World Hydropower Capacity Evaluation

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Abstract

A continuous population growth and increasing energy demand combined with depleting traditional energy reserves puts a pressure on conventional methods of electricity generation. Hydropower already plays a significant role in global energy production, and estimations on the capacity potential have been made. These estimations tend be inconsistent and incomplete. Recent studies pointed out that GIS-based analysis are useful to estimate the hydropower potential for a specific region. This study, based on a new global approach, aims to give better insight in the hydropower capacity potential, the spatial distribution and the distribution of potential between micro, small and large hydropower. Global input data on DEM and Runoff are processed in a model with a raster based approach to systematically simulate hydropower potential capacity. It is computed that the total gross theoretical hydropower capacity potential is about 20TW with Asia as the largest contributor. Large hydropower accounts for over 80% of this potential while micro hydropower only accounts for 2% of the total potential capacity. This paper demonstrates new, insightful images on spatial hydropower distribution, showing that Colombia, Myanmar, Indonesia and Madagascar are examples of areas with extensive hydropower potential. Overall this study provides a consistent global modeling approach that allows both a quick comparison of hydropower potential between regions as detailed information on a specific hydropower location.

[1] Introduction

Today, the worldwide installed energy capacity is over 17 TW. In the year of 2050 this will be 32 TW. With depleting fossil fuels it is inevitable that alternative energy resources are going to play a significant role, including the 'renewables' [Mulder, 2011]. The future energy supply will have to come from a mix of different sources and techniques. There are a lot of different scenarios of compositions but the common consensus is that renewables will fulfill over 50% of the energy consumption within 40 years from now [Shell, 2011]. New renewables such as *small hydropower*, wind, solar, geothermal and biofuels are currently accounted for 3%, and they are growing rapidly [REN21, 2011]. [2] The current installed hydropower capacity was about 1050GW in 2011. Some studies have been carried out to evaluate the world hydropower capacity, and the common consensus is that there is a technical potential of about 15.000TWh/year [Bartle, 2002] and a gross theoretical potential of about 40.000TWh/year. These numbers are also presented in reports on renewable energy from the International Renewable Energy Agency (IRENA) and the World Energy Council (WEC) and are supported by data from "Hydropower and Dams", World Atlas, 2009.

Quantifying the world's hydropower capacity however is open to debate and there are significant discrepancies and inconsistencies between data for each country [Taylor, 2010]. Energy potential is typically divided into gross theoretical, technical, and economical feasible potential and hydropower is further divided into micro, small and large hydropower.

Different methods and opinions exist on how to determine both gross potential and technical hydropower potential and they might differ from country to country. In a recent report from the World Energy Council (WEC, 2010) is stated that the technical potential hydropower is mainly based on visited spots in the past and therefore excludes sites that could be developed. Micro and small hydropower spots are many and their locations are mostly unknown, therefore the accumulated potential for especially micro hydropower is unclear. IRENA (2012) states that further work on mapping global hydropower potential is required and should be encouraged. Given the inconsistencies between both countries and approaches to estimate both gross theoretical and technical hydropower potential, a general systematical method to evaluate the world's hydropower potential might give a better insight in both the capacity and the distribution of the world's hydropower potential.

Recent studies already made accurate potential estimations based on a systematical, mostly GIS-based, approach for a specific area for example the hydropower potential assessment of the La Plata basin [Palomino Cuya et al., 2012], and the Kopili River basin in Assam [Kusre et al., 2009]. Different hydrological data and approaches are used varying from poorly gauged basins in Turkey using remote sensing and hydrologic modeling [Gonca Coskun et al., 2010] to a new GIS based model applied in Korea [Yi et al., 2010]. Other studies use more specific locally recorded data to calibrate their hydrologic models. On the other hand more systematical and larger applicable methods have been generated [Larentis et al., 2010] and the GIS tool VAPIDRO-ASTE [Alterach et al. 2008b.] Among others, these studies pointed out that GIS-based tools combined with hydrological models or data are useful to assess hydropower for a specific area.

However different studies with different models indicated that GIS-based approaches are useful for hydropower potential estimations, there still is a lack of consensus on the hydrologic models that should be used, especially for large scale areas with spatial varying characteristics. Hydrologic models are primary used for prediction and understanding of hydrological processes [Savenije, 2010] and includes hydrologic processes that might not essentially be of interest for hydropower development for which in fact only the runoff or river discharge is directly important. A new approach based on consistent global runoff data instead of local hydrologic models aims to bring clarity in the difference and discussion between hydropower capacity estimations and provide with a good global approximation of the world's gross theoretical hydropower potential.

As such, this research aims to give insight in the global theoretical gross capacity of hydropower potential and its spatial distribution by providing maps which separate micro, small and large hydropower. Given the global scale this research permits annual average discharges and similar capacities. Given the systematical and consistent applied method a more accurate approach of the globally allocation of hydropower spots should be obtained, leading to better insight in the potential future role of hydropower for different regions.

The outline of this paper is as follows. Section 2 explains the methods used in this study. It explains the head and discharge calculations and limitations and deals with the hydrological assumptions necessary for global modeling. It also presents the input data used and provides a schematization of the hydropower calculation model. Section 3 presents the results of this study and gives insight in the global availability and distribution of hydropower. In section 4 the results are discussed and compared with available data. Finally section 5 contains conclusions and suggestions for improvement and further research are given.

[2] Methods

[2.2] Input Data

The Digital Elevation Model (DEM) and Flow Direction (DIR) data used in this study are taken from 'Hydrological data and maps based on Shuttle Elevation Derivatives at multiple Scales' or HydroSHEDS. A lot of effort has been taken by the USGS to improve the DEM for hydrological purposes. Modifications in the DEM and several improvements such as 'sink removal' have been carried out to obtain a Conditioned DEM (ConDEM) from which a DIR map has been derived with optimal river flow characteristics [*Lehner, 2005*].

The runoff data is taken from the UHN-GRDC Composite Runoff Fields V1.0 dataset. This dataset is produced by combining river discharge measurements with a climate-driven Water Balance Model, resulting in a monthly average, 30-minute spatial data set. The discharge measurement period varies per gauging station and as precipitation and runoff fluctuate in time and space, the runoff fields can be regarded as "best estimate" of terrestrial runoff [*Fekete et al., 2004*].

The Runoff data (Figure 1) covers all continents except Antarctica while the DEM and DIR data sets cover the globe between the latitudes 70°S and 60°N, which excludes the most northern parts of Canada, Scandinavia and Russia from this research. We are aware of the fact that locally, more detailed data, models and information might exist on both hydrology and geography but on a global scale the UHN-GRDC (0.5°) and HydroSHEDS (3") data provide us with consistent and high resolution information, suitable for a global modeling approach.

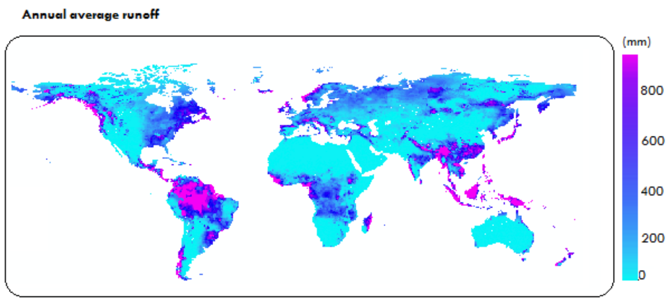

Figure 1: Annual Average Runoff

[2.1] Modeling Approach & Definitions

Our study uses a distributed, raster based approach. It is based on a 3”x3” latitude, longitude grid. The research area, nearly the whole globe, is divided into grid cells for which the elevation and flow direction are known. All hydropower potential calculations are based on the characteristics of these grid cells. The runoff weighted flow accumulation algorithm is used to calculate the accumulated runoff that drains to each cell. In section 2.3 this is explained in further detail. Selection criteria determine whether a cell should be regarded as a ‘river’ cell and for those cells the accumulated runoff is converted into river discharge (m^3/s). Other cells are assigned ‘NoData’. The result is a raster map that contains river cells and their corresponding discharge that together form a discretized approximation of all the rivers on earth. We now know the annual average discharge and the elevation for each 3” section of each river. The next step is to determine the head within each 3” river section, or river grid cell.

Runoff and discharge refer to flow of water but for this research the terms runoff, runoff input data (mm/month) and runoff per grid cell (m^3/month) are addressed to the amount of water that drains from each cell before any accumulation calculations have been executed. After these calculations the flow of water is addressed as discharge (m^3/s) and after selection has occurred flow of water is addressed as river discharge (m^3/s). Other studies address this river discharge as flow rates or stream flow. Some specific GIS-based terms are DIR (flow direction) and FlowACC (flow accumulation). Cell_Area and Cell_Length refer to the physical surface area (m^2) and cell length (m) of a single 3”grid cell. These values decrease at latitudes further removed from the equator, when the original square grid cells are approximated by trapezoids.

[2.3] Selection Criteria & Calculations

For this research we used the general hydropower defined as:

$$P = Q \cdot H \cdot \eta \cdot g \qquad (1)$$

Where P is the hydropower capacity (kW), Q is the discharge (m^3/s), H is the head (m), η is the turbine efficiency (%) and g is the gravitational acceleration (m/s^2).

[2.3.1] Discharge & Q_{min}

The river discharge is simulated using a ‘flow accumulation’ algorithm. The globe is divided into 3” resolution grid cells. Each grid cell is assigned a certain ‘drain direction’, determined by the HydroSHEDS input DIR-map and a runoff value derived from the GRDC Global Runoff Fields. The runoff (mm/month) is multiplied with the corresponding surface area (m^2), (depending on the latitude). Based on the flow direction (-), and weighted with the runoff (m^3/month) an accumulation was executed to calculate the accumulated runoff for each grid cell. This accumulated runoff should be regarded as the sum of runoff from each upstream cell. The runoff is further converted into river discharge (m^3/s). The result of this calculation is a 3” resolution global map containing the accumulated runoff and river discharge for each grid cell. The key is now to distinguish the cells that are in fact river cells (have enough accumulated runoff so that surface flow is likely).

The calculated accumulated runoff or discharge for each pixel needs to be filtered by an input variable called Q_{min} which is the minimum amount of discharge required to regard a pixel as a ‘river’ with enough discharge to be of interest for run-of-the-river hydropower development. On the other hand the calculated accumulated runoff needs to be surface runoff. High discharges for a specific grid cell result in unrealistic high groundwater flow velocities and surface runoff is likely to occur. So called high-head-low-discharge turbines can operate with a very small amount of discharge (<50L/s). The key here is to select such a Q_{min} value that it is likely that surface runoff occurs and that no discharges of interest for hydropower development are neglected. This dilemma only plays a role in the smallest part of the hydropower spectrum since larger discharges (>>Q_{min}) are without questioning regarded as a river cell. With the previous arguments in mind we selected a Q_{min} of 100L/s.

[2.3.2] Head & H_{min}

For ‘run-of-the-river’ hydropower we are interested in the slope and the head within the river. A systematical slope calculation therefore should be executed regarding only the elevation of a river cell with respect to its up- and downstream neighbors. A separate RiverDEM map was generated, assigning only an elevation value to a cell if the discharge meets the selection criteria for a river. As a result a map is obtained which contains the slope of each cell that actual is a river. This slope is further multiplied with the corresponding cell length to obtain the head within each river cell.

The minimum head as an input variable filters the head required for hydropower development. Basically the minimum head is determined by the type of turbine, the low-head turbine in specific. Low-Head turbines deal with a head in the range between 2m and 35m [Krompholz, 2008]. The accuracy of the input data should be taken into account as well. Gorokhovich and Voustianiouk [2006] showed that the accuracy of CGIAR DEM products increases for terrains with slopes greater than 10^0, this suggest a higher H_{min} than the minimum head required for turbines. The higher the head difference over the grid cell, the more feasible it becomes to develop hydropower, and the more accurate the approximation will be. On the other head we don't want to exclude micro hydropower locations. Sensitivity studies showed that a minimum head less than 10m per grid cell tends to exclude micro hydro potential. Since we are interested in the total of theoretical gross potential we selected a minimum head per grid cell of 4m.

[2.3.3] Turbine Efficiency

Several losses are involved during the conversion of potential and kinetic energy of water to electricity. Typical efficiencies for hydropower turbines range between 60% and 90% [Paish, 2002]. In our approach we use annual average discharge which implies that it is unrealistic to assume optimum design flows. The actual efficiency is very hard to estimate on annual average and global scale and therefore could be assumed to be 1 and be modified for specific locations or regions. To give a more realistic first impression of the global hydropower capacity an average efficiency of 70% is assumed here.

[2.4] Model Assumptions

Global modeling of both river discharge and hydropower potential includes simplifications and assumptions and there are certain limitations. The river discharge is simulated as an annual average value, and therefore the hydropower capacities are annual averages as well. The annual average has been derived from the monthly averages. The actual discharges will fluctuate strongly around these averages. For run-of-the-river hydropower development the installed capacity will mainly be based on the average fluxes because no reservoirs are used. For global average capacity estimations the annual average discharges are therefore justified.

The selection criteria Q_{min}, H_{min} and Turbine Efficiency remain arbitrary. This research' results can be easily modified by other selection criteria values by filtering the lower discharges or head values. The turbine efficiency can be adjusted by multiplying the results with another factor. We aimed for criteria values that would give the most complete impression of the total amount of theoretical hydropower capacity.

Other studies used a more complex site location algorithm based on DEM characteristics. Larentis et al. [2010] included possible powerhouse and penstock configurations and Yi et al. [2010] derived potential reservoir storages and dam specifications from a DEM. Our global approach is only based on the actual head within the river, which suits run-of-the-river hydropower development. No complex penstock configurations are included in this research.

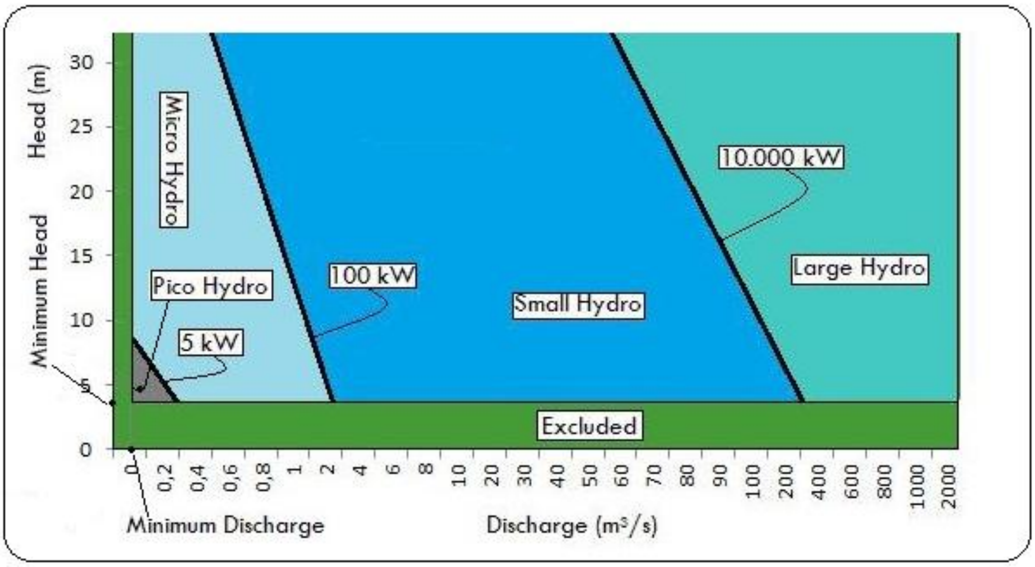

Figure 2: Research Area

[3] Results

[3.1] Discharge Simulation

The runoff weighted flow accumulation as explained under 'methods' results in a global river discharge raster database. Table 1presents the observed and simulated discharges of a selection of rivers from different continents. The difference between observed and simulated annual average discharge is indicated as well. For this research the annual average discharge of each river larger than 100L/s has been simulated. Some examples are presented here to give an impression.

Table 1: Annual average observed and simulated river discharge (m3/s)

River	Observed Average Discharge (m^3/s)	Simulated Average Discharge (m^3/s)	Relative Error (%)
Amazone	209000	210111	1%
Congo	41200	40020	-3%
Orinoco	33000	32086	-3%
Madeira	31200	42947	38%
Yangtze	30166	28563	-5%
Paraná	17290	16911	-6%
Mississippi	16792	19585	17%
Mekong	16000	15302	-4%
Niger	9570	10235	7%
Volga	8060	7569	-6%
Ohio	7957	7928	0%
Columbia	7500	7215	-4%
Danube	7130	6368	-11%
Zambezi	7070	10174	44%
Rhine	2330	2434	4%
Rhone	1710	1658	-3%
Colorado	614	539	-12%

The comparison between simulated discharge and observed discharge is used as a validation indication. In general it is found that the annual average discharge is simulated quite accurate for regular river configurations. The location of the rivers as derived from a DEM using DIR is very accurate as well, this can be, and has been validated by a graphical overlay of the simulated river network over satellite image data. Figure 3 shows an overlay for the river mouth of the Magdalena, Congo and Orinoco River. The delta of these rivers is not as complex as other rivers such as the Amazon. Complex Delta systems, confluences and bifurcations and artificial elements as irrigation and dams are the main source of simulation errors. The flow direction algorithm is not capable of diverging flows so in deltas or artificial split-ups the simulation can be less accurate. In almost any delta these bifurcations occur in lower areas (with very little head) which are not suitable for hydropower development and therefore the effect on the hydropower potential is damped out.

Figure 3: Simulated and Satellite river mouth of Magdalena, Congo and Orinoco River

[3.2] Spatial Hydropower Distribution

The global, spatial distribution of large, small and micro hydropower is presented in Figure 4, Figure 5 and Figure 6. The regional spatial distribution is presented in Figure 7 and Figure 8

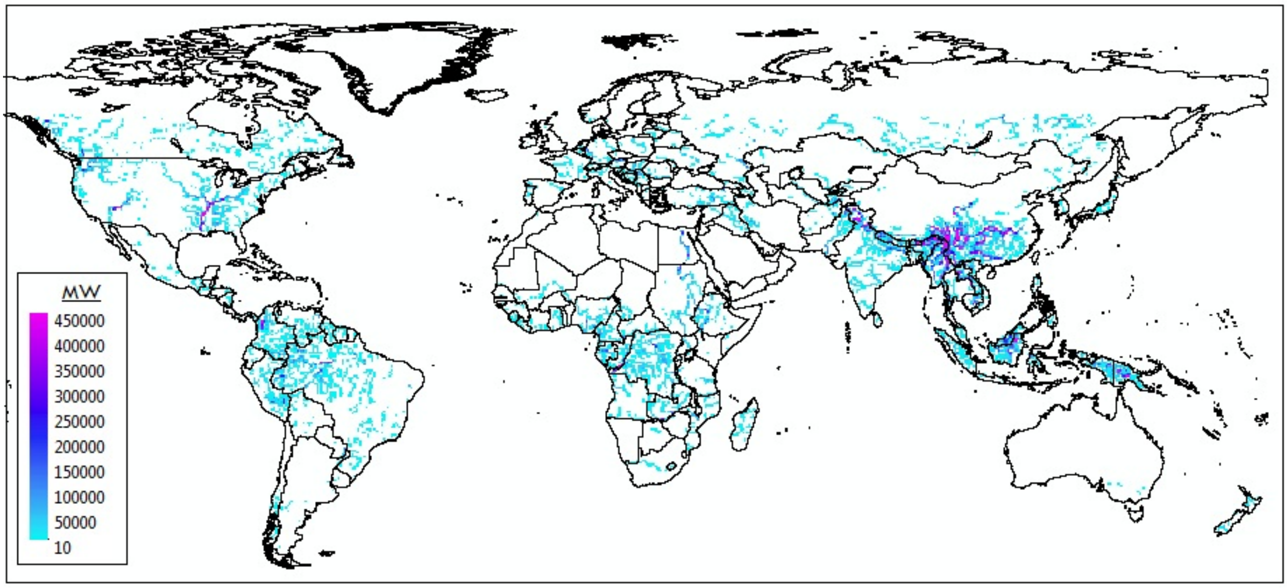

Figure 4: Large hydropower distribution *(>10.000 kw)*

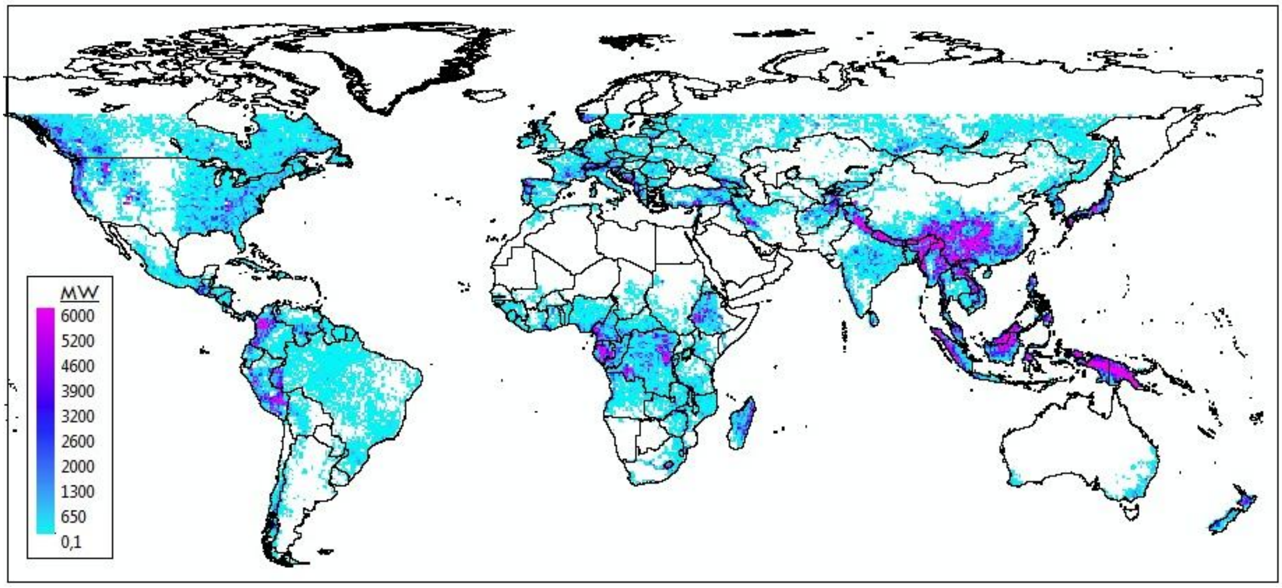

Figure 5: Small Hydropower distribution *(100<kw<10.000)*

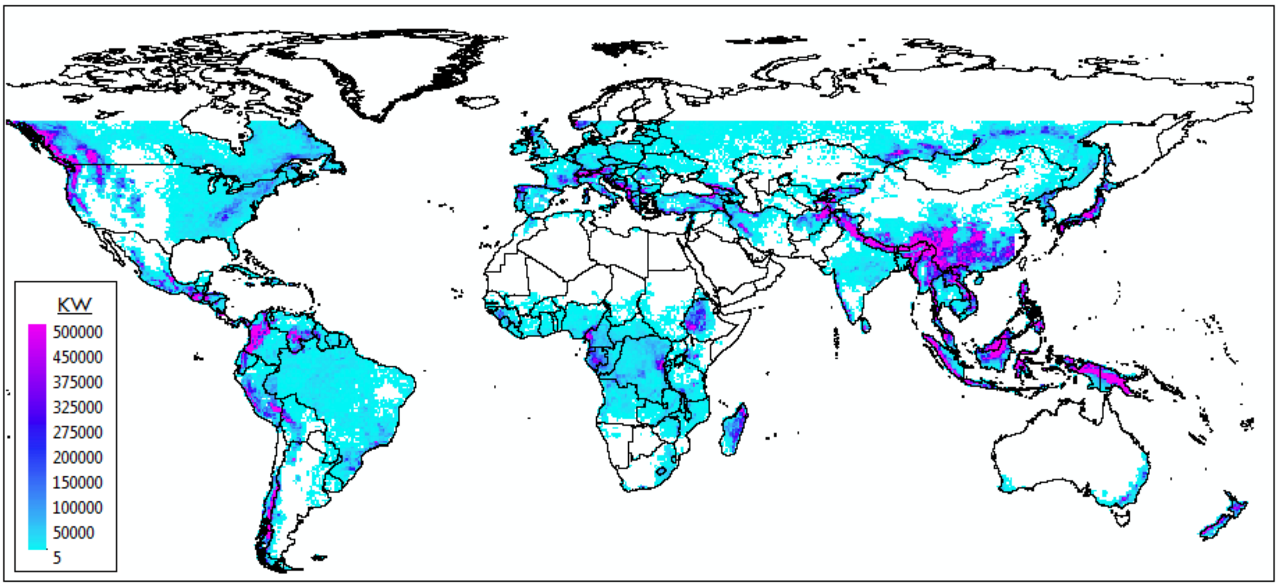

Figure 6: Micro hydropower distribution *(5<kw<100)*

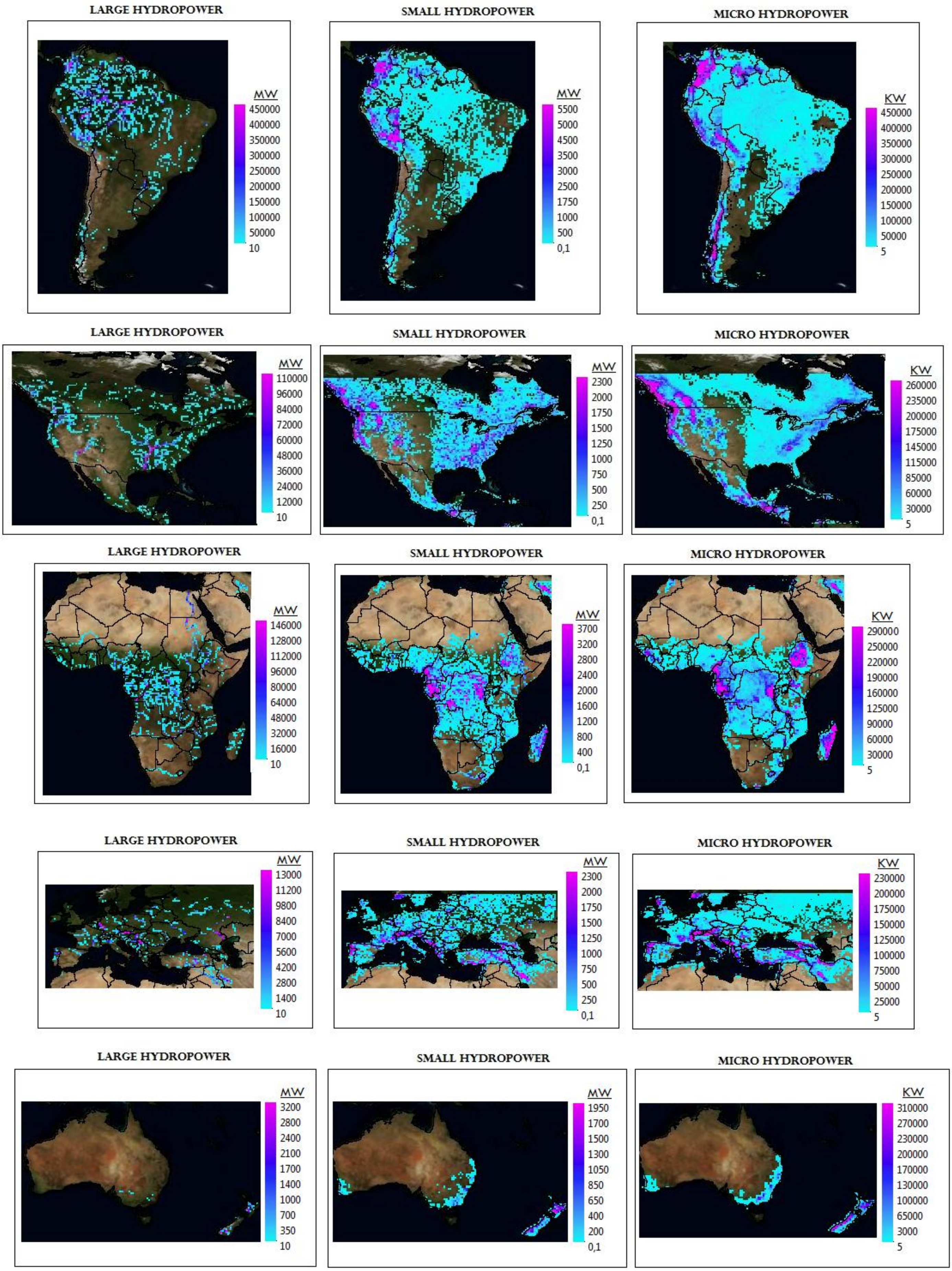

Figure 7: Large, Small and Micro hydropower presented per continent. Scale 1:100.000.000 (South America and Oceania), scale 1:120.000.000 (North America, Africa and Europe)

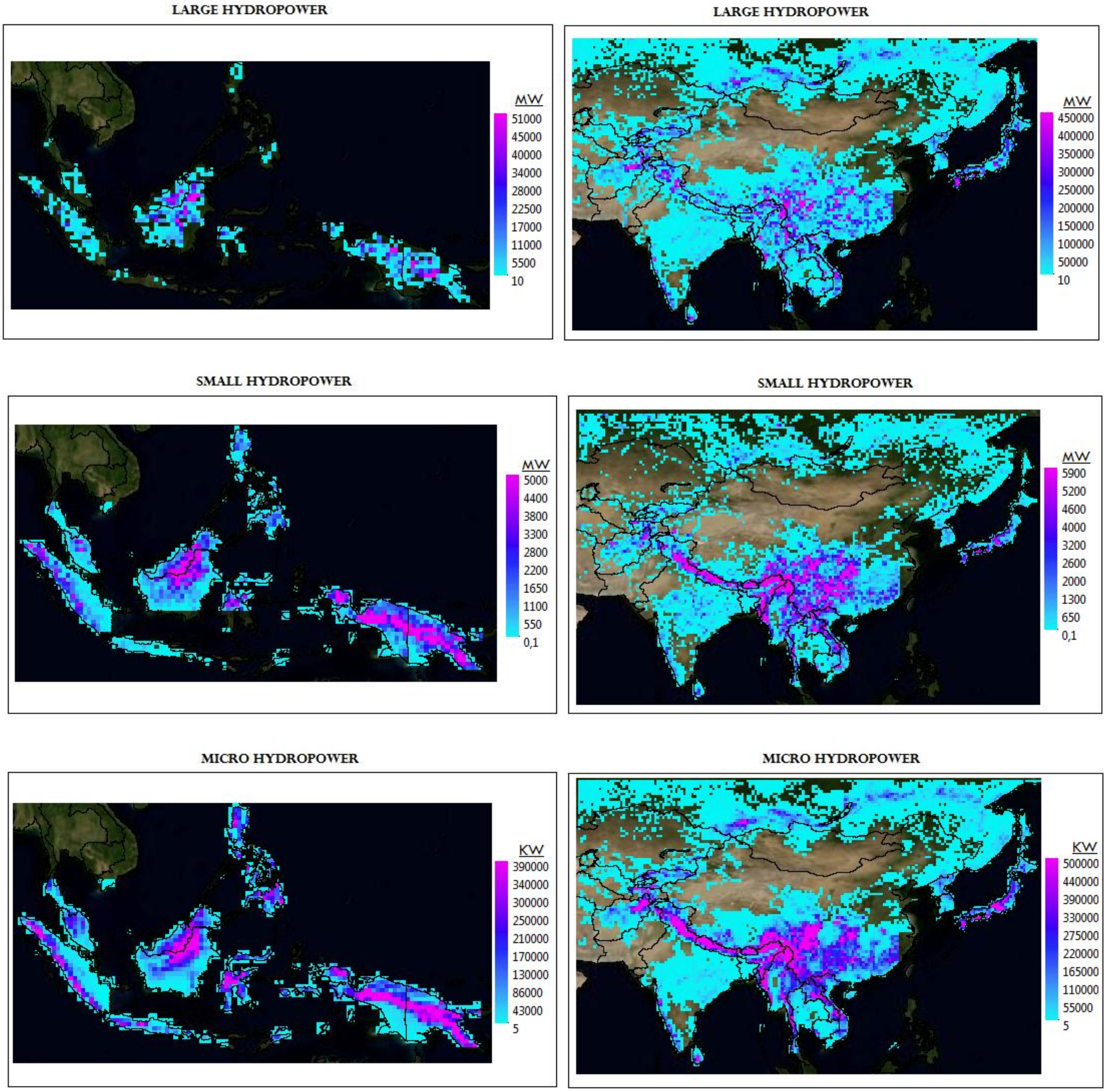

Figure 8: Large, Small and Micro Hydropower. Scale 1:50.000.000 (Indonesia) and scale 1:80.000.000 (Asia)

[3.3] World hydropower capacity potential

The accumulated global gross hydropower capacity potential is calculated as an annual average. The total capacity potentials are presented in Table 2 and Figure 9, all values in GW. The total global amount of gross theoretical hydropower potential is 19943GW or 19.9TW. Asia is the largest contributor to this potential, followed by Africa and North America. Indonesia is not included in the potential of neither Asia nor Oceania but presented separately here to show more detail on an interesting area which consists of many islands and has a huge potential.

Table 2. Annual average gross hydropower capacity per Continent

Region	Total (GW)	Large (GW)	Small(GW)	Micro(GW)
Africa	2112	1729	355	27
Asia	12121	10714	1258	149
Oceania	52	7	30	15
Europe	792	540	217	35
Indonesia	1579	1000	517	63
North America	2038	1653	327	58
South America	1251	1001	245	50
All Continents	19943	16644	2949	396

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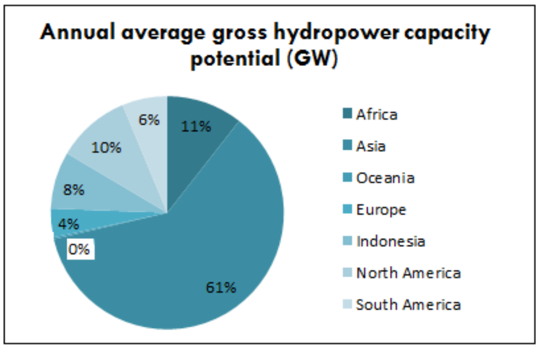

Figure 9: Visual interpretation of hydropower potential distributed per Continent

Table 2 contains information on the distribution of potential between the different sources; large, small and micro hydropower as well. Besides the distribution of hydropower potential between regions Figure 10 presents the distribution between large, small and micro hydropower for the globe (total) and per region.

Globally, large hydropower locations account for about 83% of the total capacity potential, small hydropower accounts for 15% and micro hydropower accounts for 2%. Although the amount of large hydropower locations is much less common than small and micro hydropower, and they are distributed more unequally (Figure 4), they account for the largest part of the hydropower capacity potential. On regional scale, there are significant differences to be found in this distribution. Oceania has a large (30%) contribution of micro hydropower and Indonesia has a significant contribution of small hydropower (33%). In this research is found that for larger areas, regions or continents the contribution of large hydropower is dominant. For smaller catchments or islands, micro and small hydropower play a larger role. The reason for this can be found logically in the development of large rivers for larger areas.

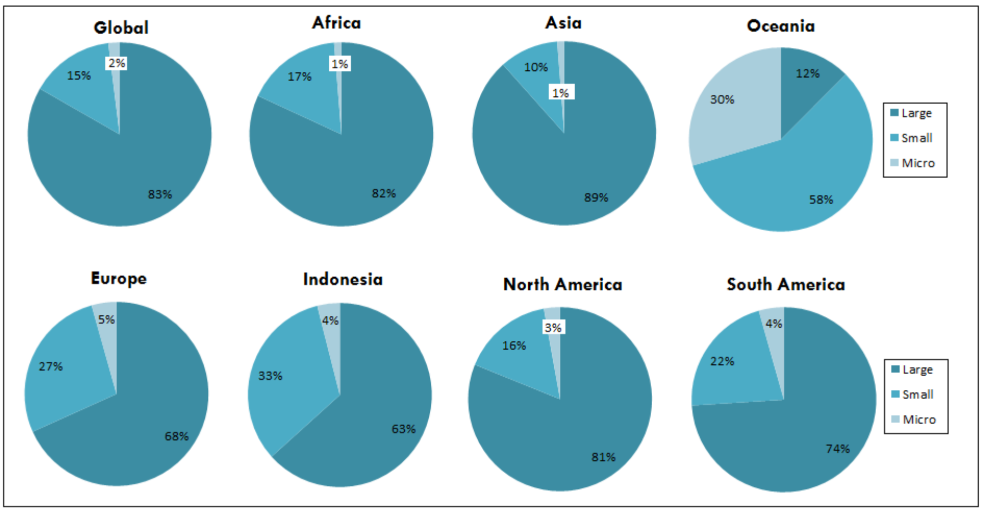

Figure 10: Hydropower capacity potential distribution per category; large, small and micro hydropower. Global and regional distributions.

[4] Discussion

The aim of this research was to give insight in the global gross theoretical hydropower capacity and its spatial distribution. We attempted to do this by creating a consistent model and simulate input data. Since our model is only an approximation of reality, the discrepancy between the actual situation and the simulated results determines the effectiveness of the model and the significance of the results. The significance of the results is here considered by an evaluation of the results, a selective comparison with reality (validation) and a comparison with results of recent studies on hydropower potential.

[4.1] Evaluation of results

Basically the main components that have been simulated here are the head and the discharge. The head is derived from the calculated slope within the river. The accuracy of the head depends on the accuracy of the input DEM data which increases for areas with steeper slopes (see section 2.3.2). Inaccuracies and errors in the DEM reduce the reliability of GIS and DEM-based approaches but Larentis et al. [2010] and several other studies already concluded that DEM based studies yielded relevant results regarding hydropower potential evaluation.

The annual average river discharge gives a good indication of the rivers magnitude, however the actual monthly and daily river discharges can and will fluctuate strong around the annual average, and so will the hydropower potential. No reservoirs are included in this research (run-of-the-river hydropower) so the actual hydropower potential for a specific site or region might differ significantly from the value indicated in this research. The accuracy of the simulated annual average value and the spatial consistency of the used hydrologic input data (runoff from GRDC) gives a good impression on the annual average hydropower potential for a specific region or a single location. This leads to a good comparison of hydropower potential between regions, and gives a good indication of the range of hydropower capacity to be installed at a specific site.

[4.2] Validation on existing large hydropower plants

A very effective way of validating single simulated results is to compare them directly with reality by means of an overlay evaluation. Simulated large hydropower locations are here compared with actual installed hydropower capacity. This is just a random selection of large hydropower plants, selected for availability of clear satellite images. Figure 11presents six large hydropower plants and the simulated potential at the same location. From this image it becomes clear that the model is able to simulate the location of large hydropower plants quite accurate.

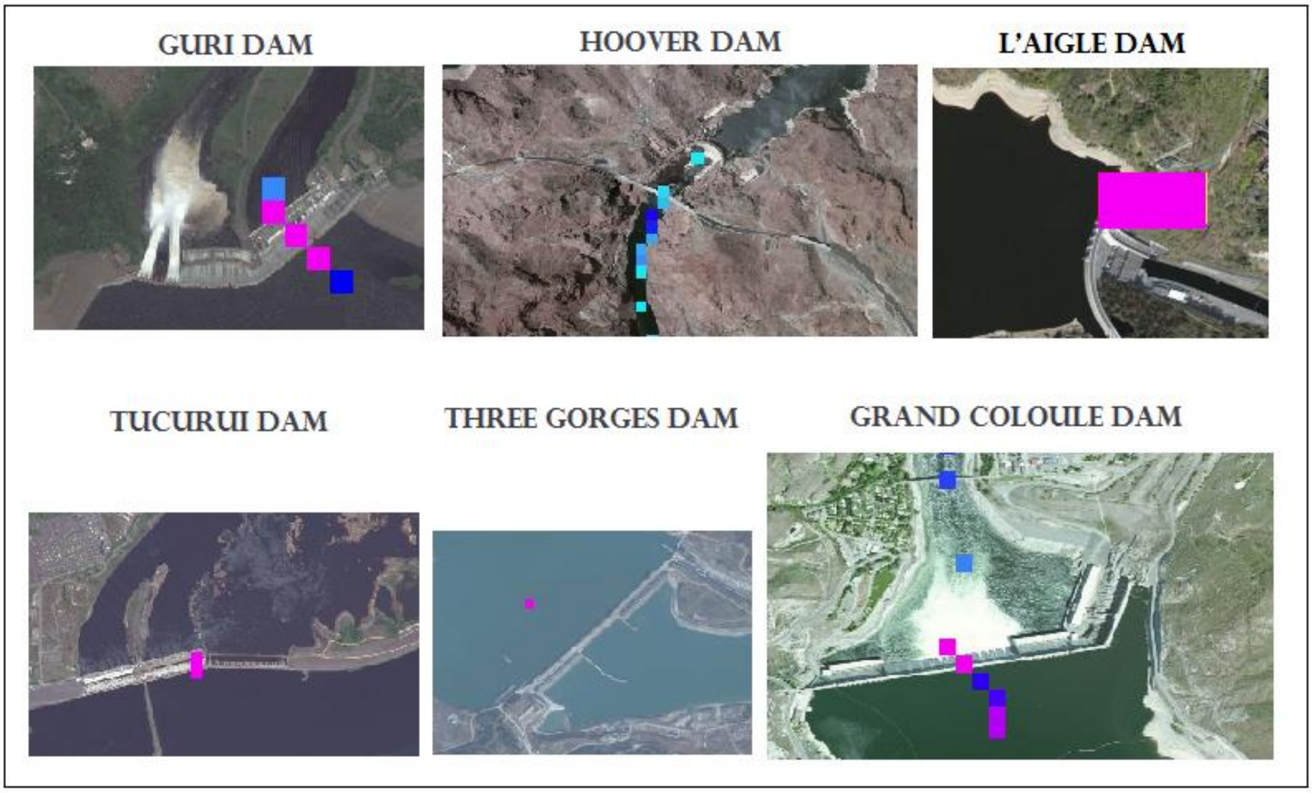

Figure 11: Actual large hydropower plants versus simulated hydropower potential locations

The trend is that there is a difference in installed and simulated capacity in large hydropower plants. This can be explained by the fact that large hydropower dams use an increased head obtained by the elevation of the dam. In the case this difference in elevation is included in the DEM it is still possible that the technical installed capacity is larger in order to be able to deal with peak discharges. Table 3 gives a comparison of a random selection of large hydropower dams. Error! Reference source not found. shows an example of hydropower potential locations.

[4.3] Comparison with existing data on hydropower potential

In reports from the WEC, quite detailed estimations on continental and national hydropower potentials are presented. As described in the introduction these estimations appear mainly based on visited sites, and different approaches are used for different areas which makes a comparison of no practical use [WEC, 2010].

Table 4: Comparison annual average capacity

Region	This Research gross potential calculation (GW)	Estimated by Hydropower & Dams World AtlasA (GW)	Difference factor (-)
Africa	2112	272	7,8
Asia	12121	1940	6,2
Europe	792	614	1,3
Indonesia	1579	265	6,0
North America	2038	847	2,4
Oceania	52	55	1,0
South America	1251	660	1,9
Global	19943	4652	4,3

Table 4 contains a comparison between average annual capacities between this research outcomes and earlier estimations made by Hydropower & Dams World Atlas and published by the WEC. [A]The original values from the WEC report are presented in production (GWh/yr) and are converted to GW here. As mentioned before, the gross potential estimates from earlier studies are based on different methods and appear to be based on visited sites as well. This could explain the large difference in estimations for especially Africa and Indonesia. Other regions tend to have a better correlation, but in general this research tends to yield higher values of gross potential hydropower.

Table 4: Comparison annual average capacity

Region	This Research gross potential calculation (GW)	Estimated by Hydropower & Dams World Atlas[A] (GW)	Difference factor (-)
Africa	2112	272	7,8
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South America	1251	660	1,9
Global	19943	4652	4,3

[4.4] Cautionary notes

The gross potential hydropower capacity as presented in this research suffers like any model from some assumptions and simplifications. For further research and better interpretation of the results some cautionary notes are made here. This research is a raster-based approach with a 3" resolution grid. Since the head is calculated over a single grid cell, the resolution might influence the result. This is taken into account in the fact that a steeper slope over a longer distance than one grid cell, and thus a greater head, will result in more separate hydropower potential locations in a row. The linear relation of the hydropower formula allows this assumption. Furthermore, complicated penstock configurations with short-cuts are not considered here. Reservoirs are not included in the model as well. The selected input variables, turbine efficiency, H_{min} and Q_{min} are dealt with in section 2. There is a significant difference between annual electricity production and annual average capacity potential. This research focusses on capacities. Further processing the results to technical capacity potential requires more detailed information on local characteristics as geology, sediment transport and many more.

[5] Conclusions

We conclude that the gross theoretical, annual average, global hydropower capacity potential is about 19943GW or about 19.9TW and this is more than estimations made by previous studies. Asia is the largest contributor of hydropower potential. Large, small and micro hydropower account for respectively 83%, 15% and 2% of this potential. Today, the global installed energy capacity exceeds 17TW and this will be 32TW in the year of 2050 (Mulder, 2011). This implies that the total amount of gross theoretical hydropower capacity cannot fulfill the global electricity demand, however, especially large hydropower plants are already large contributors and their untapped potential is still huge. This research clearly indicates areas with a lot of hydropower potential, and has successfully provided insight in the spatial distribution of hydropower potential.

In general, we conclude that the runoff weighted flow accumulation based on a 3" DIR raster results in an accurate global river discharge database which contains the discharge of each section of each river. Validation and interpretation of our results suggest that modeling the gross theoretical hydropower potential on a global scale results in significant and practical results.

We suggest further research to focus on simulating 12 runoff months instead of the annual average runoff to give better insight in the annual fluctuations of both river discharge and hydropower capacity potential. Improvements in the DEM algorithm might allow more accurate capacity estimations. As earlier studies indicated, a local hydrologic model can improve river discharge simulation for relative small areas. Altogether the results of this global approach can locally be optimized for more accurate results. Validation of our results basically can be done by executing a flow accumulation calculation based on HydroSHEDS' DIR data, weighted with the GRDC Runoff Fields or by contacting the author's for accessing the processed data. Further research should mainly focus on improving the dataset as produced by this research by improving DEM-head algorithms or adding local data. Finally this could lead to global modeling approach of technical hydropower potential and more information on hydropower production. Based on our global map, a more detailed evaluation can be carried out for an area with a lot of potential as well.

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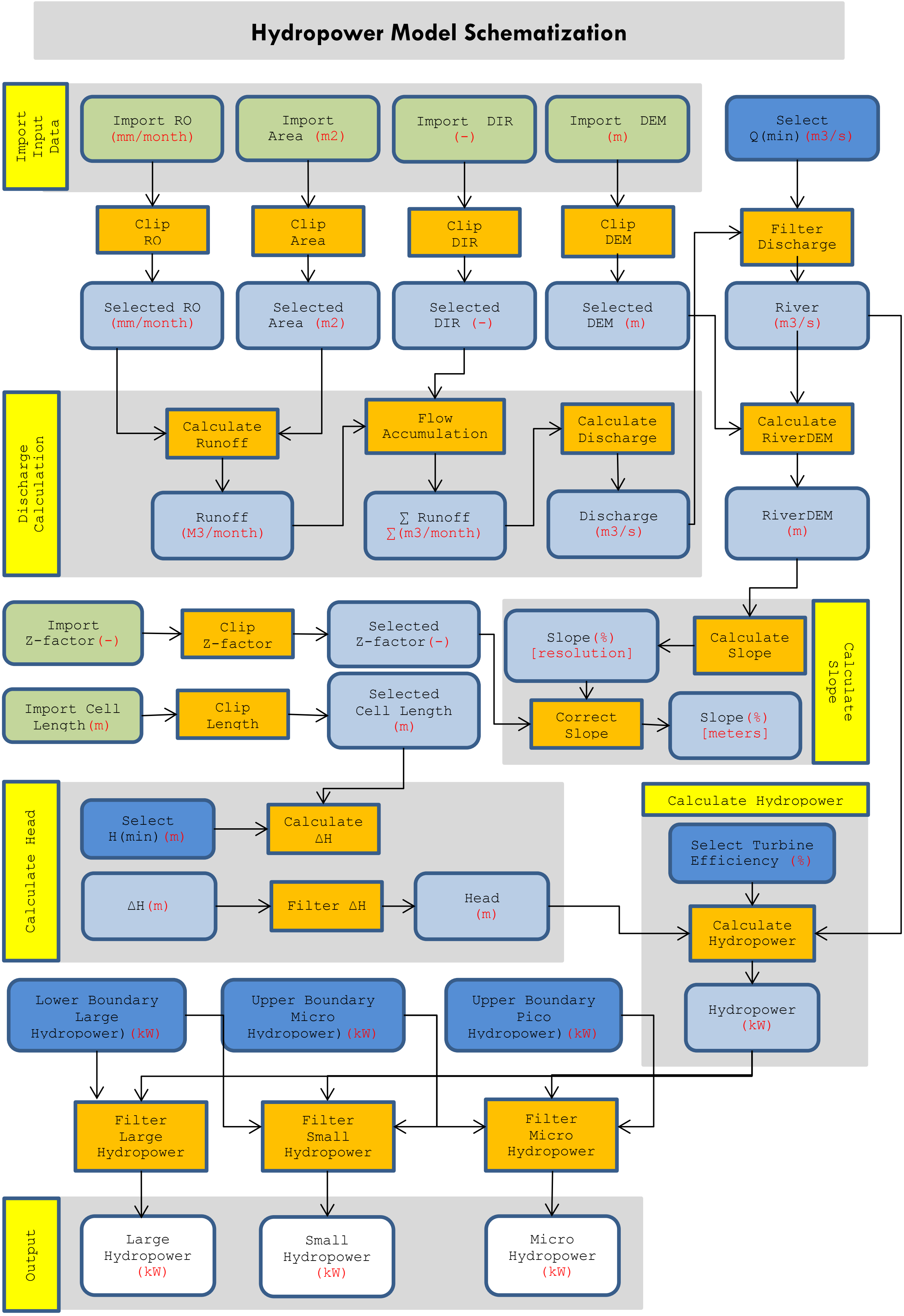
Appendix


Hydropower Model Schematization
Import Input Data
Import RO (mm/month)
Import Area (m2)
Import DIR (-)
Import DEM (m)
Select Q(min) (m3/s)
Clip RO
Clip Area
Clip DIR
Clip DEM
Filter Discharge
Selected RO (mm/month)
Selected Area (m2)
Selected DIR (-)
Selected DEM (m)
River (m3/s)
Discharge Calculation
Calculate Runoff
Flow Accumulation
Calculate Discharge
Calculate RiverDEM
Runoff (M3/month)
∑ Runoff ∑(m3/month)
Discharge (m3/s)
RiverDEM (m)
Import Z-factor (-)
Clip Z-factor
Selected Z-factor (-)
Slope (%) [resolution]
Calculate Slope
Calculate Slope
Import Cell Length (m)
Clip Length
Selected Cell Length (m)
Correct Slope
Slope (%) [meters]
Calculate Head
Select H(min) (m)
Calculate ΔH
ΔH (m)
Filter ΔH
Head (m)
Calculate Hydropower
Select Turbine Efficiency (%)
Calculate Hydropower
Hydropower (kW)
Lower Boundary Large Hydropower) (kW)
Upper Boundary Micro Hydropower) (kW)
Upper Boundary Pico Hydropower) (kW)
Filter Large Hydropower
Filter Small Hydropower
Filter Micro Hydropower
Output
Large Hydropower (kW)
Small Hydropower (kW)
Micro Hydropower (kW)