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GLOBELAND30 LULC AND GLOBAL FOREST CHANGE GEODATA MERGING FOR ENVIRONMENTAL MODELLING

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GlobeLand30 LULC and Global Forest Change geodata merging for environmental modelling

Reference land use and land cover (LULC) geodata is an important input parameter for environmental modeling in GIS. GlobeLand30 (GLC30) LULC geodata, released in 2015, has the highest spatial resolution of 30 m globally. Another important tool for Landsat-based global geodata is – Global Forest Change (GFC), which defines the tree cover state of the year 2000, including its density, tree cover loss and gain from the years 2000 to 2012, with a spatial resolution of 25 m. The methodology to produce the GFC geodata, as well as its accuracy to determine the forest class, is superior to the GLC30. In this study, an ArcGIS geoprocessing model is proposed to merge the GLC30 and GFC geodata, based on the Shuttle Radar Topography Mission Global 1 arc second (SRTMGL1) Digital Elevation Model (DEM) pixel grid, in order to control the layers of consistency (cell alignment and spatial resolution). 535 points were randomly distributed within each LULC class in the Desna River sub-basin study area, proportional to the class relative area. Quality assessment by means of Error matrix and Kappa coefficient of the merged geodata shows that overall classification accuracy increased from 70% to 77,8% (Kappa from 0,57 to 0,68) with a 23% increase in the Producer`s accuracy for the forest class. The geoprocessing model with the test data sample are available at https://github.com/dmy3tka/GIScience. The approaches taken in this study could be used to improve quality of the input geodata for distributed environmental and hydrological models, especially when dealing with corresponding geodata from multiple sources.

Key words: GlobeLand30, Global Forest Change, geoprocessing model, merging, Desna river sub-basin

INTRODUCTION

Released in 2015, GlobeLand30 LULC geodata has the highest spatial resolution of 30 m globally. Due to the limitations of remote sensing technology, most of the global coverage LULC datasets exist at coarser resolutions, e.g. 300 m or more. GlobeLand30`s features of being reference, global, freely available, and easy to use by non-remote sensing specialists are useful. Accurate land cover geodata is utilised for a range of applications such as observation of land cover change detection, environmental monitoring and modelling of environmental changes including vegetation phenology, observation of agricultural drought, fire occurrence, greenhouse gas emissions due to deforestation and forest degradation. The type of land cover also determines the behaviour of precipitation on Earth. This includes the infiltration rate, runoff, evapotranspiration of water (UN-SPIDER 2014) and is used as input in the distributed hydrological models and flood risk analysis.

In GIScience, quality control (QC) of the geodata is used to contain, evaluate, adjust and resolve any defects found in order to enhance the accuracy of the geodata (Soran and Halldora 2013). However, QC of an already classified (derivative) land cover can support a decision on whether or not its quality is sufficient for research purposes. As a new, object-oriented classification of datasets (wetlands, forests, tree species, etc.) arises, techniques such as integration/combination and merging/fusion (Savopol and Armenakis 2002) can be used to improve the overall quality, accuracy, resolution or relevance of the output GlobeLand30 geodata.

Recently published research has addressed: accuracy assessment at the national level of GLC30 (Brovelli et al. 2015, Hussein et al. 2015 and Bo and Qimming 2016) and GFC (Hansen et al. 2013a, Bellot et al. 2014 and Tropek et al. 2014), nationwide Landsat-derived LULC datasets (Kussul et al. 2015) and elaboration of the LULC inventory in Thailand by the GFC (Johnson 2015). The aim of this article is to provide an ArcGIS geoprocessing model that improves GlobeLand30 land cover quality by merging it with the Global Forest Change 2014 geodata. We believe that the provided original approaches would be beneficial for both non-GIS and GIS-specialists in post-processing of geodata from different sources in order to improve its accuracy and relevance for the majority of the aforementioned applications. The proposed geoprocessing model works where all of the input data sources are cross-covered.

STUDY AREA

The Desna River sub-basin, which flows into one of Europe's largest rivers, the Dnipro, was selected as the study area. The Desna River is the largest left tributary of the Dnipro River, with a length of 1126 km and an elevation difference between the river source and outlet of 146 m. Its sub-basin area is 88 824 km^2 with an altitude range from 87 to 289 m a.s.l. (Fig. 1). Because the river basin is a transboundary between Ukraine (46% of total area) and Russia, it lacks up-to-date state information, thus satellite imagery is a valuable tool to study such areas. Unevenly distributed cropland type covers the majority of the sub-basin area and is usually mixed with other land types, such as forest, grassland. Forest cover type is mainly distributed in the northern part (mixed broadleaf coniferous forests; boreal biogeographical region (Biogeographic Regions in Europe 2016) and along the left bank of the Desna River.

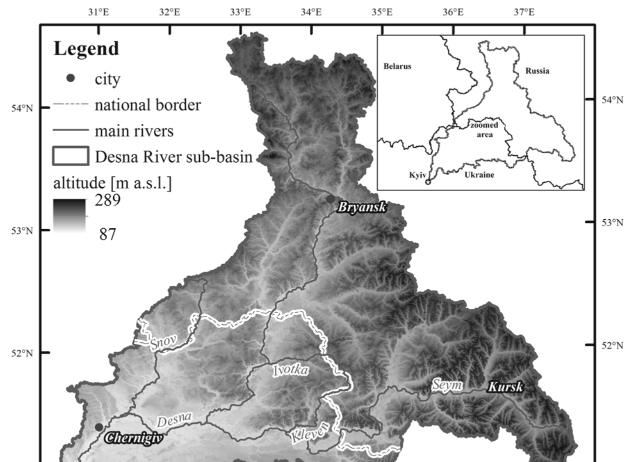

Fig. 1. The study area of the Desna River sub-basin

DATA SOURCES

To run the geoprocessing model, three freely available, and near-global coverage reference raster geodata are used (Tab. 1): GLC30, GFC, SRTMGL1, as well as a vector layer to clip the outputs. The Desna River sub-basin vector layer is delineated automatically in the feature extraction ArcHydro workflow, based on the SRTM HydroSHEDS hydrologically conditioned elevation.

Tab. 1. Properties of the geodata that were used in the model

Geodata	Satellites	Object state year/ availability year	Spatial Resolution, meters (in UTM_36N)	Raster classification
GlobeLand30 (GLC30)	Landsat, Chinese HJ -1	2000 and 2010/2014	30	10 - cultivated land; 20 – forest; 30 – grassland; 40 – shrubland; 50 – wetland; 60 - water bodies; 70 – tundra; 80 - artificial surfaces; 90 - bare land; 100 - snow and ice
Global Forest Change (GFC)	Landsat, MODIS, QuickBird	2000-2012 (2015)/2014	25.03	tree cover 0-100%; forest loss 0.1; forest gain 0.1
SRTMGL1	Endeavour	2000/2015	25.05	altitude, m
Model LULC	-	2000-2012/2016	25	21 – cultivated land; 22 – grassland; 23 – shrubland; 24 – wetland; 25 – water bodies; 26 – tundra; 27 – artificial surfaces; 28 – bare land; 29 – snow and ice; 30…100 - forest cover %

The first product, the GlobeLand30, became available for download in 2014 (Chen et al. 2015). It represents a LULC for the years 2000 and 2010. The main advantage of the GlobeLand30 data is its 30 m spatial resolution. However, because of its global coverage and training samples, the classification types are too general and stated overall accuracy is about 80%. The lowest classification accuracy is for grassland because it is difficult to separate grassland from some of the spring crops in the cultivated land class. The forest class is defined with a lower spatial variability than in the supervised learning algorithm of the GFC.

The Global Forest Change dataset became available in February 2014 and it is the first medium- to high-resolution downloadable data product detailing global forest extent, loss, and gain from the years 2000 – 2012 (loss to 2015). The definition of 'tree cover' is vague when it comes to the attributes that can be retrieved by current satellite technologies and relevance to the application aims. Therefore, it still should be clearly defined. For this classification, all vegetation taller than 5 m in height are considered trees (Lui and Coomes 2015). The GFC dataset consists of an integer raster (0 – 100) corresponding to the tree density values for the year 2000. Two binary rasters (0,1) with loss – a stand-replacement disturbance, or a change from a forest to non-forest state within the pixel (Hansen et al. 2013a), gained information during the years 2000 – 2012. In this tree density raster, we determined forest above 30% of the tree density threshold (Hlotka 2013) as the forest class based on the Kyoto Protocol, as well as be in line with the GlobeLand30 forest class definition.

Tab. 2. Definitions of the LULC types of GlobeLand30 (Liang et al. 2015)

Type	Definition
Cultivate land	Lands used for agriculture, horticulture and gardens, including paddy fields, irrigated and dry farmlands, vegetation and fruit gardens.
Forest	Lands with trees, with vegetation cover over 30%, including deciduous and coniferous forests, and sparse woodlands with cover from 10% to 30%, etc.
Grassland	Lands covered by natural grass with cover over 10%, etc.
Shrubland	Land with shrubs cover over 30%, including deciduous and evergreen shrubs and deserts steppe with cover over 10%, etc.
Wetland	Lands covered with wetlands plants and water bodies, including inland marsh, lake marsh, river floodplain wetland, forest/shrub wetland, peat bogs, mangrove and salt marsh, etc.
Water bodies	Water bodies in the land area, including rivers, lakes, reservoirs and fish ponds, etc.
Tundra	Lands covered by lichen, moss, hardy perennial herbs and shrubs in the polar regions, including shrub tundra, herbaceous tundra, wet tundra and barren tundra, etc.
Artificial surfaces	Lands modified by human activities, including the various habitation, industrial and mining area, transportation facilities, and interior urban green zones and water bodies, etc.
Bare land	Lands with vegetation cover lower than 10%, including desert, sandy fields, gobi, bare rocks, saline and alkaline lands, etc.
Permanent snow and ice	Lands covered by permanent snow, glacier and icecap.

In 2015, SRTMGL1 (NASA JPL 2013) Digital Elevation Model (DEM) became available for free download. This raster serves as a snapping grid to control the abovementioned raster's consistency, i.e., cell alignment and spatial resolution. Meanwhile, another benefit of this approach is that the resolution of the model base grid is in accordance with the DEM resolution, e.g., in MODFLOW and ArcSWAT models it is necessary to set the model grid first. More precisely, for all of the computational purposes, SRTM DEM should also be preprocessed to remove the tree cover height offset. However, this is beyond the scope of this article and there is still no adopted and reproducible methodology to obtain the Digital Terrain Model (DTM) from this DEM (Gallant et al. 2012).

METHODS

Obtaining the forest state of 2012 year (Fig. 2. step 1).

To obtain the forest cover raster for the year 2012, we reclassify binary loss and gain rasters to the values of 1 and 50 respectively. In the Mosaic raster with Sum operator, the overlapping pixels (value "51") are set as NoData. Due to the GFC Technical Documentation (Hansen et al. 2013b), in such areas during the years 2000 – 2012, both forest loss and gain was detected. Thus, these NoData pixels will not change the tree cover in the year 2000 raster. Next, we mosaic the tree cover from the year 2000 with the loss and gain from the year 2012 raster. Furthermore, the values below 30% cover are set as NoData. Finally, we use the Project Raster tool to project, resample and snap the forest cover from the year 2012 raster to the SRTMGL1 25 m resolution (Fig 2. step 4.).

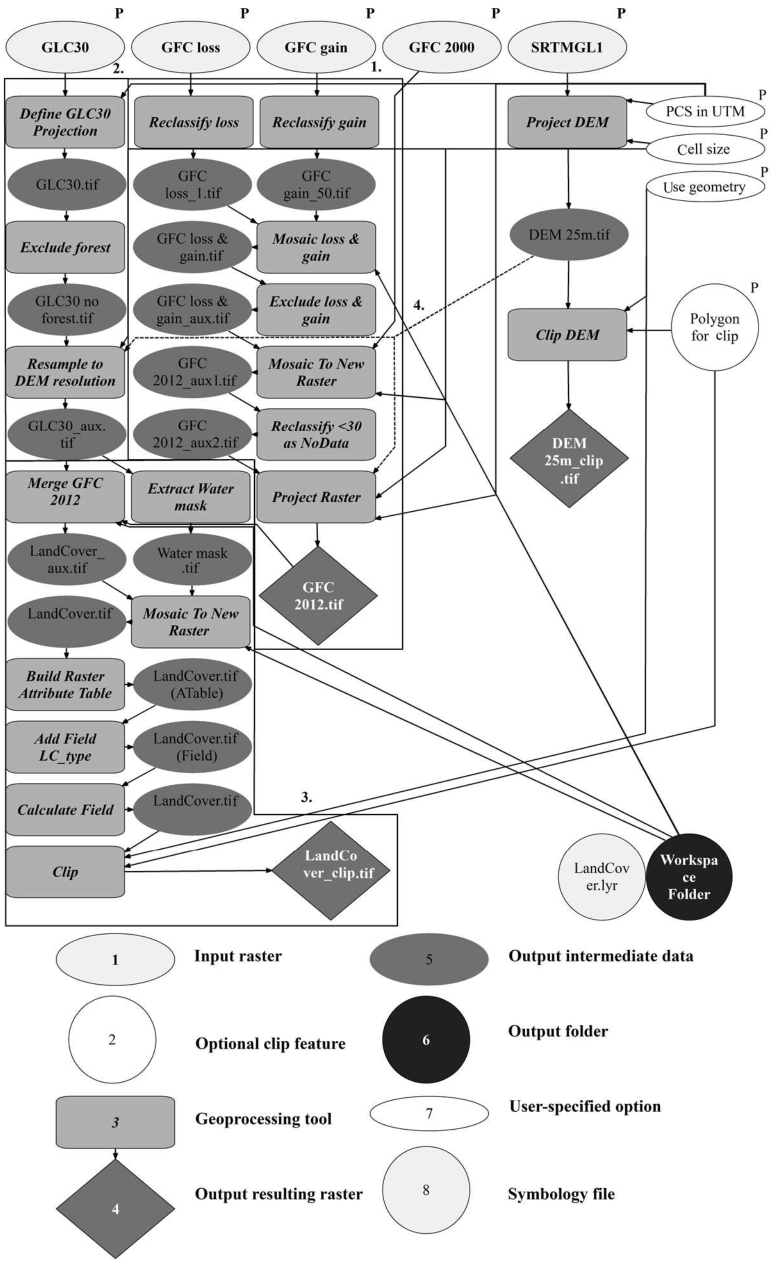

Fig. 2. Geoprocessing Model

Preparing the GlobLand30 data for merging (Fig. 2. step 2.).

The GlobeLand30 raster is preprocessed by the Reclassification tool to 20 – 29 values and excludes the forest value (21), placing it into the grassland class. This is necessary in order to eliminate the NoData gaps that will not be filled by the GFC.

To fill the gaps, we also tested the Focal Filter with the Majority setting. However, it did not give a better overall result, i.e. individual water pixels in the forests. Next, we used the nearest neighbour Resampling to the SRTMGL1 25 m resolution.

Obtaining the modelled LULC layer (Fig. 2. step 3.).

The GLC30 water class mask is extracted in order to be placed back after the Mosaic (by the Last operator) with the tree cover from the year 2012. Then we add an attribute table to the raster and use the Python dictionary data type in which we link the LandCover values to the LULC class names. Finally, the clipping option for DEM and LULC is available in order to obtain the resulting layer for this case study.

For quality assessment of the LandCover_clip.tif (merged resulting raster), ArcMap 10.5 with a Spatial Analyst extension is used. The tools, 'Create Accuracy Assessment Points' with stratified-random strategy and 'Compute Confusion Matrix' from the 'Segmentation and Classification' toolset, are utilized. The assigned ground truth LULC type was based on high resolution Google Earth and Bing imagery.

RESULTS

To run the model, the user should specify the inputs for the SRTMGL1, GLC30, GFC tree cover from the year 2000, GFC loss and gain, and an output folder for the resulting rasters (Fig.3).

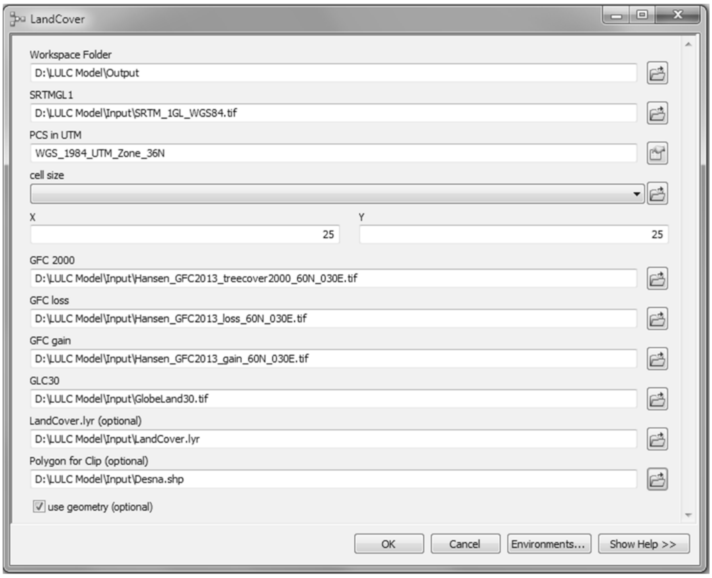

Fig. 3. User-specified input window

For accuracy assessment, 535 points were randomly distributed within each LULC type, proportional to the class relative area (Fig. 4). For each point, we assigned the ground truth LULC type based on high resolution Google Earth and

Bing imagery. Next, Error Matrix with User's accuracy (UA) and Producer's accuracy (PA) for each type, as well as an overall Kappa coefficient of agreement, were computed in order to quantify classification accuracy of both the GlobeLand30 and the merged GlobeLand30 with Global Forest Change geodata.

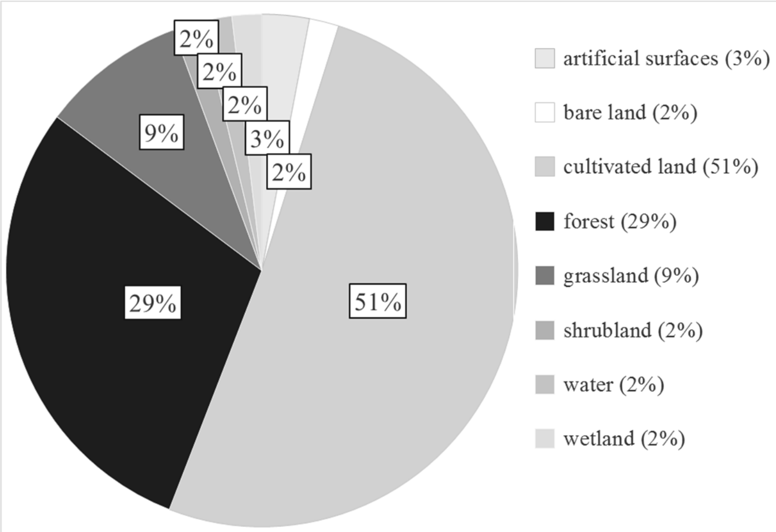

Fig. 4. Proportions of stratified-random samples by LULC type

Results show that for the GlobeLand30 LULC, overall accuracy is 70% with Kappa coefficient of 0.57 in the study area (Tab. 3). The majority of misclassification comes from shrubland and bare classes. As for specific land cover types, bare land illustrates high UA but low PA. At the same time, more than a half of the samples corresponding to shrubland and grassland types in GobeLand30 are cultivated lands by the ground truth control.

Tab. 3. Error Matrix for GlobeLand30

Classified value	Cultivated land	Grassland	Shrubland	Wetland	Water bodies	Artificial surfaces	Bare land	Forest	UA
Cultivated land	**202**	28	20	3	1	6	8	36	0.664
Grassland	3	**27**	3	0	2	0	5	14	0.500
Shrubland	0	3	**6**	0	0	0	1	0	0.600
Wetland	0	0	1	**10**	0	0	0	0	0.909
Water bodies	0	0	0	1	**9**	0	0	0	0.900
Artificial surfaces	2	3	2	0	0	**6**	2	1	0.375
Bare land	0	0	0	0	0	0	**8**	2	0.800
Forest	1	7	2	1	0	0	2	**107**	0.892
PA	0.971	0.397	0.176	0.667	0.750	0.500	0.308	0.669	**535**
								OA 0.701	**Kappa 0.570**

With the same set of random points, the results show that the merged GlobeLand30 with Global Forest Change has an overall accuracy of 77.8% with Kappa coefficient of 0.68 in the study area (Tab. 4). We may conclude an improvement in the PA for the forest class by 23% due to less misclassified samples than the cultivated land and grassland type.

Tab. 4. Error Matrix for the merged GlobeLand30 with GFC

Classified value	Cultiva-ted land	Grassland	Shrub-land	Wetland	Water bodies	Artificial surfaces	Bare land	Forest	UA
Cultivated land	**202**	28	18	2	0	6	7	10	0.740
Grassland	3	**32**	4	0	0	0	7	3	0.653
Shrubland	0	3	**6**	0	0	0	1	0	0.600
Wetland	0	0	1	**9**	0	0	0	0	0.900
Water bodies	0	0	0	1	**9**	0	0	0	0.900
Artificial surfaces	2	3	2	0	0	**6**	2	1	0.375
Bare land	0	0	0	0	0	0	**8**	2	0.800
Forest	1	2	3	3	3	0	1	**144**	0.917
PA	0.971	0.471	0.176	0.600	0.750	0.500	0.308	0.900	**535**
								OA 0.778	**Kappa 0.682**

The resulting 25 m spatial resolution LULC layer for the Desna River sub-basin (Fig. 5) is a valuable input for GIS-modelling. A pixel grid is aligned to the SRTMGL1 25 m DEM. The extracted GLC30 water mask can be used further to hydrologically preprocess the SRTMGL1 in order to extract a synthetic stream network.

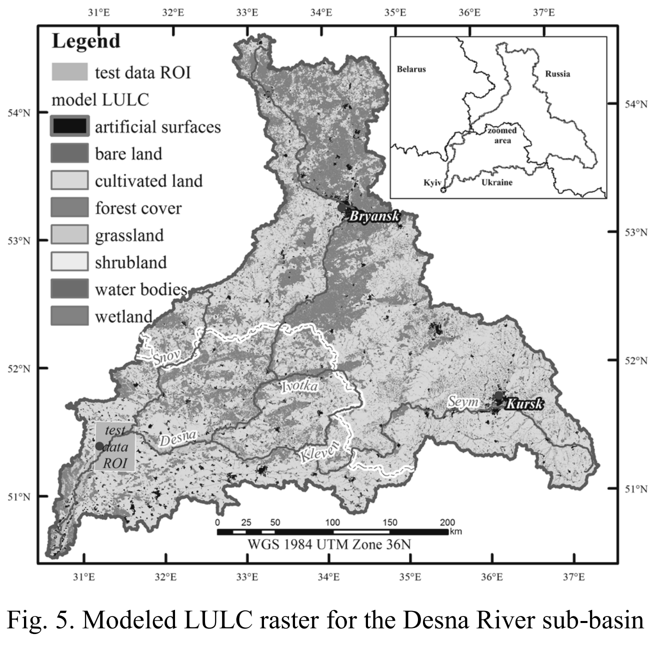

Fig. 5. Modeled LULC raster for the Desna River sub-basin

By visual comparison of the source GlobeLand30 with the modeled LULC (Fig. 6), we can see that the forest class definition has impoved, grassland is depicted and the water bodies class stays untouched. Each forest class pixel is now assigned with a forest density attribute. To demonstrate the improvement, we also attached a vectorized Open Street Map and true colour Google Earth image for Chernigiv city (51,491182° N, 31,331118° E). The test data sample, which is delivered with the model, represents the mentioned region of interest.

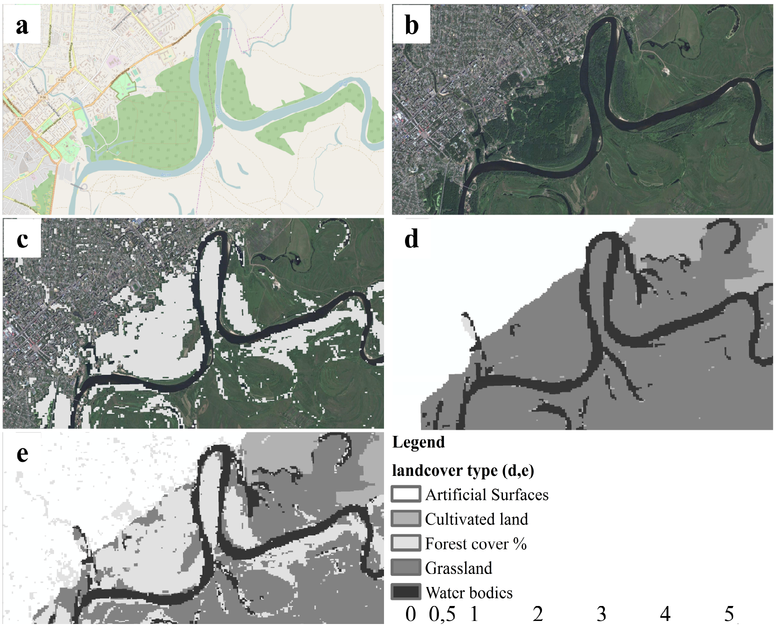

Fig. 6. Visual comparison of the various sources

a – Open Street Map, b – Google Earth imagery, c – GFC on top of the Google Earth imagery, d – GlobeLand30, e – Model LULC

DISCUSSION

In an effort to improve the quality of the forest class definition in the GlobeLand30 LULC geodata and add an attribute of the tree cover density, we designed a geoprocessing model and validated the results from 535 stratified-random samples.

Accuracy assessment of the GlobeLand30 geodata for the study area fits in among reported QC assessments: for the Central Asia – overall accuracy 46%, Kappa coefficient 0.283 (Bo et al. 2016); the case study of Shaanxi Province – overall accuracy 80.63%, Kappa coefficient 0.555 (Chen et al. 2016); Italy – overall accuracy 86.13%, Kappa coefficient – 0.78 (Brovelli et al. 2015). In addition, similar approaches of data fusion/merging using crowd-sourced geodata in creating a hybrid forest cover map (Lesiv et al. 2016) are now beginning to be published.

In the proposed model, some assumptions were made that can face amendments and criticism. GFC represents all the trees higher than 5 m tall with a cover density as low as 0 to 30%, so a national forest inventory should be made in order to exclude the trees of non-forest type (i.e. overestimation) before computing the areas. The 50% tree density value was assigned to the gained 2000 – 2012 raster, which will shift overall tree density distribution towards this value. This is mandatory since GFC tree cover gain for the years 2000 – 2012 is a binary raster, without specifying a density value. GlobeLand30 forest is reclassified to the grassland class before merging it with GFC, which may cause an overestimation of this land cover class. It is necessary to eliminate NoData gaps in the modeled LULC raster. Nevertheless, there is no overestimation of the grassland class in our study area.

In summary, the present study shows that geoprocessing of the LULC geodata, previously to its use, may improve overall quality and add relevant information to the resulting raster. In this case, this was possible because the spatial resolution of GlobeLand30, Global Forest Change and SRTMGL1 DEM rasters that are used as the model`s input, have a matching spatial resolution close to 1 arc second.

CONCLUSIONS

The Desna River sub-basin was selected as the study area to analyse classification accuracy of merged GlobeLand30 LULC and Global Forest Change geodata by the developed geoprocessing model. 535 points were randomly distributed within each LULC class, proportional to the class relative area in the Desna River sub-basin study area. Quality assessment by means of Error matrix and Kappa coefficient of the merged geodata shows that overall classification accuracy increased from 70.0% to 77.8% (Kappa from 0.57 to 0.68) with a 23% increase in Producer's accuracy of the forest class. LULC class areas can now be calculated based on the merged geodata.

With the development of Remote Sensing technologies and instruments in satellites, UAVs and aircrafts will be faced with the necessity to process: integrate, combine, fuse or merge, etc.; extensive volumes of spatial data corresponding to the different aspects of nature`s features which could be measured. New, high-resolution attribute information about the forest class will be accessible from the satellite sensors for height (TanDEM-L mission planned on 2020), biomass (originally by Simard et al. 2011) and tree species (originally by Brus et al. 2011).

Obtained results might provide helpful information for GlobeLand30 data producers to make further improvements. Tree density information may find a continuation in the adoption of empirical equations for spatial distribution of precipitation, evapotranspiration and runoff. The author shall continue to study spatial distribution of the factors that influence runoff in the Desna River sub-basin. The proposed approach is open to discussion and appropriate amendments.

When new GFC gain and loss rasters from the years 2000 to 2015 will be available, the model will be able to handle this data without any code refactoring. The geoprocessing model with the test data sample (Fig. 6) are available at https://github.com/dmy3tka/GIScience. The original idea of the geoprocessing algorithm can be further implemented in Python language or as a tool for OpenGIS.

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Dmytro Hlotka

SPÁJANIE A HARMONIZÁCIA PRIESTOROVÝCH ÚDAJOV DATABÁZ GLOBELAND30 LULC A GLOBAL FOREST CHANGE PRE ENVIRONMENTÁLNE MODELOVANIE

Objem údajov získaných satelitným snímkovaním Zeme v súčasnosti neustále rastie. Okrem priameho využitia nespracovaných satelitných snímok a z nich odvodených produktov môžu byť údaje pochádzajúce z rôznych zdrojov pomocou nástrojov na spracovanie geografických údajov vhodne zlučované/spájané alebo kombinované/integrované a môžu tak ponúkať relevantnejšie vstupné informácie využiteľné pre širokú škálu aplikácií. V tomto článku poukazujeme na možné zlepšenie kvality klasifikácie jednotlivých tried lesných porastov. Vychádzame z toho, že všetky rastrové vrstvy vstupujúce do modelu (GlobeLand30, Global Forest Change a SRTMGL1 DEM) majú približne rovnaké priestorové rozlíšenie cca 1 uhlovú sekundu (~ 30 m), čomu zodpovedajú aj kritériá definície LULC triedy lesa.

Rámec a súbor nástrojov na spracovanie geografických údajov spolu so vzorkou testovaných údajov je k dispozícii na https://github.com/dmy3tka/GIScience. Pri modelovaní boli využité tri voľne dostupné rastrové vrstvy s takmer globálnym pokrytím: GLC30, GFC, SRTMGL1 a vektorová vrstva slúžiaca na orezanie výstupov.

Prvý produkt GlobeLand30 je k dispozícii na stiahnutie od roku 2014. Ide o LULC údaje pre roky 2000 a 2010. Hlavnou výhodou vrstvy GlobeLand30 je jej 30 m priestorové rozlíšenie. Druhá vstupná vrstva Global Forest Change (GFC) je k dispozícii od februára 2014 a je prvým voľne dostupným produktom poskytujúcim údaje so stredným až vysokým rozlíšením, podrobne opisujúcim celkovú rozlohu, úbytok a nárast plôch lesa v rokoch 2000 – 2012. V prvom kroku model aktualizuje stav triedy lesa tak, aby zodpovedala roku 2012, pričom analogickú aktualizáciu bude možné urobiť v budúcnosti aj pre rok 2015, keď tieto GFC údaje budú k dispozícii. Digitálny model reliéfu SRTMGL1 DEM slúži ako podklad (zameriavacia mriežka), pomocou ktorého je zabezpečená vzájomná konzistentnosť údajov prevzatých z uvedených rastrových databáz, čiže usporiadanie buniek rastrovej mriežky (pixelov) a priestorové rozlíšenie (veľkosť buniek). Výhodou tohto prístupu je navyše aj to, že priestorové rozlíšenie je v súlade s požiadavkami niektorých štandardizovaných bežne využívaných modelov, napríklad v MODFLOW alebo ArcSWAT, pri ktorých je nastavenie modelovanej mriežky základným krokom.

V rámci záujmového územia, čiastkového povodia ukrajinskej rieky Desna, bolo náhodne distribuovaných 535 bodov, pričom body boli rozdelené v súlade s plochou, ktorú pokrývajú jednotlivé triedy LULC. Hodnotenie kvality zlúčených geodatabáz pomocou chybovej matice a Kappa koeficientu ukazuje, že celková presnosť klasifikácie v rámci triedy lesa sa zvýšila zo 70 % na 77,8 % (Kappa koeficient od 0,57 do 0,68) s nárastom presnosti z hľadiska spracovateľa (ukazovateľ Producer's accuracy) 23 %. Získané výsledky môžu byť užitočné z hľadiska zlepšenia kvality údajov GlobeLand30 a potvrdzujú využiteľnosť navrhovanej metodiky.