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3. Ecosystem services

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3.1. Regulating ES

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3.1.A. Methodology of assessment of water-related regulating ES

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3.1.A1. General modeling framework

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Four of the six regulating services assessed are closely linked to the water cycle via evapotranspiration and indicators of surface runoff and baseflow. They were assessed using the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) integrated tool:

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- Seasonal water flow regulation and baseflow provision (InVEST Seasonal Water Yield);

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- Prevention of soil water erosion and sediment export in waterbodies (InVEST Sediment Delivery Ratio);

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- Flood risk mitigation (InVEST Urban Flood Risk Mitigation);

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- Cooling effect of terrestrial ecosystems (InVEST Urban Cooling).

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The modeling framework simulated current (2023) and past (2017) conditions, as well as alternative land-cover scenarios, to evaluate ecosystem services (ES) provided by terrestrial ecosystems and to detect changes in these services (Figure 31A1-1). To calculate ES values across the different EAAs, we used the administrative boundary map from the Forest Atlas of Armenia and the vegetation map developed under the project (Section 2.3). A comparison of the modeling results with ARMSTAT water-use data was conducted to assess the supply–use balance, thereby demonstrating the relevance of ES accounting data for evidence-based decision-making on water use and territorial development.

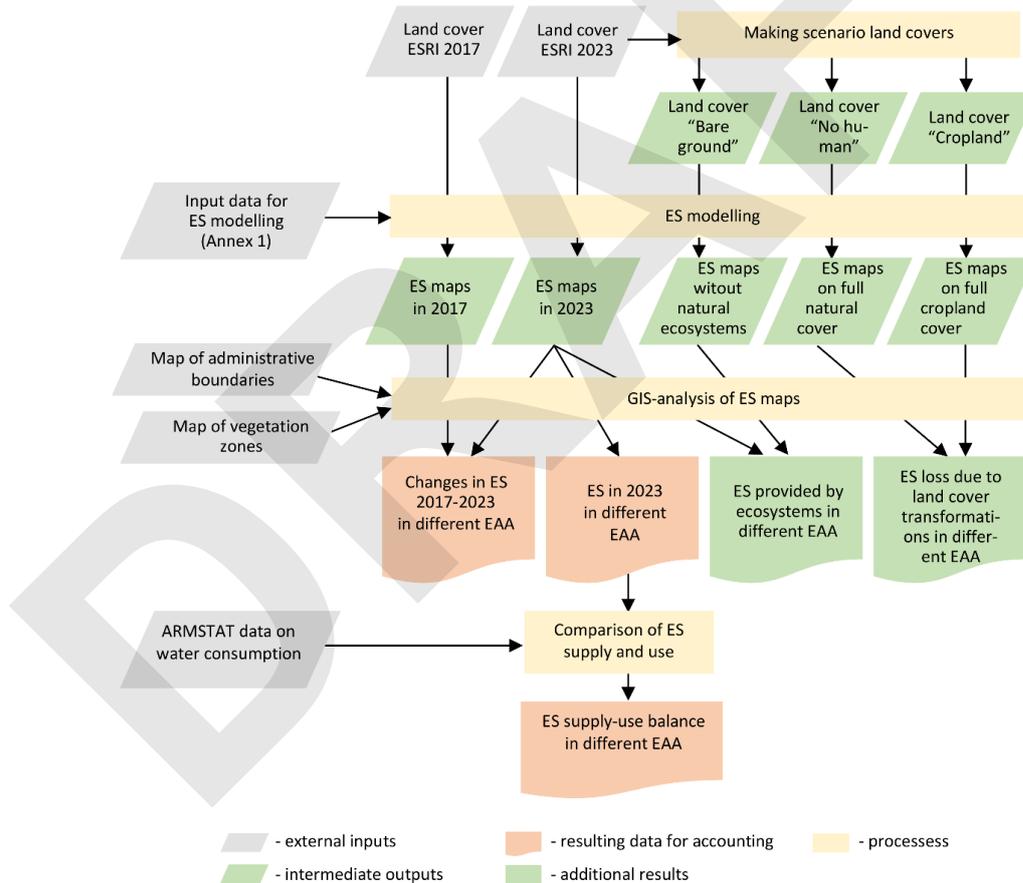
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Figure 31A1-1. Flow-chart of ES assessment.

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3.1.A2. The InVEST models used

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The ES of seasonal water flow regulation and baseflow provision was estimated and mapped with InVEST Seasonal Water Yield (SWY) model which estimates the impact of terrestrial ecosystems on the total amount of water flow and its seasonal redistribution. Based on monthly precipitation, reference evapotranspiration, soil permeability, topography, and the land use/land cover (LULC), the model calculates two key indicators: quick flow and baseflow. Quick flow

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1401 represents the portion of precipitation that runs off during or shortly after a rain event (within hours to days). Baseflow
 1402 is the portion of precipitation that gradually enters streams through subsurface flow with watershed residence times
 1403 ranging from months to years. Baseflow plays a crucial role in maintaining water flow during dry periods and mitigating
 1404 the impacts of drought.

1405 The ES of prevention of soil water erosion and sediment export in waterbodies was estimated and mapped with
 1406 InVEST Sediment Delivery Ratio (SDR) model which estimates the impact of terrestrial ecosystems on soil water erosion
 1407 and sediment export into streams. The model relies on the widely used Universal Soil Loss Equation (USLE) and Sediment
 1408 Delivery Ratio that estimates the ratio between the amount of sediment eroded from each land pixel, the amount of
 1409 sediment that is trapped along the flow path downslope from this pixel, and the amount of sediment that reaches a
 1410 stream. Based on rainfall erosivity, soil erodibility, topographic, and LULC data, the model calculates potential and
 1411 avoided erosion and sediment export into streams. Thus, the model evaluates and maps two ecosystem services
 1412 simultaneously: prevention of soil water erosion and ensuring water flow quality.

1413 The ES of flood risk mitigation was estimated and mapped with InVEST Urban Flood Risk Mitigation (UFRM) model
 1414 which calculates two main indicators: (1) the runoff retention, i.e., the amount of runoff retained by soil and vegetation
 1415 when modeling rainfall; (2) the runoff (Q), mm, which is a potentially hazardous factor that can cause flooding. These
 1416 calculations were based on LULC, soil hydrologic groups, watersheds and climate data.

1417 Cooling effect of terrestrial ecosystems was estimated and mapped with InVEST Urban Cooling (UC) model which is
 1418 primarily aimed at assessing the cooling effect of green spaces within urban areas. However, it also allows for evaluating
 1419 this effect over large areas outside of cities. Since the assessment of urban ES is not a goal of our project, we focused on
 1420 the ES of areas outside settlements. We used the Cooling Capacity Calculation Method, which estimates *cooling capacity*
 1421 based on evapotranspiration, albedo, shade (the proportion of area that is covered by tree canopy), air temperature in a
 1422 rural reference area, and the Urban Heat Index (UHI), i.e., the difference between the rural reference temperature and
 1423 the maximum temperature observed in the city. We modeled this ES for the hottest season in Armenia—July and August.

1424 Detailed descriptions of the models can be found in the above-mentioned sections of the InVEST website and in the
 1425 InVEST User Guide [42].

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3.1.A3. Model inputs

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Table 31A3-1. Model inputs.

Data Type	Models	Sources	Resolution	Notes
LULC	SWY, SDR, UFRM, UC	ESRI land cover data	10 m	Data for 2017 and 2023
Soil hydrologic groups	SWY, UFRM	Soil map of Armenia from [38]	Vector map	The hydrological soil groups were defined in accordance with USDA recommendations [44]: A—slightly and moderately stony sand; very stony sandy loam; B—slightly and moderately stony sandy loam; very stony loam; C— slightly and moderately stony loam; very stony clay; D—slightly and moderately stony clay. The obtained map of soil hydrologic groups is presented on the project's webGIS [45]
Soil erodibility (K- factor)	SDR	Soil map of Armenia from [38]	Vector map	A soil erodibility map was obtained on the basis of soil textures using the following coefficients from the InVEST User Guide [42]: 0.0290 for clay, 0.0395 for loam, 0.0171 for sandy loam, 0.0026 for sand.
Digital elevation model	SWY, SDR	[46]	30 m	-
Watershed boundaries	SWY, SDR, UFRM	[HydroSHEDS]	Vector map	The analysis was made for parts of watersheds that are located on the territory of Armenia: Aghstev, Akhuryan, Arpa, Debed, Hrazdan, Metsamor, and Vorotan (Figure 31A3-1)
Climate data (annually and monthly precipitation and temperature)	SWY, UFRM, UC	[47]	30 arc seconds *	The amount of liquid precipitation has been adjusted to take into account the snow period (see below)
Rain events table	SWY, UFRM	[48]		The number of rainy days for each climatic zone was calculated as the average for several cities located within that zone. In the moderate-cool climate zone, where there are no cities, the average data for this zone is based on three cities situated near its border [49]
Climate zones of Armenia	SWY, SDR, UC, UFRM	The map of climate zones of Armenia from [38]	Vector map	The digital vector map of climate zones of Armenia was generalized to the four climate zones: (1) Arid; (2) Moderate dry; (3) Moderate cool; (4) Moderate humid. For details, see the project's webGIS [45] Figure 31A3-2
Monthly refe- rence evapotrans- piration (ETO)	SWY, UC	[50]	30 arc seconds *	-

Crop coefficients Kc	SWY, UC	[51,52]		Kc were determined for the four climate zones. The used Kc are presented at the project website [49]
Crop vegetation periods	SWY, UC	[53]		Vegetation periods were determined for the four climate zones
Leaf Area Index	SWY, UC	[54]		The LAI values for dates in the middle of the months were used
Curve numbers (CN)	SWY, UFRM	[55–57]		Coefficients for medium hydrological conditions and vegetation states were used. For croplands and rangelands, differences in climatic zones were taken into account [48]
C-factor for crops	SDR	[58]		C-factor was defined as average values for Europe: 0.3 for crops and sparse vegetation, 0.05 for rangelands (average between pastures and low productive grasslands), and 0.0014 for forests (average value for Southern European countries). C-factor was considered equal to zero for water, flooded vegetation, built areas, and snow/ice on the InVEST recommendations.
P-factor	SDR	-		P-factor was considered equal to 1 because we did not take into account special anti-erosion measures
Rainfall erosivity	SDR	[59]	30 arc sec *	
Albedo	UC	[58]		The following albedo values were used for land cover classes: water and flooded vegetation 0,6; trees 0.15; rangeland 0.2; crops 0.2; built-up area 0.17; bare ground 0.25; snow/ice 0.9
Shade	UC	-		The following shade values were used for land cover classes: built-up – 0.2; forests – 1.0; croplands, taking into account the share of orchard area, in the arid climate zone – 0.35, in the moderate-dry and moderate-cool zones – 0.03, in the moderate-humid zone – 0.34, other land cover classes – 0.
UHI effect	UC	[59]		The UHI value was set to zero

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* At latitude 40°, 30 arc seconds correspond to an area of approximately 709 by 390 m.

1429 For the SWY, SDR and UFRM models, we used those portions of HydroSHEDS level-6 watersheds that lie within
 1430 Armenia. These parts of the watersheds are further named after their largest rivers (Figure 31A1-3a):

- 1431 – Aghstev (involves Getik and Voskepar tributaries)
- 1432 – Akhuryan
- 1433 – Arpa (involves the Arpa River, the Azat River and the Vedi River)
- 1434 – Debed (involves Pambak and Dzoraget tributaries)
- 1435 – Hrazdan (involves two parts – Lake Sevan drainage basin and its outlet River Hrazdan)
- 1436 – Metsamor (involves Kasagh tributary)
- 1437 – Vorotan (involves Vorotan River, the Voghji River, and the Meghri River).

1438 Note that these are not the basins of the named rivers themselves, but the portions of larger basins, named after the
 1439 largest river present in each portion.

1440 For comparing ES supply and use, it is important that the watershed boundaries largely coincide with marz boundaries
 1441 (Figure 31A1-3b).



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1443 *Figure 31A3-1. Watersheds used for ES modeling: a) Watersheds and points of cumulative baseflow values in the lower*
 1444 *reaches of rivers; b) Boundaries of marzes and watersheds, the boundaries and names of the marzes are shown in black;*
 1445 *the watersheds are shown in different colors with blue labels.*

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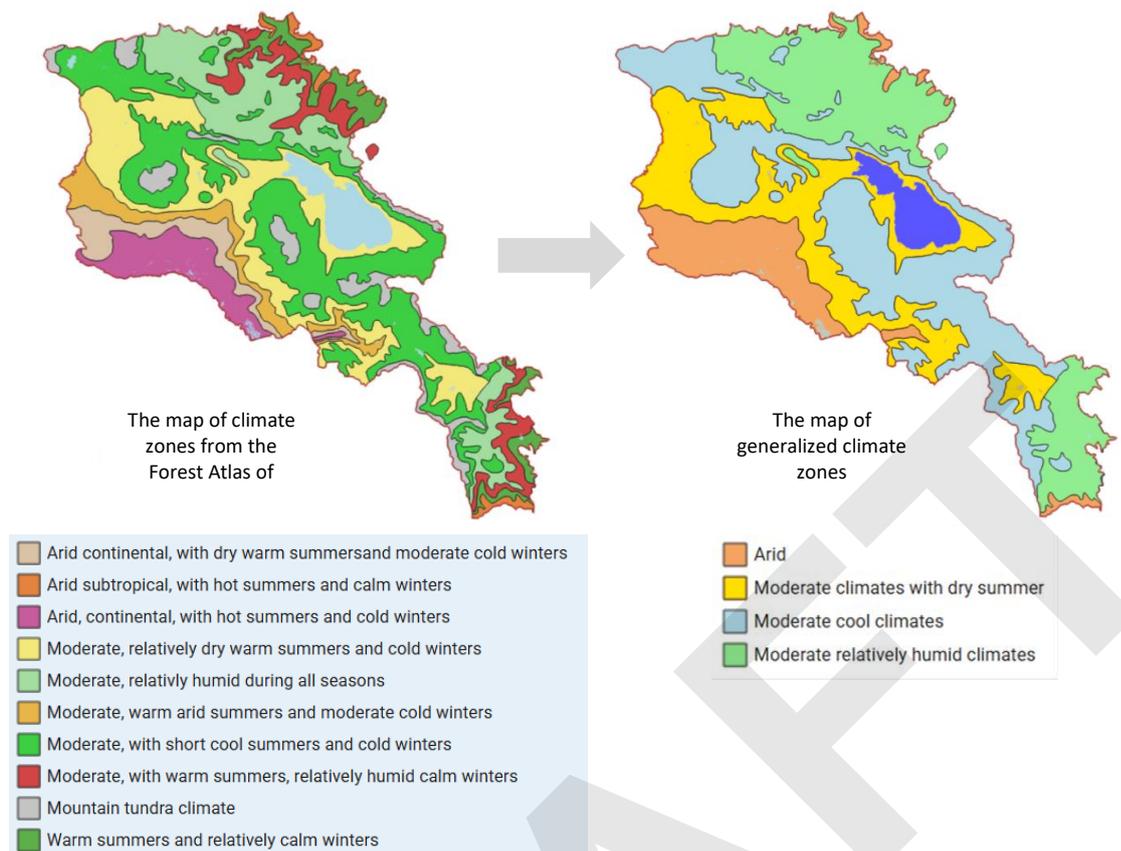


Figure 31A3-2. Generalization of climate zones for ES modeling

Crop coefficients (K_c) were defined as average values for the main groups of agricultural crops, based on FAO data [51,52]. Areas of various agricultural crops such as grains and legumes, vegetables, potatoes, melons, fruits and berries, and grapes in the provinces of Armenia in 2023 were obtained from the Statistical Committee of the Republic of Armenia [41]. To calculate K_c for croplands, we averaged the area shares of different crops for four climatic zones based on data from provinces predominantly located in one or another zone. Average K_c values were then calculated for croplands in each climatic zone, taking into account the share of the area of different agricultural crops within it. K_c values for bare soil were determined based on [60] as the average values for different soil types. For natural vegetation (rangeland and trees), in accordance with the recommendations of InVEST [42], K_c values were set as $K_c = 1$ if $LAI > 3$ and $K_c = LAI/3$ if $LAI \leq 3$. According to InVEST and FAO [52] recommendations, $K_c = 1$ was used for water and flooded vegetation, $K_c = 0.35$ —for built-up areas (assuming that impervious surfaces account for 50%), and $K_c = 0.4$ —for permanent snow. The values of other coefficients were taken from the InVEST User Guide recommendations [42].

UHI effect is incorporated into UC model as a single value. Calculations based on a single UHI value for all of Armenia are impractical due to the significant variation in conditions across different cities. The global UHI effect map [59] shows that in Armenia, it has varying values with opposite signs in different settlements—some settlements are warmer than their surroundings, while others are colder, which makes the use of this factor biased [62]. Therefore, we decided not to account for this factor and set the UHI value to 0.

The values of other coefficients were taken from the InVEST User Guide recommendations [42].

Regional ArmStat statistics on water consumption in 2023 were used to estimate the consumption of ESs.

3.1.A4. Scenarios used for ES modeling and assessment the ES provided by ecosystems

To estimate the role of natural ecosystems in ES provisioning, we used three hypothetical LULC scenarios:

- Bare ground scenario: all vegetation, including forests and grasslands, was replaced with bare ground;
- Cropland scenario: all areas, except for urban territories and water bodies, were converted to cropland;
- No-human scenario: urban areas and croplands were replaced with grasslands, simulating a landscape without human activity.

One of the tested models—SDR—directly calculates ES values provided by ecosystems, i.e., indicators of avoided erosion and avoided sediment export. The other models calculate ES indicators for a given LULC but do not determine what portion of these values is attributable to ecosystems rather than to physical processes. In the SWY and UFRM models, we estimated the volume of ES provided by ecosystems as the difference between ES values for the current land

1477 cover and the bare ground scenario. Thus, negative indicator values (for the ecosystem effect) mean that ecosystems
 1478 decrease the indicator, while positive values mean that ecosystems increase it.

1479 The cropland scenario was used in the SWY model to compare ES loss resulting from the replacement of natural
 1480 vegetation with bare ground and croplands. The no-human scenario was used in the UFRM model to estimate possible
 1481 ES loss in historical time due to anthropogenic land transformation.

1482 We tested the flood mitigation ES model (UFRM model) for average and extreme spring rainfall scenarios. The highest
 1483 precipitation in Armenia falls in May and June. While precipitation levels vary significantly across different climatic zones,
 1484 for the initial model testing, we considered it reasonable to use countrywide average values. During these months, an
 1485 average rainfall event delivers 12 mm of precipitation. For the extreme

1486 **3.1.A6. Data preprocessing and assimilation**

1487 ***Data preprocessing***

1488 To ensure the correct use of data in InVEST models, preprocessing was performed using the QGIS 3.40 application
 1489 [62] and custom Python 3.10.4 scripts.

1490 Land cover data plays a critical role in all InVEST models. The source data were provided as raster files in GeoTIFF
 1491 format, which we cropped based on Armenia's national borders. Distinct versions of land cover rasters were created for
 1492 different modeling scenarios using custom Python scripts—bare ground, cropland, and grassland—by modifying pixel
 1493 values according to each scenario. For example, in the bare ground scenario, all pixels with values 2 (forest) and 11
 1494 (rangeland) were converted to 8 (bare land).

1495 We then juxtaposed land cover rasters for different scenarios with the climate zones dataset using a raster calculator,
 1496 which allowed a transition from basic categories such as “forest” and “cropland” to enriched classifications like “forest in
 1497 an arid zone” and “cropland in a moderately humid zone”. The climate zone data were originally provided as a vector
 1498 layer in GeoPackage format. It was rasterized in QGIS to ensure that the resulting raster matched the land cover raster in
 1499 extent, resolution, and spatial reference system, with climate zones assigned numerical values from 1 to 4.

1500 Then, we combined land cover and climate zone rasters in a two-step process:

1501 1 - The pixel values of the land cover raster were multiplied by 100;

1502 2 - These adjusted values were added to the corresponding pixel values of the climate zone raster, resulting in a
 1503 unified dataset.

1504 For example, a final pixel value of 204 indicates that the pixel represents land cover type 2 (e.g., trees) and climate
 1505 zone 4 (e.g., moderate humid zone).

1506 ***Incorporating snow dynamics in the SWY model***

1507 Since the SWY model does not account for the snow period, we assumed zero liquid precipitation during the winter
 1508 months when the average temperature is below zero, and added this amount to the precipitation of the spring months,
 1509 when the average temperature rises above zero. The estimation was made without taking into account the sublimation
 1510 of snow at subzero air temperatures. Digital monthly maps of liquid precipitation are presented on project web GIS [45].

1511 To calculate monthly liquid precipitation, we used a combination of mean monthly air temperature and mean monthly
 1512 precipitation data. These datasets were provided as raster coverages in GeoTIFF format and unified in terms of spatial
 1513 extent and resolution.

1514 A Python script was used to iterate through the rasters based on the following logic:

1515 - If the mean monthly air temperature in a pixel was below zero, precipitation in that pixel for that month was set to
 1516 0, and its value was carried over to the same pixel in the next month's precipitation raster;

1517 - If the mean monthly temperature remained negative in the following month, the accumulated total was carried
 1518 forward again until the temperature became positive. At that point, all accumulated snow melted, generating a
 1519 cumulative water flow.

1520 ***Data preparation for InVEST and statistic calculation***

1521 For compatibility with InVEST, all raster datasets were resampled to match the spatial domain of the land cover
 1522 dataset, ensuring uniform spatial extent, resolution, and coordinate reference system for accurate model execution.
 1523 These tasks were carried out using standard QGIS 3.40 tools [62], including raster alignment and raster calculator. All
 1524 raster files were prepared in GeoTIFF format, which is supported by both QGIS and InVEST.

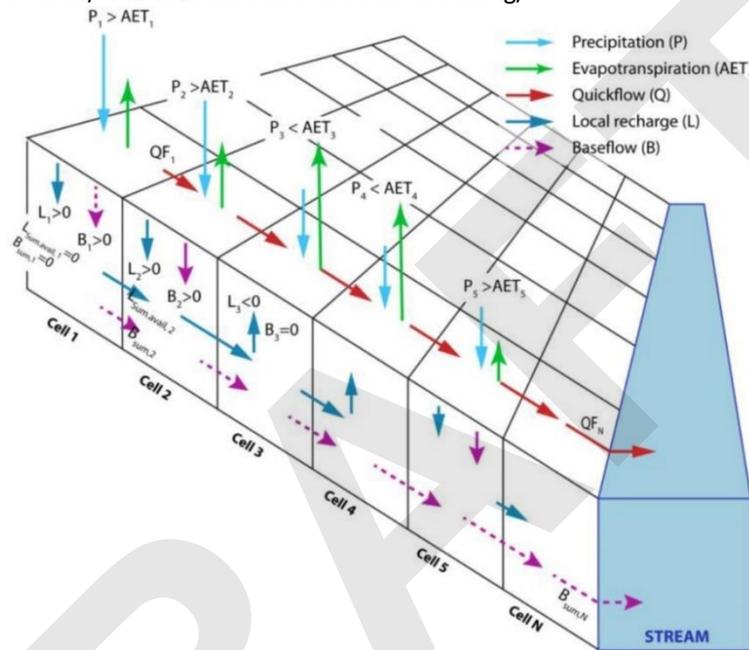
1525 Vector zones required for InVEST models were stored in GeoPackage format 1.3.1 and projected into the same
 1526 coordinate reference system as the raster datasets.

1527 The results of InVEST model computations, represented as raster coverages, were aggregated based on the
 1528 boundaries of three vector layers: Armenia's provinces, major river basins, and vegetation zones. Two standard QGIS
 1529 tools were used for aggregation, zonal statistics for calculating pixel-based sums and averages within the zones, and zonal
 1530 histogram for counting the number of pixels of different values within each zone.

1531 **3.1.B. Baseflow provision (InVEST SWY)**

1532 The ES of seasonal flow redistribution and baseflow provision is extremely important for Armenia, which has a
 1533 seasonal climate with dry summers over a significant part of the territory. The ES was estimated and mapped using **InVEST**
 1534 **Seasonal Water Yield model**. The model takes into account the monthly amount of precipitation, soil permeability, and
 1535 the water balance of each pixel, including moisture that comes into it from the overlying pixels. The main resulting
 1536 indicators for assessing the ecosystem service are quick flow (QF), that is, the generation of streamflow with watershed
 1537 residence times of hours to days; and baseflow (B), that is the generation of streamflow with watershed residence times
 1538 of months to years. Values of cumulative baseflow (Bsum) show the flow through a pixel, contributed by all upslope pixels
 1539 (Figure 31B-1). Baseflow ensures runoff maintaining during the dry season and possible droughts.

1540 The baseflow and quick flow values computed by the SWY model are relative measures [InVEST User Guide].
 1541 **The coefficients used for the modeling can be found here** <https://biodiversity-armenia.am/en/sea-ea/ongoing-projects/preliminary-results-on-ea/%d1%81oefficients-used-for-modeling/>
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 1544 *Figure 31B-1. The InVEST Seasonal Water Yield model diagram (from Hamel et al., 2020)*

1545 **3.1.B1. Potential ES provided by terrestrial ecosystems**

1546 **Modelled relative ES indicators**

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 1548 The baseflow values (B) for the actual land cover (ESRI 2023) are much higher, while the quick flow (QF) values, on
 1549 the contrary, are lower compared to hypothetical cases where all natural ecosystems are replaced with bare ground or
 1550 croplands (Table 31B1-1). The difference between runoff values for the actual land cover and bare ground can be
 1551 interpreted as the ES provided by terrestrial vegetation: B = 47.8 mm in average, and QF = -22.2 mm in average. Thus,
 1552 ecosystems provide 93% of baseflow and reduce quickflow by 22%.

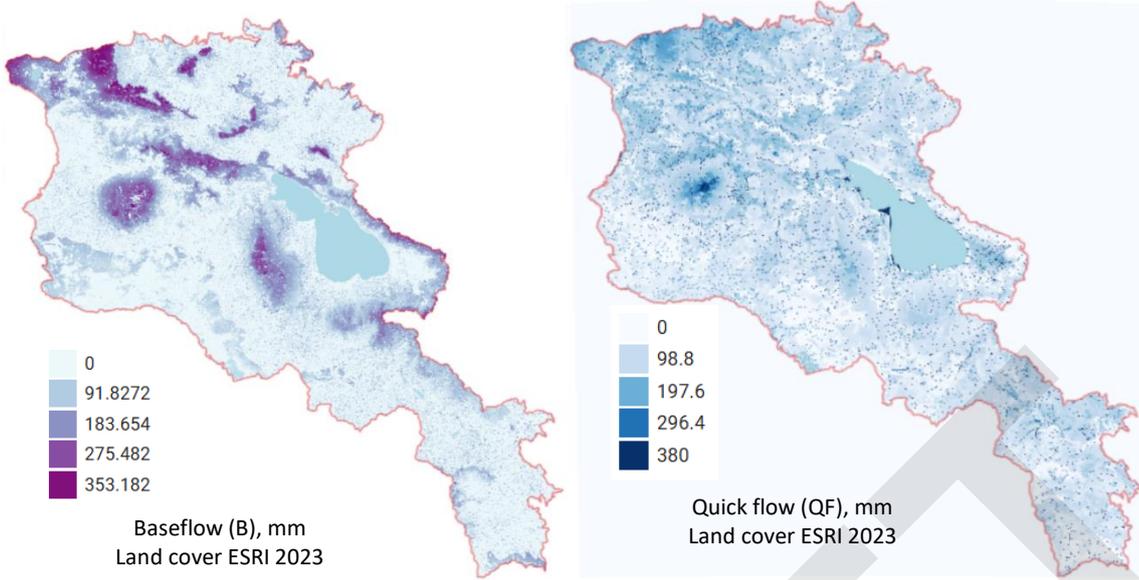
1553 ES maps show that under the bare ground and cropland scenarios, baseflow is almost absent (Figure 31B1-2), meaning
 1554 that the existing baseflow is almost entirely provided by terrestrial ecosystems.

1555 With the current landcover, the baseflow is on average 35% of the total flow (from 28 to 40% in different watersheds).
 1556 With the bare ground scenario, the baseflow is only 3% (from 2 to 4%) (Table 31B1-2; Figure 31B1-3). The values of these
 1557 indicators across the marzes largely mirrors them for the corresponding watersheds (Figure 31 B1-4).

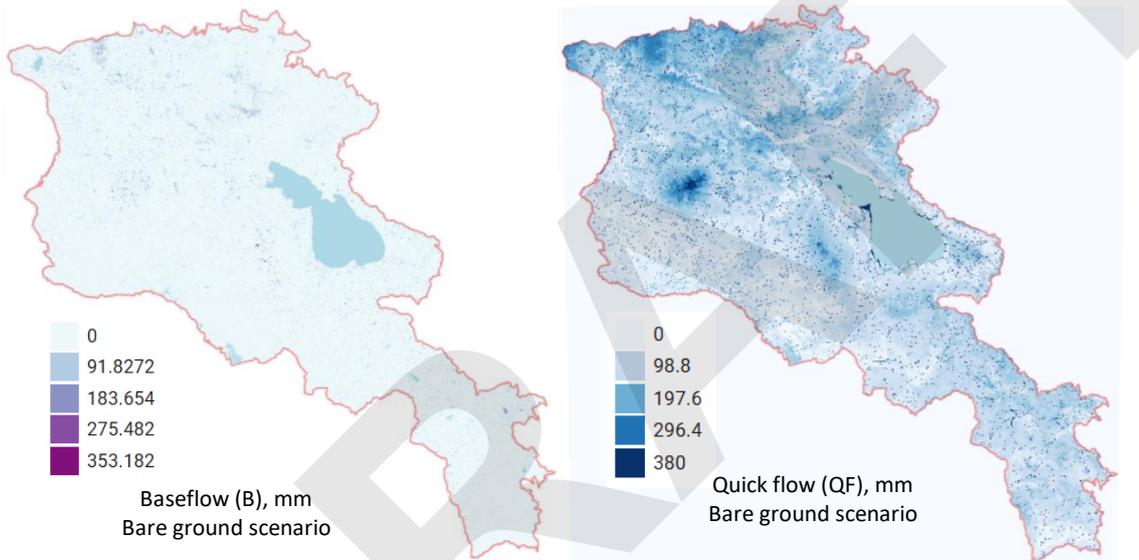
1558 *Table 31B1-1. ES indicator values for Armenia under different scenarios*

Scenario	Baseflow, mm (B)	Quick flow, mm (QF)	(B+QF)	Share of B in total flow, %
Land cover 2017	51.97	97.01	148.97	34.88
Land cover 2023	51.28	98.04	149.32	34.34
Bare ground scenario	3.43	120.22	123.65	2.78
Cropland scenario	3.58	124.96	128.54	2.78

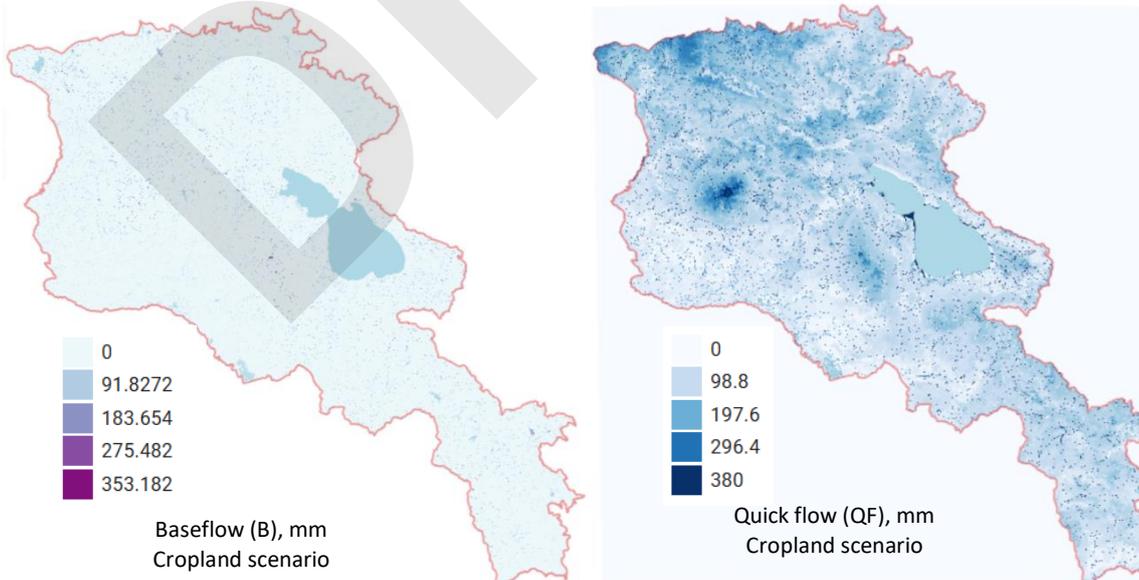
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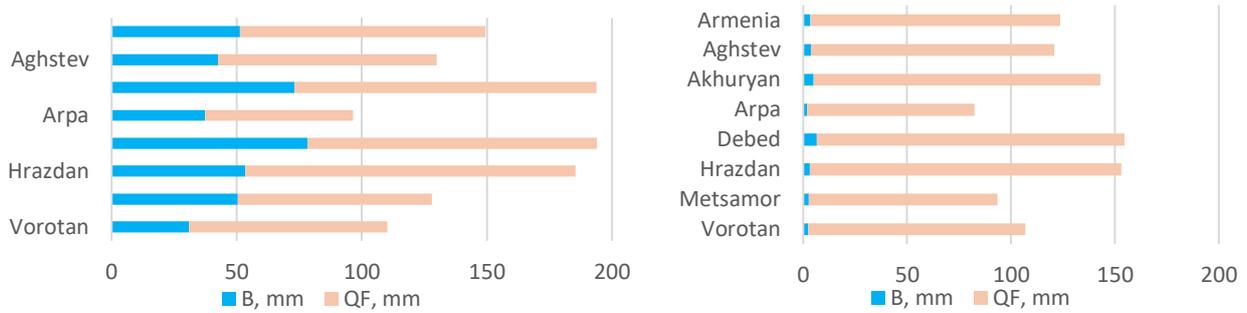
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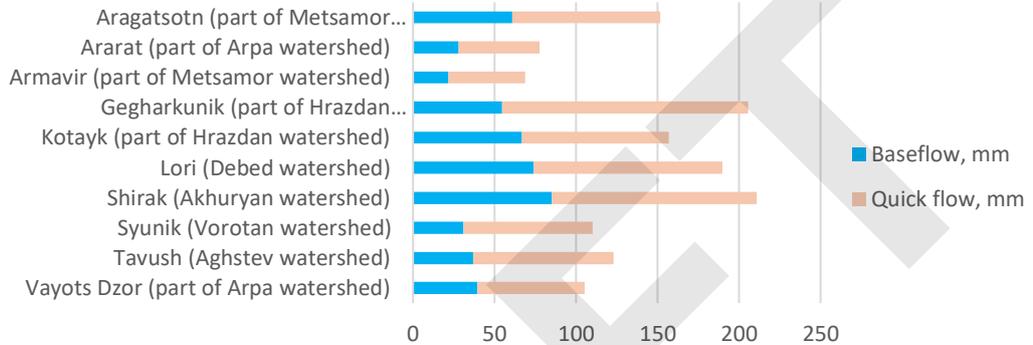
Figure 31B1-2. Maps of ES indicators for different scenarios. For detailed maps see section "Seasonal Water Yield" in the project WebGIS



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Figure 31B1-3. Baseflow and quick flow under the current land cover and the bare ground scenario across watersheds



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Figure 31 B1-4. Baseflow and quick flow under the current land cover across marzes

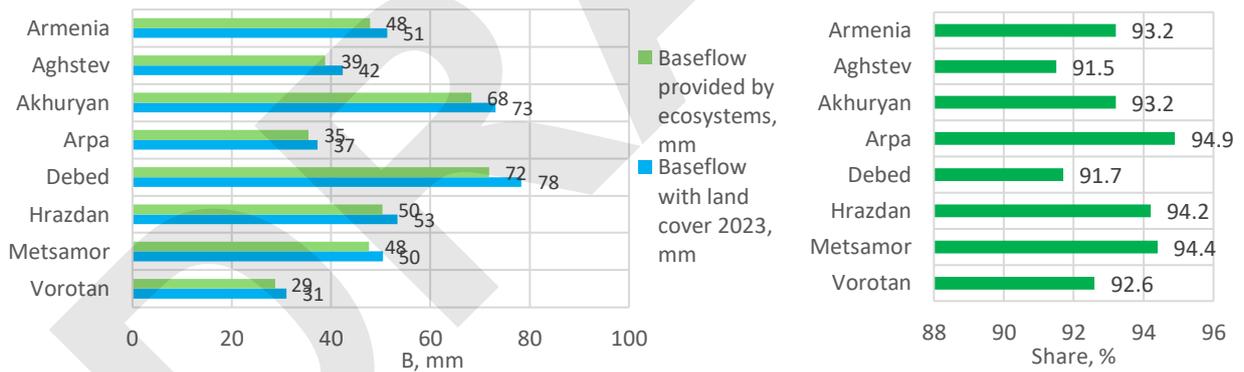
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We estimated potential ES volume provided by terrestrial vegetation as difference between ES indicator values for the current land cover in 2023 and the bare ground scenario where all grasslands and trees were replaced by bare ground. Across watersheds, ecosystems provide 92%–95% of baseflow (Table 31 B1-2; Figure 31 B1-5) and reduce quick runoff by 13%–36% (Table 31 B1-2; Figure 31 B1-6).

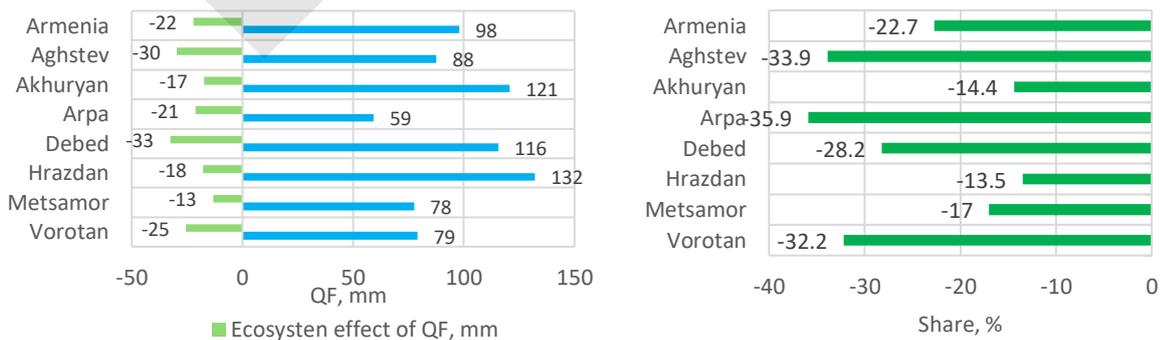


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Figure 31 B1-5. Ecosystem effects on baseflow: (a) baseflow under current land cover and the component provided by ecosystems; (b) share of baseflow provided by ecosystems (%).



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Figure 31 B1-6. Ecosystem effects on quick flow: (a) quick flow under current land cover and its part reduced by ecosystems; (b) share of quick flow reduced by ecosystems (%).

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Table 31 B1-2. Potential ES indicators under the current land cover and the bare ground scenario across watersheds

Indicators		Vorotan	Metsamor	Hrazdan	Debed	Arpa	Akhuryan	Aghstev	Armenia
Land cover ESRI 2023	Baseflow, mm, B ₂₀₂₃	31.0	50.4	53.4	78.3	37.3	73.2	42.4	51.3
	Quick flow, mm, QF ₂₀₂₃	79.2	77.5	132.0	115.6	59.3	120.7	87.6	98.0
	Share of B in total flow, %	28.2	39.4	28.8	40.4	38.6	37.7	32.6	34.3
Bare ground scenario	Baseflow, mm, B _{bg}	2.3	2.8	3.1	6.5	1.9	4.9	3.6	3.4
	Quick flow, mm, QF _{bg}	104.6	90.7	149.9	148.2	80.6	138.1	117.3	120.2
	Share of B in total flow, %	2.1	3.0	2.0	4.2	2.3	3.5	3.0	2.8
Ecosystem effects	Baseflow provided by ecosystems, mm B _{eco} =B ₂₀₂₃ -B _{bg}	28.7	47.6	50.3	71.8	35.4	68.2	38.8	47.8
	Share of baseflow provided by ecosystems, % B _{eco} *100/B ₂₀₂₃	92.6	94.4	94.2	91.7	94.9	93.2	91.5	93.2
	Reduction of quickflow by ecosystems, mm QF _{eco} =QF ₂₀₂₃ -QF _{bg}	-25.5	-13.2	-17.8	-32.6	-21.3	-17.4	-29.7	-22.2
	Share of quick flow reduced by ecosystems, % QF _{eco} *100/QF ₂₀₂₃	-32.2	-17.0	-13.5	-28.2	-35.9	-14.4	-33.9	-22.7

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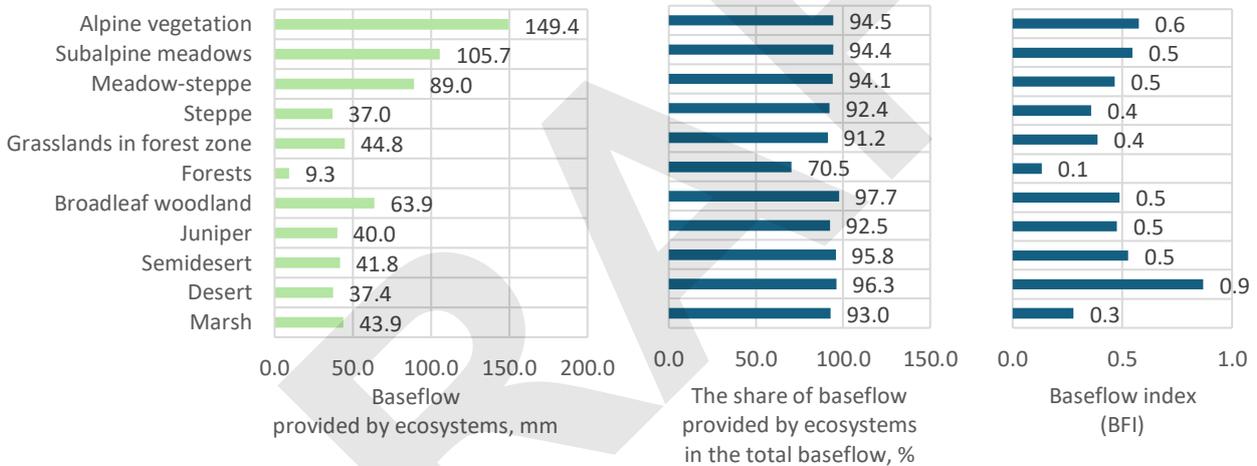
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Analysis of ES indicators across vegetation types shows that the highest average baseflow values occur in alpine, subalpine and meadow-steppe zones, while forests surprisingly exhibit the lowest baseflow level. The share of baseflow provided by ecosystems and baseflow index also are lowest in forest while baseflow index is highest in desert (Figure 31B1-7; Table 31B1-3). These results are discussed below in the Section 3.5.



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Figure 31B1-7. Baseflow indicators across vegetation zones.

Table 31B1-3. Potential ES indicators under the current land cover across vegetation types

	Alpine veg.	Sub-alpine meadows	Mea-dow-steppe	Steppe	Grasslands in forest zone	Forests	Broadleaf woodland	Juniper	Semi-desert	Desert	Marsh
Baseflow provided by ecosystems, B _{eco} , mm	149.40	105.67	89.01	36.98	44.78	9.31	63.90	39.98	41.76	37.35	43.88
Baseflow in 2023, B ₂₀₂₃ , mm	158.10	111.94	94.58	40.04	49.10	13.21	65.38	43.25	43.59	38.80	47.21
Quick flow in 2023, QF ₂₀₂₃ , mm	117.12	93.07	109.15	72.06	77.76	86.47	68.97	47.58	39.08	5.88	122.81
B ₂₀₂₃ + QF ₂₀₂₃	275.21	205.01	203.73	112.10	126.86	99.68	134.35	90.83	82.67	44.68	170.02
Baseflow index BFI= B/(B+QF)	0.57	0.55	0.46	0.36	0.39	0.13	0.49	0.48	0.53	0.87	0.28

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Baseflow volume

The volume of baseflow provided by ecosystems can not be assessed directly on the base of modelling results. Since the baseflow and quick flow values computed by the SWY model are relative measures [InVEST User Guide], the baseflow

1591 volume V_B was calculated as follows: $V_B = BFI \cdot V_{tot}$ where V_{tot} is the river discharge according to the data reported by the
 1592 Government of Armenia and ARMSTAT (Table 31B1-4); BFI is baseflow index, $BFI = B / (B + QF)$, where B and QF are
 1593 baseflow and quick flow values computed by SWY model. The volume of baseflow provided by ecosystems across
 1594 watersheds is presented in Table 31B1-5.

1595 This analysis is approximate, because we used river flow data by watersheds and water-use data by marzes (Appendix
 1596 5). The boundaries of provinces and watersheds largely coincide (Section 3.1.A), which allows such a rough estimate. For
 1597 watersheds that include two or three marzes, the data for those marzes were summed. Obviously, the balance should be
 1598 refined in the future using data from the same EAAs.

1599 *Table 31B1-4. Data on river flow*

Watershed	River flow, mln of m_3	Data source	Details
Aghstev	260	ArmStat Regional Statistics handbooks 2023 https://armstat.am/en/?nid=651	-
Akhuryan	700.7	Basin management plan https://www.arlis.am/hy/acts/112336	River flow was calculated as the sum of utilizable river flow (506.2) and environmental flow (194.5).
Arpa	1177.0	Basin management plan https://www.arlis.am/hy/acts/104697	The sum of river flows of Azat, Vedi, and Arpa
Debed	960	ArmStat Regional Statistics handbooks 2023 https://armstat.am/en/?nid=651	-
Hrazdan	788	Basin management plan https://www.arlis.am/hy/acts/171449	Sum of river flow (469 mln m_3) and ecological river flow (319 mln m_3)
Metsamor	1043.3	Basin management plans https://www.arlis.am/hy/acts/171449 https://www.arlis.am/hy/acts/112336	Total river flow was calculated as the sum of Qasagh (265.5) and Metsamor (777.8) rivers. Metsamor river flow was calculated as the sum of utilizable river flow (1,786.7) and environmental flow (106.0) excluding water available from the reach downstream of the confluence of the Araks and Akhuryan rivers (1,114.9)
Sevan	615.66	Basin management plan https://www.arlis.am/hy/acts/171479	Сток рек в Севан
Vorotan	1319.6	Basin management plan https://www.arlis.am/hy/acts/106124	The sum of river flows of Southern BMA

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Table 31B1-5. The volume of baseflow provided by ecosystems across watersheds

	River flow*, millions of m^3	BFI	Baseflow, millions of m^3
Aghstev (a part of the marz Tavush)	260.00	0.33	84.78
Akhuryan (marz Shirak)	700.70	0.38	264.46
Arpa (marzes Ararat and Vayots Dzor)	1177.00	0.39	454.50
Debed (marz Lori)	960.00	0.40	387.69
Hrazdan (marz Kotayk and Yerevan City)	788	0.29	228.52
Metsamor (marzes Armavir and Aragatsotn)	1043.30	0.39	411.06
Sevan (marz Gegharkunik)	615.66	0.27	166.23
Vorotan (marz Syunik)	1319.60	0.28	371.51

1602

1603 A direct assessment of ES potential, supply and use for different ecosystem/vegetation types based on the obtained
 1604 modeling data is not possible for the following reasons:

- 1605 • as mentioned above, the model estimates of baseflow and quickflow are relative values, and the absolute
 1606 volume of baseflow can only be derived from the baseflow index (BFI) and the known river flow;
- 1607 • the river flow generated from areas with different vegetation types is unknown.

1608 Therefore, this assessment was derived through the relative contribution of different vegetation types to the
 1609 formation of watershed river flow, which was calculated from the model data on baseflow as follows:

1610 1) The relative contribution of vegetation type i to the baseflow formation in watershed j was calculated as

$$SB_{ij} = B_{ij}^{norm} \times SA_{ij}$$

1612 where B_{ij}^{norm} — baseflow (mm) from vegetation type i in watershed j , normalized to the mean baseflow (mm) in
 1613 watershed j ; SA_{ij} — share of the area of vegetation type i within watershed j .

1614 2) Baseflow volume (millions of m^3) from vegetation type i in watershed j was then defined as

$$VB_{ij} = VB_j \times SB_{ij}^{norm}$$

1616 Where VB_j is baseflow volume in watershed j from the Table 31A2-5; SB_{ij}^{norm} is the relative contribution of vegetation
 1617 type i to the river flow in watershed j , normalized so that the sum of all vegetation types' contributions within watershed
 1618 j equals 1.

1619 3) Baseflow volume (millions of m3) provided by vegetation type *i* in watershed *j* was then defined as

1620
$$VBE_{ij} = VB_{ij} \times SBE_{ij}$$

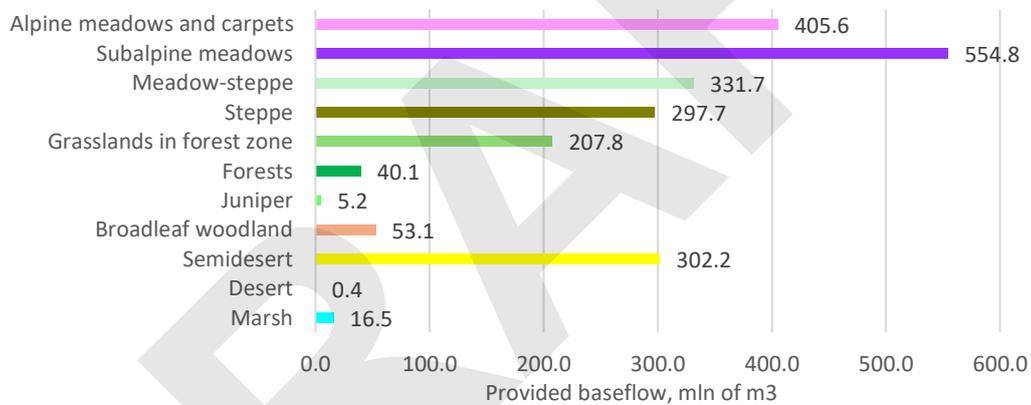
1621 Where SBE_{ij} - the share of provided baseflow provided by ecosystems in total baseflow.

1622 The final evaluations of baseflow volume provided by vegetation types are presented in Table 31B1-6. Intermediate
1623 calculation tables are presented in the Appendix 4.

1624 *Table 31B1-6. Baseflow volume provided by vegetation types across watersheds, millions of m3*

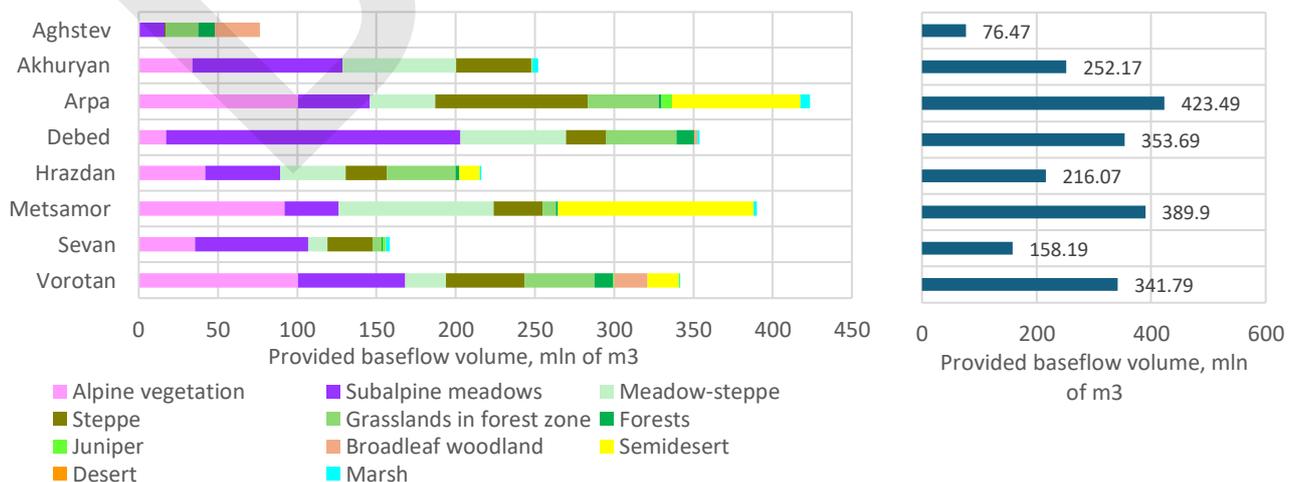
	Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grasslands in forest zone	Forests	Juniper	Broadleaf woodland	Semidesert	Desert	Marsh	Total in watersheds
Aghstev	0.08	16.35	0.00	0.55	20.75	10.28	0.00	28.47	0.00	0.00	0.00	76.47
Akhuryan	33.80	94.65	71.86	47.41	0.00	0.24	0.00	0.00	0.22	0.00	3.99	252.17
Arpa	100.43	45.41	41.32	96.20	44.70	1.74	6.91	0.00	80.61	0.00	6.18	423.49
Debed	17.19	185.76	66.66	25.53	44.09	11.22	0.00	1.88	0.00	0.00	1.37	353.69
Hrazdan	41.83	47.49	41.32	25.97	43.32	2.44	0.00	0.08	12.69	0.00	0.94	216.07
Metsamor	91.88	34.47	97.68	30.75	8.44	1.42	0.00	0.00	123.33	0.00	1.94	389.90
Sevan	35.71	71.25	11.99	28.70	5.60	0.71	1.72	0.15	0.00	0.00	2.35	158.19
Vorotan	100.63	67.45	25.75	49.61	44.26	11.69	0.57	21.12	19.90	0.00	0.81	341.79
Armenia	421.56	562.83	356.57	304.71	211.15	39.74	9.20	51.68	236.75	0.00	17.58	2211.78

1625 For Armenia as a whole, the largest volume of baseflow is provided by subalpine meadows, followed by alpine
1626 vegetation, various steppe types, and semidesert. Meadows within the forest zone also make a substantial contribution.
1627 The remaining vegetation types—including forests—contribute only a minor share of baseflow (Figure 31B1-8).
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1629 *Figure 31B1-8. The volume of baseflow provided by different vegetation types in Armenia*

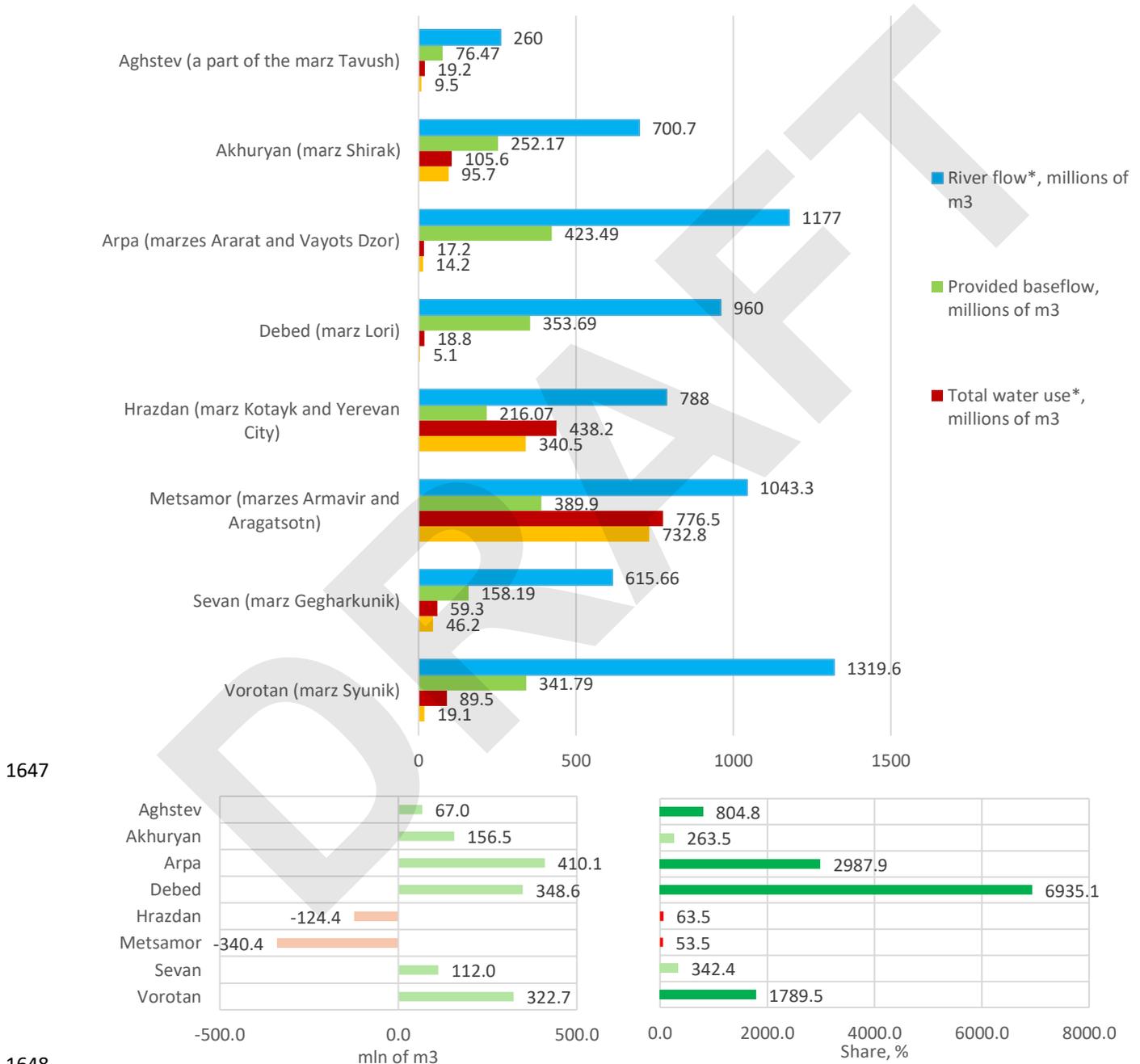
1631 The largest volumes of baseflow are provided by the ecosystems of the Arpa, Debed, Metsamor, and Vorotan basins,
1632 and the smallest by the Aghstev basin (Figure 31B1-9b). Alpine vegetation is most important for baseflow provision in the
1633 Arpa and Vorotan basins; subalpine vegetation—in the Debed basin; steppe—in the Arpa basin; and semidesert—in the
1634 Metsamor basin (Figure 31B1-9a).



1635 *Figure 31B1-9. The volume of baseflow provided by different vegetation types (a) and total values across watersheds (b)*

1637 **3.1B2. ES potential-supply-use balance**

1638 Water use nowhere exceeds the river flow. The water-use figures are closest to river flow in the basins of Metsamor
 1639 and Hrazdan. The overwhelming majority of water consumption is accounted for by the sector of agriculture, fisheries,
 1640 and forestry, which underscores the importance of assessing the ES of baseflow provision. In two watersheds —
 1641 Metsamor and Hrazdan—water consumption exceeds baseflow volume, provided by ecosystems (Table 31B2-1; Figure
 1642 31B2-1a,b). In the Metsamor and Hrazdan watersheds, baseflow provides 63% and 54% of agricultural water
 1643 consumption, respectively. In the other watersheds baseflow exceeds water consumption by many times (Figure 31B2-
 1644 1c). The water-use data for Tavush marz used in the analysis pertain to an area larger than the Aghstev River watershed
 1645 for which river flow data are available. Therefore, in reality the total river flow from the entire area exceeds water
 1646 consumption even more than indicated by these results.



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 1648
 1649 *Figure 31B2-1. ES potential–use balance of ES: (a) river flow, baseflow and water consumption across watersheds (**
 1650 *data reported by ARMSTAT and the Government); (b) Difference between provided baseflow volume and water*
 1651 *consumption in agriculture, fishery and forestry; (c) Share of provided baseflow in agriculture, fisheries and forestry*
 1652 *water consumption (%).*

1653

Table 31B2-1. ES potential–use balance of ES across watersheds

	Water use in agriculture, fish breeding, forestry*, mln of m ³	Total water use*, millions of m ³	Provided baseflow, millions of m ³	River flow*, millions of m ³	Difference between provided baseflow volume and water consumption in agriculture etc., mln of m ³	Share of provided baseflow in agriculture etc. water consumption (%)
Aghstev (a part of the marz Tavush)	9.5	19.2	76.47	260.00	322.7	1789.5
Akhuryan (marz Shirak)	95.7	105.6	252.17	700.70	112.0	342.4
Arpa (marzes Ararat, Vayots Dzor)	14.2	17.2	423.49	1177.00	-340.4	53.5
Debed (marz Lori)	5.1	18.8	353.69	960.00	-124.4	63.5
Hrazdan (marz Kotayk and Yerevan City)	340.5	438.2	216.07	788	348.6	6935.1
Metsamor (marzes Armavir, Aragatsotn)	732.8	776.5	389.90	1043.30	410.1	2987.9
Sevan (marz Gegharkunik)	46.2	59.3	158.19	615.66	156.5	263.5
Vorotan (marz Syunik)	19.1	89.5	341.79	1319.60	67.0	804.8

*Data reported by ARMSTAT: Environment and Natural Resources in the Republic of Armenia for 2022, <https://armstat.am/en/?nid=82&id=2603>

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To assess the potential-use balance across vegetation types, we estimated the demand for baseflow, disaggregated by vegetation type, required to satisfy current water use (how much baseflow ecosystems must provide to meet current water-use volumes) was estimated as $D_{ij}=WU_j \times SB_{ij}^{norm}$ —where WU_j is total water use, and SB_{ij}^{norm} - the relative contribution of vegetation types to baseflow formation computed above. This allowed us to estimate also actual ESflow (supply=use), unused ES potential and unmet demand (provided baseflow volume minus demand) following the recommendations of the INCA project [Vallecillo et al., 2019] (Table 31B2-3 and Figure 31B2-2). In the Metsamor and Hrazdan basins, all vegetation types—and, for Armenia as a whole, the semidesert ecosystems—provide baseflow volumes that are lower than water consumption. In all other cases, the volume of provided baseflow exceeds total water consumption.

In line with the SEEA-EA understanding of ES supply, the volumes of baseflow equal to its use constitute the supplied ES. However, in the Metsamor and Hrazdan watersheds, water consumption exceeds baseflow; therefore the demand is unmet there. According to the SEEA EA approach, in the final ES accounting table the “unmet demand” values should be replaced with the volumes of baseflow provided by ecosystems, while the indicators of ES use should be made equal to the supplied ES. The SEEA table format does not require reporting demand for ES; however, for clarity we highlighted in red cases where water use exceeds the ES supply-use — in the Metsamor and Hrazdan watersheds and for total water use in Armenia (Table 31B2-4).

The assessment of the ES potential–use balance, carried out in accordance with the INCA recommendations, shows that in the Arpa, Debed and Vorotan watersheds there is a substantial unused potential of baseflow, whereas the ecosystems of the Hrazdan and Metsamor watersheds do not meet the demand for water consumption (unmet demand) (Figure 31B2-2).

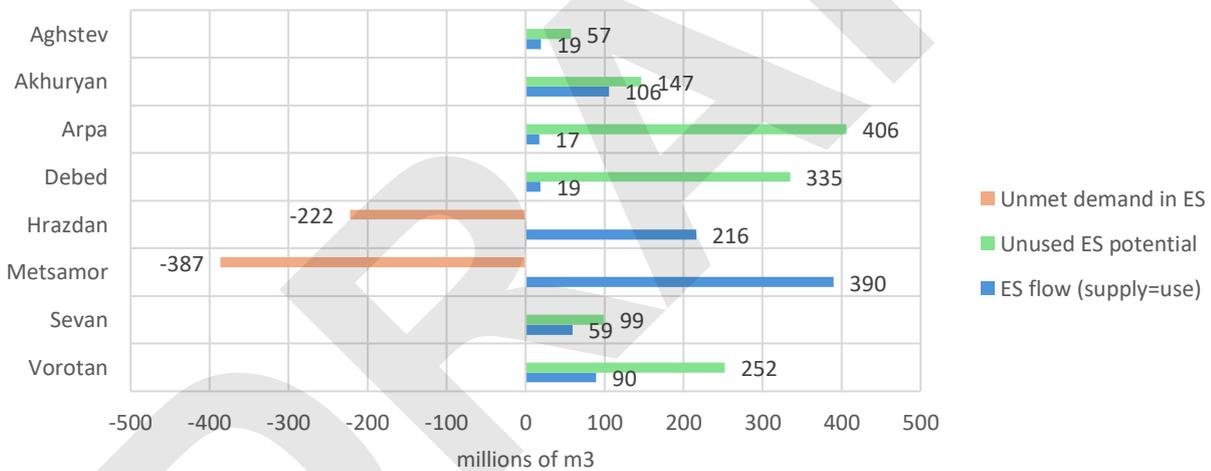
In conclusion, it should be emphasized that this assessment of ES potential-supply-use balance was made for methodological purposes, to demonstrate different approaches to assessing the balance. It is obvious that water demand is satisfied not only by baseflow but by total river flow, which in all watersheds exceeds current water consumption.

Table 31B2-3. ES indicators across watersheds and vegetation types, millions of m³ (according INKA recommendations)

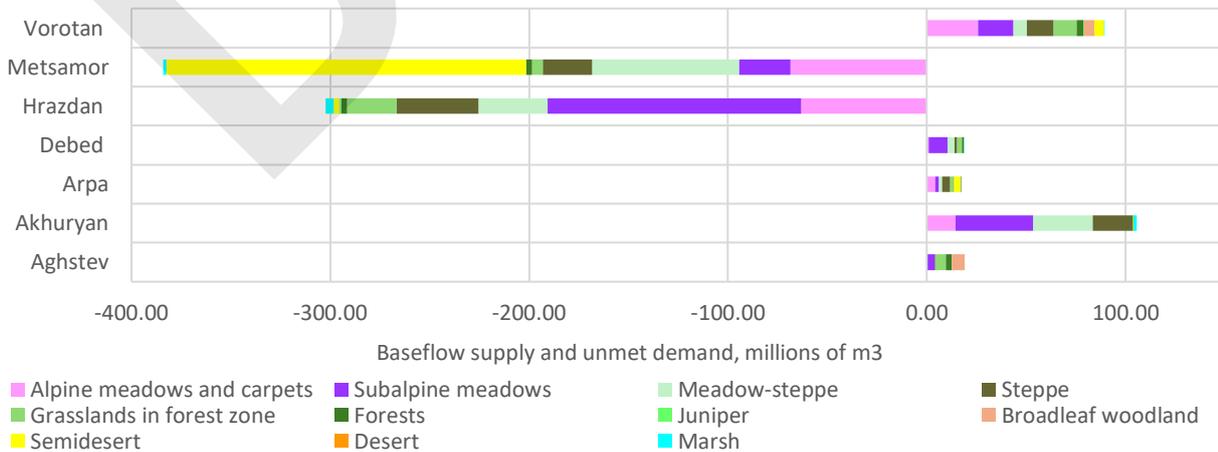
		Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grasslands in forest	Forests	Juniper	Broadleaf woodland	Semidesert	Desert	Marsh	Total in watersheds
Potential ES: baseflow volume provided by ecosystems	Aghstev	0.08	16.35	0.00	0.55	20.75	10.28	0.00	28.47	0.00	0.00	0.00	76.47
	Akhuryan	33.80	94.65	71.86	47.41	0.00	0.24	0.00	0.00	0.22	0.00	3.99	252.17
	Arpa	100.43	45.41	41.32	96.20	44.70	1.74	6.91	0.00	80.61	0.00	6.18	423.49
	Debed	17.19	185.76	66.66	25.53	44.09	11.22	0.00	1.88	0.00	0.00	1.37	353.69
	Hrazdan	41.83	47.49	41.32	25.97	43.32	2.44	0.00	0.08	12.69	0.00	0.94	216.07
	Metsamor	91.88	34.47	97.68	30.75	8.44	1.42	0.00	0.00	123.33	0.00	1.94	389.90
	Sevan	35.71	71.25	11.99	28.70	5.60	0.71	1.72	0.15	0.00	0.00	2.35	158.19
	Vorotan	100.63	67.45	25.75	49.61	44.26	11.69	0.57	21.12	19.90	0.00	0.81	341.79
	Armenia	421.56	562.83	356.57	304.71	211.15	39.74	9.20	51.68	236.75	0.00	17.58	2211.78
Baseflow demand	Aghstev	0.02	4.15	0.00	0.13	5.32	3.04	0.00	6.55	0.00	0.00	0.00	19.2
	Akhuryan	14.52	39.13	29.82	20.23	0.00	0.16	0.00	0.00	0.10	0.00	1.65	105.6
	Arpa	4.26	1.84	1.54	4.04	1.83	0.10	0.12	0.06	3.19	0.01	0.21	17.2

	Debed	0.96	9.55	3.53	1.32	2.38	0.89	0.00	0.10	0.00	0.00	0.08	18.8
	Hrazdan	83.65	93.94	83.09	54.63	87.27	7.36	0.00	0.17	26.11	0.00	1.97	438.2
	Metsamor	137.02	52.80	149.13	48.10	10.61	5.05	0.00	0.00	370.28	0.00	3.52	776.5
	Sevan	13.21	26.58	4.62	10.87	2.16	0.38	0.63	0.06	0.00	0.00	0.92	59.3
	Vorotan	25.86	17.82	6.78	13.29	11.74	3.53	0.15	5.26	4.88	0.00	0.21	89.5
	Armenia	279.50	245.81	278.52	152.61	121.31	20.51	0.90	12.20	404.56	0.01	8.56	1524.3
Actual flow (supply=use)	Aghstev	0.02	4.15	0.00	0.13	5.32	3.04	0.00	6.55	0.00	0.00	0.00	19.21
	Akhuryan	14.52	39.13	29.82	20.23	0.00	0.16	0.00	0.00	0.10	0.00	1.65	105.61
	Arpa	4.26	1.84	1.54	4.04	1.83	0.10	0.12	0.00	3.19	0.00	0.21	17.13
	Debed	0.96	9.55	3.53	1.32	2.38	0.89	0.00	0.10	0.00	0.00	0.08	18.81
	Hrazdan	41.83	47.49	41.32	25.97	43.32	2.44	0.00	0.08	12.69	0.00	0.94	216.07
	Metsamor	91.88	34.47	97.68	30.75	8.44	1.42	0.00	0.00	123.33	0.00	1.94	389.90
	Sevan	13.21	26.58	4.62	10.87	2.16	0.38	0.63	0.06	0.00	0.00	0.92	59.42
	Vorotan	25.86	17.82	6.78	13.29	11.74	3.53	0.15	5.26	4.88	0.00	0.21	89.52
	Armenia	192.54	181.02	185.29	106.60	75.19	11.95	0.90	12.05	144.19	0.00	5.95	915.68
Unused potential/ unmet demand	Aghstev	0.06	12.20	0.00	0.42	15.43	7.24	0.00	21.92	0.00	0.00	0.00	57.26
	Akhuryan	19.28	55.52	42.04	27.18	0.00	0.08	0.00	0.00	0.12	0.00	2.34	146.56
	Arpa	96.17	43.57	39.78	92.16	42.87	1.64	6.79	-0.06	77.42	-0.01	5.97	406.29
	Debed	16.23	176.21	63.13	24.21	41.71	10.33	0.00	1.78	0.00	0.00	1.29	334.88
	Hrazdan	-41.82	-46.46	-41.77	-28.66	-43.95	-4.92	0.00	-0.09	-13.42	0.00	-1.03	-222.13
	Metsamor	-45.14	-18.33	-51.45	-17.35	-2.17	-3.63	0.00	0.00	-246.95	0.00	-1.58	-386.61
	Sevan	22.51	44.68	7.36	17.84	3.44	0.34	1.09	0.09	0.00	0.00	1.43	98.76
	Vorotan	74.77	49.63	18.97	36.32	32.52	8.16	0.42	15.86	15.02	0.00	0.60	252.27
	Armenia	142.06	317.02	78.05	152.11	89.84	19.23	8.29	39.49	-167.81	-0.01	9.02	687.29

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Figure 31B2-2. Baseflow supply and unmet demand across vegetation types and watersheds, millions of m3

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Table 31B2-4. Supply-use table for ES of baseflow maintenance in format recommended by SEEA EA. The figures in parentheses indicate the volumes of water use that exceed the supplied ES, i.e., unmet demand.

		Drinking	Industrial, domestic and construction	Agriculture, fish breeding and forestry	Total ES use		Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grasslands in forest zone	Forests	Juniper	Broadleaf woodland	Semidesert	Desert	Marsh	Total ES supply
Aghstev	Supply						0	4	0	0	5	3	0	7	0	0	0	19
	Use	8	1	10	19													
Akhuryan	Supply						15	39	30	20	0	0	0	0	0	0	2	106
	Use	8	2	96	106													
Arpa	Supply						4	2	2	4	2	0	0	0	3	0	0	17
	Use	2	1	14	17													
Debed	Supply						1	10	4	1	2	1	0	0	0	0	0	19
	Use	10	4	5	19													
Hrazdan	Supply						42	47	41	26	43	2	0	0	13	0	1	216
	Use	28	19	169	216													
	Demand	57 (13%)	41 (9%)	341(78%)	438													
Metsamor	Supply						92	34	98	31	8	1	0	0	123	0	2	390
	Use	12	12	367	390													
	Demand	23 (3%)	21 (3%)	733(94%)	777													
Sevan	Supply						13	27	5	11	2	0	1	0	0	0	1	59
	Use	12	1	46	59													
Vorotan	Supply						26	18	7	13	12	4	0	5	5	0	0	90
	Use	7	63	19	90													
Armenia	Supply						193	181	185	107	75	12	1	12	144	0	6	916
	Use	46	55	815	916													
	Demand	133 (5%)	140 (6%)	2150 (89%)	2422													

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3.1.B3. ES changes from 2017 to 2023

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Assessment of ES changes based on the 2017 and 2023 modelled baseflow maps

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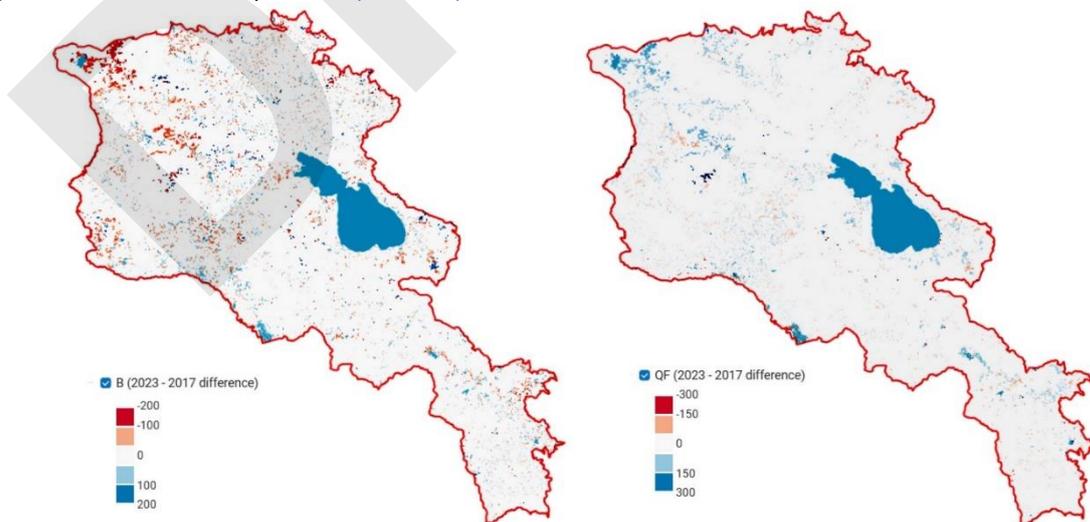
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From the modeled ES maps, we can directly assess only the changes in the relative indicators of baseflow and quickflow, expressed in mm. All changes identified are determined only by changes in the landcover (Section 2.2.B). Weather and climate changes are not taken into account. The maps show that the changes are sporadic and oppositely directed (Figure 31B3-1). Nevertheless, overall, they can be characterized as negative. In cases where ES indicators changed significantly, baseflow (B) decreased while quick flow (QF) increased. This means that the ability of terrestrial ecosystems to sustain baseflow during dry periods is declining. The only exception is the Arpa basin, where B has increased. The most significant negative changes occurred in the Shirak province and the Akhuryan watershed corresponding to land cover changes in the Shirak province. The reason is the expansion of the croplands at the expense of the grasslands in the Shirak province (see here).



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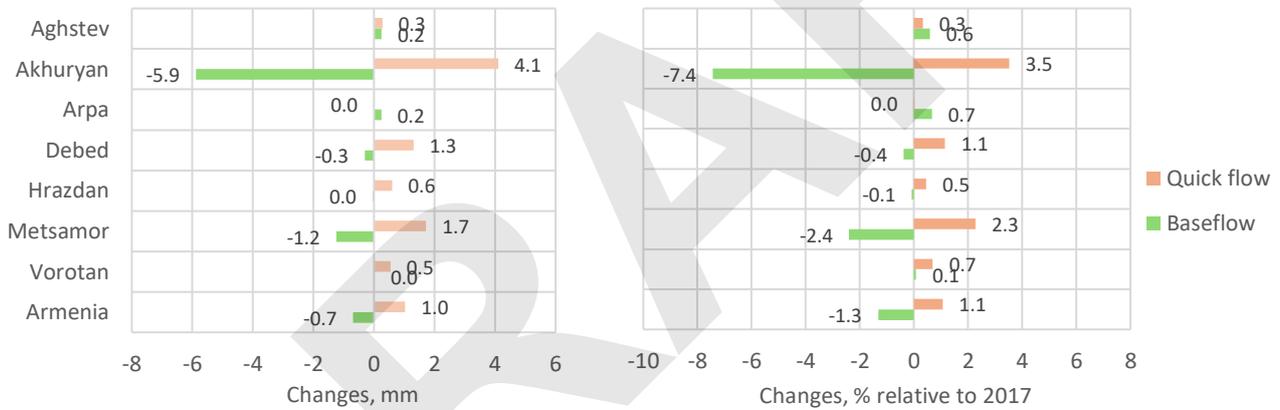
1701

Figure 31B3-1. Changes in baseflow (a) and quickflow (b) from 2017 to 2023, mm. For detailed maps see sections "Seasonal Water Yield - Dynamics" in the project Web GIS

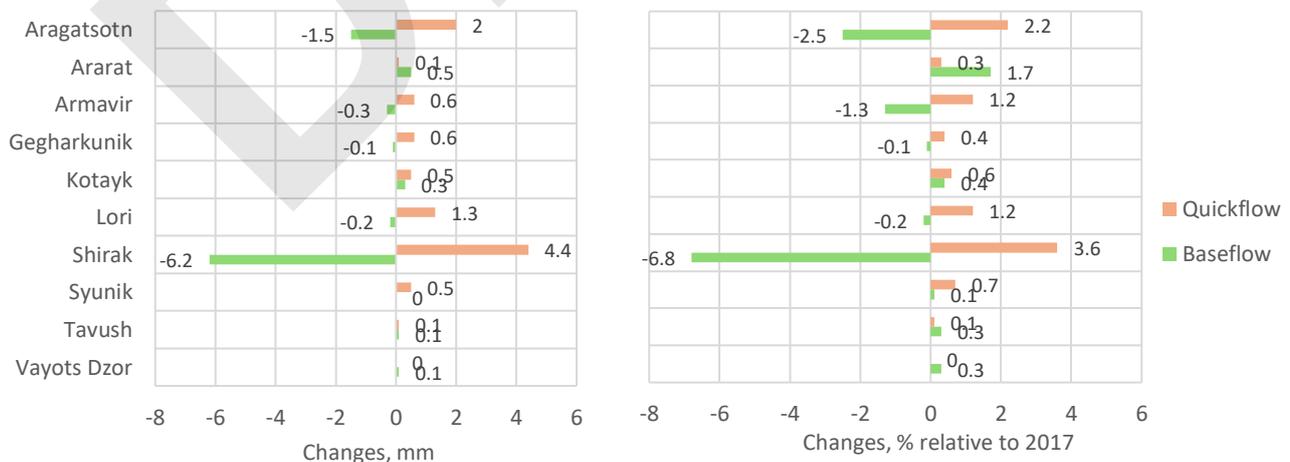
1702 The most notable changes across watersheds and marzes are a decrease in baseflow and an increase in quickflow.
 1703 These negative changes are most pronounced in the Akhuryan and Metsamor watersheds and in the marzes Shirak and
 1704 Aragatsotn. A slight increase in baseflow is observed in the Arpa and Aghstev watersheds and in Ararat marz (Table 31B3-
 1705 1; Figures 31B3-2 and 31B3-3).

1706 Table 31B3-1. Changes in baseflow and quick flow from 2017 to 2023 across watersheds and marzes

EAA		Baseflow, mean				Quick flow, mean			
		B 2017, mm	B 2023, mm	Change in B, mm	Change in B, % relative to 2017	QF 2017, mm	QF 2023, mm	Change in QF, mm	Change in QF, % relative to 2017
Watersheds	Aghstev	42.1	42.4	0.2	0.6	87.3	87.6	0.3	0.3
	Akhuryan	79.0	73.2	-5.9	-7.4	116.6	120.7	4.1	3.5
	Arpa	37.0	37.3	0.2	0.7	59.3	59.3	0.0	0.0
	Debed	78.6	78.3	-0.3	-0.4	114.3	115.6	1.3	1.1
	Hrazdan	53.5	53.4	0.0	-0.1	131.4	132.0	0.6	0.5
	Metsamor	51.7	50.4	-1.2	-2.4	75.8	77.5	1.7	2.3
	Vorotan	31.0	31.0	0.0	0.1	78.6	79.2	0.5	0.7
Provinces	Aragatsotn	62.5	61.0	-1.5	-2.5	88.5	90.5	2.0	2.2
	Ararat	27.6	28.1	0.5	1.7	49.5	49.6	0.1	0.3
	Armavir	22.2	21.9	-0.3	-1.3	46.2	46.8	0.6	1.2
	Gegharkunik	54.6	54.5	-0.1	-0.1	150.5	151.1	0.6	0.4
	Kotayk	66.4	66.7	0.3	0.4	89.8	90.3	0.5	0.6
	Lori	74.1	74.0	-0.2	-0.2	114.5	115.8	1.3	1.2
	Shirak	91.3	85.1	-6.2	-6.8	121.3	125.7	4.4	3.6
	Syunik	30.9	30.9	0.0	0.1	78.6	79.1	0.5	0.7
	Tavush	36.7	36.9	0.1	0.3	86.2	86.3	0.1	0.1
	Vayots Dzor	39.3	39.4	0.1	0.3	66.0	66.0	0.0	0.0
Armenia		52.0	51.3	-0.7	-1.3	97.0	98.0	1.0	1.1



1707 Figure 31B3-2. Changes in baseflow and quickflow from 2017 to 2023 in absolute (a) and relative (b) indicators across
 1708 watersheds
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1710 Figure 31B3-3. Changes in baseflow and quickflow from 2017 to 2023 in absolute (a) and relative (b) indicators across
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Assessment of changes in baseflow volume based on the changes in area of vegetation types

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At this stage, changes in the volume of ecosystem-provided baseflow can only be assessed via changes in the area of those ecosystem types. From the maps of modeled baseflow for 2017 and 2023, this is difficult: we don't know actual water flow volumes for the areas that changed, and converting relative model baseflow indicator (in mm) into total baseflow volume is challenging.

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Changes in the volume of baseflow provided by ecosystems can be assessed using the indicator of ecosystem-provided baseflow per 1 km² (Table 31B3-2), derived from the previously computed values of this indicator for vegetation types (Table 31B1-6), together with their area and its changes between 2017 and 2023 (Table 2.3C-2). This indicator makes it possible to calculate the data for the table recording the dynamics of the ES potential/capacity (Table 31B3-3).

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With respect to changes in ES potential/capacity, the same comment applies as for changes in ecosystem extent (Section 2.3.A). Additions to ecosystem area resulting from transitions out of croplands or built-up areas do not possess full ecosystem functionality. Therefore, the closing ES capacity is defined more by the extent of ecosystems that remained untransformed during the reporting period than by the total closing ecosystem area.

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The ES potential of meadow-steppes decreased the most—by 35.6 million m³; the potential of steppe ecosystems also declined substantially. The potential of grasslands within the forest zone increased slightly. Changes in the ES potential of other vegetation types were less pronounced (Table 31B3-3; Figure 31B3-4).

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Table 31B3-2. Baseflow volume provided by vegetation types, millions of m³/km²

	Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grassl. in forest zone	Forests	Juniper	Broadleaf woodland	Semi-desert	Desert	Marsh	Total in watersheds
Provided baseflow volume, millions of m ³	421.6	562.8	356.6	304.7	211.2	39.7	9.2	51.7	236.8	0.00	17.6	2211.8
Area km ²	1652.2	4280.1	2557.1	5243.1	2896.5	3129.0	130.3	703.9	2459.2	6.9	281.0	23339.3
Provided baseflow volume, millions of m ³ /km ²	0.26	0.13	0.14	0.06	0.07	0.01	0.07	0.07	0.10	0.00	0.06	0.09

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Table 31B3-3. Accounting table for the ES capacity for 2017 and 2023

	Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grasslands in forest zone	Forests	Juniper	Broadleaf woodland	Semidesert	Desert	Marsh	Total
Opening ES capacity in 2017	156.0	407.5	269.3	515.8	270.1	12.2	67.3	234.9	0.7	22.4	310.8	2267.1
Additions to ES capacity	0.5	7.3	3.3	18.3	25.5	0.2	5.4	18.3	0.0	1.7	21.9	102.3
Managed/Unmanaged	NA											
Reductions in ES capacity	0.3	7.9	27.4	38.3	21.0	0.1	6.7	19.3	0.0	2.3	35.1	158.4
Managed/Unmanaged	NA											
Net change in ES capacity	0.2	-0.7	-24.1	-20.0	4.4	0.1	-1.2	-1.0	0.0	-0.6	-13.2	-56.1
Closing ES capacity in 2024	156.1	406.9	245.2	495.9	274.5	12.3	66.1	233.8	0.6	21.9	297.6	2211.0
Additional row – see Section 2.3.C												
Closing ES capacity in 2024 of eco-systems unconverted since 2017	427.15	548.16	357.30	302.37	183.97	29.10	8.93	44.83	227.49	0.00	12.75	2142.05

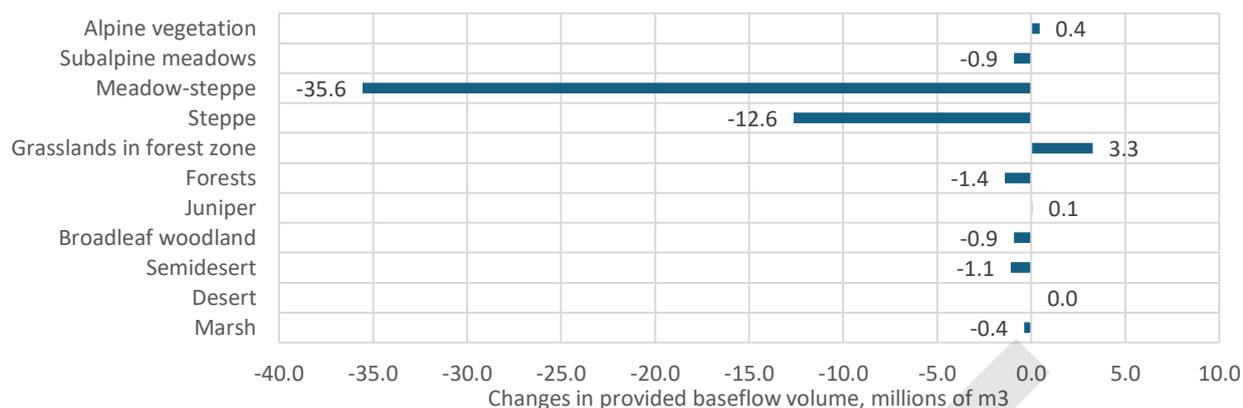


Figure 31B3-4. Changes in baseflow volume, provided by different vegetation types

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1733 The analogous assessments for watersheds can be produced in the same way, if land-cover classes transition matrices
 1734 for watersheds are available for the reporting period. Alternatively, the assessment can be obtained by a simpler
 1735 approach that, however, shows only the net change in ES capacity/potential without separating gains and losses over the
 1736 reporting period. Changes in the volume (million m³) of baseflow provided by ecosystems were calculated as BE₂₀₂₃ –
 1737 BE₂₀₁₇, where BE₂₀₂₃ and BE₂₀₁₇ are the volumes of provided baseflow in 2023 and 2017, respectively. BE₂₀₂₃ values are
 1738 taken from Table 31B2-3, while BE₂₀₁₇ was calculated as BE₂₀₂₃ × E_{2017%}, where E_{2017%} is the extent of each vegetation type
 1739 in 2017 relative to 2023 (E₂₀₁₇ / E₂₀₂₃ × 100, derived from the data in Table 23D-1). The results across watersheds are
 1740 presented in Table 31B3-4.

1741 The volume of baseflow provided by ecosystems decreased most strongly in the Akhuryan watershed due to the
 1742 reduction in the area of steppes and subalpine meadows. Significant reductions in ecosystem-provided baseflow also
 1743 occurred in the Debed and Metsamor watersheds—again as a result of shrinking steppe area. In the Vorotan watershed,
 1744 substantial changes likewise occurred, but the effects of declines in steppe and forest area and increases in grasslands
 1745 within the forest zone and in subalpine meadows largely offset one another (Figure 31B3-4). For relative indicators, these
 1746 changes exactly mirror the changes in the area of vegetation types (Table 23D-1), since they are calculated from those
 1747 areas.

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Table 31B3-4. Changes in baseflow provided by vegetation types from 2017 to 2023 across watersheds

		Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grasslands in forest zone	Forests	Juniper	Broadleaf Woodland	Semidesert	Desert	Marsh
Extent in 2017, relative to 2023	Aghstev	1.00	0.97	0.00	0.91	1.00	0.99	0.00	1.02	0.00	0.00	0.00
	Akhuryan	1.00	1.06	1.24	1.11	0.00	0.98	0.00	0.00	1.01	0.00	1.39
	Arpa	1.00	1.00	1.00	1.00	0.98	1.21	1.00	1.01	0.98	1.03	0.93
	Debed	0.98	1.00	1.08	1.14	1.05	0.98	0.00	1.20	0.00	0.00	1.01
	Hrazdan	0.96	1.02	0.85	1.12	0.99	0.96	0.99	1.01	0.99	0.00	1.00
	Metsamor	1.00	1.01	1.12	0.99	0.99	1.13	0.00	0.00	1.01	0.00	0.93
	Sevan	1.02	0.78	0.95	1.04	1.00	1.01	1.05	1.07	1.02	1.00	0.83
Vorotan	0.99	0.98	1.08	1.03	0.92	1.25	0.94	0.96	1.00	0.00	1.21	
Baseflow volume provided by ecosystems in 2023, millions of m ³	Aghstev	0.08	16.35	0.00	0.55	20.75	10.28	0.00	28.47	0.00	0.00	0.00
	Akhuryan	33.80	94.65	71.86	47.41	0.00	0.24	0.00	0.00	0.22	0.00	3.99
	Arpa	100.43	45.41	41.32	96.20	44.70	1.74	6.91	0.00	80.61	0.00	6.18
	Debed	17.19	185.76	66.66	25.53	44.09	11.22	0.00	1.88	0.00	0.00	1.37
	Hrazdan	41.83	47.49	41.32	25.97	43.32	2.44	0.00	0.08	12.69	0.00	0.94
	Metsamor	91.88	34.47	97.68	30.75	8.44	1.42	0.00	0.00	123.33	0.00	1.94
	Sevan	35.71	71.25	11.99	28.70	5.60	0.71	1.72	0.15	0.00	0.00	2.35
	Vorotan	100.63	67.45	25.75	49.61	44.26	11.69	0.57	21.12	19.90	0.00	0.81
Armenia	421.56	562.83	356.57	304.71	211.15	39.74	9.20	51.68	236.75	0.00	17.58	
Baseflow volume provided by ecosystems in 2017, millions of m ³	Aghstev	0.08	15.90	0.00	0.50	20.85	10.19	0.00	29.14	0.00	0.00	0.00
	Akhuryan	33.70	100.09	88.97	52.41	0.00	0.24	0.00	0.00	0.23	0.00	5.53
	Arpa	100.43	45.39	41.32	96.04	43.93	2.10	6.90	0.00	78.71	0.00	5.72
	Debed	16.77	186.46	71.95	29.14	46.43	11.05	0.00	2.25	0.00	0.00	1.38
	Hrazdan	41.61	45.57	40.85	26.27	43.08	2.74	0.00	0.08	13.14	0.00	0.98
	Metsamor	91.79	34.82	109.67	30.34	8.34	1.60	0.00	0.00	124.55	0.00	1.81
	Sevan	35.66	71.91	12.59	30.82	5.69	0.74	1.71	0.12	0.00	0.00	2.38

	Vorotan	99.60	65.85	27.92	50.91	40.61	14.60	0.54	20.38	19.97	0.00	0.99
	Armenia	419.63	566.00	393.28	316.43	208.93	43.25	9.15	51.97	236.59	0.00	18.81
Changes in provided baseflow from 2023 to 2017, millions of m3	Aghstev	0.00	0.44	0.00	0.05	-0.10	0.09	0.00	-0.67	0.00	0.00	0.00
	Akhuryan	0.11	-5.44	-17.12	-5.01	0.00	0.01	0.00	0.00	0.00	0.00	-1.54
	Arpa	0.00	0.02	0.00	0.15	0.77	-0.36	0.01	0.00	1.90	0.00	0.45
	Debed	0.42	-0.70	-5.30	-3.62	-2.34	0.17	0.00	-0.38	0.00	0.00	-0.02
	Hrazdan	0.22	1.92	0.47	-0.30	0.24	-0.30	0.00	0.00	-0.45	0.00	-0.05
	Metsamor	0.09	-0.35	-11.99	0.42	0.10	-0.18	0.00	0.00	-1.22	0.00	0.13
	Sevan	0.05	-0.66	-0.60	-2.11	-0.10	-0.03	0.01	0.02	0.00	0.00	-0.03
	Vorotan	1.04	1.60	-2.18	-1.30	3.65	-2.91	0.03	0.74	-0.07	0.00	-0.18
	Armenia	1.93	-3.17	-36.72	-11.72	2.23	-3.51	0.05	-0.28	0.17	0.00	-1.23
Changes in provided baseflow from 2023 to 2017, % relative to 2017	Aghstev	0.00	2.78	0.00	10.17	-0.48	0.92	0.00	-2.30	0.00	0.00	0.00
	Akhuryan	0.31	-5.43	-19.24	-9.55	0.00	2.24	0.00	0.00	-0.57	0.00	-27.86
	Arpa	0.00	0.04	0.00	0.16	1.76	-17.10	0.10	0.00	2.42	0.00	7.89
	Debed	2.51	-0.38	-7.36	-12.41	-5.03	1.56	0.00	-16.73	0.00	0.00	-1.26
	Hrazdan	0.53	4.21	1.14	-1.14	0.55	-10.86	0.00	0.00	-3.40	0.00	-4.65
	Metsamor	0.10	-1.02	-10.93	1.37	1.18	-11.49	0.00	0.00	-0.98	0.00	7.02
	Sevan	0.15	-0.91	-4.80	-6.86	-1.69	-4.27	0.48	20.45	0.00	0.00	-1.17
	Vorotan	1.04	2.43	-7.79	-2.56	8.99	-19.93	5.88	3.63	-0.36	0.00	-17.72
	Armenia	0.46	-0.56	-9.34	-3.70	1.07	-8.12	0.52	-0.55	0.07	0.00	-6.54

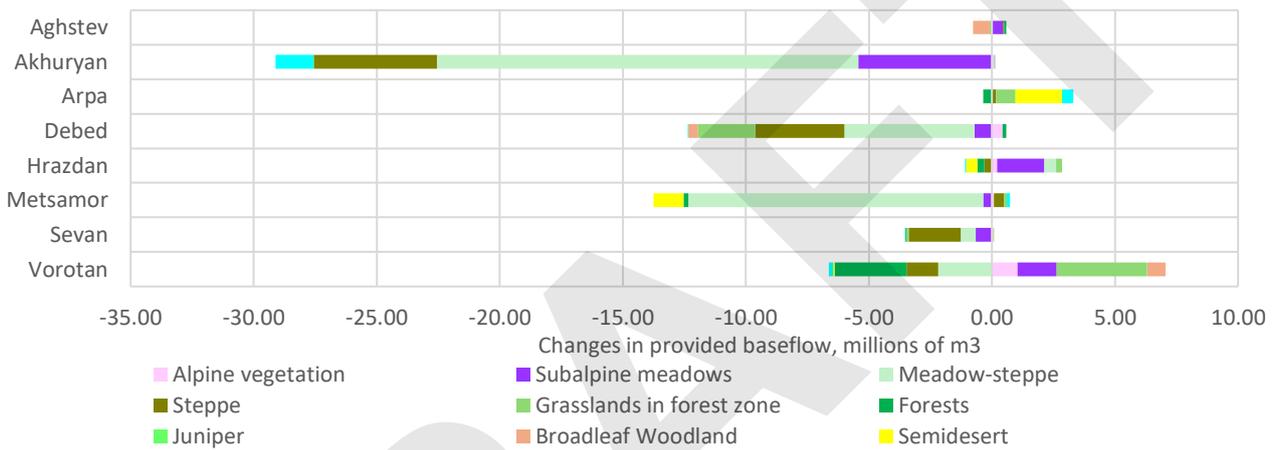


Figure 31B3-4. Changes in provided baseflow from 2023 to 2017, millions of m3.

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3.1.C. Prevention of soil water erosion and sediment transport to waterbodies (InVEST SDR)

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Two ES - 1) prevention of soil water erosion and 2) ensuring water flow quality due to prevention of sediment transport to waterbodies - were estimated and mapped using InVEST Sediment Delivery Ratio (SDR) model. The InVEST SDR model focuses only on overland erosion. Outputs from the model include the sediment load delivered to the stream at an annual time scale, as well as the amount of sediment eroded in the catchment and retained by vegetation and topographic features. The main indicator of the ES of prevention of soil erosion is avoided erosion, and the main indicator of the ES of ensuring water flow quality is avoided sediment export to streams (Figure 31C1-1).

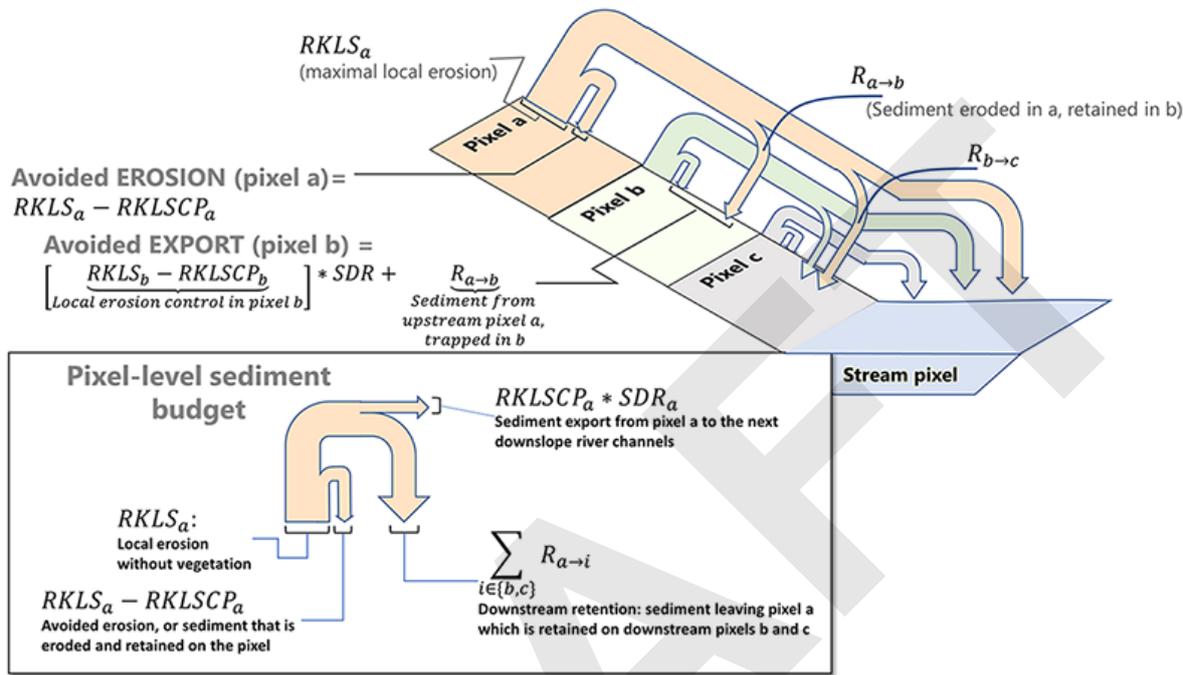
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Figure 31C1-1. Schematic of InVEST SDR model (InVEST User Guide [42]).

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3.1.C1. Potential ES provided by terrestrial ecosystems

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In 2023, total avoided erosion was estimated as 140.7 million tons per year, and total avoided sediment export to streams was estimated as 12.1 million tons per year. ES maps show that current erosion and sediment export are negligible, whereas avoided erosion and sediment export is many times higher (Figure 31C1-2, note that the scale values for current sediment export are one-tenth of those for avoided export). On average, terrestrial ecosystems prevent about 95% of erosion and 96% of sediment export in Armenia (Table 31C1-1).

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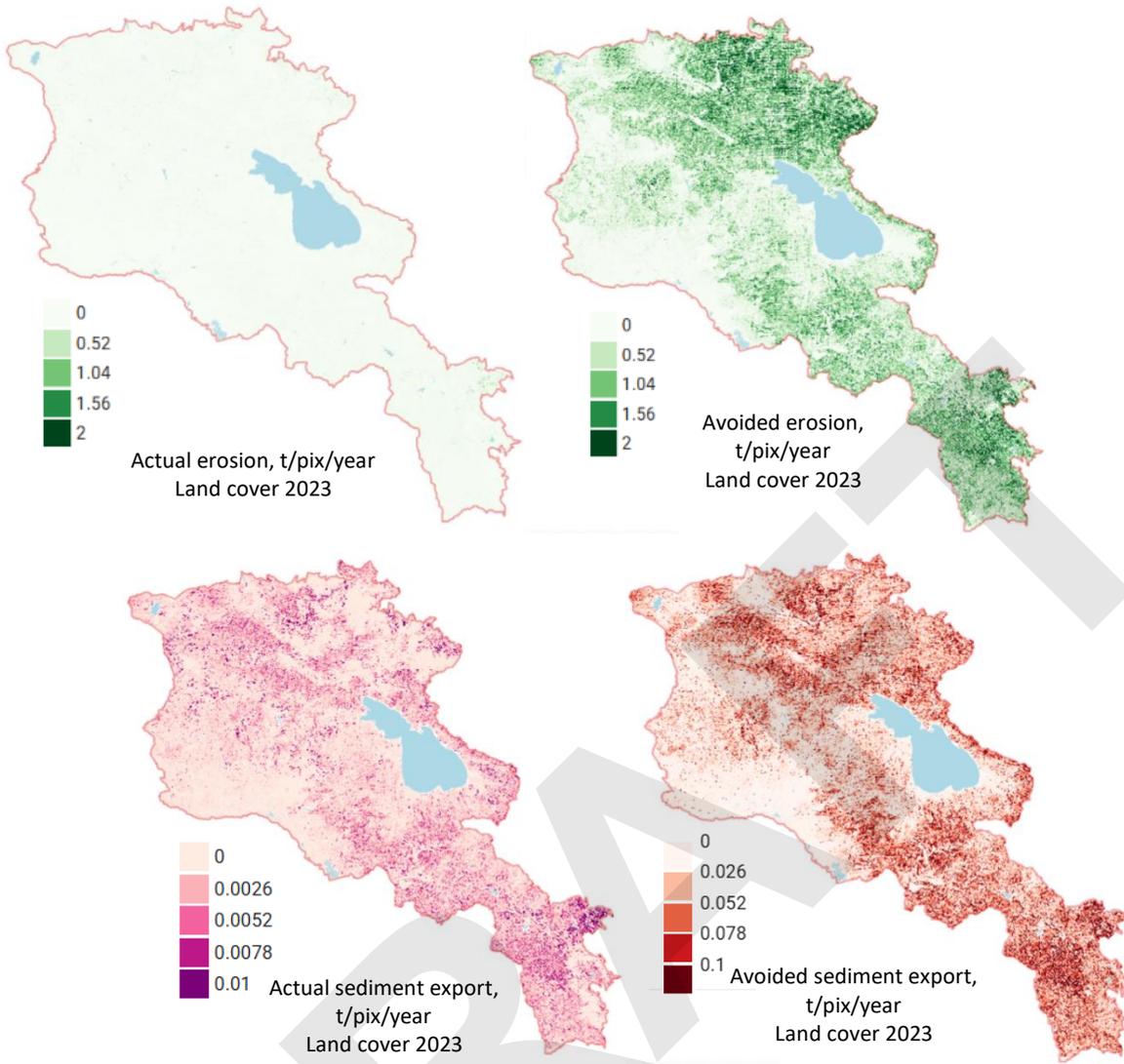
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Table 31C1-1. Potential ES indicators in Armenia (the calculations were carried out for the entire territory of Armenia)

Indicator	Land cover 2023	Bare ground scenario	ES Provided by ecosystems	Change in ES due to ecosystem functioning %
Erosion	2.3 t/ha/year 6.8 Mt/year	48.6 t/ha/year 147.2 Mt/year	Avoided erosion -46.4 t/ha/year -140.7 Mt/year	-95%
Sediment export	0.15 t/ha/year 0.47 Mt/year	4.5 t/ha/year 13.5 Mt/year	Avoided sediment export -4.3 t/ha/year -12.1 Mt/year	-96%

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Figure 31C1-2. Potential ES indicators with current land cover, 2023. For detailed maps see the section "Ecosystem Services - Sediment Delivery Ratio - Basic scenario 2023" in the project Web GIS

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Table 31C1-2. Indicators of erosion across watersheds and marzes (the calculations were carried out for the entire territory of Armenia)

		Erosion under bare ground scenario, t/ha/year	Current erosion in 2023, t/ha/year	Avoided erosion, t/ha/year	Total erosion under bare ground scenario, Mt/year	Total current erosion, Mt/year	Total avoided erosion, Mt/year	Share of avoided erosion*, %
Watersheds	Aghstev	96.0	2.5	93.5	29.7	0.8	28.9	97.4
	Akhuryan	24.7	2.0	23.0	6.6	0.5	6.1	92.0
	Arpa	49.6	2.5	47.0	21.1	1.1	20.1	95.0
	Debed	75.2	2.9	72.4	28.7	1.1	27.6	96.1
	Hrazdan	34.3	1.9	32.3	19.8	1.1	18.6	94.3
	Metsamor	20.3	1.3	19.0	7.1	0.5	6.6	93.6
	Vorotan	78.8	4.0	75.0	34.3	1.7	32.6	94.9
Marzes	Aragatsotn	26.8	1.6	25.2	7.1	0.4	6.6	93.9
	Ararat	33.8	1.7	32.1	6.9	0.3	6.5	94.9
	Armavir	3.9	0.4	3.5	0.5	0.1	0.4	89.1
	Gegharkunik	41.1	2.3	38.8	15.8	0.9	14.9	94.4
	Kotayk	37.7	2.0	35.7	7.7	0.4	7.3	94.6
	Lori	76.5	2.9	73.6	28.0	1.1	26.9	96.2
	Shirak	27.4	2.1	25.3	7.1	0.5	6.6	92.3
	Syunik	78.8	4.0	74.8	34.3	1.7	32.6	94.9
	Tavush	99.2	2.4	96.8	26.4	0.6	25.7	97.6
	Vayots Dzor	60.8	3.1	57.7	13.6	0.7	12.9	95.0

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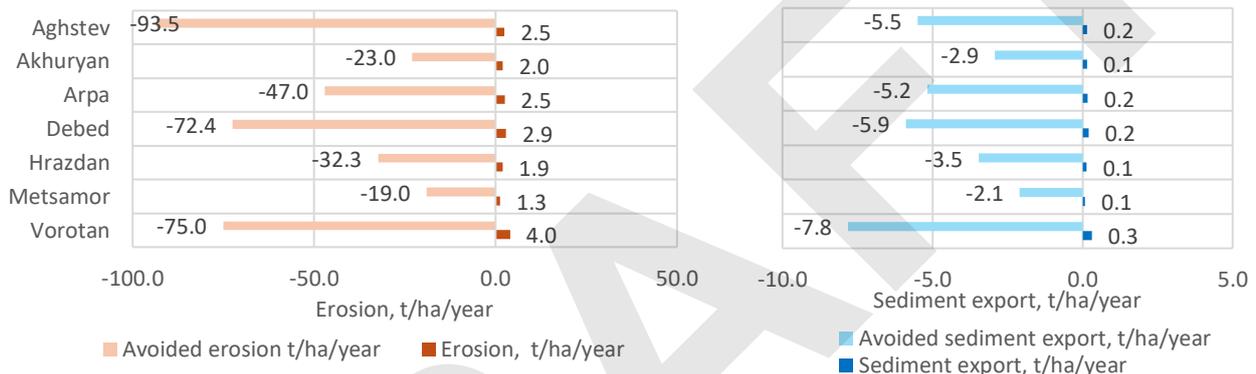
* Share from the sum of current and avoided sediment export

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Table 31C1-3. Indicators of sediment export across watersheds and marzes (the calculations were carried out for the entire territory of Armenia)

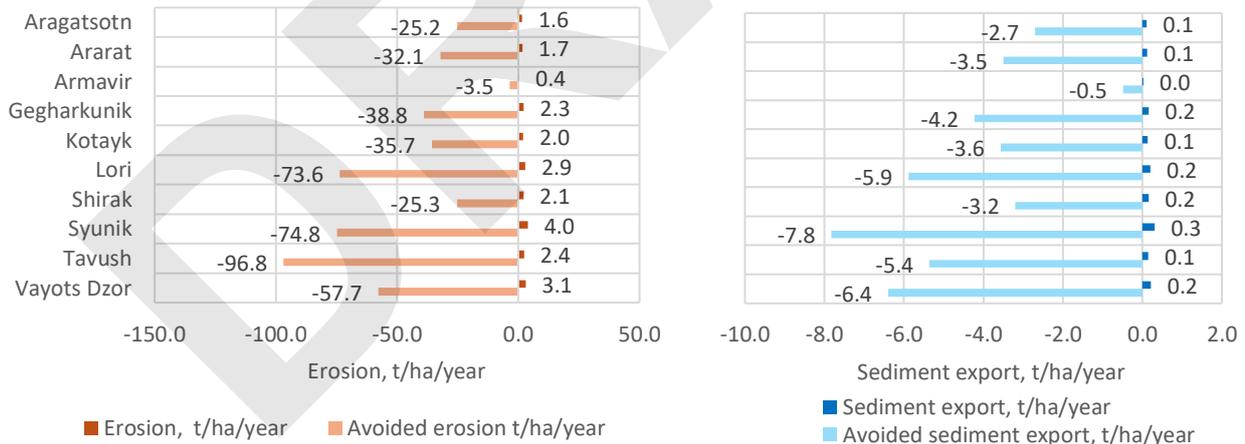
		Current sediment export in 2023, t/ha/year	Avoided sediment export, t/ha/year	Total current sediment export 2023, Mt/year	Total avoided sediment export 2023, Mt/year	Share of avoided sediment export, %*
Watersheds	Aghstev	0.2	5.5	0.0	1.7	97.3
	Akhuryan	0.1	2.9	0.0	0.8	95.3
	Arpa	0.2	5.2	0.1	2.2	96.7
	Debed	0.2	5.9	0.1	2.2	96.7
	Hrazdan	0.1	3.5	0.1	2.0	96.4
	Metsamor	0.1	2.1	0.0	0.7	96.1
	Vorotan	0.3	7.8	0.1	3.4	96.2
Marzes	Aragatsotn	0.1	2.7	0.0	0.7	96.2
	Ararat	0.1	3.5	0.0	0.7	96.5
	Armavir	0.0	0.5	0.0	0.1	95.1
	Gegharkunik	0.1	4.2	0.1	1.6	96.6
	Kotayk	0.1	3.6	0.0	0.7	96.1
	Lori	0.2	5.9	0.1	2.1	97.0
	Shirak	0.1	3.2	0.0	0.8	96.2
	Syunik	0.3	7.8	0.1	3.4	96.6
	Tavush	0.2	5.4	0.0	1.4	97.2
	Vayots Dzor	0.2	6.4	0.0	1.4	96.6

1788 * Share from the sum of current and avoided sediment export



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Figure 31C1-3. Potential ES indicators across watersheds



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Figure 31C1-4. Potential ES indicators across marzes

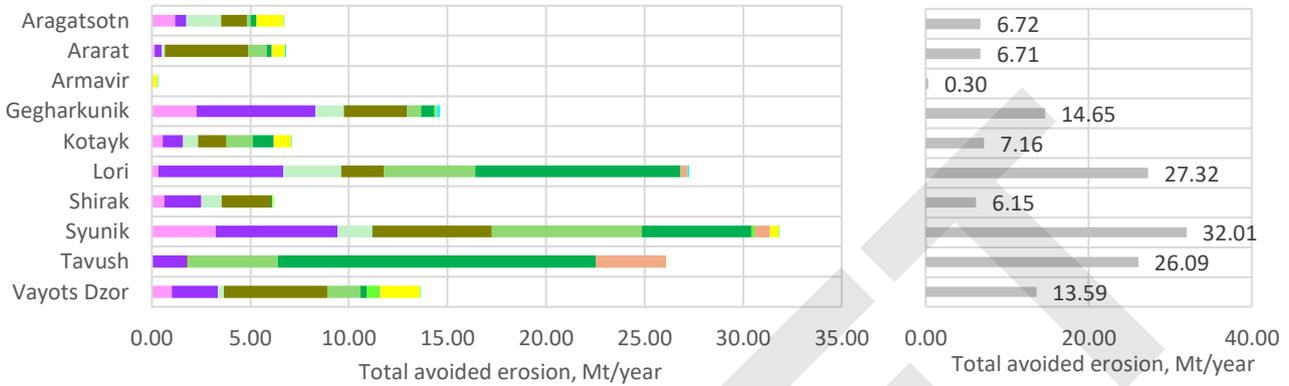
1793 Further analysis was conducted only for natural areas—excluding croplands and built-up areas.

1794 The highest rates of total avoided erosion and sediment export were calculated for marzes Syunik, and Lori. High total
1795 avoided-erosion values were also modeled for Tavush marz. The lowest values of avoided erosion and sediment export
1796 were found for Armavir (Table 31C1-2; Figure 31C1-3 b, d).

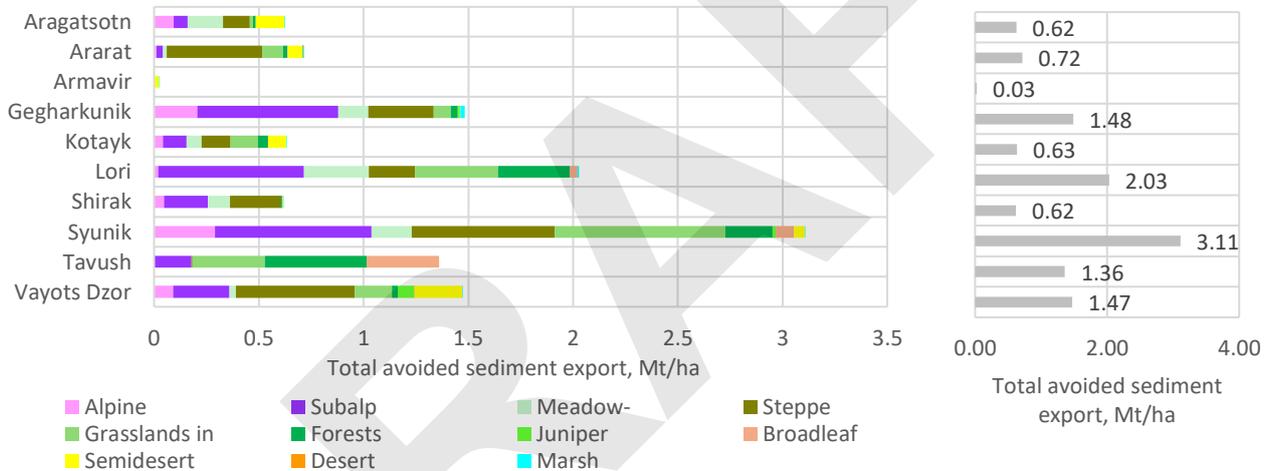
1797 In Tavush marz, forests provide the largest share of erosion prevention (62%). In other marzes, erosion is prevented
1798 mainly by steppe and subalpine ecosystems, although forests also play a significant role in Lori and Syunik. In preventing
1799 sediment export to water bodies, the role of forests is substantially smaller. It contributes a substantial share to this ES

1800 only in Tavush marz (Table 31C1-2; Figure 31C1-3 a, c). Due to the reduced role of forests, this marz’s role in preventing
 1801 sediment export also decreases compared to erosion prevention.

1802 Among vegetation types, forests are the most effective in preventing erosion and provide the largest overall
 1803 contribution to this ES in Armenia, despite their relatively small area (Figure 31C1-4, a, b). All types of woodlands and
 1804 grasslands, except for semi-desert and desert, are also highly effective in erosion prevention (Figure 31C1-4, a). The total
 1805 avoided erosion values are high for subalpine meadows, steppes, and grasslands within the forest zone (Figure 31C1-4,
 1806 b). The pattern for avoided sediment export generally mirrors that of avoided erosion, except for the substantially
 1807 reduced role of forests (Figure 31C1-4 c, d).

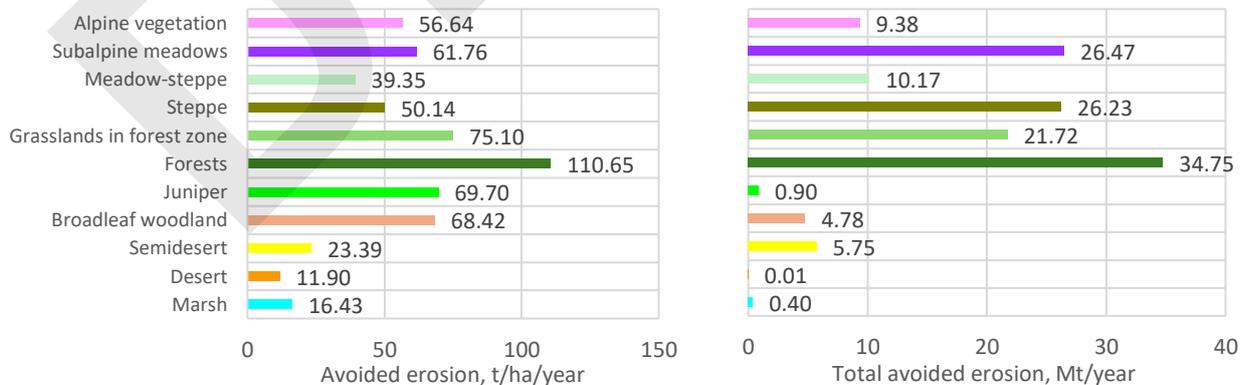


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1810 *Figure 31C1-3. Total avoided erosion (a, b) and sediment export (c, d) across marzes. The charts on the left (a, c) show*
 1811 *values broken down by vegetation types, the charts on the right (b, d) show aggregate totals by marzes.*



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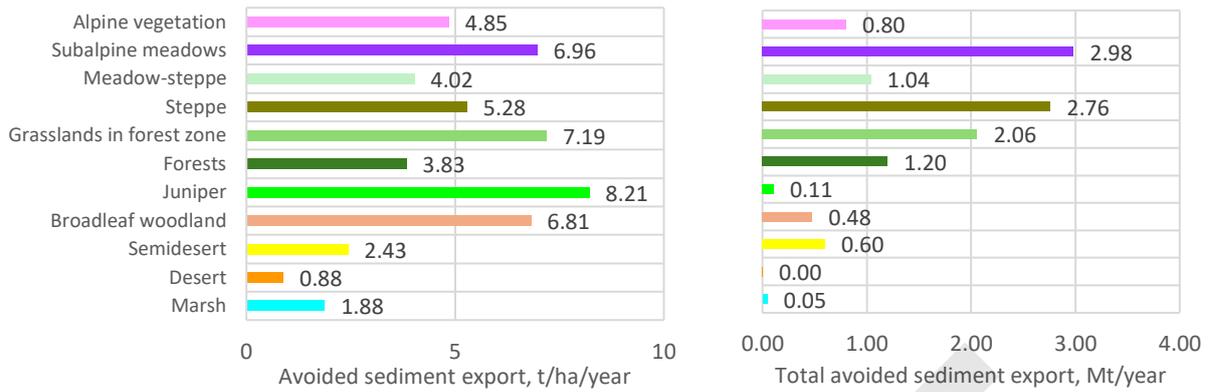


Figure 31C1-4. ES indicators across vegetation types

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Table 31C1-2. Avoided erosion and avoided sediment export across vegetation types and marzes in 2023

		Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grassl. in forest zone	Forests	Juniper	Broadleaf woodland	Semidesert	Desert	Marsh	Average
Avoided Erosion T/ha	Aragatsotn	57.94	51.91	35.29	25.07	46.38	59.27	0.00	0.00	18.80	0.00	22.66	30.90
	Ararat	38.72	55.87	49.59	57.64	54.50	88.79	0.00	32.03	14.78	11.90	9.23	42.54
	Armavir	0.00	0.00	0.00	0.00	0.00	5.21	0.00	0.00	6.77	0.00	1.80	6.69
	Gegharkunik	58.30	47.04	35.99	39.40	31.41	52.91	39.77	10.99	0.00	0.00	19.53	43.49
	Kotayk	47.17	59.63	34.25	31.76	49.26	69.04	0.00	38.14	31.55	0.00	36.47	42.61
	Lori	75.77	74.73	45.10	64.91	87.87	115.76	0.00	83.98	0.00	0.00	28.25	80.86
	Shirak	49.50	46.21	25.47	30.17	0.00	52.42	0.00	0.00	19.12	0.00	5.20	33.60
	Syunik	61.99	75.87	60.46	77.63	87.46	113.87	118.30	55.54	41.12	0.00	39.87	79.16
	Tavush	71.59	84.26	0.00	86.04	85.58	120.09	0.00	73.59	0.00	0.00	0.00	101.17
	Vayots Dzor	48.06	60.87	38.33	68.83	68.55	82.97	69.27	33.03	55.30	0.00	30.54	62.13
	Average	56.64	61.76	39.35	50.14	75.10	110.65	69.70	68.42	23.39	11.90	16.43	
Total avoided Erosion Mt/year		Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grassl. in forest zone	Forests	Juniper	Broadleaf woodland	Semidesert	Desert	Marsh	Total
	Aragatsotn	1.18	0.56	1.77	1.30	0.20	0.29	0.00	0.00	1.40	0.00	0.01	6.72
	Ararat	0.14	0.35	0.15	4.23	0.96	0.23	0.00	0.03	0.66	0.01	0.05	6.71
	Armavir	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.30
	Gegharkunik	2.27	6.02	1.44	3.22	0.71	0.68	0.08	0.01	0.00	0.00	0.18	14.65
	Kotayk	0.54	1.05	0.76	1.43	1.34	1.07	0.00	0.01	0.88	0.00	0.03	7.16
	Lori	0.34	6.34	2.93	2.19	4.63	10.41	0.00	0.35	0.00	0.00	0.09	27.32
	Shirak	0.64	1.87	1.05	2.49	0.00	0.07	0.00	0.00	0.03	0.00	0.02	6.15
	Syunik	3.25	6.17	1.76	6.07	7.62	5.55	0.15	0.81	0.45	0.00	0.03	32.01
	Tavush	0.00	1.78	0.00	0.06	4.57	16.14	0.00	3.56	0.00	0.00	0.00	26.09
Vayots Dzor	1.01	2.34	0.30	5.25	1.69	0.31	0.67	0.02	2.02	0.00	0.00	13.59	
	Total	9.38	26.47	10.17	26.23	21.72	34.75	0.90	4.78	5.75	0.01	0.40	140.70
Avoided sediment export, T/ha		Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grassl. in forest zone	Forests	Juniper	Broadleaf woodland	Semidesert	Desert	Marsh	Average
	Aragatsotn	4.55	6.20	3.37	2.46	4.02	2.72	0.00	0.00	1.82	0.00	2.43	2.88
	Ararat	3.30	4.95	5.60	6.22	5.67	7.30	0.00	3.44	1.60	0.88	0.95	4.50
	Armavir	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.56	0.00	0.37	0.56
	Gegharkunik	5.27	5.26	3.57	3.83	3.56	2.64	4.95	1.57	0.00	0.00	2.26	4.43
	Kotayk	3.70	6.37	3.26	3.08	4.80	3.04	0.00	4.26	3.12	0.00	3.53	3.78
	Lori	4.60	8.19	4.75	6.57	7.52	3.80	0.00	8.63	0.00	0.00	2.74	6.01
	Shirak	3.66	5.24	2.52	2.99	0.00	2.73	0.00	0.00	1.56	0.00	1.21	3.39
	Syunik	5.54	9.19	6.64	8.74	9.32	4.63	13.28	5.97	4.44	0.00	5.01	7.71
	Tavush	4.29	8.39	0.00	7.52	6.47	3.63	0.00	7.14	0.00	0.00	0.00	5.28
Vayots Dzor	4.35	6.95	3.93	7.45	7.15	7.35	8.21	4.56	6.22	0.00	3.35	6.72	
	Average	4.85	6.96	4.02	5.28	7.19	3.83	8.21	6.81	2.43	0.88	1.88	

		Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grassl. in forest zone	Forests	Juniper	Broadleaf woodland	Semidesert	Desert	Marsh	Total
Total avoided sediment export, Mt/year	Aragatsotn	0.093	0.066	0.169	0.127	0.017	0.013	0.000	0.000	0.136	0.000	0.001	0.623
	Ararat	0.012	0.031	0.017	0.456	0.100	0.019	0.000	0.003	0.071	0.001	0.005	0.716
	Armavir	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.000	0.000	0.026
	Gegharkunik	0.206	0.674	0.143	0.314	0.081	0.034	0.010	0.002	0.000	0.000	0.021	1.483
	Kotayk	0.042	0.112	0.072	0.139	0.131	0.047	0.000	0.001	0.087	0.000	0.003	0.634
	Lori	0.021	0.695	0.309	0.222	0.396	0.342	0.000	0.036	0.000	0.000	0.009	2.028
	Shirak	0.047	0.212	0.104	0.246	0.000	0.004	0.000	0.000	0.003	0.000	0.003	0.619
	Syunik	0.290	0.747	0.193	0.683	0.813	0.226	0.017	0.087	0.049	0.000	0.003	3.108
	Tavush	0.000	0.177	0.000	0.005	0.345	0.487	0.000	0.345	0.000	0.000	0.000	1.360
	Vayots Dzor	0.092	0.268	0.031	0.569	0.176	0.028	0.079	0.002	0.227	0.000	0.000	1.471
	Total	0.803	2.981	1.038	2.760	2.059	1.200	0.106	0.476	0.598	0.001	0.046	12.068

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3.1.C2. Changes in ES potential from 2017 to 2023

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We assessed only changes in ES potential, since we have no data on ES use for 2017.

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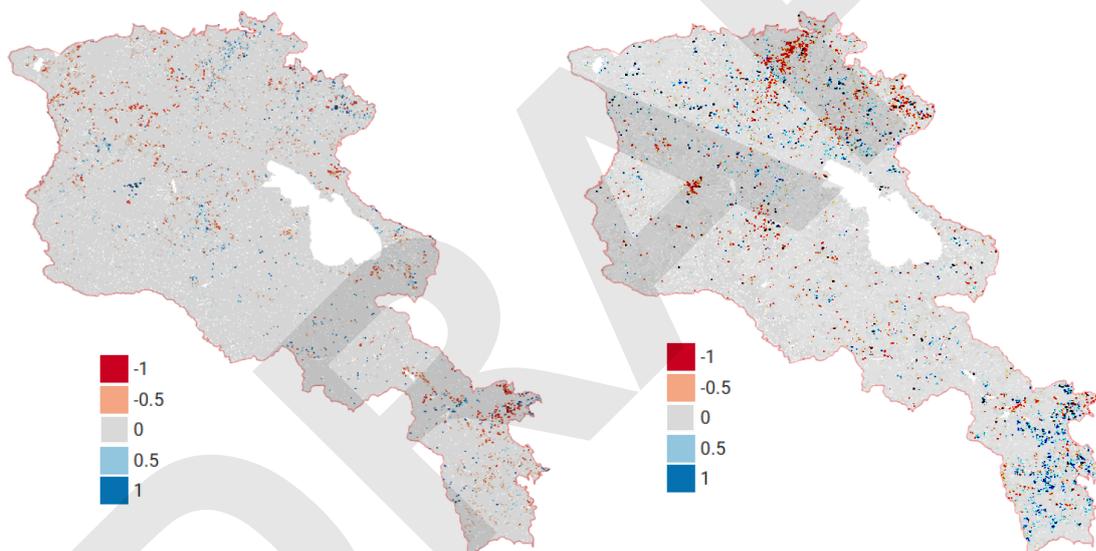
Assessment of ES changes based on the 2017 and 2023 modelled ES maps

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Changes in the landcover from 2017 to 2023 resulted in changes in avoided erosion and sediment export. The maps show that the changes are sporadic and oppositely directed (Figure 31C2-1). These changes represent only tenths of a percent of total ES volume, but can be important for tracking trends.



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Figure 31C2-1. Potential ES changes from 2017 to 2023: a) Changes in avoided erosion; b) Changes in avoided sediment export. For details see maps in the section "Sediment Delivery Ratio - Dynamics" in the project Web GIS

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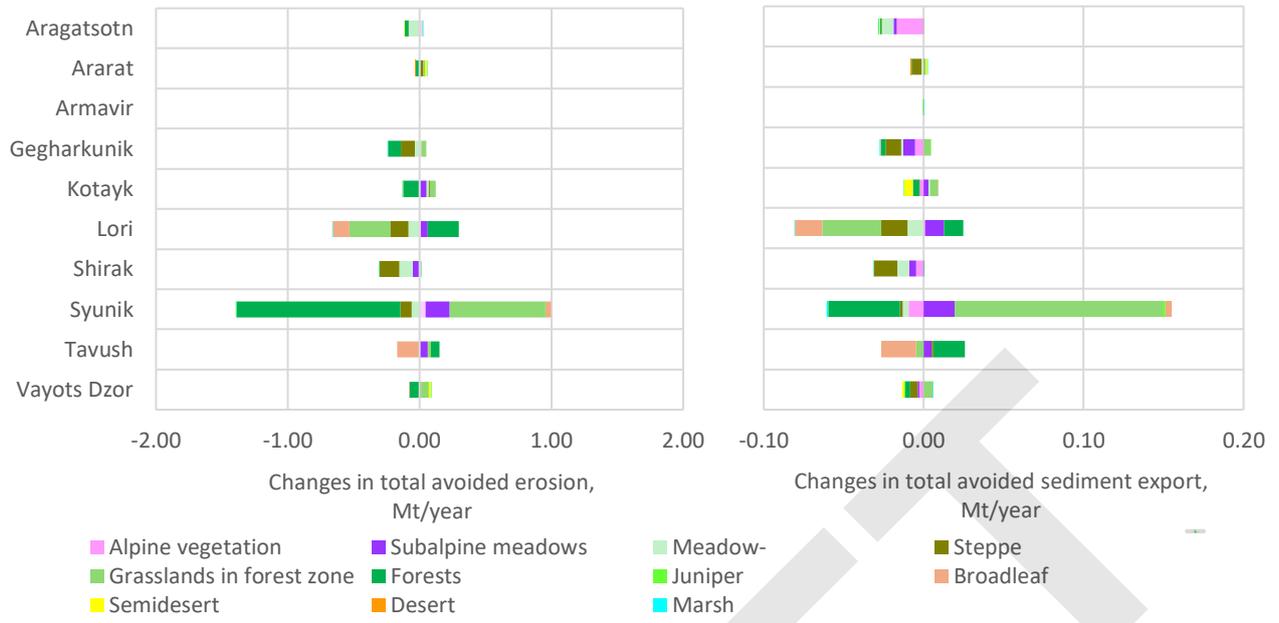
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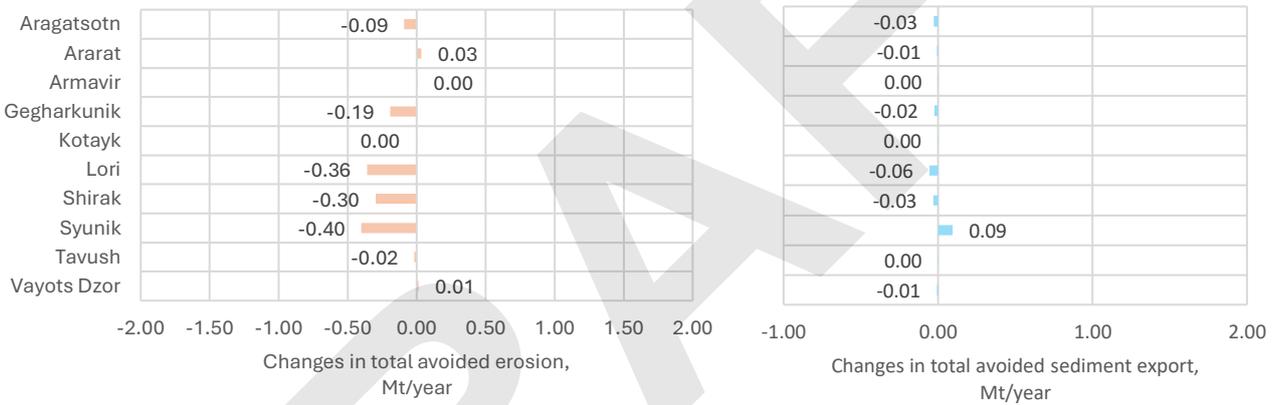
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The difference between the modeled potential ES values in 2023 (Table 31C1-2) and 2017 (Appendix 6) gives the change in ES over this period (Table 31C2-1). Aggregate changes in ES capacity indicators relative to 2017 are small—0.1–5% for marzes and 0.6–7% for vegetation types. However, for certain vegetation types within marzes, changes reach up to 71% for avoided erosion and 88% for avoided sediment export (forests in Armavir). In absolute terms, the most noticeable changes occurred in the marzes of Syunik and Lori. In Syunik, the ES capacity of forests decreased while the capacity of grasslands within the forest zone increased, apparently due to the replacement of some forests by grasslands (Section 2.3). In Lori, the opposite pattern is observed: ES capacity increased for forests and decreased for forest grasslands and steppes (Figure 31C2-2, a, b). However, these opposing changes largely offset one another within the marzes (Figure 31C2-2, c, d).



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Figure 31C2-2. Changes in avoided erosion and avoided sediment export across vegetation types and marzes.

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Table 31C2-1. Changes in avoided erosion and avoided sediment export across vegetation types and marzes

		Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grassl. in forest zone	Forests	Juniper	Broadleaf woodland	Semidesert	Desert	Marsh	Total	
Total avoided Erosion Mt	Aragatsotn	0.02	-0.01	-0.08	0.00	0.00	-0.03	0.00	0.00	0.00	0.00	0.00	-0.09	
	Ararat	0.00	0.00	0.00	0.02	0.01	-0.03	0.00	0.00	0.02	0.00	0.00	-0.07	
	Armavir	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	Gegharkunik	0.01	0.00	-0.04	-0.11	0.03	-0.09	0.00	0.00	0.00	0.00	0.00	-0.17	
	Kotayk	0.01	0.05	0.02	0.01	0.04	-0.12	0.00	0.00	0.00	0.00	0.00	0.04	
	Lori	0.01	0.05	-0.09	-0.14	-0.31	0.24	0.00	-0.13	0.00	0.00	0.00	0.00	-0.31
	Shirak	0.01	-0.05	-0.10	-0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.31
	Syunik	0.05	0.18	-0.06	-0.08	0.72	-1.25	0.01	0.05	0.00	0.00	0.00	0.00	-0.24
	Tavush	0.00	0.06	0.00	0.01	0.02	0.07	0.00	-0.17	0.00	0.00	0.00	0.00	-0.02
	Vayots Dzor	0.00	0.00	0.00	0.01	0.06	-0.08	0.00	0.00	0.02	0.00	0.00	0.00	-0.01
	Total	0.11	0.28	-0.34	-0.43	0.58	-1.29	0.01	-0.25	0.03	0.00	-0.01	-1.18	
Total avoided sediment export, Mt	Aragatsotn	-0.02	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03	
	Ararat	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	
	Armavir	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	Gegharkunik	-0.01	-0.01	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02	
	Kotayk	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	
	Lori	0.00	0.01	-0.01	-0.02	-0.04	0.01	0.00	-0.02	0.00	0.00	0.00	-0.06	
	Shirak	0.00	0.00	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03	
	Syunik	-0.01	0.02	0.00	0.00	0.13	-0.04	0.00	0.00	0.00	0.00	0.00	0.09	

	Tavush	0.00	0.01	0.00	0.00	0.00	0.02	0.00	-0.02	0.00	0.00	0.00	0.00
	Vayots Dzor	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	-0.01
	Total	-0.04	0.02	-0.03	-0.05	0.11	-0.02	0.00	-0.04	-0.01	0.00	0.00	-0.06
Total avoided erosion, % relative to 2017	Aragatsotn	1.69	-1.17	-4.18	-0.06	2.18	-9.14	0.00	0.00	-0.12	0.00	6.67	-1.33
	Ararat	0.33	0.97	0.69	0.55	1.22	-10.83	0.00	0.07	3.03	-1.00	3.87	0.48
	Armavir	0.00	0.00	0.00	0.00	0.00	-70.89	0.00	0.00	0.13	0.00	46.00	0.09
	Gegharkunik	0.53	-0.03	-2.39	-3.19	4.86	-12.25	0.32	9.77	0.00	0.00	-0.74	-1.30
	Kotayk	1.22	4.51	2.15	0.75	3.37	-10.36	0.00	-0.16	-0.16	0.00	-0.35	-0.04
	Lori	3.10	0.81	-2.83	-5.96	-6.23	2.33	0.00	-26.40	0.00	0.00	-2.34	-1.31
	Shirak	1.34	-2.74	-8.78	-5.66	0.00	3.77	0.00	0.00	-0.34	0.00	-26.22	-4.61
	Syunik	1.47	2.99	-3.27	-1.37	10.36	-18.35	5.64	6.00	-0.11	0.00	-14.99	-1.24
	Tavush	-0.65	3.53	0.00	12.44	0.39	0.42	0.00	-4.52	0.00	0.00	0.00	-0.06
	Vayots Dzor	0.12	0.07	0.05	0.16	3.60	-19.70	0.18	-0.30	0.88	0.00	16.24	0.09
	Total	1.14	1.07	-3.25	-1.62	2.73	-3.59	1.06	-4.92	0.59	-1.00	-2.50	-0.93
Total avoided sediment export, % relative to 2017	Aragatsotn	-15.25	-2.89	-4.31	-0.12	2.16	-5.58	0.00	0.00	-0.31	0.00	-39.62	-4.33
	Ararat	-2.70	0.24	-5.71	-1.28	1.37	-3.11	0.00	0.19	1.34	-1.65	1.96	-0.76
	Armavir	0.00	0.00	0.00	0.00	0.00	-87.93	0.00	0.00	-1.21	0.00	9.66	-1.90
	Gegharkunik	-2.50	-1.12	-0.93	-2.95	5.78	-8.43	0.06	-11.70	0.00	0.00	-0.62	-1.52
	Kotayk	-5.24	2.81	1.10	-0.28	4.03	-7.69	0.00	1.37	-6.36	0.00	-1.73	-0.58
	Lori	4.07	1.76	-3.21	-6.80	-8.56	3.57	0.00	-32.26	0.00	0.00	-3.55	-2.70
	Shirak	-9.10	-1.97	-6.61	-5.68	0.00	8.25	0.00	0.00	-2.26	0.00	-7.34	-4.80
	Syunik	-3.19	2.66	-1.78	-0.24	19.06	-16.58	10.16	5.11	-0.55	0.00	-23.99	3.13
	Tavush	-1.31	2.91	0.00	20.16	-1.35	4.23	0.00	-5.97	0.00	0.00	0.00	-0.08
	Vayots Dzor	-2.74	-0.45	0.06	-0.82	3.29	-9.51	-0.67	0.74	-0.58	0.00	22.60	-0.52
	Total	-4.83	0.82	-2.84	-1.87	5.38	-2.01	0.97	-6.86	-1.21	-1.65	-5.14	-0.52

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In terms of vegetation types across Armenia as a whole, the most noticeable trend is the increase in ES capacity of grasslands within the forest zone and the decrease in the capacity of forests, steppes, and meadow-steppe, which corresponds to changes in their area (Section 2.3). Changes in forest area (decrease in that case) affect the ES of erosion prevention more strongly than changes in other vegetation types, since forests are the most effective in this ES (Figure 31C1-4a). The ES of sediment export prevention is most affected by the increase in forest-zone grasslands, as these ecosystems are effective in this ES (Figure 31C2-3). Alpine and subalpine grasslands, as well as woodlands, are also effective, but their contribution to overall changes is minor due to their small area or small changes in it (Section 2.3).

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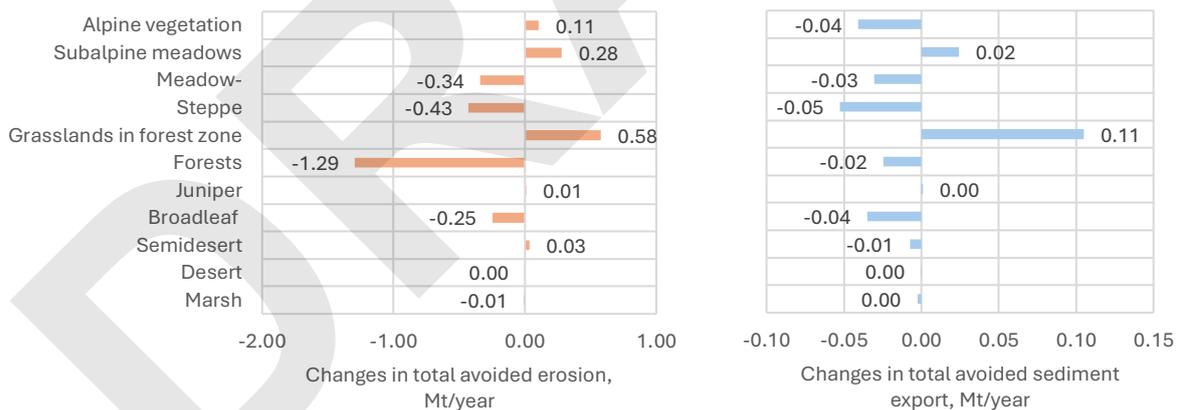
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Figure 31C2-3. Changes in avoided erosion and avoided sediment export across vegetation types in the whole Armenia.

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When assessing the contribution of different vegetation/ecosystem types to ES performance, it should be kept in mind that ES capacity is determined not only by ecosystem type, but also by many other factors—such as slope, soil type, precipitation, proximity to watercourses, and others. Therefore, the functions of areas belonging to the same ecosystem type may vary significantly, as may the results of changes in ecosystem area.

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Per-hectare ES provision by different vegetation types, averaged across Armenia, changed from 2017 to 2023 (Figure 31C2-4). The range of such changes within marzes is even larger (Appendix 7). These changes are not due to modifications of the ecosystems themselves—which we did not model—but to shifts in the mean conditions across their extent. For example, slope within the distribution of natural ecosystems in the woodland zone decreased while their total area increased, likely because gentler sites were taken out of agriculture. Conversely, slope within the distribution of various steppe types increased as their total area declined, likely because their gentler sites were ploughed. Thus, these changes affected the ES performance of vegetation types, since slope strongly influences the water-regulating and soil-conservation functions of ecosystems.

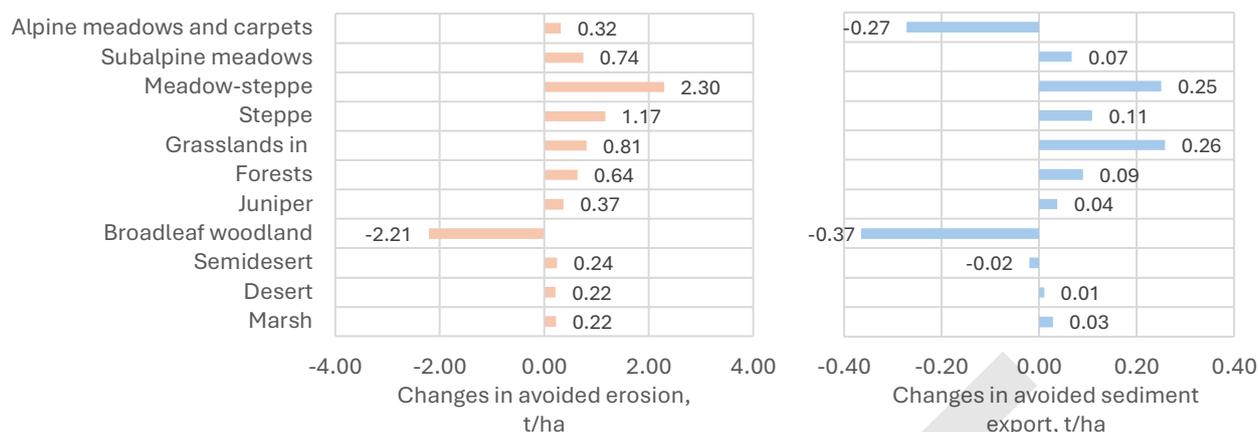


Figure 31C2-4. Changes in per-hectare ES provision by different vegetation types, averaged across Armenia.

Assessment of ES changes based on the changes in area of vegetation types

Changes in potential ES can be assessed using the indicators of ES provisioning per ha across different vegetation types in 2023 (Table 31C1-2) and 2017 (Appendix 6), together with their area and its changes between 2017 and 2023 (Table 2.3C-2). This approach makes it possible to calculate the data for the table recording the dynamics of the ES potential/capacity (Table 31C2-2). For converting ES indicators into aggregate totals (Mt/yr), different per-hectare ES values were used for 2017 and 2023. Therefore, the totals in the accounting table do not coincide, because the changes are driven not only by shifts in the area of vegetation types but also by changes in the mean conditions across their distributions (see above sub-section).

With respect to changes in ES potential/capacity, the same comment applies as for changes in ecosystem extent (Section 2.3.A). Additions to ecosystem area resulting from transitions out of croplands or built-up areas do not possess full ecosystem functionality. Therefore, the closing ES capacity is defined more by the extent of ecosystems that remained untransformed during the reporting period than by the total closing ecosystem area.

Table 31C2-2. Accounting table for the ES potential changes **[To be checked]**.

	Value of per-ha ES provisioning used	Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grassl. in forest zone	Forests	Juniper	Broadleaf woodland	Semi-desert	Desert	Marsh	Total	
Avoided erosion, Mt/year	Opening ES capacity in 2017	2017	9.27	26.24	10.53	26.66	21.18	36.08	0.89	5.02	5.74	0.01	0.38	142.00
	Additions to ES capacity	2023	0.03	0.47	0.14	0.97	2.02	2.55	0.02	0.39	0.45	0.00	0.03	7.07
	Managed/unmanaged	NA												
	Reductions ES capacity	2017	0.02	0.51	1.07	1.98	1.65	4.07	0.01	0.50	0.47	0.00	0.04	10.31
	Managed/unmanaged	NA												
	Net change ES capacity	2023	0.01	-0.04	-1.00	-1.06	0.35	-1.54	0.01	-0.09	-0.03	0.00	-0.01	-3.40
	Closing ES capacity in 2023	2023	9.33	26.52	10.18	26.24	21.76	34.75	0.90	4.77	5.77	0.01	0.38	140.61
	Additional row – see discussion below													
Closing ES capacity in 2023 of ecosystems unconverted since 2017,	2023	9.30	26.04	10.04	25.27	19.74	32.20	0.89	4.38	5.32	0.01	0.35	133.54	
Avoided sediment export, Mt/year	Opening ES capacity in 2017	2017	0.844	2.966	1.072	2.817	1.977	1.227	0.105	0.510	0.608	0.001	0.044	0.844
	Additions to ES capacity	2023	0.002	0.054	0.014	0.102	0.193	0.088	0.002	0.039	0.047	0.000	0.003	0.002
	Managed/unmanaged	NA												
	Reductions ES capacity	2017	0.002	0.058	0.109	0.209	0.154	0.138	0.001	0.050	0.050	0.000	0.004	0.002
	Managed/unmanaged	NA												
	Net change ES capacity	2023	0.001	-0.005	-0.102	-0.111	0.034	-0.053	0.001	-0.009	-0.003	0.000	-0.001	0.001
	Closing ES capacity in 2023	2023	0.800	2.990	1.041	2.765	2.084	1.203	0.107	0.475	0.600	0.001	0.043	0.800
	Additional row – see discussion below													
Closing ES capacity in 2023 of ecosystems unconverted since 2017,	2023	0.797	2.937	1.027	2.663	1.891	1.114	0.105	0.436	0.553	0.001	0.040	0.797	

1877 **3.1.C3. ES potential – supply/use balance**

1878 The indicators of total current and avoided sediment export in streams (Table 31C1-2) allow as to determine the
 1879 current and avoided sediment concentrations in river flow by dividing the aggregate totals by the river flow volume.
 1880 Sediment concentrations in river flow due to current sediment export are from 22 to 126 grams of sediments per m³ of
 1881 river flow (Table 31C3-1). At the same time, current sediment concentrations in water amount to only 2–4% of those
 1882 under the bare-soil scenario, where the effect of terrestrial ecosystems is absent (Table 31C3-1).

1883 We did not find suspended-sediment MPC indicators for Armenia's rivers for water use that would allow the used ES
 1884 to be determined accurately. Therefore, we proceeded from the temporary assumption that wherever river and stream
 1885 water is used, the avoided-sediment-export ES is fully utilized.

1886 The ES flow (supply=use) F_{ij} in watershed i for water use category j was calculated as the amount of avoided sediment
 1887 within the consumed volume of water $F_{ij}=U_{ij}*C^{eco}_i$, where U_{ij} – water use in watershed i in category j ; C^{eco}_i – ecosystem
 1888 effect on sediment concentrations in river flow due to a voided sediment export in watershed i (Table 31C3-2). The ES
 1889 flow (supply=use) is greatest in the watersheds with the highest water consumption—Metsamor and Hrazdan—and
 1890 lowest in the Arpa and Debed watersheds (Fig. 31C3-1).

1891 *Table 31C3-1. Data to estimate ES use*

	Water use*, millions of m ³				River flow*, millions of m ³	Ecosystem effect on sediment concentrations in river flow due to a voided sediment export, g/m ³ C^{eco}_i	Sediment concentrations in river flow due to current sediment export, g/m ³	The share of current sediment export in those on bare ground, %
	Drinking water	Industrial, domestic and construction	Agriculture, fish breeding, forestry	Total				
Aghstev	8.3	1.4	9.5	19.2	260.00	-5230.8	126.3	2.4
Akhuryan	7.9	2	95.7	105.6	700.70	-883.4	38.7	4.2
Arpa	2.2	0.8	14.2	17.2	1177.00	-1857.3	65.0	3.4
Debed	9.5	4.2	5.1	18.8	960.00	-2112.5	66.1	3.0
Hrazdan	56.7	41	340.5	438.2	788	-804.6	28.0	3.4
Metsamor	22.6	21.1	732.8	776.5	1043.30	-622.1	22.5	3.5
Sevan	12.1	1	46.2	59.3	615.66	-2408.8	83.4	3.3
Vorotan	7.4	63	19.1	89.5	1319.60	-2355.3	90.4	3.7
Armenia	132.5	139.7	2 150.1	2 422.3		-1758.1	60.6	3.3

1892 * For data sources see Section 3.1.B1

1893 *Table 31C3-2. Supply-use table for ES of prevention of sediment export to streams. Sediment amount in water use, prevented by ecosystems, Mt*

Watershed		Drinking	Industrial, domestic and construction	Agriculture, fish breeding and forestry	Total	Total ES supply by all ecosystems
Aghstev	ES supply					0.100
	ES use	0.043	0.007	0.050	0.100	
Akhuryan	ES supply					0.093
	ES use	0.007	0.002	0.085	0.093	
Arpa	ES supply					0.032
	ES use	0.004	0.001	0.026	0.032	
Debed	ES supply					0.040
	ES use	0.020	0.009	0.011	0.040	
Hrazdan	ES supply					0.353
	ES use	0.046	0.033	0.274	0.353	
Metsamor	ES supply					0.483
	ES use	0.014	0.013	0.456	0.483	
Sevan	ES supply					0.143
	ES use	0.029	0.002	0.111	0.143	
Vorotan	ES supply					0.211
	ES use	0.017	0.148	0.045	0.211	
Armenia	ES supply					1.455
	ES use	0.181	0.216	1.057	1.455	

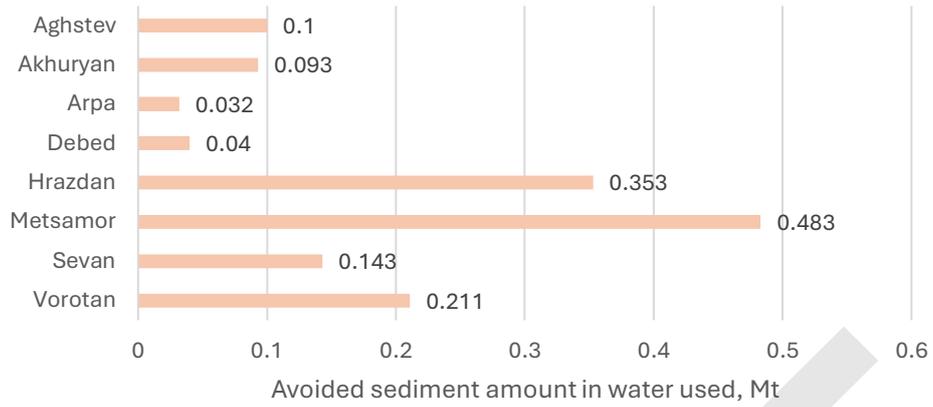


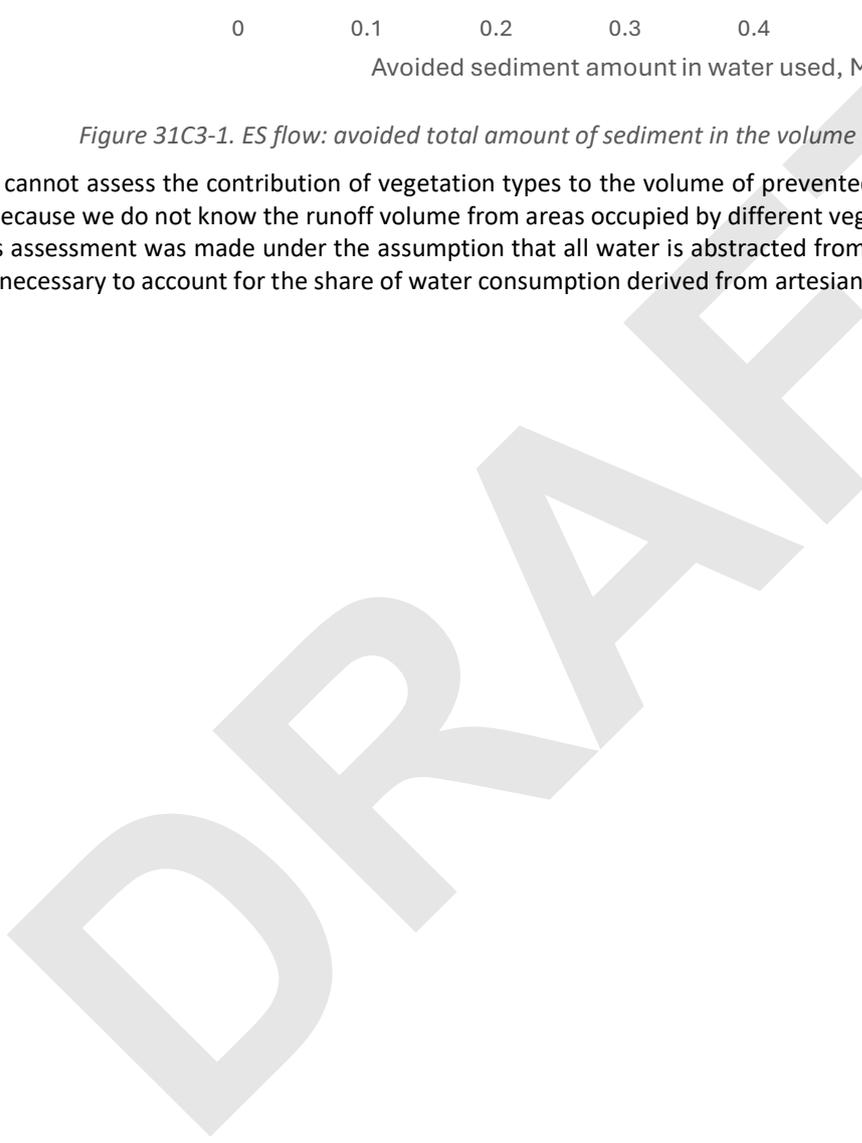
Figure 31C3-1. ES flow: avoided total amount of sediment in the volume of water consumed

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1897 We cannot assess the contribution of vegetation types to the volume of prevented sediment export into the water
1898 used, because we do not know the runoff volume from areas occupied by different vegetation types.

1899 This assessment was made under the assumption that all water is abstracted from surface sources. In the future, it
1900 will be necessary to account for the share of water consumption derived from artesian and groundwater.

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3.1.D. Flood risk mitigation (InVEST Urban Flood Risk Mitigation)

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We tested the model for two scenarios—average and extreme spring rainfall. The highest precipitation in Armenia occurs in May and June. While precipitation levels vary significantly across different climatic zones, for the initial model testing, we considered it reasonable to use countrywide average values. During these months, an average rainfall event delivers 12 mm of precipitation. For the extreme rainfall scenario, we assumed approximately half of the monthly precipitation in either of these months, which is 50 mm (Table 31D-1).

1909

Table 31D-1. Precipitation and the number of days with rain in selected cities (<http://armenia.pogoda360.ru/>)

Climate zones	Cities	May			June			Catastrophic rain, mm (50% of monthly precipitation)
		Days with rain	Precipitation, mm	Average rain, mm	Days with rain	Precipitation, mm	Average rain, mm	
Moderate cool	Sevan	12	140	12	13	157	12	79
	Hrazdan	10	113	11	10	120	12	60
	Stepanavan	11	141	13	10	130	13	65
	Vanadzor	13	177	14	13	189	15	95
	Average	12	143	12	12	149	13	75
Moderate relatively humid	Idjevan	10	127	13	8	97	12	64
	Dilijan	11	133	12	12	133	11	67
	Alaverdi	10	134	13	8	100	13	67
	Goris	9	103	11	5	63	13	52
	Average	10	124	12	8	98	12	62
Arid	Armavir	7	33	5	7	28	4	17
	Ararat	2	39	20	1	20	20	20
	Meghri	6	81	14	3	44	15	41
	Average	5	51	10	4	31	8	26
	Moderate with dry summer	Gyumri	6	78	13	5	71	14
Gavar		13	147	11	13	166	13	74
Vardenis		9	109	12	9	99	11	55
Sisian		8	112	14	7	84	12	56
Average		9	112	12	9	105	12	56
Average		9	110	12	8	99	12	48

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3.1.D1. ES provided by terrestrial ecosystems

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The average spring rainfall scenario (12 mm)

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ES maps (Figure 31D1-1) show that precipitation is almost entirely retained by vegetation and soil. Quick runoff across most of Armenia is less than 1 mm, slightly exceeding this value in some valleys. Under the bare ground scenario, runoff retention (RT) reduces very slightly. Quick runoff (Q) increases slightly in absolute terms, but the relative changes in some watersheds are noticeable. The ES provided by ecosystems is estimated as the difference between the ES on current land cover 2023 and on bare ground. The influence of ecosystems on ES indicators is minor, amounting to a decrease in quick runoff by 0.01–0.08 mm and an increase in runoff retention by 1–8 liters per pixel; for the Hrazdan watershed a very small but opposite effect is observed. In relative terms, the effect on runoff retention is extremely small—everywhere under 1% of the 2023 value—and there is a wide spread in the share of quick runoff chnges, ranging from +55% to -3%. (Table 31D1-2; Figures 31D1-2 and 31D1-3).

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Table 31D1-2. ES indicators across watersheds under the average rainfall scenaiio, 12 mm (the calculations were carried out for the entire territory of Armenia)

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	Indicator	Aghstev	Akhuryan	Arpa	Debed	Hrazdan	Metsamor	Vorotan
Current land cover, ESRI 2023	Quick flow, mm, Q_{2023}	0.11	0.40	0.16	0.10	0.24	0.27	0.07
	Runoff retention, m^3/pix , RT_{2023}	1.19	1.16	1.18	1.19	1.18	1.17	1.19
	Total runoff retention, mln of m^3 , $RT_{2023Tot}$	37.76	32.07	52.19	46.71	70.43	42.78	53.42
Bare ground scenario	Quick flow, mm, Q_{bare}	0.19	0.41	0.16	0.16	0.26	0.26	0.13
	Runoff retention, m^3/pix , RT_{bg}	1.18	1.16	1.18	1.18	1.17	1.17	1.19
	Total runoff retention, mln of m^3 , RT_{bgTot}	37.51	32.04	52.16	46.49	70.30	42.81	53.16
Effect of terrestrial ecosystems	Reduction of quick runoff by ecosystems, mm $Q_{eco} = Q_{2023} - Q_{bg}$	-0.06	-0.08	-0.01	-0.06	0.01	-0.02	-0.01
	Share of Q reduced by ecosystems, % $Q_{eco} * 100 / Q_{2023}$	-54.88	-19.81	-3.94	-54.91	3.05	-8.13	-13.14
	Runoff retention, provided by ecosystems, m^3/pix $RT_{eco} = RT_{2023} - RT_{bg}$	0.01	0.01	0.00	0.01	0.00	0.00	0.00
	Share of RT provided by ecosystems, % $RT_{eco} * 100 / RT_{2023}$	0.50	0.69	0.05	0.47	-0.06	0.18	0.08
	Total provided runoff retention, mln of m^3 $RT_{ecoTot} = RT_{2023Tot} - RT_{bgTot}$	0.26	0.25	0.03	0.22	-0.03	0.13	0.03
	Share of total RT, provided by ecosystems $RT_{ecoTot} * 100 / RT_{2023Tot}$	0.70	0.79	0.05	0.47	-0.04	0.30	0.05

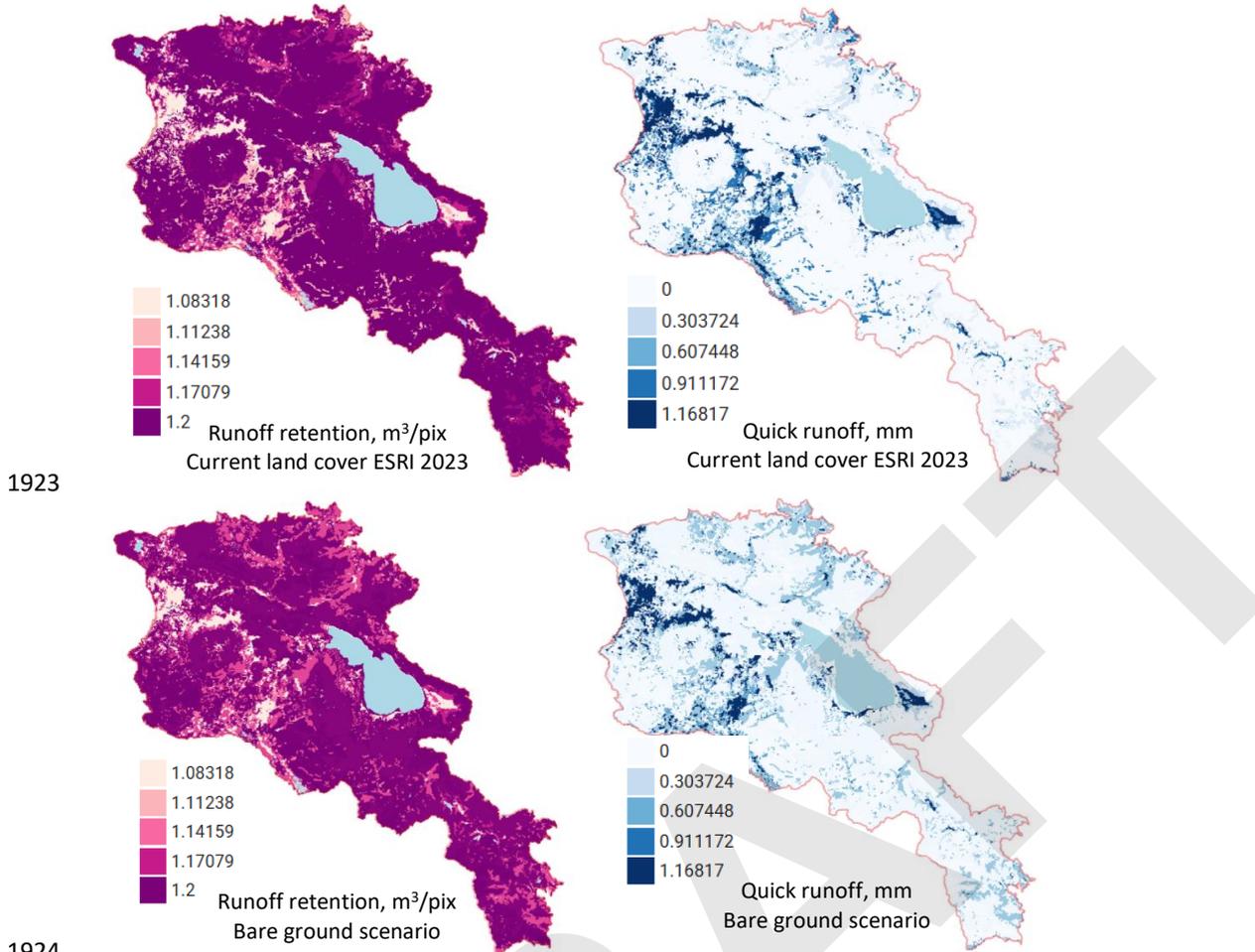


Figure 31D1-1. Maps of ES indicators under the average spring rainfall scenario (12 mm). For detailed maps see the section "Ecosystem Services - Urban Flood Risk Mitigation – Average rainfall (12 mm) in the project WebGIS

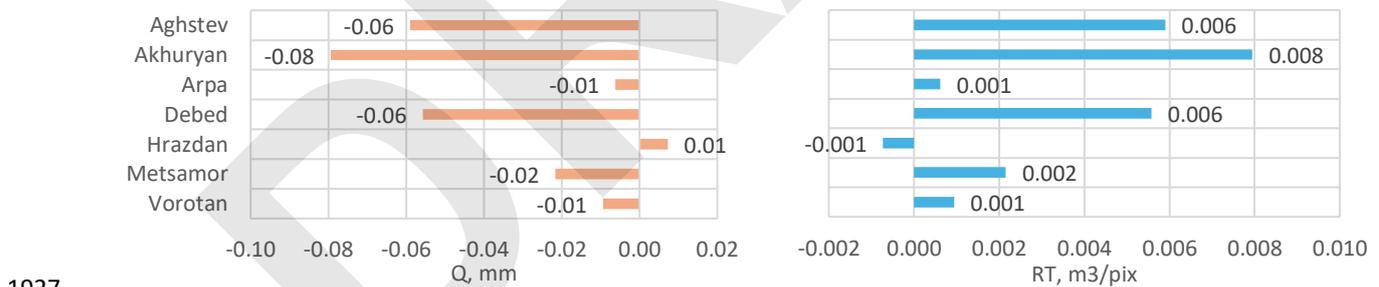


Figure 31D1-2. Ecosystem effect on quick runoff and runoff retention across watersheds under the average spring rainfall scenario (12 mm).

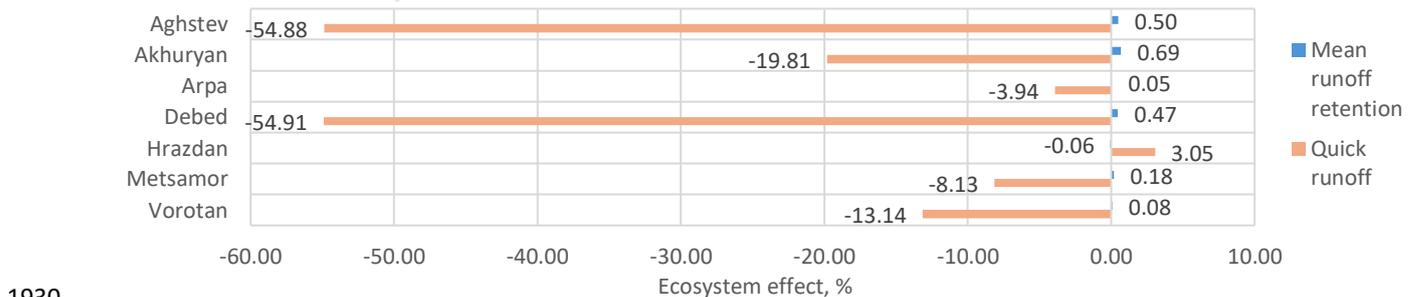


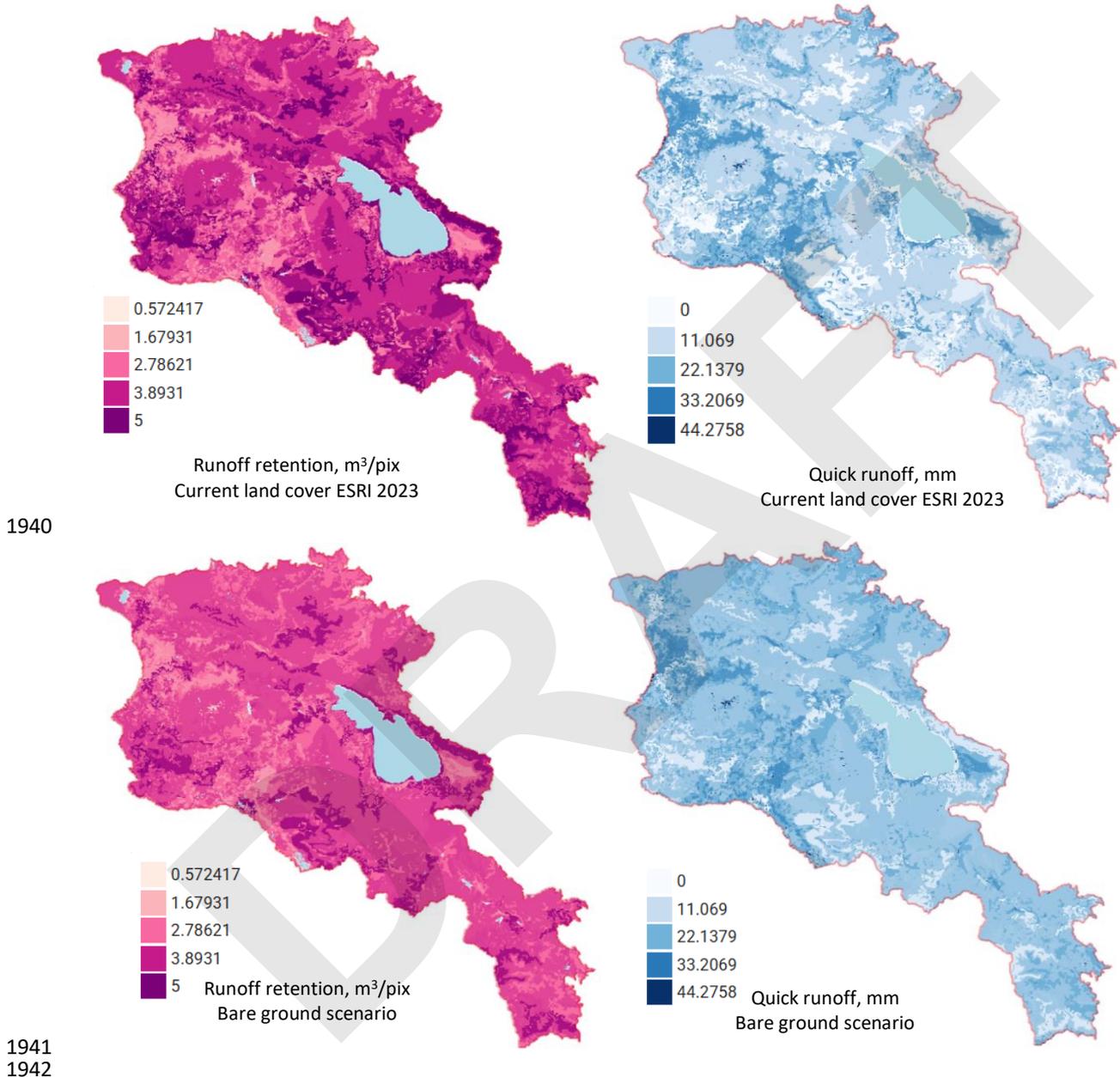
Figure 31D1-3. Ecosystem effect on quick runoff and runoff retention relative to ES on current land cover (2023), %

1930

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1932 **The extreme spring rainfall scenario (50 mm)**

1933 Precipitation is fully retained only in a small part of the territory (the darkest areas on the map of runoff retention).
 1934 As a result, quick runoff exceeds 10 mm across most of the territory and exceeds 20 mm in a significant portion. If all
 1935 natural vegetation is replaced with bare ground, runoff retention decreases significantly, and quick runoff also increases
 1936 noticeably. Unlike the average-rain scenario, under an extreme-rain event the ecosystems' influence on the ES indicators
 1937 is substantial: they reduce quick runoff by an average of 4 mm (-32% relative to the value in 2023) and increase runoff
 1938 retention by 0.4 m³/pix (+11% relative to the value in 2023). Totally, ecosystems increase runoff retention by 118 millions
 1939 of m³



1940

1941
1942

1943 *Figure 31D1-4. Maps of ES indicators under the extreme spring rainfall scenario (50 mm). For detailed maps see the*
 1944 *section "Ecosystem Services - Urban Flood Risk Mitigation – Extreme rainfall (50 mm) in the project WebGIS*

1945 Ecosystems increase runoff retention across all watersheds by 0.3–0.5 m³ and reduce quick runoff by 2.9–5.3 mm
 1946 (Fig. 31D1-5; Table 31D1-3). In relative terms, compared to 2023 values, the ecosystem effect is most pronounced in the
 1947 Arpa and Vorotan watersheds, where runoff retention increased by 13% and quick runoff decreased by 43–49% (Fig.
 1948 31D1-6; Table 31D1-3).

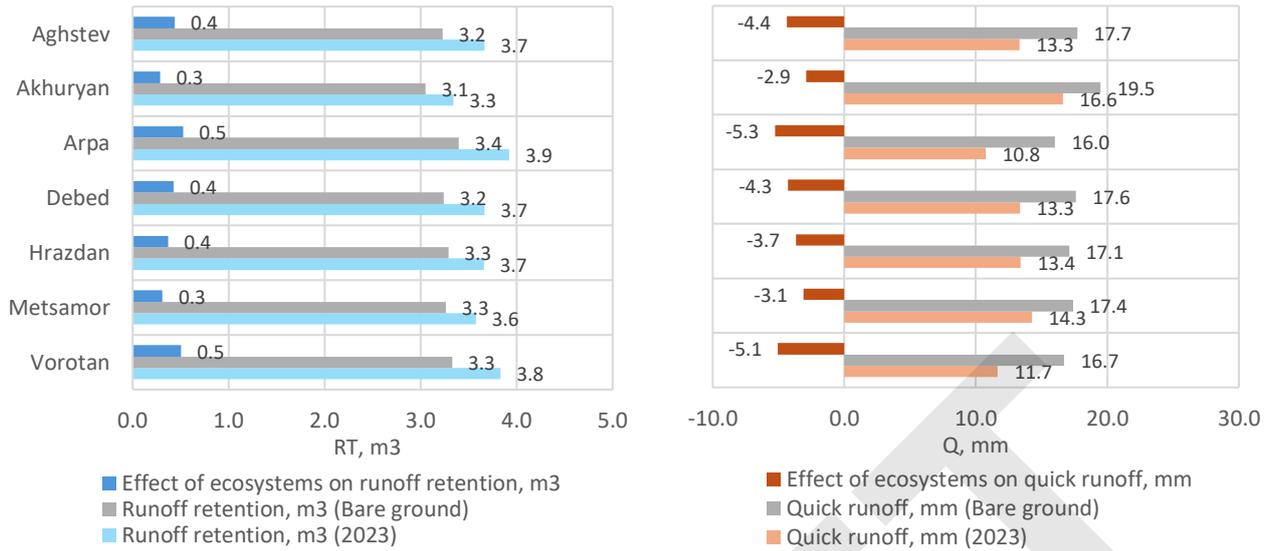


Figure 31D1-5. ES indicators under the extreme spring rainfall scenario (50 mm) across watersheds

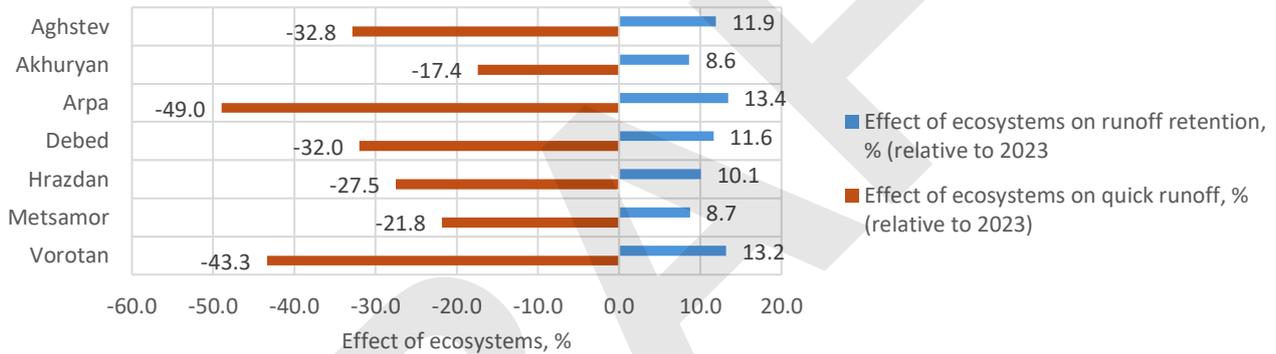


Figure 31D1-6. Ecosystem effect: percentage change in runoff retention (R) and quick runoff (P) relative to 2023, by watershed

Table 31D1-3. ES indicators across watersheds under the extreme rainfall scenario, 50 mm (the calculations were carried out for the entire territory of Armenia)

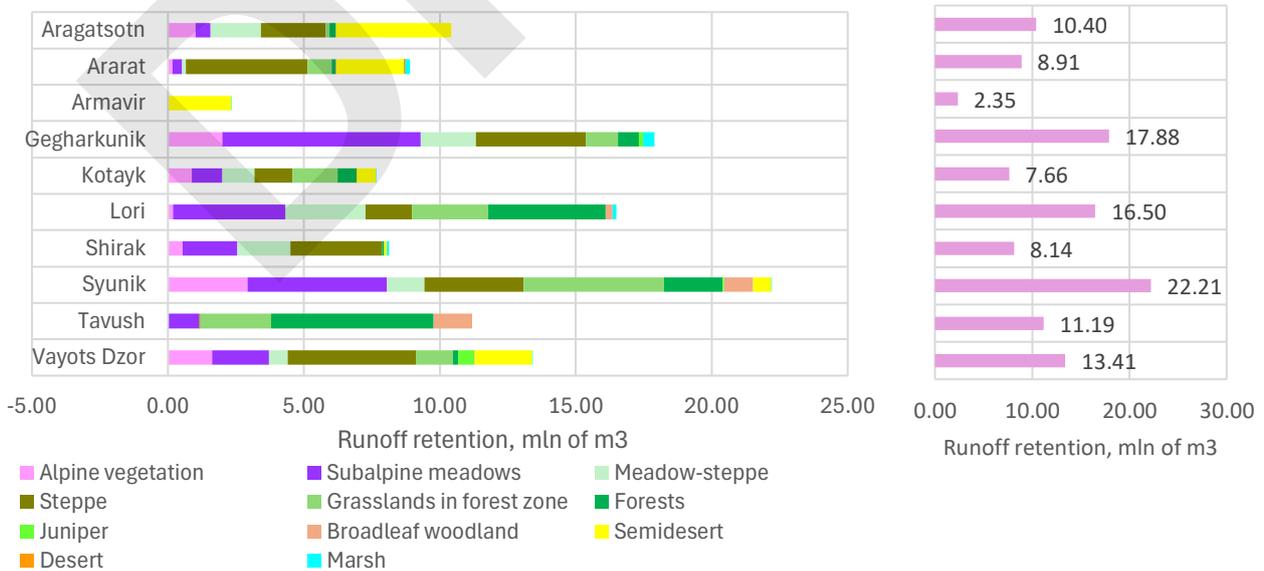
Indicator		Aghstev	Akhuryan	Arpa	Debed	Hrazdan	Metsamor	Vorotan
Current land cover, ESRI 2023	Quick flow, mm, Q_{2023}	13.3	16.6	10.8	13.3	13.4	14.3	11.7
	Runoff retention, m^3/pix , RT_{2023}	3.7	3.3	3.9	3.7	3.7	3.6	3.8
	Total runoff retention, mln of m^3 , $RT_{2023Tot}$	116	92	173	144	219	130	172
Bare ground scenario	Quick flow, mm, Q_{bare}	17.7	19.5	16.0	17.6	17.1	17.4	16.7
	Runoff retention, m^3/pix , RT_{bg}	3.2	3.1	3.4	3.2	3.3	3.3	3.3
	Total runoff retention, mln of m^3 , RT_{bgTot}	103	84	150	127	197	119	149
Effect of terrestrial ecosystems	Reduction of quick runoff by ecosystems, mm $Q_{eco} = Q_{2023} - Q_{bg}$	-4.4	-2.9	-5.3	-4.3	-3.7	-3.1	-5.1
	Share of Q reduced by ecosystems, % $Q_{eco} * 100 / Q_{2023}$	-32.8	-17.4	-49.0	-32.0	-27.5	-21.8	-43.3
	Runoff retention provided by ecosystems, m^3/pix $RT_{eco} = RT_{2023} - RT_{bg}$	0.4	0.3	0.5	0.4	0.4	0.3	0.5
	Share of RT provided by ecosystems, % $RT_{eco} * 100 / RT_{2023}$	11.9	8.6	13.4	11.6	10.1	8.7	13.2
	Total runoff retention, provided by ecosystems, mln of m^3 $RT_{ecoTot} = RT_{2023Tot} - RT_{bgTot}$	14	8	23	17	22	11	23
	Share of total RT, provided by ecosystems $RT_{ecoTot} * 100 / RT_{2023Tot}$	11.9	8.6	13.4	11.6	10.1	8.7	13.2

1958 Further analysis was conducted only for natural areas—excluding croplands and built-up areas.

1959 Table 31D1-4. Runoff retention provided by ecosystems across marzes and vegetation types

	Marzes	Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grasslands in forest zone	Forests	Juniper	Broadleaf woodland	Semidesert	Desert	Marsh	Average
RT m3/ha	Aragatsotn	49.70	50.64	36.88	46.23	31.30	48.13	0.00	0.00	56.77	0.00	16.59	47.91
	Ararat	44.06	57.30	43.16	61.04	50.46	53.11	0.00	42.63	55.78	67.01	36.49	56.60
	Armavir	0.00	0.00	0.00	0.00	0.00	23.13	0.00	0.00	51.91	0.00	24.22	51.43
	Gegharkunik	51.26	57.04	50.41	49.53	51.75	60.89	70.18	2.11	0.00	0.00	44.19	53.19
	Kotayk	76.28	64.27	53.72	30.94	60.25	46.34	0.00	27.59	24.49	0.00	30.19	45.90
	Lori	43.04	48.75	45.22	50.83	53.36	47.99	0.00	58.48	0.00	0.00	47.16	48.88
	Shirak	42.90	49.35	47.29	41.09	0.00	57.80	0.00	0.00	51.83	0.00	30.54	44.57
	Syunik	55.89	62.98	47.43	46.71	59.13	44.28	54.45	72.66	60.46	0.00	31.33	54.56
	Tavush	90.08	54.84	0.00	43.06	48.74	44.46	0.00	29.40	0.00	0.00	0.00	43.37
	Vayots Dzor	77.05	54.41	89.59	61.60	55.57	49.85	61.14	59.83	57.98	0.00	39.68	61.28
	Average	56.61	55.63	47.06	49.50	54.36	46.38	61.94	40.44	51.49	67.01	39.96	47.91
Total RT, millions of m3	Aragatsotn	1.02	0.54	1.85	2.39	0.13	0.24	0.00	0.00	4.24	0.00	-0.01	10.40
	Ararat	0.16	0.36	0.13	4.48	0.89	0.14	0.00	0.04	2.48	0.05	0.18	8.91
	Armavir	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.33	0.00	0.02	2.35
	Gegharkunik	2.00	7.31	2.02	4.05	1.17	0.78	0.15	0.00	0.00	0.00	0.41	17.88
	Kotayk	0.87	1.13	1.19	1.40	1.64	0.72	0.00	0.00	0.68	0.00	0.02	7.66
	Lori	0.19	4.13	2.94	1.71	2.81	4.32	0.00	0.24	0.00	0.00	0.15	16.50
	Shirak	0.55	1.99	1.96	3.39	0.00	0.08	0.00	0.00	0.09	0.00	0.09	8.14
	Syunik	2.93	5.12	1.38	3.65	5.16	2.16	0.07	1.06	0.67	0.00	0.02	22.21
	Tavush	0.00	1.16	0.00	0.03	2.60	5.97	0.00	1.42	0.00	0.00	0.00	11.19
	Vayots Dzor	1.62	2.10	0.70	4.70	1.37	0.19	0.59	0.03	2.11	0.00	0.00	13.41
	Total	9.35	23.84	12.16	25.79	15.77	14.59	0.80	2.80	12.60	0.05	0.88	118.64

1960 As seen in Table 31D1-4, per-hectare values of runoff retention (RT) differ only modestly across vegetation types. The
 1961 total RT volume is highest in the marzes of Syunik and Gegharkunik, where mountain grasslands make a substantial
 1962 contribution in both cases. The total RT volume is lowest in Armavir marz (Figure 31D1-7). Among vegetation types,
 1963 steppe and subalpine meadows provide the largest total contribution. The smallest contribution comes from open
 1964 woodlands, deserts, and marshes due to their limited area (Figure 31D1-8).
 1965



1966 Figure 31D1-7. Total runoff retention provided by ecosystems across marzes, million of m3

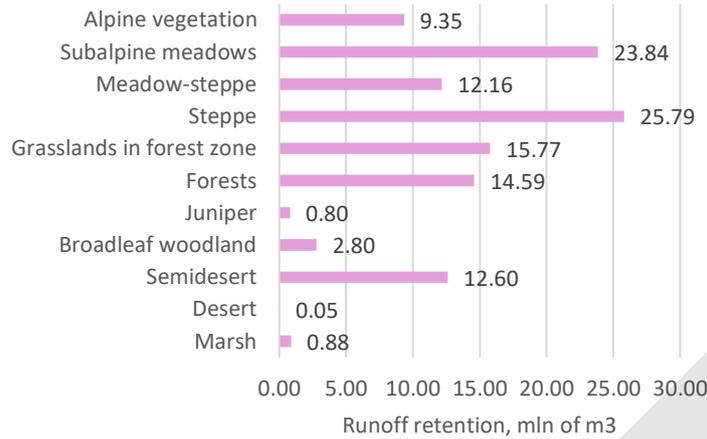


Figure 31D1-8. Total runoff retention provided by different vegetation types, million of m3

3.1.D2. Changes in potential ES (extreme rainfall scenario, 50 mm)

Assessment of ES changes based on the 2017 and 2023 modelled ES maps

Land-cover changes from 2017 to 2023, as captured in ESRI data, resulted in negative changes across all watersheds except Arpa. The most pronounced negative changes are modeled for the Akhuryan watershed, where runoff retention decreased by 1.5% and quick runoff increased by 3.8%. In the other watersheds (except Arpa), runoff retention decreased by 0.1–0.7%, while quick runoff increased by 0.3–1.5% (Figure 31D2-1; Table 31D2-1). Changes in ES at the marz level mirror those at the watershed level. The changes are negative everywhere except in Vayots Dzor marz. The most pronounced negative changes are modeled for Shirak marz, which lies within the Akhuryan watershed (Figure 31D2-2; Table 31D2-1).

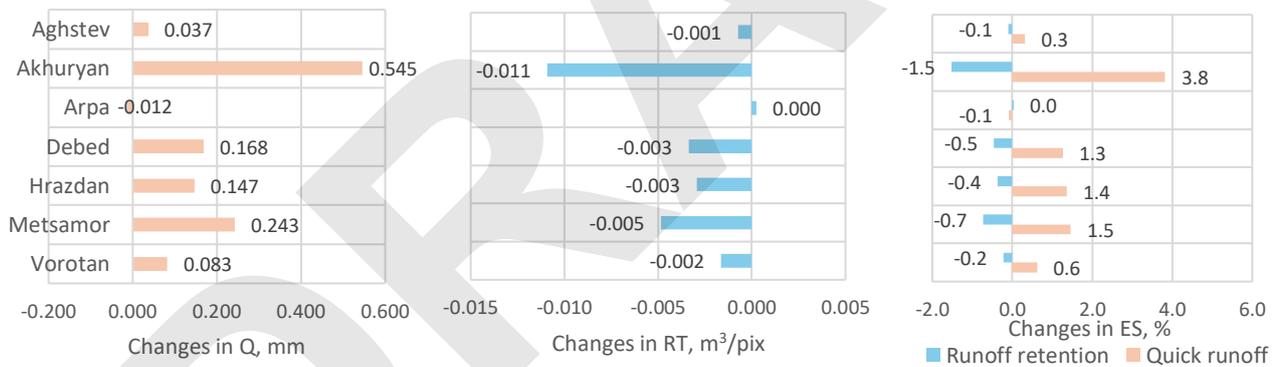


Figure 31D2-1. Changes in ES under the extreme rainfall scenario (50 mm) from 2017 to 2023 across watersheds

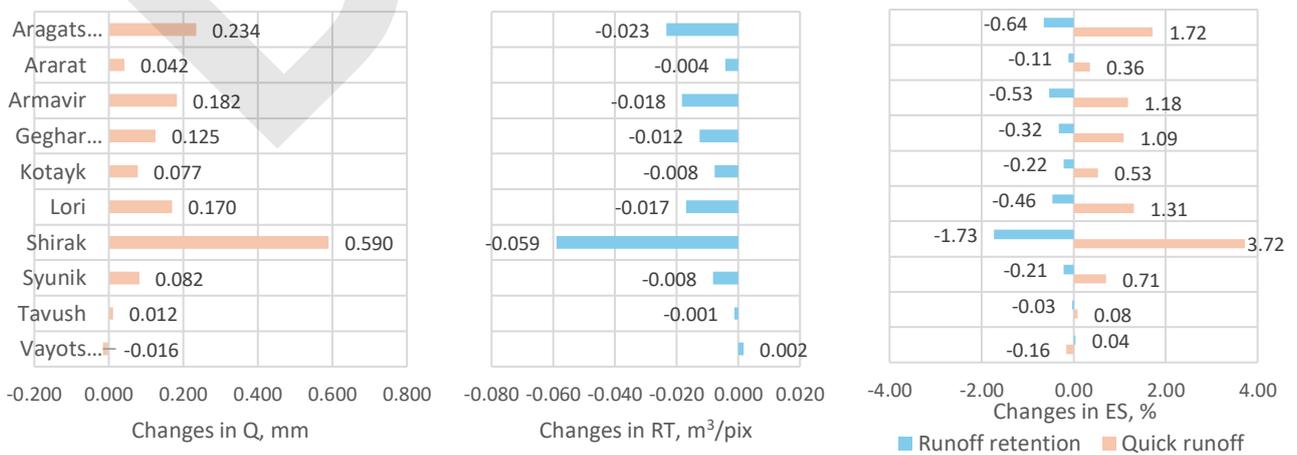


Figure 31D2-2. Changes in ES under the extreme rainfall scenario (50 mm) from 2017 to 2023 across marzes

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1984

Table 31D2-1. Changes in ES under the extreme rainfall scenario (50 mm) from 2017 to 2023 (the calculations were carried out for the entire territory of Armenia)

EAA		Changes in absolute terms		Changes relative to the values in 2017, %	
		Quick runoff, Q, mm	Runoff retention, RT, m ³ /pix	Quick runoff, Q	Runoff retention, RT
Watersheds	Aghstev	0.037	-0.001	0.315	-0.096
	Akhuryan	0.545	-0.011	3.822	-1.526
	Arpa	-0.012	0.000	-0.091	0.034
	Debed	0.168	-0.003	1.262	-0.460
	Hrazdan	0.147	-0.003	1.362	-0.373
	Metsamor	0.243	-0.005	1.461	-0.727
	Vorotan	0.083	-0.002	0.619	-0.225
Marzes	Aragatsotn	0.082	-0.008	0.706	-0.213
	Ararat	-0.016	0.002	-0.157	0.041
	Armavir	0.042	-0.004	0.357	-0.110
	Gegharkunik	0.182	-0.018	1.180	-0.527
	Kotayk	0.125	-0.012	1.089	-0.324
	Lori	0.662	-0.066	2.901	-2.438
	Shirak	0.234	-0.023	1.720	-0.643
	Syunik	0.077	-0.008	0.532	-0.217
	Tavush	0.590	-0.059	3.722	-1.728
Vayots Dzor	0.012	-0.001	0.084	-0.033	

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1993

Using this ES as a case study, we tested the feasibility of assessing ES loss resulting from the historical conversion of natural grasslands by humans. The loss was assessed as the difference between the ES indicator values for the 2023 land cover and for a fully natural land-cover scenario in which all croplands and built-up areas are replaced by grasslands. ES loss is greatest—both in absolute and relative terms—in the Akhuryan watershed (a 5% decrease in runoff retention and a 10% increase in quick runoff), and smallest in the Arpa watershed (-0.7% and +2.7%, respectively) (31D2-3). Nonetheless, the results suggest that the ES has been mostly retained. As expected, the most significant loss of ES occurred in areas that are currently built-up where quick runoff increased the most—by 49%. For croplands, the ES loss is less substantial (Figure 31D2-4).

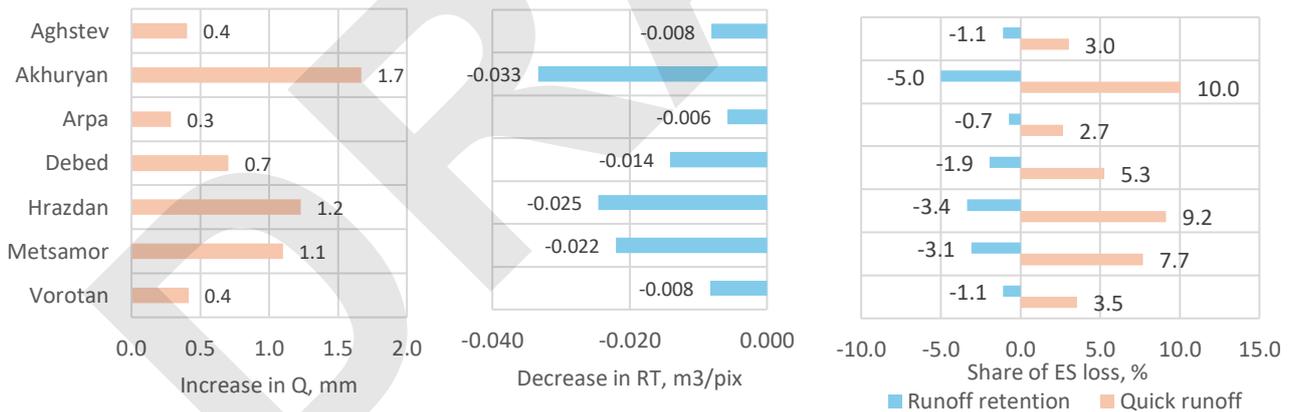


Figure 31D2-3. ES loss resulting from the historical conversion of natural grasslands by humans

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Figure 31D2-4. ES loss loss in built-up areas and in croplands

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Assessment of ES changes based on the changes in area of vegetation types

Changes in potential ES can be assessed on the base of changes in area of vegetation types from accounting table for ecosystem extent (Table 23C-2) using the indicators of ES provisioning per ha across different vegetation types in 2023 (Table 31D1-4). In this calculation, we did not take into account the changes in per-hectare ES potential values between 2017 and 2023. This approach makes it possible to calculate the data for the table recording the dynamics of the ES potential/capacity (Table 31D2-2).

With respect to changes in ES potential/capacity, the same comment applies as for changes in ecosystem extent (Section 2.3.A). Additions to ecosystem area resulting from transitions out of croplands or built-up areas do not possess full ecosystem functionality. Therefore, the closing ES capacity is defined more by the extent of ecosystems that remained untransformed during the reporting period than by the total closing ecosystem area.

Table 31D2-2. Accounting table for the changes in ES potential

	Alpine vege- tation	Subalpine meadows	Meadow- steppe	Steppe	Grassl. in forest zone	Forests	Juniper	Broadleaf woodland	Semi-desert	Desert	Marsh	Total
Opening ES capacity in 2017	9.32	23.92	13.37	26.95	15.49	15.21	0.80	2.87	12.76	0.05	0.95	121.69
Additions to ES capacity	0.03	0.43	0.17	0.96	1.46	1.07	0.01	0.23	0.99	0.00	0.07	5.42
Managed/unmanaged	NA											
Reductions ES capacity	0.02	0.47	1.36	2.00	1.21	1.72	0.01	0.28	1.05	0.00	0.10	8.21
Managed/unmanaged	NA											
Net change ES capacity	0.01	-0.04	-1.20	-1.04	0.25	-0.64	0.01	-0.05	-0.06	0.00	-0.02	-2.79
Closing ES capacity in 2023	9.33	23.89	12.18	25.90	15.75	14.57	0.80	2.82	12.71	0.05	0.92	118.91
Closing ES capacity in 2023 of ecosystems unconverted since 2017,	9.30	23.46	12.01	24.95	14.29	13.50	0.79	2.59	11.71	0.05	0.85	113.49

2009
2010
2011

3.1.E. Cooling effect of terrestrial ecosystems (InVEST Urban Cooling)

3.1.E1. Methodological issues

InVEST model Urban Cooling Effect is primarily aimed at assessing the cooling effect of green spaces within urban areas. However, it also allows for evaluating this effect over large areas outside of cities. Since the assessment of urban ecosystem services is not a goal of our project, we focused primarily on the entire territory of Armenia and its impact on settlements. Green spaces within settlements was not the focus of the assessment. The InVEST Urban Cooling model calculates an index of heat mitigation based on cooling capacity of green spaces and distance from them. The model computes the cooling capacity (CC) index for each pixel based on local shade, evapotranspiration, and albedo. CC is used to estimate a temperature reduction by ecosystems. Heat Mitigation index (HM) estimates the cooling effect of large green spaces (>2 ha) on surrounding urban areas. In our case, it shows the impact of the surrounding area on the settlements. HM is equal to CC if the pixel is unaffected by any large green spaces, but otherwise set to a distance-weighted average of the CC values from the large green spaces and the pixel of interest.

The model calculations are based on indicators of evapotranspiration, albedo, the proportion of area in LULC classes that is covered by tree canopy (shade), air temperature in a rural reference area, and the UHI Effect (Urban Heat Index). The last coefficient shows the difference between the rural reference temperature and the maximum temperature observed in the city. UHI is incorporated into the model as a single value. Calculations based on a single UHI value for all of Armenia are impractical due to the significant variation in conditions across different cities. Thermal images (Landsat 8 Surface temperature data courtesy of the U.S. Geological Survey; Scene ID: LC08_L2SP_170032_20240823_02_T1) show that during the hottest period (August), Yerevan is cooler than the surrounding areas, Gyumri has approximately the same temperature, and Dilijan is warmer (Figures 31E-1 – 31E-3). Data from Global Surface UHI Explorer confirm that there is no single UHI coefficient for Armenia. The coefficient varies not only from city to city (Yerevan is cooler, Gyumri is warmer than surrounding area) but also across different parts of the same city (Figures 31E-4). Therefore, we used UHI=0, meaning we did not account for the influence of this factor.

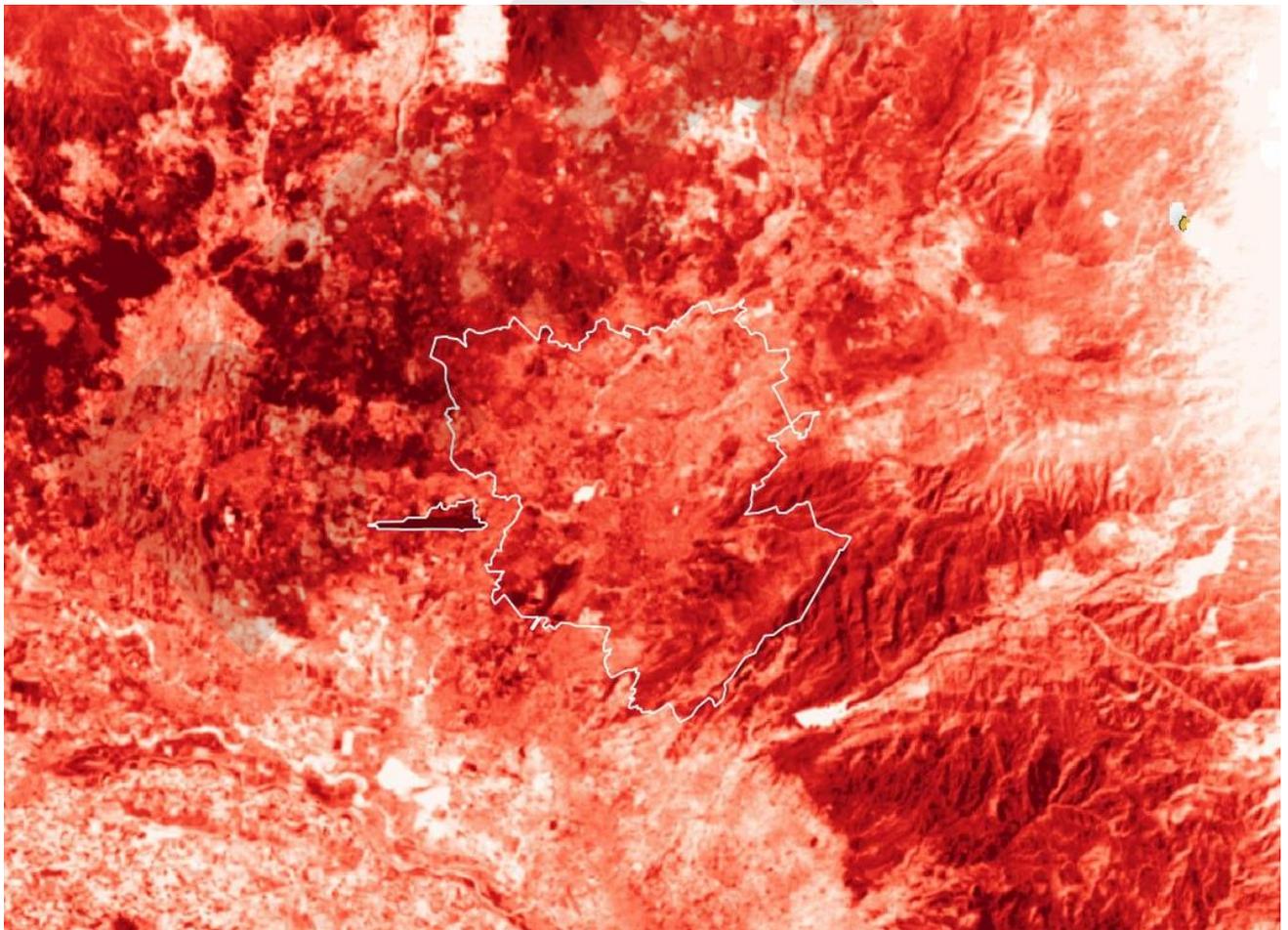


Figure 31E-1. Thermal image of Yerevan

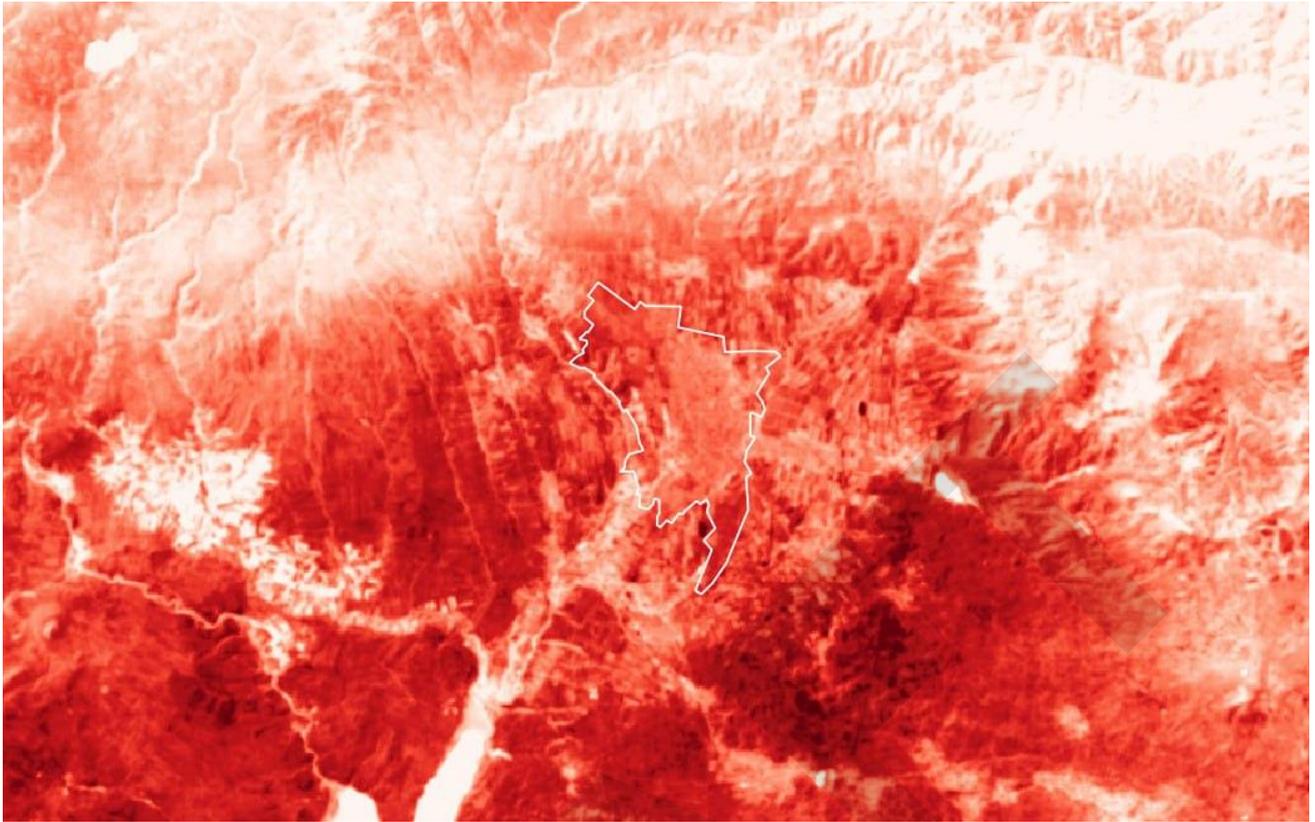


Figure 31E-2. Thermal image of Gyumri

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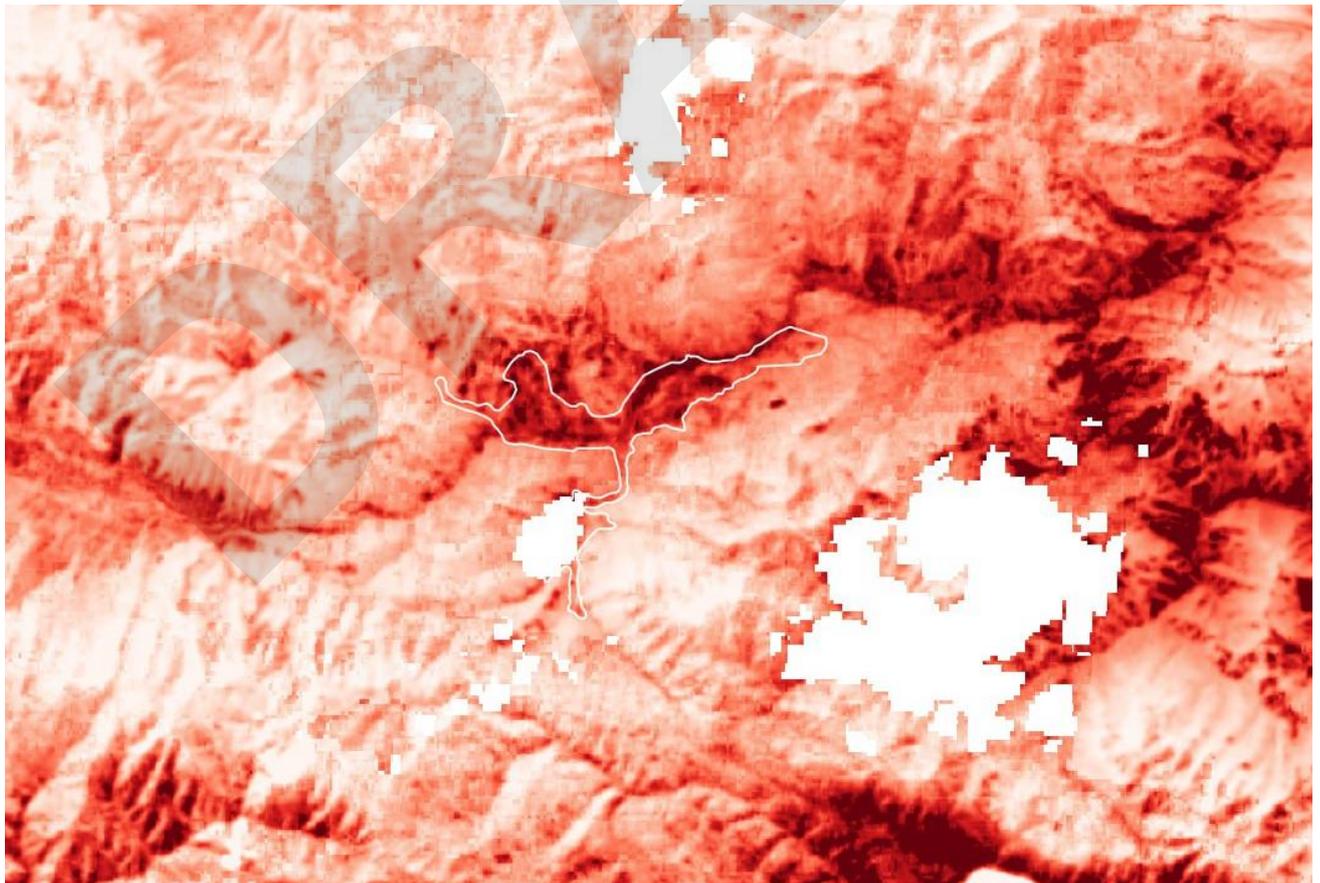


Figure 31E-3. Thermal image of Dilijan

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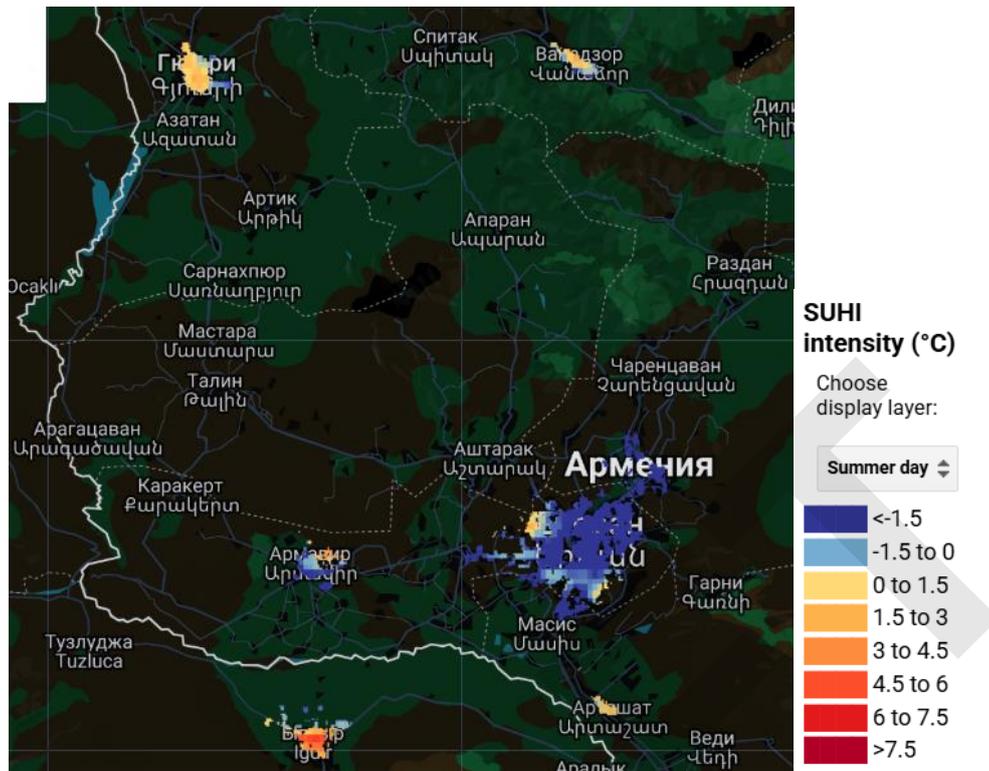


Figure 31E-4. UHI values in summer (western part of Armenia)

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3.1.E2. ES provided by terrestrial ecosystems

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Estimates of Cooling Capacity (CC) of land cover classes are based on the balance between coefficients of albedo, evapotranspiration cooling, and shade (i.e., the proportion of area covered by tree canopy). The Kc and albedo coefficients, applied in accordance with InVEST recommendations, yielded the following CC values for land-cover classes (Table 31E2-1; Figure 31E2-1):

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- The highest CC is associated with forests due to high evapotranspiration cooling.
- The high CC values for croplands in arid and humid climate zones is explained by the large proportion of orchard areas in those regions (according to ArmStat data). CC of croplands in moderate dry and cool climate zones where orchards are scarce, is much lower, approaching the values for bare ground and grasslands.
- The relatively high CC values for built-up areas are due to our assumption that, on average, 20% of the area in settlements is covered by trees (shadow=0.2). Increasing the area of tree cover in settlements will increase CC of built-up areas; decreasing it will reduce CC.
- CC of grasslands is lower than that of bare ground in three of the four climatic zones, and only slightly higher in the humid zone.

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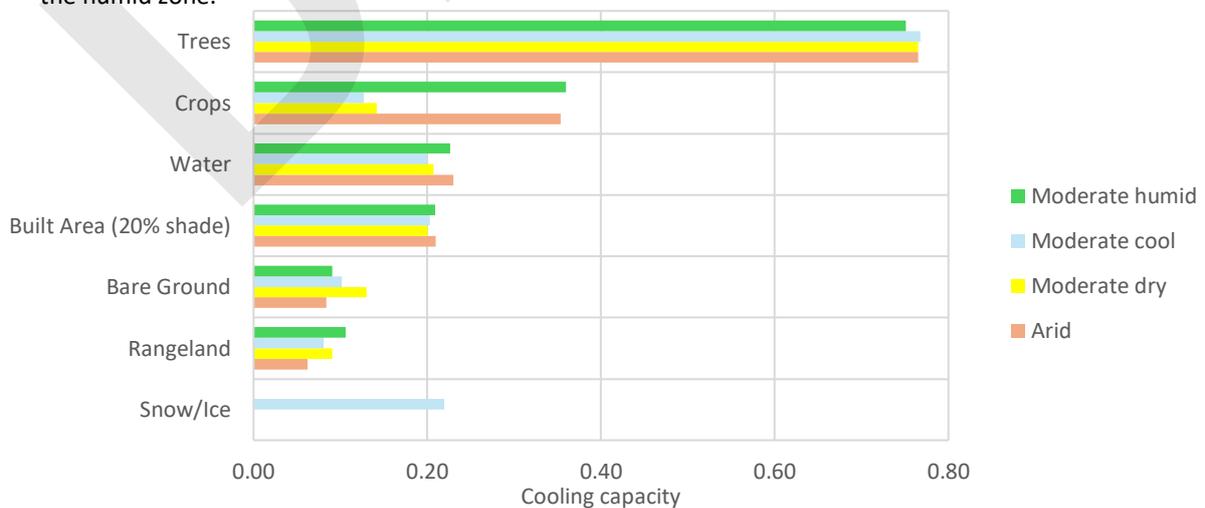
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Figure 31E2-1. Cooling capacity of land cover classes in different climate zones

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Table 31E2-1. Cooling capacity of land cover classes in different climate zones

	Arid zone	Moderate dry zone	Moderate cool zone	Moderate humid zone
Snow/Ice			0.22	
Rangeland	0.06	0.09	0.08	0.11
Bare Ground	0.08	0.13	0.10	0.09
Built Area (20% shade)	0.21	0.20	0.20	0.21
Water	0.23	0.21	0.20	0.23
Crops	0.35	0.14	0.13	0.36
Trees	0.77	0.77	0.77	0.75

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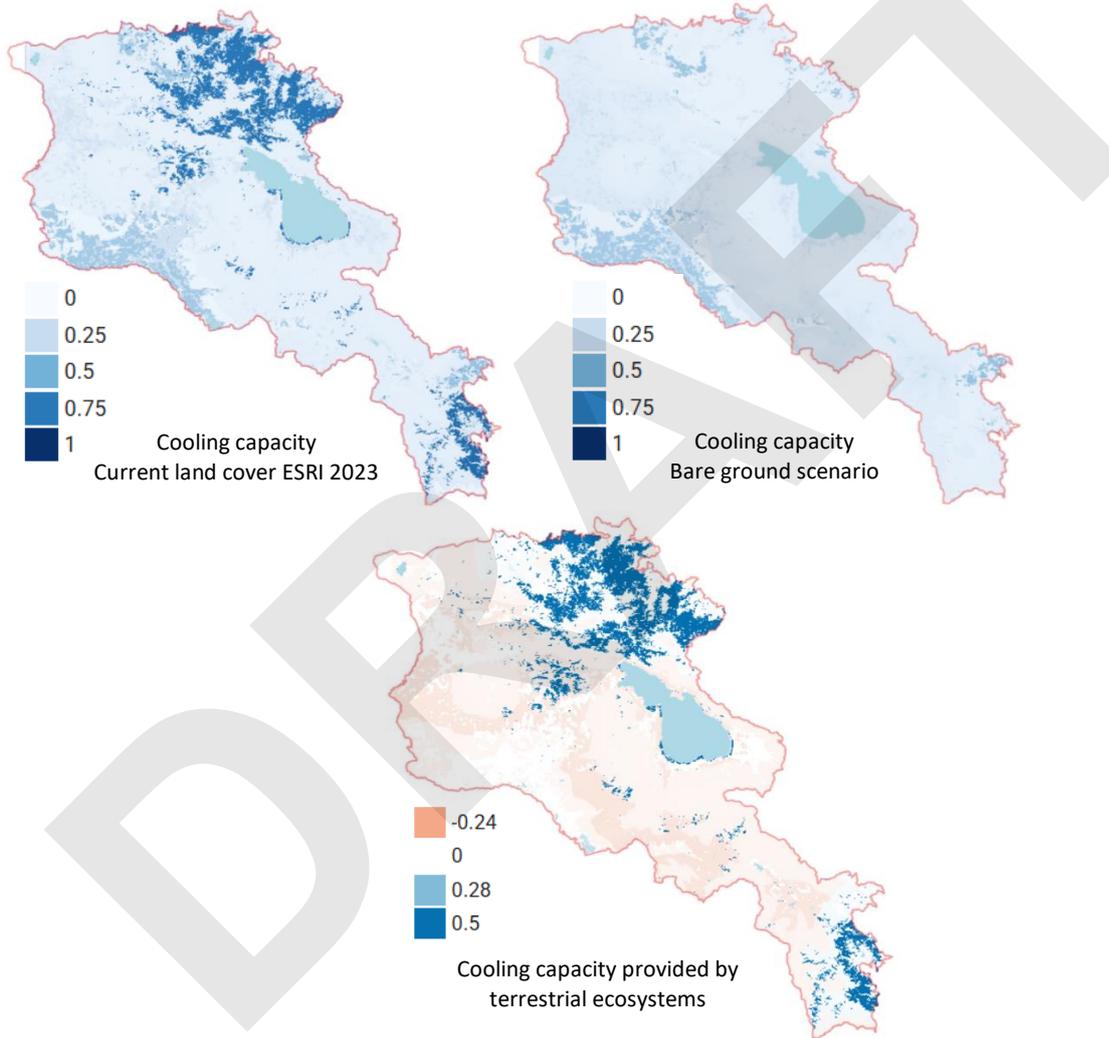
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The ES provided by natural terrestrial ecosystems was estimated as the difference in indicator values between the 2023 land cover and a bare-ground scenario. In the bare-ground scenario, CC decreases markedly over areas that are currently forested and increases slightly over areas that are currently grassland in moderate cool, dry, and arid zones. Natural vegetation yields substantial cooling in forested areas, slight cooling in grasslands in moderate humid zone and slight warming in grasslands in other zones (Fig. 31E2-2). Discussion see below in Section 3.5.

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Figure 31E2-2. Maps of cooling capacity. For detailed maps see project Web GIS. section "Ecosystem Services/Urban Cooling"

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[for the entire marz territories]

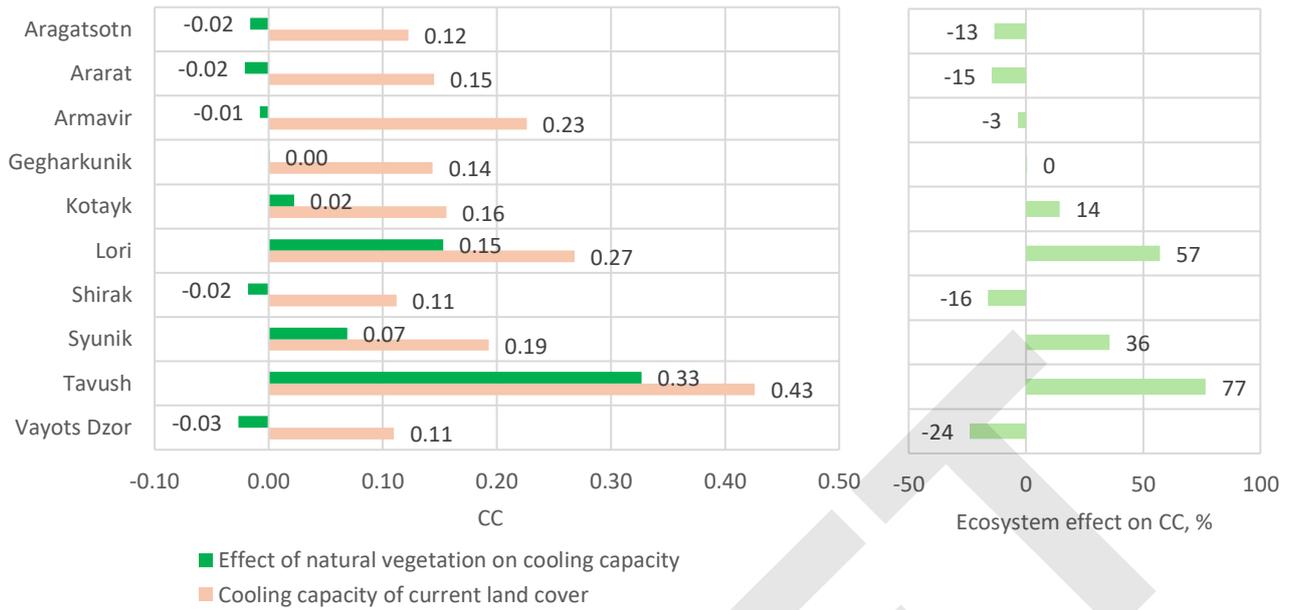
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Natural vegetation cools the marzes Tavush, Lori, Syunik, and Kotayk and slightly warms marzes that lack forests. In the marzes Tavush and Lori, where forest area is substantial, forest increases CC by 77% and 57%, respectively (Figure 31E2-3). On average in Armenia, CC for the current land cover is 0.19, while for the bare-ground scenario it is 0.15; thus, ecosystems on average cool the land surface, raising CC by 0.04 (21%).



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Figure 31E2-3. Cooling capacity of the current land cover and the effect of natural vegetation on cooling capacity

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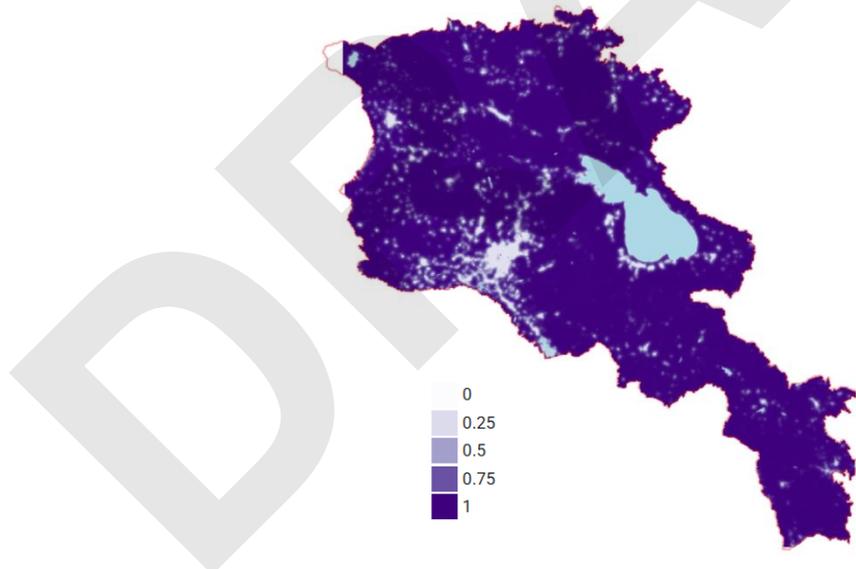
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Since we did not assess ES within settlements, our estimate concerns the influence of surrounding ecosystems on CC within settlements, assuming a uniform 20% tree-cover (shade) for all settlements. Heat Mitigation index (HM) estimates the cooling effect of large green spaces (>2 ha) on surrounding urban areas. In our case, it shows the impact of the surrounding area on the settlements. HM is equal to CC if the pixel is unaffected by any large green spaces, but otherwise set to a distance-weighted average of the CC values from the large green spaces and the pixel of interest (Figure 31E2-4).



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Figure 31E2-4. Heat Mitigation index. For detailed maps see project Web GIS. section "Ecosystem Services/Urban Cooling"

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The cooling/warming effect of the surrounding ecosystems will depend on the CC of ecosystems, as well as by the geometry of the settlement boundaries, i.e., the proportion of the settlement's area influenced by the surrounding territory. Following the InVEST recommendation, we set the maximum cooling distance—the distance over which green areas larger than 2 ha exert a cooling effect—at 450 m. Across the 1,016 assessed settlements, average CC ranges from 0.06 to 0.50 (i.e., half of the maximum possible value). (Table of CC values for 1,016 settlements in Armenia). The effect of ecosystems on CC within settlements was calculated as the difference between CC values under the current land cover and under a bare-ground scenario. In most settlements (729, or 72% of those assessed), the surrounding ecosystems produce virtually no change in CC relative to bare ground. In 133 settlements (13%), the ecosystems reduce CC, i.e., exert

2097 a warming effect; these are evidently settlements surrounded by grasslands in one of three climatic zones—moderately
 2098 dry, cold, or arid. In 154 settlements (15%), ecosystems increase CC, i.e., exert a cooling effect; these settlements are
 2099 surrounded by forests or by grasslands in the moderately humid zone. For 20 settlements surrounded by forest, including
 2100 Dilijan, Jermuk, Tsakhkadzor, the cooling effect is especially noticeable, increasing CC by 0.10–0.35 (Figure 31E2-5; [Table](#)
 2101 [of ecosystem effect on CC values for 1,016 settlements in Armenia](#)).

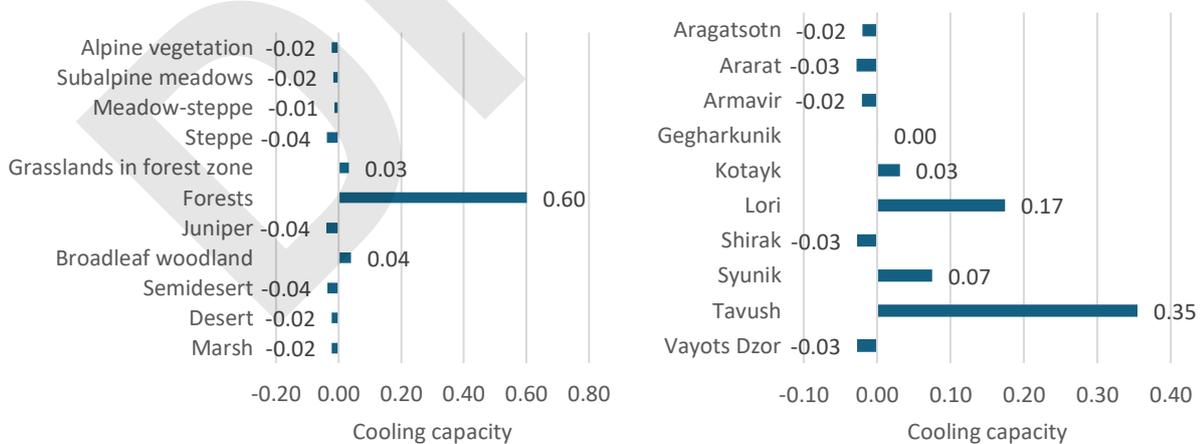


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Figure 31E2-5. The effect of surrounding ecosystems on CC within settlements

2104 *[assessment for the natural areas excluding croplands and built-up areas]*

2105 As noted earlier, the CC of different vegetation types varies across climatic zones due to different cooling effects from
 2106 evaporation (Figure 31E2-1). Therefore, the CC of different vegetation types varies across marzes because different area
 2107 of climatic zones across marzes (Table 31E2-2). Overall, forests in Armenia have the highest cooling CC. Broadleaf
 2108 woodlands and grasslands within the forest zone also provide a slight cooling effect. According to the coefficients used
 2109 for modeling, other vegetation types, on the contrary, have a very weak, but still warming effect compared to bare ground
 2110 (Figure 31E2-6 a). The average CC in marzes, if only natural vegetation is taken into account, differs from the average for
 2111 the entire territory, essentially repeating the effect of natural vegetation (compare Figure 31E2-3 and Figure 31E2-6 b).



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Figure 31E2-6. Cooling capacity of different vegetation types (a) and across marzes (b)

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Table 31E2-2. Cooling capacity of different vegetation types across marzes

	Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grasslands in forest zone	Forests	Juniper	Broadleaf woodland	Semidesert	Desert	Marsh	Average
Aragatsotn	-0.02	-0.02	-0.02	-0.04	-0.03	0.55			-0.04		-0.05	-0.02
Ararat	-0.02	-0.02	-0.02	-0.05	-0.03	0.51		-0.02	-0.03	-0.02	-0.02	-0.03
Armavir						0.16			-0.02		-0.02	-0.02
Gegharkunik	-0.02	-0.02	-0.01	-0.03	-0.02	0.56	-0.02	-0.05			-0.03	0.00
Kotayk	-0.02	-0.02	-0.02	-0.04	-0.02	0.56		-0.04	-0.05		-0.05	0.03
Lori	-0.02	-0.01	0.01	0.00	0.08	0.62		0.15			0.02	0.17
Shirak	-0.02	-0.02	-0.02	-0.04		0.57			-0.06		-0.03	-0.03
Syunik	-0.02	-0.02	-0.02	-0.03	0.04	0.54	0.03	0.01	-0.01		-0.04	0.07
Tavush	-0.02	0.02		0.00	0.08	0.64		0.04				0.35
Vayots Dzor	-0.02	-0.03	-0.02	-0.04	-0.03	0.47	-0.05	-0.04	-0.05		-0.02	-0.03
Average	-0.02	-0.02	-0.01	-0.04	0.03	0.60	-0.04	0.04	-0.04	-0.02	-0.02	

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3.1.E3. Potential ES changes from 2017 to 2023

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Assessment of ES changes based on the 2017 and 2023 modelled ES maps

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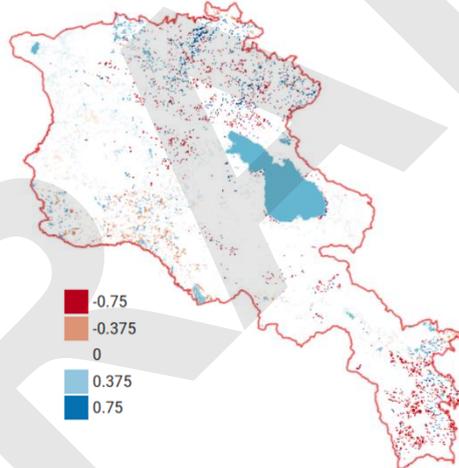
From 2017 to 2023, there were slight changes in CC oppositely directed in different locations (Figure 31E3-1). Significant decrease in CC occurred in the Syunik due to replacement of some forests with grasslands, as well in the Ararat due to replacement of some croplands with grasslands and built-up areas. Increase in CC occurred in the Shirak and the Lori due to replacement of some grasslands with croplands (Figure 31E3-2; for changes in land cover see Section 2.2). Changes in CC in settlements range from a decrease of 61% to an increase of 65% (Table of CC changes in settlements).

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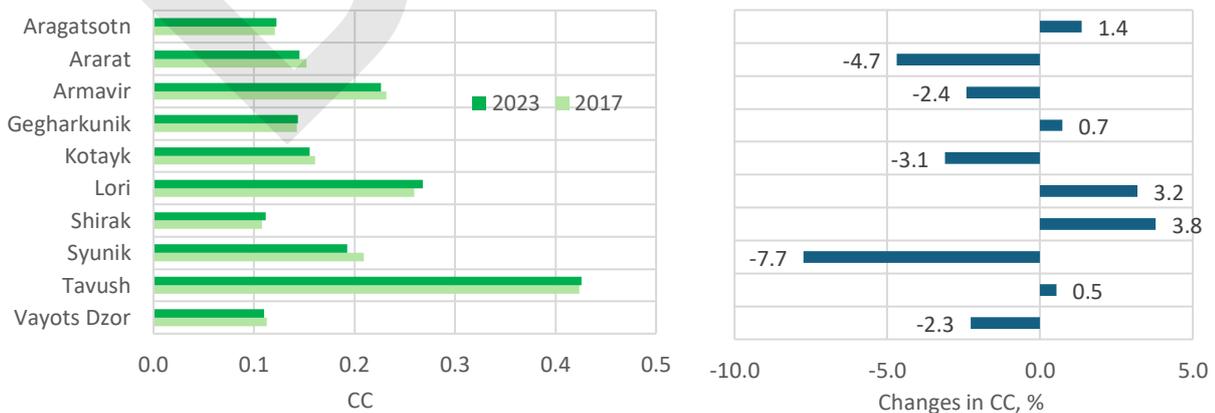
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Figure 31E3-1. Changes in CC from 2017 to 2023.

For detailed maps see project Web GIS, section "Ecosystem Services/Urban Cooling/Dynamics"



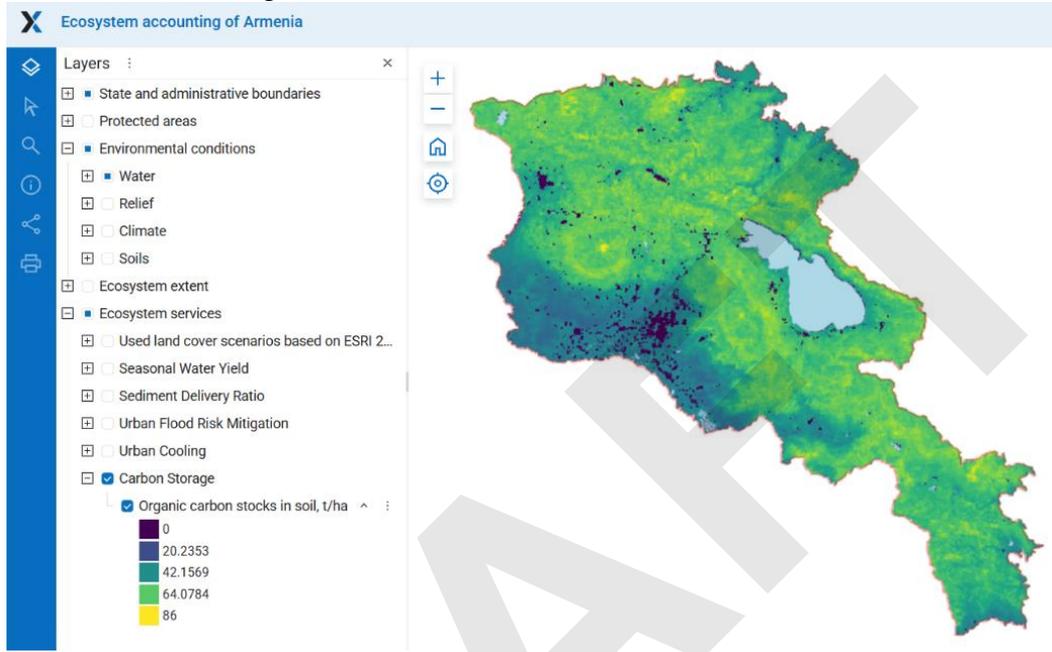
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Figure 31E3-3. Changes in CC from 2017 to 2023 across marzes

2131 **3.1.G. Carbon storage in soil and tree biomass**

2132 The assessment of soil carbon stocks at 0-30 cm depth was made using data from the World Soils 250m Organic
 2133 Carbon Stocks dataset (<https://www.arcgis.com/home/item.html?id=496c19426413472194b10b2b0952fccd#>) (Figure
 2134 31G-1). Carbon stock in tree biomass was estimated using the area of tree cover from Esri (2023) and the average carbon
 2135 content of wood. According to the Acopian Center, a pilot study conducted in forests near the town of Vanadzor
 2136 (northeastern Armenia) revealed a value of 98 tC/ha. However, data from [State of the World's Forests \(FAO, 2011\)](#)
 2137 estimate the total carbon stock in living forest biomass in Armenia at 13 million tons, with an average of 48 tC/ha across
 2138 the country. We used 48 tC/ha average in our calculations.

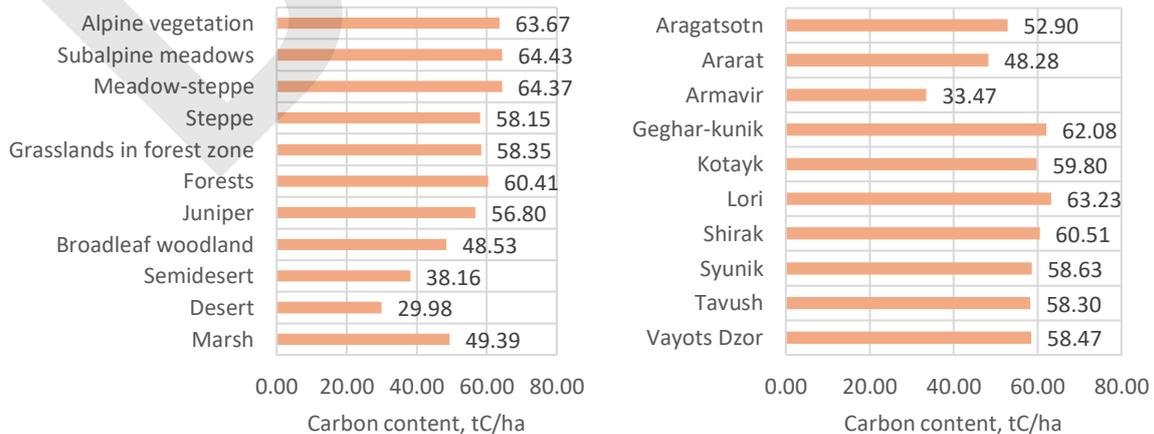


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 2140 *Figure 31G-1. Soil carbon stocks, t/ha; for details see project web-GIS (<https://bccarmenia.nextgis.com>), section*
 2141 *Ecosystem Services*

2142 **3.1.G1. Carbon stocks in Armenia, marzes and vegetation zones**

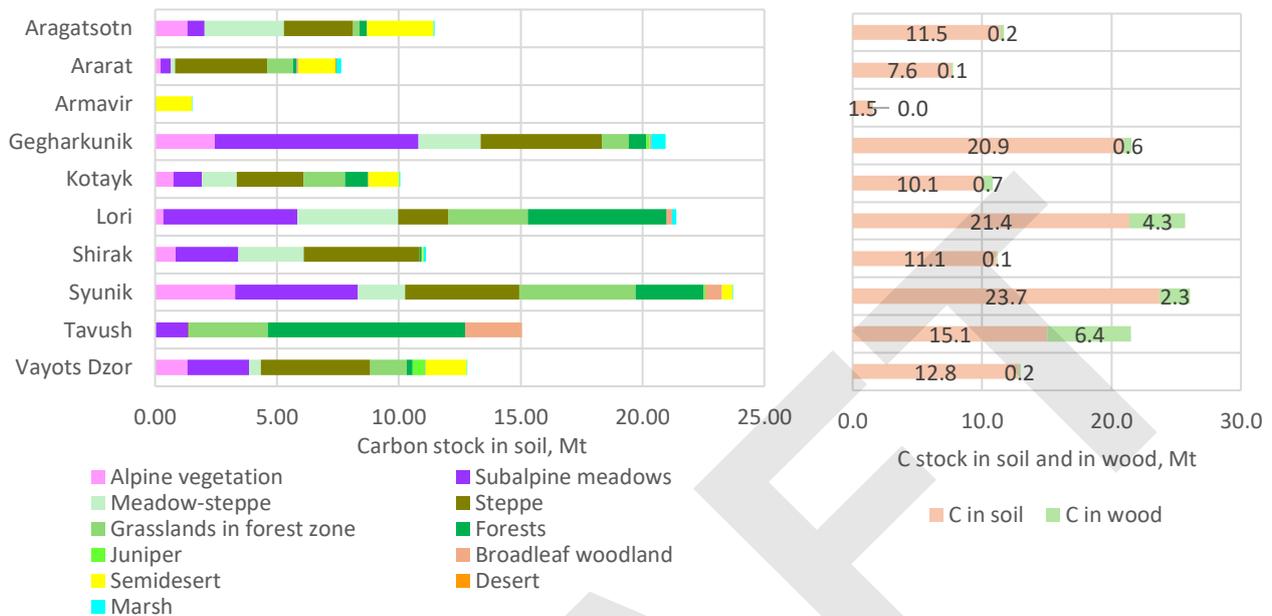
2143 Total carbon stock in 0-30 cm depth soils in Armenia within natural areas (excluding croplands and built-up areas)
 2144 amounts to 135.7 MtC, and in tree biomass 15.1 MtC (in 2023) that totally amounts to 150.9 MtC. Due to the relatively
 2145 small forest area in Armenia, the main carbon stock (90%) is stored in soils.

2146 The average carbon content in the 30-cm soil layer across vegetation types ranges from 30 t/ha in desert to 64 t/ha
 2147 in mountaine grasslands. Average C-content in the most marzes varies around 60 tC/ha. In Armavir and Ararat, it is lower
 2148 (33 and 48 t/ha, respectively) due to the carbon-poor semi-desert soils (Figure 31G1-1; Table 31G1-1).

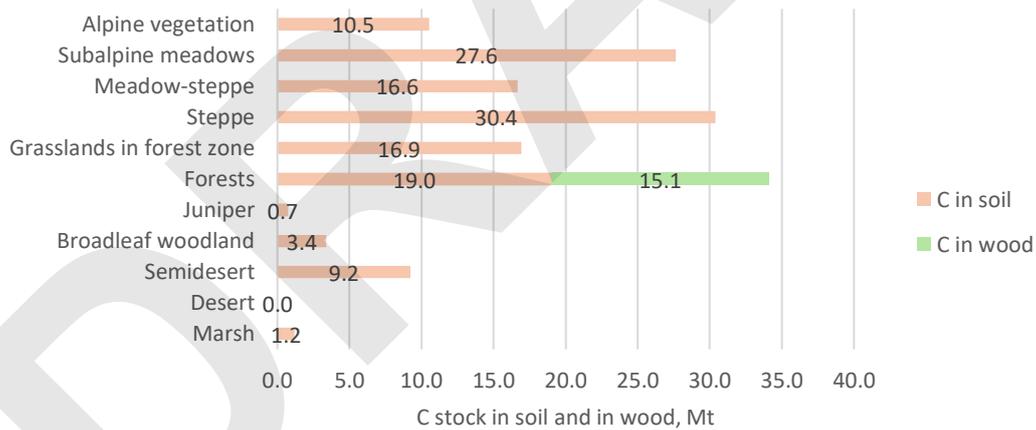


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 2150 *Figure 31G1-1. Carbon content in soil, tC/ha, across vegetation types (a) and marzes (b). Area of the marz Gegharkunik*
 2151 *is accounted excluding Lake Sevan*

2152 The total carbon stock is highest in marzes Syunik and Lori (24 and 21 MtC), and lowest in marz Armavir (1.5 MtC)
 2153 because of low carbon content in soil and small area of ecosystems (Figure 31G1-2; Table 31G1-1). The carbon stock in
 2154 tree biomass makes a noticeable addition to soil carbon only in marzes Tavush and Lori. Across vegetation types total
 2155 carbon stock is highest in forests with a large portion of C in wood, followed steppe and subalpine zones. C stock is lowest
 2156 in woodlands, marshes and desert due to their limited extent (Figure 31G1-3).



2157 Figure 31G1-2. Carbon stock, MtC in soil in different vegetation types across marzes (a) total C stock in soil and wood
 2158 across marzes (b). Area of the marz Gegharkunik is accounted excluding Lake Sevan
 2159



2160 Figure 31G1-3. Carbon stock, MtC, across vegetation types

2161 Table 31G1-1. Carbon content and carbon stocks in different vegetation types across marzes

		Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grasslands in forest zone	Forests	Juniper	Broadleaf woodland	Semidesert	Desert	Marsh	Average
Carbon content, t/ha	Aragatsotn	65.18	66.04	64.39	54.84	62.07	62.85			36.76		51.85	52.90
	Ararat	62.53	63.93	63.08	51.47	60.18	61.52		63.02	34.71	29.98	37.50	48.28
	Armavir						37.79			33.41		35.38	33.47
	Gegharkunik	62.84	65.18	63.70	61.03	48.58	55.87	65.33	55.00			64.41	62.08
	Kotayk	65.40	66.39	64.45	61.00	62.19	61.76		64.33	45.17		58.24	59.80
	Lori	72.37	64.93	63.69	61.18	62.13	63.24		51.23			58.33	63.23
	Shirak	65.84	63.68	64.64	57.76		62.43			38.69		40.02	60.51
Syunik	62.51	62.07	66.30	59.99	54.87	57.08	54.52	46.49	40.84		20.22	58.63	

	Tavush	72.52	64.03		65.37	60.70	60.19		48.35				58.30
	Vayots Dzor	62.87	65.54	64.16	58.69	60.67	64.26	55.29	54.74	45.70		33.45	58.47
	Average	63.67	64.43	64.37	58.15	58.35	60.41	56.80	48.53	38.16	29.98	49.39	
	Mt												Total
Carbon stock, Mt	Aragatsotn	1.33	0.71	3.24	2.84	0.27	0.31	0.00	0.00	2.74	0.00	0.03	11.46
	Ararat	0.23	0.40	0.19	3.77	1.06	0.16	0.00	0.06	1.54	0.02	0.19	7.63
	Armavir	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.00	0.02	1.53
	Gegharkunik	2.45	8.35	2.55	4.99	1.10	0.71	0.14	0.06	0.00	0.00	0.60	20.95
	Kotayk	0.74	1.17	1.43	2.75	1.70	0.96	0.00	0.01	1.26	0.00	0.05	10.07
	Lori	0.33	5.51	4.14	2.06	3.27	5.69	0.00	0.21	0.00	0.00	0.18	21.39
	Shirak	0.84	2.57	2.67	4.76	0.00	0.09	0.00	0.00	0.07	0.00	0.12	11.12
	Syunik	3.28	5.05	1.93	4.69	4.78	2.78	0.07	0.68	0.45	0.00	0.01	23.72
	Tavush	0.00	1.35	0.00	0.04	3.24	8.09	0.00	2.34	0.00	0.00	0.00	15.06
	Vayots Dzor	1.32	2.52	0.50	4.48	1.49	0.24	0.53	0.03	1.67	0.00	0.00	12.79
	Total	10.54	27.63	16.65	30.39	16.91	19.03	0.74	3.38	9.23	0.02	1.20	135.71

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3.1.G2.Changes in carbon stock in tree biomass from 2017 to 2023

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Changes in carbon stock in natural areas of different vegetation types were assessed on the base of changes in area of vegetation types from accounting table for ecosystem extent (Table 23C-2) using the indicator of carbon content per ha across different vegetation types in 2023 (Table 31G1-1). **In this calculation, we did not take into account the changes in per-hectare ES potential values between 2017 and 2023.** This approach makes it possible to calculate the data for the table recording the dynamics of the ES potential/capacity (Table 31G2-1).

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It's important to remember that this analysis doesn't show a reduction in soil carbon content. We don't know how soil carbon content changes in areas converted from nature to agriculture or development and vice versa. This analysis only shows how carbon stocks in natural areas change due to changes in their area.

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Totally, C stocks in natural areas decreased by 4.26 Mt, that is by 2.7% of 2017 stocks. The most significant decreases occurred in steppe and meadow-steppe zones, as well as in forests, including reductions in C stocks in soils and wood. Stocks in grasslands in the forest zone increased slightly due to an increase in their area (Table 31G2-1; Figure 31G2-1).

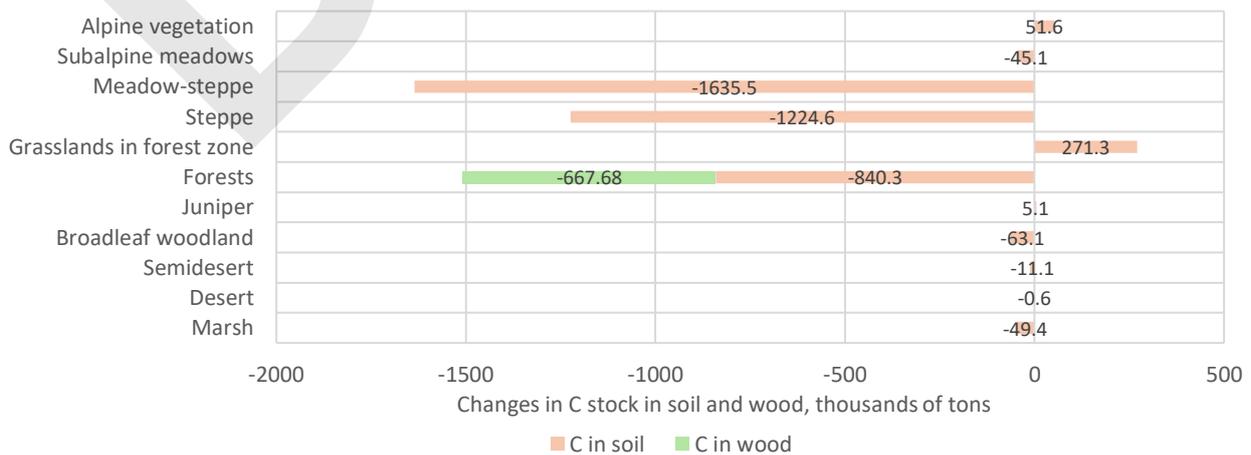
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Table 31G2-1. Accounting table for the changes in ES potential

	Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grassl. in forest zone	Forests		Juniper	Broadleaf woodland	Semi-desert	Desert	Marsh	Total
						C in soil	C in wood						
Opening ES capacity in 2017	10.48	27.71	18.29	31.65	16.63	19.81	15.74	0.73	3.45	9.46	0.02	1.17	155.14
Additions to ES capacity	0.03	0.50	0.23	1.12	1.57	1.39	1.11	0.01	0.28	0.74	0.00	0.09	7.06
Managed/unmanaged	NA												
Reductions ES capacity	0.02	0.54	1.86	2.35	1.30	2.23	1.78	0.01	0.34	0.78	0.00	0.12	11.32
Managed/unmanaged	NA												
Net change ES capacity	0.01	-0.04	-1.64	-1.22	0.27	-0.84	-0.67	0.01	-0.06	-0.04	0.00	-0.03	-4.26
Closing ES capacity in 2023	10.49	27.66	16.65	30.43	16.90	18.97	15.08	0.74	3.39	9.42	0.02	1.14	150.88

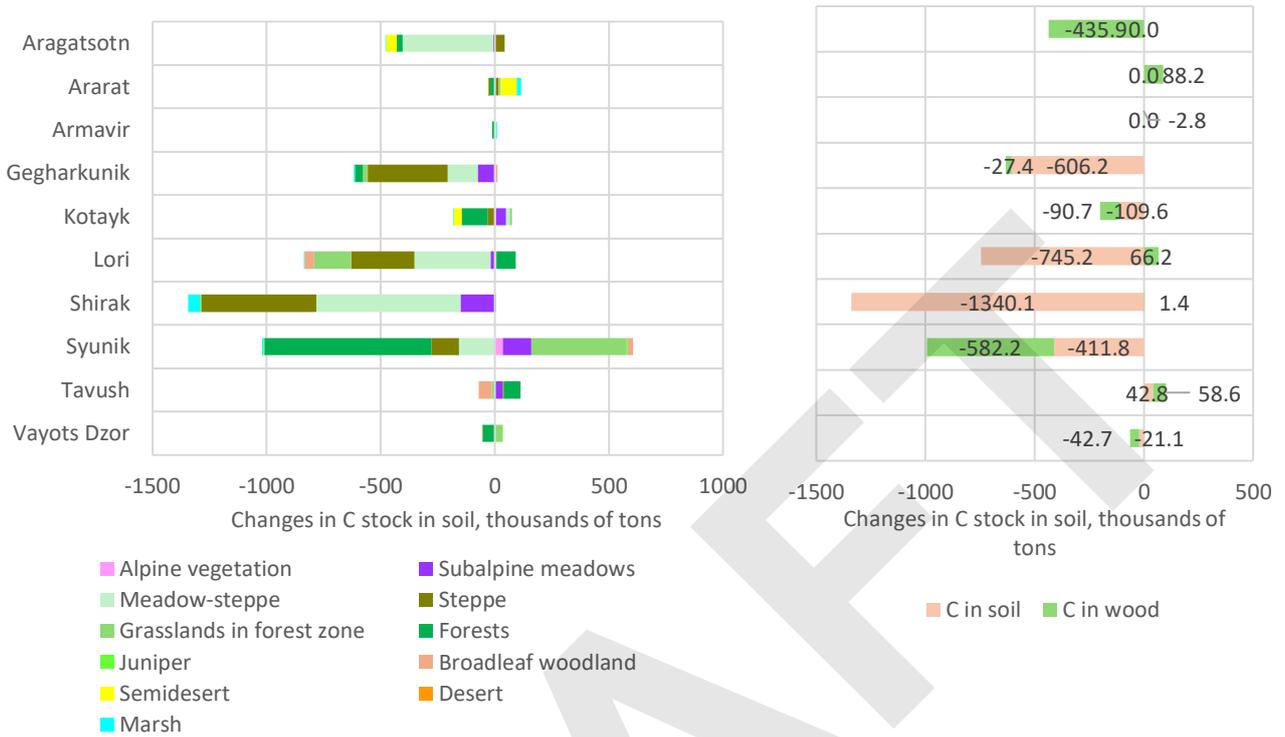


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Figure 31G2-1. Changes in carbon stock across vegetation types, thousands of tons

2180 At the marz level, carbon stocks declined primarily. Declines in the marzs of Shirak, Lori, Gegharkunik, and Aragatsotn
 2181 were due to a reduction in grassland area and, consequently, a reduction in soil carbon stocks. In Syunik marz, stocks
 2182 declined in both soil and timber due to a reduction in forest area, which failed to offset the increase in grassland area
 2183 (Figure 31G2-2).



2184 Figure 31G2-. Changes in carbon stock across marzes, thousands of tons

2185 Table 31G2-2. Changes in C stock in soils in different vegetation types across marzes, thousands of tons

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	C stock in soil, thousands of tons												C stock in wood	Total
	Alpine vegetation	Subalpine meadows	Meadow-steppe	Steppe	Grasslands in forest zone	Forests	Juniper	Broadleaf woodland	Semidesert	Desert	Marsh	Total		
Aragatsotn	0.6	-7.1	-397.1	41.3	2.3	-25.4	0.0	0.0	-48.1	0.0	-2.5	-435.9	-20.16	-456.0
Ararat	-0.6	1.9	0.0	14.5	8.2	-26.0	0.0	0.0	72.5	-0.6	18.3	88.2	-20.64	67.6
Armavir	0.0	0.0	0.0	0.0	0.0	-12.7	0.0	0.0	3.4	0.0	6.4	-2.8	-10.08	-12.9
Gegharkunik	3.8	-76.0	-130.0	-350.1	-22.8	-34.4	0.0	8.7	0.0	0.0	-5.4	-606.2	-27.36	-633.5
Kotayk	3.8	45.7	16.1	-30.8	8.8	-114.2	0.0	0.0	-37.0	0.0	-2.0	-109.6	-90.72	-200.3
Lori	7.0	-20.0	-332.1	-277.9	-162.8	83.4	0.0	-40.8	0.0	0.0	-2.0	-745.2	66.24	-679.0
Shirak	2.5	-149.5	-634.0	-505.3	0.0	1.8	0.0	0.0	-0.4	0.0	-55.3	-1340.1	1.44	-1338.7
Syunik	34.4	124.3	-158.3	-119.2	419.5	-732.8	4.0	24.7	-1.5	0.0	-6.9	-411.8	-582.24	-994.0
Tavush	0.0	36.1	0.0	3.5	-15.2	73.7	0.0	-55.3	0.0	0.0	0.0	42.8	58.56	101.3
Vayots Dzor	0.0	-0.6	0.0	-0.6	33.3	-53.8	1.1	-0.5	0.0	0.0	0.0	-21.1	-42.72	-63.8
Total	51.6	-45.1	-1635.5	-1224.6	271.3	-840.3	5.1	-63.1	-11.1	-0.6	-49.4	-3541.7	-667.7	-4209.3

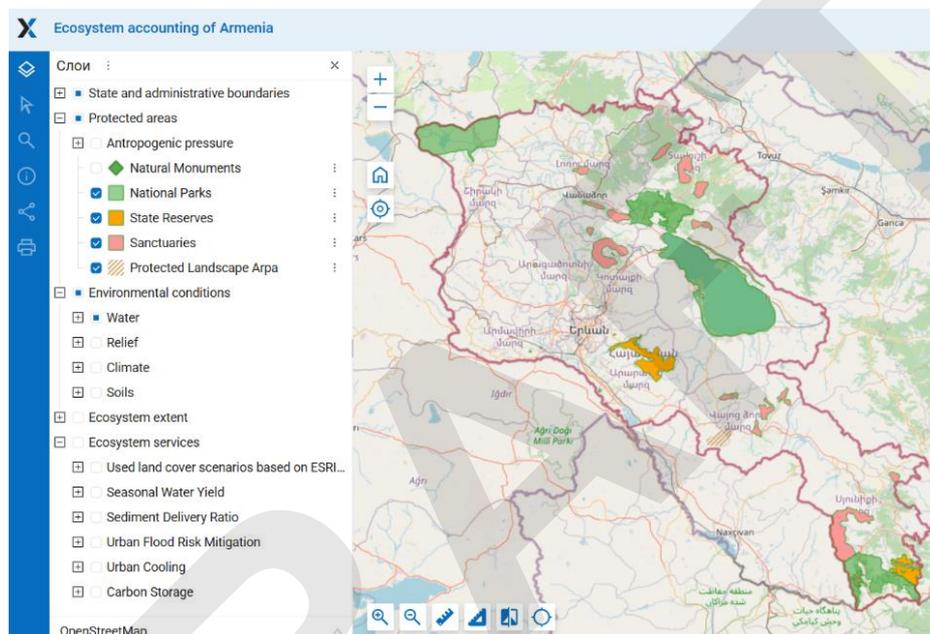
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2380 3.1.1. Regulating ES of Protected Areas

2381 At the present stage, we do not have access to official data covering all Armenian PAs for the period after 2014, official
 2382 digitized maps of PA boundaries, or land cover data specifically refined for the territory of Armenia. Therefore, the
 2383 following analyses are based on the available digital PA map referenced below and the global ESRI land cover dataset.

2384 The use of the ESRI land cover dataset for relatively small PA areas leads to significant errors in area estimation. In
 2385 the examples below, we demonstrate only the type of analysis that can, in principle, be conducted for ecosystem
 2386 accounting of PAs based on land cover data. **All estimates are of methodological value only and should be refined using**
 2387 **official PA boundaries and land cover data provided by the PAs.**
 2388

2389 This example of accounting is based on the PA map provided by [Acopian Center for the Environment, American](#)
 2390 [University of Armenia](#) (Figure 311-1), the vegetation map prepared in the framework of our project (Section 2.3), and ESRI
 2391 land cover data from 2017 and 2023.
 2392



2393
 2394 *Figure 311-1. The map of protected areas of Armenia. For details see [project WEB GIS, Protected areas here](#). (The*
 2395 *location of the Goravan Sands Sanctuary needs to be clarified)*

2396 ES of seasonal flow regulation and baseflow provision

2398 In most PAs, the baseflow is lower than the national average for Armenia (Figure 311-2). However, in several PAs, it
 2399 significantly exceeds the average values. The highest baseflow has been identified in Aragats Alpine sanctuary, Arpi Lake
 2400 National park and Pine of Banx sanctuary, which are located in regions with relatively high precipitation. These three PAs
 2401 are located in alpine, subalpine and meadow-steppe vegetation zones (Section 2.6.B), which are characterized by both a
 2402 high level of baseflow and a high proportion of baseflow in the total water flow (Section 3.1.A).

2403 ES of flood risk mitigation

2404 In most PAs, the runoff retention is higher than the national average for Armenia (Figure 311-3). The lowest values of
 2405 runoff retention are observed in PAs located in the Ararat Valley, which has been heavily modified by human activity. The
 2406 pattern for runoff retention differs from that of baseflow, as it reflects the influence of land cover and soil type, but does
 2407 not account for topography.

2408 ES of prevention of soil erosion and sediment transport into waterbodies

2409 Value of avoided erosion in most protected areas exceeds the national average for Armenia. This is explained by the
 2410 fact that PAs are primarily composed of natural grasslands and forests, which effectively prevent erosion (Section 2.6.B).
 2411 All PAs where Indicator avoided erosion exceeds 100 t/ha/year are mostly or entirely covered by woody vegetation, with
 2412 the exception of the Goris sanctuary, which has a small forested area (Figure 311-4).
 2413

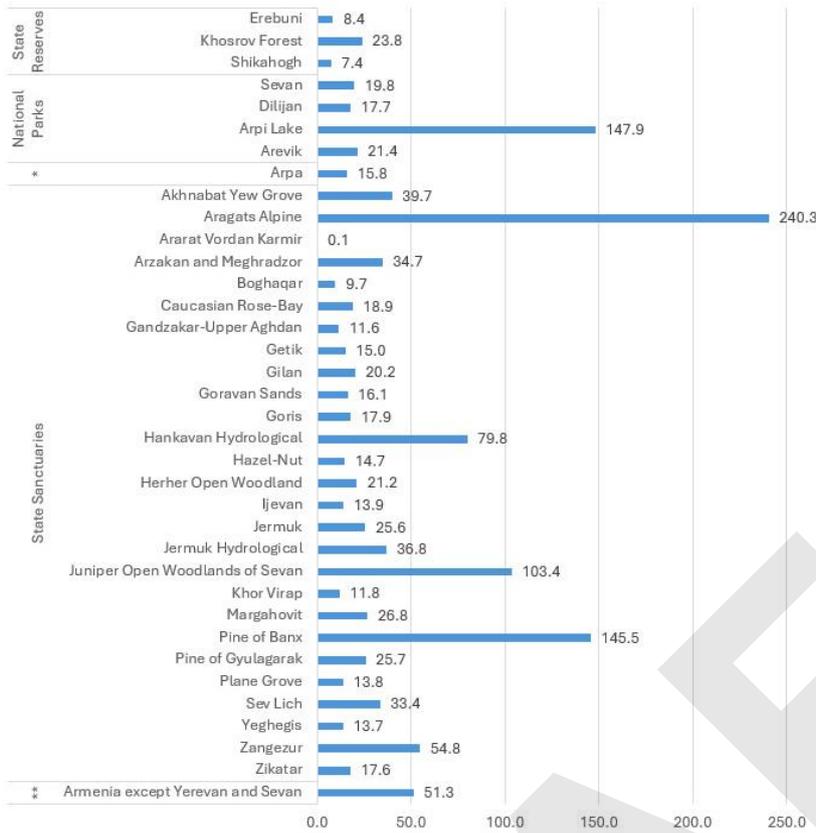


Figure 31I-2. Baseflow in PAs, mm

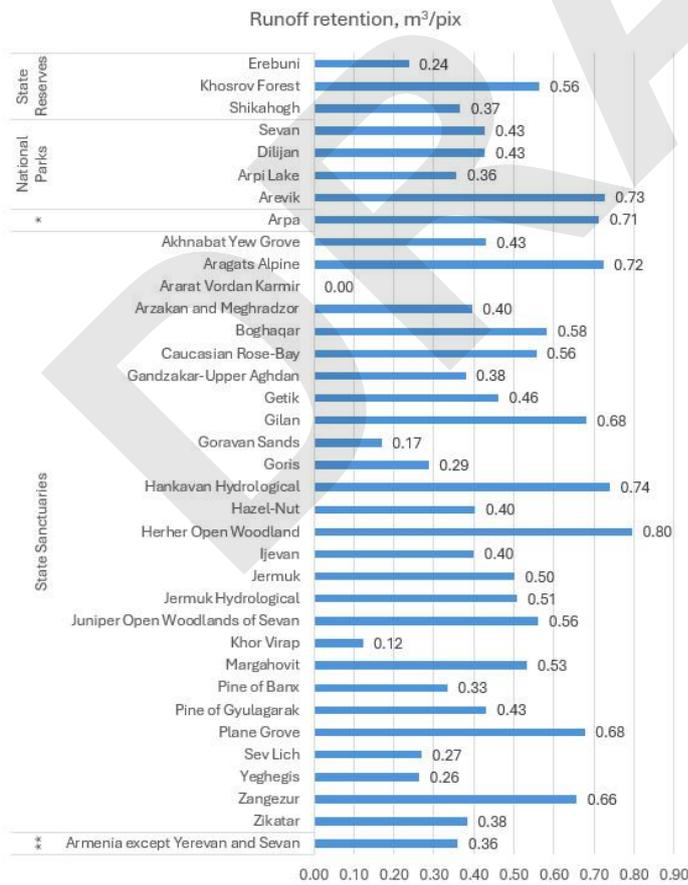


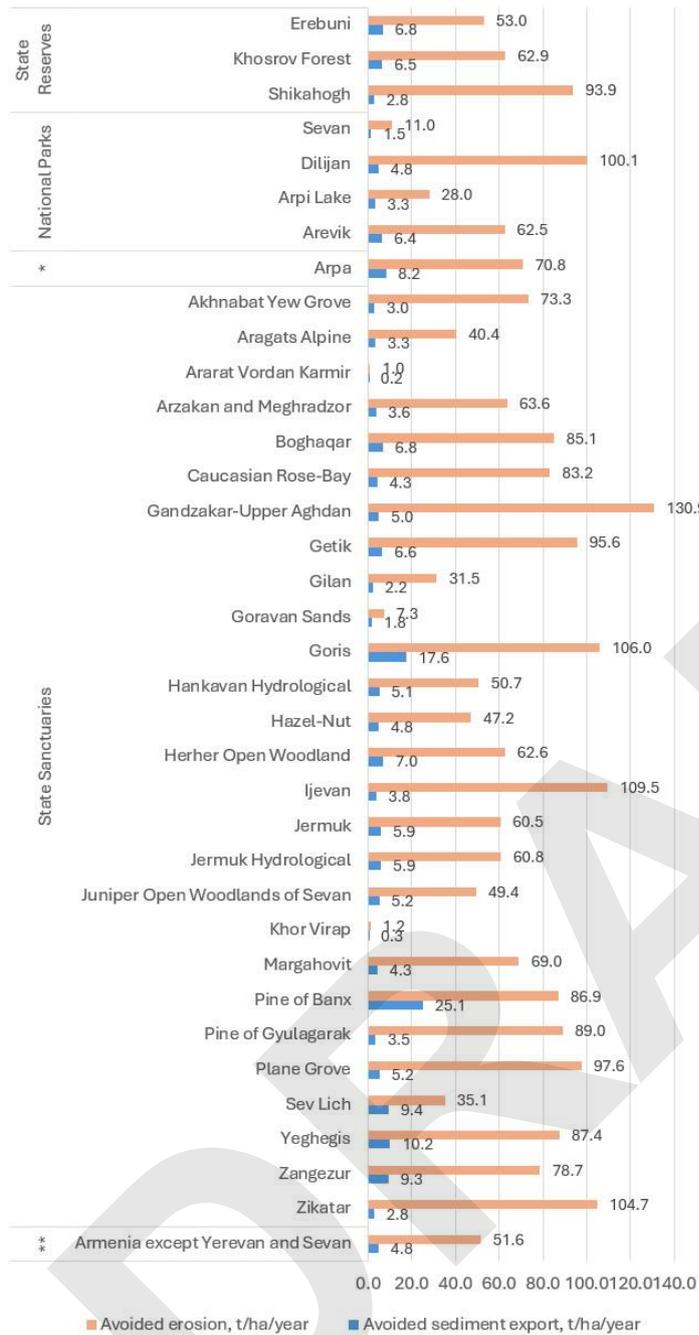
Figure 31I-3. Runoff retention in PAs, m³/pixel

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Figure 31I-4. Indicators of the ES of prevention of erosion and sediment delivery to water bodies

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Carbon storage in PAs

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Carbon content in soil in the PAs fluctuate around the national average for Armenia. PAs located in the semi-desert zone have the lowest soil carbon content. The total carbon stock depends primarily on the size of each PA. The highest carbon stock in tree biomass is found in Dilijan National Park, which has the largest forest area (Figure 31D-5). ES assessment for small PAs based on low-resolution maps is not advisable. For example, for the sanctuary Sev Lich, are inaccurate due to the low resolution (250 m) of the soil carbon map used (Figure 31D-6). The carbon map we used accounts for carbon content only in terrestrial ecosystems, assigning a value of zero to water bodies. The sanctuary Sev Lich includes part of a water body. Due to the low resolution of the map, pixels with zero values overlapped significant part of small terrestrial area of this sanctuary. As a result, both the average soil carbon content and the total carbon stock in this PA are significantly underestimated.

2430

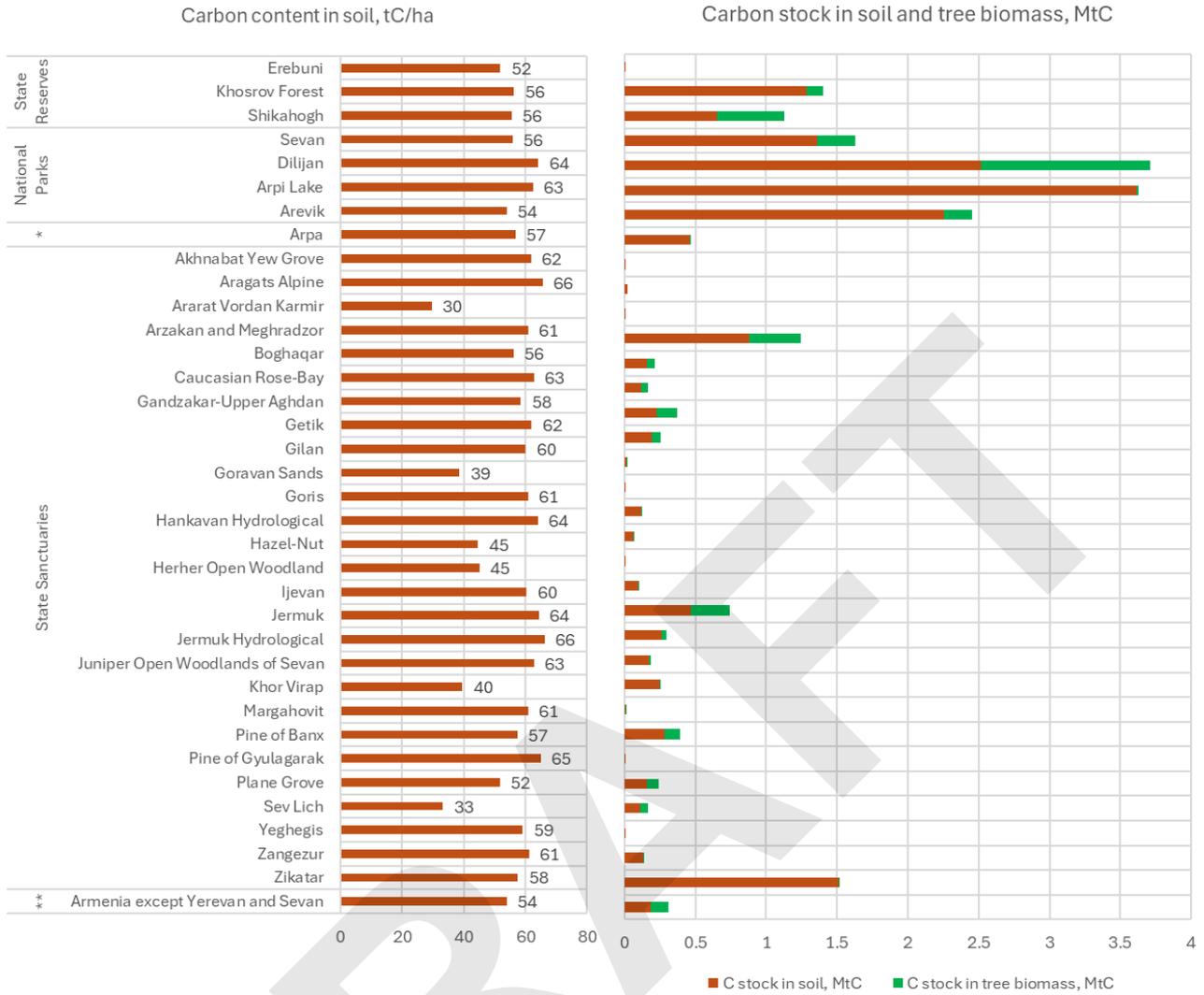


Figure 31-5. Carbon content in soil and total carbon stock in PAs

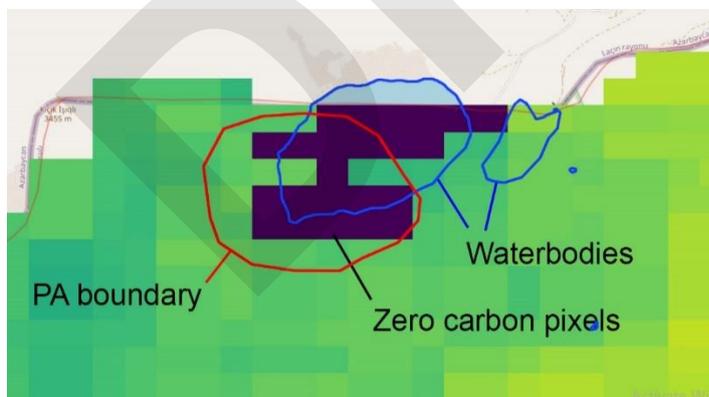


Figure 31-6. An example of a significant error in estimating carbon content in a small PA is observed in the case of the sanctuary Sev Lich.