2.1.Testing available land cover datasetss

The data for Armenia from the following five publicly available global land cover datasets were tested (Fig. 21-1): 1) Dynamic World; 2) ESRI Land Cover; 3) ESA WorldCover; 4) GLC_FCS30D; 5) GLAD Global Land Cover and Land Use Change. See short datasets description in the Table 21-1 and maps in the project web GIS. The following datasets were excluded from analysis (see for details Table 21-1): MODIS MCD12Q1; Copernicus Global Land Cover; ESA CCI/C3S Global Land Cover product; Globeland30; GlobCover; World Terrestrial Ecosystems; The Global Land Cover by National Mapping Organizations (GLCNMO).

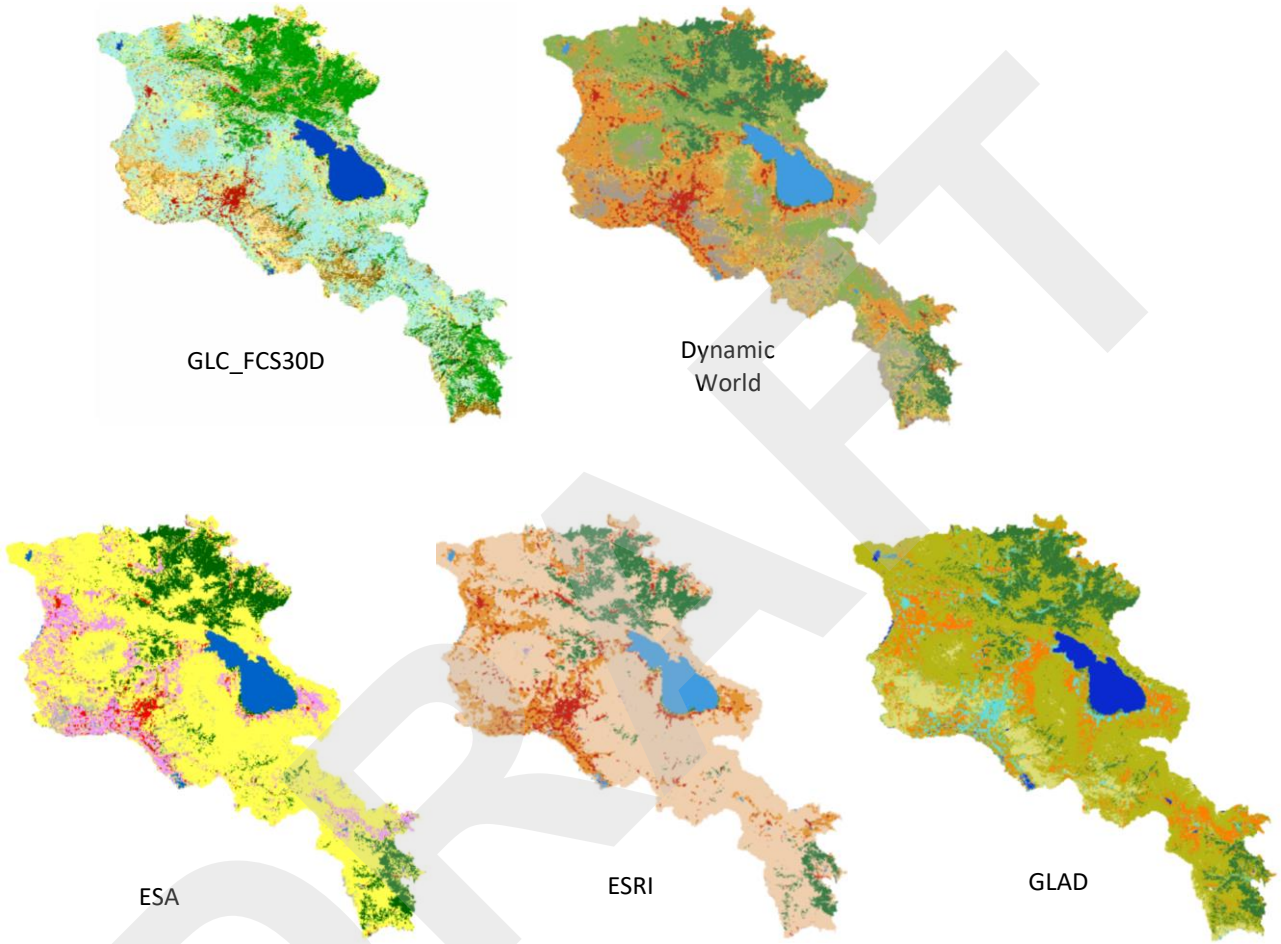


Figure 21-1. Tested land cover datasets

Table 21-1. Brief description of land cover datasets, which were tested and excluded from analysis

	Links	**Data provider**	**Spatial resolution**	**Temporal availability and resolution**	**Land cover classes**	**Future availability**	**General commentary and issues**
Tested land cover datasets							
Dynamic World	**Primary link** https://dynamicworld.app/ **Documentation** https://dynamicworld.app/about, https://www.nature.com/articles/s41597-022-01307-4 **Where to get the data** Google Earth Engine	Google, World Resources Institute. **License** – Creative Commons BY-4.0	10 m	2015 –**2024** near real-time	1. Water 2. Trees 3. Grass 4. Flooded veg. 5. Crops 6. Shrub & scrub 7. Built 8. Bare 9. Snow and ice	Project is based on two mature, well-known technologies: Google Earth Engine as processing and publishing engine and ESA Copernicus Sentinel-2 as data source. GEE is one of the key modern geospatial technologies. Sentinel-2 is a long-term program with scheduled activity up to 2033 (ref). These facts point to a secure future of Dynamic World	Initially published in 2022, Google Earth Engine (GEE) based dynamic land cover dataset. Transparent and open-sourced. It is based on Sentinel-2 data and dynamically updated with new data acquisitions (3-5 days revisit time, excluding cloudy periods). Could be challenging for inexperienced users to get data from GEE as files for analysis (designed to be used inside GEE). Very basic classification scheme (e.g. single class "trees" for all forest types). In general, there is no dataset in basic terms. There is a published machine learning algorithm which could be applied to any set of Sentinel-2 imagery, and this algorithm published together with the data at GEE. So users could request land cover data for particular territory based on a given period of Sentinel-2 acquisitions. Python code sample to retrieve data from GEE (using GEE-map package): https://gist.github.com/eduard-kazakov/6bfa6ca1ab4ead0b2d6a3ed3e94dd277
ESRI Land Cover	**Primary link** https://livingatlas.arcgis.com/landcover/ **Documentation** https://www.impactobservatory.com/static/lulc_methodology_accuracy-ee742a0a389a85a0d4e7295941504ac2.pdf **Where to get the data** https://livingatlas.arcgis.com/landcoverexplorer	ESRI. **License** – Creative Commons by Attribution (CC BY 4.0)	10 m	2017 – **2023** 1 year	1. Water 2. Trees 3. Flooded veg. 4. Crops 5. Built area 6. Bare ground 7. Snow/Ice 8. Clouds 9. Rangeland	Land cover is provided by the world leader in geospatial, ESRI, and based on the well-known ESA Copernicus Sentinel-2 data. Sentinel-2 is a long-term program with scheduled activity up to 2033 (ref). These facts point to a secure future of ESRI Land Cover.	Primary land cover product by ESRI, based on machine learning algorithms and Sentinel-2 data. Published every year. Available for direct download as GeoTIF for each year since 2017. Very basic classification scheme (e.g. single class "trees" for all forest types).
ESA WorldCover	**Primary link** https://esa-worldcover.org/en **Documentation** https://worldcover2021.esa.int/documentation **Where to get the data** https://viewer.esa-	ESA. **License** – Creative Commons Attribution 4.0 International	10 m	2020 –**2021** 1 year	1. Tree cover 2. Shrubland 3. Grassland 4. Cropland 5. Built-up 6. Bare/sparse veg. 7. Snow and Ice 8. Permanent water bodies 9. Herbaceous wetland	ESA has not officially confirmed that updates will follow annually, but the project has been extended due to its success and user demand. The current release patterns suggest that future updates might continue, though no fixed schedule has been guaranteed by ESA.	Flagman land cover project directed by ESA in cooperation with many partners. Based on Sentinel-2 and Sentinel-1 data (mixing optic and radar data). Distributed in GeoTIFF format via simple web interface.

	worldcover.org/worldcover/				10. Mangroves 11. Moss & lichen		
GLAD Global Land Cover and Land Use Change	**Primary link** https://glad.umd.edu/dataset/GLCLUC2020 **Documentation** https://www.frontiersin.org/journals/remote-sensing/articles/10.3389/frsen.2022.856903/full **Where to get the data** https://storage.googleapis.com/earthenginepartners-hansen/GLCLU2000-2020/v2/download.html	University of Maryland. **License** – Creative Commons Attribution 4.0 International	30 m	2000 –**2020** 5 years	1. Terra Firma – True desert 2. Terra Firma – Semi-arid 3. Terra Firma – Dense short vegetation 4. Terra Firma – Tree cover 5. Wetland – Salt pan 6. Wetland – Sparse vegetation 7. Wetland – Dense short vegetation 8. Wetland – Tree cover 9. Open surface water 10. Snow/ice 11. Cropland 12. Built-up 13. Ocean	Dataset is based on Landsat imagery. Three Landsat satellites are still active, the last one (Landsat 9) was launched in 2021. There are plans to continue the mission with Landsat Next in 2030/2031 (ref), so it seems that mission continuity is secure. The GLAD project of University of Maryland is well-known and highly regarded by the community.	Well-known dataset by University of Maryland based on Landsat imagery archives. Project is focused on estimating global land use changes. Important property of this dataset is how it is detailed, with differentiation of trees by height, water retention time etc.
GLC_FCS30D	**Primary link** – https://essd.copernicus.org/articles/16/1353/2024/ **Documentation** – https://essd.copernicus.org/articles/16/1353/2024/ **Where to get the data** – https://zenodo.org/records/8239305	Liangyun Liu, Xiao Zhang, & Tingting Zhao. **License** – Creative Commons Attribution 4.0 International	30 m	1985 –**2022** 1 year	1. Rainfed cropland 2. Herbaceous cover cropland 3. Tree or shrub cover (orchard) cropland 4. Irrigated cropland 5. Open evergreen broadleaved forest 6. Closed evergreen broadleaved forest 7. Open deciduous broadleaved forest 8. Closed deciduous broadleaved forest 9. Open evergreen needle-leaved forest 10. Closed evergreen needle-leaved forest 11. Open deciduous needle-leaved forest 12. Closed deciduous needle-leaved forest 13. Open mixed leaf forest (broadleaved and needle-leaved) 14. Closed mixed leaf forest (broadleaved and needle-leaved) 15. Shrubland 16. Evergreen shrubland 17. Deciduous shrubland 18. Grassland 19. Lichens and mosses 20. Sparse vegetation 21. Sparse shrubland 22. Sparse herbaceous 23. Swamp 24. Marsh 25. Flooded flat 26. Saline 27. Mangrove 28. Salt marsh	Dataset is based on Landsat imagery. Three Landsat satellites are still active, the last one (Landsat 9) was launched in 2021. There are plans to continue the mission with Landsat Next in 2030/2031 (ref), so it seems that mission continuity is secure. According to latest publications, authors have intention to continue providing this data in the future. On the one hand they are supported and funded by the Chinese government, on the other hand the project obviously depended on particular scientists, which could be insecure.	This dataset is developed and supported by a group of scientists from different Chinese institutes. It's well-known and cited hundreds of times, authors support it and add data for new years. Land cover is based on Landsat data time series. Project is supported by the National Natural Science Foundation of China. Product has a diverse classification scheme compared to other datasets. Data is distributed in zip archives available at famous scientific open data portal Zenodo, each GeoTIFF inside zip contains data for 20+ years (one band – one year).

					29. Tidal flat 30. Impervious surfaces 31. Bare areas 32. Consolidated bare areas 33. Unconsolidated bare areas 34. Water body 35. Permanent ice and snow		
Datasets excluded from analysis							
MODIS MCD12Q1*	**Primary link** https://lpdaac.usgs.gov/products/mcd12q1v061/; **Documentation** https://lpdaac.usgs.gov/documents/1409/MCD12_User_Guide_V61.pdf; **Where to get the data** https://search.earthdata.nasa.gov/search	NASA. **License** – No restrictions on reuse, redistribution, or modification	500 m	2000 –**2023** 1 year		MCD12Q1 data is based on the MODIS sensor installed at Terra and Aqua satellites. According to the current plan, Terra MODIS will remain operational and generate the full suite of products until the end of the mission in **December 2025**, and Aqua MODIS will remain operational and generate the full suite of products until the end of the mission in **August 2026** (ref)**.** So we can await product availability **up to 2025**. This product will probably be replaced by a new generation one, but there is no particular information about it yet	We did not consider the MODIS data as a possible landcover for creating an ecosystem map due to its low resolution. However, these data can be used to assess ecosystem services. Well-known global Land Cover dataset, referenced thousands of times. Distributed with 8 different classification schemes. Training data haven't been updated since 2021, so authors ask to be careful about data released after 2021 (ref). Relatively low spatial resolution.
Copernicus Global Land Cover	https://land.copernicus.eu/en/products/global-dynamic-land-cover			2015-2020			Data is available only for 2015-2019, no further updates are planned. Other Copernicus products may be useful for assessing ecosystem services.
ESA CCI/C3S Global Land Cover product	https://www.esa-landcover-cci.org/			1992-2020			Data is available only for 1992-2020. New releases were promised, but there were no actual updates in scheduled dates.
Globeland30	https://www.webmap.cn/commres.do?method=globeDetails&type=brief			2000-2010			Data is available only for 2000 and 2010, no further updates are planned.
GlobCover	https://due.esrin.esa.int/page_globcover.php			2009			Data is available only for 2009, no further updates are planned.
World Terrestrial Ecosystems	https://www.arcgis.com/home/item.html?id=926a206393ec40a590d8caf29ae9a93e			2020			Data is available only for 2020, no further updates are planned.
The Global Land Cover by National Mapping Organizations (GLCNMO)	https://globalmaps.github.io/glcnmo.html			2003-2013			Data is available only for 2003-2013, no further updates are planned.

2.1.A. Area of land cover classes in the tested datasets

To ensure dataset comparability, all tested land cover datasets and Governmental data on land cover area were generalized into five land cover classes: 1) trees; 2) non-woody natural areas; 3) water, wetlands, flooded vegetation; 4) crops; 5) built-up areas.

The Decision of the Government of the Republic of Armenia in April 11, 2019 defined the following land cover classes for national accounting: Cultivated lands; Grasslands; Tree-covered areas; Shrub-covered areas; Water covered areas; Vegetation-free areas. The more detailed disaggregation of land cover classes by land fund categories provided in the Government-reported data, enables the separation of vegetation-free anthropogenic areas, i.e., built-up areas from natural ones (see here) and makes it possible to compare Governmental data and land cover datasets. How to classify grasslands and cultivated lands located within settlement boundaries is a question that needs to be addressed in order to harmonize satellite-based land cover classifications with official land cover statistics. At this stage of the analysis, we kept these lands within grasslands and cultivated lands, respectively.

Further, to ensure comparability of tested datasets and Government-reported data three land cover classes - Grasslands, Shrub-covered areas, and Vegetation-free natural areas - were combined into one class Non-woody natural areas. The data for 2022 were used for comparison, as it represents the midpoint between the dates of the tested land cover datasets.

Share of land cover classes in Armenia

GLC_FCS30D landcover data shows very strong excess of cropland area and excess of forest area. The results of the three land cover datasets — ESRI, ESA, and GLAD — are similar and show a smaller cropland area nd larger grassland area than the Government-reported data. In contrast, the DW dataset shows a larger cropland area and smaller grassland area than the Government data (Fig. 21A-1, 21A-2). Dataset GLC_FCS30D 2022 was excluded from the further analysis, as it differed most significantly from all the other datasets and from Government-reported data.

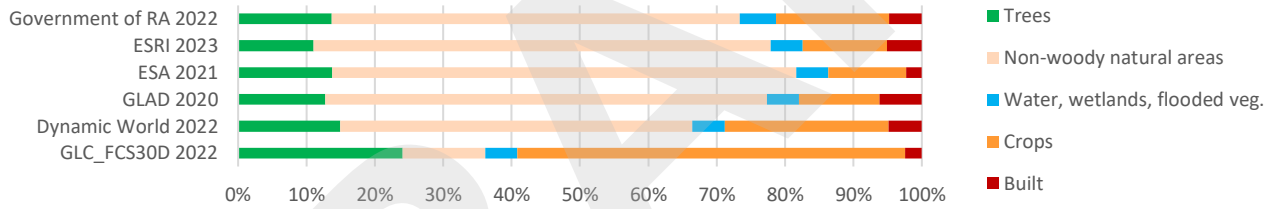


Figure 21A-1. Share of land cover classes in Armenia according the five tested datasets

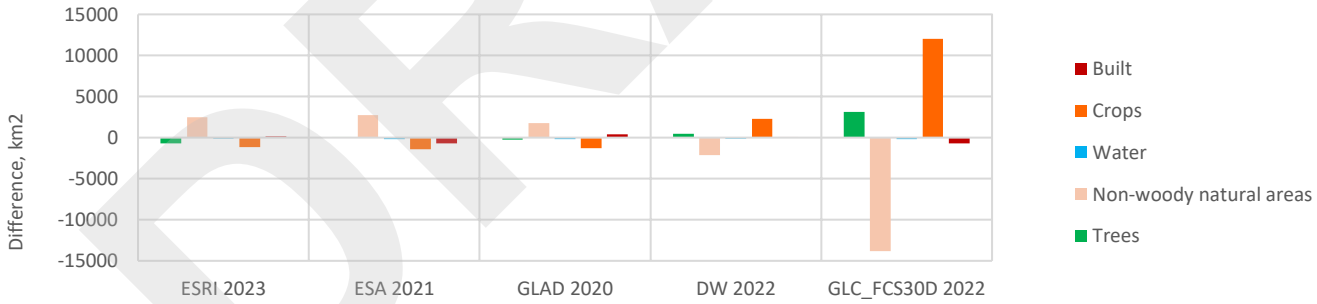


Figure 21A-2. Difference between Government-reported area of land cover classes (2022) and tested datasets

Share of land cover classes across marzes

All four remaining datasets differ significantly from the Government-reported data (Fig. 21A-3). The discrepancies identified at the national level are largely maintained across individual marzes: ESRI, ESA, and GLAD show larger areas of non-woody natural lands and smaller cropland areas compared to the Government data. In contrast, DW shows smaller non-woody areas and larger cropland areas than the Government data (Fig. 21A-4). This shift persists across the majority of marzes (Fig. 21A-4), suggesting that it is systemic and driven by the differences in the methodology used for satellite image classification. Discrepancies between the land cover datasets and Government data for forest cover and built-up areas are smaller in magnitude and do not follow the pattern observed in the relationship between cropland and non-woody natural areas. The most prominent shifts include for forest area a reduction in the ESRI data, and increase in the DW data, as well as for built-up area a reduction in the ESA data and increase in the GLAD data. Differences between the land cover datasets and the Government data in terms of water area are minor and fairly consistent across all datasets — each identifies a slightly smaller water area. Figure 21A-5 provides a more detailed view of the area differences across the marzes.

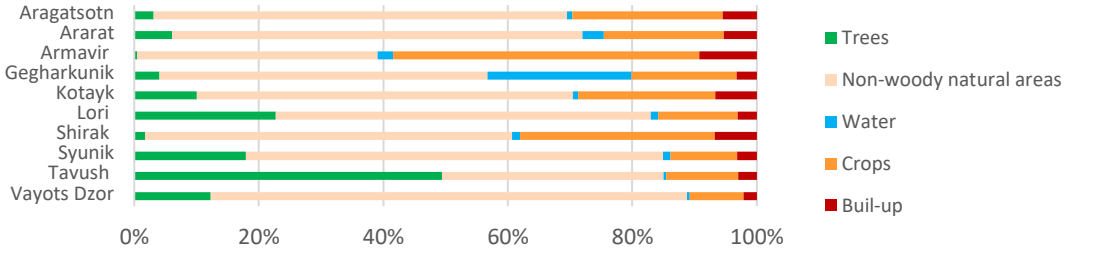
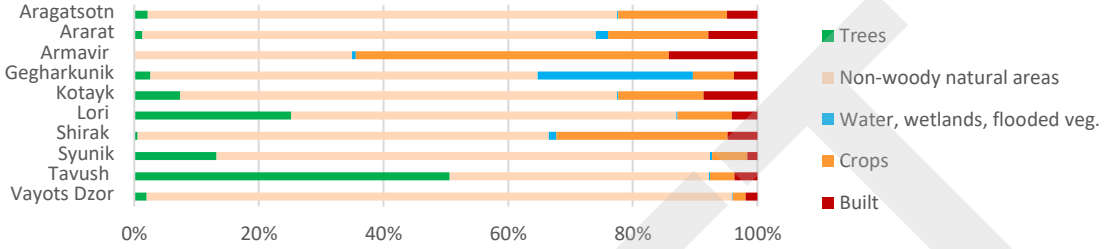
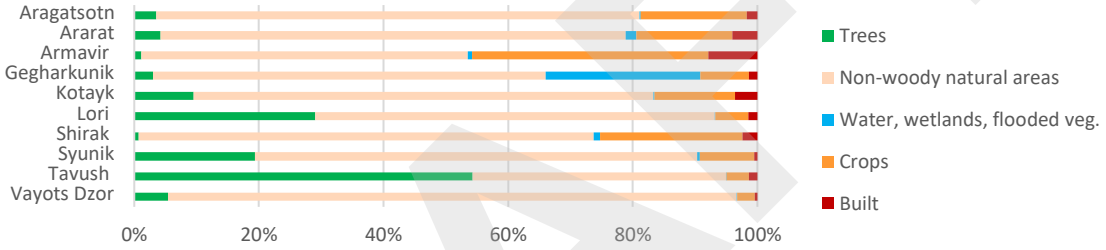
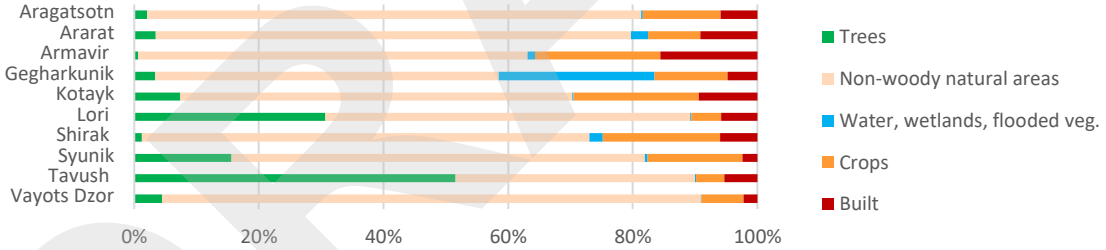
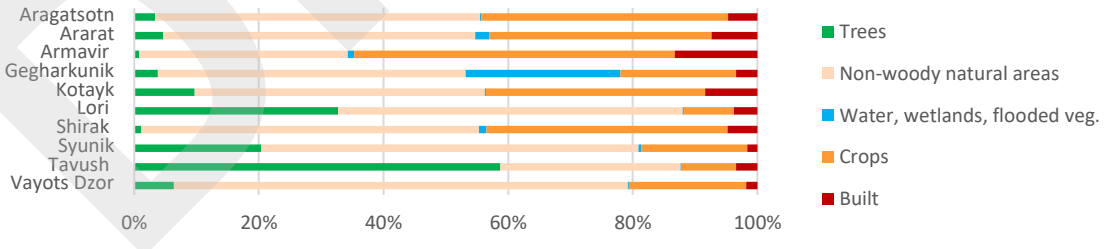
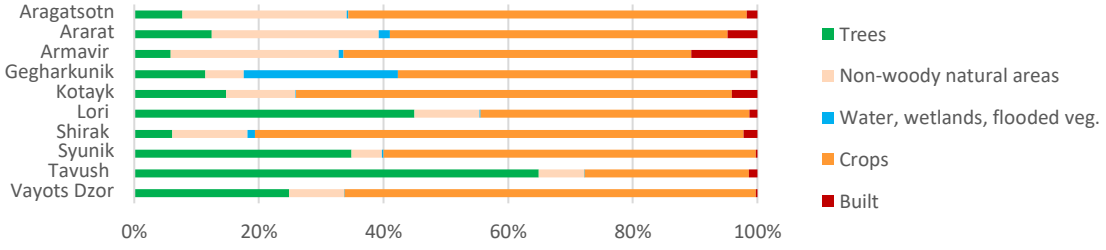
Dataset	*The share of land cover classes area in marzes*
Government-reported data 2022	
ESRI 2023	
ESA 2021	
GLAD 2020	
Dynamic World 2022	
GLC_ FCS30D 2022	

Figure 21A-3. Land cover class shares across marzes according Government-reported data and tested datasets

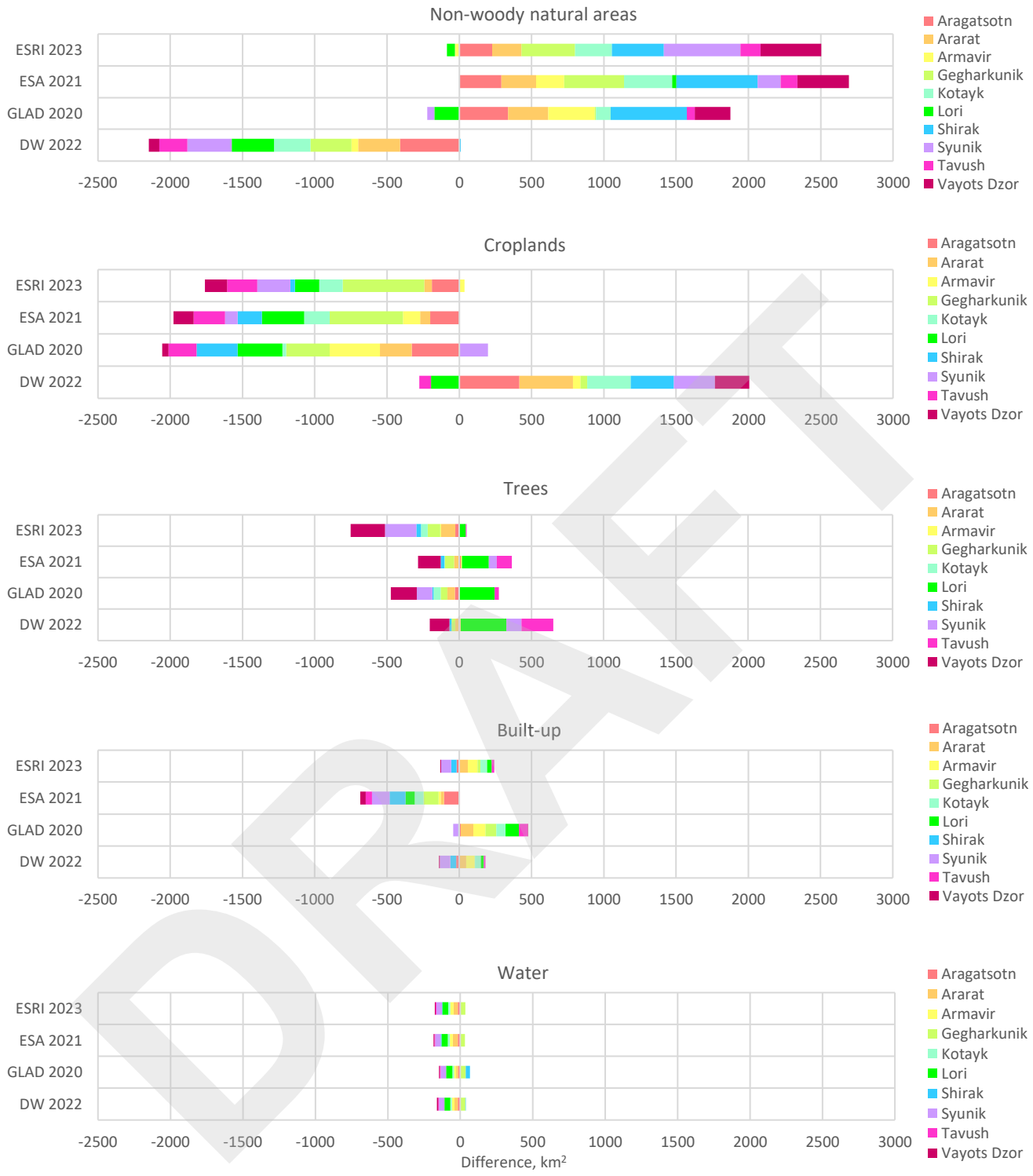


Figure 21A-4. Land cover area difference: Government-reported areas minus areas from tested datasets. Differences between tested datasets and Government-reported data in marzes are shown in different colors. Provincial differences for each land cover class are combined into a single bar to show the total deviation from the Government-reported data.

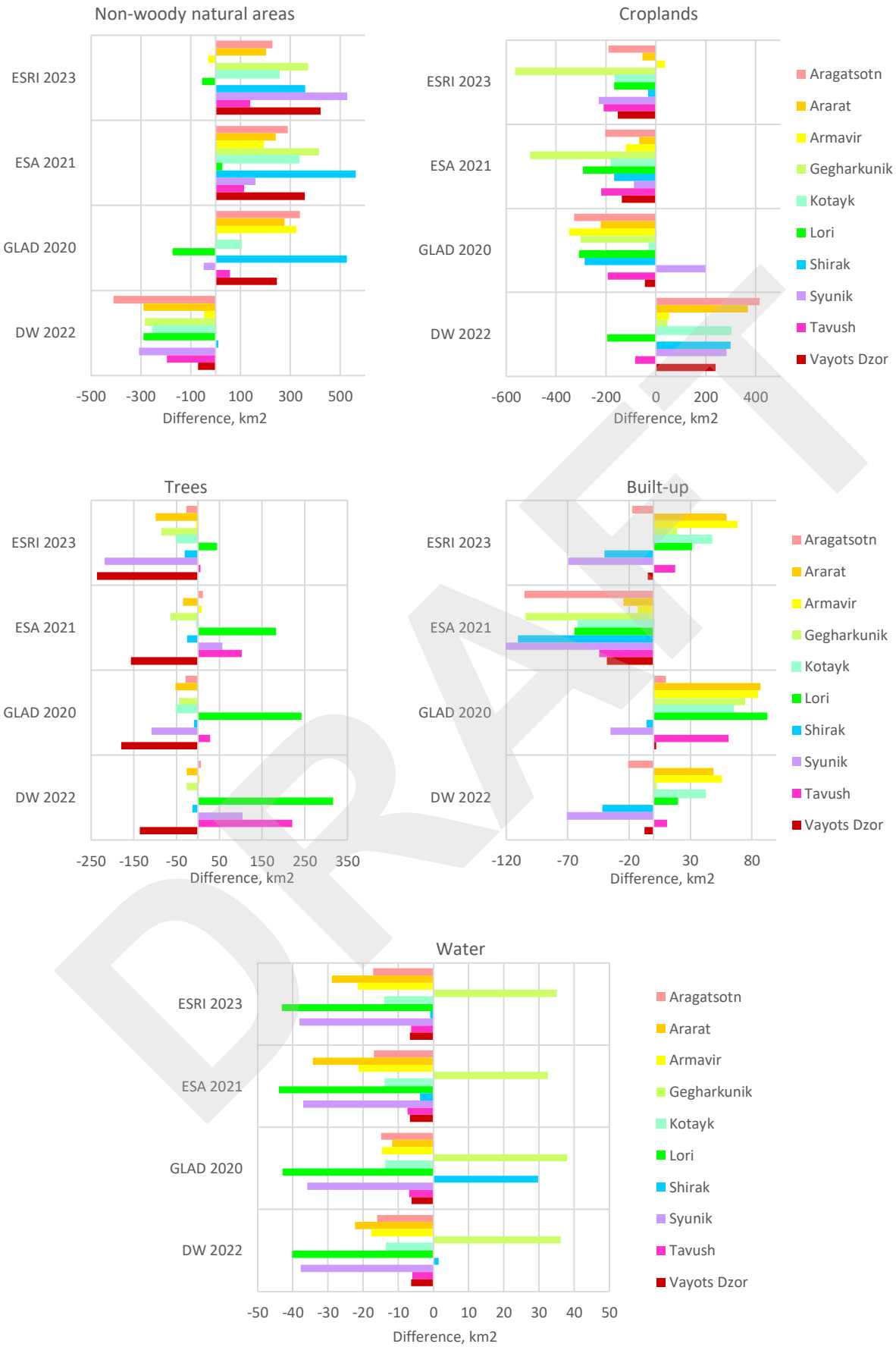


Figure 21A-5. Land cover area difference across marzes: Government-reported areas minus areas from tested datasets

The absolute discrepancy (km^2) is largest for croplands and grasslands, while in relative terms (percentage relative to Government-reported data), it is greatest for croplands and built-up areas (Figure 21A-6).

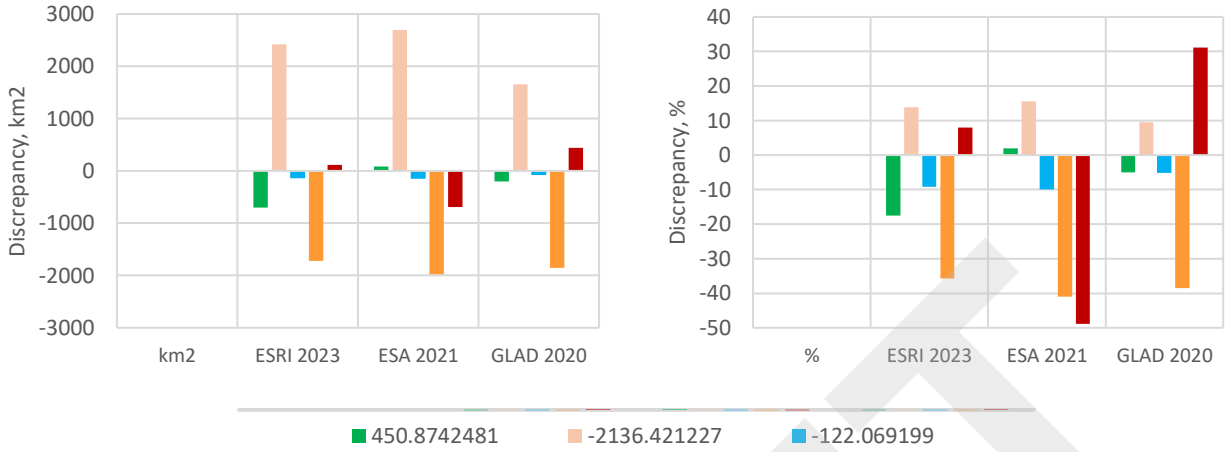


Figure 21A-6. Absolute (km²) and relative discrepancy (% relative to Government-reported data) in area of land cover classes

The smaller area of built-up area in ESA data can be explained by the fact that ESA identifies trees, grasslands, and crops within settlements. The ESA data generally feature smaller patches across all land cover classes (Fig. 21A-7).

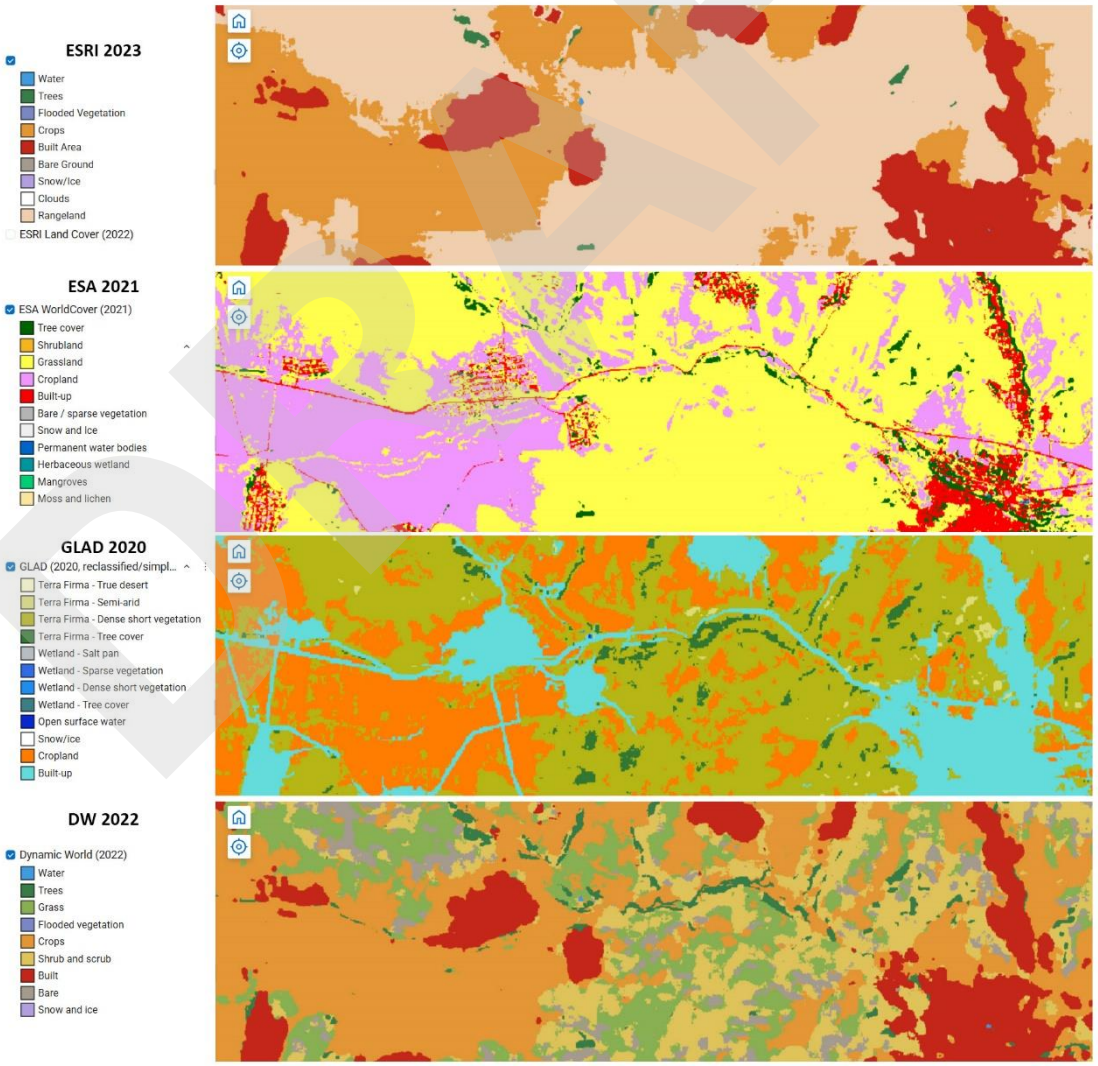


Figure 21A-7. The same area as represented in different land cover datasets

The Government classification of land cover types includes, among others, shrub-covered areas. Of the four land cover datasets retained for analysis, two — ESA and DW — also include this class. However, the shrub areas identified in these datasets differ greatly from the Government-reported areas. According to ESA, shrub area is very small and consistently lower than the Government figures across all marzes. DW, on the contrary, identifies a very large shrub area — several times greater than the Government data (Table 21A-1, Fig. 21A-8). Thus, the presence of a "shrubs" class in these two datasets does not make them more consistent with the Government data.

Table 21A-1. Area of shrub-covered areas in Government-reported data and in two land cover datasets

Marzes	GOV 2022	ESA 2021	DW 2022
Aragatsotn	3.925	0.000	361.594
Ararat	24.962	0.001	387.490
Armavir	6.341	0.001	58.548
Gegharkunik	36.351	0.000	611.396
Kotayk	23.135	0.000	372.450
Lori	48.307	0.057	345.520
Shirak	0.000	0.000	246.146
Syunik	157.423	1.042	1147.185
Tavush	29.433	8.913	310.120
Vayots Dzor	11.479	0.000	843.881

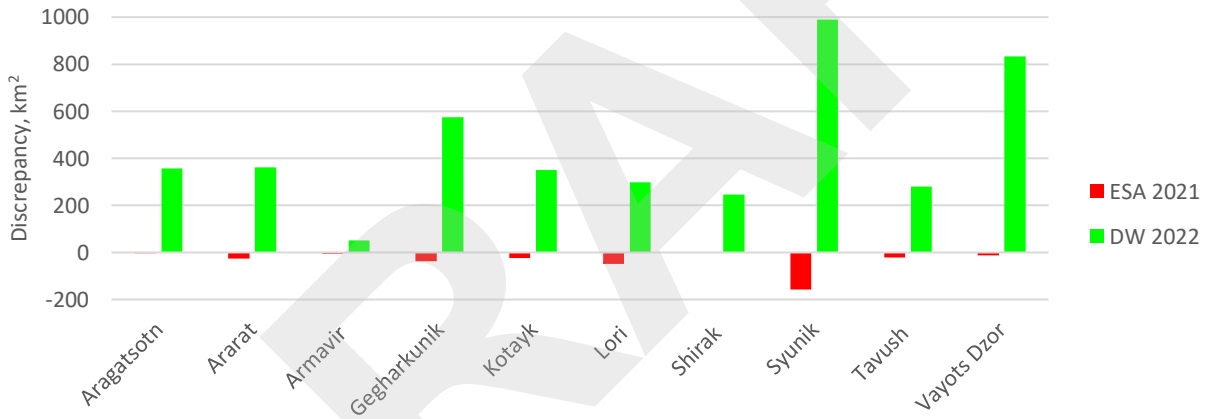


Figure 21A-8. Discrepancy with Government-reported data in shrubland area.

A preliminary overall indicator for assessing land cover data accuracy can be the total discrepancy between land cover class areas in datasets and Government data. The reliability of this indicator increases when absolute errors are summed across the smallest spatial units. In this case, however, data are available only at the marz level, so the indicator we used represents the sum of absolute area discrepancies (by modulus, regardless of sign) across marzes. Overall, all four datasets show a similar total discrepancy from the Government data, ranging from 19.4% to 20.9% of Armenia's total area. The smallest discrepancy is observed in the ESRI dataset, and the largest in ESA (Fig. 21A-9).

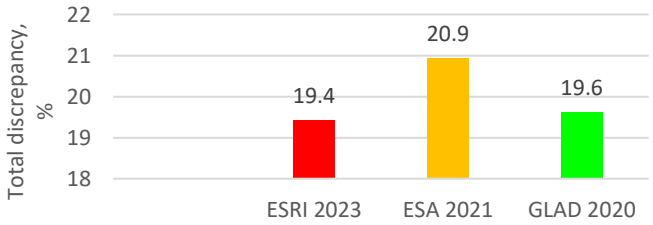


Figure 21A-9. Total relative discrepancy (% relative to total area of Armenia) between tested datasets and Government-reported data

Share of land cover classes across landscape zones

Comparison of land cover class areas across landscape zones according different datasets shows that ESRI, ESA, and GLAD are generally similar to each other (Fig. 21A-10). Dynamic World (DW 2022) data show a significantly larger cropland area compared to the other datasets. This is especially noticeable in mountainous landscapes. Croplands were identified on nearly 10% of the area of the high-altitude and alpine zones. In some mountain ranges (Gegham Range and southwestern slope of the Karabakh plateau) croplands occupy about 20% (Fig. 21A-11), which is inconsistent with reality. In the subalpine zone, croplands occupy more than 10% in total.

Comparison of ESRI, ESA, and GLAD datasets shows that in ESRI, the cropland area is significantly larger in mountain-valley semi-desert and dry steppe zones, whereas in GLAD, the cropland area in mountain-valley semi-desert zone is smaller than in the other two datasets (Fig. 21A-10). The ESA dataset is characterized by larger area of tree cover and smaller built-up area, which is particularly noticeable in the semi-deserts, dry steppe, and forest shelter belt. One of the reasons for this is that, as mentioned above, ESA identifies trees within settlements. The presence of trees in submountain semidesert zone in the ESA data is entirely due to this factor – all trees there are located inside settlements. ESRI and GLAD datasets do not show any tree cover in this zone.

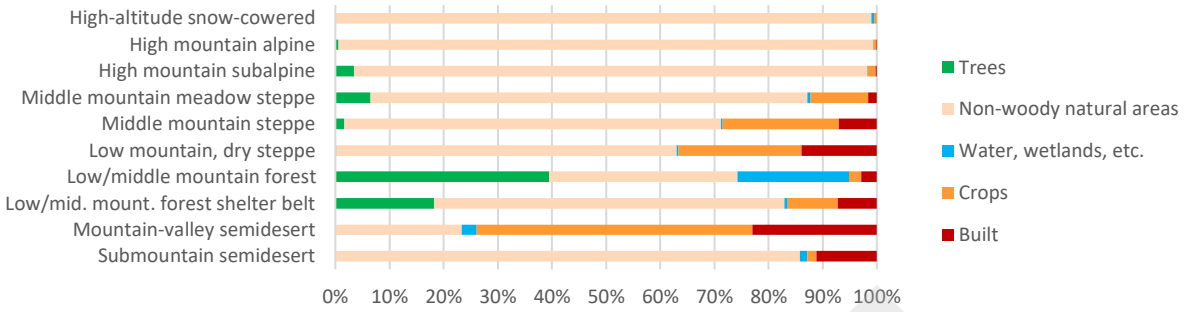
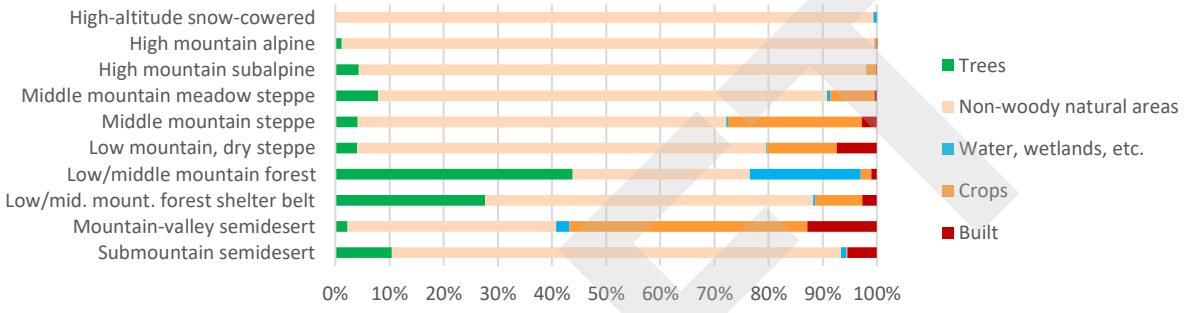
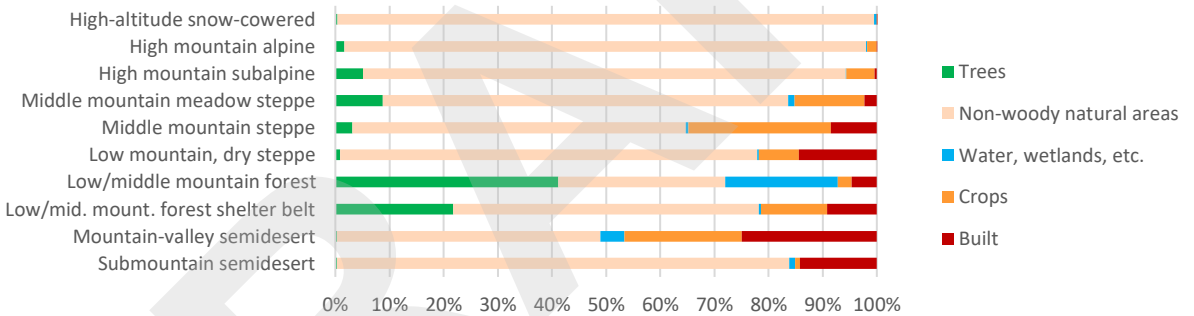
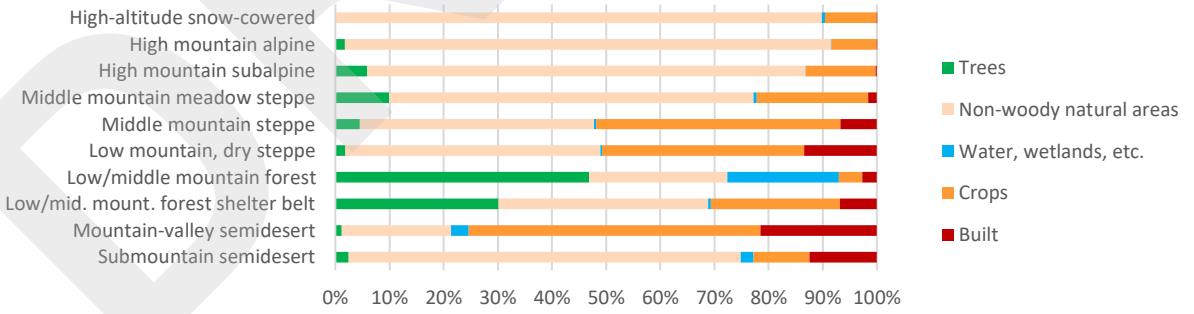
Dataset	*The share of land cover classes area in landscape zones*
ESRI 2023	
ESA 2021	
GLAD 2020	
Dyna-mic World 2022	

Figure 21A-10. Land cover class shares across landscape zones according tested datasets

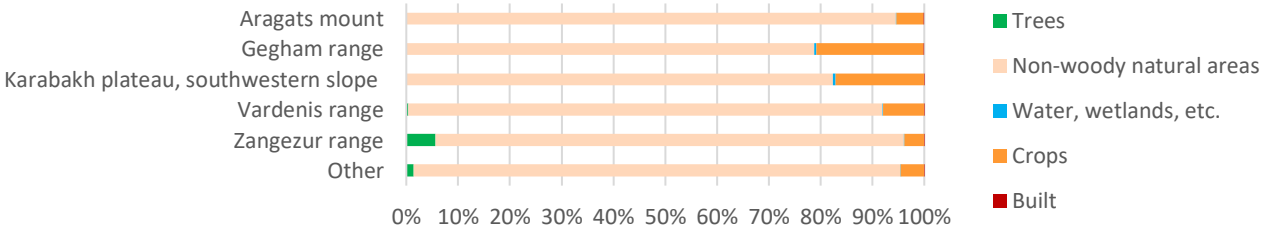


Figure 21A-11. Land cover class shares in high-altitude snow-cowered and high mountain alpine zones across highland systems of Armenia according DW 2022 data

2.1.B. Comparison of cropland area according to land cover datasets and ARMSTAT data

A comparison with ARMSTAT data on cultivated areas was conducted for four land cover datasets – ESRI, ESA, GLAD, and Dynamic World (GLC_FCS30D was excluded from the analysis, see Section 2.1.A). For comparison, we also used 2022 Government-reported data on the area of cultivated land in Armenia.

Cropland area according to landcover data was compared with three ARMSTAT indicators for the same year as the landcover data:

1) Arable land (**Arable** in Figures) , that is, an area intended for cultivation, but not necessarily used every year;

2) Annually cultivated area (**Cultivated** in Figures), that is the sum of annually plowed area, the area of fruit and berry plantations (including greenhouses, hothouses and inter-row fruit-bearing plantations), and vineyards;

3) Annually plowed area (**Plowed** in Figures) that is plantations of grains and leguminous crops, potatoes, vegetables and melons.

According to ESRI, ESA, and GLAD datasets, the cropland area in most marzes is smaller than the area of arable land but larger than annually cultivated area reported by ARMSTAT. The cropland area identified by DW exceeds the arable land reported by ARMSTAT in almost all marzes, except for marzes Lori and Tavush (Figure 21B-1). The cultivated area reported in the 2022 Government data exceeds the arable land area in all marzes (GOV (A) in Fig.21B-1). If the cultivated area within settlements is excluded, the difference with the ARMSTAT data becomes smaller (GOV (B) in Fig.21B-1).

The cropland areas identified by all datasets exceed the annually cultivated area reported by ARMSTAT, except for the GLAD data in marzes Ararat and Armavir.

Figure 21B-2 provides a more detailed breakdown by marz.

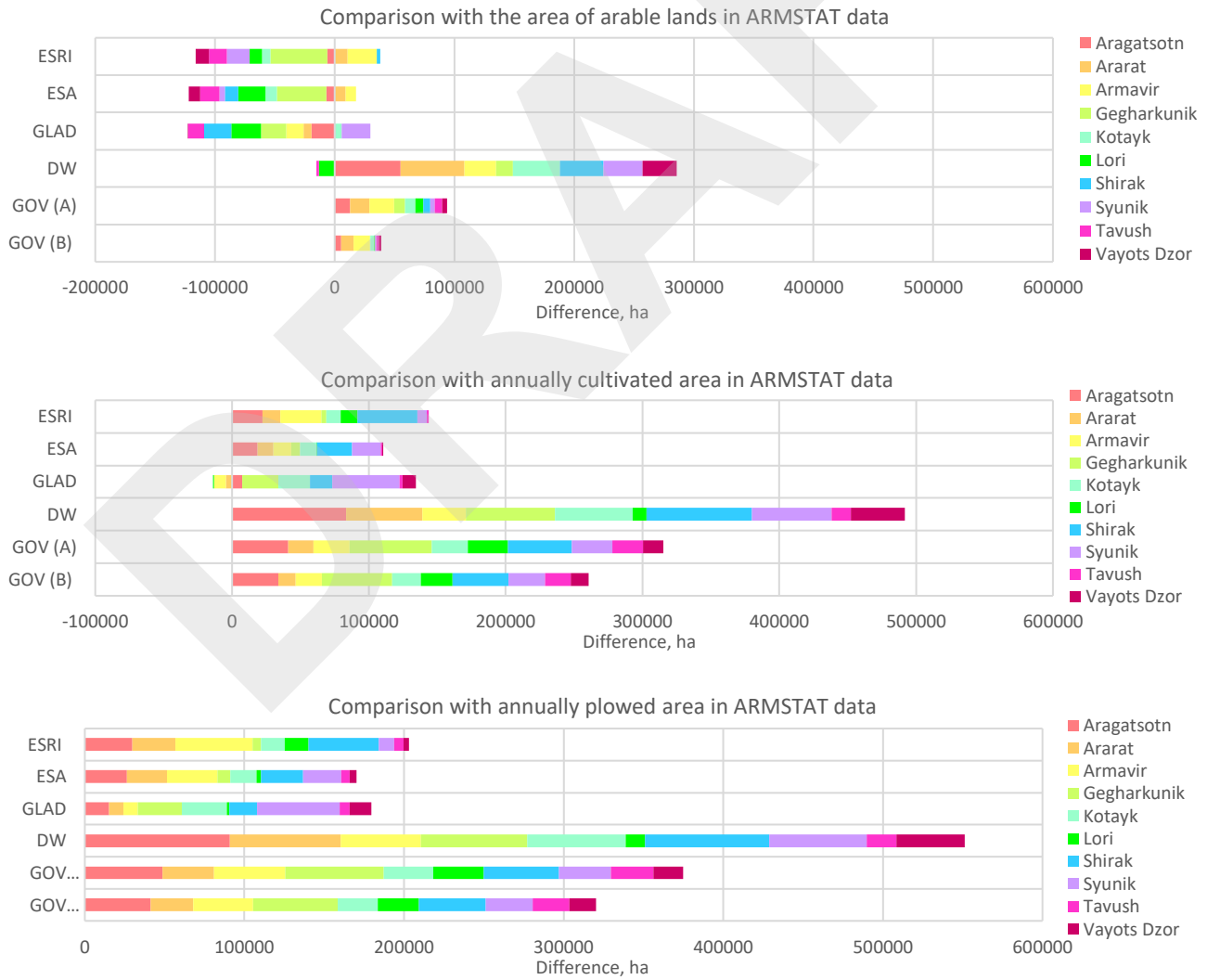


Figure 21B-1. Difference between areas of croplands in tested datasets and ARMSTAT data on arable lands, annually cultivated, and annually plowed areas (dataset data minus ARMSTAT data)

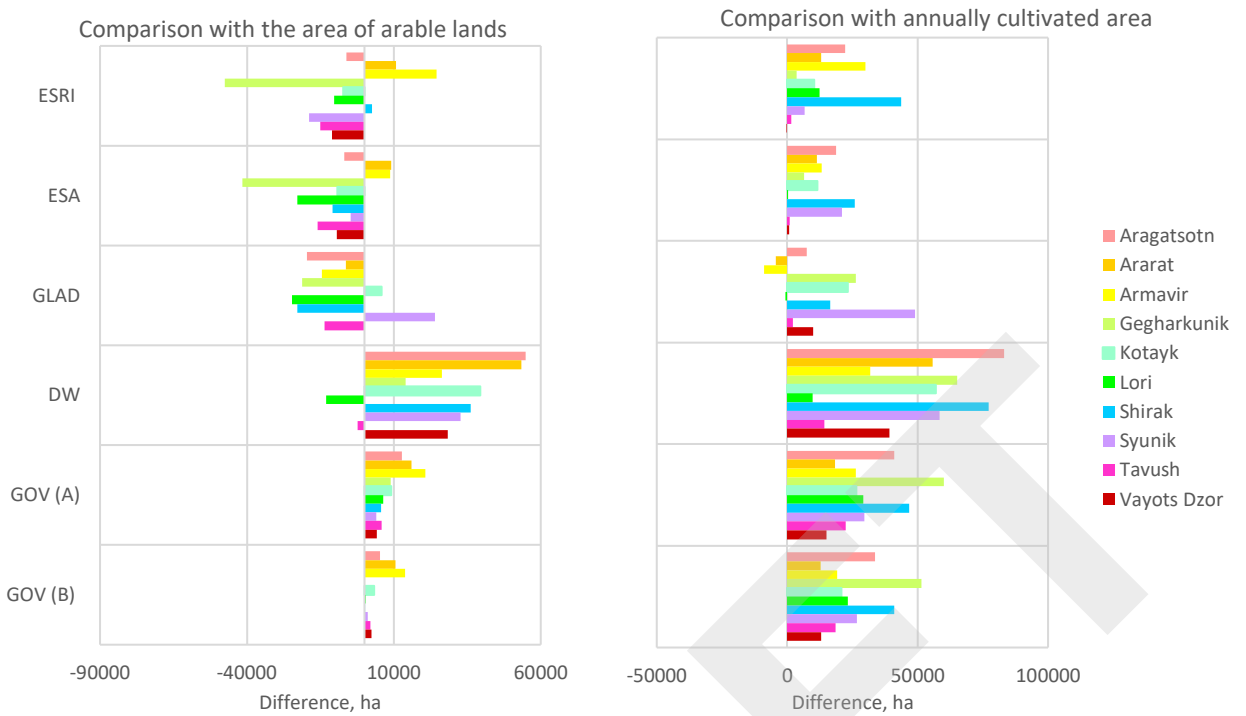


Figure 21B-2. Difference between areas of croplands in tested datasets and ARMSTAT data on arable lands, annually cultivated, and annually plowed areas (dataset data minus ARMSTAT data) across marzes

The fact that in ESRI, ESA, and GLAD datasets the cropland area is smaller than the area of arable land but larger than annually cultivated indicates that these datasets classify a part of lands designated for cultivation but not cultivated during the reference year as croplands. The area of land designated for cultivation that was left uncultivated in the given year is equal to Astat-Cstat, where Cstat is cultivated area in ARMSTAT data; Astat is arable area in ARMSTAT data. Thus, the share of uncultivated fields that are identified in ESRI, ESA, and GLAD datasets as croplands can be defined as U=(C-Cstat)/(Astat-Cstat), where C is cropland area in a dataset. Across the marzes, this figure varies between 0% and 100% (Fig. 21B-3). In cases where the cropland area from land cover datasets exceeds arable land area reported by ARMSTAT, this indicator exceeds 100%. This is most evident in the ESA and ESRI data for the Ararat and Armavir marzes, where these datasets estimate the cropland area to be 20–40% larger than the arable land area reported by ARMSTAT, while approximately 90% of the arable land in these marzes is annually cultivated. The cropland area in all datasets exceeds the annually plowed area. The Government data exceed both annually cultivated and annually plowed area reported by ARMSTAT.

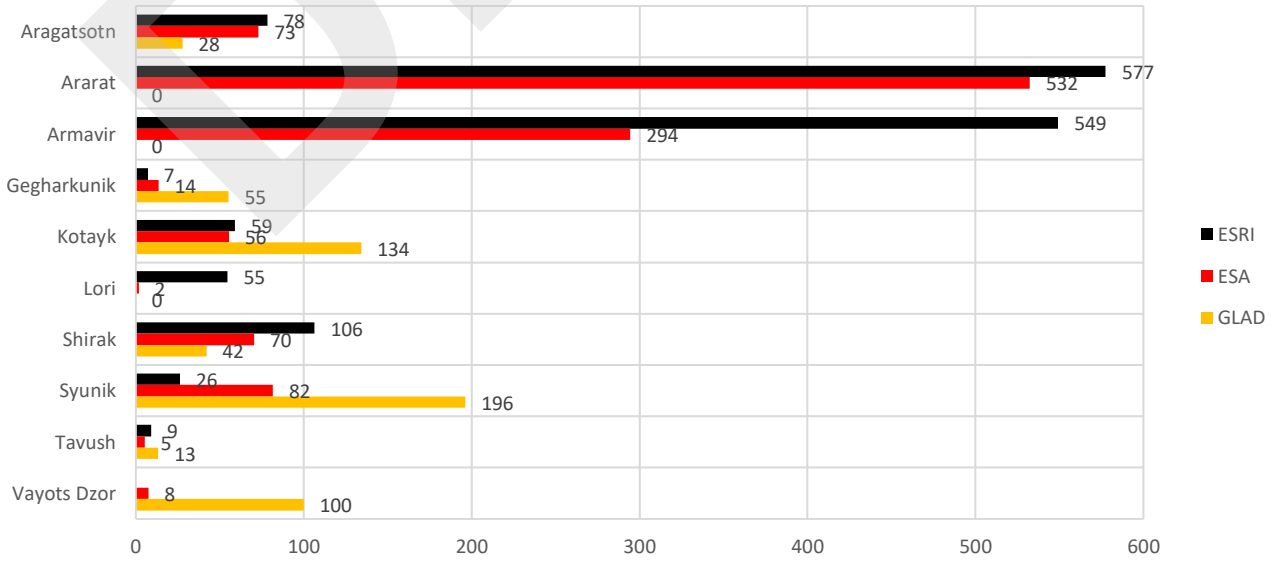


Figure 21B-3. The share (%) of uncultivated arable land that is classified as cropland by the land cover datasets

Similar to the comparisons with Government-reported data (Section 2.1.A), a preliminary overall indicator for assessing land cover data accuracy can be the total discrepancy between cropland areas in datasets and ARMSTAT data which is the sum of absolute area discrepancies (by modulus, regardless of sign) across marzes (Figure 21B-4). Overall, ESRI, ESA, and GLAD datasets show a similar total discrepancy from the ARMSTAT data, DW shows a substantial overestimation of cropland area.

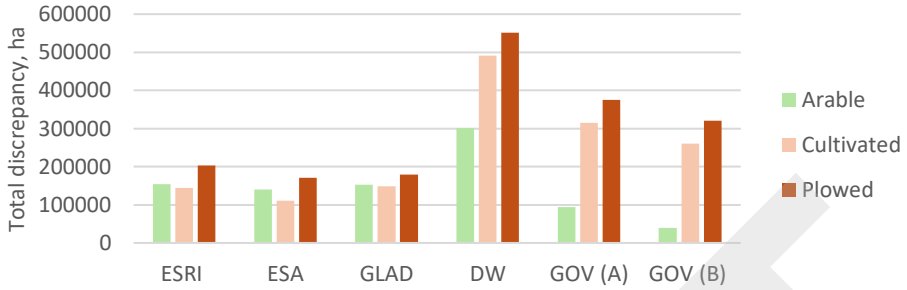


Figure 21B-4. Total discrepancy between cropland areas in datasets and ARMSTAT

2.1.C. Selection of land cover dataset for use in the project

The ESRI land cover dataset was selected as the basis for the project implementation. The ESA and GLAD datasets can be additionally used for specific methodological tasks. The choice was made based on the following reasons:

- GLC_FCS30D land cover data shows very strong excess of cropland area and excess of forest area and was therefore excluded.

- Dynamic World dataset shows good agreement with the Government-reported data in indicator of total area discrepancy. However, it significantly overestimates cropland area compared to ARMSTAT data and shows strong excess of cropland area in the mountains. Therefore, it was excluded.

- ESA, ESRI and GLAD are similar in identified areas of of the generalized land cover classes and are most consistent with ARMSTAT data on cropland area.

- ESRI data provide the best opportunity for demonstrating the accounting of ecosystem indicator dynamics from 2017 and 2023.