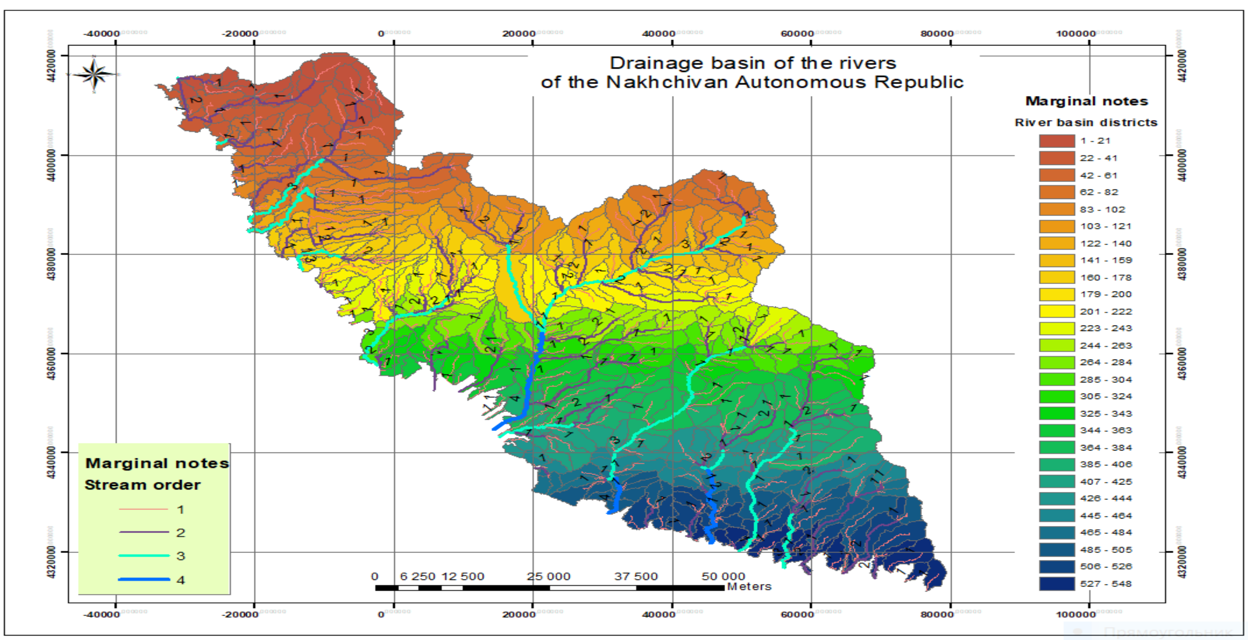
Fig 15. Launch of the complete model for creating a drainage basin for the rivers of the Nakhchivan Autonomous Republic.



Source: own elaboration.

After running the full model (Figure 15), on return, we obtain the vector layers of the drainage basin of the rivers and the linear vector layers of the rivers and the order of the rivers, based on which an integral map is compiled (Figure 16).

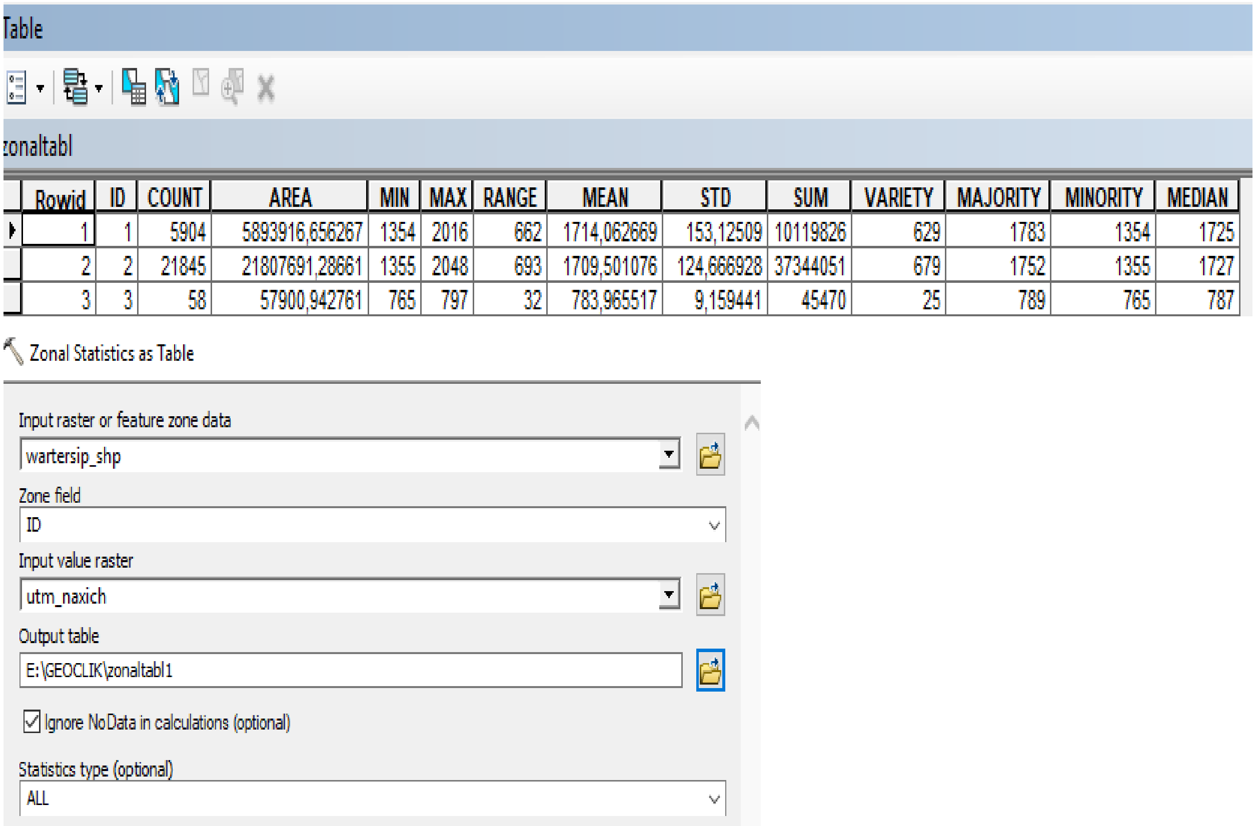
Fig 16. Map of the drainage basins of the rivers of the Nakhchivan Autonomous Republic.



Source: own elaboration.

Different statistics from DEM data can be estimated within the watersheds. The research has calculated height statistics using the Spatial Analyst Tools > Zonal > Zonal Statistics as Table module (Figure 17). In this case, a table is compiled by height parameters, where the input file is a DEM model in layered colour (Figure 8) and a watershed vector layer (Figure 10). In this case, a table is created with the following parameters.

Fig 17. Dialog box for calculating height statistics.

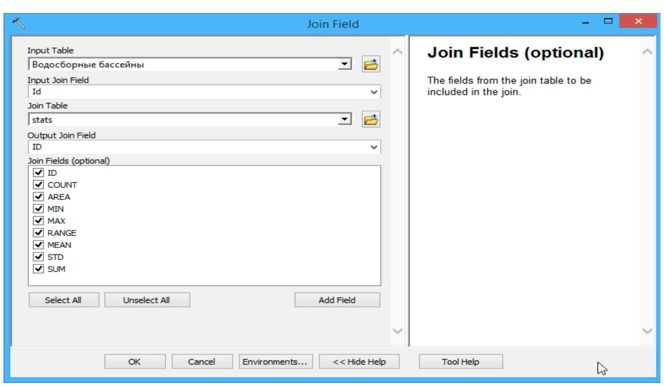


Rowid	ID	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM	VARIETY	MAJORITY	MINORITY	MEDIAN
1	1	5904	5893916,656267	1354	2016	662	1714,062669	153,12509	10119826	629	1783	1354	1725
2	2	21845	21807691,28661	1355	2048	693	1709,501076	124,666928	37344051	679	1752	1355	1727
3	3	58	57900,942761	765	797	32	783,965517	9,159441	45470	25	789	765	787

Source: own elaboration.

Furthermore, the table of height statistics for watersheds should be attached to the original basin layer (watershed) (Berland, 2002; Mamedov, 2017b; Safronova & Kilchenko, 2014; Yermolayev et al., 2018). This procedure is conducted using the Data Management Tools ÞJoinsÞJoinField tool with the following parameters (Figure 18).

Fig 18. Dialog box for join tables.



Source: own elaboration.

After carrying out the actions of the tool, it was obtained an attribute table of the Watershed layer, where each basin with the GRIDCODE code will be associated with statistics parameters in the following form (Figure 19).

Fig 19. Attribute table of the Watershed layer.

Таблица

baseyn

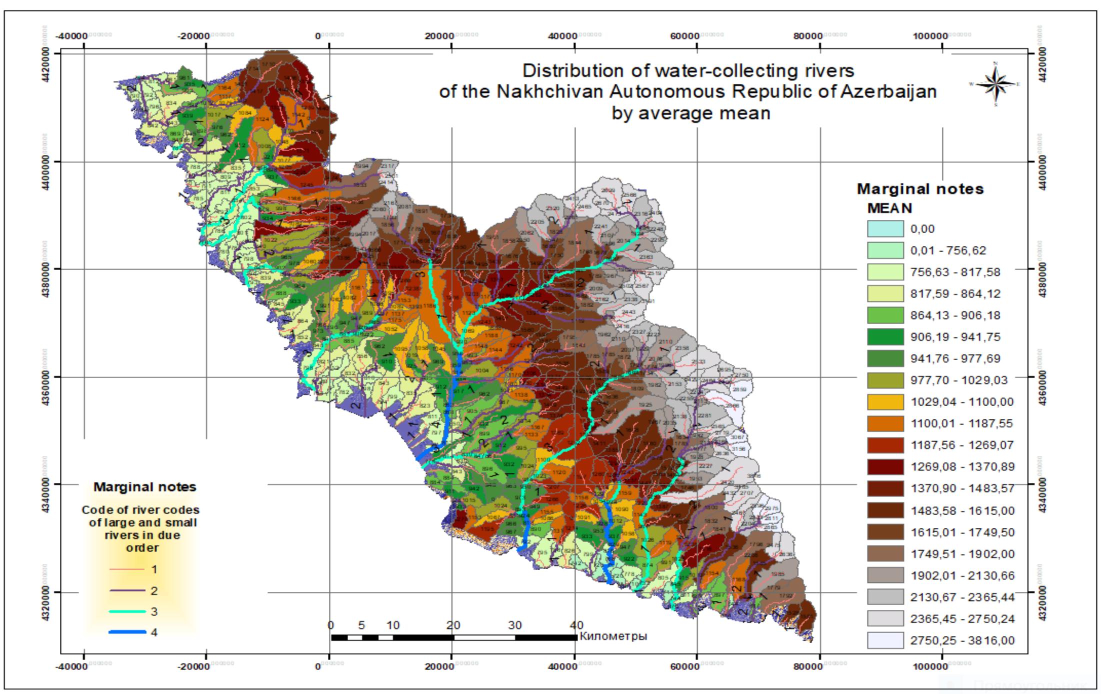
FID	Shape	ID	GRIDCODE	ID 1	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM	VARIETY	MAJORITY	MINORITY	MEDIAN
1	Полигон	2	1	2	21845	21807691,2866	1355	2048	693	1709,501076	124,666928	37344051	679	1752	1355	1727
0	Полигон	1	2	1	5904	5893916,65627	1354	2016	662	1714,062669	153,12509	10119826	629	1783	1354	1725
15	Полигон	16	3	16	20179	20144536,6204	1145	1919	774	1416,702116	135,842727	28587632	709	1308	1145	1405
6	Полигон	7	4	7	7941	7927437,69773	768	957	189	812,04269	29,427126	6448431	176	798	768	802
2	Полигон	3	5	3	58	57900,942761	765	797	32	783,965517	9,159441	45470	25	789	765	787
16	Полигон	17	6	17	8072	8058213,965	740	825	85	792,065783	11,136931	6393555	82	799	740	793
4	Полигон	5	7	5	3615	3608826,00142	801	1113	312	860,617151	53,737933	3111131	254	824	801	837
7	Полигон	8	8	8	15801	15774013,734	944	2029	1085	1435,807417	224,054589	22687193	1041	1554	944	1437
8	Полигон	9	9	9	15866	15838902,7216	925	2054	1129	1332,249086	254,865237	21137464	1070	957	926	1318
3	Полигон	4	10	4	6868	6856270,25665	822	1204	382	960,983401	85,886107	6600034	369	857	824	964
19	Полигон	20	11	20	9205	9189278,93309	948	1911	963	1440,471266	248,606742	13259538	939	959	948	1435
5	Полигон	6	12	6	5039	5030393,97543	823	1233	410	935,104981	85,24218	4711994	390	885	823	919
13	Полигон	14	13	14	9334	9318058,61612	935	1602	667	1164,029034	133,211576	10865047	617	1088	935	1130
10	Полигон	11	14	11	12461	12439718,0647	773	1155	382	902,520103	76,566774	11246303	371	829	774	894
9	Полигон	10	15	10	5303	5293943,0942	935	2026	1091	1448,832925	254,672162	7683161	997	1587	937	1475
11	Полигон	12	16	12	5673	5663311,17734	1133	1987	854	1430,968271	204,340321	8117883	789	1221	1133	1395

Source: own elaboration.

Based on the average heights for each drainage basin, a final map of the distribution of the drainage basins of the rivers of the Nakhchivan Autonomous Republic was compiled (Figure 20).

The map (Figure 20) for each drainage basin shows the average height and order of large and small rivers in this basin.

Fig 20. Map of drainage basins of rivers distributed over the territory according to average heights.



Source: own elaboration.

CONCLUSIONS

Geographic information systems are considerably used in hydrology to perform operational calculations and assess water resources. They are also applied while studying the hydrological regime of water bodies. Many problems of collecting, processing, and interpreting data, as well as designing hydrological networks and preparing proposals for decision-making with the widespread use of GIS technology and personal computers can be solved more quickly and efficiently than it has been so far in hydrological practice. The ability of GIS technology to promptly represent water bodies on digital or paper maps, together with their hydrographic characteristics, hydrological posts, and measurement data, makes it possible to quickly carry out automated complex analysis and interpretation of observation materials to obtain a detailed picture of ongoing processes.

Recently, in hydrology, mathematical-cartographic modelling methods have been widely used when introducing computer technologies to solve engineering and scientific problems, as well as in other areas of natural science. These include the modelling of the drainage basin of rivers. The spatial organisation of the physical properties of the drainage basin is a result of the long-term interconnected evolution of erosive landforms, soils, and landscapes, including under the influence of climatic factors and biota, i.e., the river basin is an evolving system, the physical parameters of which change over time. In addition to natural factors, the parameters of the river basin can change due to anthropogenic impact: urbanisation, land reclamation, etc. The rate of these changes is usually much higher than the rate of natural changes.

The research has generalised the morphometric characteristics of the relief to the operational-territorial units of analysis - river basins. For each basin, it was determined the average, minimum, and maximum height, range of heights, average values of slope steepness, exposure, erosion potential of the relief, and other statistical parameters. The results of the model were coincidentally compared with the rivers' lines on satellite images, which showed their full compatibility. The establishment and functioning of the geomodel for the Nakhchivan Autonomous Republic, presented in this article, can be extended to creating a drainage basin of any territory in an automated mode, changing only the initial data.

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