MAPPING WETLANDS IN EUROPEAN HEADWATER AREAS

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The paper describes the first approach to wetlands mapping in headwater areas at the continental scale. Given the size of the minimum mapping unit it is evident that a class like wetlands is underestimated in the final assessment, as it is often characterized by objects smaller than 25 ha. It is known that this is a drawback affecting in particular the "water" classes of the CORINE classification. The following assessment has been carried out on the area covered by CORINE data, covering the EU15 Countries (excluding Sweden) plus Poland, Estonia, Latvia, Lithuania, Czech Republic, Slovakia, Slovenia, Hungary, Bulgaria, Romania, Bosnia and Herzegovina, Albania, Macedonia, for a total of 4,650,000 ha. Using a 250-meter resolution DEM, only headwater areas larger than 1 km^2 are reported in the presented map of headwaters in south-western Europe. The process of mapping can be further developed by deeper characterising the identified areas, for example by assigning them to corresponding drainage basins, altitudinal areas, landscape or administrative units. The results are based on the data available. Updating and improvement will be possible in the short term with the delivery of the new CORINE 2000 system (based on satellite images acquired between 1999 and 2001) and using more detailed Digital Elevation Models (e.g. Shuttle Radar Topography Mission).

1. Introduction

Over the last century or so, wetlands in Europe have undergone thorough changes. Many of them have been drained, exploited and/or converted to arable land or settlements. Only during the last decades of the 20th century has the importance of wetlands been highlighted by the scientific community and recognised by the general public. An important role in this process was played by NGOs active in the field of environmental protection. The value of wetlands as habitat for many endangered species

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or as rest sites for migrating birds, for example, is highlighted in an extended body of literature.

At the same time, it has been recognised that wetlands are particularly sensitive areas and that European and national policies, especially in the agricultural sector, are likely to result in continued pressure on these precious resources. If the protection of wetlands in Europe is to be efficient, a first step should be an exhaustive survey of their distribution and characteristics across Europe. This is a non-trivial task, since relevant information is not always easily accessible and needs to be updated on a regular basis.

This paper describes a first attempt to map wetlands in headwater areas across Europe. It is based on the analysis of CORINE land cover data in combination with data on European rivers and catchments elaborated in the framework of the CCM Activity of the Institute for Environment and Sustainability at the European Commission's Joint Research Centre.

2. Developing a GIS for European environmental data

European-wide spatial datasets with relevant information for assessing the state of the environment have been collected by Eurostat since 1992. Eurostat, for example, elaborated geographical layers and statistical information on land use, soils, hydrography, natural resources and transportation networks through its GISCO (Geographic Information System for the European Community) project. These layers correspond to mapping scales between 1:500,000 and 1:3,000,000 and are useful for a general overview and for overall assessments. More detailed data exist at national, regional and local levels and efforts for harmonization, integration and management of these data through a modern spatial data infrastructure are bundled under the so-called INSPIRE (Infrastructure for Spatial Information in Europe) initiative of the European Commission. The study presented in this paper is based on the work carried out within the Catchment Characterisation and Modelling (CCM) activity of JRC's EuroLandscape Project (now part of the Agri-Environment Action of the Soil and Waste Unit of the Institute for Environment and Sustainability - IES, for the development of a European-wide database of drainage networks and catchment boundaries. The aim of the CCM project is the development of algorithms for the analysis of Digital Elevation Models (DEM) and ancillary data in order to produce a pan-European database of river networks and catchment boundaries at a mapping scale of 1:250,000 to 1:500,000, using highly automated processing tools. Version 1.0 of the database is available, covering the area from Scandinavia to the Mediterranean and from Portugal to 38 degrees Longitude East.

3. The critical contributing area and headwaters

A central question in all studies dealing with the extraction of rivers from DEMs is the location of the channel head. Analyses at the field scale show that related processes are very complex. In general terms, however, a channel head is located where linear fluvial processes start to dominate over diffuse slope processes. Depending on the prevailing geomorphic processes, this condition may be met at a variety of scales, which means that the drainage area for a channel head can vary to a large degree, depending on local conditions [1], [8].

When deriving drainage networks from digital elevation data, the spatial resolution of the DEM is the key characteristic, determining the level of detail at which geomorphic processes can be inferred from the DEM. Using DEMs of high spatial resolution, detailed information on hill-slope processes and channel formation can be derived. At coarse grid resolutions (> 100 m), detailed geomorphic processes and channel initiation cannot be modelled. As an alternative, particularly for studies covering extended areas, a critical contributing area can be defined for deriving the approximate position of channel heads [6], [11], [10], [5], [12], [3].

This critical contributing area can be derived from the analysis of the relationship between contributing area and local slope. If values of local slope versus contributing area for each grid cell are plotted, a graph of the so-called scaling response can be determined (Figure 1). On this graph characteristic changes in the scaling response can be identified, corresponding to changes in the dominance of the prevalent processes.

In particular, two points are interesting for defining channel heads:

(a) the point where dS/dA turns from positive to negative, indicating the critical contributing area corresponding to the change of dominance form hill-slope to fluvial processes, and

(b) the point where dS/dA becomes stable, identifying the value of critical contributing area above which all points are channelised. Point (a) is detectable only when the DEM grid cell size is smaller than approx. 30 m. Point (b) can still be identified from coarse DEMs.

Given the extent of the area covered by CCM and the 250-meter grid cell size of the available DEM, the analysis of the local slope – contributing area relationship for deriving the critical contributing area was the evident choice. In order to overcome the drawback of using a single critical contributing area for all of Europe, representing a large variety of landscapes with highly varying drainage densities, a landscape stratification has been elaborated, and for each landscape type a dedicated critical contributing area was derived from the analysis of the corresponding local slope – contributing area plot.

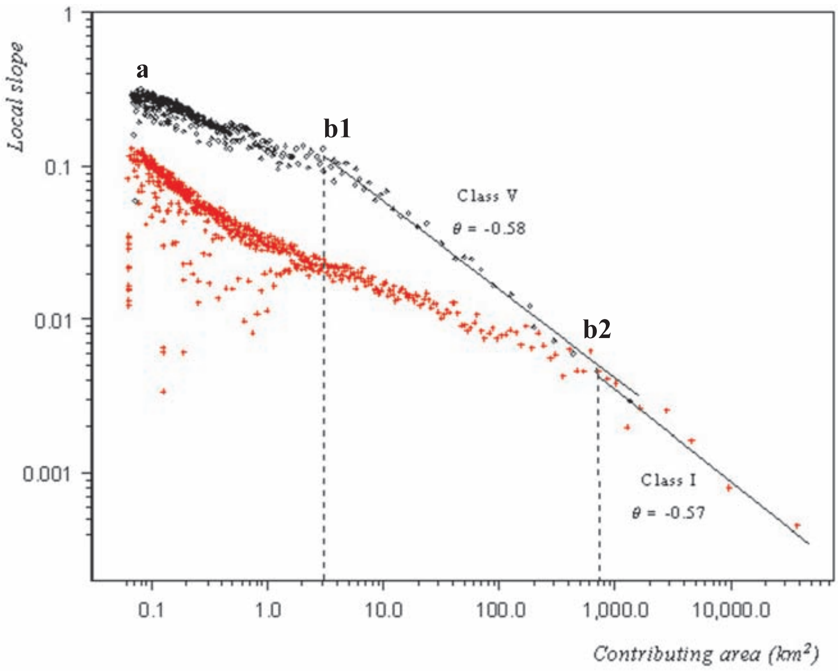

Figure 1. The local slope plotted versus contributing area in logarithmic scale.

In order to elaborate a suitable landscape stratification, five variables have been identified on the basis of a literature survey as the most important factors governing drainage density: relief type, vegetation cover, soil transmissivity, rock erodibility, and climate. Each variable has been classified into three to seven classes and a Landscape Drainage Density Index has been derived from a weighted combination of these variables, using a multi-criteria evaluation technique [16]. In short, the variables have been parameterised following:

- Relief type has been considered through relative relief, defined as the maximum altitude difference in a moving window of 3 by 3 grid cells [9], [13].

- The percentage vegetation cover was derived from CORINE land cover data with a grid cell size of 250 m, reclassified in 14 classes to which an average value of yearly surface cover was assigned on the basis of the scheme derived for Europe by Kirkby [7].
- As a proxy indicator of soil transmissivity, soil texture was selected as the main soil factor affecting channel initiation [2], [15]. Soil texture was derived from the Soil Map of Europe [4].
- Rock erodibility was estimated according to the Gisotti's scale based on the parent material as given in the Soil Map of Europe.

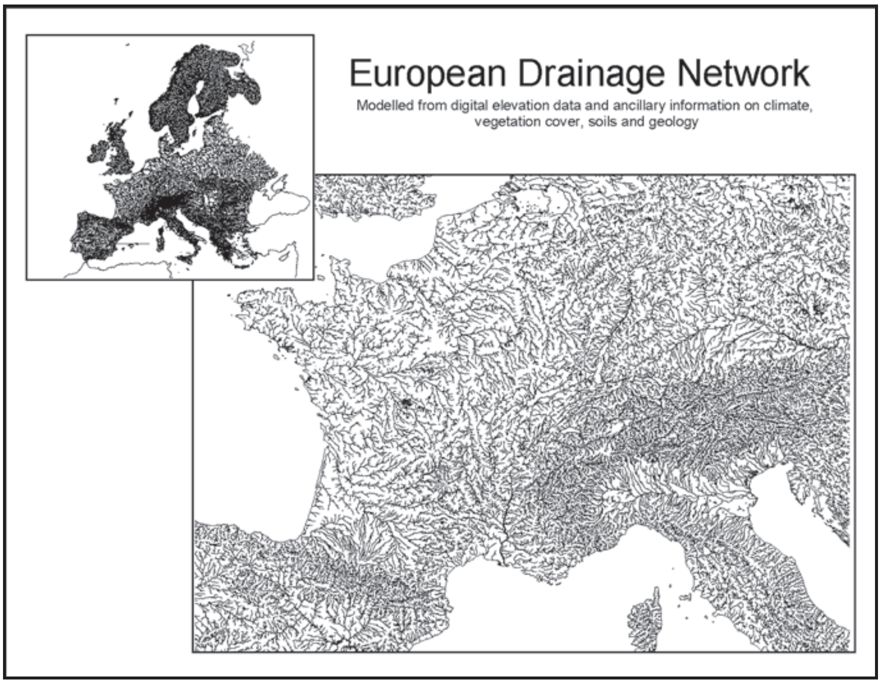

Figure 2. European Drainage Network as derived by the CCM project.

The climate factor was synthetised by the mean annual precipitation, derived from the daily meteorological database of the European MARS project, covering the period 1977-1999 on a 50 km grid [16], [14]. A critical contributing area has then been assigned to each landscape class by analysing the specific relationship between local slope and contributing area and identifying point b in the corresponding plots. This analysis resulted in critical contributing areas varying from a few square kilometres to a few tenths of square kilometres that is, in fact, a stratification of Europe with direct reference to the size of headwater areas.

4. Mapping of European headwaters

An example of the river network resulting from the described methodology is represented in Figure 2. Due to the underlying landscape stratification, it reflects the natural variability in drainage density. Starting from the points identified as channel heads, all down-slope river cells can be mapped. Interim processing results (e.g., flow accumulation and flow direction grids) allow for reversing the mapping process so that cells draining towards the channel head can be identified and headwater areas can be mapped.

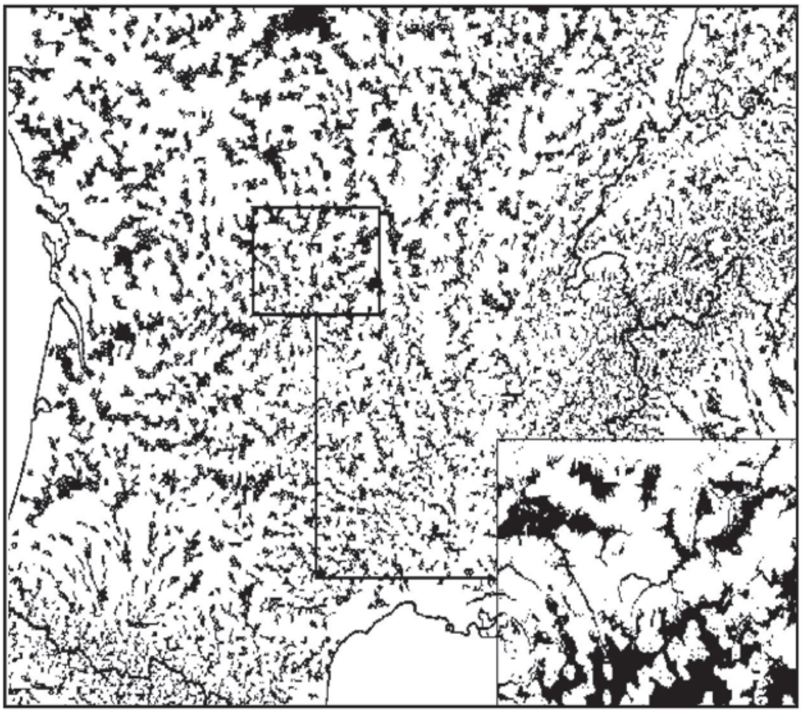

Figure 3. Headwater areas in south-western Europe, extracted from the CCM database.

A resulting map of headwaters in a part of south-western Europe is shown in Figure 3. It must be stressed that from a 250-meter resolution DEM not all headwater areas can be mapped. In our study only headwater areas larger than 1 km^2 are reported. On the other hand, sometimes very large areas are mapped as headwaters. This is due to the fact that the critical contributing area can be quite large, especially in flat areas such as the north European continental planes. In such areas headwaters with a surface as large as 50 to 60 km^2 may be mapped. As a result of this analysis over the entire mapped area, a total surface of about 6,500,000 km^2, 27% or 1,750,000 km^2 have been assigned to headwater areas

5. Wetlands in headwater areas

The main homogeneous source of data on land cover for Europe is CORINE Land Cover (CLC), a data layer realised by the European Commission in the frame of the CORINE programme (Co-ordination of Information on the Environment). The principal sources of information are Landsat Thematic Mapper images recorded in 1985-1994, that have been analysed using photo-interpretation techniques. Given the resolution of the images (10 to 30 m pixel), a minimum mapping unit of 25 ha and a minimum width of 100 m for linear elements have been retained. The CLC legend is hierarchically structured in three levels, with 44 classes in the most detailed level.

At level 1 a main class "wetlands" exists, that is sub-divided at level 2 in "inland" and "coastal" wetlands. At level 3 inland wetlands (defined as *"Non-forested areas either partially, seasonally or permanently waterlogged; the water may be stagnant or circulating")* are further detailed into inland marshes and peat bogs, and it is on these two classes that the attention has been focused.

Inland marshes are defined as "Low-lying land usually flooded in winter, and more or less saturated by water all year round. Marshes may be made up of river ox-bows, areas in which waterways shift from their course, depressions where the ground water table reaches the surface permanently or seasonally, or basins where run off or drainage water accumulates ".

The peat bogs are defined as "Peat-land consisting mainly of decomposed moss and vegetable matter. May or may not be exploited – peat-bogs are peaty ecosystems populated by hygrophilous plants and developing either in flooded hollows in plains (lowland bogs, raised or flat) or at altitude in very rainy countries (blanket or sloping upland bogs).

Under the effect of biochemical and mechanical factors, the accumulated vegetal mass is transformed into a compact, combustible matter made up of over 50% carbon: peat. To qualify as a peat-bog, the accumulated deposits must contain at least 30% organic matter if they are argillaceous and at least 20% in all other cases, and must be more than 40 cm thick. Peat-bogs will remain active (produce peat) for as long as the water supply remains adequate. Any water shortage will kill them. Both categories - active bogs and dead bogs - can be exploited".

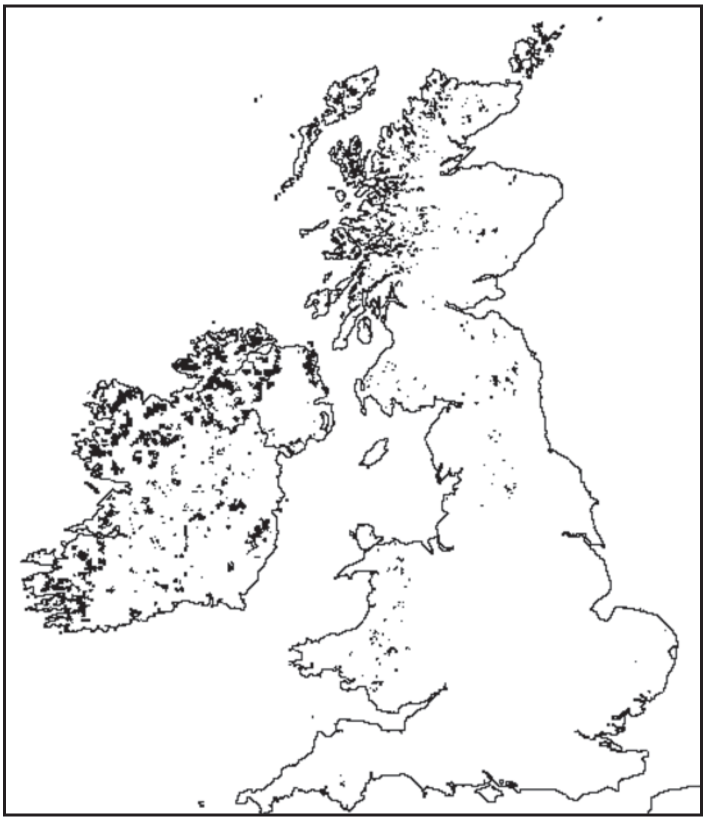

Figure 4. Wetlands in headwaters in Ireland and the UK.

Given the size of the minimum mapping unit, it is evident that a class like wetlands is underestimated in the final assessment because it is often characterized by objects smaller than 25 ha. It is known that this is a drawback affecting many of the "water" classes in the CORINE classification.

The following assessment has been carried out on the area covered by CORINE data, covering the EU15 Countries (excluding Sweden) plus Poland, Estonia, Latvia, Lithuania, Czech Republic, Slovakia, Slovenia, Hungary, Bulgaria, Romania, Bosnia and Herzegovina, Albania, Macedonia, for a total of 4,650,000 ha.

Inland wetlands cover some 36,000 ha in this area, that is, less than 1% of the total surface. For the same area, headwaters amount to 1,000,000 ha, and wetlands in headwaters to 10,600 ha, which is about 1% of the headwater area. Figure 4 shows the wetlands in headwater areas in Ireland and the UK, mapped with the described methodology.

6. Conclusions

This paper describes the first approach to wetlands mapping in headwater areas at the continental scale. The process of mapping can be further developed by deeper characterizing the identified areas, for example by assigning them to corresponding drainage basins, altitudinal areas, landscape or administrative units. The results are based on the data available. Updating and improvement will be possible in the short term with the delivery of the new CORINE 2000 system (based on satellite images acquired between 1999 and 2001) and using more detailed Digital Elevation Models (e.g. Shuttle Radar Topography Mission).

It has been clearly stated that the limits of the approach are due to the resolution of data. In fact, at this scale, isolated wetlands below the 25 ha threshold or even complex systems of small elements are neglected; it is clear that a more detailed approach is needed for the management at the medium/large scale.

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