Hydropower Solutions

HYPOSO

Hydropower solutions for developing and emerging countries

D3.4

Report on completed HYPOSO Map module with high performance web site interface

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Introduction

HYPOSO is a multi-approach project to tackle several objectives; identification and mapping of the European hydropower industry, hydropower stakeholders in the HYPOSO target countries, education of new hydropower experts through capacity-building activities and bringing together relevant actors from the EU hydropower sector with stakeholders in the target countries. Interaction with stakeholders is, therefore, an integral part of the activities, as workshops, capacity-building activities and interviews with national/local stakeholders are envisaged in all target countries which are outside the European Union, namely workshops in Bolivia, Colombia and Ecuador in Latin America, and Cameroon and Uganda in Africa.

Executive Summary

Deliverable D3.4 is an outcome of Task 3.3, Mapping of Potential Hydropower Hotspots in the Target Countries (Task leader: VDU; Partners: IHE Delft, FN, TS, CELAPEH, HPAU, SHW, EPN, UMSS). It focuses on small and medium-sized rivers where small hydropower plants (SHP) could be installed. The primary outcome of task 3.3 was the development of a user-friendly GIS (Geographical information system) tool – the HYPOSO Map viewer or Interactive Hydropower Atlas with a geospatial representation of potential hydropower locations in the five target countries, namely: two African (Cameroon and Uganda) and three Latin American (Bolivia, Colombia and Ecuador) countries. It is available in English, French and Spanish and accessible at https://www.opengis.lt/projects/hyposo/#9/-1.3944/-79.4295.
Strategic development of hydropower resources in most countries has been constrained by economic conditions and the lack of information on river flow, river topography and hydropower potential, especially in the African and some Latin American river systems. Therefore, collected and stored multisource geospatial information will be vital for deriving the necessary thematic GIS layers, accessible through an interactive map (Open Street Map), providing visual and digital data for users. Exploring or downloading the geodata sets in KML or Shape format and respective metadata is also possible. The mapping platform is based on open-source GeoServer software. GIS modelling was used to determine hydropower resources based on geospatial, hydrological, terrain elevation and hydropower databases. The data displayed by the application are either publicly available or were acquired under a public use agreement (i. e., data from external sources). Local experts provided part of the data sets.
It should be noted that the modelled estimates do not represent the actual numbers for engineering design. This so-called virtual hydropower atlas can be only a kind of discovery tool, automatically identifying sites worthy of further investigation (pre-feasibility or feasibility study). In doing so, the feasibility assessment would be much quicker and more affordable. This may be a critical aspect of the development of SHP plants.
The HYPOSO Map viewer comprises 20 layers broken down into five groups:

1. Base Map (Open Street Map, Open Topo Map, Satellite imagery),
2. Background & Infrastructure (National boundaries, Protected areas, Power grid),
3. Operational Hydropower Plants (and under construction),

4. Climate and Hydrology (Climate zones, Precipitation, Climate change projections of precipitation, River basins, Stream order, Small catchments, Gauging stations, Mean annual flow, Normal annual specific runoff,
5. Hydropower Potential (Potential sites of hydropower plants, Stream-reach potential capacity, Total hydropower potential of river basins, Specific hydropower potential),

More than 2,900 potential hydropower sites across the target countries with the following essential features can be identified on the HYPOSO Map viewer:

- Site type (e.g., run-of-the-river, reservoir, off-grid, or central grid);
- Address, stream or river name, basin (hydrologic unit or water management district name), coordinates (longitude and latitude);
- Approximate capacity (MW), flow (m^3/s), and head (m);
- Environmental sensitivity (e.g., protected areas);
- Any development opportunities (e.g., prior studies).

A brief, user-friendly instruction on using the HYPOSO Map is provided (Information about the usage of the map viewer).

1 Methodology

The HYPOSO map viewer is accessible at https://www.opengis.lt/projects/hyposo/#9/-1.3944/-79.4295. Its front page is shown in Figure 1.1, left. Available geospatial datasets can be explored and visualised by zooming, panning, and clicking on the map layers or icons to open the legend of this map. The map comprises 20 layers broken into five groups (Fig. 1.1, right). They are visualised once the map has been opened and layers activated (Fig. 1.1, left). The map's interface also allows for identifying any given feature attributes using a pop-up window or downloading KML or shapefiles with a complete list of attributes.

#	Group	Layer	
1	**Base Map**	1.1	Open Street Map (OSM)
		1.2	Open Topo Map
		1.3	Satellite Imagery
2	**Background & Infrastructure**	2.1	National Boundaries
		2.2	Protected Areas
		2.3	Power Grid
3	**Operational Hydropower Plants and under Construction**	3.1	Large, Medium, Intermediate, Small, Micro and Mini Hydro
4	**Climate and Hydrology**	4.1	Climate Zones
		4.2	Precipitation
		4.3	Climate Change Projections of Precipitation
		4.4	River Basins
		4.5	Stream Order
		4.6	Small Catchments
		4.7	Gauging Stations
		4.8	Mean Annual Flow
		4.9	Normal Annual Specific Runoff
5	**Hydropower Potential**	5.1	Potential Sites of Hydropower Plants
		5.2	Stream-Reach Potential Capacity
		5.3	Total Hydropower Potential of River Basins
		5.4	Specific Hydropower Potential
6	**Help**		

Figure 1.1. Desktop of the HYPOSO web map viewer (L) and the structure of the layers (R).

The development of this web-based hydropower atlas incorporates the best practices from similar hydropower atlases currently in use in the US, Europe and Africa (ORNL, 2018, GECOsistema and SWITCH-ON, 2017, RESTOR Hydro Map, 2014, ECOWAS ECREEE and Pöyry, 2017, World Bank et al., 2018). Hydropower atlases (web map viewers) are primarily published on commercial ESRI ArcGIS, ArcGIS Online, Google Earth (nonprofit use) or open-source QGIS software. The HYPOSO Map – a web-based platform, is published on the open-source GeoServer software. It allows users to input, process and publish geospatial data and supports data interchange from most spatial data sources using open standards (GeoServer, 2023). The map coordinate system is WGS84 (World Geodetic System 1984) and is provided in decimal degrees (geographic coordinates). The HYPOSO project experts in target countries contributed the required data for the HYPOSO Map.

The data for the operational (or under construction) hydropower plants (a geospatially comprehensive point-level data set) were compiled by the HYPOSO from various sources. Many individual pieces of information were collected from HPP design documents, research studies, reports by governmental authorities and NGOs, articles etc. The existence and location of the facilities were checked with the aid of satellite imagery. The exact coordinates (WGS84) were taken when a location was verified. Existing information was compared and cross-checked, and the most plausible values were included in the attribute table. At several HPPs, different data sources listed different values, e.g., installed capacity, discharge, head and other variables.

The World database on protected areas (WDPA (UNEP-WCMC and IUCN, 2021) and the updated World Map of the Köppen-Geiger climate classification (World Maps, 2006)) are included in the HYPOSO Map. The updated Köppen-Geiger map provides a higher resolution of 5 arc minutes using the downscaling algorithms. It is representative of the more recent 25-year period 1986-2010. To produce the map of the mean annual precipitation (mm), data sets from the Global Precipitation Climatology Centre (GPCC) were used (GPCC, 2022). All these geospatial polygon layers can be used as contextual information for evaluating hydropower sites.

Climate change will likely alter stream flow, impacting water availability and hydropower generation. The key resource for hydropower generation is runoff, which directly depends on precipitation. There is a close relationship between precipitation and run-of-river (RoR) scheme generation. Therefore, any changing trend in precipitation amount can be reflected in hydropower potential. As a result of geographic variability, hydropower generation has the potential to increase in the basins, which are becoming wetter, while the opposite is true of drier basins. The projected Precipitation Percent Change Anomaly for 2020-2099 (Annual) was taken from the Climate Change Knowledge Portal (CCKP), mean projections (CMIP6), and scenario SSP2-4.5 (CCKP, 2021).

The river basin layer (geospatial polygons) represents hydrologic/hydrographic units (regions), water management districts, or large to medium-sized river basins. This information was collected from the national hydrological institutions. In case of the absence of this data (e.g. Cameroon and Uganda), their boundaries were rendered by GIS tools and surface areas were calculated.

The stream order (geospatial polyline layer) was used to describe the hierarchy of streams from the top to the bottom of a catchment according to the Strahler system (Strahler, 1957). For instance, the highest one was attributed to Albert and Victoria Nile in Uganda and the Sanaga River in Cameroon. In this system, the smallest headwater tributaries are called first-order streams. Where two first-order streams meet, a second-order stream is created; where two second-order streams meet, a third-order stream is made, and so on. When considering this order, a general insight into the flow size of a stream to assess its power capacity on a large scale can be made.

The study used the historical mean annual river gauging stations (GS) flow series. The network of stream gauging stations was mapped, including their key characteristics provided on the map. The data was compiled from various sources, primarily national hydrologic yearbooks and national hydrologic services. To cross-check for the information on the gauging stations and consistency of streamflow data, a number of research papers and hydrological and river basin management reports available at open sources were used, including websites of hydrological data (GRDC, SIREM).

Long-term mean annual flow allows for calculating the stream-reach hydropower capacity. The normal specific runoff (q – river discharge per square kilometre – l/s·km2) was derived from mean annual flow, and maps were produced in a colour palette to characterise long-term mean annual river flow (except Colombia). A geospatial interpolation method (GIS geography, 2023) based on historical flow records from river gauging stations was applied to produce the specific runoff maps. They were used to compute stream flow for ungauged basins. Beforehand, validation against gauged flow records was carried out.

The river network and sub-catchment GIS layers were created with relevant attributes, displaying the hydropower potential. To delineate the river network and sub-basins (small catchments), the MERIT Hydro digital elevation model (DEM) representing the terrain elevations at a 3 arcseconds resolution (~90 m at the equator) was used (Yamazaki et al., 2019, MERIT DEM??). It was developed from the existing spaceborne DEMs (SRTM3 v2.1), JAXA AW3D-30m v1, and Viewfinder Panorama DEM (SRTM, 2000). This DEM was hydrologically conditioned, and a well-known gravitation-based model was applied to delineate stream networks and sub-basins (Tarboton et al.,1991). ESRI ArcGIS Pro with the ArcHydro toolset was employed for data processing. Detailed river basin hydrological modelling, i.e., river flow simulation, was not performed due to the extensive hydrographic areas under consideration and, consequently, a massive undertaking for five countries.

For small hydropower development, it is essential to identify stream catchment (sub-basin) boundaries of flow-contributing areas and derive hydrologic metrics. According to the DEM data, small sub-basin areas were produced for all the countries. A threshold of 25 km^2 was used to define streams and sub-basins, which means that small streams with a flow-contributing area under 25 km^2 were not considered in this project.

Hydropower resources include existing operational plants (as described above) and prospective potential locations. Future hydropower potential was calculated based on the longitudinal river profile between two successive confluences. It has been proven that when a 200 km long river is divided into 5 or 6 segments (reaches), the potential energy found differs by less than 10% from that obtained when divided into 30 or 40 segments. Therefore, a very detailed splitting of the stream into short segments does not significantly increase the accuracy of the potential energy estimation (Punys et al., 2023). The gross hydraulic head (in our case, the height difference) and flow for the segmented rivers (close to 70,000 stream reaches) were determined. The hydropower capacity or potential was calculated based on this formula:

$$P = c \cdot H \cdot (Q_u + Q_d)/2 \qquad (1)$$

where *P* is the hydropower potential [MW];

c is a constant for considering unit conversion and approximate overall plant efficiency, including hydraulic losses (USACE, 1983, Kao et al., 2014). This study assumed the following value: c=8.5/1,000;

H is the elevation difference from the start to the end of a river reach [m];

Q is the long-term mean annual discharge upstream and downstream of a river reach [m^3/s].

The core of the HYPOSO Map is the potential hydropower sites (2962 georeferenced point locations). The following essential features can be identified on the HYPOSO Map viewer:

- Site type (e.g., run-of-the-river, reservoir, off-grid, or central grid);
- Address, stream or river name, basin (hydrologic unit or water management district name), coordinates (longitude and latitude);
- Approximate capacity (MW), flow (m^3/s), and head (m);
- Environmental sensitivity (e.g., protected areas);
- Any development opportunities (e.g., prior studies).

GIS modelling tools generated the most potential hydropower site locations in Uganda and Cameroon. The remaining sites were provided by local experts (collected from prior studies). Hydropower development considerations for new stream-reach development are largely site-specific and vary based on stream-reach characteristics, the surrounding landscape, and other factors.

The power capacity frequency distribution pattern of the potential sites for development in Uganda is illustrated in Figure 1.2 (right). The data for analysis is extracted from the HYPOSO Map datasets. Only the sites with a head over 5 m and a capacity above 0.1 MW were considered.

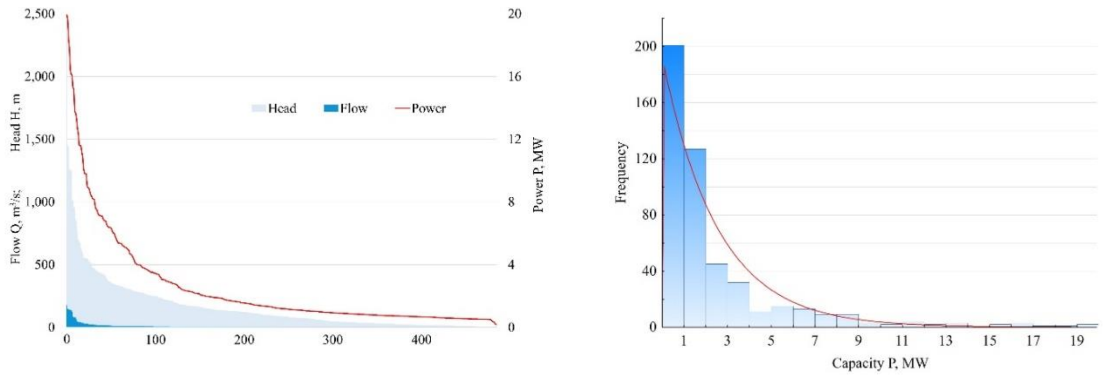

Figure 1.2. Key characteristics of the potential hydropower sites at large (L) and their frequency distribution of capacities (P<20 MW) in Uganda.

2 Validation of the HYPOSO Map

The HYPOSO Map was introduced to the stallholders during international events (conferences, project workshops), and its validation issues are not detailed here. The best and independent way to validate the results of any project is to publish papers or reports in peer-reviewed journals. To do so, an article on the Ugandan hydropower potential was prepared (Punys et al., 2023). Two more papers have already been drafted. One of them considers the structure of the HYPOSO Map itself, and another considers the hydropower potential of Cameroon based on the data sets of this map.

For the initial validation of the modelled data, various strategies were adopted. The modelled flow data was compared with the collected hydrological data records from the river gauging stations. The digital elevation model was validated by comparing the longitudinal river cross sections according to the DEM and topographic maps. The estimated hydropower capacity was compared to the prior studies. Some data validation outcomes are published in peer-reviewed journal (Punys et al., 2023). All the data published in the GIS layers were based on modelling results. Although the modelled estimates do not represent the actual numbers feasible for engineering design, they provide the basis for follow-up pre-feasibility or feasibility studies. This is also true for identified potential sites of hydropower plants. Their selection considers protected areas, the proximity of the grid, and settlements. However, georeferenced points of potential sites do not differentiate between SHP intake and powerhouse but rather indicate the best-suiting river reaches for SHP development. If the site is considered for further development, exact locations should be determined during field studies.

The accuracy of determining key parameters of potential hydropower sites (or stream-reach capacity) is dependent on the following significant factors:

- The spatial location of the sites along the river depends on the accuracy of DEM (Digital Elevation Model).
- Quality of the hydrological data (stream flow).

The magnitude of hydropower potential, particularly the river channel slope or a drop in river channel elevation (see formulae 1), is subject to DEM accuracy. The SRTM (Shuttle Radar Topography Mission) was designed with specific mapping accuracy thresholds to help ensure a consistent and accurate global topographic dataset. However, there is no clear consensus in the literature on assessing the accuracy of SRTM DEM. It depends on geographic region, individual variability of topography, and land cover conditions (Uuemaa et al., 2020). For South America, the SRTM dataset has an average horizontal error of 9.0 m and an average absolute vertical (height) error of 6.2 m (Rodriguez and others, 2006). For Africa, the SRTM dataset has an average horizontal error of 11.9 m and an average absolute vertical (elevation) error of 5.6 m. In mountain regions, reported vertical accuracy is slightly lower.

To validate the DEM for assessing stream capacities (based on a stream-reach slope or difference in elevation) from generated longitudinal stream profiles was conducted. These profiles were extracted from the DEM data and compared with those produced from topographic maps (Fig. 2.1). The statistical estimates were satisfactory or suitable for the steep topography areas of Uganda. At the same time, the evaluation fell short of engineering standards in the flat landscape.

Hydrological data quality requirements are outlined in WMO technical regulations (WMO, 2020). Our study showed that sufficiently good quality hydrological data were available in Latin American countries (BO, CO and EC). For African countries (CM and UG), the reliability and quality of input data series for this study were judged sufficient only at a minimal level. The long-term mean annual river flow was used to calculate stream reach and potential site power capacities. It is commonly accepted that the seasonal flow distribution (at daily or monthly intervals) can significantly affect the results of the assessment of hydropower potential at a site. Based on the construction of the daily flow duration curve, this method is applied for more detailed studies, for instance, in pre- or feasibility analysis of SHP schemes. When calculating site power capacity, an error can be between ± 20% and more than 30% when mean annual river flow is used instead of daily flow values (Punys et al., 2019).

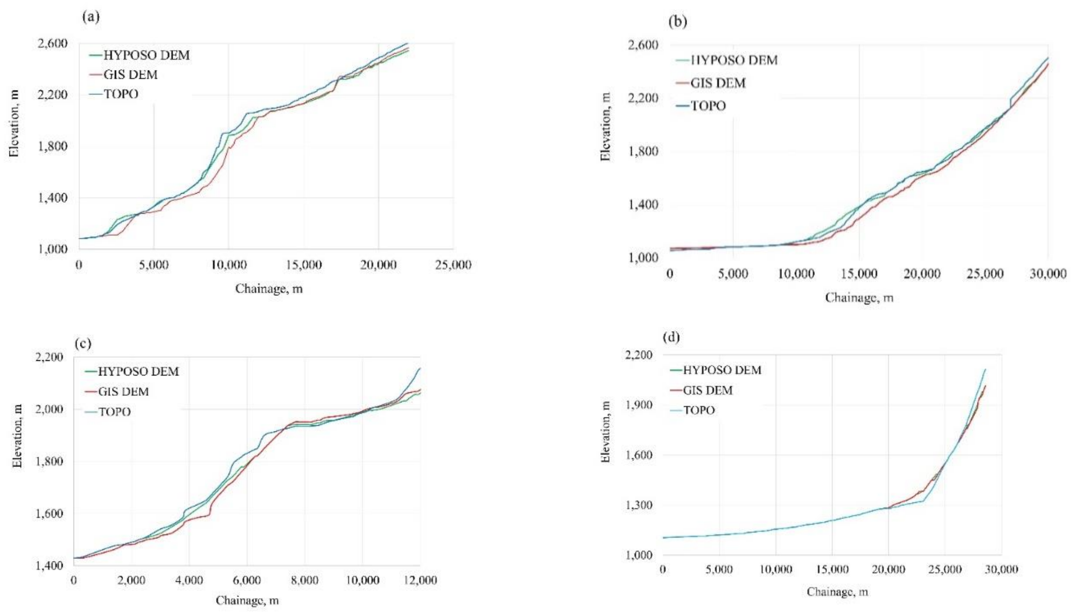

Figure 2.1. Comparison of longitudinal stream profiles of the datasets of HYPOSO DEM, GIS DEM and the reference profile (topographic map with contour lines). a) Sipi, b) Simu, c) Ririrma and d) Sironko.

3 Structure of the HYPOSO Map

3.1 Base Maps

Open Street Map, Open Topo Map and Satellite Imagery are the base maps (Fig. 3.1)

Figure 3.1. Open Street Map and Open Topo Map (Boundaries of the Ecuadorian territory)

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3.2 Background & Infrastructure

3.2.1 National Boundaries

The country's boundaries can be outlined (Fig. 3.2).

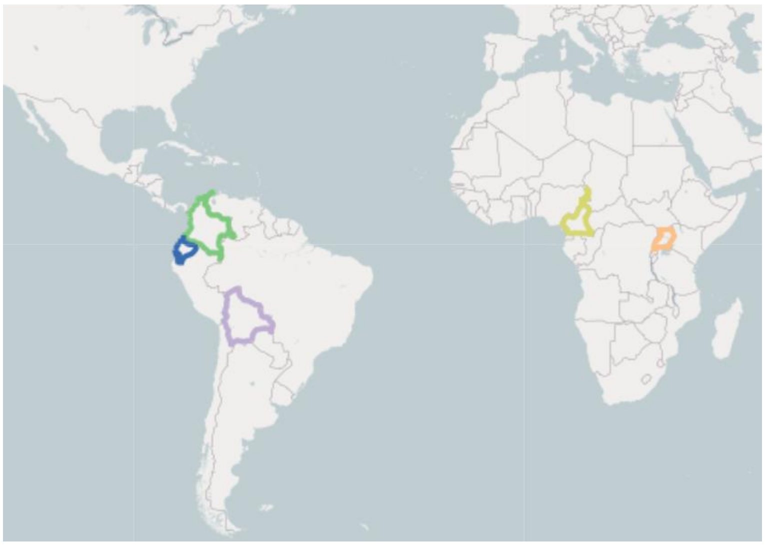

Figure 3.2. National boundaries of the target countries.

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3.2.2 Protected Areas

The World Database on Protected Areas (WDPA) was presented for individual countries (Fig. 3.3).

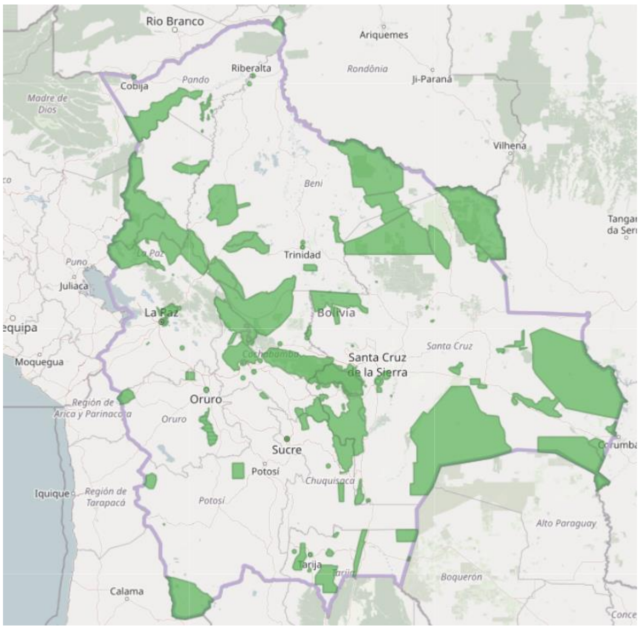

Figure 3.3. Protected areas in Bolivia.

Data is available for downloading (Shape and KML files). The following attributes are available for Bolivia (pop-up windows highlight only relevant attributes on the HYPOSO Map).

Bolivia		
#	Attribute	Description
1.	fid	Fid
2.	WDPAID	Unique identifier for a protected area
3.	WDPA_PID	Unique identifier for parcels or zones within a protected area
4.	PA_DEF	1 (meets IUCN and CBD protected area definitions)
5.	NAME	Name of the protected area (PA)
6.	ORIG_NAME	Name of the protected area in the original language
7.	DESIG	Name of designation
8.	DESIG_ENG	Designation in English
9.	DESIG_TYPE	National, Regional, International, Not Applicable
10.	ICUN_CAT	Ia, Ib, II, III, IV, V, VI, Not Applicable, Not Assigned, Not Reported
11.	INT_CRIT	For World Heritage and Ramsar sites, only

12.	MARINE	0 (predominantly or entirely terrestrial), 1 (Coastal: marine and terrestrial), and 2 (predominantly or entirely marine). The value' 1' is only used for polygons.
13.	REP_M__AREA	Marine area in square kilometres
14.	GIS_M_AREA	Area in square kilometres
15.	REP_AREA	Area in square kilometres
16.	GIS_AREA	Area in square kilometres
17.	NO_TAKE	All, Part, None, Not Reported, Not Applicable (if no marine component)
18.	NO_TK_AREA	Area of the no-take area in square kilometres
19.	STATUS	Proposed, Inscribed, Adopted, Designated, Established
20.	STATUS_YR	Year of enactment of status
21.	GOV_TYPE	Federal or national ministry or agency, Sub-national ministry or agency, Government-delegated management, Transboundary governance, Collaborative governance, Joint governance, Individual landowners, Nonprofit organisations, For-profit organisations, Indigenous peoples, Local communities, Not Reported
22.	OWN_TYPE	State, Communal, Individual landowners, For-profit organisations, Nonprofit organisations, Joint ownership, Multiple ownership, Contested, Not Reported
23.	MANG_AUTH	Individual or group that manages the protected area, Not reported.
24.	MANG_PLAN	Link or reference to the protected area's management plan, Not Reported
25.	VERIF	Fixed values: State Verified, Expert Verified, Not Reported
26.	METADATAID	Assigned by UNEP-WCMC
27.	SUB_LOC	ISO 3166-2 sub-national code where the PA is located.
28.	PARENT_ISO3	ISO code of the country
29.	ISO3	ISO code of the country

For more details, please refer to UNEP-WCMC (2019). User Manual for the World Database on Protected Areas and world database on other effective area-based conservation measures: 1.6. UNEP-WCMC: Cambridge, UK. Available at: http://wcmc.io/WDPA_Manual

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3.2.3 Power Grid

Data for the transmission and distribution grid were obtained from various open sources, including transmission and distribution companies of the target countries.

Transmission and distribution of power lines (in some countries, even substations) are visualised on the map (Fig. 3.4).

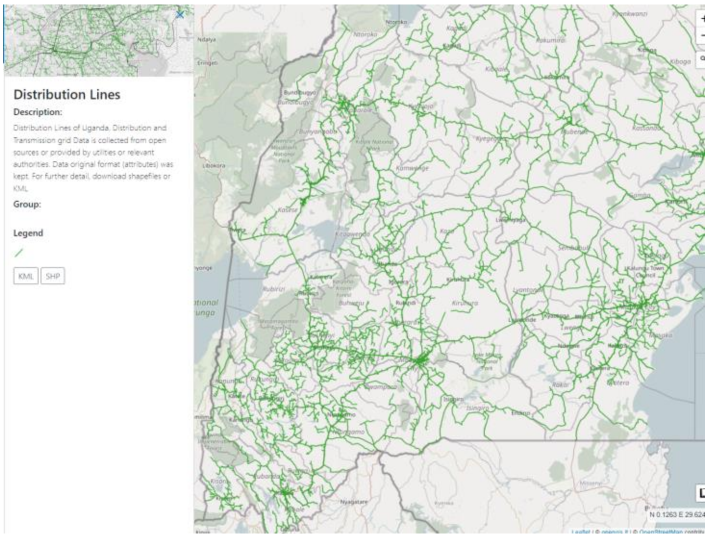

Figure 3.4. Transmission and distribution lines of Uganda (western part).

Data is available for downloading (Shape and KML files). The following attributes are available (shown only for Uganda):

Uganda		
Transmission Lines		
#	**Attribute**	**Description**
1.	fid	Fid
2.	objectid	Object ID
3.	line_id	Line ID
4.	line_name	Line Name
5.	voltage_kv	Voltage, kV
6.	status	Status
7.	status_det	Status
8.	year_commi	Year commissioning
9.	year_upgra	Year upgrade
10.	year_decom	Year decommissioning
11.	installati	Installation type
12.	structure_	Structure
13.	no_structu	No structure
14.	constructi	Construction
15.	circuits	Circuits
16.	line_ratin	Line class
17.	Conductor1	Conductor

18.	contractor	Contractor
19.	financier	Financier
20.	shape_leng	Shape length
		Distribution Lines
1.	fid	Fid
2.	objectid	Object ID
3.	voltage	Voltage
4.	status	Status
5.	alignment	Alignment
6.	dblcircuit	Dbl circuit
7.	phase	Phase
8.	substation	Substation
9.	line_name	Line name
10.	feedername	Feeder name
11.	feedercode	Feeder code
12.	district	District
13.	service_te	Service area
14.	operator	Operator
15.	built_by	Built by
16.	funding	Funding
17.	source	Source
18.	shape_leng	Shape length

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3.3 Operational hydropower plants and plants under construction

Includes data for Hydro Power Plants (HPP) and Small Hydropower Plants (SHP), categorised accordingly to a wide range of installed capacities (large, medium, intermediate, small, micro and mini hydro) as operational plants or under construction (Fig. 3.5).

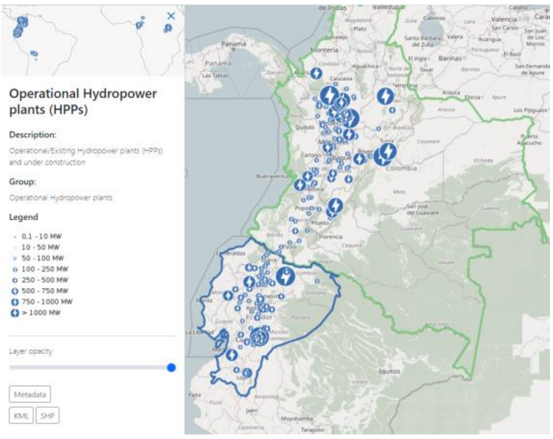

Figure 3.5. Operational HPPs in Colombia and Ecuador

Data is available for downloading (Shape and KML files). For hydropower plants, the following attributes are available:

#	Attribute	Description
1.	ID	ID number of HPP (internal)
2.	Country	Country name
3.	HPP_name	Hydropower plant (HPP) name
4.	Address	Address
5.	Lat_In	Latitude (decimal degrees North) at intake or dam
6.	Lon_In	Longitude (decimal degrees East) at intake or dam
7.	Lat_Pwh	Latitude (decimal degrees North) at powerhouse (if relevant)
8.	Lon_Pwh	Longitude (decimal degrees East) at powerhouse (if relevant)
9.	HPP_Class	HPP Types: RoR: Run-of-River; RoR-D: Run-of-River with Diversion; S: Storage (reservoir); S-D: Storage with Diversion
10.	Status	Operational or under construction
11.	Owner	Ownership or developer
12.	Grid	Connection (on-grid or off-grid)
13.	Comments	Any further information
14.	River_en	River name English
15.	River_loc	River name Local
16.	River_bas	River basin or hydrological unit
17.	Commiss	Commissioning year
18.	HPP_Type	HPP type
19.	Res_km2	Reservoir area, km^2
20.	Res_hm3	Reservoir storage, hm^3
21.	Cap_Inst	Installed capacity, MW
22.	Q_m3_s	Discharge, m^3/s
23.	Head_m	Head, m
24.	Exp_com	Expected year of commissioning
25.	Date_Oper	Date
26.	Lat_Pub	Latitude of publication of HPP (point level)
27.	Lon_Pub	Longitude of publication of HPP (point level)

3.4 Climate and Hydrology

3.4.1 Climate Zones

The climatic zones layer (geospatial polygons) contains the updated World Map of the Köppen-Geiger climate classification (based on temperature and Mean Annual Precipitation - MAP). This data set is not intended for local studies but only for regional comparison (Fig. 3.6).

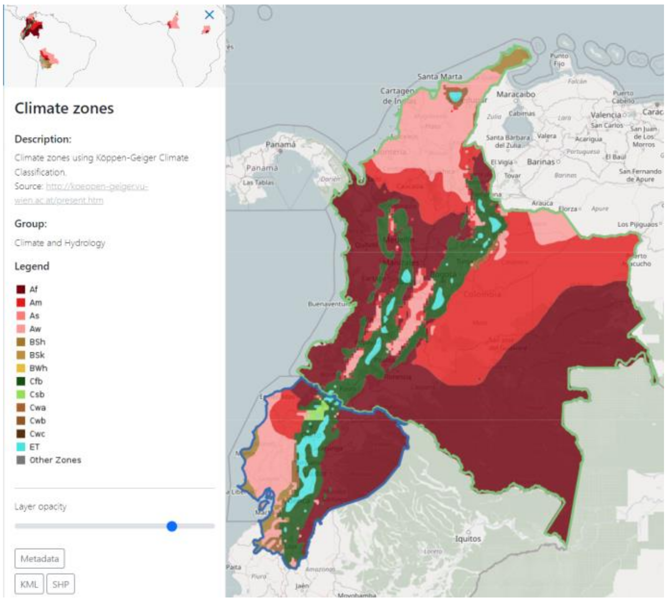

Figure 3.6. Climate zones in Ecuador and Colombia.

Data is available for downloading (Shape and KML files). For climate zone polygons, the following attributes are available:

#	Attribute	Description
1.	fid	ID number of Climate Zone (internal)
2.	Zone	Climate zone
3.	Area_km2	Climate zone area in square kilometres
4.	Perimeter_km	Climate zone perimeter in kilometres

Legend (http://koeppen-geiger.vu-wien.ac.at/present.htm)

- Af
- Am
- As
- Aw
- BSh
- BSk
- BWh
- Cfb
- Csb
- Cwa
- Cwb
- Cwc
- ET.
- Other zone

Main climates	Precipitation	Temperature	
A: equatorial	W: desert	h: hot arid	F: polar frost
B: arid	S: steppe	k: cold arid	T: polar tundra
C: warm temperature	f: fully humid	a: hot summer	
D: snow	s: summer dry	b: warm summer	
E: polar	w: winter dry	c: cool summer	
	m: monsoonal	d: extremely continental	

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3.4.2 Precipitation

This map (geospatial polygon layer) is not intended for local studies but only for regional comparison (Fig. 3.7).

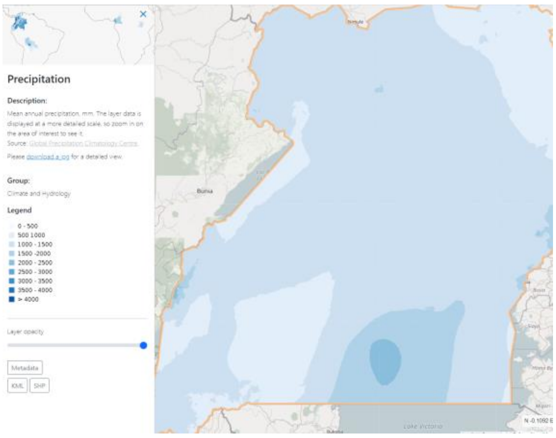

Figure 3.7. Mean annual precipitation of Uganda.

Data is available for downloading (Shape and KML files). In addition, the pictures (jpg) of the mean annual precipitation can be downloaded for a particular country. For the mean annual precipitation, the following attributes are available:

#	Attribute	Description
1.	Range_mm	Range of the mean annual precipitation (mm) at an interval of 500: 0–500 mm; 500–1000 mm; 3500–4400 mm; and >4000 mm
2.	Class	Classes of the mean annual precipitation with the interval of 500 mm (from 1 to 9)

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3.4.3 Climate Change Projections of Precipitation

The user can identify projected reduction or increase in precipitation (in percentage from the baseline) for a particular period of time and administrative region (geospatial polygon layer) (Fig. 3.8). Short-term (2020–2039), medium-term (2040–2059) and long-term (2060–2079, 2080–2099) projections are available as attributes. Long-term projection (2080–2099) was used for data visualisation.

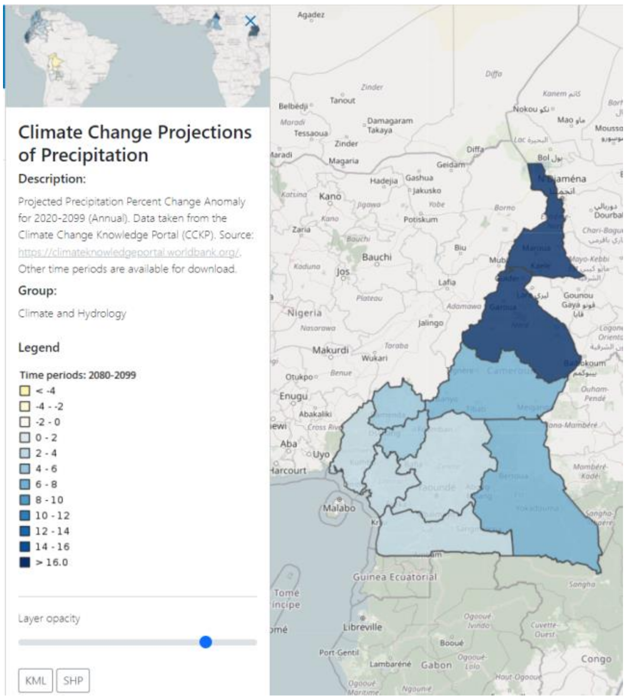

Figure 3.8. Climate change projections of precipitation in Cameroon.

Data is available for downloading (Shape and KML files). For the climate change projections of precipitation, the following attributes are available:

#	Attribute	Description
1.	ADM	Name of an administrative unit (e.g., district)
2.	ADM_FR	Name of an administrative unit (e.g., district) in French
3.	CODE	Country code
4.	AREA_km2	Area of administrative unit, km^2
5.	20_39	Time period 2020–2039
6.	40_59	Time period 2040–2059
7.	60_79	Time period 2060–2079
8.	80_99	Time period 2080–2099

External sources (Legal constraints)	https://climateknowledgeportal.worldbank.org/ https://www.openstreetmap.org/copyright © OpenStreetMap contributors

3.4.4 River Basins

The river basin layer (geospatial polygons) represents hydrologic/hydrographic units (regions), water management districts, or large to medium-sized river basins (Fig. 3.9).

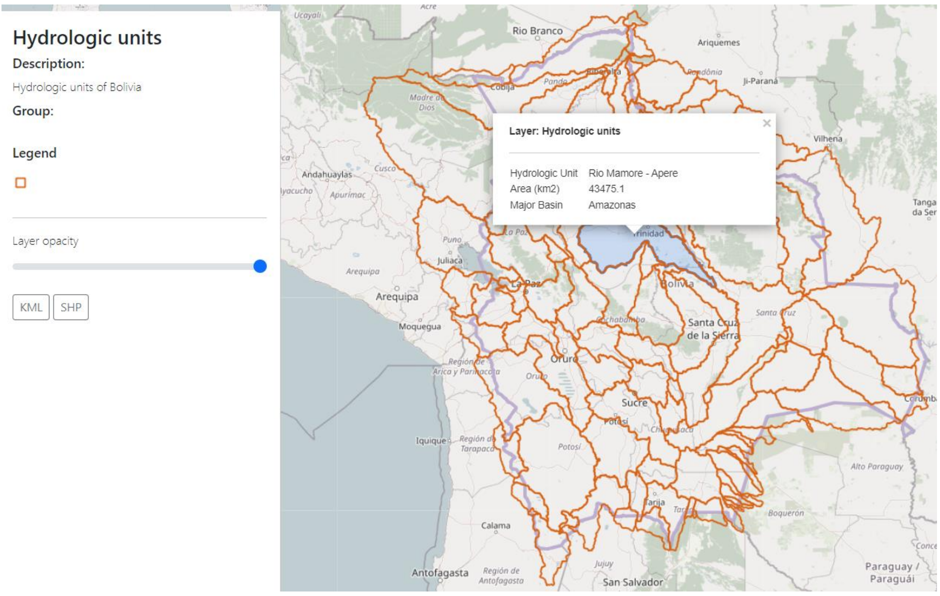

Figure 3.9. Hydrologic units of Bolivia.

Data is available for downloading (Shape and KML files). The following attributes are available (shown only for Bolivia):

Bolivia		
Major basins		
#	**Attribute**	**Description**
1.	fid	Fid
2.	Name	Name of the major basin
3.	Area_km2	Area, km^2
Hydrologic units		
1.	fid	Fid
2.	Name	Name of the hydrologic unit
3.	Area_km2	Area, km^2
4.	Main_Basin	Name of the major basin

External sources (Legal constraints)	https://www.mmaya.gob.bo/ http://www.ideam.gov.co/ https://www.gob.ec/senagua https://www.openstreetmap.org/copyright © OpenStreetMap contributors

3.4.5 Stream Order

Stream order was used to describe the hierarchy of streams from the top to the bottom of a catchment according to the Strahler system (Fig. 3.10).

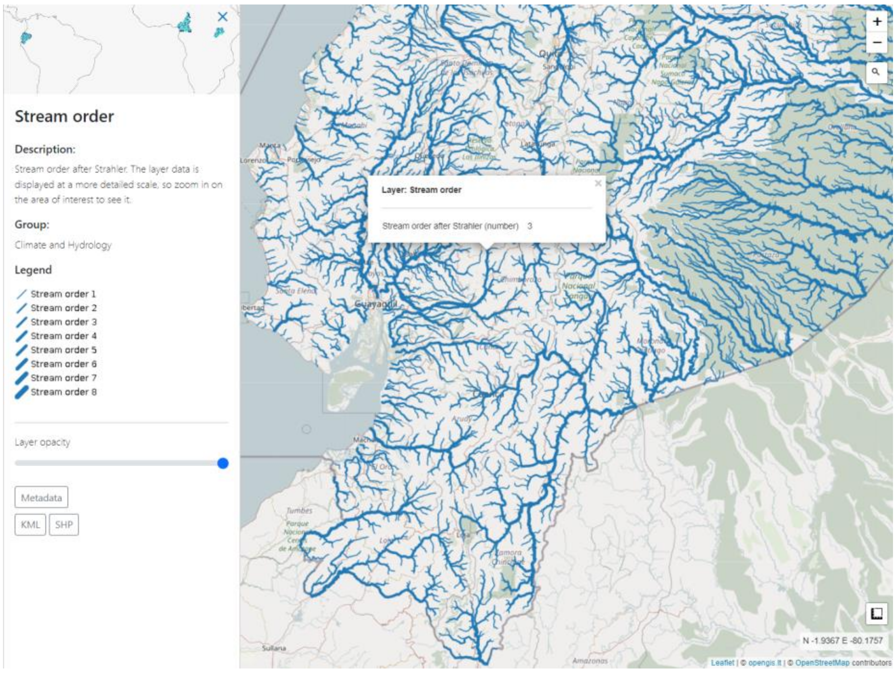

Figure 3.10. Rivers and streams (geospatial polyline layer) with the Strahler stream order highlighted in Ecuador.

Data is available for downloading (Shape and KML files). The following attributes are available:

#	Attribute	Description
1.	GridID	Grid ID, which can be used to determine the corresponding sub-basin
2.	Country	Country
4.	River	River or stream name
5.	Riv_Order	River order (Strahler system)
6.	Length_km	Stream-reach length, km
7.	A_us_km2	Upstream (start) catchment area of a stream reach, km^2
8.	A_ds_km2	Downstream (end) catchment area of a stream reach, km^2
9.	Q_us_m3_s	The upstream flow of a river reach, m^3/s
10.	Q_ds_m3_s	The downstream flow of a river reach, m^3/s
11.	H_m	The elevation difference from the start to the end of a river reach, m.
12.	Slope_m_km	Slope, m/km
13.	P_MW	Stream-reach potential capacity, MW.
14.	P_MW_km	Specific hydropower potential, MW/km
15.	Area_km2	Catchment area between the start and end of a stream reach km^2
16.	Env_sens	Environmental sensitivity
17.	Exploited	Exploited stream reach
18.	Date	Date

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3.4.6 Small Catchments (sub-basins)

Includes mapped boundaries of small catchments with their respective areas, km^2 (Fig. 3.11).

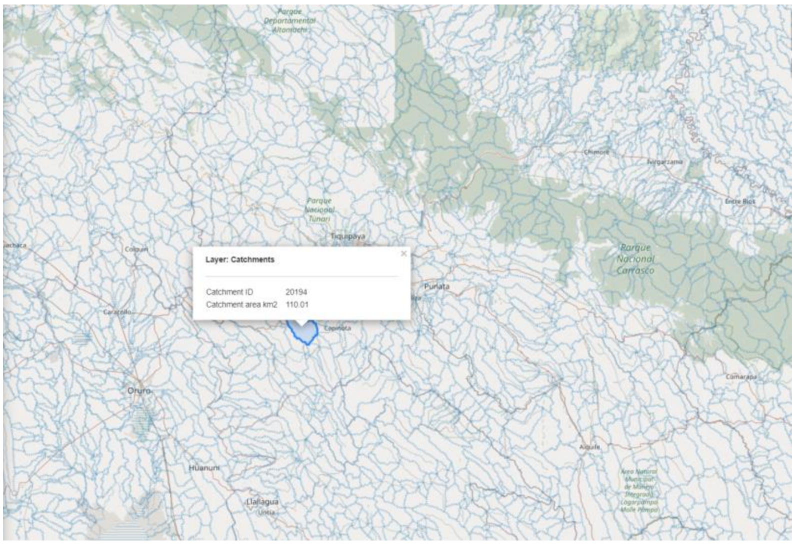

Figure 3.11. An extract of the small catchment area in Bolivia (geospatial polygon layer) A pop-up with a catchment area of 110.01 km^2 is highlighted.

The following attributes are available:

#	Attribute	Description
1.	fid	Fid
2.	GridID	ID of the sub-basin, which can be used to determine the corresponding river reach
3.	Country	Country
4.	Area_km^2	Sub-basin area, km^2

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3.4.7 Gauging Stations (GS)

The river and stream gauging network was mapped (geospatial point layer), including key characteristics of gauging stations (Fig. 3.12). The data was compiled from various sources, primarily national hydrologic yearbooks and respective national hydrologic services.

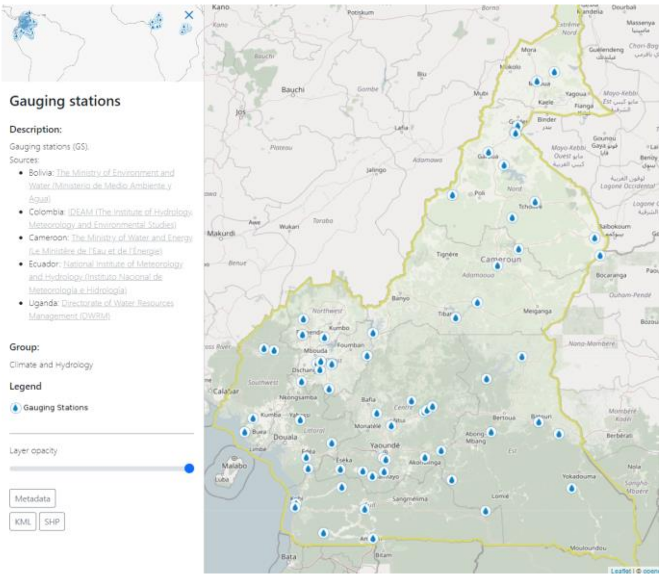

Figure 3.12. River and stream gauging stations (GS) network in Cameroon.

Data is available for downloading (Shape and KML files). The following attributes are available (shown only for Bolivia):

#	Attribute	Description
		Bolivia
1.	Country	Country
2.	Name_Gauge	Name of gauging station (GS.)
3.	Lat	Latitude (decimal degrees North)
4.	Lon	Longitude (decimal degrees East)
5.	Province	Province
6.	Municipali	Municipality
7.	River_Name	River name
8.	Conven	Year of the setup of conventional GS.
9.	Telemetry	Year of setup telemetry observation
10.	GS_Order	G.S. order
11.	Datum_m	G.S. datum
12.	Operator	G.S. operator
13.	Records	Record, yrs.
14.	Sediment	Sediment (yes/no)
15.	Flow	Flow (yes/no)
16.	Level	Level (yes/no)
17.	Precip	Precipitation (yes/no)
18.	Distance	Distance
19.	Comments	Comments
20.	Date	Date

External sources (Legal constraints)	• Bolivia: The Ministry of Environment and Water (Ministerio de Medio Ambiente y Agua). https://www.mmaya.gob.bo/ • Colombia: IDEAM (The Institute of Hydrology, Meteorology and Environmental Studies). http://www.ideam.gov.co/ • Ecuador: National Institute of Meteorology and Hydrology (Instituto Nacional de Meteorología e Hidrología). https://www.inamhi.gob.ec/ • Cameroun: The Ministry of Water and Energy (Le Ministère de l'Eau et de l'Énergie). https://minee.cm/ • Uganda: Directorate of Water Resources Management (DWRM). https://mwe.go.ug/directorates/directorate-water-resource-management • https://creativecommons.org/licenses/by-sa/4.0/. • https://www.openstreetmap.org/copyright • © OpenStreetMap contributors

3.4.8 Mean Annual Flow

Stream-reach mean annual flow (m^3/s) was mapped, including relevant metrics (geospatial polyline layer) (Fig. 3.13).

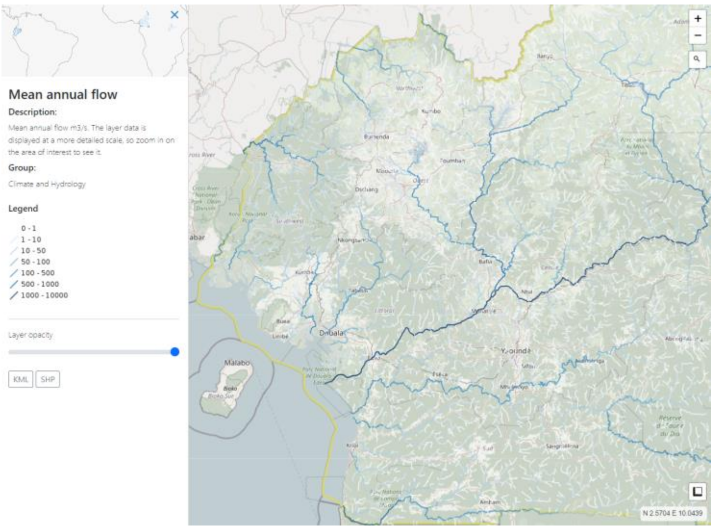

Figure 3.13. The mean annual flow of the rivers in Cameroon.

Data is available for downloading (Shape and KML files). The following attributes are available:

#	Attribute	Description
1.	GridID	Grid ID
2.	Country	Country
4.	River	River or stream name
5.	Riv_Order	River order (Strahler system)
6.	Length_km	Stream-reach length, km
7.	A_us_km2	Upstream (start) catchment area of a stream reach, km^2
8.	A_ds_km2	Downstream (end) catchment area of a stream reach, km^2
9.	Q_us_m3_s	The upstream flow of a river reach, m^3/s

10.	Q_ds_m3_s	The downstream flow of a river reach, m^3/s
11.	H_m	The elevation difference from the start to the end of a river reach, m.
12.	Slope_m_km	Slope, m/km
13.	P_MW	Stream-reach potential capacity, MW.
14.	P_MW_km	Specific hydropower potential, MW/km
15.	Area_km2	Catchment area between the start and end of a stream reach km^2
16.	Env_sens	Environmental sensitivity
17.	Exploited	Exploited stream reach
18.	Date	Date

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3.4.9 Normal annual specific runoff

Normal annual specific runoff is displayed to compute stream flow for ungauged basins (Fig. 3.14).

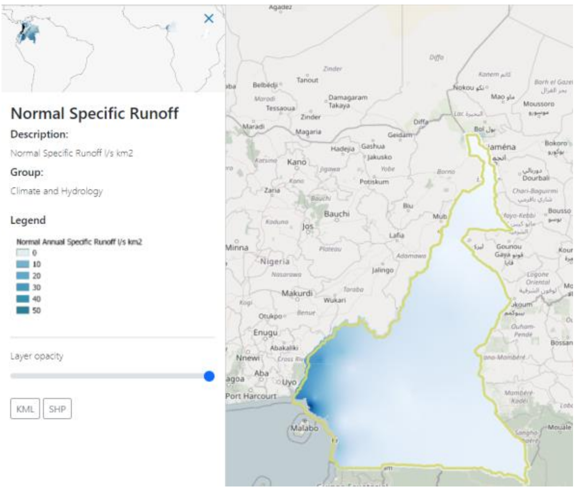

Figure 3.14. Normal annual specific runoff in Cameroon (geospatial polygon layer).

Data is available for downloading (Shape and KML files). The following attributes are available:

#	Attribute	Description
1.	fid	Fid
2.	Code	Country code
3.	Name	Name of the river basin
4.	Area_km2	Area of the river basin, km^2
5.	Major_Name	Name of the major river basin
6.	q_ls_km2	The normal specific runoff, $l/s{\cdot}km^2$

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3.5 Hydropower Potential

3.5.1 Potential sites of hydropower plants

Potential sites of hydropower plants, including stream reaches with high energy density, were compiled by local experts and GIS modelling tools (Fig. 3.15).

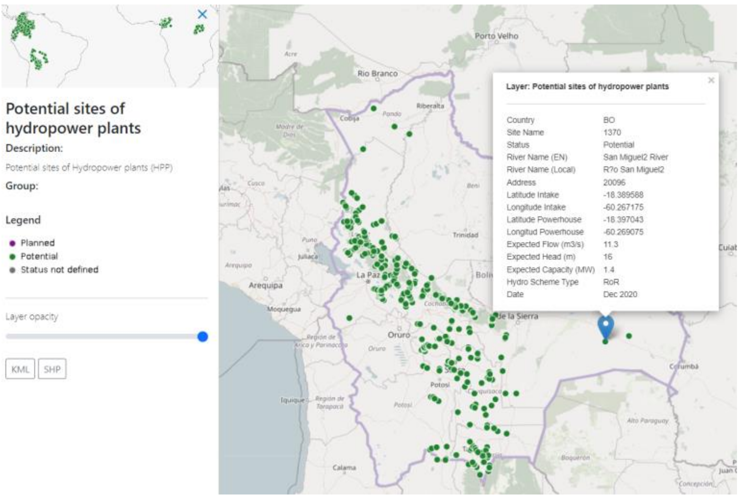

Figure 3.15. Potential sites of hydropower plants in Bolivia (geospatial point layer).

Data is available for downloading (Shape and KML files). The following attributes are available:

#	Attribute	Description
1.	fid	Fid
2.	Id	ID
3.	Country_Co	Country code
4.	Site_Name	Site name
5.	Status	Status (planned, potential, not defined)
6.	River_name	River or stream name
7.	River_local	River or stream local name
8.	River_Basin	River basin or hydrologic unit
9.	Address	Address
10.	Lat_Int	Latitude (decimal degrees North) at intake or dam
11.	Lon_Int	Longitude (decimal degrees East) at intake or dam
12.	Lat_PwH	Latitude (decimal degrees North) at powerhouse (if relevant)
13.	Lon_PwH	Longitude (decimal degrees East) at powerhouse (if relevant)
14.	Flow_m3_s	Discharge Q, m^3/s

15.	Head_m	Head H, m
16.	Capacity_MW	Hydropower capacity, MW. Calculated: P=0.0085QH
17.	Exp_Q_m3_s	Expected flow (preliminary), m^3/s
18.	Exp_Head_m	Expected head (preliminary), m
19.	Exp_P_MW	Expected power capacity (preliminary), MW
20.	Max_P_MW	Max power availability, MW.
21.	Scheme	Scheme type (RoR, RoR-D; S, S-D)
22.	Site_read	Site readiness for development
23.	Env	Environmental sensitivity
24.	Grid	On-grid or off-grid or distance, km
25.	Comments	Comments
26.	Date	Date

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3.5.2 Stream-reach potential capacity

Hydropower potential from New Stream-Reach Development (NSD), MW is displayed (Fig. 3.16).

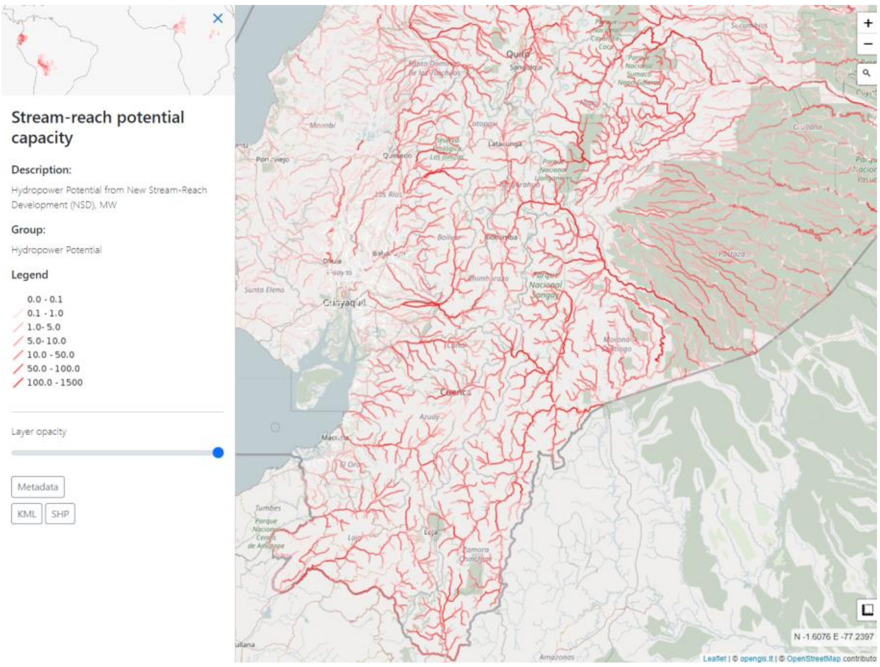

Figure 3.16. Hydropower potential from New Stream-Reach Development (NSD), MW in Ecuador (geospatial polyline layer).

Data is available for downloading (Shape and KML files). The following attributes are available:

#	Attribute	Description
1.	GridID	Grid ID
2.	Country	Country
3.	River	River or stream name
4.	Riv_Order	River order (Strahler system)
5.	Length_km	Stream-reach length, km
6.	A_us_km2	Upstream (start) catchment area of a stream reach, km^2
7.	A_ds_km2	Downstream (end) catchment area of a stream reach, km^2
8.	Q_us_m3_s	The upstream flow of a river reach, m^3/s
9.	Q_ds_m3_s	The downstream flow of a river reach, m^3/s
10.	H_m	The elevation difference from the start to the end of a river reach, m.
11.	Slope_m_km	Slope, m/km
12.	P_MW	Stream-reach potential capacity, MW.
13.	P_MW_km	Specific hydropower potential, MW/km
14.	Area_km2	Catchment area between the start and end of a stream reach km^2
15.	Env_sens	Environmental sensitivity
16.	Exploited	Exploited stream reach
17.	Date	Date

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3.5.3 The total hydropower potential of river basins

The total hydropower potential of the major river basins, MW, is displayed (Fig. 3.17).

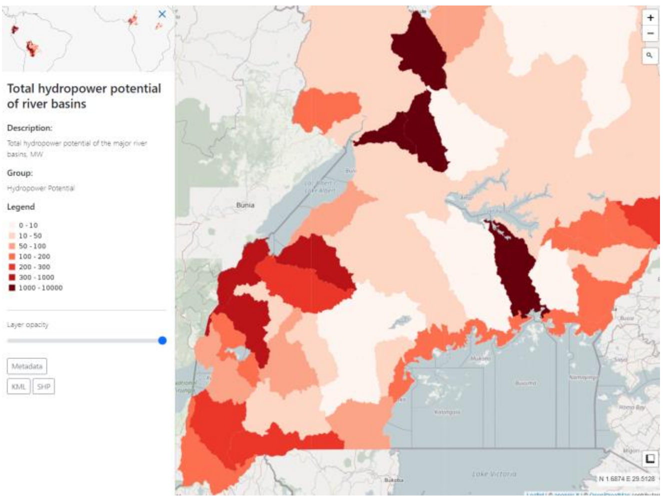

Figure 3.17. The total hydropower potential (MW) of the major river basins of Uganda (geospatial polygon layer).

Data is available for downloading (Shape and KML files). The following attributes are available:

#	Attribute	Description
1.	Fid	FID
2.	GridID	ID
3.	Power_MW	The total hydropower potential of the river basin, MW.
4.	Area_km2	River basin area, km^2
5.	Country	Country

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3.5.4 Specific hydropower potential

Stream reach specific hydropower potential (MW/km), including relevant metrics, was mapped (Fig. 3.18).

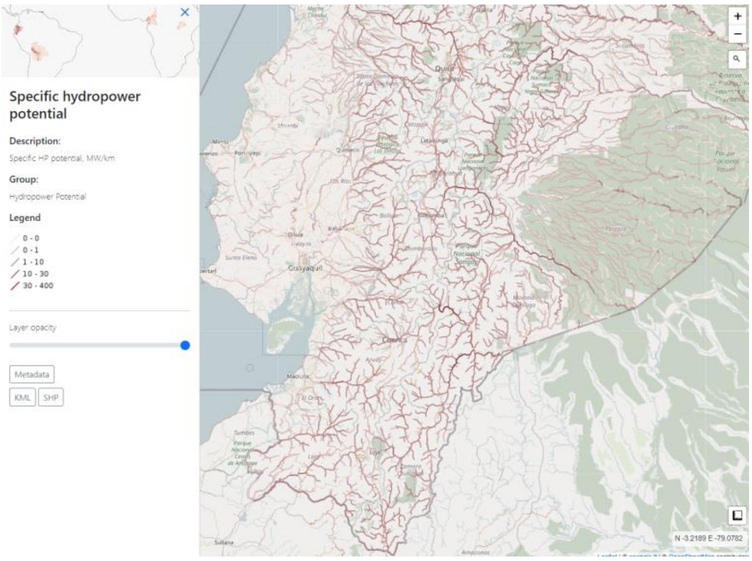

Figure 3.18. Specific hydropower potential (MW/km) in Ecuador (geospatial polyline layer).

Data is available for downloading (Shape and KML files). The following attributes are available:

#	Attribute	Description
1.	GridID	Grid ID
2.	Country	Country
3.	River	River or stream name
4.	Riv_Order	River order (Strahler system)
5.	Length_km	Stream-reach length, km
6.	A_us_km2	Upstream (start) catchment area of a stream reach, km^2
7.	A_ds_km2	Downstream (end) catchment area of a stream reach, km^2
8.	Q_us_m3_s	The upstream flow of a river reach, m^3/s
9.	Q_ds_m3_s	The downstream flow of a river reach, m^3/s
10.	H_m	The elevation difference from the start to the end of a river reach, m.

11.	Slope_m_km	Slope, m/km
12.	P_MW	Stream-reach potential capacity, MW.
13.	P_MW_km	Specific hydropower potential, MW/km
14.	Area_km2	Catchment area between the start and end of a stream reach km^2
15.	Env_sens	Environmental sensitivity
16.	Exploited	Exploited stream reach
17.	Date	Date

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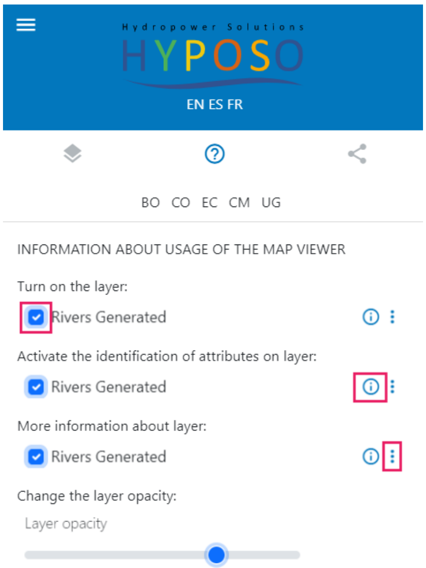
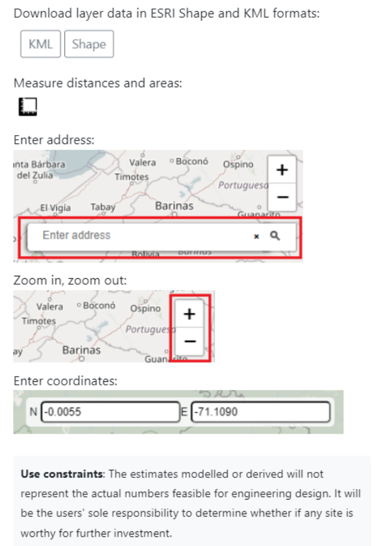
3.6 Help (Information window)

The following information about the usage of the map viewer is available:

- Turn on the layer
- Activate the identification of attributes on the layer
- More information about a layer
- Change the layer opacity
    - Layer opacity
- Download layer data in ESRI Shape and KML formats
- Measure distances and areas
- Enter address
- Zoom in, zoom out
- Enter coordinates

Use constraints: The estimates modelled or derived will not represent the actual numbers feasible for engineering design. The user will be responsible for determining whether any site is worth further investment.





3.7 Metadata information

The data displayed by the HYPOSO hydropower map viewer are publicly available or acquired under a public use agreement.

Contact: VMU (Vytautas Magnus University): petras.punys@vdu.lt
Publication date: 2023 04 30.
Technological solution and support of the mapping platform: Geographic information technologies, OpenGIS.lt, info@opengis.lt

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