Findings of the CCM pre-conference workshop at AGILE Helsinki 2016

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Abstract

During the workshop, five presentations demonstrated software to process structured hydrographic data and to create updates of CCM. Three other presentations and a poster discussed use cases of CCM in which catchments where characterized in order to gain more insight in hydrological planning processes. The presentations covering parts of Macedonia and parts of Turkey revealed interesting errors in the dataset. The discussion that followed the presentations addressed mainly the importance of CCM and how a better version could be made in the near future. Important aspects are to create an internet community to process the new data as well as the availability of new, higher detailed data, such as SRTM of 30 meters.

1 Software Tools

The two presented software tools were RivTool and TerraHidro. RivTool takes CCM or elsewise connected hydrographic data as input in csv or txt format and computes network derivable parameters. The tool is built upon a Windows NET environment and can be installed as a small windows application. The current version computes, for example, the distance between segments, the distance to the river mouth, the distance to the source, the relative distance and the total source segments in addition to the already existing CCM2 attributes.
The tool functions fast and it would be logic to add access to the tool from the CCM website. The tool was developed to fulfil requirements for a thesis on migratory fish species and as such, the main user and developer are interested to enhance the tool also to a wider community. In addition, more parameters could be of interest such as the Otto Pfafstetter coding system.

TerraHidro is a tool to compute a hydrological network from a digital elevation model. The tool is used to compute a network for the whole world below 60 degrees, the area covered by the STRM elevation model. A resolution of nominal 30 by 30 meters is available. The TerraHidro team had to resolve the STRM void issue using their own optimizations. TerraHidro is a C++ application that can be freely installed on a windows PC.

In TerraHidro also performance issues were addressed making the tools suited to iterate over various DTM's quickly.

The presentation compared an analysis of TerraHidro based on SRTM 30 and 90 meter with CCM (on SRTM 90). The TerraHidro displayed correct results but in the plains, CCM was better due to its feature to follow ancillary data, if provided. TerraHidro further has a feature called 'HAND', which can be used to quickly, identify areas prone to flooding. The various results on South America and Africa are complementary to CCM and of great interest for the Hydrologic community.

2 Applications

An application to use CCM and ECRINS in Macedonia was displayed. Apart from some confusion on which dataset to take, CCM could cater for various map requests especially for making people in Macedonia aware on the possibilities and value of such a system. Subsequently a project was started to generate a higher resolution catchments system since a high resolution DEM of the country was available to the project. This project resulted is maps that were problematic on the country border, especially for a catchment that exits the country and re-enters further downstream. The project made a strong request for a higher quality or higher resolution version of CCM especially for the cross-border areas.

The next application was less affected by operational errors, in an application describing the hydrology of Romania. Overview maps of the country were displayed, giving insight in ecologically vulnerable regions. In addition, a poster with the results of a characterization of the climate in Bulgaria was displaying that at country level CCM can give adequate insight in the ecological characterization.

The last presentation described catchments and river segments in Turkey and notified significant errors in the border region with west Syria. The errors were significant; a river went into a wrong valley and made it more difficult for the project to create credibility for the displayed data. The Turkish presenters in analogy to the Macedonian presenter are in a consistent need of an improved version of CCM even at the same resolution of 100 meters. For the Romanian presenter a more enriched CCM would be beneficial.

2.1 Storing more derived data

The RivTool application and the three end user applications clearly showed a need to make CCM data intersection results more readily available. Some data are already available in CCM, but a new version of CORINE Land cover and various climate assessments and meteorological data would be of great use if made directly available at the primary catchment and river segment level. In addition, also a platform where users could upload their own results would be appreciated to enhance the discussion and debate on hydrologic issues. To avoid the download of too many and unrelated attributes it was suggested to define groups of data.

In addition to this issue, also a mention of an improved description of the existing attributes in the CCM geodatabase could be of use. Some terms are not directly clear due to abbreviations and the articles that describe them might be too long and cumbersome to go through for a simple application.

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2.2 Errors in Macedonia and Turkey

The errors in Macedonia and Turkey can be explained by the fact that the CCM team in 2005 had no experts in those areas. In addition, reference data, taken from submissions of the Water Framework directive, were not available. CCM used three additional reference data sets in conjunction with the SRTM 90 meter elevation model. The first one is an image with the number of contributing pixels in order to start surface flow. This dataset is made using soil and land cover maps and can be enhanced if better data is available for example in karstic regions. The second one is a map containing the rivers and canalized rivers to follow in areas were the drainage is not following the lowest point. Such areas can be found especially in lowlands or in narrow valleys and close to reservoirs. This map also contains the lakes, in which CCM computed a centreline to be used as reference to connect the various rivers that flow into a lake.

The third map is a map containing the so-called pits, which are the endorheic reservoirs such as Lake Trasimeno, Lake Tuz and the Dead Sea. If these maps can be made with more detail for the accession countries CCM could be rerun and improved for such specific processing windows.

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2.3 Next Steps

The workshop and the usage statistics of CCM demonstrate a stable interest for CCM like data for applications regarding flood control, ecological assessments, impact of dams and fauna protection. In the nearby future, in which the pressure on the hydrologic environment is expected to grow due to climate-change, economic and population pressure, the interest in CCM like products will increase as well. In addition, easier the access to GIS systems will create an increasing demand for high quality and topological intelligent data. Open Data initiatives such as Open StreetMap are not addressing hydrological challenges. However, such initiatives could provide information on dams, rivers, ponds and lakes at very high detail thanks to direct contribution of the users living in a specific area.

Since an improvement of CCM requires detailed local hydrological knowledge, it would make sense to create an internet community improving in controlled steps the model output by allowing users to adjust the input layers in order to make a new run of the model for a selected hydrological region.

Table 1: CCM input layers.

Source	Current Resolution	Improvement	
Digital Elevation Model	100 m	30 m	National DEMS
# Contributing Pixel	Divers, Soil maps	Local Knowledge	Soil Texture maps
Reference Rivers	1:25.000 WFD countries in 2005, Image 2000 data	Open Street map	Official Topo maps
Reference Lakes	25 m Only Image 2000 area	Open Street map	Water surface detection
Pits	100 m		

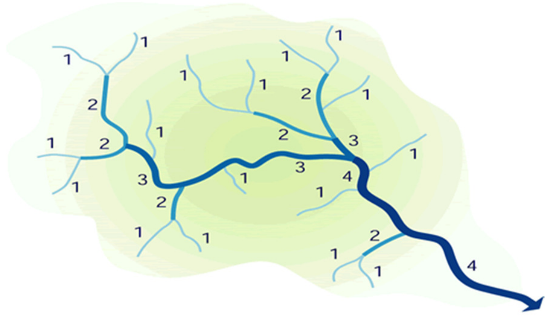
In table 1, the five input layers for CCM as shortly listed. In order to make a system better than just classical GIS generated drainage systems from a DEM, a tool should be developed to accommodate such functionality. TerraHidro might be such a tool although at this moment TerraHidro only takes the # Contribution Pixels as correction factor, which is then applied to the entire watershed. The tool therefore has to be adapted to take into account the other four input layers and in addition a web tool could be developed, allowing users to upload corrected data for the 5 input layers. In this case, the user submits the five new layers, runs the software and checks whether the new output is an improvement to be uploaded to the full system.

This web platform can be started with an effort to make the CCM website more interactive and to adapt TerraHidro to additional input layers.

In addition the CCM website can be enriched with more map examples of what can be done with CCM, for example with links to projects using the data and with facilities to download topological derivable attributes and intersected attributes from valuable scientific databases. Crucial to recomputing CCM is to adapt TerraHidro or a similar tool since the software used to build CCM in 2005 is outdated (partly build on LISP and AML).

The request for delivering more derived attributes and intersected attributes can be fulfilled in a shorter time span since no new software development is needed. The participants from the CCM workshop could give hints to which data to intersect whilst the RivTool software could be used to generate (and store) more derivable data.

Figure 1: Example of topological derived attributes, Strahler order.



2.4 Short term Action Points

As a follow-up of the workshop the following short-term actions have been proposed:

- Creation of a Google User group to enable short discussions with colleagues on the net.
- Locations and descriptions of errors in CCM2 could be geotagged on a simple MapViewer
- Introduction of links to TerraHidro and RivTool on the CCM web site and other projects that relate to CCM.
- Further developing TerraHidro using # contributing pixels test data in tiff image format. After such adaption, studying in how far also the three other CCM reference data sets can be integrated in the TerraHidro algorithm.
- Addition of Otto Pfaffstetter coding to RivTool by integrating the respective JRC software library.

2.5 Participants to the Workshop

The following participants contributed with presentations and short articles to the workshop:

- Duarte Gonçalo, Oliveira Tiago, University of Lisbon, Forest Research Centre, Lisbon (PT),
- de Freitas Oliveira João Ricardo, National Institute for Space Research INPE, São Jose dos Campos (BR)
- Baudry François, Rhine-Meuse Water Agency, Metz (FR),
- Bodescu Florian, Romanian Space Agency, Bucharest (RO),
- Gül Ali, Dokuz Eylul University, Izmir (TR).

The short papers are bundled in this set of articles, with the two software package descriptions first, and followed by the three applications.
Notabene, during the AGILE conference a presentation was given of CyberGIS (Wang) in which hydrologists of the United States collaborate for generating stream and watershed models for the territories of their country.

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 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.

1 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].

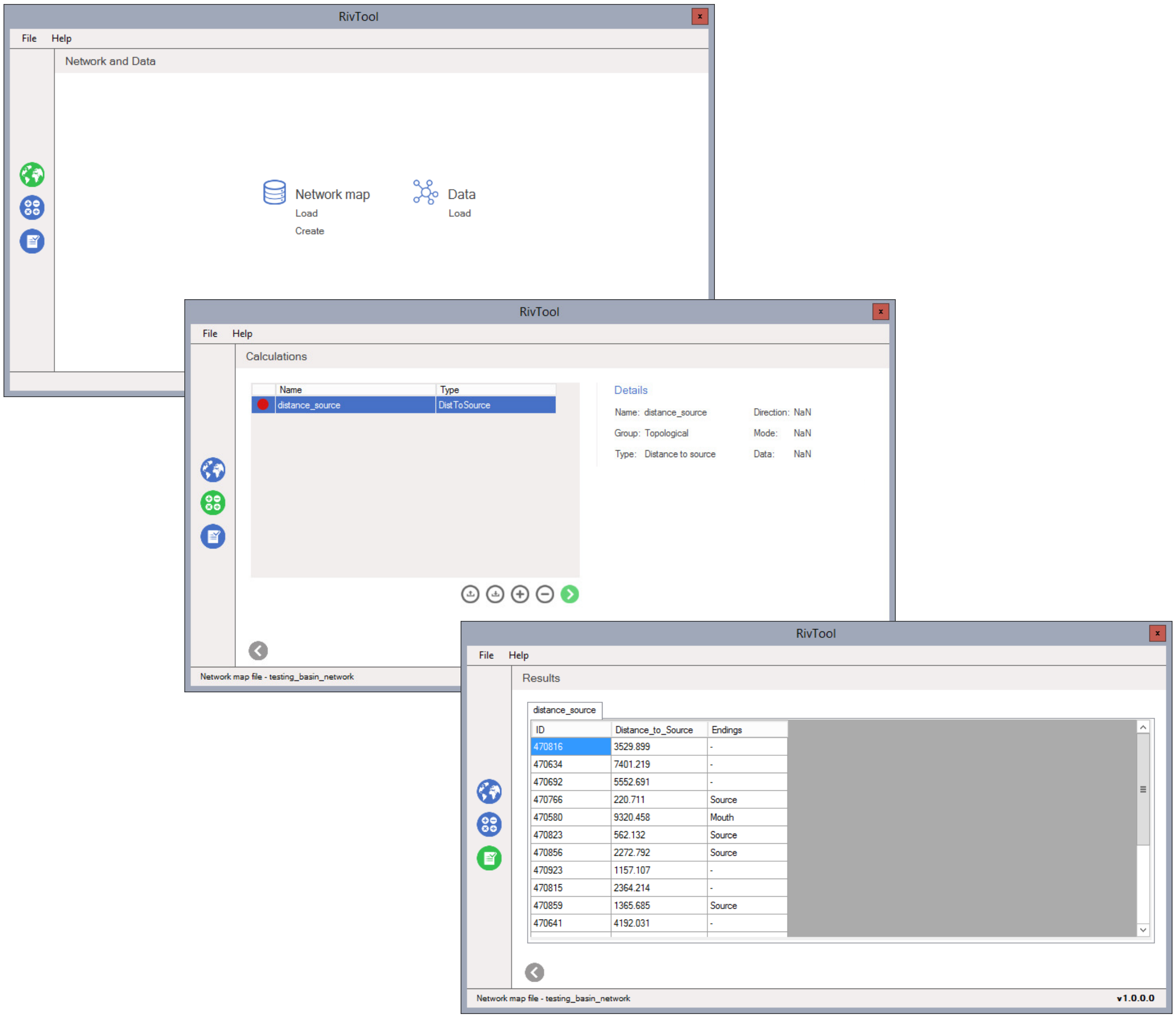
2 The River Network toolkit

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), Mathematical (e.g., Average, Sum, Range) and Conditional (e.g., Conditional sub-basin, Sum if). 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.



2.1 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 affect 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).

2.2 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.

3 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 (**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

References

1. Dudgeon, D., et al., Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews, 2006. 81(2): p. 163-182.
2. Hoekstra, J.M., et al., Confronting a biome crisis: global disparities of habitat loss and protection. Ecology Letters, 2005. 8(1): p. 23-29.
3. Chapin III, F.S., et al., Consequences of changing biodiversity. Nature, 2000. 405 (6783): p. 234-242.
4. Ricciardi, A. and J.B. Rasmussen, Extinction Rates of North American Freshwater Fauna. Conservation Biology, 1999. 13(5): p. 1220-1222.
5. Nel, J.L., et al., Progress and challenges in freshwater conservation planning. Aquatic Conservation: Marine and Freshwater Ecosystems, 2009. 19(4): p. 474-485.
6. Sala, O.E., Global Biodiversity Scenarios for the Year 2100. Science, 2000. 287 (5459): p. 1770-1774.
7. Ward, J.V., The Four-Dimensional Nature of Lotic Ecosystems. The North American Benthological Society, 1989. 8(1): p. 2-8.
8. Vannote, R.L., et al., The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Sciences, 1980. 37(1): p. 130-137.
9. Johnson, B.L., W.B. Richardson, and T.J. Naimo, Past, Present, and Future Concepts in Large River Ecology: How rivers function and how human activities influence river processes. BioScience, 1995. 45(3): p. 134-141.
10. Vogt, J., et al., A pan-European River and Catchment Database. 2007, European Commission - Joint Research Centre - Institute for Environment and Sustainability: Luxembourg. p. 120.
11. Ostrom, E., Revisiting the Commons: Local Lessons, Global Challenges. Science, 1999. 284 (5412): p. 278-282.
12. Filipe, A.F., et al., Forecasting fish distribution along stream networks: brown trout (Salmo trutta) in Europe. Diversity and Distributions, 2013. 19(8): p. 1059-1071.
13. Clavero, M. and V. Hermoso, Historical data to plan the recovery of the European eel. Journal of Applied Ecology, 2015. 52(4): p. 960-968.
14. Imbert, H., et al., Evaluation of relative distance as new descriptor of yellow European eel spatial distribution. Ecology of Freshwater Fish, 2008. 17(4): p. 520-527.
15. Markovic, D., J. Freyhof, and C. Wolter, Where Are All the Fish: Potential of Biogeographical Maps to Project Current and Future Distribution Patterns of Freshwater Species. PLoS ONE, 2012. 7(7): p. e40530.
16. Leathwick, J.R., et al., Using multivariate adaptive regression splines to predict the distributions of New Zealand's freshwater diadromous fish. Freshwater Biology, 2005. 50 (12): p. 2034-2052.
17. Béguer, M., L. Beaulaton, and E. Rochard, Distribution and richness of diadromous fish assemblages in Western Europe: large-scale explanatory factors. Ecology of Freshwater Fish, 2007. 16(2): p. 221-237.
18. Logez, M., P. Bady, and D. Pont, Modelling the habitat requirement of riverine fish species at the European scale: sensitivity to temperature and precipitation and associated uncertainty. Ecology of Freshwater Fish, 2012. 21(2): p. 266-282.

Assessment of the drainage network extracted by the TerraHidro system using the CCM2 drainage as a reference data

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Abstract

The objective of this study is to compare the drainage networks extracted by the TerraHidro system, developed in the Image Processing Division (DPI) of the National Institute for Space Research (INPE), using SRTM data with resolutions of 30 and 90 meters, with the existing drainages in the pan-European drainage network database, called Catchment Characterization and Modelling version 2.1 (CCM2), river and catchment database developed at the Institute for Environment and Sustainability (IES) of the Joint Research Centre (JRC). In other words, CCM2 data set was used as the reference data for qualitative analysis of the extracted drainages by TerraHidro. The SRTM 30m data contains altimetry points with value -32767, called *void* points, that must be substituted by some estimated altimetry data. TerraHidro automatically performs these corrections using any available altimetry data set grid as an alternative value grid. In this work, we used the SRTM 90m as the alternative grid. To do so, TerraHidro uses a bilinear interpolator, which performs a linear interpolation weighting by the inverse of the distance using the four nearest values. A conversion process of these drainages, called *upscaling*, was executed in order to adapt them to lower resolutions, in this case 900m. Again, this new set of drainage was compared with the reference data. Finally, a procedure called HAND was executed and the result is displayed indicating areas with varying levels of flooding potential. The data used in this work are the SRTM 90m and SRTM 30m from the UK. The basic TerraHidro features have also been described.
Keywords: TerraHidro, drainage network, SRTM, HAND, upscaling.

1 Introduction

Digital elevation model (DEM) is useful and important. It is used in several applications such as slope calculation for landslide occurrences, flood alerts, drainage network and watershed delimitation, hydrological models, agricultural studies, protected geographical areas, among others. High-resolution altimetry data sets are expensive.

This data is obtained only for small regions. In countries like Brazil, with continental dimensions, it is time consuming to analyse large areas using high-resolution data sets. The common solution is to use the datasets available as SRTM [1] with horizontal resolution of 90 meters (SRTM-90) and 30 meters (SRTM-30), and Aster GDEM [2] with 30-meter resolution. These data sets are freely available for the entire Earth surface for latitudes lower than 60º.

The main limitation of using these data is that in a dense forest they represent the tree canopy surface, and not the terrain surface. If in a satellite collected image a forest parcel was cut, the altimetry values on the parcel are different from those in its neighbourhood, leading to some errors in the extracted drainage.

Another problem related to Aster GDEM data set images of different dates used for composing the stereoscopy mosaic, is that they do not usually have the same spectral response.

SRTM data set presents another problem: large aquatic areas, such as large rivers and lakes are represented by flat levels. Flat areas must be properly treated to assure a correct water flow path determination.

The SRTM-30 data was recently made available, but it does not have valid values at all grid positions. These positions, called *voids*, are marked with the value -32767, and it must be substituted by some estimated altimetry data. TerraHidro system [3], which is a software system for hydrological studies, was employed to perform this task. A linear interpolator was implemented in TerraHidro: it uses the four nearest values from the void position taken from a lower resolution grid of the same area, usually an SRTM-90 data grid.

This work shows qualitatively the precision of drainages extracted by the TerraHidro system, using SRTM-90 and SRTM-30 data sets, in comparison with the pan-European Catchment Characterization and Modelling version 2.1 (CCM2), river and catchment database [4] developed and generated by the JRC [5].

The paper is organized as follows: Section 2 briefly presents the TerraHidro system and the geographic region used in this work, and Section 3 shows the results and some comparison.

2 Materials and methods

The United Kingdom was the geographic region used in the development of this work. Although it is not a significantly large area, it is an isolated area, bordered only by the ocean.

The SRTM-90 and SRTM-30 data of this region were used. Figure 1 shows in grey levels the SRTM-30 data set.

Figure 1: SRTM-30 data for the United Kingdom.

The drainage information of the CCM2 database was used as reference information in this work. The CCM2 database was designed, developed and implemented by the JRC in accordance with the European Water Framework Directive (WFD, 2000/60/EC). CCM2 used an Otto Pfafstetter [6] codification extension to code drainages and watersheds extracted from a digital elevation model at 100-meter spatial resolution, regarding a scale of at least 1:500,000. Figure 2 shows the SRTM-90 and the CCM2 drainages of United Kingdom.

Figure 2: SRTM-90 and CCM2 drainage (in yellow) for the United Kingdom.

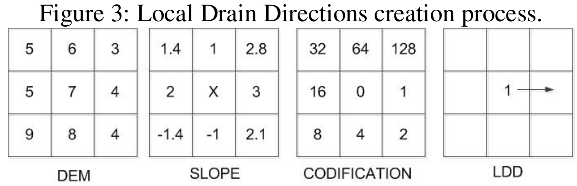
TerraHidro system was used to process these data sets. It has been developed at the Digital Image Processing Division of the National Institute for Space Research (DPI-INPE), situated in São José dos Campos, Brazil. It's free for download under the GNU (GPL) license, as published by Free Software Foundation. TerraHidro has functions to perform: local drain direction determination, contributing area grid calculation, drainage definition using an arbitrary threshold value, drainage segmentation, watershed delineation by segments and isolated points, vectorised drainage and watershed, drainage upscaling, Height Above the Nearest Drainage (HAND) [7] that computes the difference between the altimetry grid value of each point and the closest drainage value reached by following the local drain directions, among others.

TerraHidro is, in fact, a plugin of the geographic viewer TerraView that loads and stores data in a geographical library called TerraLib [8], an open source geographical library implemented in C++ language that has also been developed at DPI-INPE. TerraLib is an open source Geographical Information System (GIS) software library. TerraLib supports coding of geographical applications using spatial databases, and stores data in different *database management system* (DBMS) including MySQL, PostgreSQL and others. Some TerraHidro functions are described below.

2.1 Local Flow Determination

The Local Drain Direction (LDD) grid gives the local water flow [9]. For each DEM grid cell, the LDD was calculated considering the steepest downstream regarding the 8-neighbour grid cells. At the end of the task, a new grid was created with the same number of columns and rows as the original DEM. Each grid cell receives a code indicating the water flow direction from this cell. Figure 3 shows LDD construction.

Figure 3: Local Drain Directions creation process.

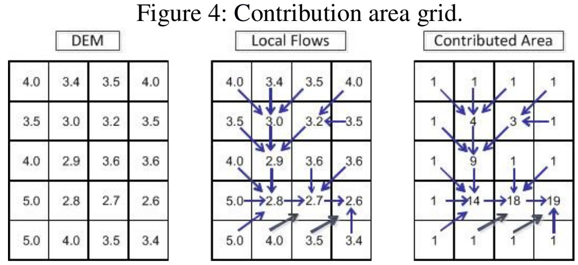


The drainage extracted from TerraHidro is unidirectional, but the codification expressed in power of two will allow using multipath local flows.

2.2 Contribution Area Grid

It is usual to work only with representative drainage regarding an application, and not with all the LDD's drainage. Each cell of the contribution area grid receives a value that is the amount of the areas of all cells participating in the paths arriving at that cell. Figure 4 presents an example.

Figure 4: Contribution area grid.

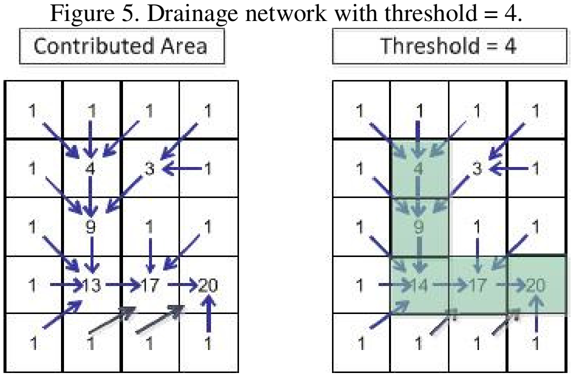


The contribution area grid is used to select a particular drainage network.

2.3 Drainage Network Definition

A particular drainage network is defined by choosing a threshold value. The value of each cell from the contribution area grid is compared with the threshold value. If the value of contribution area grid is equal to or greater than the threshold value, the cell is selected as a drainage network cell. At the end of this process, a new grid is created, defining the drainage network. Figure 5 presents an example of drainage network creating process.

Figure 5. Drainage network with threshold = 4.



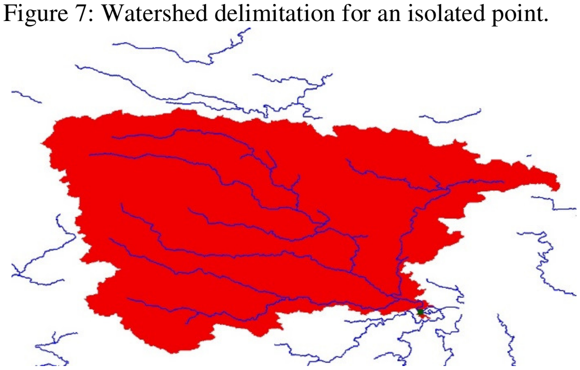
The threshold value controls the density of the drainage network; for instance, low threshold values produce denser networks.

2.4 Watershed Delineation

Watershed can be delimitated considering isolated watershed points or drainage segments. A watershed point is a location on the drainage defined by the user. A segment is a drainage path between water springs and junctions, between junctions, or between junctions and the mouth of the drainage. The watershed areas are calculated for each isolated point or for all drainage segments. Figure 6 and Figure 7 show an example of each watershed delimitation type.

Figure 6: Watershed delimitation for each segment.

Figure 7: Watershed delimitation for an isolated point.



2.5 Upscaling - Drainage Conversion from High to Low Resolution

The determination of good quality drainage network, extracted from altimetry grids of high or at least medium resolution, is basic information for developing applications involving surface and underground water resources.

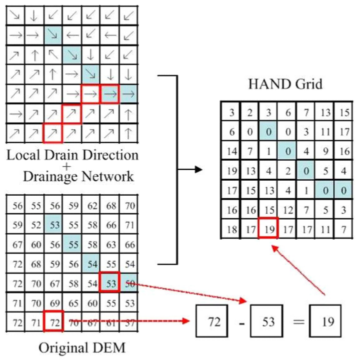
When the target is a large watershed, high and medium resolutions might not be adequate. The drainage network for a low resolution grid is better represented when obtained from a higher resolution drainage network than when obtained directly from a lower resolution grid. This process is called *upscaling* and it is implemented in TerraHidro.

TerraHidro has an edition tool to change the local flow directions, whenever necessary.

2.6 HAND - Height Above the Nearest Drainage

TerraHidro uses the HAND procedure to identify potential flood areas. It calculates, for every DEM cell, the altimetry difference between this cell and the nearest cell belonging to the drainage network, following the local drain directions. Figure 8 shows a numeric example of HAND process.

Figure 8: HAND process.

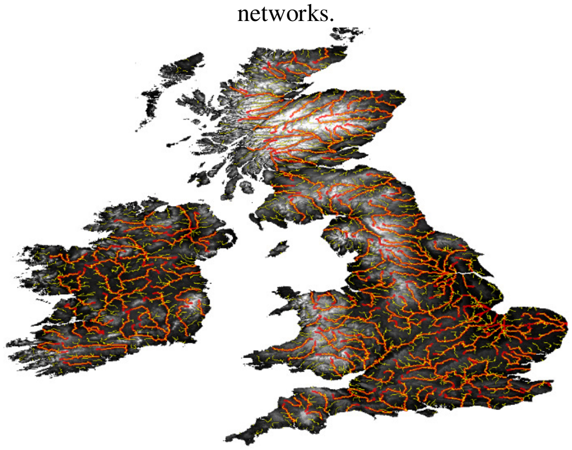


HAND process can only identify areas with potential for flooding. This information allows the water resource manager to focus his efforts on the most susceptible areas regarding the occurrence of extreme events involving water. For a more precise study, hydrological models must be used.

3 Results and Comparison

TerraHidro generated the results of this work for the UK region using SRTM-90 and SRTM-30 data. A threshold value was used to provide a reasonable drainage density, considering the study area. Figure 9 shows the SRTM-90 and the SRTM-30 drainages over the CCM2 drainage.

Figure 9: CCM2, SRTM-90 and SRTM-30 drainage networks.



In the following pictures, enlarged remarkable areas are shown from Figure 9 providing a more detailed analysis. Four remarkable areas were analysed: two areas that the drainages match well in large extensions (Figure 10 and Figure 11), and two areas that present important discrepancies (Figure 12 and Figure 13).

For each enlarged area, three scenes are presented: the first scene shows a combination of the drainages using SRTM-90 data (green), SRTM-30 data (blue), and CCM2 database (red); the second scene, SRTM-90 and CCM2; and the third scene, SRTM-30 and CCM2.

Figure 10: First area with good drainage representation.

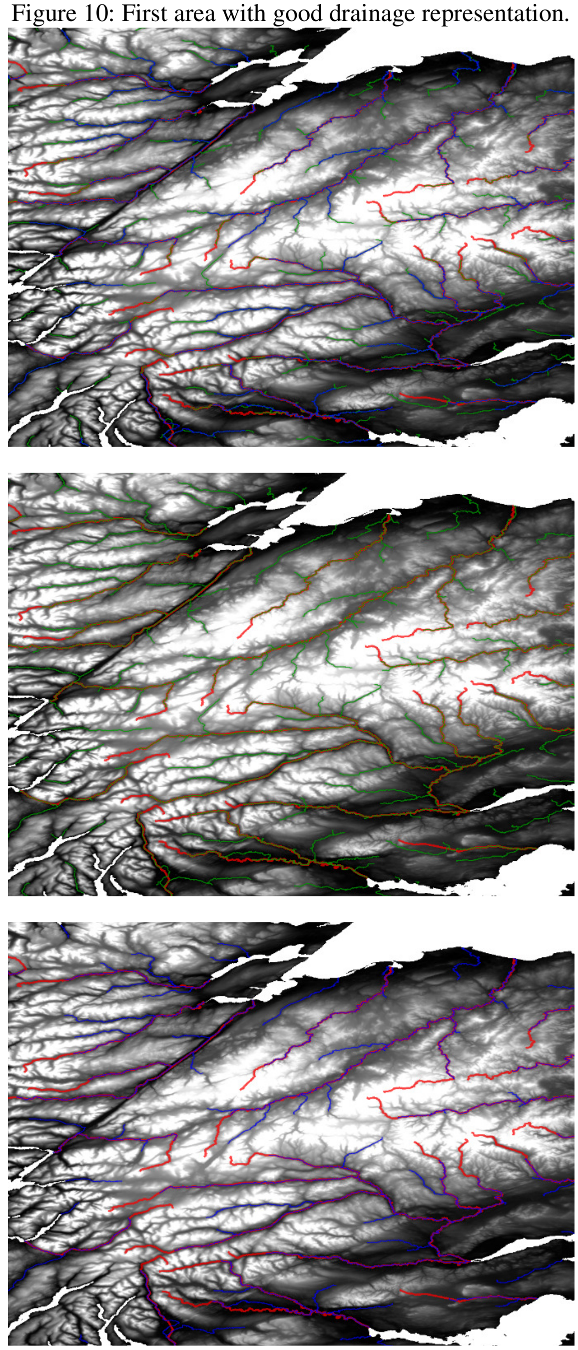
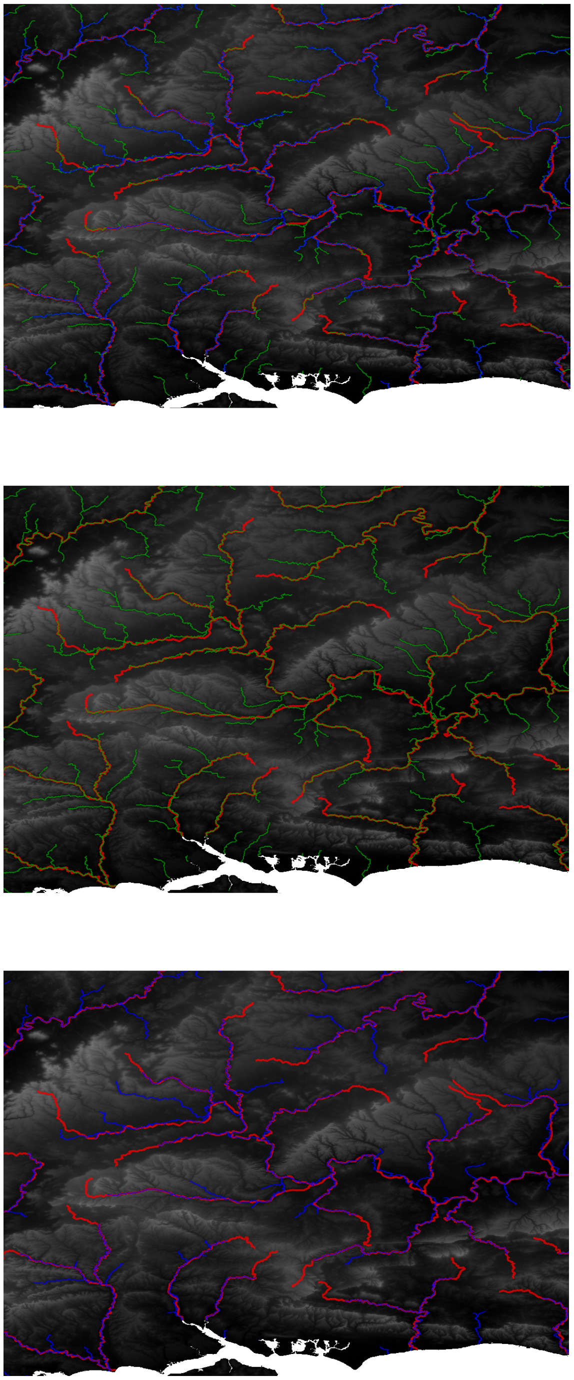


Figure 11: Second area with good drainage representation.



It is noted that in rugged areas TerraHidro, using SRTM data, extracts the drainage with good precision, largely agreeing with the CCM2 drainage.

Figure 12: First area with drainage discrepancies.

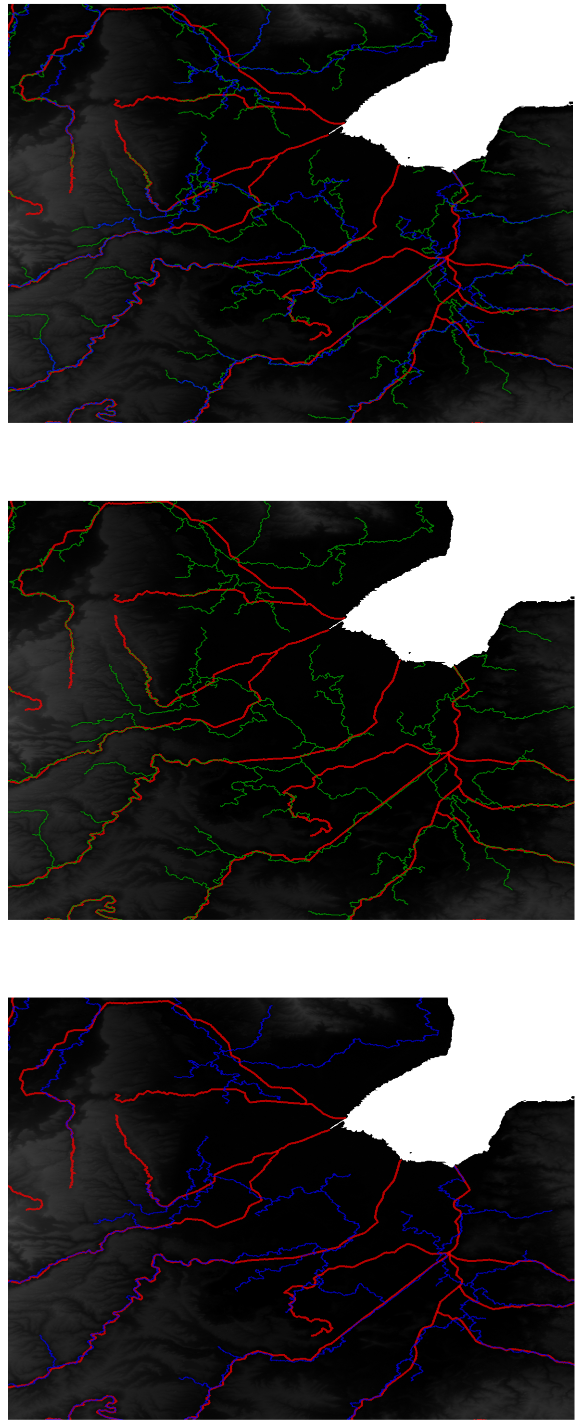
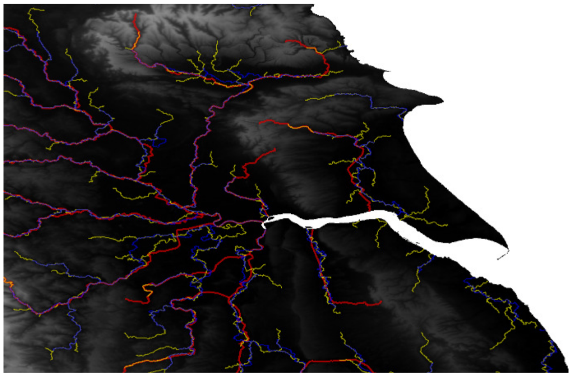
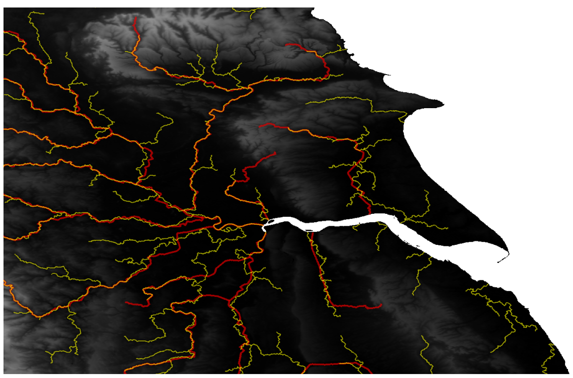
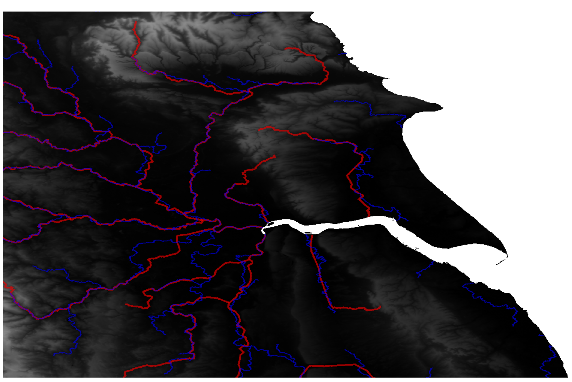


Figure 13: Second area with drainage discrepancies.







In other areas, such as flat areas, forest areas, or urban areas, the drainage obtained using SRTM data and TerraHidro are substantially different from the CCM2 drainage.

In very flat areas, cultivated areas or wetlands, it is very difficult to precise the exact drainage path, even because in these areas minor terrain modifications may lead to large changes in riverbeds.

In fact, some flat area rivers change their riverbeds seasonally. In forest areas, the SRTM data represents the top of the trees, given rise to discrepancies. If a road cuts through a forest, it is likely that this road is identified by TerraHidro as part of the drainage.

In some situations, as in studies related to climate changes, it is desirable to use a drainage defined in a lower resolution grid.

The result of this process to obtain lower resolution drainage, called upscaling, is presented in Figure 14 for a drainage obtained using a 900m of horizontal resolution grid, together with the CCM2 drainage, with different zoom levels.

Figure 14: Upscaling representation.

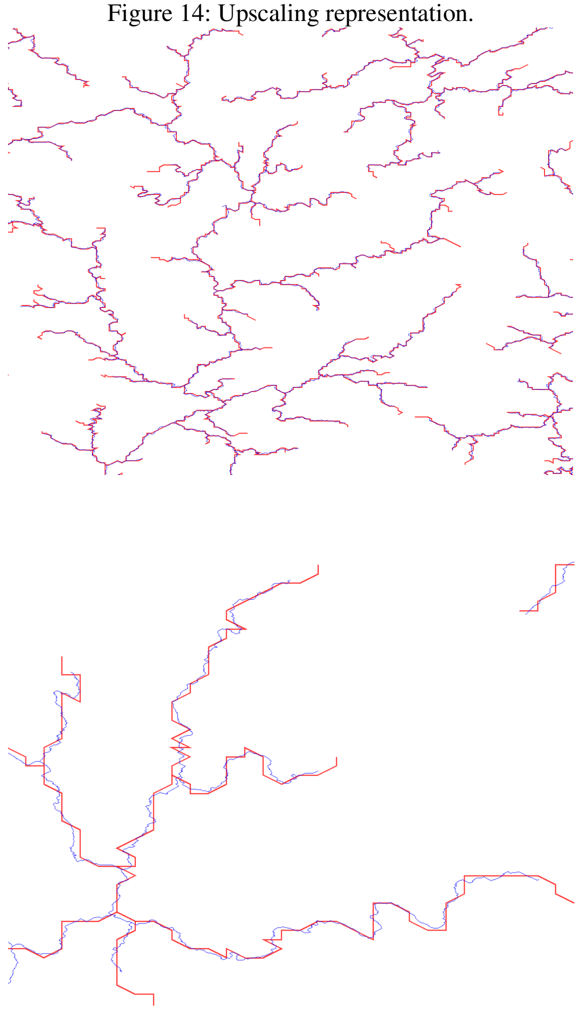
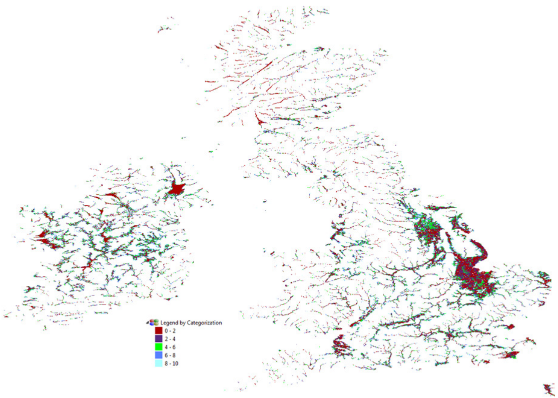
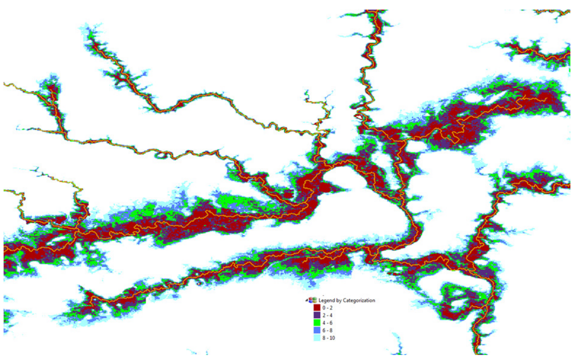


Figure 15 shows different levels of flooding potential with the HAND tool of the TerraHidro system, very useful in analysing the most endangered areas for flooding, for the entire United Kingdom and for an enlarged area.

Figure 15: Flooding potential levels.





TerraHidro system showed good capability of representing the drainages in the studied area using SRTM-90 and SRTM-30 data, providing good results despite some few errors, which needed little processing time and few resources.

A more detailed study of the drainage discrepancies found in this work would be very interesting, possibly using satellite images or fieldwork data, to better understand these results.

4 References

[1] E. Rodriguez, C. S. Morris, J. E. Chapin, J. M. Martin and W. Daffer, S. Hensley. An assessment of the SRTM topographic products. *Technical Report JPL D-31639, Jet Propulsion Laboratory*, Pasadena, California, 143 pages, 2005.

[2] D. J. Meyer, T. Tachikawa, M. Abrams, R. Crippen, T. Krieger, D. Gesch and C. Carabajal. Summary of the validation of the second version of the ASTER GDEM. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, V. XXXIX-B4, 2012 XXII ISPRS Congress, 25 August – 01 September 2012, Melbourne, Australia, 2012.

[3] S. Rosim, J. R. F. Oliveira, J. O. Ortiz, M. Z. Cuellar and A. C. Jardim. Drainage network extraction of Brazilian semiarid region with potential flood indication áreas. *Proc. SPIE 9239, Remote Sensing for Agriculture, Ecosystems, and Hydrology XVI*, 923919 (21 October 2014); doi:10.1117/12.2066906, 2014.

[4] CCM2, CCM River and Catchment Database, version 2.1. *Institute for Environment and Sustainability (IES) of Joint Research Centre (JRC)* site, http://ccm.jrc.ec.europa.eu , download in May, 03, 2016.

[5] A. L. Jager and J. V. Vogt. Development and demonstration of a structured hydrological feature coding system for Europe, *Hydrological Sciences Journal*, 55, 5, 661, ISSN: 0262-6667 (Print) 2150-3435 (Online), Taylor and Francis, http://dx.doi.org/10.1080/02626667.2010.490786., 2010.

[6] O. Pfafstetter. *Classificação de bacias hidrográficas*. Manuscript not published. *Departamento Nacional de Obras de Saneamento*. In portuguese. 1989.

[7] C. D. Rennó, A. D. Nobre, L. A. Cuartas, J. V. Soares, M. G. Hodnett, J. Tomasella and M. J. Waterloo. HAND, a new terrain descriptor using SRTM-DEM: Mapping terra-firme rainforest environments in Amazonia. *Remote Sensing of Environment* 112 3469–3481, 2008.

[8] G. Câmara, L. Vinhas, K. R. Ferreira, G. G. R. Queiroz, R. C. M. Souza, A. M. V. Monteiro, M. T. Carvalho, M. A. Casanova and U. M. Freitas. TerraLib: An open source GIS library for large-scale environmental and socio-economic applications. *Open Source Approaches to Spatial Data Handling*, Berlin, Springer-Verlag, 2008.

[9] P. A. Burrough and R. A. MacDonnell. Principles of Geographical Information Systems. *New York: Oxford University Press*, 1998.

CCM2 and ECRINS files use for Water Framework Directive (WFD) water body delineation and River Basin characterisation in the Vardar/Axios River Basin

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Abstract

The 25 000 km² Vardar/Axios River Basin is shared by Kosovo, Serbia, the Republic of Macedonia and Greece. Water body delineation and River Basin characterisation are initial steps of the Water Framework Directive (WFD). For this purpose, shape files representing rivers and catchments are necessary. In riparian countries Digital Elevation Models (DEM) are regularly updated using aerial photos, satellite imagery and other sources. The accuracy of the DEM derived shape files is an issue. From the CCM2 (Catchment Characterisation and Modelling) of the EU Joint Research Centre (JRC) was derived the ECRINS (European catchments and RIvers network System) shape files for River Systems, Lakes and Elementary Catchments. They offer interesting information River Basin characterisation and mapping. However, when delineating water bodies in flat areas many errors of confluence were detected in the ECRINS river features. Therefore, in the Republic of Macedonia, more accurate River and Catchment shape files were produced in June 2015, by using a 5 meter resolution national DEM. These files were introduced in a Water Information System (WIS). River segments were attributed Pfafstetter codes for the Vardar River Basin within the territory of the Republic of Macedonia. The precise River and Catchments files serve as basis for Water Body delineation. But, as the GIS files of riparian countries do not match between them, ECRIN files were used to map transboundary watersheds in border areas. More accurate CCM2 and ECRINS files would enable correspondence with rivers and catchments for better water management within transboundary River Basins.

Keywords: River Basin, GIS resolution, Transboundary, Water Body Delineation.

1. WFD objectives achievement and Water Body delineation

The Water Framework Directive (WFD) [1] requires delineating surface and ground water bodies and characterizing them. During the process of development of the River Basin Management Plan (RBMP), environmental objectives have to be set on water bodies (WB). Natural conditions, technical difficulties or disproportionate costs may be advocated by each E.U. Member State to postpone the deadline of objective achievement to 2021 or 2027. Even less stringent objectives may be set, under particular circumstances. The impact of anthropogenic pressures and the resulting expected status of the water bodies have to be taken into account in the WB delineation process. Achieving the WB environmental objectives is an important commitment of the Member States.

The WB delineation process is therefore, the basis on which is constructed many WFD elements: the delineated water bodies are the foundation bricks of WFD processes, as explained in the guidance document on water bodies [2]. Hence, the selection of the GIS file sources to be used for delineating has far-reaching and strategic implications.

2 GIS files available for delineation

Delineating the surface water bodies includes the production of sufficiently accurate Geographical Information System (GIS) files of the water bodies (usually shape files). In this regard, the availability and quality of the existing GIS files of the rivers network and their catchments are critical.

To represent the WFD International River Basin Districts on maps, it is necessary to put together GIS files of the rivers network of several riparian countries. In each of the States, Universities, Institutions or Projects have developed Digital Elevation Model (DEM). These are usually produced and regularly updated by using aerial photos, satellite imagery, Google or OpenStreetMap and other sources, such as 1/25000 topographic maps.

The derived DEM GIS files, which are useful for WFD, include Rivers segments, Lake Polygons, Nodes of rivers confluences and the boundaries of rivers and streams drainage basin (catchment). Each State uses country specific geographical projections and DEM.

Since the resolution of the DEM and their accuracy vary, the GIS files derived from them vary also. As a result, it is not easy to put together riparian Rivers and Catchments files to produce a common GIS file for a whole International River Basin District. Moreover, as far as River Basin Management (RBM) data are concerned, depending on the riparian country, the tables of attributes of the Rivers and Catchments GIS files are more or less rich in characterisation data.

3 Files covering international River Basin in Europe: CCM2 and ECRIN files

The EU Joint Research Centre (JRC) produced files on rivers systems in the frame of the Catchment Characterisation and Modelling Project (CCM2). Under the European Catchments and Rivers Network System (ECRINS) Project, GIS shape files were derived from the CCM2 and other sources to facilitate the use of the information for WFD implementation. The CCM2 and ECRINS files cover an area larger than Europe.

The CCM2 shape files are freely downloadable on the web (http://ccm.jrc.ec.europa.eu/ and the ECRINS files on the European Environmental Agency website (EEA). They can be used with, for instance, the free OpenSourceSoftware QGIS. Hence, without any payment, maps can be easily produced by non-specialists to represent hydrological features such as river network systems for various Strahler number, lakes or 'mosaics' of Functional Elementary Catchments (FEC) for particular areas.

The CCM2 and ECRINS shape files are particularly interesting to map water related information for International River Basins. They cover many countries and along border areas, by using them, there is no need to put together heterogeneous GIS files from different countries to represent Transboundary Rivers, Lakes and their watersheds.

The methodology and the attribute tables of CCM2 and ECRIN GIS files are described in a report prepared by the EU Joint Research Centre (JRC) [3]. The descriptors in the fields in these attribute tables are relevant for River Basin characterisation, as described in section 5.

However, the features of the ECRINS shape files representing River Network and Catchment do not have a resolution better than 100 m. In 2014, while attempting to delineate Surface Water Bodies in the Vardar sub-basins, errors of representation of the River Network System were identified. Consequently, the accuracy of the ECRIN shape was considered as an issue in flat areas, as described in the section 6.

4 The international Vardar/Axios River Basin

The Republic of Macedonia is aiming at accessing to the European Union. In this connection, the EU funds projects to assist the Ministry of Environment and Physical Planning (MoEPP) and other water institutions to implement the WFD. The Project entitled "Technical assistance for strengthening the institutional capacities for approximation and implementation of the environmental legislation in the area of water management in Macedonia" (EuropAid132/08/D/SER) was implemented jointly by Ramboll (Denmark), and the Office International for Water (France) from January 2014 to December 2015.

The Project main geographical area was the Vardar River Basin in the Republic of Macedonia. The Vardar River is called 'Axios' when entering into in Greece.

Figure 1: Location of the Vardar/Axios River Basin among the WFD River Basin Districts in South Europa

Source: ECRINS shape files, EEA; CCM2 shape files, E.U JRC.

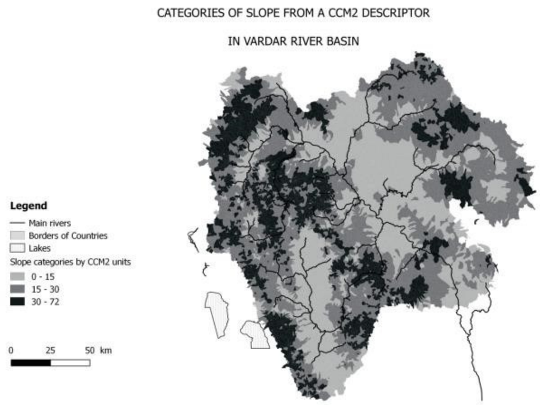
The Vardar/Axios River Basin is an international River Basin. The riparian countries are Serbia, Kosovo, Macedonia and Greece (see Figure 2 and 3 in the Annex: maps). It expands over a rather mountainous territory (see Figure 4). Its average elevation is about 790 m. This River Basin covers about 25,000 km² of which around 20600 km² are in the Republic of Macedonia. The total length of the Vardar/Axios River is 389 km, with 87 km being in Greece. The transboundary Lake Dojran/Doirani is located in the Vardar/Axios River Basin. It is shared by the Republic of Macedonia and Greece.

5 The use of CCM2 and ECRIN files for mapping and characterising the Vardar/Axios River Basin

For mapping on an A4 format, basins and sub-basins of the Vardar/Axios the accuracy of the shape files representing the River Network system of CCM2 and ECRINS files is of satisfactory quality. This is why, these shape files were often used during the above mentioned EU funded Vardar Project to represent the river systems, other main geographical features of the Vardar/Axios River Basin. Hence, many maps were produced to give a general picture of this River Basin and its sub-basins (see Figure 2 and Figure 3 in Annex). In this regards, the number of Strahler is very useful to make distinction between the small and large rivers for instance to represent on a map only the large ones. During the Project, when accuracy was not an issue, thematic maps of the basins and sub-basins, were produced using particular ECRINS and CCM2 descriptors for pedagogical and communication purpose (Figures 2, 3, 4, 5).

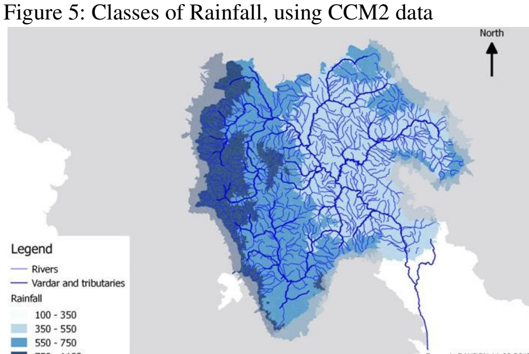
The CCM2 shape files included indicators such as the slope, the altitude, the rainfalls and Pfafstetter code. They are relevant for the description of surface water bodies. Classes of slope and classes of rainfalls were mapped for the Vardar River Basin (see Figures 4 and 5).

Figure 4: Classes of slope using CCM2 data



Source, CCM2, EU –JRC, EU 'Vardar Project 2014-2015'

Figure 5: Classes of Rainfall, using CCM2 data

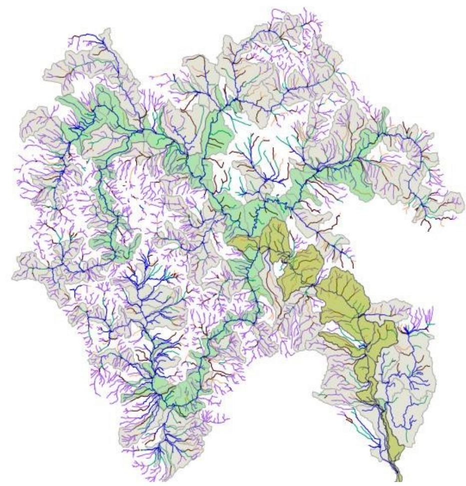


Source: CCM2, JRC, EU 'Vardar Project 2014-2015'

One of the WFD steps for characterising Surface Water Bodies is to define a typology [2], [4]. As per WFD, under system A and B, various descriptors have to be utilised, these are: altitude, geology, size of the river basin and the WFD ecoregions.

The tables of attributes of the ECRINS shape files include fields that appeared interesting also to map and characterise the surface water bodies. The fields regarding 'surface' and 'altitude" of the ECRINS files Functional Elementary Catchment (FEC) enable to characterise the River Basin by classes of size and altitude (Figure 6). During the above mentioned EU funded Vardar Project 2014-2015, the ECRIN shape file were used also to explain the delineation methodology to the staff of the Macedonian water institutions (see Figures 6 and 7).

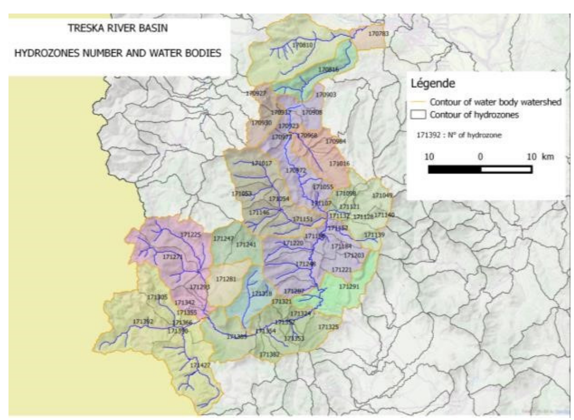
Figure 6: Use of the field size of the River Basin of the ECRINS Catchment GIS files



Source: ECRINS files, working map of EU 'Vardar Project 2014-2015' (Legend: over 1000 km² below 10 000 km², above 10 000 km² green-yellow, blue Large River, red small rivers).

A first water body delineation test was performed in July 2015 by using the ECRINS GIS files for the sub-basin Treska. As this basin is mountainous, the FEC seemed appropriate to delineate water body catchment by merging the FEC, where appropriate.

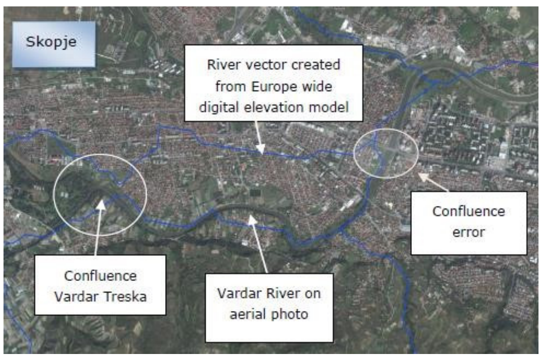
Figure 7: First delineation of water bodies by merging elementary unit FEC (called hydrozones in the map).



Source: ECRINS file, (EEA), EU 'Vardar River Basin 2014 -2015'

But, when checking the location where the Treska River merges with the Vardar River, it became apparent that the geometry of ECRINS River network shape file need to be corrected. In plains, the ECRINS shape file appeared of insufficient accuracy to be used for the Surface Water Body delineation (see Figure 8). This was explained in a first report on delineation submitted to the Macedonian Authorities [4].

Figure 8: Identification of an error in the river network as featured on the ECRINS files (confluence Treska River /Vardar River)



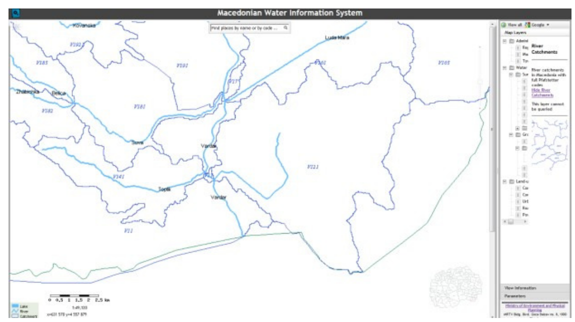
Source: ECRINS River Network and Typology report from the EU 'Vardar Project 2014-2015' and its Typology report [4].

In August 2014, it was assumed that it might be possible to correct the ECRINS GIS files, in flat areas. To this end, it was proposed to use other geographical sources of information such as OpenStreetMap, Google maps, topographic maps or existing DEM. But, in December 2014, it became clear that it was not the best option. Beginning of 2015, the use of ECRINS shape files for Water Body (WB) delineation was abandoned. It was decided to create a more accurate River Network for the whole Vardar River Basin by using high resolution DEM of the Republic of Macedonia. The best national DEM available had a resolution of 5 m.

A very detailed River Network was derived from this DEM by Ivan Mincev, a consultant of the Vardar Project. It was decided also to produce the corresponding River catchment shape file by creating a River catchments of above 10 km². Each catchment should have only one river segment inside. Each river segment was given the name of the river or streams figuring in the corresponding 1/25000 paper topographic map. Finally, two precise shape files were completed in July 2015. One was for River segments and the other for the corresponding River Segment Catchments. The quality check of the shape files went on in July 2015. When the two shape files for rivers and catchments were of sufficient quality, the Water Bodies were delineated and the pressure and impact analyses could be launched and were carried out from August to October 2015.

The corrected River and Catchment shapes files and other water related data were uploaded on a web mapping tool designed by Henning Mejer, a consultant of the Vardar Project. They are now part of the information system of the Ministry of Environment and Physical Planning (MoEPP) http://wis.moepp.gov.mk/# (Figure 9). It is called "Macedonia Water Information System" (MWIS). This tool includes many user friendly functions. Many water related datasets prepared and checked during the Vardar Project were uploaded in the MWIS and they can be displayed in graphics and maps. The datasets are freely downloadable. The staffs of the water institutions were trained to the use of the web mapping tool and participated to the creation of the datasets and select options for the design of the MWIS.

Figure 9: River segments and their catchments as displayed by the Macedonia Water information System (MWIS).



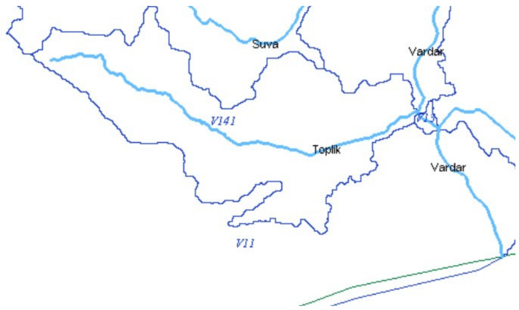
Source: http://wis.moepp.gov.mk/# Henning Mejer, creator of the web mapping tool. Ivan Mincev, producer of the Rivers and Catchments Shape file derived from 5 m resolution national DEM of the republic of Macedonia.

Each river segment was attributed a Pfafstetter code. The code was generated automatically after the logical tree of the river network in the Republic of Macedonia has been completed and carefully checked. The code in the Macedonia Water Information System (MWIS) does not take into account the downstream small tributaries of the Axios (see Figure 10 in Annex). The Pfafstetter code in MWIS is therefore specific to the Republic of Macedonia.

As for the CCM2, the Pfafstetter coding of the delineated catchment units and the corresponding river segment has been done differently (Figure 11 in Annex). The CCM2 coded river tree includes all the rivers and streams in all the riparian countries. However, due to the insufficient resolution, it is likely that it contains errors.

The coding of the MWIS is for the whole country, as they are several River Basin the river segment code in the MWIS includes two elements, on for the River Basin, the other for the Pfafstetter code. For instance, the river segment 'Toplik' was attributed the code "V141", with 'V' standing for Vardar, and '141' for its Pfafstetter code (see Figure 12)

Figure 12 : River Segment named "Toplik" and its catchment and Pfafstetter code as displayed on the web by MWIS.

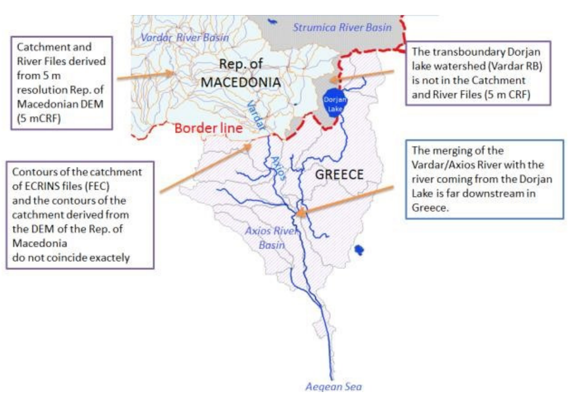


Source: http://wis.moepp.gov.mk/# , designer and producer of the web mapping tool Henning Mejer. Shape file produced with the Rep of Macedonia DEM by Ivan Mincev in 2015.

In the borders areas, a country specific high resolution DEM does not enable a full representation of Transboundary Rivers and their Catchments. To be able to do so, it is necessary that GIS data be shared between riparian countries. Transboundary cooperation has to be organised in order to facilitate such exchange of GIS files. This can be a long process.

Therefore, for the WFD related maps in transboundary areas, GIS files covering Greece and the Republic of Macedonia were needed. In this connection, the ECRINS files were useful for mapping in the border areas. In these areas, two GIS shape files, one being ECRN files , the other the high resolution DEM derived GIS files were superposed to create maps representing transboundary Rivers and Lakes as well their entire catchments (see Figure 13 and Figure 14 and 15 in the Annex : maps). This representation is not completely satisfactory as the vectors of the two shape files do not correspond exactly. It would be better to have accurate shape files, with the same geographic projection over border areas.

Figure 13: Coverage by ECRINS Rivers and Catchment files of transboundary areas.



Source: ECRINS River and Catchment files and high Resolution River and Catchment Files of the Rep. of Macedonia.

For calculating the surface of the transboundary catchments, the ECRINS field 'surface' of the FEC file was used. For each transboundary sub-basin of the Vardar/Axios Basin was distinguished (see table 1):

- the surface of the sub-basin within the Republic of Macedonia,
- the surface of the whole sub-basin including the surface in riparian countries.

Table 1: Estimation of Sub-basins surface with ECRIN file and with the high resolution DEM of the Rep. of Macedonia

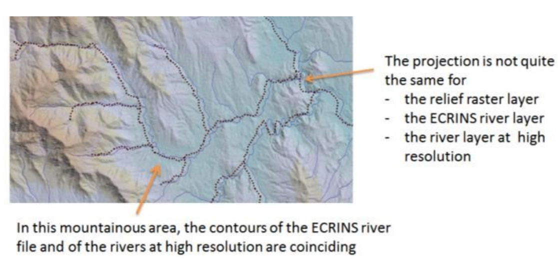
Sub-basins of Vardar/Axios River Basin	Surface for the sub-basins within the Rep. Maced. (km²)	Surface for the whole subbasin (km²)
Upper Vardar	1616	1629
Middle Vardar	2570	2577
Vardar downstream	2822	3122
Bregalnica	4320	4322
Crna Reka	5044	5180
Pcinja	2058	2878
Treska	2071	2071
Lepenec	133	831
Total	20634	22608

Source: ECRINS (EEA) and 5m resolution DEM derived GIS files from the Rep. of Macedonia.

6 Insufficient accuracy for delineating Surface Water Body in flat areas

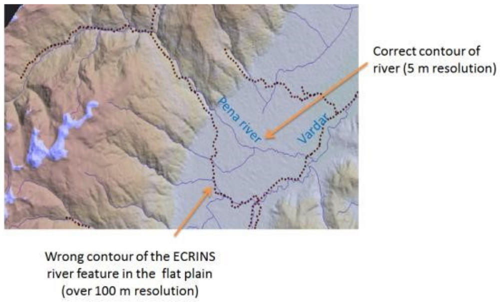
In mountainous areas, the ECRINS shape file contours correspond to the more detailed one deriving from a 5 meter resolution DEM (see Figure 16).

Figure 16: Case 1 - satisfactory corespondance between the ECRIN files and the rivers contours in Treska sub-basin.



Source: ECRINS file, EAA, and high resolution river network derived from national DEM of Republic of Macedonia.

Figure 15: Case 2 - Error in the contour of the rivers derived from ECRINS river features near Tetovo.

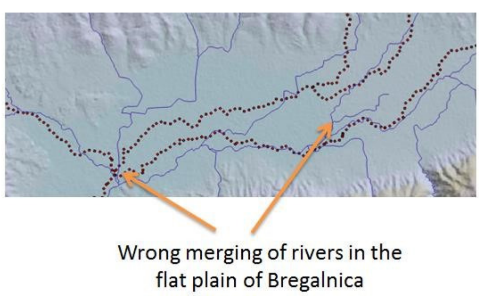


Source: ECRINS file, EAA, and high-resolution river network derived from national DEM of Republic of Macedonia.

In flat areas, on the contrary, the resolution of the ECRINS shape file is not sufficient. For instance, near the town of Tetovo in the upper Vardar River Basin the contour of the rivers are not correct. During the preparation of the ECRINS file preparation the junction between rivers, which are close from one another, was forced. In reality, these rivers are not connected. In this case, the confluence between the Pena River and the River Vardar, as per ECRINS file, is at the wrong place (see Figure 15).

In the Bregalnica sub-basin, a Project has already proceeded to the delineation of Surface Water Bodies, using a DEM. In mountainous areas, it was possible to replicate the same delineation with the ECRINS files but in flat area it is not the case (see Figure 16).

Figure 16: Case 3 - Error in the contour of the rivers derived from ECRINS file in the Begalnica River Basin near Kochani.



Source: ECRINS file and high-resolution river network (RoM).

To estimate the magnitude of the errors in a whole River Basin, it is possible to calculate the part of the flat areas within the River Basin where errors occur. A threshold for a class of slope can be defined and then the areas affected by errors can be mapped by using for instance the CCM2 slope descriptor.

The ECRINS file can be used also in transboundary area in EU member state where the EU water Directive are implemented or for other water management purpose. A test was performed in administrative area of the Rhine-Meuse Water Agency. The aim was to see the correspondence between the WFD delineated Water Body catchment and the ECRINS catchments. Actually, they were only few catchment units from the two files, which were corresponding. In the future, it would be interesting to be able to have a better correspondence between the ECRINS and CCM2 units and the countries 'official' river network and their delineated catchment units.

- Conclusions

During the EU funded 'Vardar Project 2014-2015', the CCM2 and ECRIN shape files were used extensively for general mapping and characterisation. They were especially precious in borders areas around the Republic of Macedonia. For communication and training, when accuracy was not a main concern, the files were very interesting and gave good results.

The files served also to assess particular situation, in places where it was known that the errors are minor, such as in mountainous areas or when the ECRIN or CCM2 descriptors give the best information available.

To better benefit from the ECRINS and CCM2 advantages, the challenge would be to use more precise DEM over the countries covered by CCM2 in order to create more accurate shape files at international level. It would be better if they correspond, as much as possible to the official rivers and catchment shape files in the countries.

If not yet available, it will be also interesting to refer, in the CCM2 and ECRINS files to the codes of the existing delineated water bodies in countries. The corresponding Pfafstetter code and the national Water Bodies codes could be introduced in downloadable new versions of the CCM2 and ECRIN shape files. This issue concerns not only relatively small transboundary river basins like the Vardar/Axios one, but also large ones expanding over many countries, such as the Rhine, Meuse and Danube River Basins,

References

[1] Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy.

[2] Common Implementation Strategy for the Water Framework Directive (2000/60/EC) Guidance document n.o 2 'Identification of Water Bodies'. Produced by Working Group on Water Bodies, *Luxembourg: Office for Official Publications of the European Communities, 2003.*

[3] Vogt, J.V. et al. (2007). *A pan-European River and Catchment Database.* EC-JRC (Report EUR 22920 EN) Luxembourg, 120 p.

[4] François Baudry, Steve Hansen, Yannick Pochon, Ivan Mincev, Martin Wolff. Report on typologies, delineation and GIS files of Water Bodies – Vardar River Basin Macedonia (FYR) Ramboll, Denmark, Office

International for Water, October 2015. *EU funded Project EuropeAid/132108/D/SER/MK for the Ministry of Environment and Physical Planning of the Republic of Macedonia* .

[5] Jürgen Vogt, Roberto Colombo, Maria Luisa Paracchini, Alfred de Jager, Pierre Soille, ‘CCM2 River and Catchment Database Version 1.0’, *in Hydrological Sciences Journal 2003.*

[6] de Jager, A. L. and Vogt, J. V.(2010) 'Development and demonstration of a structured hydrological feature coding system for Europe', *in Hydrological Sciences Journal, 55: 5, 661 — 6751].*

Assessment of aquatic ecosystems state based on their main services

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Abstract

European legislative framework like WFD, HD, BD, INSPIRE demonstrates a unified approach to characterize the state of the environment. Extensive spatial datasets to quantify mechanisms and processes at regional level can be used by processing data such as those provided by CCM21 (rivers and catchments database) closely related to the CLC 2012 dataset, allowing a quantitative assessment of ecosystem services such as surface water resources and ground water resources. The approach of ecological systems and mass flow at catchment level are important steps in the functional use of structural models to quantify the nonlinear dynamics of ecosystems. Quantification of reference values for ecosystem services at a regional level by a deterministic mathematical model is the goal to estimate the degree of transformation from a reference state. Comparative analysis of habitats and species distributions (article 17 report from HD) with the state of aquatic ecosystems will reflect the correspondence between these two assessments.

Keywords: MAES process, WFD, HD, CCM21 and COPERNICUS.

1 Introduction

Since the evaluation of Millennium Ecosystem Assessment (MEA) scenarios of socio-ecological systems, sustainable development was generally perceived only to be possible after identifying and characterizing the diversity of structural and functional ecological systems [1], which means quantification of ecosystem services for accurate dimensioning the level of their use by human societies. In line with current initiatives, we intend to quantify countrywide specific ecosystem services on implementing the Mapping and Assessment of Ecosystems and their Services (MAES) [5] [6] process. The activities will focus on specific aquatic ecosystems, using the proposed methodology of MAES [7] and ARIES [2], based on data structures developed under European programs, like COPERNICUS and CORINE Land Cover, but also on other high quality products provided by JRC (CCM21) [3][4]. Comparative analysis of our results with Habitat directive report and Water Framework directive report [11] will show us the level of interdependence of those assessments [10].

2 Material and methods

The activities are in compliance with the methodology of assessing water balance at the catchment level [8] as presented in the guidance document on the application of water balances for supporting the implementation of WFD [11] [4] to quantify on a regional scale the Common International Classification of Ecosystem Services (CICES) for freshwater ecosystems, from provisioning of water supplies to maintain and support the hydrological cycle and water flow maintenance.

We have adapted the input value, related to CCM21 catchments distribution, based on zonal statistics of each catchment on MODIS evapotranspiration (ET) and CLC2012 land cover classes, to model water availability at the catchment level. For the water infiltration model, we used the estimated average percentage from 0.001% to 20% based on slope and soil type aggregation [12]. For evapotranspiration, we used the MODIS assessment MOD16 program. This assessment is based on annual average values to predict water availability for each catchment related to water use model like proposed by Villa et all [9], but implemented in a simple way ARCGIS add-in.

2.1 CICES

Common International Classification of Ecosystem Services (CICES) was selected for Romanian assessment of the MAES process. In this respect, the assessment of aquatic ecosystems services was focused on surface and subsurface water availability extracted from general water balance equation to characterize the provisioning services of freshwater ecosystems.

In case of regulation and maintenance services, we focus on freshwater ecosystems on flow regulation based on results of the ratio of available water and water used.

2.2 CCM21

CCM21 represent the main derived tool for hydrological structure assessment and is based on topology of rivers, lakes and catchments [3]. The derived data from geomorphological structure at the regional level is an important source for mathematical modelling and for regional assessment of complex hydrological structures. We have used this structural model at the Danube catchment level to extract the sub-catchments covering all national territories. We have selected 30860 catchments grouped in 25 basins from Danube tributaries. We have used the data attributes of each catchment, like average precipitation, average slope and average altitude in relation with soil type distribution for water infiltration or land cover/land use classes for water use

Figure 1: CCM21 extraction to cover Romania.

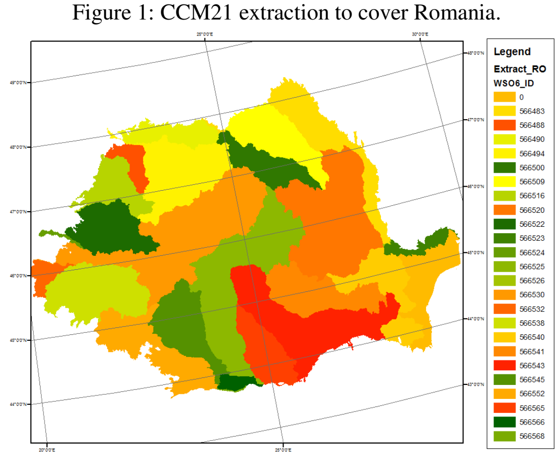
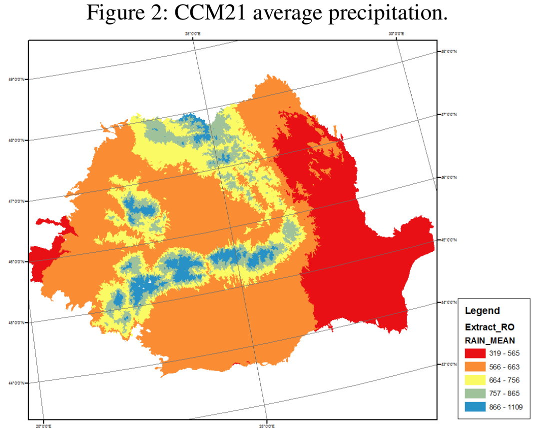


Figure 2: CCM21 average precipitation.



2.3 CLC2012

The project activities have benefited from the use of the pan-European CORINE Land Cover 2012 products. The repartition of land cover/land use classes allows us to have a general picture on the spatial dimension of land distribution for different types of management (agricultural, forestry, industrial or residential). It is clear that these types of management have impact in water use based on quantity of water abstractions for production or functioning processes. In addition, at regional level, these different types of LC/LU classes also have influence on water percolation and water runoff process. Considering the annual water balance, this influence can be considered negligible.

2.4 MODIS – MOD16

The MOD16 dataset is based on the Penman-Monteith equation and developed on estimation used by improved algorithm of ET by Mu et al [13]. The ET from MOD16 distribution at 1 km resolution was extracted for each catchment based on zonal statistics and reflected by ET mean from 2000 to 2013.

Figure 3: CCM21 – MOD16 annual average ET

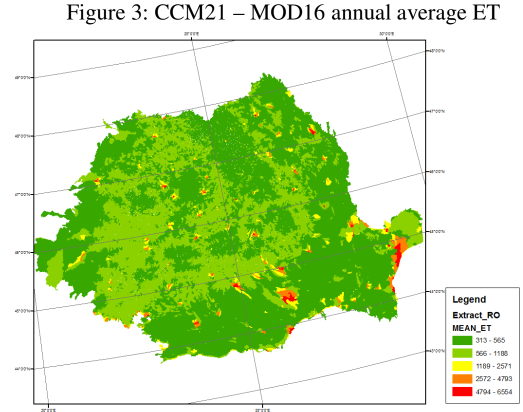
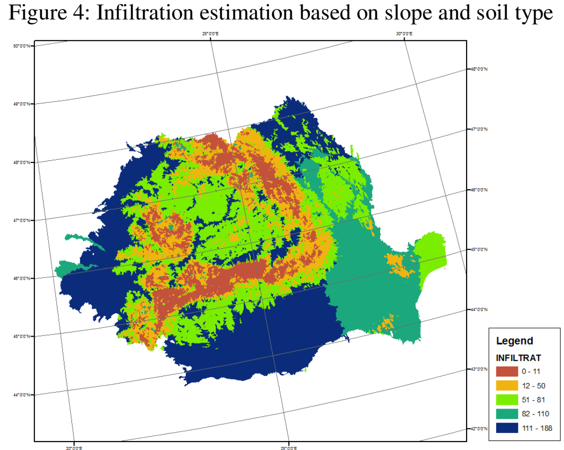


Figure 4: Infiltration estimation based on slope and soil type

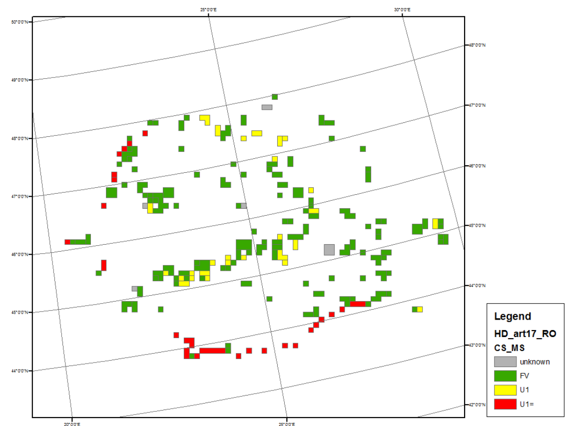


2.5 HD art 17 report

The HD report was developed based on in field monitoring of aquatic habitats and assessment of their state based on four parameters habitat distribution, species composition, structure and functioning synthesis and pressures and aggressions presence. In figure 5 we have presented the spatial distribution of aquatic habitats and their state assessed by 4 classes: 1. unknown (gray) – where we don't have enough information; 2. Favorable state (green); 3. Unfavorable state (yellow); 4. Total unfavorable state (red).

For our analysis, we assessed how many reported habitats (number of cell on assessment grid) in various state are present in catchments with positive or negative ratio of water availability and water use.

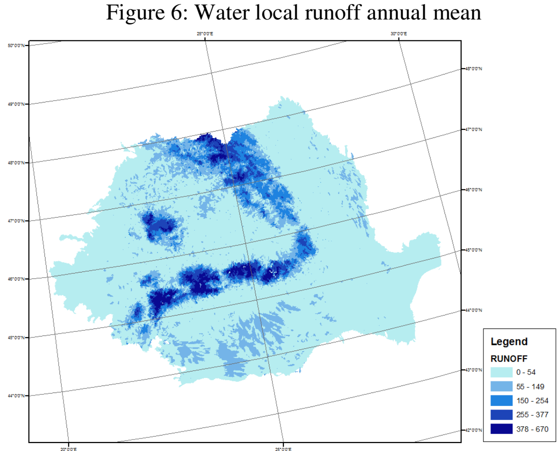
Figure 5: HD report results for aquatic habitats state conclusion



3 Results and discussions

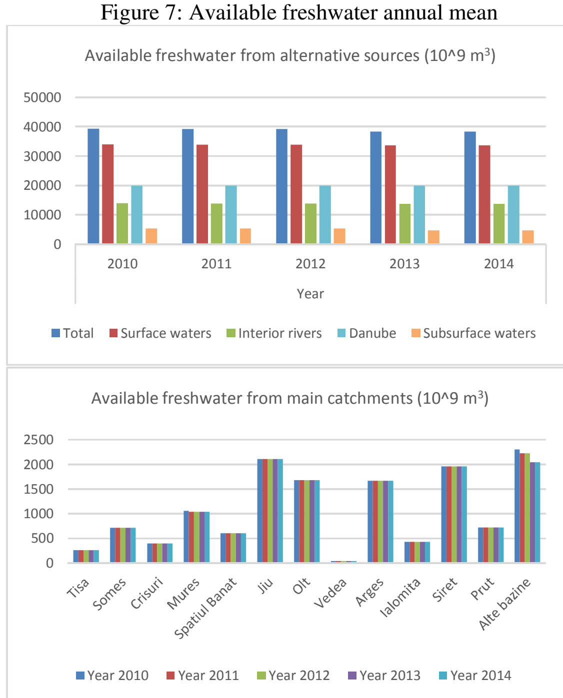
In figure 6 we have presented the local runoff for each catchment and we have followed the topology of CCM21 structural dataset to process the input values from one catchment to another. The process was simulated based on ARCGIS add-in build to support processing inflow water from one catchment to another. The catchment WFO1_ID no 712122 was used to support the Danube inflow from outside of Romania based on assessed average inflow water as 6500 m3/s.

Figure 6: Water local runoff annual mean



Assessment of available fresh water has two components subsurface water and surface water. Subsurface water is estimated from infiltration proportion multiplied by the surface of the catchment. For the surface water is annual estimates for input water available for run-off based on balance equation also multiplied by the surface of the catchment and the second components based on available inflow from other catchments. To estimate inflow components we develop and deterministic algorithms based on line of processing each time all the chain of catchments based on starting catchment to available water for runoff to next-down catchment.

Figure 7: Available freshwater annual mean



Source: National Institute of Statistics

In figure 7 we are presenting the available data at National Institute of Statistic level used for validation of our model results.

The water abstraction at this moment is assessed to cover the water use from different type on land cover classes at the catchment scale, in the following steps we will estimates the water use based on associated coefficient values. The integrated report on ratio water availability / water use will be analyzed complementary with Habitat Directive report and Water Framework report on water quantity and quality.

4 Conclusions

The current approach is representing a test process of structural model aggregation and knowledge integration to reflect actual level of available information to support decision making for quantification of aquatic ecosystems services at regional scale.

At the European level, we have high quality results from projects/programs implemented and developed for member state with potential to be integrated in mathematical models.

Regional testing at the member state level permit us to cross validate results from European programs and identify the errors patterns and alternative ways to compensate them.

The standardized MAES process at European scale is a priority of all member states and the current assessment level can be improved from new achievements of JRC programs (CCM21), Environmental European Agency and European Space Agency programs (SENTINEL, COPERNICUS –CLC, high resolution products).

5 Acnowlegments

We have done this analysis with the support of the project "Demonstrating and promoting natural values to support decision-making in Romania" (Short title: Nature4Decision-making – N4D). We want to thank the financing mechanism EEA grants / Norwegian grants / Norwegian Financial Mechanisms 2009 – 2014 – Biodiversity and Ecosystems services Program.

References

[1] Millenium Ecosystem Assessment. *Ecosystems and Human Well-Being: Synthesis*. Washington, DC: Island Press; 2005

[2] J. Barquin et al. *Coupling virtual watersheds with ecosystem services assessment: a 21st century platform to support river research and management*, Wiley Periodicals, Inc., *WIREs Water* 2015. doi: 10.1002/wat2.1106, 2015..

[3] J. Vogt at al. *A pan-European River and Catchment Database*, JRC reference report – Report EUR 22920 EN, 2007

[4] G. Wriedt, F. Bouraoui. *Towards a General Water Balance Assessment of Europe.* JRC 53258, EUR 23966 EN, ISBN 978-92-79-12979-7, ISSN 1018-5593, DOI 10.2788/26925, Luxembourg: Office for Official Publications of the European Communities © European Communities, 2009

[5] Mapping and Assessment of Ecosystems and their Services. An analytical framework for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020. Discussion paper – Final, April 2013

[6] J. I. Barredo, et al. Mapping and assessment of forest ecosystems and their services – Applications and guidance for decision making in the framework of MAES. EUR 27751 EN; doi:10.2788/720519, 2015

[7] Mapping and Assessment of Ecosystems and their Services, Mapping and assessing the condition of Europe's ecosystems: Progress and challenges 3rd Report – Final, March 2016

[8] S.Werth, A. Guntner. *Calibration analysis for water storage variability of the global hydrological model WGHM.* Hydrol. Earth Syst. Sci., 14, 59–78, 2010 www.hydrol-earth-syst-sci.net/14/59/2010/, 2010

[9] F. Villa, Bagstad KJ, Voigt B, Johnson GW, Portela R, et al. *A Methodology for Adaptable and Robust Ecosystem Services Assessment*. PLoS ONE 9(3): e91001. doi:10.1371/journal.pone.0091001, 2014

[10] R. Naidoo et all. *Global mapping of ecosystem services and conservation priorities*. PNAS, July 15, 2008, vol. 105, no. 28, 9495–9500, www.pnas.org/cgi/doi/10.1073/pnas.0707823105, 2008

[11] G. Wriedt, F. Bouraoui. *Guidance document on the application of water balances for supporting the implementation of the WFD Final – Version 6.1 – ISBN 978-92-79-52021-1 doi: 10.2779/352735 © European Union, 2015*

[12] D. Scradeanu. *Hidrogeologie – ISBN 978-92-79-52021-1 doi: 10.2779/352735 © European Union, 2008*

[13] Q. Mu, et al. *Brief Introduction to MODIS Evapotranspiration Data Set (MOD16)– http://ntsg.umt.edu, 2011*

Generating catchment typologies on river basin systems in Turkey for setting priorities in flood mitigation

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Abstract

Floods are still considered among the most common natural disasters in Europe and the adverse impacts associated with floods are widely estimated to diversify and intensify due to changing climatic conditions. Flood maps effectively address priority locations for further examination toward flood preparedness, control, mitigation and recovery. They principally help scientific communities in orienting research interests by allowing case-study selections from threatened areas as well as the involved authorities in making/ implementing flood policies, taking necessary decisions and accomplishing relevant measures for an effective flood mitigation strategy. Flood mapping substantially relies on the availability of spatial data sources on different components involved in flooding process as well as the accuracy and precision of the data itself. Flood research in Turkey that mostly concentrates on local case-studies needs upscaling toward geographically wider assessments. This necessitates generation and use of larger-scale geographic datasets and expanded repositories on topographic, hydrologic, hydromorphologic, hydrographic and meteorological information. The presented study involves endeavours for obtaining a spatial typology for river basin systems in Turkey for depicting the ranked priorities in flood assessments. The geodatabase resulted from the CCM initiative by JRC is used as the main spatial object basis to this end. Despite the analytical strength of the database and concordance with the historically recorded national datasets, spatial incompatibilities (e.g. faulty hydrologic connections, insufficient bifurcation) in the database for different parts of the river basins are also discussed. In the very general sense, however, strong needs for continuous improvements in such sources of spatial information are emphasized through recommendations for integrating precise datasets at sub-national and/or national scales.

Keywords: Flood mapping, catchment typology, CCM2 dataset, micro-catchments.

1 Introduction

Floods are still considered among the most common natural disasters in Europe and the adverse impacts associated with floods are widely estimated to diversify and intensify due to changing climatic conditions. Flood maps are generally used by many stakeholders for spatial planning to prevent the build-up of new risks, reduce existing risks and adapt to changing risk factors (due to changes in ambient conditions and climate) [1]. Maps prepared in forms of event-, risk- or potential-based views effectively address priority locations that require further examination and necessary measures for flood preparedness, control, mitigation and recovery. For similar needs appearing in Turkey, the Disaster and Emergency Management Presidency operating under the Turkish Prime Ministry published a comprehensive report from the records of disaster events experienced in the period 1955–2008, where a number of flood maps are provided for administrative units as well as major river basins [2]. Right along with the event maps, another basic type of flood mapping is the flood potential map where a spatial characterization for floods is depicted through certain flood related variables (topographic, meteorological, hydrologic, etc.) by taking no account of most features relevant to flood hydraulics (runoff depths, velocities, etc.) or flood event probabilities.

Due to estimated impacts of global warming and the resulting climate change, intensification and frequency increases for future floods are greatly foreseen as a primary factor that governs flood management strategies and orients research initiatives in the world. This poses new challenges to researchers, water managers and policy makers at different scales [3] while requiring thorough understanding and common consideration of climate change estimations and flood risk assessments.

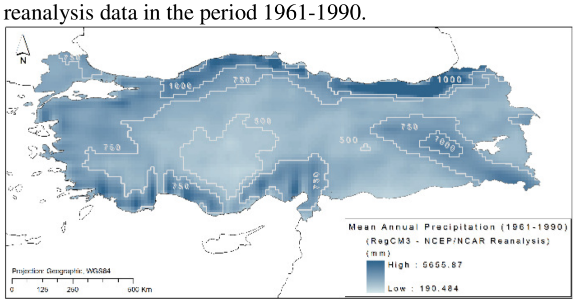
The presented study aims at providing a spatial basis for flood policy orientation in Turkey and is based on a relative assessment of a number of topographic, hydrologic and meteorological factors over the catchment units constituting river basin systems. A typology based on a spatial and multi-criteria characterization for micro-catchments is revealed with different flood potentials, which eventually help spatially exhibit primary areas with notable flood potentials.

2 Data requirements and sources

The CCM2 geodatabase resulted from the Catchment Characterisation and Modelling (CCM) initiative by JRC [4] was used as the main spatial object basis in the presented study. The database holds detailed information on hydrographic features in European river basin systems starting from the smallest hydrological units up to larger-scaled agglomerations, which form parts of bigger river systems and corresponding drainage catchments. In the study, the smallest possible catchment units, so-called micro-catchments, were considered in the analyses with the use of complementary attribute information such as unit catchment areas, stream ordering and downstream drainage identification between neighbouring units.

Information on land use or land cover as proxy to land use was obtained from the Corine Land Cover (CLC) data sets generated for the years 2000 and 2006 in Turkey. The required climatic variables for characterizing catchments were mainly adapted from two sources. Rainfall depths for standard and relatively shorter time periods (from less than an hour up to 24 h) were obtained from the Frequency Atlas of Maximum Precipitation in Turkey [5]. Long-term annual averages of climate variables, on the other hand, were computed from the data outputs of a national research project implemented for contribution to the climate change assessments of Turkish State Meteorological Service (DMI) [6] (Fig. 1).

Figure 1: Mean annual precipitation based on NCEP/NCAR reanalysis data in the period 1961-1990.



All dams built with flood mitigation purposes in various reservoir capacities were extracted from the national database of the State Hydraulic Works as well as the international sources of ICOLD (International Commission on Large Dams).

3 Methodology

Priority ranking between catchment units with the final objective of performing a characterization based on flood assessment priorities was conducted in the study through a set of spatial indices derived from topographic, hydrologic, meteorological and land use-related phenomena.

3.1 Index-based characterization based on relative catchment characteristics

The indices included the average slope index (S) computed for individual micro-catchments to represent average terrain slopes within the corresponding drainage areas, the open spaces (OS) index expected to represent relative share of non-vegetated and impervious surfaces which trigger flood occurrence within catchment units, four other indices (PR, TR, PS, and TR) representing precipitation and temperature conditions in the reference period 1961-1990 and the selected scenario period 2010-2039 (Fig. 2), high altitudes share (HA) and temperature change in high altitudes (TCHA) indices to approximate snow melting impact on flood conditions in catchments (Fig. 3), forest cover index (FC) for representing the positive aspect of flood cover on flooding, reservoir storage index (RES) to involve the positive contribution of storage reservoirs to flood mitigation due to their operations, and a separate index (DPR) for taking account of the rainfall depths for standard durations (5, 10, 15, 30 min and 1, 2, 3, 4, 5, 6, 8, 12, 18, 24 hrs), which are estimated to have considerable significance on flood occurrence due to higher intensities.

Figure 2: Spatial distribution of the reference period precipitation index at the micro-catchments level.

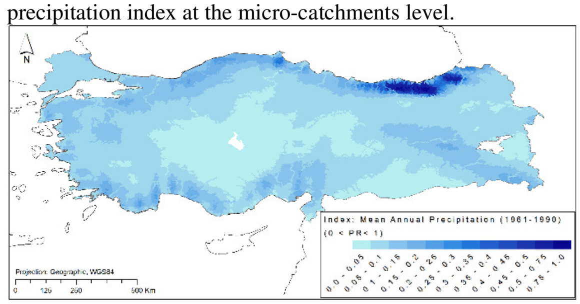
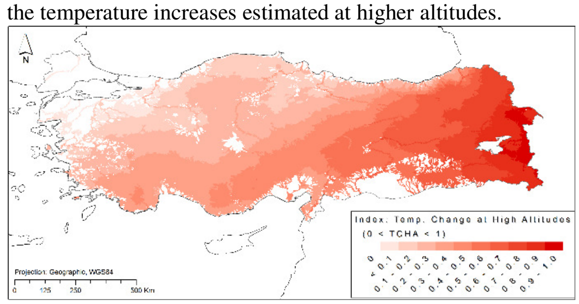


Figure 3: TCHA index generated for micro-catchments from the temperature increases estimated at higher altitudes.



3.2 Thematic combination of catchment indices for spatial characterization

Separate indices generated for the micro-catchments belonging to larger river basin systems are mainly designed for a generic typology of the basin systems to reflect the priorities for a more targeted orientation of potential flood studies in the future. Each index gives an insight into the local/regional classification with respect to the specific issue of concern, but individually is somehow insufficient to reflect the general view especially when the flood phenomenon with its multi-criteria nature is considered. To this end, all spatial indices were transferred into spatial index groups to acquire thematic compositions with more rational indications on flood priorities (Fig. 4).

As the index components considered in generating the final distribution of priority catchments were primarily employed to represent average conditions for various physical, hydrologic, topographic and meteorological factors in the associated drainage areas, the resulting priority ranks actually indicate the priorities assigned to the micro-catchments due to the physical characteristics of their upstream (Fig. 5).

Figure 4: Setting priorities for catchment units based on the overall index combination.

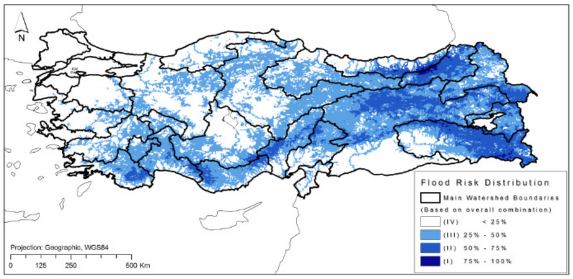
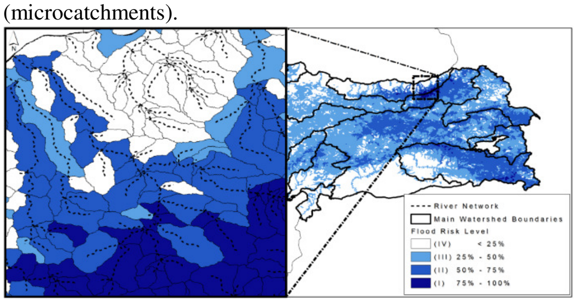


Figure 5: Zoomed display of analytical catchment units (microcatchments).

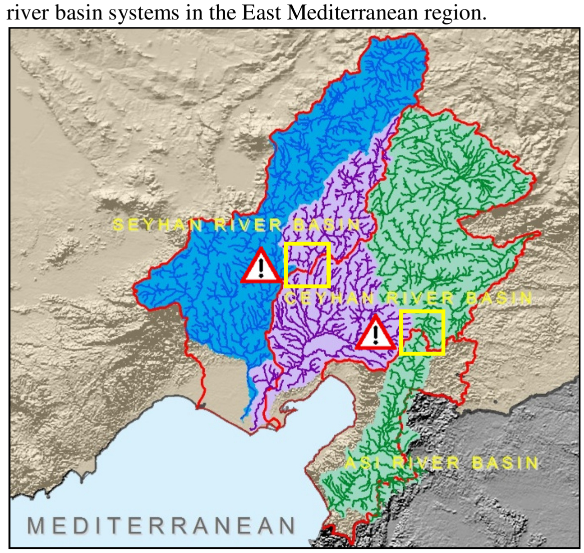


The highest flood potentials were estimated in the Eastern Black Sea River Basin System. This was an expected outcome as far as the dense precipitation pattern, potential snowmelt contribution and comparably higher terrain slopes are considered. Relatively smaller but still considerable flood potentials extend in the Eastern Black Sea region, in the upper sections of Fırat River Basin, Çoruh Basin, Dicle Basin and partially along the Mediterranean coastline.

3.3 Major drawbacks encountered with the use of spatial data sets

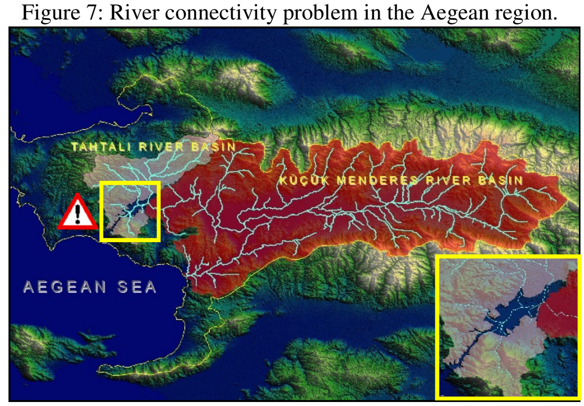
The accuracy of the series of computations and spatial operations followed in the presented study is correlated up to a great extent with the accuracy and precision of the spatial data sets. Spatial features embedded in the CCM2 database holds primary significance in this respect as they constitute the analytical basis of the spatial computations performed in the study. Despite the analytical strength of the database and concordance with the national datasets, spatial incompatibilities (e.g. faulty hydrologic connections, insufficient bifurcation) are still observed in the database for different parts of the river basin systems in Turkey. The level of accuracy in representing the hydrographic features and their mutual relationships is primarily governed by the digital terrain model considered and the inabilities arise from the poor definition of terrain elevations therein. Figs. 6-8 indicate such incompatibilities between the CCM2 data set and the national repositories in terms of the spatial display of hydrographic features. The most prominent problem stands with the inaccuracies in river connectivity, and thus the associated streamline ordering and basin area definitions. Three major river basins, Seyhan, Ceyhan and Asi Basins, neighbouring each other in the Eastern Mediterranean region are shown (in red) in Fig. 6. As can be seen from the figure, the mis-connectivity of the rivers results in significant problems in the spatial definition of the river basin boundaries. CCM2 river and sub catchment features extracted for this region seem to wrongly connect the river branches in the Eastern part of the Seyhan Basin with the Ceyhan River, while a greater part of the Ceyhan River connects again wrongly with the Asi River System in the south.

Figure 6: Mis-connectivity or loss of connectivity problem for river basin systems in the East Mediterranean region.



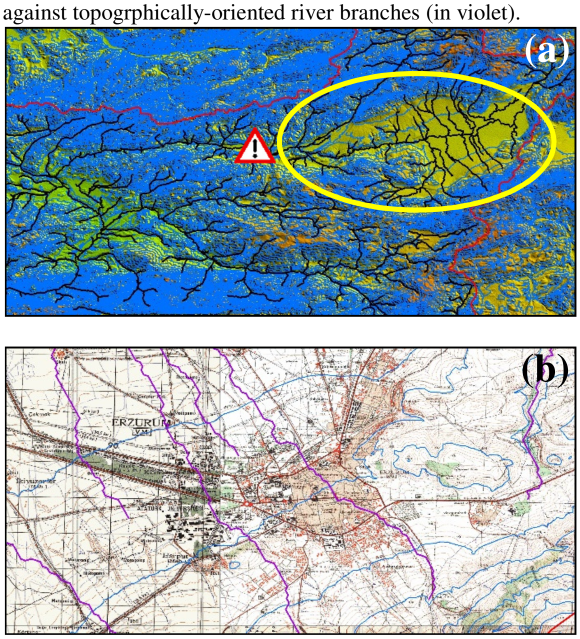
A similar drawback originating from the mis-connectivity of the stream lines in the CCM2 database results primarily from the available water bodies in the river network, where the connectivity rules go wrong without traversing the reservoir body, but jumping onto neighbouring basin systems. In Fig. 7, this inconsistency due to the presence of the Tahtalı reservoir in the Tahtalı Basin is shown in detail.

Figure 7: River connectivity problem in the Aegean region.



A basic solution for overcoming spatial accuracy problems as such can be the revision of the CCM data set with the updated version of the ASTER GDEM elevation model in the place of or in combination with the SRTM model. The use of national datasets, which may include elevation contours and points digitized from photogrammetric materials, vector layers of storage reservoirs and natural water bodies, etc., may be considered in support of increased accuracies over the globally defined digital terrain models. Yet, some problems with the adequacy of the national vector data sources can still be expected in these efforts. In Fig. 8, a spatial example about the inability of vector elevation contours, which especially relates to plain terrains, is *displayed*. As can be seen in Fig. 8(a), elevation contour lines become wide apart around the plains of the Erzurum province in the East Anatolia, making it difficult to model flow accumulation lines in the river network. Besides, man-made hydraulic interventions in the forms of canals or closed conduits along the flow of drainage water bring in additional difficulties for displaying river connectivity and identifying catchment boundaries for different river segments (Fig. 8(b)). The level of detail gained through this consideration may not be so significant, and even, may be very difficult to attain when generating large-scale spatial data sets. However, it should be assured that slight divergence in spatial representations from the natural network conditions will not lead to improper connectivity for the rivers, and more importantly, will not end up with inaccurate catchment delineations.

Figure 8: Potential problems confronted when using national data sets in support to global DEMs. (a) Less frequent elevation contours in the lowlands of Erzurum, and (b) Raster image from the central Erzurum showing improved conveyance systems against topogrphically-oriented river branches (in violet).



4 Conclusions

Flood mapping, especially with extensive coverage, substantially relies on the availability of spatial data sources on different components involved in flooding process as well as the accuracy and precision of the data itself. Flood research in Turkey that mostly concentrates on local case studies needs upscaling toward regional (or much wider in the sense of geographic representation) assessments. This necessitates the generation and use of larger-scale geographic datasets and expanded repositories on topographic, hydrologic, hydromorphologic, hydrographic and meteorological information, which would contribute to mapping accuracy and thus the performance of comprehensive assessments. This is indeed essential also for standardizing common spatial layers that will be used in different studies/projects with the desired accuracy and confidence.

Data sets originating from international sources may contain spatial errors at local levels (e.g. river connectivity and basin delineation errors contained in the CCM2 database for Turkey's catchments) and faulty attributes assigned. In fact, one can expect this as far as the broad assessment objectives set for the generation of these data sets and exhaustive workload of collecting and combining data from quite heterogeneous sources are considered. Nevertheless, quality assurance for international data sets should be seen as an integral part of the studies at the national level to secure the derivation of accurate and consistent results. Periodic updates through the use of improved international datasets, integration of data from sub-national levels and national expert consultation can be considered useful to this end.

References

[1] G. Onusluel Gul. Estimating flood exposure potentials in Turkish catchments through index-based flood mapping. *Natural Hazards*, 69(1):403-423, 2013.

[2] O. Gokce, S. Ozden¸ A. Demir. *Spatial and statistical distribution of disasters in Turkey*: inventory of disaster information. Turkish Ministry of Public Works and Settlement, Ankara (in Turkish), General Directorate of Disaster Affairs, 2008.

[3] L. Feyen, R. Dankers, J. I. Barredo, A. de Roo, C. Lavalle. Climate change and floods in Europe. *Climate Change and Natural Hazards series 8*, Directorate-General for Research, 2007.

[4] A. L. de Jager and J. V. Vogt. Development and demonstration of a structured hydrological feature coding system for Europe. *Hydrological Sciences Journal*, 55(5):661-675, 2010.

[5] State Hydraulic Works (DSI). *Frequency atlas of maximum precipitation in Turkey*, vol. 1: Frequency analysis of point precipitations. Ankara, 1990.

[6] B. Onol, Y. S. Unal, H. N. Dalfes. Modelling the impacts of climate change scenarios on Turkey. *ITU Journal*, 8(5):169-177, 2009.