Mon-21-054

Input data sources for environmental models (case study - Ukrainian transboundary watersheds)

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SUMMARY

River basin management should consider an entire basin due to the continuity of the water cycle. In Ukraine, eight of nine large river basins are transboundary with influential upstream parts in Belarus, Russian Federation, and Moldova. This paper aims to evaluate local (country-scale) and global geospatial and climate data for environmental modeling within the Ukrainian basins, including the Dnipro, Don, and Dniester upstream parts. Input data list is based on SWAT and MONERIS models and included: topography, river network, land cover, soils, meteorological parameters, water discharges, hydrochemical observations, and atmospheric disposition. Based on literature review and our expertise, we recommend datasets for meso- and large-scale modeling: SRTM or ALOS DEMs, river network from the State cadastre merged with OpenStreetMap waterways, Esri land cover, local soil maps, and local weather observational archives. Measured precipitation should be corrected on wind-induced undercatch. Climate reanalysis ERA5 and ERA5-Land could be used as alternatives to meteorological data. Despite the most relevant input data being proposed, the problems with data completeness still exist for soils, groundwater aquifers, and meteorological and hydrochemical observations.

Introduction

River basin management requires data on transboundary basin areas, especially upstream ones (Strokal, 2021). In Ukraine, eight of nine river basins are transboundary, the largest ones are the Dnipro basin located in Belarus (23.1%) and Russian Federation (RF) (19.8%), Don basin (Siverskyi Donets subbasin) - in RF (30.2%), Dniester basin - in Moldova (25.5%). These basins cover 66.4% of Ukraine's area with 73% population of the country (http://geoportal.davr.gov.ua:81/).

Available study omits evaluation of local (country-scale) sources and the latest global land cover and climate reanalysis datasets (Rouholahnejad et al., 2014). To select the input data and ensure better modeling quality, the data representativity and compatibility should be assessed for different scales.

This study aimed (1) to summarize local and global data sources for environmental modeling within the Ukrainian basins, including transboundary upstream parts of the Dnipro, Siverskyi Donets, and Dniester basins and (2) evaluate geospatial and climate datasets. As an input data list, we took the process-based SWAT and conceptual MONERIS models (Arnold et al., 2012, Behrendt et al., 2007).

Methods

Reference land cover map (2019, 10 m) was created by an artificial neural network with a back-propagation learning method using time-series satellite images and sample set collected in the Sula river catchment (18207 km^2, Middle Dnipro Subbasin). Training and validation sets were divided 50/50%. Validation loss was 5.71%.

Long-term annual temperature and precipitation were compared between meteorological station data (187 stations, 1980-2019, at least 20-year track for station), E-obs (ver. 23.1), ERA5, and ERA5-Land. Measured precipitation was corrected on wind-induced undercatch (Bogdanova et al., 2002). The nearest to station grid cells of ERA5, ERA5-Land, and E-obs were used. We have not assessed daily dynamics and mountainous regions because E-obs and ERA5 represent area-mean, not point values like meteorological stations.

Results and Discussion

Table 1 summarizes data available for the Ukrainian authorities, including local sources in Belarus and RF.

Coarse DEMs (200-500 m grid) may satisfy runoff, sediment, and nutrients modeling in plain basins with low mean annual precipitation (< 800 mm/yr) (Chaplot, 2014). Fine DEMs (20-30 m) benefit in wet regions (> 1200 mm/yr) like the Carpathians. ALOS and SRTM DEMs outperformed ASTER DEM on SWAT streamflow simulations (Tan et al., 2018).

River networks from the State water cadastre of Ukraine and OpenStreetMap (OSM) most closely reflect the actual stream geometry, unlike DEM-based products (HydroSHEDS, Ecrins) that could miss head, outlet, and river pass. Osypov et al. (2018) used OSM in the SWAT Desna basin model after editing breaks, "circular" formations, and bifurcations. Rouholahnejad et al. (2014) corrected Ecrins to achieve a right flow direction in the SWAT Black Sea catchment model.

***Table 1** The sources of input data for hydrological and water quality models**

Input data	Local (L) and global (G) data sources	Resolution
Topography	G: ● SRTM DEM, https://earthexplorer.usgs.gov/ ● ALOS PALSAR DEM, https://search.asf.alaska.edu/#/ ● ASTER DEM, https://earthexplorer.usgs.gov/	30 or 90 m 12.5 m 30 m
River network	L: ● State water cadastre, http://geoportal.davr.gov.ua:81/ G: ● OpenStreetMap, https://download.geofabrik.de/europe/ukraine.html ● HydroSHEDS, https://www.hydrosheds.org/ ● European catchments and Rivers network system (Ecrins), https://www.eea.europa.eu/data-and-maps/data/european-catchments-and-rivers-network	 15 arc-sec 3 arc-sec

Input data	Local (L) and global (G) data sources	Resolution
Land cover	G: ● Esri Land Cover (2020), https://www.arcgis.com/apps/instant/media/index.html?appid=fc92d38533d440078f17678ebc20e8e2 ● GlobeLand30 (2000, 2010, 2020), http://www.globallandcover.com/ ● Copernicus Global Land Service (Proba-v) (2015-2019), https://land.copernicus.eu/global/products/lc ● GlobCover European Space Agency (2004-2006, 2009), http://due.esrin.esa.int/page_globcover.php ● MODIS land cover (2001-2019), https://modis-land.gsfc.nasa.gov/	10 m 30 m 100m 300 m 500 m
Soil map and properties for genetic horizons: - sand/silt/clay fractions, - horizons depth, - bulk density, - organic carbon, - available water capacity, - phosphorus and nitrogen content, - filtration coefficient, - soil erosion	L: ● Soil map of Ukraine (198 soil classes) (Krupskyi, 1977) ● Soil map of Ukraine (78 soil classes) (Krupskyi, 1972a) ● Soil map of Ukraine (40 soil classes) (Krupskyi, 1972b) ● Soil atlas of RF (29 soil classes), https://soil-db.ru/soilatlas/ ● Unified State Register of Soil resources of Russia, http://egrpr.esoil.ru/ ● Soil map of Belarus (24 soil classes), (National Atlas of Belarus, 2002) ○ Ukrainian soil properties database (Laktionova et al., 2012) ● Map of content of mobile phosphorus compounds in Ukrainian soils (Medvedev and Khrystenko, 2007) ● Soil filtration map of Ukraine (Soil melioration zoning, 1978) ● Average annual washout of the fertile soil horizon (Shvebs et al., 2003) G: ● Harmonized World Soil database (HWSD) (43 soil classes in Ukraine, 15 in Belarus, 20 in RF, 13 in Moldova) http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/ ● FAO Soil Map of the World (21 soil classes in Ukraine, 5 in Belaurs, 8 in RF, 8 in Moldova), http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/ ● Soil Erosion map, https://esdac.jrc.ec.europa.eu/content/global-soil-erosion	1:2500000 1:750000 1:200000 1:2500000 1: 8000000 1:4000000 admin. rayon 1:5000000 1:5000000 25000 m
Meteorological parameters: - mean/min/max air temperature, - precipitation, - wind speed, - relative humidity, - snow cover, - solar radiation	L: ◐ Central Geophysical Observatory named after Boris Sreznevsky (CGO), (digital 1976-present, paper archive 1881-present), http://cgo-sreznevskyi.kyiv.ua/ ○ Belhydromet, https://belgidromet.by/ G: ● E-OBS (1950-present), https://www.ecad.eu/download/ensembles/download.php ● European Climate Assessment & Dataset (ECAD) (1881-present), https://www.ecad.eu/dailydata/index.php ● National Climate Data Center (1881-present) (NCDC), http://www.ncdc.noaa.gov/ ● Climate Research Unit reanalysis (CRU) (1900-present), http://www.cru.uea.ac.uk/ ● Climate reanalysis ERA5 (1950-present), ERA5-Land (1981-present), https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5	subdaily, 187[1, 2] subdaily, 44[1] daily, 0.1° grid[5] daily, 87[1, 3, 5] daily, 220[1, 4, 5] monthly, 0.5° grid hourly, 0.25°/0.1° grid
Water discharge	L: ◐ CGO, http://cgo-sreznevskyi.kyiv.ua/ ○ Belhydromet, https://belgidromet.by/ G: ● The Global Data Runoff Center, https://www.bafg.de/GRDC/	daily, 83[6] daily, 16[6] daily/monthly, 1[6]
Hydrochemical observations	L: ◐ CGO, http://cgo-sreznevskyi.kyiv.ua/	4-12 samples per year, 208[6]
Groundwater aquifer type and retention time	L: ● Engineering geological map (1978) ● Hydrogeological map (1978) ● Map of underground waters (Slyva and Shestopalov, 2007) G: ● International hydrogeological map of Europe (IHME1500), https://data.europa.eu/data/datasets/5f7a4364-6943-48e2-ba0e-da67e26a8e3a?locale=en	1:4000000 1:2500000 1:2500000 1:1500000
Atmospheric deposition	L: ◐ Precipitation chemical composition, CGO, http://cgo-sreznevskyi.kyiv.ua/ G: ● EMEP Centre on Emission Inventories and Projections, https://www.ceip.at	31[1] annual, 0.1° grid

Data access: ● - open source, ◐ - request from official authority, ○ - paid

* The following parameters are omitted in the table because of lack of space: point sources (https://www.davr.gov.ua/), agriculture and population (http://www.ukrstat.gov.ua/, https://www.belstat.gov.by/, https://rosstat.gov.ru/).

[1] Number of meteorological stations with, at least, 20-years track during 1980-2020.

[2] Solar radiation is measured only at 13 meteorological stations out of 187.

[3] 44 and 25 in Ukraine, 29 and 4 in Belarus, 13 and 12 in RF, 1 and 1 in Moldova for precipitation and min/max air temperature, respectively, within Ukrainian basins (except Danube river basin).

[4] 168 and 31 in Ukraine, 35 and 15 in Belarus, 16 and 13 in RF, 1 and 1 in Moldova for precipitation and min/max air temperature, respectively, within Ukrainian basins (except Danube river basin). Data include 1-3-day gaps.

[5] E-obs, ECAD, and NCDC include only mean/min/max temperature and precipitation data.

[6] Number of gauges with catchment area more than 2000 km^2 with, at least, 20-years track during 1980-2020.

Esri land cover most closely agrees with the reference map - the difference for all classes is less than 2.5% (Table 2). Proba-v land cover overestimates flooded vegetation misclassifying crops and trees in shadow and irrigated areas. MODIS and GlobCover land covers miss small objects because of low resolution placing them into dominant class 'Crops'.

***Table 2** Comparison of land cover products for the Sula river catchment*

Land cover source	Crops	Trees	Shrub	Grass	Flooded vegetation	Built Area	Bare ground	Water
Reference (2019), 10 m	72.06	16.41	4.13	2.99	0.19	3.62	0.01	0.58
Esri (2020), 10 m	73.42	13.87	4.58	3.37	0.31	3.85	0.02	0.58
GlobeLand30 (2020), 30 m	75.66	7.34	9.58	1.18	0	5.73	0	0.49
Proba-v[1] (2019), 100 m	64.78	14.31	1.02	15.36	2.18	2.21	0	0.15
GlobCover (2009), 300 m	89.90	9.14	0.21	0	0.02	0.17	0.34	0.22
MODIS (2019), 500 m	84.20	7.79	5.00	2.52	0.10	0.38	0	0.01

[1] Different classification scheme for medium and low vegetation.

For the soil map, Chaplot (2014) recommended fine resolution (~ Scale 1:25000) for high-wet areas (>1200 mm/yr) and coarser resolution (~1:250000) for low-wet areas (<800 mm/yr).

Climate reanalysis ERA5 (ERA5-Land) overestimates long-term (1980-2019) annual temperature by 0.16°C (0.09°C), 0.01°C (0.05°C), 0.14°C (0.21°C), and 0.26°C (0.44°C) as well as precipitation by 16%, 12%, 8%, and 2% for mixed forests, broad-leaf forests, forest-steppe, and steppe zones, respectively. However, the precipitation bias is 1.5-2 times lower for the period 2000-2019. E-obs also overestimates temperature by 0.13°C, 0.2°C, 0.2°C, and 0.15°C but underestimates precipitation by 7%, 9%, 11%, and 20% for mixed forests, broad-leaf forests, forest-steppe, and steppe zones, respectively. In the Carpathians, Bandhauer et al. (2021) has found that ERA5 and E-obs precipitation datasets are on a par in regions with sparse data, and partly ERA5 has a better resolution of mesoscale patterns (mean, wet-day frequency, 95% quantile) and more accurate day-to-day variations.

Conclusions

We recommend the following datasets for meso- and large-scale modeling of Ukrainian watersheds:

- *Topography*: SRTM or ALOS DEMs. To process large DEM, original products could be resampled to 200-500 m mesh for low-wet basins (mean annual precipitation < 800 mm/yr).
- *River network*: Ukrainian water cadastre merged with the OSM of neighboring countries.
- *Land cover*: Esri land cover map.
- *Soils*: Merged Ukrainian (Scale 1:200000), Belarus, and RF soil maps (1:12500000 or finer if available) parametrized by Ukrainian and Russian databases as well as thematic literature.
- *Soils (alternatively)*: HWSD for Moldova or if open source is required.
- *Climate*: Meteorological station data from CGO and Belhydromet. Measured precipitation should be corrected on wind-induced undercatch.
- *Climate (alternatively)*: reanalysis ERA5-Land in sparse station network or data unavailability.

We found that climate reanalysis ERA5 and ERA5-Land better represents mean annual precipitation across Ukraine than the gridded observational E-obs dataset. E-obs omits wind-induced precipitation correction, therefore, underestimates actual precipitation.
To sum up, problems with high data resolution still exist for soil parameters, meteorological and hydrochemical observations, and groundwater aquifer.

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