River Network Toolkit (RivTool) – A new software for river networks

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Abstract

Studying freshwater environments at broad spatial scales using detailed river network information is a challenging task. Acquiring and relating biological, environmental, hydraulic and hydrological data along a river and then perform calculations taking into consideration the network nature of such systems is difficult and computationally complex.

Here we present an innovative software, the River Network Toolkit, which has the ability to use different types of data linked to a river network to obtain information about the river network basic features and generate new variables by conducting complex computations that take into account topological relationships among river segments. Though its use is not restricted to a specific network, it was implemented and tested using the version 2.1 of the River and Catchment Database from the Catchment Characterisation and Modelling (CCM2). Besides specific functions (e.g., stream power, relative distance) and functions to obtain variables from the topological nature of the river network (e.g., source ID, sub-basin ID, mouth ID), the program allows calculations to be performed for a group or for all segments of one or several river networks, in 2 directions (upstream and downstream), in 2 different ways (path and relatives) and using any variable that has been uploaded. The output tables can be visualized in the program and/or exported into one or several .csv files that can easily be imported to a GIS environment.

This software has the advantage of grouping a comprehensive set of functions, while adding specific functionalities and also giving the possibility of creating personalised calculations. It is able to work with large datasets, such as the CCM2 dataset (1.4 million plus segments), and nevertheless have a swift performance (e.g., it calculates the distance to the river source in 3 seconds and the upstream drainage area in less than 3 minutes for all the CCM2 dataset segments).

This software not only facilitates the spatial characterisation of a river network but also allows the computation of variables taking into consideration the network nature of the river. Regardless of the extension and/or complexity of a freshwater network system, the River Network Toolkit is a useful tool that enhances the use of environmental (e.g., climate, land-use), hydraulic and hydrologic information.

Framework

Covering only 0.8% of the Earth's surface and representing merely 0.01% of the world's water, fresh water supports almost 6% of all known species [1]. Because they provide valuable ecosystems services, inland waters and their biodiversity are crucial natural resources for Humankind [1]. Even considering the ongoing biodiversity crisis [2, 3] freshwater ecosystems are amongst the most endangered environments worldwide [1, 4]. These environments have been deteriorating [5], suffering population declines and biodiversity loss [1], mainly as the result of threats and stressors such as resources overexploitation, land-use changes, pollution, water abstraction, loss of longitudinal connectivity, habitat destruction and degradation, climate change and invasive species [1, 5, 6]. Most of these threats are anthropogenic in nature, meaning that they will not cease or decrease in the near future. Because many of these threats are acting at a global scale, there is an urgent need to develop and standardize tools that deal with large trans-national river network databases. This is a crucial step to generate new knowledge on large scale patterns and processes in rivers.

Ward [7] has conceptualised the dynamic and hierarchical nature of river systems in a four-dimensional framework. Linkages and interactions in the upstream-downstream direction establish the longitudinal dimension [7, 8]. The lateral dimension is constituted by the exchanges of matter and energy between the channel and the riparian/floodplain system [7]. Interactions between the channel and contiguous groundwater are considered the third (vertical) dimension and, the fourth dimension is the temporal scale, i.e., the overlaying of a temporal hierarchy on the other three dimensions [7]. This conceptualisation provides a synthetic framework for lotic ecology that may be helpful to understand the dynamics of river ecosystems and better comprehend the anthropogenic effects on these pathways [7]. Rivers are also functions of other attributes (e.g., geology, vegetation, land cover, human activities, etc.); the effects of these features can be linked to hierarchical spatial units (basin, sub-basin, river segment) that characterise freshwater systems.

Successful river management requires an understanding of processes that operate at different spatial and temporal scales, while also comprehending the spatial and hierarchical relationships between land and water [9, 10]. International cooperation is an additional requirement for a correct management of large scale resources [11]. This is particularly relevant for freshwater international basins. Dudgeon, Arthington [1] state that in many parts of the globe inventories of freshwater biodiversity are incomplete. Thus, cooperation and international efforts are required to suppress this lack of knowledge. Conscious of these challenges, the European Commission's Joint Research Centre (JRC) has developed a River and Catchment Database for Europe (CCM – Catchment Characterisation and Modelling). This is the first all-inclusive database of river networks and catchments available for the pan-European continent that is hierarchically structured and a fully integrated system [10]. The hierarchical structure from segment drainage catchment to large river basins, along with the link between river and drained area enables numerous research possibilities at a variety of scales and independently of political or administrative boundaries [10]. Considering it was developed to fulfil the requirements of European institutions but also of the scientific community, this unique database is pivotal for modelling activities, studying freshwater environmental processes, analysis of environmental impacts of different policy scenarios, development of environmental indicators and analysis of pressures and impacts [10]. Moreover, CCM data ranges from the Mediterranean – including Turkey – to the north of Scandinavia, from the Urals to the Atlantic – large and small islands included –, thus complying with the spatial requirements of the Environmental European Agency (EEA) which are wider than those of the European Union (EU) [10].

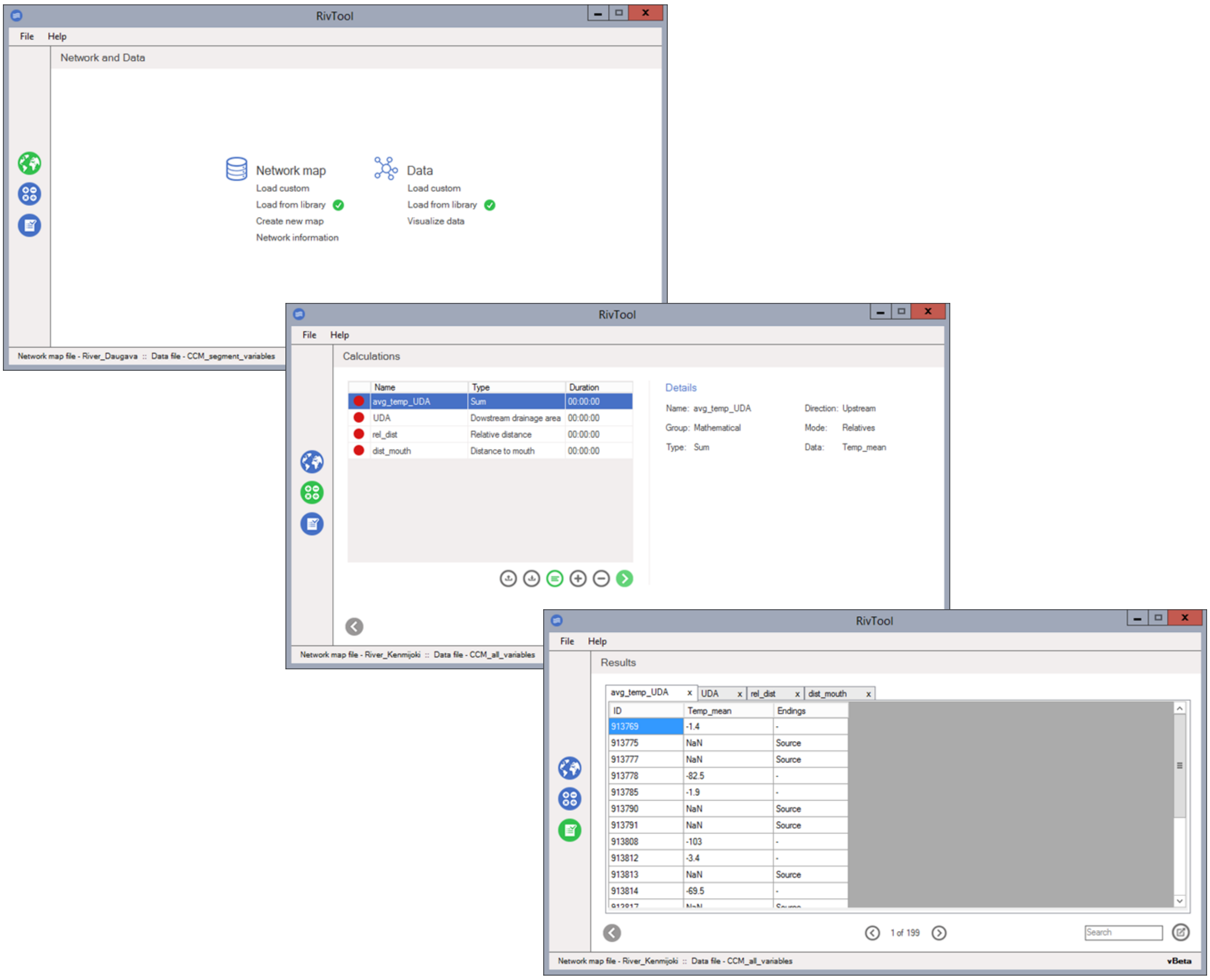
The River Network toolkit

In freshwater ecological research, connecting and integrating a hierarchically structured river database with environmental or landscape data may help to predict and comprehend the effects of threats and stressors on freshwater ecosystems. Adding to this, studies often require obtaining data along a river network taking into consideration precisely its network nature, e.g., upstream drainage area [12], relative distance to mouth [13, 14], cumulative length [15], upstream and downstream average slope [16] and Stream Power [17, 18]. This type of information is not mathematically complex to obtain but can be time-consuming when working at a national or continental scale and using small resolution units. General-purpose geographic information systems (GIS) software and related river network toolsets contain some tools to cope with these necessities. Nevertheless, these applications have limitations: most are focused on creating river networks based on digital elevation models, delineate and characterise watersheds, topologically manage and improve a river network and assigning key identifiers and attributes to a hierarchical river network. If one's objective is to preform calculations considering routes or flow directions of freshwater networks connected to environmental data, then most of these applications are either useless or very limited. These type of calculations fall within the field of network analysis, and though some programs have specific modules or toolsets for this purpose, they are inevitable more orientated to solve problems for the transport industry.

Here we present a novel software, the River Network Toolkit, that integrates river networks and environmental data. Designed to be a straightforward and user-friendly application, it facilitates: (1) obtaining information that characterises the network based only on its topographic nature; and (2) by linking environmental data to freshwater networks, acquiring new data through mathematical calculations that account for the hierarchical nature of these systems. This program is table-driven and was developed to work with two distinct basic units: segment and sub-basin. The output tables can be exported and used in other software (e.g., geographical Information systems, statistical software).

After opening the application, the first window (Figure 1) deals with choosing the river network map file, allowing the user to search for one in the program's libraries or create it from a file to be provided by the user. The network map is the pivot file for RivTool thus, if users intend to use a specific freshwater network, they should create an adequate csv file to characterise their network (please check the templates information in the RivTool Manual for more details). With this file the program creates a network map. Also in the first window the user can optionally link environmental data to the selected network. Again, libraries with environmental data or a user's custom file (check templates information for more details) can be added. The second window (Figure 1) allows the user to choose the calculations to be performed. These are divided into Topological (e.g., Main River, Source ID, Distance between Segments), Watersheds (e.g., Basin Stats, Sub-basin Stats), Custom (e.g., Relative Distance, Stream Power, Upstream Drainage Area), Conditional (e.g., Conditional sub-basin, Sum if) and Mathematical (e.g., Average, Sum, Range). For some of the operations of the Mathematical and Conditional calculations the user will be able to choose the Direction, upstream or downstream, and the Mode, path or parents (check the RivTool manual for more detailed information). Finally, the third window (Figure 1) will show the results of the chosen calculations.

Figure 1 – Snapshots of the River Network Toolkit interface. From top to bottom: first, second and third window.



Why is Rivtool relevant?

Research about freshwater systems will inevitably have to link basin information with biotic data. Considering that freshwater systems are amongst the most threatened ecosystems [1, 4], obtaining detailed and accurate information about rivers is essential [10]. The river continuum concept [7, 8] shows that inputs in headwaters affect all downstream river segments. Conversely, from an anadromous species point of view, inputs in river reaches closer to the mouth may impact these animals as they navigate upstream. The River Network Toolkit is a software that integrates river network information and environmental data. Depending on provided files the user has the possibility of obtaining information to characterise the river network based solely on its topological features or perform a network analysis that uses network and environmental data (e.g., for a given segment a user can calculate the maximum channel slope towards the mouth or compute the average temperature associated with the upstream drainage area).

Rivtool advantages

It is obvious that other software, such as GIS orientated applications, have a plethora of other functions relevant for researchers working with freshwater networks and water resources. Nonetheless, RivTool provides unique features to take full advantage of hierarchical river networks, such as a set of comprehensive specific designed functions for calculations in river network analysis. Able to deal with large datasets while maintaining fast computations (e.g., calculating upstream drainage basin for 1.4 million segments takes less than 30 seconds), it is significantly faster than common GIS applications since it only uses tables to compute functions. This characteristic encompasses another attribute that adequately used can be advantageous: there are no topological restrictions or issues when performing a network calculation. Contrastingly, some general-purpose GIS programs, although allowing the user to perform network analysis, the network has to be completely free of topological errors. For example, when trying to perform a network analysis of the Volga basin (164 506 segments), having just one segment that is not integrally connected to the next closest segment is a problem that artificially introduces an inexistent disconnectivity. Initially implemented to be used only with the CCM database, it has now a universal applicability because it allows a user to introduce a custom network. Moreover, besides networks that have segments as the unit of resolution, it is possible to use a network of sub-basins. Finally, it is a user-friendly software with a straightforward implementation that also provides some ready-to-use libraries with processed environmental data (e.g., climate data) and river network maps.

Final Remarks

RivTool is a unique software that uses the connection between drainage basins and river segments provided by a river network and integrates it with environmental data. It gives users the possibility of calculating new information via network analysis. This application has numerous advantages (Figure 2**Error! Reference source not found.**) and, when compared with network analysis modules of general-purpose GIS programs, tends to be more efficient. This freshwater related software can be a powerful tool for researchers, policymakers and environmental assessment companies.

Figure 2 – Advantages of the River Network Toolkit

Advantages:

- Takes full advantage of a river network database like the CCM
- Enables a straightforward linkage between environmental and a river network data
- Extensive set of functions, all in one program
- Functions can use both network and environmental data
- No topological restrictions as it is database driven
- Fast performance even with large datasets
- Universal applicability
- Works with segment or sub-basin as a basic analysis unit
- A set of ready-to-use libraries
- Easy & simple to use with straightforward implementation

The beta version of the River Network Toolkit can be downloaded using this link, http://bit.ly/RivTool_beta or the following QR Code:

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