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A NEW DINAMIC AND FLEXIBLE MAP ACCOUNTING FOR HYDROLOGICAL LANDSCAPE CLASSES USING GOOGLE EARTH ENGINE CLOUD PLATFORM

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Abstract
Grouping the landscape in terms of hydrological similarity is very useful for understanding the processes occurring in soil and vegetation. Many hydrological modelling approaches rely on some sort of landscape classification to define and constrain parameters. Having a reasonable map of these classes, therefore, can be very useful for these purposes. In this study, we propose a Hydrological Landscape Classes (HLC) mapping tool that uses cloud computing from the Google Earth Engine (GEE) database and is adaptable to a range of usages. The map is build up on principles of landscape coevolution, and uses topography and land cover as its main drivers. The tool is publicly available through a web app.
Key-words – Hydrological Landscape Classes, Google Earth Engine.

INTRODUCTION

Landscape factors, such as climate, topography, vegetation and soil have influence on each other's long-term formation. This concept is called landscape coevolution or catchment coevolution (Troch *et al.* 2013, 2015, Sivapalan and Blöschl 2015). We can imagine the long-term physical processes of erosion and sediment deposition that are shaped by topographic gradients (slopes) and chemical processes of weathering that are shaped by water content (Lepsch 2016). As a self-organizing system, therefore, landscape features are developed in a way to efficiently fulfil hydrological processes of drainage and water storage (Savenije 2010). The partitioning and destination of incoming and outgoing water fluxes are mostly defined by soil moisture conditions, and its spatial distribution plays important roles in controlling infiltration, evapotranspiration, recharge and runoff generation (Dunne and Black 1970, Beven and Kirkby 1979, Moore *et al.* 1991, Famiglietti *et al.* 1998, Sørensen *et al.* 2006, Nobre *et al.* 2011).

Considering that many points in a region have similar soil moisture characteristics – and, by consequence, similar hydrological behavior – they can be grouped in terms of hydrological similarity (Flügel 1997, Beven 2012). Separating the landscape in units of hydrological similarity, therefore, is a very useful tool in hydrology for understanding governing processes on soil and vegetation. It allows hydrologists to simplify landscape physical representation by accounting processes in a

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lumped way, while information can be accessed in a distributed way. Hydrological modelling has been using this conceptual approach for decades for distributed applications (Beven and Kirkby 1979, Arnold *et al.* 1993, Collischonn *et al.* 2007, Savenije 2010) as a less demanding alternative to the complex and high computational cost physically-based approaches (Abbott *et al.* 1986, Kollet and Maxwell 2006).

Topography can be a valuable tool in grouping landscape features, as it greatly influences local energy and water budget, and so hydrological conditions such as groundwater flux and soil moisture are strongly controlled by it. Hydrological conditions of fluxes and accumulation controlled by topography, hence, can also be used as proxy for soil formation (Park and van de Giesen 2004, Lin and Zhou 2008, Pelletier and Rasmussen 2009, Behrens *et al.* 2010, Kopecký and Čížková 2010) and vegetation cover (Furley 1999, Kopecký and Čížková 2010, Fan 2015, Fan *et al.* 2017, Bartels *et al.* 2018).

A simplified approach on topographic controls in hydrological behavior was proposed by Savenije (2010) and applied in different catchments throughout the world (Gharari *et al.* 2011, Gao *et al.* 2016, 2018, Nijzink *et al.* 2016). In this approach, landscape is divided into (1) wetlands, (2) hillslopes and (3) plateaus by Digital Elevation Model (DEM) processing using the Height Above Nearest Drainage (HAND) (Rennó *et al.* 2008, Nobre *et al.* 2011) and local slope. The former is used to identify wetlands and the latter to separate the remaining regions according to defined thresholds (more details in the METHODS section). We can call the resulting map classification as Terrain Classes (TC).

This approach can be complemented using a Land Cover (LC) classification, and the two maps merged classes can be then called Hydrological Landscape Classes (HLCs). In this study, we present a web application to compose HLC maps and download it for any region of the world, that allows flexibility in terms of databases, parameters and scale definitions.

APPLICATION OVERVIEW

The web application can be accessed in the link: https://hlc-generator.herokuapp.com/. The repository with the documentation is in: https://github.com/rbfont/hlc-generator. It was made using Python code language, relying in the libraries “geemap” to access GEE database and “widgets” to build an interactive platform. The interface of the application can be visualized in Figures 1 and 2. The user must define: a DEM map, a HAND map and a LC map from one of the databases available; the scale at which maps will be downloaded; the extent limits of the region of interest; some parameters to compute the maps (more details ahead). Three maps are generated and available to download (Figure 2): a map of Terrain Classes (TC), computed with slope and HAND; a map of Land cover Classes (LC), computed by simplifying LC classifications; and a HLC map, computed with the two previous maps overlayed. The databases available for map computations, alongside with their description, are presented in Table 1. More details on map computations will be covered next.

Figure 1 – HLC web app view: Selection of map atributes, extent of region of interest and map computation parameters.

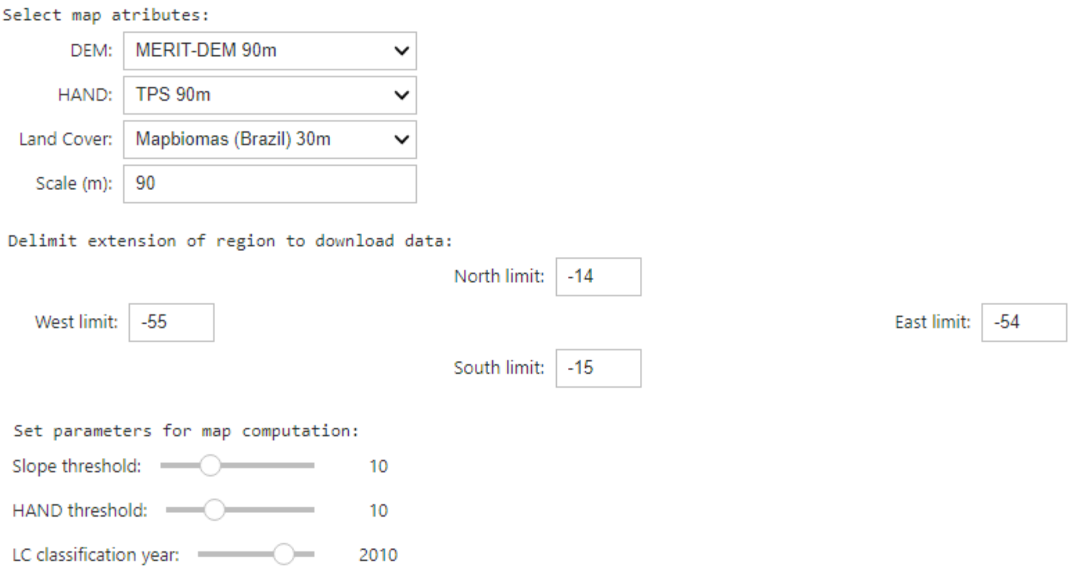


Figure 2 – TC, LC and HLC map visualization through the web app platform.

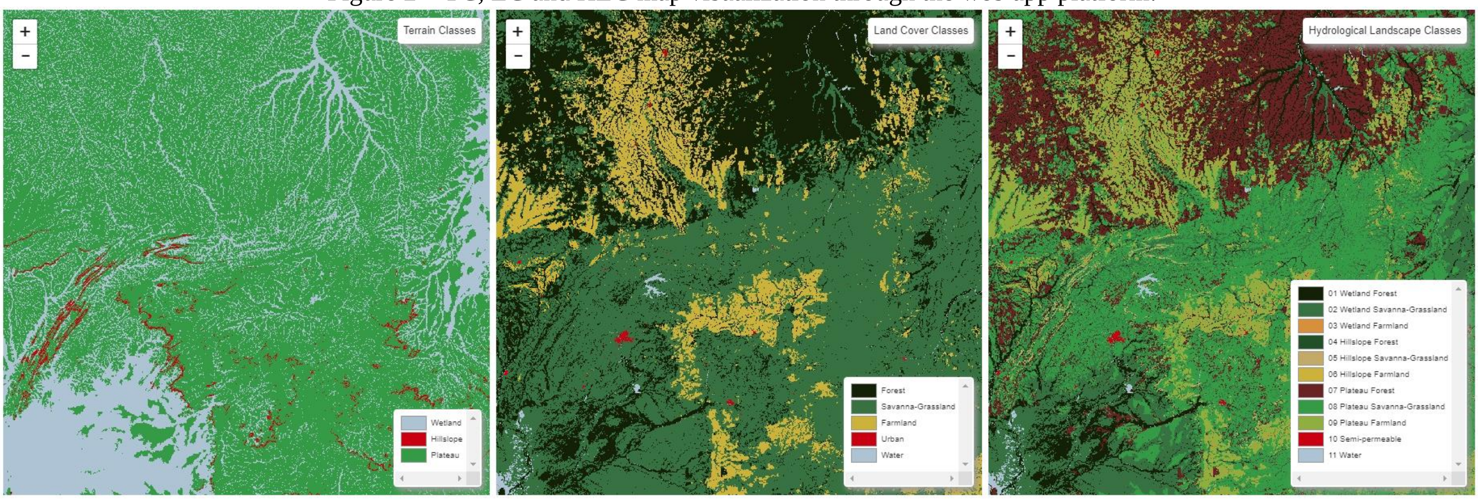


Table 1 – Databases available to compute HLC map.

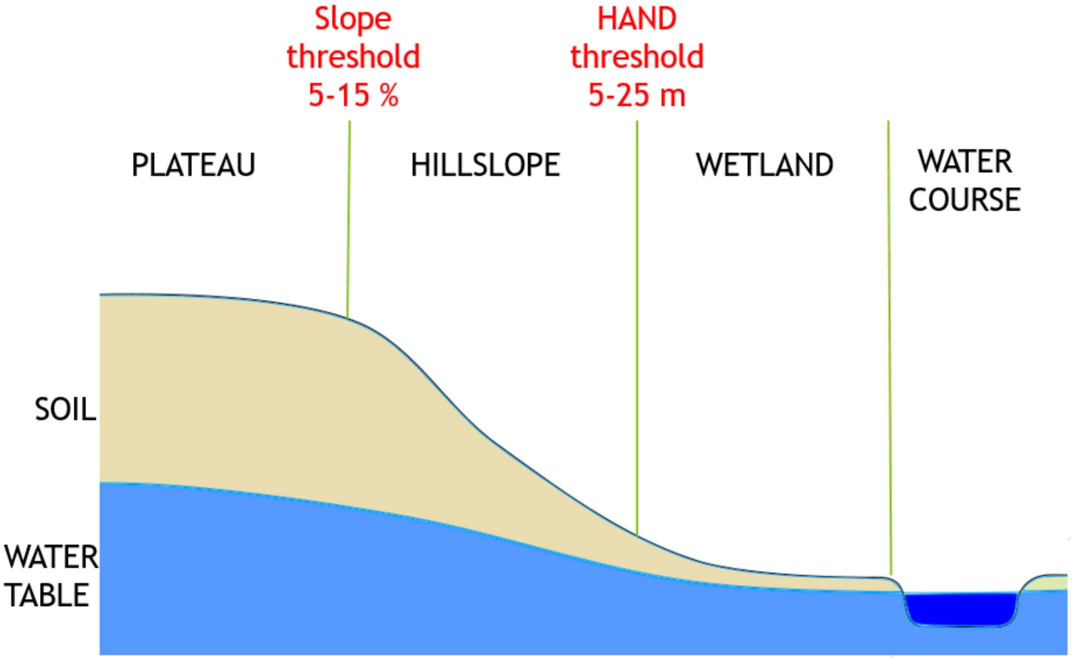
	Description	Resolution (m)	Coverage	For more information, consut:
Digital Elevation Model (DEM)				
MERIT	Multi-Error-Removed Improved-Terrain DEM; produced by eliminating major error components from existing DEMs (NASA SRTM3 DEM, JAXA AW3D DEM, Viewfinder Panoramas DEM)	90	World	http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_DEM/
SRTM v4	Shuttle Radar Topography Mission; international research effort that obtained digital elevation models on a near-global scale.	90	World	https://srtm.csi.cgiar.org/
SRTM v3		30	World	https://www2.jpl.nasa.gov/srtm/
NASADEM	Reprocessing of STRM data, with improved accuracy by incorporating auxiliary data from ASTER GDEM, ICESat GLAS, and PRISM datasets	30	World	https://lpdaac.usgs.gov/products/nasadem_hgtv001/
Height Above Nearest Drainage (HAND)				
TPS	Topographic Position based Stream defintition (TPS); uses the pixel's topographic position as a condition to define stream-heads; built on MERIT-DEM	90	South America	https://github.com/rbfont/TPS
FA = 8 km²	Pixels with Flow Accumulation (FA) greater than 8 km²; built on SRTM v4	90	World	-
FA = 5 km²	Pixels with Flow Accumulation (FA) greater than 5 km²; built on SRTM v3	30	World	-
FA = 1 km²	Pixels with Flow Accumulation (FA) greater than 1 km²; built on SRTM v3	30	World	-
Land Cover				
MapBiomas	Brazilian Annual Land Use and Land Cover Mapping Project; at yearly intervals from 1985 to 2019	30	Brazil	https://mapbiomas.org/
MODIS (several)	Moderate Resolution Imaging Spectroradiometer (MODIS) Land Cover Type (MCD12Q1); provides global land cover types at yearly intervals (2001-2019), derived from six different classification schemes	500	World	https://lpdaac.usgs.gov/products/mcd12q1v006/

MAP COMPUTATIONS

Terrain Classes (TC) map

The TC map is obtained with local slope and HAND maps (Figure 3). Local slope is used to separate the landscape into plateaus (lower values) and hillslopes (higher values) and HAND is used to identify wetlands (low HAND values). The slope can be obtained directly from the DEM. The HAND map computation requires, in addition to a DEM map, computed flow directions and a defined drainage network. In the HLC generator application, the user defines a DEM map to compute the slopes and an already computed HAND map.

Figure 3 – A simplified vision of landscape features by which TC map is computed.



Land Cover (LC) map

The LC used for the HLC map composition is a reclassification of LC classification obtained from the databases available, in order to prioritize differences in hydrological behavior. That way, the final LC classes were (1) Forest, (2) Savanna-Grassland, (3) Farmland, (4) Semi-permeable and (5) Water. All forest formations were grouped in the Forest class. Savannas, grasslands and shrublands were grouped into the Savanna-Grassland class. Pastures and croplands were grouped into the Farmland class. Non-vegetated areas were grouped into the Semi-permeable class. And, finally, water bodies of any kind (rivers, lakes, etc) were grouped into the Water class. Yet, LC maps also have a Wetland class, but they were added to the class Savanna-Grassland, because wetlands in this method would be defined by the TC map.

Hydrological Landscape Classes (HLC) map

The final HLC map is made with the two previous maps overlapped. Thus, forests in wetlands become wetland forests, in hillslopes they become hillslope forests, and so on. This happens except for the LCs Water and Semi-permeable, which do not dependent on TC.

DISCUSSION AND CONCLUSIONS

This study presented a web application to generate Hydrological Landscape Classes (HLC) using state-of-the-art geoprocessing tools and remote sensing databases. The Terrain Classes (TC) map is generated following principles of landscape coevolution and hydrological similarity, in which topography serves as a key variable to identify hydrological behavior. The Land Cover (LC) map is a general simplification of the remote sensing products' actual classification, for which we believe suits hydrological relevant processes. The final HLC map is composed using the classes of the two previous maps.

The web application generates a HLC map with user-defined parameters and can be used in any region in the world. There are, of course, some limitations. (1) Currently, maps can be generated using only two slope classes separated by one threshold, which can be a limiting factor in some cases, particularly if one wants to model erosion processes. (2) There is no user control in LC classes, only in the year of the classification. (3) The map is most suitable in Brazilian basins because of MapBiomas – the most detailed LC database available. (4) Outside of South America, the HAND maps available do not consider variable drainage density, which in some basins can be very relevant.

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