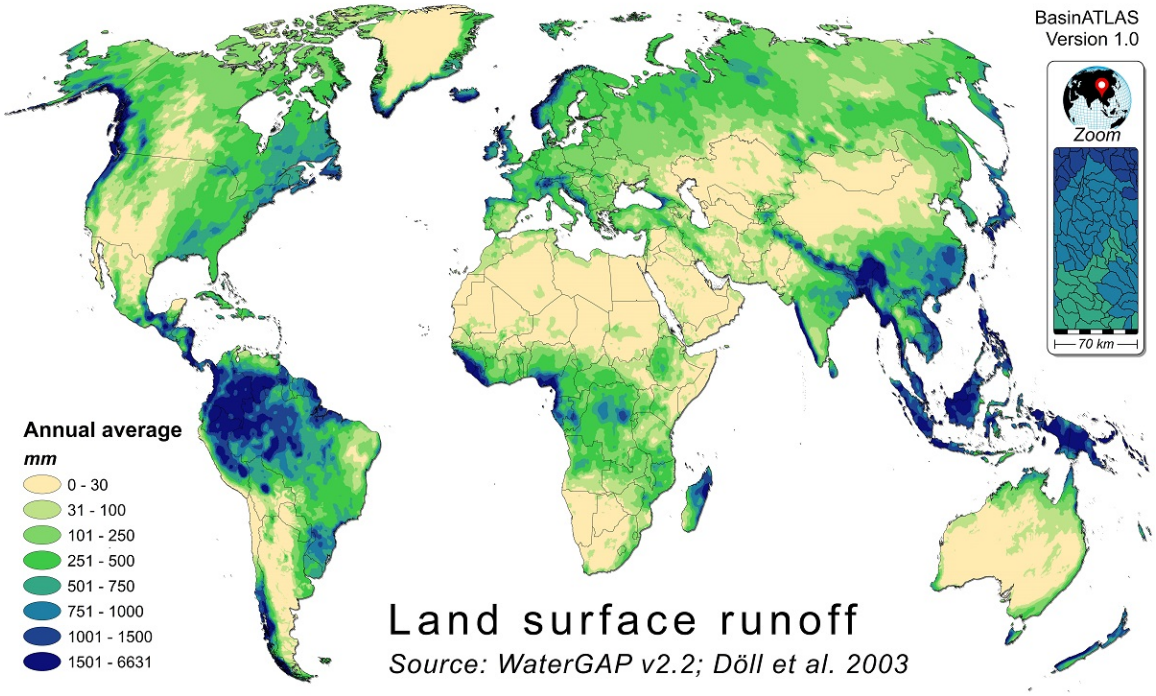
HydroATLAS

A global compendium of hydro-environmental sub-basin and river reach characteristics at 15 arc-second resolution

Technical Documentation Version 1.0

prepared by Bernhard Lehner
(bernhard.lehner@mcgill.ca)

December, 2019



1. Background and introduction

The goal of HydroATLAS is to provide a broad user community with a standardized compendium of hydro-environmental attribute information for all watersheds and rivers of the world at high spatial resolution. Version 1.0 of HydroATLAS offers data for 56 variables, partitioned into 281 individual attributes and organized in six categories: hydrology; physiography; climate; land cover & use; soils & geology; and anthropogenic influences (Table 1 and Appendix 1). HydroATLAS derives the hydro-environmental attributes by reformatting original data from well-established

global digital maps. The attributes are then linked to hierarchically nested sub-basins at multiple scales, as well as to individual river reaches, both extracted from the global HydroSHEDS database at 15 arc-second (~500 m) resolution. The sub-basin and river reach information is offered in two companion datasets: BasinATLAS and RiverATLAS. The standardized format of HydroATLAS ensures easy applicability while the inherent topological information supports basic network functionality such as identifying up- and downstream connections. HydroATLAS is fully compatible with other products of the overarching HydroSHEDS project enabling versatile hydro-ecological assessments. Updates of HydroATLAS are envisioned as new data become available.

The HydroATLAS documentation is organized in two parts: Part 1 (this document) provides an overview of the database and general explanations. Part 2 is provided in two alternative files: 'BasinATLAS_Catalog' or 'RiverATLAS_Catalog'. Each catalog file first provides a summary table listing all hydro-environmental variables and their basic characteristics. This is followed by detailed information on each individual variable, including source data descriptions, units, conversion methodology, and citations. Each variable is presented on one standardized sheet which includes a map at global extent indicating the spatial distribution of values of the respective variable. Note that the summary table and information sheets are hyperlinked within each catalog.

The development of HydroATLAS is fully described in Linke et al. (2019). For data citations and acknowledgements see section 4.4 below. General citations of HydroATLAS should refer to:

> *Linke, S., Lehner, B., Ouellet Dallaire, C., Ariwi, J., Grill, G., Anand, M., Beames, P., Burchard-Levine, V., Maxwell, S., Moidu, H., Tan, F., Thieme, M. (2019). Global hydro-environmental sub-basin and river reach characteristics at high spatial resolution. Scientific Data 6: 283. DOI: 10.1038/s41597-019-0300-6.*

Table1. Categories of hydro-environmental variables offered in the HydroATLAS database.

Identifier	Category	Description
H	Hydrology & hydrography	Hydrological and hydrographic characteristics related to quantity, quality, location and extent of terrestrial water *Examples: natural runoff and discharge, groundwater table depth, lake cover*
P	Physiography	Topographic characteristics related to terrain, relief or landscape position *Examples: elevation, slope*
C	Climate	Climatic characteristics *Examples: mean temperature, climate moisture index, global aridity*
L	Land cover & land use	Land cover and land use characteristics including biogeographic regions *Examples: land cover classes, permafrost extent, freshwater ecoregions*
S	Soils & geology	Soil and geology related characteristics including substrate types and soil conditions *Examples: percentage clay in soil, soil water stress, lithography, soil erosion*
A	Anthropogenic influences	Anthropogenic characteristics including demographic and socioeconomic aspects *Examples: population density, human footprint, GDP per capita*

2. Methods and data characteristics

The methods used to create HydroATLAS are fully described in Linke et al. (2019). All spatial units of HydroATLAS, i.e. either sub-basin polygons or river reach lines, were extracted from World Wildlife Fund's HydroSHEDS database (Lehner et al. 2008; Lehner and Grill 2013) at a grid resolution of 15 arc-seconds (approx. 500 m at the equator). For more information please refer to the Technical Documentation of HydroSHEDS at http://www.hydrosheds.org.

HydroATLAS consists of two complementary parts: BasinATLAS and RiverATLAS. BasinATLAS provides hydro-environmental attributes for sub-basins (polygons). RiverATLAS provides hydro-environmental attributes for stream and river reaches (line segments).

Basin and sub-basin delineations have been pre-processed as a derivative of HydroSHEDS at 15 arc-second resolution and are available as a stand-alone product termed HydroBASINS (for details see https://www.hydrosheds.org/page/hydrobasins). The HydroBASINS dataset offers a suite of 12 layers, each containing nested sub-basins that were subdivided and coded using the topological concept of the Pfafstetter system, which provides a methodology for the breakdown of sub-basins at different scales in a hierarchical and systematic manner (Figure 1a). It should be noted, however, that at the lowest Pfafstetter levels (i.e. 1-3) multiple river basins may be lumped into larger regions, and for coastal sub-basins (at any level) multiple smaller rivers may be lumped into one sub-basin—in these cases, the association of some particular attributes (such as river discharge) is ambiguous and the assigned attribute value may refer to only one river within the sub-basin unit.

Also, a global river network delineation has been extracted from HydroSHEDS at 15 arc-second resolution and is available as a stand-alone product termed HydroRIVERS (for details see https://www.hydrosheds.org/page/hydrorivers). For this network, rivers have been defined to start at all pixels where the accumulated upstream catchment area exceeds 10 km², or where the long-term average natural discharge exceeds 0.1 cubic meters per second, resulting in a line network consisting of individual stream and river reaches (Figure 1b).

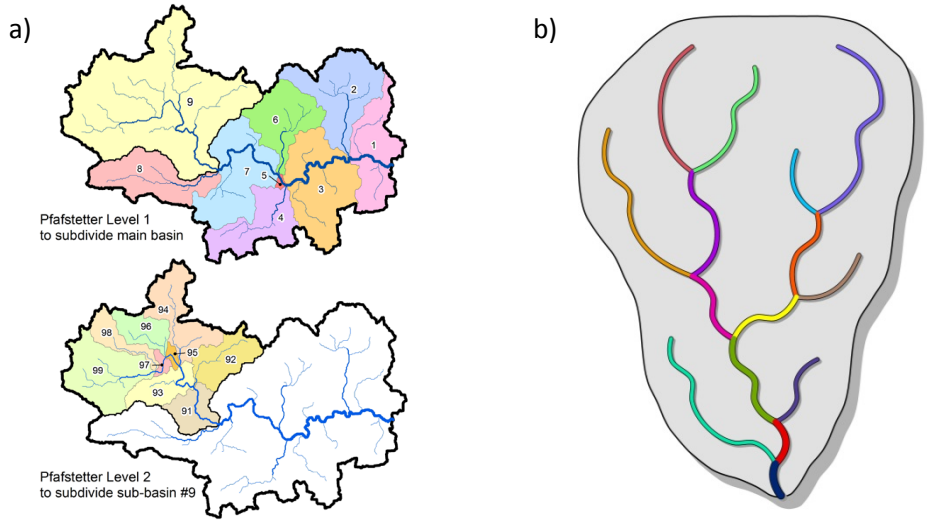


Figure 1: Overview of Pfafstetter sub-basin coding scheme used in BasinATLAS (a); and river reach concept used in RiverATLAS (b). Sub-basins are nested within 12 hierarchical levels. A river reach is defined as a stretch between two tributaries, or between the start/end of the network and a tributary.

It should be noted that the quality of HydroSHEDS data is significantly inferior for regions above 60 degrees northern latitude as there are no underlying SRTM elevation data available and thus a coarser scale DEM has been inserted (HYDRO1k provided by USGS).

3. Data format and distribution

a) Data format and projection

HydroATLAS is publicly available for download at http://www.hydrosheds.org/page/hydroatlas and from the *figshare* data repository at https://doi.org/10.6084/m9.figshare.9890531. All map data layers, including attribute tables, are provided in ESRI© Geodatabase and Shapefile formats. The data are projected in a Geographic Coordinate System using the World Geodetic System 1984 (GCS_WGS_1984). The attribute table can also be accessed as a stand-alone file in dBASE format which is included in the Shapefile format. HydroATLAS data are available electronically in compressed zip file format. To use the data files, the zip files must first be decompressed. Each zip file includes a copy of the HydroATLAS Technical Documentation.

b) Layer name syntax and spatial coverage

HydroATLAS data layers are provided in two spatial extents:

- primarily as a seamless, fully global coverages;
- but for some datasets also (or only) as regional tiles (see Figure 2 for definition of regions).

The layer names follow the syntax:

- ***BasinATLAS_v10_levXX*** (for BasinATLAS layers with global coverage), where *XX* indicates the Pfafstetter level (1-12);
- ***RiverATLAS_v10*** (for RiverATLAS layer with global coverage); or
- ***RiverATLAS_v10_YY*** (for RiverATLAS layers in regional tiles), where *YY* indicates the region.

The regional extents are defined by a two-digit identifier:

Identifier	*Region*
af	Africa
ar	North American Arctic
as	Central and South-East Asia
au	Australia and Oceania
eu	Europe and Middle East
gr	Greenland
na	North America and Caribbean
sa	South America
si	Siberia

Note that the Shapefile format is limited to a maximum file size of 2 GB; therefore the RiverATLAS data in Shapefile format are only provided in regional tiles (with further subdivisions into north and south parts where needed). Currently, all other data layers are provided in full global coverage, but more versatile regional breakdowns and data packages may be offered in future iterations.

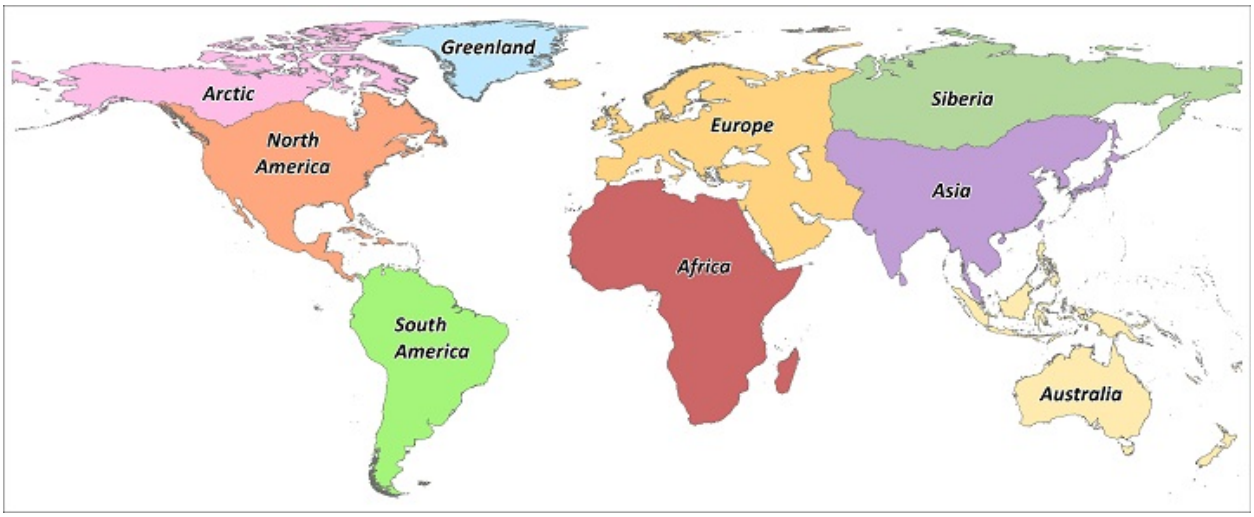


Figure 2: Spatial extent of regional tiles of HydroATLAS layers.

c) <u>Available columns and column name syntax</u>

The attribute tables of HydroATLAS contain the pre-existing columns of HydroBASINS and HydroRIVERS, respectively (see their Technical Documentations at http://www.hydrosheds.org for details). The hydro-environmental attributes are then appended in a series of additional columns. This section provides information on the column name syntax used for the identification of each sub-basin or river reach attribute provided in the HydroATLAS database. All existing attributes and their associated column names are summarized in Appendix 1 and at the beginning of the BasinATLAS and RiverATLAS catalogs.

Each hydro-environmental attribute column name has 10 digits (for example '*dis_m3_syr*') and its syntax is as follows:

<Layer name key>_<Unit key>_<Spatial key>< Dimension key>

Layer name key:

Three digits that describe the name of the attribute. The layer name key is unique to the attribute it represents. *Example: 'dis' for discharge.*

Unit key:

Two digits that describe the units of the attribute value. See Table 2 for possible keys.

Spatial extent key:

One digit that describes the spatial extent of the attribute. See Table 3 for possible keys.

Dimension key:

Two digits that describe the dimension of the attribute in terms of its aggregation level or other type of spatio-temporal association. The dimension key can refer to a temporal dimension, a statistical aggregation, or a class or year association. See Table 4 for possible keys.

Table 2: Unit keys. Note that some values are stored in factors of the given units (to efficiently store them as integers without losing precision), e.g. temperature is stored in tenths of degrees; these factors are listed in the respective data sheet of each variable in the BasinATLAS or RiverATLAS catalogs.

Key	Unit of values
cl	Classes
cm	Centimeters
ct	Count (e.g. number of people)
dc	Degrees Celsius (°C)
dg	Degrees
dk	Decimeters per kilometer
ha	Hectares
id	ID number
ix	Index value
kh	Kilogram per hectare (kg/ha) per year
m3	Cubic meters per second (m^3/s)
mc	Million cubic meters (mcm)
mk	Meters per square kilometer (m/km^2)
mm	Millimeters
mt	Meters *or* Meters above sea level (m.a.s.l.)
pc	Percent *or* Percent cover
pk	Per square kilometer (e.g. people per square kilometer)
tc	Thousand cubic meters
th	Tonnes per hectare
ud	US dollars

Table 3: Spatial extent keys. Note that all attributes represent average values within the spatial unit unless stated otherwise in the attribute's catalog sheet.

Key	Spatial representation
c	In reach catchment (i.e. the local catchment that drains directly into the reach)
p	At sub-basin pour point *or* At reach pour point
r	Along reach segment
s	In sub-basin
u	In total watershed upstream of sub-basin pour point *or* In total watershed upstream of reach pour point *or*

Table 4: Dimension keys.

Key	Temporal or statistical aggregation or other association
01-12	Calendar month (January to December) for monthly data
00-99	Class number (e.g. for spatial extent calculations of individual classes)
00-99	Other numbers may be used & explained as needed (e.g. to represent a specific year)
av	Average
g1-g9	Class groupings (individual groups are defined in HydroATLAS catalog)
lt	Long-term maximum
mj	Spatial majority (dominant value)
mn	Minimum *or* Annual minimum
mx	Maximum *or* Annual maximum
se	Spatial extent (%)
su	Sum
va	Value
yr	Annual average

4. License, disclaimer and acknowledgement

4.1 License agreement

HydroATLAS forms a Collective Database, i.e. a collection of information from independent datasets, and as a whole is licensed under a Creative Commons Attribution 4.0 International License (CC-BY 4.0; http://creativecommons.org/licenses/by/4.0/). However, the individual parts (content) of this Collective Database are still governed by their own licenses. In version 1.0 of HydroATLAS, all attribute columns are licensed under either a Creative Commons Attribution 4.0 International License (CC-BY 4.0) or an Open Data Commons Open Database License (ODbL 1.0; https://opendatacommons.org/licenses/odbl/1-0/index.html), both permitting reuse of the data for any purpose including commercial. In cases where original licenses differ from CC-BY 4.0 or ODbL 1.0, special permission was obtained from the original author(s) to release their works in the format of HydroATLAS under a CC-BY 4.0 or ODbL 1.0 license. Note that the licenses of the underpinning source datasets in their original format are not affected or altered by these licenses. Detailed information regarding the specific license that applies to each attribute column is provided in the respective data sheet of the BasinATLAS and RiverATLAS catalogs.

By downloading and using the data the user agrees to the terms and conditions of these licenses.

4.2 Disclaimer of warranty

The HydroATLAS database and any related materials contained therein are provided “as is” without warranty of any kind, either express or implied, including, but not limited to, the implied warranties of merchantability, fitness for a particular purpose, noninterference, system integration, or noninfringement. The entire risk of use of the data shall be with the user. The user expressly acknowledges that the data may contain some nonconformities, defects, or errors. The authors do not warrant that the data will meet the user's needs or expectations, that the use of the data will be uninterrupted, or that all nonconformities, defects, or errors can or will be corrected. The authors are not inviting reliance on these data, and the user should always verify actual data.

4.3 Limitation of liability

In no event shall the authors be liable for costs of procurement of substitute goods or services, lost profits, lost sales or business expenditures, investments, or commitments in connection with any business, loss of any goodwill, or for any direct, indirect, special, incidental, exemplary, or consequential damages arising out of the use of the HydroATLAS database and any related materials, however caused, on any theory of liability, and whether or not the authors have been advised of the possibility of such damage. These limitations shall apply notwithstanding any failure of essential purpose of any exclusive remedy.

4.4 Data citations and acknowledgements

When using an attribute contained in HydroATLAS, citations and acknowledgements should be made to both the original data source and the HydroATLAS compendium. For example, the following template illustrates a reference to precipitation data sourced from HydroATLAS:

> "*Precipitation data from the WorldClim v1.4 database (Hijmans et al. 2005) have been used in the spatial format as provided by HydroATLAS v1.0 (Linke et al. 2019).*"

Information regarding the reference(s) for each hydro-environmental attribute is provided on the individual attribute sheets in the BasinATLAS and RiverATLAS catalogs. In addition, every data source may have individual requests for acknowledgements, and users of HydroATLAS are asked to honor those requests when using the respective attributes.

General citations and acknowledgements of HydroATLAS should be made as follows:

> *Linke, S., Lehner, B., Ouellet Dallaire, C., Ariwi, J., Grill, G., Anand, M., Beames, P., Burchard-Levine, V., Maxwell, S., Moidu, H., Tan, F., Thieme, M. (2019). Global hydro-environmental sub-basin and river reach characteristics at high spatial resolution. Scientific Data 6: 283. DOI: 10.1038/s41597-019-0300-6.*

We kindly ask users to cite both source data and HydroATLAS in any published material produced using the data. If possible, online links to the HydroATLAS website should be provided (http://www.hydrosheds.org/page/hydroatlas).

5. References

Lehner, B., Grill G. (2013). Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes 27(15): 2171-2186.

Lehner, B., Verdin, K., Jarvis, A. (2008). New global hydrography derived from spaceborne elevation data. Eos, Transactions, AGU 89(10): 93-94.

Linke, S., Lehner, B., Ouellet Dallaire, C., Ariwi, J., Grill, G., Anand, M., Beames, P., Burchard-Levine, V., Maxwell, S., Moidu, H., Tan, F., Thieme, M. (2019). Global hydro-environmental sub-basin and river reach characteristics at high spatial resolution. Scientific Data 6: 283. *DOI: 10.1038/s41597-019-0300-6*.

Appendix 1: Attributes included in version 1.0 of HydroATLAS (for details see HydroATLAS catalogs)

HydroATLAS Attributes (version 1.0)						
ID	**Category**	**Variable**	**Source Data**	**Citation**	**Column(s)**	**Count**
H01	Hydrology	Natural Discharge	WaterGAP v2.2	Döll et al. 2003	dis_m3_---	x3
H02	Hydrology	Land Surface Runoff	WaterGAP v2.2	Döll et al. 2003	run_mm_---	x1
H03	Hydrology	Inundation Extent	GIEMS-D15	Fluet-Chouinard et al. 2015	inu_pc_---	x6
H04	Hydrology	Limnicity (Percent Lake Area)	HydroLAKES	Messager et al. 2016	lka_pc_---	x2
H05	Hydrology	Lake Volume	HydroLAKES	Messager et al. 2016	lkv_mc_---	x1
H06	Hydrology	Reservoir Volume	GRanD v1.1	Lehner et al. 2011	rev_mc_---	x1
H07	Hydrology	Degree of Regulation	HydroSHEDS & GRanD	Lehner et al. 2011	dor_pc_---	x1
H08	Hydrology	River Area	HydroSHEDS & WaterGAP	Lehner & Grill 2013	ria_ha_---	x2
H09	Hydrology	River Volume	HydroSHEDS & WaterGAP	Lehner & Grill 2013	riv_tc_---	x2
H10	Hydrology	Groundwater Table Depth	Global Groundwater Map	Fan et al. 2013	gwt_cm_---	x1
P01	Physiography	Elevation	EarthEnv-DEM90	Robinson et al. 2014	ele_mt_---	x4
P02	Physiography	Terrain Slope	EarthEnv-DEM90	Robinson et al. 2014	slp_dg_---	x2
P03	Physiography	Stream Gradient	EarthEnv-DEM90	Robinson et al. 2014	sgr_dk_---	x1
C01	Climate	Climate Zones	GEnS	Metzger et al. 2013	clz_cl_---	x1
C02	Climate	Climate Strata	GEnS	Metzger et al. 2013	cls_cl_---	x1
C03	Climate	Air Temperature	WorldClim v1.4	Hijmans et al. 2005	tmp_dc_---	x16
C04	Climate	Precipitation	WorldClim v1.4	Hijmans et al. 2005	pre_mm_---	x14
C05	Climate	Potential Evapotranspiration	Global-PET	Zomer et al. 2008	pet_mm_---	x14
C06	Climate	Actual Evapotranspiration	Global Soil-Water Balance	Trabucco & Zomer 2010	aet_mm_---	x14
C07	Climate	Global Aridity Index	Global Aridity Index	Zomer et al. 2008	ari_ix_---	x2
C08	Climate	Climate Moisture Index	WorldClim & Global-PET	Hijmans et al. 2005	cmi_ix_---	x14
C09	Climate	Snow Cover Extent	MODIS/Aqua	Hall & Riggs 2016	snw_pc_---	x15
L01	Landcover	Land Cover Classes	GLC2000	Bartholomé & Belward 2005	glc_cl_---	x1
L02	Landcover	Land Cover Extent	GLC2000	Bartholomé & Belward 2005	glc_pc_---	x44
L03	Landcover	Potential Natural Vegetation Classes	EarthStat	Ramankutty & Foley 1999	pnv_cl_---	x1
L04	Landcover	Potential Natural Vegetation Extent	EarthStat	Ramankutty & Foley 1999	pnv_pc_---	x30
L05	Landcover	Wetland Classes	GLWD	Lehner & Döll 2004	wet_cl_---	x1
L06	Landcover	Wetland Extent	GLWD	Lehner & Döll 2004	wet_pc_---	x22
L07	Landcover	Forest Cover Extent	GLC2000	Bartholomé & Belward 2005	for_pc_---	x2
L08	Landcover	Cropland Extent	EarthStat	Ramankutty et al. 2008	crp_pc_---	x2
L09	Landcover	Pasture Extent	EarthStat	Ramankutty et al. 2008	pst_pc_---	x2
L10	Landcover	Irrigated Area Extent (Equipped)	HID v1.0	Siebert et al. 2015	ire_pc_---	x2
L11	Landcover	Glacier Extent	GLIMS	GLIMS & NSIDC 2012	gla_pc_---	x2
L12	Landcover	Permafrost Extent	PZI	Gruber 2012	prm_pc_---	x2
L13	Landcover	Protected Area Extent	WDPA	IUCN & UNEP-WCMC 2014	pac_pc_---	x2
L14	Landcover	Terrestrial Biomes	TEOW	Dinerstein et al. 2017	tbi_cl_---	x1
L15	Landcover	Terrestrial Ecoregions	TEOW	Dinerstein et al. 2017	tec_cl_---	x1
L16	Landcover	Freshwater Major Habitat Types	FEOW	Abell et al. 2008	fmh_cl_---	x1
L17	Landcover	Freshwater Ecoregions	FEOW	Abell et al. 2008	fec_cl_---	x1
S01	Soils & Geology	Clay Fraction in Soil	SoilGrids1km	Hengl et al. 2014	cly_pc_---	x2
S02	Soils & Geology	Silt Fraction in Soil	SoilGrids1km	Hengl et al. 2014	slt_pc_---	x2
S03	Soils & Geology	Sand Fraction in Soil	SoilGrids1km	Hengl et al. 2014	snd_pc_---	x2
S04	Soils & Geology	Organic Carbon Content in Soil	SoilGrids1km	Hengl et al. 2014	soc_th_---	x2
S05	Soils & Geology	Soil Water Content	Global Soil-Water Balance	Trabucco & Zomer 2010	swc_pc_---	x14
S06	Soils & Geology	Lithological Classes	GLiM	Hartmann & Moosdorf 2012	lit_cl_---	x1
S07	Soils & Geology	Karst Area Extent	Rock Outcrops v3.0	Williams & Ford 2006	kar_pc_---	x2
S08	Soils & Geology	Soil Erosion	GloSEM v1.2	Borrelli et al. 2017	ero_kh_---	x2
A01	Anthropogenic	Population Count	GPW v4	CIESIN 2016	pop_ct_---	x2
A02	Anthropogenic	Population Density	GPW v4	CIESIN 2016	ppd_pk_---	x2
A03	Anthropogenic	Urban Extent	GHS S-MOD v1.0 (2016)	Pesaresi & Freire 2016	urb_pc_---	x2
A04	Anthropogenic	Nighttime Lights	Nighttime Lights v4	Doll 2008	nli_ix_---	x2
A05	Anthropogenic	Road Density	GRIP v4	Meijer et al. 2018	rdd_mk_---	x2
A06	Anthropogenic	Human Footprint	Human Footprint v2	Venter et al. 2016	hft_ix_---	x4
A07	Anthropogenic	Global Administrative Areas	GADM v2.0	University of Berkeley 2012	gad_id_---	x1
A08	Anthropogenic	Gross Domestic Product	GDP PPP v2	Kummu et al. 2018	gdp_ud_---	x3
A09	Anthropogenic	Human Development Index	HDI v2	Kummu et al. 2018	hdi_ix_---	x1