DEVELOPMENT OF HYDROGRAPHIC DATASET FOR TURKEY: INITIAL STUDIES

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Abstract
A national hydrographic data set can be defined as a comprehensive set of digital spatial data that encodes information about naturally occurring and constructed bodies of water, paths through which water flows, and related entities. In the study, national hydrographic datasets of several countries are reviewed. Based on the reviewed datasets, initial studies are conducted in a small watershed in Turkey, Küçük Menderes Basin, to develop a similar national hydrographic data set for Turkey. Using GIS methods, the drainage network of the watershed has been obtained from the digital elevation model (DEM). Connectivity information, Strahler order, flow length, slope, and similar hydrologic information are calculated and linked to the stream reaches. The boundaries of the catchments are created from the DEM, and a three-level hydrologic cataloging unit hierarchy is formed.

Introduction

A national hydrographic dataset can be defined as a collection of digital spatial data that includes information on natural and constructed water bodies (i.e. lakes, dams) and water flow paths (i.e. streams, rivers and channels). Delineation, geographic name, classification, direction of water flow and similar hydrographic information and a unique identifier should be available for each feature in such a dataset. The dataset should also contain metadata and information that supports future updates and improvements to the data. If present, such a dataset may support many applications, such as environmental and hydrologic modeling, geo-coding environmental and hydrologic observations along the waterways, and map making. A watershed dataset showing the delineations of water drainage areas as a supplement may also enhance these applications. Being aware of the importance and functionality of such datasets, many countries like U.S. and European countries developed their own national hydrographic and catchment datasets.

National Hydrographic Datasets

River Reach File (RF) developed by U.S. Environmental Protection Agency (EPA) is a hydrographic database of the surface waters of the United States. The structure and content of the RF were created primarily to establish hydrologic ordering, to perform hydrologic navigation for modeling applications, and to provide a unique identifier for each surface water feature [1]. A key characteristic of the RF is its attributes, which define the connected stream network regardless of the presence of topologic continuity. The attributes also include unique identifier, flow direction and hydraulic characteristics for each stream reach. The development of RF dates back to early 70’s and it has progressed through four versions until 1997. The latest version, RF-3, has a scale of 1/100.000 and includes more than 3 million reaches.

In addition to RF, U.S. also has a standardized hydrologic unit system, referred to as the Hydrologic Unit Code (HUC) system that was developed by the U.S. Geological Survey (USGS). HUC system divides U.S. into successively smaller hydrologic units, which are classified into six levels: regions, sub-regions, basins, sub-basins, watersheds and sub-watersheds. The underlying concept is a topographically defined set of drainage areas organized in a nested hierarchy by size [2]. The units are defined along natural hydrologic breaks based on land surface and surface water flow, and they are generally subdivided into 5 to 15 units from one level to the next. A 2 to 12 digit unique code based on its level in the classification identifies each hydrologic unit.

In Europe, many countries have their own national hydrographic datasets. However, the European Union (EU) recently developed a common hydrographic dataset, which is called European Rivers and Catchments (ERICA). ERICA is a hydrologically-valid digital database of EU that includes rivers, canals, lakes, coastlines and catchment boundaries [3]. In this quality-controlled and validated dataset that is developed on the GIS, each river stretch is uniquely identified and includes flow direction. All stretches are node matched and flow paths are continuous through lakes. All individual feature sets are mutually consistent, including automatically derived catchment boundaries, and both local and English names (if present) are made available for features. In order to identify catchments, the dataset uses ERICA Coding System (ERICA-CS), which is a combination of Norwegian and German coding systems and includes a marine code, a marine border code, a series of nested catchment codes and a catchment size indicator for each catchment. Two different versions of ERICA are available: 1/1.000.000 scale ERICA-1M which covers whole Europe and 1/250.000 scale medium resolution ERICA which is currently available only for two pilot catchments.

Situation in Turkey

Turkey, being a bridge between Europe and Asia, is surrounded by three international seas (Black Sea, Aegean Sea, and Mediterranean Sea) and also has an interior sea (Sea of Marmara). There exist 26 officially defined major hydrologic regions that cover the whole country (Figure 1). The surface areas of these basins range from 6374 km^2 to 127304 km^2, the average being 30000 km^2. Four of the basins are closed basins that drain to interior lakes, while six of the others belong to cross-boundary rivers that drain to neighbor countries. Turkey has an average precipitation of 642 mm, which results in a total water potential of 501 km^3. 186 km^3 of this potential becomes surface runoff, but only approximately half of it (95 km^3) is usable. As runoff per capita this value is equal to 1475m^3, which shows that Turkey is not too water-poor but also not water-rich [4]. Therefore, development and protection of water resources reflects great importance. National hydrographic and catchment datasets, which are currently not present, may significantly speed up and facilitate planning and application of projects related with water resources.

Figure 1. Surface water resources of Turkey

A Case Study: Küçük Menderes Basin

As a pilot study area for the development of hydrographic and catchment datasets for Turkey, Küçük Menderes Basin is selected, which is extending in east-west direction toward the Aegean coastline at western Turkey (Figure 1).

In order to determine the boundaries of the hydrologic units, first watersheds are created from the DEM by applying Jenson and Domingue's D8 algorithm [5]. The implementation of the algorithm found in the Hydrological Modeling extension of ArcView 3.2 is used for this purpose. In this algorithm, a single downstream cell among its eight neighbors is defined for each grid cell, so that the descent slope is the steepest. Once the flow directions are determined, the number of cells located upstream of each cell is calculated as a measure of flow accumulation. Applying a threshold value to these flow accumulation values and selecting the cells with higher accumulation values than the threshold yields a uniquely spanning drainage network. This network represents the paths of the DEM-based watershed flow system, the drainage density of which can be controlled by changing the threshold value. In order to determine the boundaries of the watersheds, the intersection points of the drainage reaches can be used as the outlets of watersheds, above which the contributing area are determined. A threshold value other than the one used to define the drainage network can be used to determine the watersheds, if one-to-one correspondence of drainage reaches and watersheds is not required or if a watershed should contain more than one drainage reach. Low threshold values result in enormous number of small watersheds that do not have hydrologic meaning, while high threshold values result in very large watersheds that are not very useful to create a nested-level hierarchy. Therefore a try-and-error approach is required to determine an optimum threshold value. For the Küçük Menderes Basin, a threshold of 100 cells for the drainage network and a threshold of 500 cells for the watersheds are found to be consistent with the actual river network and hence reasonable.

Some of the watersheds among the initially produced 96 watersheds are found to be artifacts from raster-to-vector conversion and they are deleted. The watersheds that are outside the Küçük Menderes Basin are also removed. Very small watersheds that are produced due to the topography of the land are combined with the neighboring watersheds for the generalization. At the end, 52 hydrological units are obtained that are given in Figure 2.

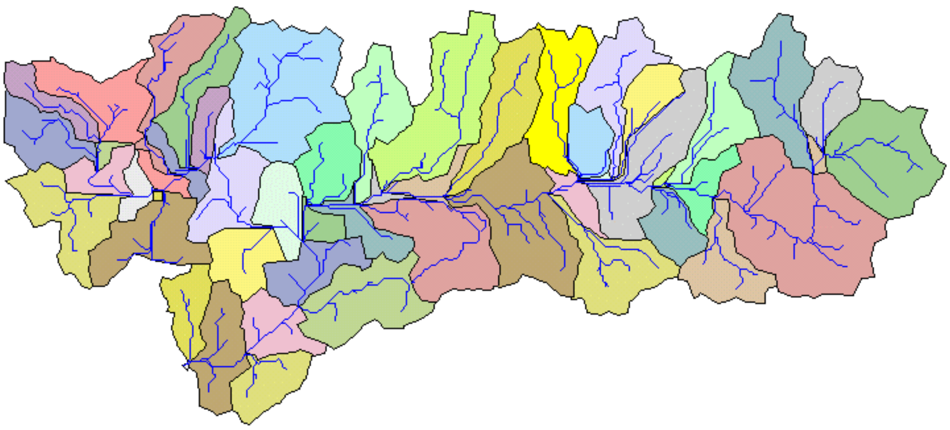

Figure 2. Watersheds and the drainage network for Küçük Menderes Basin

For the Küçük Menderes Basin, a three-level hydrologic unit categorization is found to be appropriate when its size is taken into consideration. Produced watersheds are used directly for the third level of the categorization. The union of all hydrologic units is taken in order to form the first level of the categorization, which is named as "Basin". Production of the second level "Sub-Basins" is the most difficult step, since it requires selection criteria for the hydrological units that will be combined together to form this level. Information like hydraulic characteristics, flow rate and seasonality of the streams are required in addition to the expert judgment for a satisfactory selection. Since such information and expertise on the basin were not available at the time of the study, a different and simple approach has been utilized. The stream orders are found according to the Strahler ordering [6], and the hydrologic units are combined together based on the stream orders to form the sub-basins (Figure 3). In this method proposed by Strahler in 1952, stream order starts with 1 for the up-most streams and increases only when streams of the same order intersect. Therefore the intersection of a first order and second order reach will remain a second order reach rather than create a third order reach. Based on Strahler orders of the streams, 8 sub-basins composed of 5 to 10 watersheds are created (Figure 4). The summary of the hydrologic units are given in Table 1.

Table 1. Summary of hydrologic units

Level	Name	Digits	Number of Units	Average Size (km^2)
1	Basin	2	1	4064
2	Sub-basin	4	8	508
3	Watershed	6	52	78.15

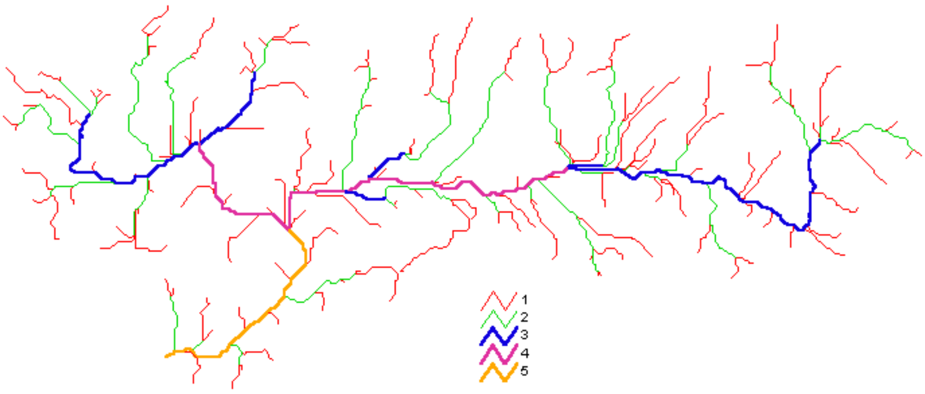

Figure 3. Strahler orders of the drainage reaches

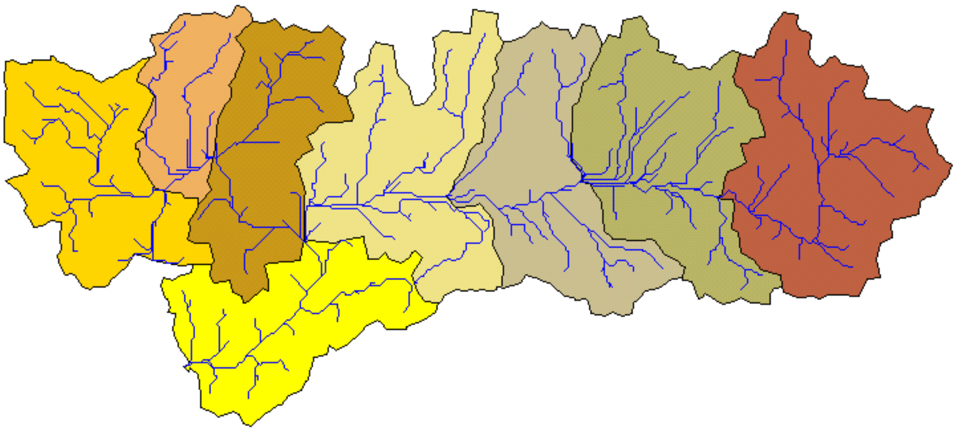

Figure 4. Sub-basins of the Küçük Menderes Basin

In order to create the hydrographic dataset, DEM-based drainage network is used. Head, tail and intersection nodes of the drainage reaches are extracted from the vector drainage network and their elevations are calculated from the DEM of the study area. Attribute tables of stream reaches and nodes are joined together to obtain information on the elevations of starting and ending points of the streams, which are used to determine the direction of water flow along the reaches. Also the elevation difference between the starting and ending points and the length of the reaches are used to calculate the average slope of each reach. Since reaches are continuous at their intersections, topological relationships (i.e. connectivity information) have been built automatically using a custom Arcview Avenue script. Finally drainage reaches are uniquely identified. Each stream reach has also the hydrologic unit code of its watershed in its attribute table. Obtained drainage network with reach nodes and flow directions is given in Figure 5.

Discussions and Conclusions

During the study, DEM-based drainage network and hydrologic unit boundaries are created and uniquely identified, flow directions are assigned and topological/hydrological relationships are build for Küçük Menderes Basin, which is selected as a pilot basin for the development of national hydrographic and catchment datasets for Turkey. A set of extensions and scripts are collected and developed within GIS in order to fulfill the requirements. These scripts and extensions are gathered in a single GIS project file for easy usage.

In order to create hydrographic dataset for the basin, DEM-based drainage network is used. Since hydrologic units are also created from the DEM, inconsistency problems between the datasets are not observed and they are found to be mutually consistent to each other. However, when using such a 'derived' dataset, closeness to the actual stream network should always be checked. DEM-based drainage network may deviate from the actual stream network, if the resolution of DEM is coarse, terrain is flat, and underlying geography is carstic in nature. When available, actual stream network should be preferred as a starting point in hydrographic dataset development. But again the consistency of DEM and actual stream network should be checked.

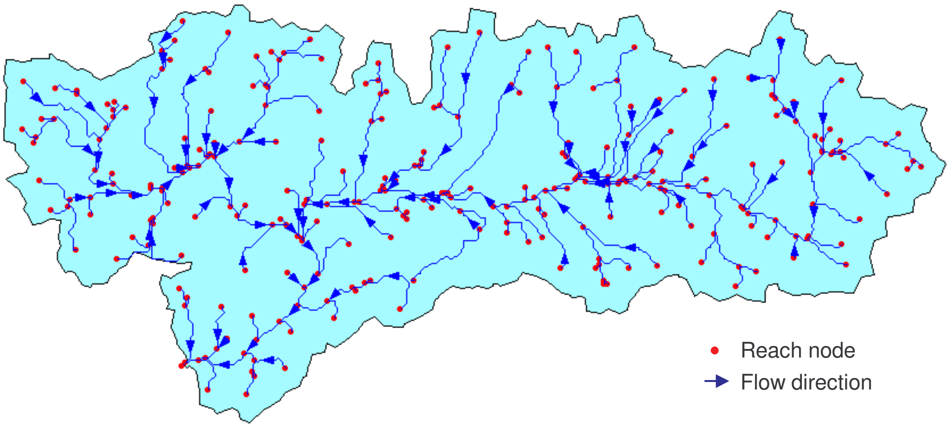

Figure 5. DEM-based drainage network of Küçük Menderes Basin

One method to create the level-hierarchy of hydrologic units is first creating the lowest (smallest) level units and then repetitively combining them to obtain higher (larger) levels. Another methodology may be starting from the highest hydrologic units and dividing them repetitively to obtain lower levels. Both of the methods require some pre-defined rules for combination or division. The former method is applied in this study to create a three-level hierarchy and Strahler orders of the streams are used as a combination criteria. Although this approach yields satisfactory results for three-levels, generalization of the catchments from lower level to higher level gets complicated as the number of levels increases. Strahler ordering alone may not be enough and additional information and combination criteria may be required. This should be especially taken into consideration if nation-wide hydrographic dataset is to be produced, since Küçük Menderes Basin is one of the smallest basins of Turkey. There are many larger basins (up to 20 times for some basins), which most probably will require more levels. Other classification methods, like ERICA-CS, may be a better alternative if additional information cannot be obtained.

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