Modeling ecosystem services in Armenia using InVEST: a scenario-based approach with NextGIS Web integration for public awareness and engagement

Eduard Kazakov[1], Elena Bukvareva[2]

[1] NextGIS OÜ, Tallinn, Estonia - ee.kazakov@gmail.com
[2] Biodiversity conservation center, Yerevan, Armenia - bukvareva@gmail.com

Keywords: Ecosystem Accounting, Ecosystem Services, Web GIS, InVEST.

Abstract

This study explores the application of the open-source InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) tool to model ecosystem services in Armenia, utilizing a scenario-based approach. By simulating three hypothetical scenarios, where all natural terrestrial land cover classes are replaced with bare ground or croplands, and the reverse scenario replacing anthropogenic areas with grasslands, the study emphasizes the critical role of terrestrial ecosystems in ecosystem service provisioning. The results are published through Web GIS platforms powered by open-source framework NextGIS Web, providing an interactive medium for engaging civil society and fostering public awareness. This integration of advanced modeling techniques with accessible web-based dissemination aims to influence strategic policy-making in forest management, water resource allocation, and urban planning. The findings highlight the potential of scenario analysis and Web GIS to support sustainable development by illustrating the value of ecosystem services to both policymakers and the public.

1. Introduction

Ecosystem services (ESs), the benefits humans derive from nature, are crucial for supporting human well-being, and a key factor influencing them, alongside climate change, is land use and land cover change, LULCC (IPBES, 2019). In the context of Armenia, a country with diverse landscapes and significant environmental challenges, there is an understanding of the vital importance of ESs and their sustainable management (GIZ Eco-Serve project, 2017). The adoption of the law to launch the EU accession process (Republic of Armenia, 2025) strengthens Armenia's strategic integration into European processes, including ES assessment and accounting, as well as raising public awareness about maintaining ESs and protecting biodiversity.

One of the main methods for assessing the impact of LULCC on ESs is the use of various land cover scenarios. Most studies analyze past land cover changes or model various future scenarios to assess changes in ESs and to forecast their future dynamics (Hasan et al., 2020, Liu et al., 2022, Stürck et al., 2015). These approaches require LULC maps for previous periods or a set of future LULC scenarios related to climate and socio-economic projections or territorial development plans.

This study was carried out as part of a scoping ES assessment in Armenia to develop recommendations for initiating ecosystem accounting in the country (Biodiversity conservation center (BCC Armenia), 2025). To demonstrate the importance of ecosystem accounting for tracking ES changes we used ESRI land cover data from 2017 and 2023. Since maps of planned LULC changes at the national level were not available at this stage of the research, we did not consider future LULC scenarios. However, we found it useful to test the most general hypothetical scenarios that make it possible to assess in physical terms the full volume of key regulating ecosystem services provided by natural ecosystems.

This study employs the InVEST tool (Natural Capital Project, 2025), an open-source software suite designed for ecosystem service modeling, to assess critical services on example of Sediment Delivery Ratio, Seasonal Water Yield, and Urban Flood Risk Mitigation models. By adopting a scenario-based approach, we aim to estimate the physical volume of ES provided by natural ecosystems and changes in it from 2017 and 2023. Our approach involves several key steps: data collection and preprocessing, scenario development, models parametrization, statistics calculations over model outcomes, mapping and results publishing via Web GIS.

2. Materials and methods

2.1 Study area

Armenia, which shares borders with Iran, Azerbaijan, Turkey, and Georgia, located in the Caucasus Mountains, spans 29,743 km² with altitudes ranging from 375 to 4,090 m and an average elevation of 1,800 m (Fig. 1). Only 18% of the land consists of flat valleys. The climate varies vertically, with average temperatures from +9 to +26°C in summer and +1.2 to -12.8°C in winter. Annual precipitation averages 500 mm, ranging from 230 to 1,100 mm, and the country has several climate zones, from arid to humid (Fifth National Report of the Republic of Armenia to the Convention on Biological Diversity, 2014).

Grasslands dominate the landscape, covering 67% of the area, followed by forests (11%), croplands (12%), and built-up areas (5%). Forests are mainly in the more humid northeast and southeast. Agricultural development is moderate overall. Semi-deserts are the most altered by human activity, now largely croplands and settlements. Steppes have also been significantly transformed, (from 9% to 28% of area of different types of steppes). Mountain forest landscape zone have only 4% of their area converted. High mountain zones remain least impacted. Irrigated farming in semi-deserts has led to soil degradation, while steppes and alpine zones are heavily grazed or used for haymaking, contributing to grassland decline. Forests suffered major losses from logging (1930–1950) and an energy crisis

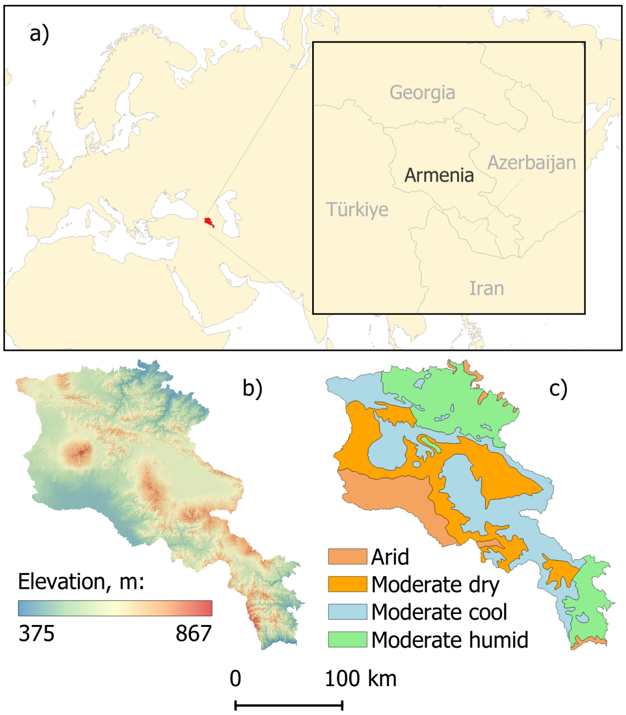

Figure 1. Geography of Armenia. Position on the global map and regional neighbors (a), relief map (b), climate zones map (c). Data sources: Natural Earth Data (land, borders), Copernicus DEM (relief), Forest Atlas of Armenia (climate zones).

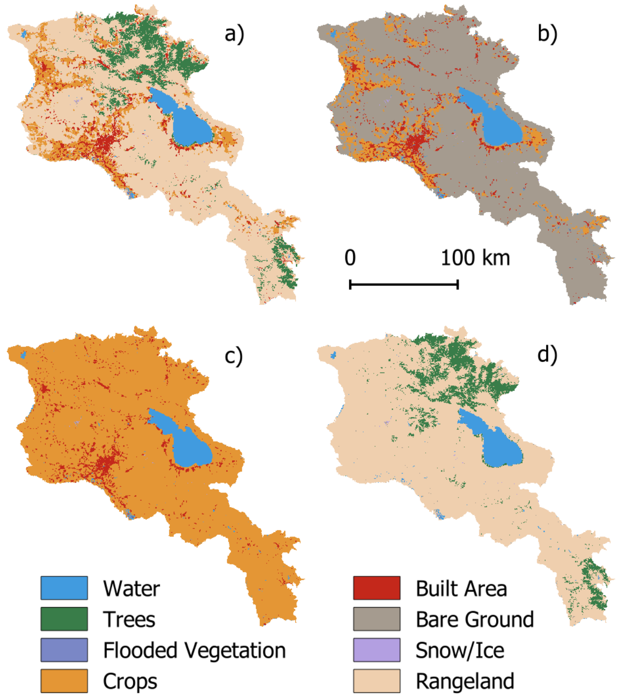

Figure 2. Armenia landcover under different scenarios. Current landcover (a), bare ground scenario (b), cropland scenario (c), no-human scenario (d).

(1992–1995) (Fifth National Report of the Republic of Armenia to the Convention on Biological Diversity, 2014).

Due to geology and climate, surface water distribution is uneven. The northeast and southeast receive more rainfall and have dense drainage due to sedimentary rocks. In contrast, the central and western areas, in a rain shadow and covered by porous igneous rocks, have sparse drainage. Armenia has 379 rivers over 10 km in length, mostly flowing into the transboundary Kura or Araqs rivers. Peak flow typically occurs in May to early June. Rivers are managed within six river basin areas.

2.2 Scenarios and models

To highlight the role of natural ecosystems, a scenario-based approach was used, aiming to estimate ecosystem contributions by comparing model outputs under different scenarios. Four base scenarios were proposed (Fig. 2):

1. Current land cover: represents the actual state of ecosystems based on the land cover map used.
2. Bare ground scenario: all vegetation, including forests and grasslands, was replaced with bare groud. This hypothetical scenario illustrates the importance of vegetation by modeling its complete disappearance.
3. Cropland scenario: all areas, except for urban territories and water bodies, were replaced with cropland, simulating a situation where agricultural expansion eliminates natural ecosystems.
4. No-human scenario: urban areas and croplands were replaced with rangelands, representing a landscape where human activity is removed and replaced by grasslands.

Then we selected three InVEST models for the first set of experiments related to ecosystem accounting in Armenia:

1. Sediment Delivery Ratio (SDR)
2. Seasonal Water Yield (SWY)
3. Urban Flood Risk Mitigation (UFRM).

2.2.1 The Sediment Delivery Ratio model is designed to estimate the role of ecosystems, especially vegetation and land management practices, in preventing soil erosion and retaining sediment before it reaches water bodies. It builds upon the widely used RUSLE (Revised Universal Soil Loss Equation) framework (Renard, 1997) by adding a spatially explicit sediment delivery component, which allows mapping not just erosion risk, but the actual sediment load likely to be delivered to streams. The model identifies critical areas where erosion is a problem and evaluates the capacity of current land cover to mitigate sediment movement. It supports land-use planners, conservationists, and policymakers in targeting areas for restoration or protection, by identifying where vegetation and land cover changes can most effectively reduce sediment transport and improve water quality. Its key outputs are potential soil loss from each pixel, estimated sediment exported from each pixel to streams, sediment retained due to vegetation and management and sediment export and retention at subwatershed level (Fig. 3).

2.2.2 The Seasonal Water Yield model simulates the availability of water across seasons by estimating the partitioning of precipitation into different hydrological components - namely surface runoff (quickflow), baseflow, and actual evapotranspiration. Unlike simpler annual water yield models, this model captures monthly variability, which is essential in regions with distinct wet and dry seasons. It conceptualizes the

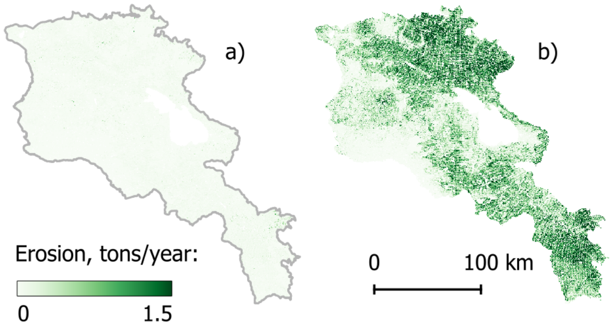

Figure 3. Sediment Delivery model key outputs. Erosion for current landcover (a), Erosion for bare ground scenario (b).

hydrological cycle through a simplified water balance approach, taking into account land cover, soil properties, and climatic conditions. This model is especially valuable for understanding how land use influences seasonal water availability, and it can be used to support decisions related to watershed management, irrigation planning, and climate adaptation. It helps reveal how ecosystem characteristics (like forest cover or agricultural use) regulate the flow and storage of water throughout the year. Its key outputs are water yield for each month, total annual water yield, surface runoff component (quickflow) and subsurface flow component (baseflow) (Fig. 4).

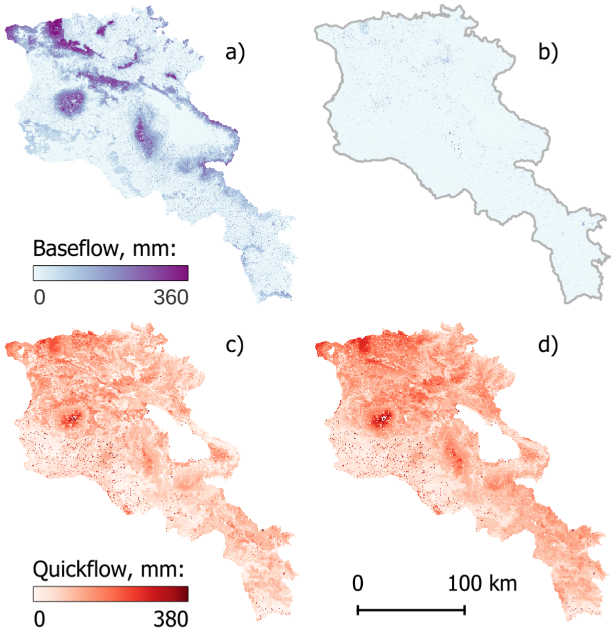

Figure 4. Seasonal Water Yield model key outputs. Baseflow for current landcover (a), Baseflow for bare ground scenario (b), Quickflow for current landcover (c), Quickflow for bare ground scenario (d).

2.2.3 The Urban Flood Mitigation model estimates the potential of green infrastructure — such as vegetation, pervious surfaces, and natural landscapes — to reduce flood risk in urban environments. It focuses on stormwater retention during extreme rainfall events, especially in areas where urbanization has increased impervious surface cover (e.g., roads, rooftops), which prevents water infiltration and heightens flood risk. This model simulates how different land cover types retain stormwater, and it calculates how much water is retained on-site before contributing to surface runoff. The model also identifies downstream areas that would benefit from this retention by estimating which populations and assets (like infrastructure or buildings) are shielded from flooding as a result of upstream vegetation. Its key outputs are amount of rainwater (in mm) retained by each pixel and the reduction in runoff volume due to vegetation and green surfaces.

2.3 Data sources

In order to provide necessary data to run InVEST models, we used mostly public domain global spatial databases. Their quality and availability also open wide way to reproduce the approach at any region. But still several key inputs required more detailed information compared to global public domain datasets, so we used several specific datasets from Armenian sources.

- Land use / Land cover. This data is a key input for all 4 used InVEST models. After process of different global landcover datasets analysis we decided to use **ESRI landcover** (Karra et al., 2021) as a primary layer. Having high spatial resoltion (10 meters / pixel), simple but clear land cover classification and acceptable quality for Armenia, it has solid retrospective with 1 year temporary resolution and secure future. We used ESRI Landcover for 2017 and 2023.

- Digital elevation model. Relief related data is also one of the most important for esosystem services modeling, because it defines water transport processes and all connected phenomenons. We selected **Copernicus DEM** (European Space Agency (ESA), 2024) data as a primary source for elevation data due its high resolution (30 meters / pixels) and global-proven quality.

- Precipitation and temperature data. We used **WorldClim average montly precipitation data** as general source of rain- and snowfall data and WorldClim average montly temperature data as general source of intra-annual temperature dynamics. It has acceptable spatial resolution of 30 arc-seconds / pixel (Fick and Hijmans, 2017). Statistics on rain events in different climate zones were obtained using online meteorological archive (pogoda360, 2025) as the average for several cities located within every climate zone. We also used ESDAC Global Rainfall Erosivity (Panagos et al., 2017) data to support sediment delivery ratio model calculation.

- Reference evapotranspiration. Global Aridity Index and Potential Evapotranspiration (ET0) Database (Zomer et al., 2022) was used. It is based on WorldClim data so well compatible with precipitation and temperature data.

- Watersheds. We used 6th level watersheds from **HydroBASINS database** (Lehner and Grill, 2013) as primary source of hydrological basins information.

- Soil data. For determining soil groups spatial distribution first we tried to use global databases as HYSOGs250m (Ross et al., 2018) but found there was too little detail. Taking into account critical value of soil data for water-related ecosystem services we used high-detailed soil map from Interactive Forest Atlas of Armenia (UN Environment, 2025).

- Climate zones. To distinct behavior of different land-cover classes under differen climate conditions we used climate zones, proposed by Armenian scientists and published in Interactive Forest Atlas of Armenia (UN Environment, 2025).
- Crop coefficients (Kc) were determined expertly based on FAO recommendations (Food and Agriculture Organization of the United Nations, 1998) and Leaf Area Index data (Copernicus Land Monitoring Service, 2020).
- Armenia border as study extent was taken from Interactive Forest Atlas of Armenia (UN Environment, 2025) as the most relevant public national source of such data.

2.4 Data preprocessing

Several preprocessing steps were necessary to prepare the data for modeling.

The first preprocessing task addressed snow accumulation and melting. The SWY model requires precipitation data as a key input; however, the WorldClim dataset does not distinguish between liquid precipitation and snow. This creates a significant inconsistency, as snow does not contribute to runoff until it melts. To account for this, we applied the following logic: for each pixel, if the mean monthly temperature was below 0°C, the corresponding precipitation was assumed to fall as snow and was excluded from that month's liquid precipitation total. Instead, the snow was accumulated and carried over to the same pixel in the next month's data. This process continued until the temperature exceeded 0°C, at which point all accumulated snow was assumed to melt, contributing a single, cumulative pulse of liquid water input.

The second preprocessing step involved generating land cover maps for each scenario by modifying pixel values. For example, in the cropland scenario, all pixels originally classified as 2 (forest), 4 (flooded vegetation), 8 (bare ground), and 11 (rangeland) were reclassified to 5 (crops).

The third task addressed the limitation of land cover classes as the sole proxies for territorial properties. In a country with diverse landscapes like Armenia, identical land cover classes can represent very different ecosystems, for example, grasslands in alpine versus semidesert zones. To account for this variability, we synthesized the land cover data with a climate zones map, effectively shifting from general land cover types (e.g., ”forest”, ”cropland”) to composite categories such as “forest in an arid zone” or “cropland in a moderately humid zone.” The climate zones were originally provided as a vector layer in GeoPackage format. We rasterized this layer to match the land cover rasters in terms of spatial extent, resolution, and coordinate reference system. During rasterization, numeric codes from 1 to 4 were assigned to the climate zones. The merging process involved two steps:

1. Multiplying the land cover raster pixel values by 100.
2. Adding the climate zone raster values to these scaled land cover values to create a composite dataset.

For example, a pixel value of 204 would indicate land cover class 2 (e.g., forest) in climate zone 4 (e.g., moderately humid). The final preprocessing step was to reproject all source and derived datasets into a common coordinate reference system. We selected UTM Zone 38N (EPSG:32638) to minimize spatial distortion over the territory of Armenia.

All preprocessing was carried out using the open-source software QGIS (QGIS Development Team, 2025) and custom Python scripts built on top of the GDAL (GDAL/OGR contributors, 2025) library.

2.5 Data publishing

From the first day of the project we decided to publish every bit of data and all analytical observations and conclusions we have.

To publish maps and geospatial data we utilized the open-source NextGIS Web framework (NextGIS, 2025), dedicated to store and publish geospatial data in the web. It supports both publishing web-maps with graphical interface and publishing geospatial data services as WMS, WFS, TMS and other, which open possibilities to integrate stored data to external portals and databases. Built-in web-maps interface allows users to explore rich styled raster and vector data and it's descriptions.

In parallel, a web site with all information about the project is beeing maintained.

3. Results and Discussion

3.1 Ecosystem services estimations

The hypothetical scenarios we used (Bare ground, Cropland, No-human), which are highly unlikely in practice, nonetheless proved useful for demonstrating ES magnitude provided by ecosystems and, thus, for highlighting the importance of ecosystems for the well-being of the population and the country's economy. The LULC scenarios for 2017 and 2023 demonstrated predominantly negative changes in ESs driven by land cover transformations. Below are examples of how these scenarios were applied to three regulating ESs:

1. Seasonal redistribution of water flow (SWY)
2. Prevention of soil water erosion and sediment runoff into water bodies (SDR)
3. Flood risk mitigation (UFRM).

3.1.1 Bare ground scenario: we used this scenario to demonstrate to the general public and decision-makers the full volume of regulating ESs provided by terrestrial ecosystems. The SWY and UFRM models calculate and map the indicators of ecosystem functions (baseflow, quick flow, runoff retention, quick runoff), but these indicators do not show which part of the functions is determined by the abiotic environment (such as sunlight, precipitation, topography, geological substrate) and which part is performed by living nature. In other words, we need to determine the contribution of the biotic component of ecosystems to these functions. We estimated ES volume provided by terrestrial ecosystems as difference between ES indicator values for the current land cover in 2023 and the bare ground scenario. The SDR model directly calculates ES volume that is specifically provided by ecosystems—the indicators of avoided erosion and avoided sediment export in waterbodies. However, in this case, the balance between ES portion provided by living nature and ES portion formed by the abiotic environment remains unclear. Therefore, for this model, we also applied the bare ground scenario to determine this balance. The use of the bare ground scenario provided estimates of the full volume of ESs performed by the living components of ecosystems. In other words, this represents the portion of ESs that can be lost with the complete removal of vegetation, as can occur locally during extensive surface mining or development without green infrastructure. Estimates of ES provided by ecosystems were obtained (Fig. 5).

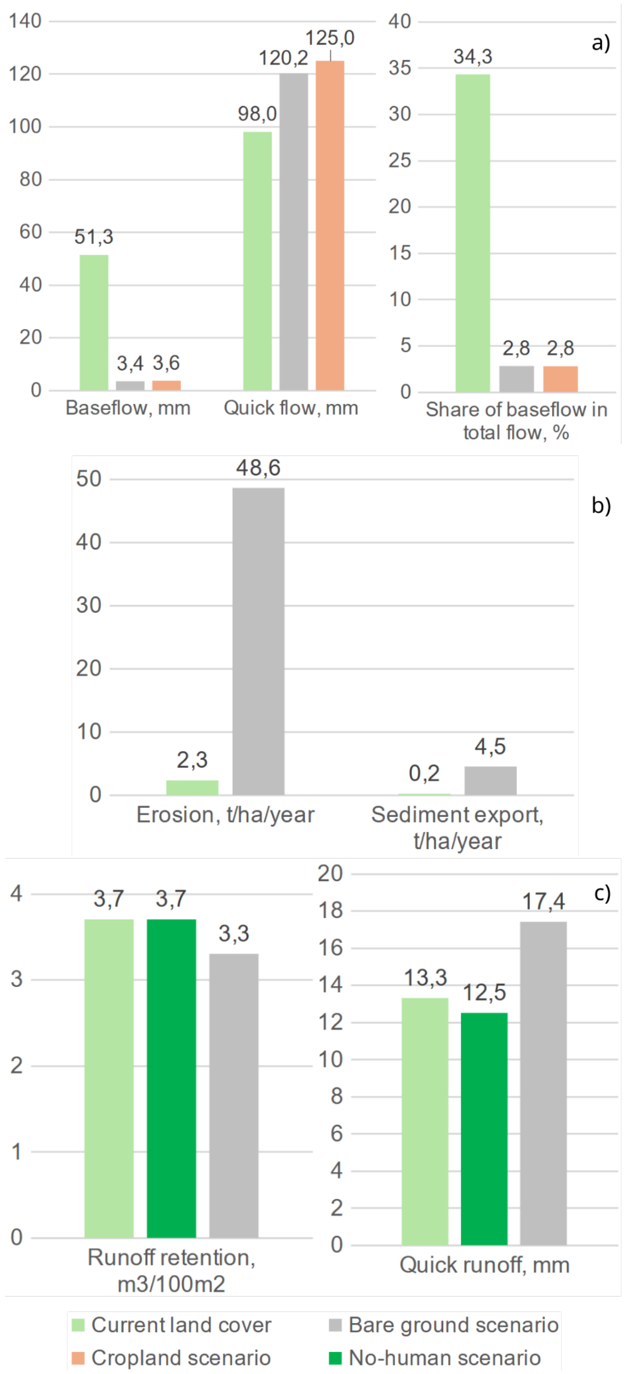

Figure 5. ES indicators for different scenarios: a) Seasonal redistribution of water flow (SWY); b) Prevention of soil water erosion and sediment runoff into water bodies (SDR); c) Flood risk mitigation (UFRM).

These results have highlighted the crucial role of terrestrial ecosystems for the well-being of the population and the economy of Armenia. Ecosystems provide 93% of baseflow. Under the current land cover, baseflow accounts for an average of 35% of the total flow, whereas under the bare soil scenario, it drops to just 3%. Ecosystems prevent of more than 95% of erosion and sediment wash-off into water bodies. This means that ecosystems almost entirely ensure the quality of runoff and its continuation during the dry and hot summer period, which is critically important for Armenia. Ecosystems reduce spring and early summer flood risk by increasing runoff retention by 11% and decreasing quick flow by 24% compared to bare ground.

3.1.2 Cropland scenario: this scenario was tested for the ES of seasonal redistribution of water flow (SWY) to assess potential ES loss that could occur if ecosystems are replaced by cropland. SWY model predicts that ES loss in this case could be no less than in the bare soil scenario (Fig. 5a). In other words, croplands cannot even partially help to maintain water flow in dry and hot summer.

3.1.3 No-human scenario: this scenario was tested for the ES of flood risk mitigation (UFRM) to assess ES loss that has occurred historically due to the anthropogenic conversion of natural grasslands into croplands and built-up areas. On average in Armenia, this loss is almost negligible in terms of runoff retention and minor in terms of the increase in quck runoff (Fig. 5c). However, in areas occupied by human activity, ES loss is much more pronounced: quick runoff increased by 15% in croplands and by one-third in built-up areas (Fig. 6).

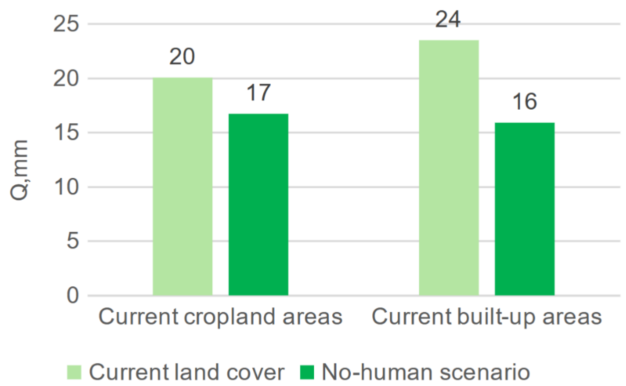

Figure 6. Quick runoff (UFRM) in areas currently occupied by croplands and built-up zones.

3.1.4 2017 and 2023 land covers: land cover data for different years can also be considered scenarios for ES modeling, because in order to identify changes in ESs, the model needs to be run for each of these land covers. Determining changes in ESs directly based on changes in the area of land cover classes in Armenia can lead to significant errors, as the same land cover class can play completely different roles in ES providing across regions with diverse topography, climate, and soil conditions.

Despite the insignificant changes in the absolute area of different land cover classes from 2017 to 2023, a negative trend was identified in the dynamics of all ecosystem services (Fig. 7). The values of all positive ES indicators, except for avoided sediment expert, decreased (shown in green in Fig. 7). The values of negative indicators (shown in pink) increased.

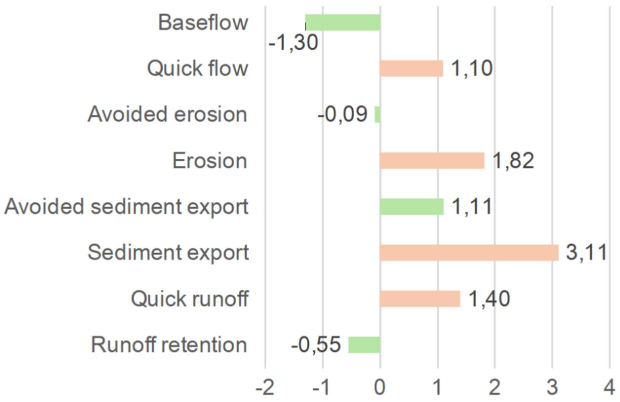

Figure 7. Changes in mean ES indicators from 2017 to 2023, % relative to 2017.

3.2 Public engagement

Publishing data from day one in both data-centered (Web GIS) and analysis-centered (article-based) formats increased the project's visibility and elicited reactions from the Armenian public. After six months of working with full transparency, we were able to formulate several key observations:

- National experts from various related fields (e.g., geobotany, landscape ecology, water resource management), who possess deep knowledge of local specifics, were able to identify controversial or erroneous estimates and discuss their causes and nature with us. While data is usually published at the end of a project, sharing it continuously throughout the project lifecycle encourages more communication, iterative improvement, and more effective search for future approaches to model validation based on local data.
- Interactive web maps (Fig. 8) accessible from any device and location significantly ease communication with decision-makers.
- Immediate data publication opens up broader opportunities to promote the topic of ecosystem accounting and engage a wide range of audiences, not only specialists, but also school teachers and university lecturers.

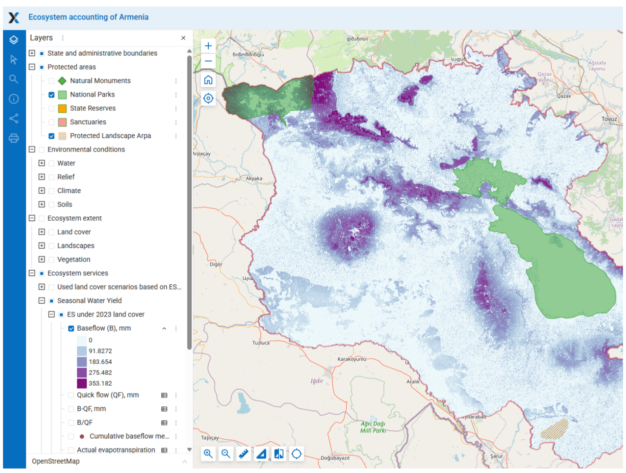

Figure 8. NextGIS Web public map web interface.

4. Conclusion

Our study demonstrates the utility of scenario-based modeling ecosystem services and open Web GIS in supporting sustainable resource management.

The hypothetical scenarios we used, involving the complete disappearance of natural land cover classes and, conversely, the replacement of anthropogenic areas with grasslands, demonstrated both the full volume of regulating services currently provided by natural ecosystems and the loss of ecosystem services that occurred historically due to human land use. These estimates are important for raising awareness among the general public and decision-makers about the critical value of natural ecosystems.

The insights gained from the InVEST models can inform policy decisions in several key areas such as spatial planning, agricultural, forest, and water resource management. Open-source technologies and public domain data as a core of the study open wide prospects for reproducing similar research for any other country.

Maps and data are published at https://bccarmenia.nextgis.com/
Project site is https://biodiversity-armenia.am/en

Funding allocation from the Federal Environment Agency (UBA), Germany. The principal organization is the Leibniz IOER, Dresden, Germany, with a service contract effective from June 1, 2024, according to Section 631 and the following sections of the German Civil Code.

References

Biodiversity conservation center (BCC Armenia), 2025. `https://biodiversity-armenia.am` (25 April 2025).

Copernicus Land Monitoring Service, 2020. Leaf area index (lai) 300m version 1.0. `https://land.copernicus.eu/en/products/vegetation/leaf-area-index-300m-v1.0`.

European Space Agency (ESA), 2024. Copernicus digital elevation model (copernicus dem). `https://spacedata.copernicus.eu/collections/copernicus-digital-elevation-model` (25 April 2025).

Fick, S. E., Hijmans, R. J., 2017. WorldClim 2: New 1-km Spatial Resolution Climate Surfaces for Global Land Areas. *International Journal of Climatology*, 37(12), 4302–4315.

Fifth National Report of the Republic of Armenia to the Convention on Biological Diversity, 2014. `https://www.cbd.int/doc/world/am/am-nr-05-en.pdf` (25 April 2025).

Food and Agriculture Organization of the United Nations, 1998. *Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper, 56, FAO, Rome.

GDAL/OGR contributors, 2025. GDAL/OGR geospatial data abstraction software library. gdal.org (10 March 2025).

GIZ EcoServe project, 2017. Ecosystem services in armenia: Overview of different activities on ecosystem services implemented by the government of armenia and different organizations in the period of 2011-2017. `https://biodivers-southcaucasus.org/uploads/files/5b461310dad8a.pdf` (25 April 2025).

Hasan, S. S., Zhen, L., Miah, M. G., Ahamed, T., Samie, A., 2020. Impact of land use change on ecosystem services: A review. *Environmental Development*, 34, 100527. https://www.sciencedirect.com/science/article/pii/S2211464520300464. Resources Use, Ecosystem Restoration and Green Development.

IPBES, 2019. Global assessment report on biodiversity and ecosystem services of the intergovernmental science-policy platform on biodiversity and ecosystem services. https://doi.org/10.5281/zenodo.6417333.

Karra, K., Kontgis, C., Statman-Weil, Z., Mazzariello, J. C., Mathis, M., Brumby, S. P., 2021. Global land use/land cover with sentinel 2 and deep learning. *2021 IEEE international geoscience and remote sensing symposium IGARSS*, IEEE, 4704–4707.

Lehner, B., Grill, G., 2013. Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. *Hydrological Processes*, 27(15), 2171–2186.

Liu, M., Wei, H., Dong, X., Wang, X.-C., Zhao, B., Zhang, Y., 2022. Integrating Land Use, Ecosystem Service, and Human Well-Being: A Systematic Review. *Sustainability*, 14(11). https://www.mdpi.com/2071-1050/14/11/6926.

Natural Capital Project, 2025. InVEST 3.15.0. naturalcapitalproject.stanford.edu(10March2025).

NextGIS, 2025. Nextgis web. https://github.com/nextgis/nextgisweb (28 April 2025).

Panagos, P., Borrelli, P., Meusburger, K., Yu, B., Klik, A., Jae Lim, K., Yang, J. E., Ni, J., Miao, C., Chattopadhyay, N. et al., 2017. Global rainfall erosivity assessment based on high-temporal resolution rainfall records. *Scientific reports*, 7(1), 4175.

pogoda360, 2025. Armenia at pogoda360. http://armenia.pogoda360.ru/ (10 March 2025).

QGIS Development Team, 2025. QGIS Geographic Information System. Open Source Geospatial Foundation. qgis.org (10 March 2025).

Renard, K. G., 1997. *Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)*. US Department of Agriculture, Agricultural Research Service.

Republic of Armenia, 2025. National Assembly of the Republic of Armenia. http://www.parliament.am/draft_history.php?id=15342 (25 April 2025).

Ross, C. W., Prihodko, L., Anchang, J., Kumar, S., Ji, W., Hanan, N. P., 2018. HYSOGs250m, global gridded hydrologic soil groups for curve-number-based runoff modeling. *Scientific data*, 5(1), 1–9.

Stürck, J., Schulp, C. J., Verburg, P. H., 2015. Spatio-temporal dynamics of regulating ecosystem services in Europe – The role of past and future land use change. *Applied Geography*, 63, 121-135. https://www.sciencedirect.com/science/article/pii/S0143622815001538.

UN Environment, 2025. Interactive Forest Atlas of Armenia. https://forestatlas.am/ (15 April 2025).

Zomer, R. J., Xu, J., Trabucco, A., 2022. Version 3 of the global aridity index and potential evapotranspiration database. *Scientific Data*, 9(1), 409.