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Original article

# Use of spatial water database as an essential element of water management – a methodological overview

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ABSTRACT

In the current digital age, spatial management seems impossible without a set of data which maps the real situation on a computer screen. However, varying technologies (software, hardware) as well as methodologies (vectorisation, automatic classification, deep learning, etc.), together with the availability of input materials, result in a huge difference in the quality and timeliness of data collected infor example different countries. This statement also applies to hydrographic data, which undeniably affects water management efficiency. With increasing globalization, it seems necessary to standardize hydrographic data on a transnational level. The main aim of this article was to review the ways and techniques of collecting, updating and sharing hydrographic data by selected countries or organizations. In addition, the use of modern geo-information and remote sensing tools was reviewed, as well as work towards interoperability of inland surface water databases. As a result of the review, the authors identified a strong need to unify hydrographic data at both the national and continental levels, and in the future, globally (considering the dynamic change of data precision when changing the digital mapping scale). In addition,good practices were identified, and methods that can be used to create a universal spatial database of surface waters were identified.

KEY WORDS: surface water database, spatial databases, GIS, geoportal

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## 1. Introduction

Water management is carried out at each administrative level based on some set of hydrographic network data (NUNES ET AL., 2023). The development of geographic information systems (GIS) has resulted in these data becoming spatialized (or, are still in the process of being mapped from analogue material, in some regions, e.g. through vectorisation) (ABSALON, 2008; SZYPUŁA, 2020; STROBL, 2010). Although digitised databases annotated with spatial attributes seem to support water management, their quality depends on the accuracy, timeliness and consistency of these data. Numerous problems arise at this stage that affect the misrepresentation of the actual state of the hydrographic network in virtual space including:

– creating data in local or regional coordinated systems. Although mapping space in a geodetic coordinate system allows millimetre precision, transformations of these systems to global systems result in discrepancies. This is already problematic at the scale of a medium-sized country (e.g. European countries) while at the scale of a large country (e.g. India, USA) it is practically impossible to merge such data.
– Lack of real-time updates. The extent of water depends on the current hydrological and meteorological situation and, in the long term, is the result of erosion (Barker et al., 2022; Strack, 2018). For this reason, it is impossible to determine the correct water extent with at least centimetre accuracy.
– Low, or inconsistent, resolution of source data. The course of the hydrographic network is rarely mapped based on geodetic measurements. It is most often based on the digitisation of orthophotos, supported by information obtained from digital terrain models (Koski et al., 2023). Satellite images, most often non-commercial (with a maximum resolution of 10 m), are also frequently used for this purpose (Janczewska et al., 2023). These materials are acquired at different times and may only be available for a selected region.
– Lack of consistent methodology and fragmentation of databases at local levels (Janczewska et al., 2023).

Another major shortcoming of existing water databases is the lack of data interoperability. The data are incompatible because they are stored in different formats and are created at different scales. For this reason, each successive harmonisation for a larger area (smaller scale) reduces the accuracy of the data. This is the reason why there is no single global vector dataset for the hydrographic network (Young, 2018; Holland et al., 2016). Nevertheless, interstate organisations are pushing for data standardisation (e.g. *INSPIRE Directive 2007/2/EC* or *Executive Order 12906*, signed in 1994 by B. Clinton: *Coordinating Geographic Data Acquisition And Access: The National Spatial Data Infrastructure)*.

Nowadays, a group of specialists makes strategic decisions for water management in front of a computer screen and this is the reason that spatial mapping of the current state of the hydrographic network integrated into a multi-purpose relational database is becoming a challenge for modern water management (Larsen, 2016).

Due to the lack of consistent information on the state of inland surface water databases, this article reviews the literature, summarises methods of creating spatial water databases and issues of concern that should be considered when designing the structure of such a database.

## 2. Surface water database worldwide

Since the proliferation of digital land surface imaging techniques (remote sensing, laser scanning) and GIS, the analyst's primary concern is to acquire suitable - reliable data and to identify its source (Panamaldeniya, 2021). The concept of good data quality includes:
– optimal resolution - data should be as detailed as possible but at the same time processable (the smaller the size the easier it is to process) (Eldrandaly, 2011),
– the fullest possible coverage - data in a uniform structure should cover the widest possible area (Nkeki & Asikhia, 2013),
– completed attribute information with a uniform structure (Haining, 2008),
– timeliness – affecting the accuracy of the representation of the terrain in relation to the actual state, and on the possibility of processing them only in relatively new software (Zhao et al., 2012).

Having good quality data for large-scale analyses raises the problem of incompatibility (data are created in different formats, structures, coordinates) (Gotway & Young, 2002). In addition, the detailed, combined data take on a considerable size (Gusman et al., 2022). Processing data of significant sizes of so-called BIG DATA (detailed data for large areas) is currently the biggest technological challenge for geo-informaticians (Brunsdon & Comber, 2020).

Brauman (2016)pointed out that any globalised hydrographic data must be generalised and will not map short, narrow channels. For this reason, global hydrographic data are most often derived from the automated classification of satellite imagery (Masetti et al., 2022; Munier & Decharme, 2021). Table 1 gives examples of current global data that contain hydrographic information.

Table 1. Global hydrographic data

| Type | Name | Hyperlink | Resolution of source raster data | Literature |
|---|---|---|---|---|
| Raster data | Hydrosheds | https://www.hydrosheds.org/products/hydrosheds | 90 m (SRTM) | Lehner et al., 2008 |
| | The Hydrography 90 m | https://fred.igb-berlin.de/data/allpackages/ | 90 m | Amatulli et al., 2022 |
| | Hydro1K | https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-hydro1k | 30 m (GTOPO 30 m) | USGS Eros Archive, 2018 |
| | MERIT Hydro | https://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_Hydro/ | 90 m | Yamazaki et al., 2019 |
| Vector data | EU-Hydro River Network Database 2006-2012 | https://land.copernicus.eu/en/products/eu-hydro/eu-hydro-river-network-database | - | Copernicus, 2019 |
| | Hydrographic Surveys (International Hydrographic Organization (IHO)) | https://iho.int/en/iho-online-catalogues | - | Golub et al., 2023 |

Although vector data of,for example, continental extent exist, they are created using modelling tools (e.g. Hydrology for ArcGIS) based on low-resolution (>30 m) Digital Terrain Models (Lin et al., 2021). They have also not assigned any attributes, or they are not as detailed as in national/local databases. For this reason, it was necessary to look at the quality of the data collected at the national level.

## 3. Methods, techniques and patterns of surface water databases in different countries of the world

When analysing the sources of hydrographic data (Table 2), some regularities can be observed. The first is that the legal conditions for the extent of data collected depend on the regime of the country concerned. In the case of unitary states (e.g. Poland, France), data on hydrography are collected at the national scale. In federal states (e.g. USA, Germany), on the other hand, each autonomous region maintains its own geoportal (Mitani et al., 2020).

As reported by Chatterjee & Sinha (2014), some of the water resources data in India was not digitised and data was collected by different agencies in a heterogeneous structure and was not merged with each other. According to the revision, the authors' demands have been partially fulfilled and hydrographic data for the entire country was made available from 28 March 2018 on the national portal of India Water Resources Information System. The India database as well as the data collector for water management (India Water Resources Information System, 2018) were established in 2018, and as intended, their purpose is to collect and make available up-to-date spatial data on the surface hydrographic network (Kumar, 2018).

Similarly, the US Geological Survey collects data on the surficial hydrographic network as part of programmes with assurances of continuity. These data, and major analyses are made available on USGS government websites. However, each US state also maintains its own database as exemplified by The DNR 24k hydro for Wisconsin at a scale of 1:24 000 (https://www.sco.wisc.edu/data/rivers-lakes-streams/). The ongoing updating of data and the change in data collection and sharing technology as technology advances (both locally and regionally) is another positive trend.

The Brazilian water agency provides data on the hydrographic network using ArcGIS Online software (ESRI server). Canadian government agencies, on the other hand, are divided in detail by competence which translates into the scope of the data produced (they are the different institutions responsible for inland waters, marine waters, etc.). Sharing of these data is done via FTP servers.

The Water Resources Planning Organisation (WARPO) of Bangladesh, as part of the National Water Resources Database (NWRD), provides hydrographic network data in vector form, and its structure is described in a data catalogue. In Sweden, the nationwide hydrographic network is presented in electronic form by the 'surveyors' (in Swedish: Lantmäteriet). In Spain, the administrative structure of water management is much more complex, with water management being handled by three ministries and each region independently having its own Basin Authorities, which are responsible for the collection, sharing of data on the hydrographic network and, in its entirety, water management in the catchments concerned (ALBIAC ET AL., 2014; MITERD, 2023). Similarly, in Italy, water management system data are collected within a single water region (set of catchments).

In the UK, data is collected for the whole territory by the government's mapping institute (*Ordnance survey*) providing vector data, while water management is handled by the *UK Hydrographic Office* and hydrological data is collected by the non-profit organisation *National River Flow Archive* and made available on the *UK Water Resources Portal*. Similarly, in the case of Poland, the Map of the Hydrographic Division of Poland is a study covering the entire country, made available on the Hydroportal maintained by the owner of the resource, i.e. the State Water Holding Polish Waters. This study is available as a Web Map Service (WMS), while vector data can be obtained for a fee. The Australian government, in collaboration with ESRI, is developing a GIS infrastructure by creating a portal called *geofabric*, where the Australian Meteorological Institute is responsible for data provision and the GIS institute for data collection and publication. In Ireland hydrographic data are provided in vector form but were last updated in 2017. In South Africa, on the other hand, according to SAMBO ET AL. (2015), the national integrated water information system, based on the 1997-1998 Acts, contains data developed in different regions of completely different quality and, despite their integration, they still contain uncertain information.

As has been shown, there is a wide variation in the timeliness, detail and formats of hydrographic data, and their collection and processing are most often done at a certain administrative level within a country. Often, within a single country, the principle of interoperability of hydrographic data is not respected. It should be noted that the portals presented were selected based solely on the criterion of a single representative for a given continent and language availability (for this reason, mainly English-, Germanic- or Spanish-speaking portals were analyzed).

Table 2. Surface water databases divided into selected countries

| Country | Institution name (data owner) | Portal or data base name | Date of creation or last update |
|---|---|---|---|
| Indie | India National Water Informatics Centre | India Water Resources Information System | 2018 |
| USA | United States Geological Survey | National Water Information System (NWIS) and The National Hydrography Dataset (NHD) and D Hydrography Program (3DHP) | 2014 (NWIS) i 2023 (3DHP – last update) |
| Poland | Państwowe Gospodarstwo Wodne Wody Polskie (En. State Water Holding Polish Water) | Mapa Podziału Hydrograficznego Polski w skali 1:10 000 (MPHP 10k) (En. Map of the Hydrographic Division of Poland at a scale of 1:10,000) | 2023 (last update) |
| Germany (Bavarian region) | In this case: Bayerisches Landesamt für Umwelt | GewässerkundlicherDienst | No data |
| Brazylia | National Water and Sanitation Agency | National Water Agency Open Data Portal | 2019 |
| Canada | Water Survey of Canada | The National Hydro Network (NHN) | No data |
| Sweden | LANTMÄTERIET | Hydrography View Service, INSPIRE and Hydrography Download Service, INSPIRE | 2023 (last update) |
| Spain (River Basin District of Catalonia) | Agencia catalana de l'aigua (ACA) | Gencat | No data |
| Great Britain | UK Hydrographic Office and Ordnance Survey | Ordnance Survey and the UK water resources portal | 2023 |
| Itlay (Eastern Alps catchment area) | Autorità di Bacino Distrettuale delle Alpi Orientali | SIGMA | No data |
| Japan | Geological Survey of Japan | Water Environment Map Hydrogeological Maps of Japan | No data |
| Australia | Australian Government - Bureau of Meteorology and Geoscience Australia | Australian Hydrological Geospatial Fabric (Geofabric) | 2023 |
| South Africa | Department of Water and Sanitation Republic of Southern Africa | National Integrated Water Information System (NIWIS) | XXI century |
| Ireland | Environmental Protection Agency | River Network Routes | 2012 (creation) 2017 (last update) |

## 4. Hydrography data collection - issues and challenges

Hydrographic network data is the most basic data, being the main element of topographic maps. The level of application of GIS techniques, as well as their development, varies from country to country (Liu & Cheng, 2020). Thus, the process of digitisation and vectorisation of hydrographic data occurred at different times and the methodology was not uniform. The input data were mainly orthophotos or scans of topographic maps (Moreira Sampaio & Rocha, 2022). In addition to the manual drawing of watercourses based on georeferenced maps, the hydrographic network was generated based on Digital Terrain Models (Cantemir et al., 2016). Both the scale of the input materials and the accuracy (e.g. expressed in pixel size), as well as their validity, affected the final precision of the representation of the hydrographic network as linear or surface vectors (Barczyńska et al., 2013). The other important aspect is the methodology for determining the course of rivers on cartographic materials differing from region to region (Kwartnik-Pruc & Mączyńska, 2023).

A huge challenge is the frequent updating of the hydrographic network. It is also important to standardise the type of data (linear data or polygons) and, in the case of linear data, to standardise the reference point methodology. This could be, for example, the coastline or the mathematical centre of the riverbed proposed by Bieda (2012).

Existing surface water databases focus their attention mainly on the course of rivers, while descriptive data (attributes) are a secondary concern. Attributional data should be structured (Safarov & Mamanazarova, 2023). On the one hand, their scope should be uniform (e.g. unified naming of watercourses or the same waterbed parameters) (Fryirs & Brierley, 2018).

An important aspect is also the classification of watercourses, which is sometimes reflected in the legal system. For efficient management of inland watercourses, the nature of the watercourse (natural/artificial) and its manager must be defined (Greer, 2021; Zhao et al., 2020).

A huge challenge in the management of inland surface waters, is therefore, both the correct spatial mapping of stream channels and reservoir reaches and a database approach to hydrographic data, while ensuring their interoperability and ongoing updating.

## 5. Modern tools hydrographic data acquisition

The contemporary level of sophistication of remote imaging tools, and techniques, as well as broader geo-information is facing the challenge of having up-to-date and reliable spatial data for effective water management.

Changes in water extent in broad watercourses and reservoirs are observed on the basis of multispectral satellite imagery, acquired over an interval of several days by various satellite platforms (e.g. Landsat, Sentinel, MODIS) (Albertini et al., 2022; Normandin et al., 2024; Pekel et al., 2016). Their acquisition, as well as advanced processing into hydrographic information, is even possible in open source GIS software and applications (Hamal, 2020). Water extent is determined, among other things, by pixel algebra based on numerous indices such as Water Index (WI), Near Difference Water Index (NDWI) or Automated Water Extraction Index (AWEI), which are described in detail in the literature (Mc Feeters,1996; Jiang et al., 2014; Feyisa et al., 2014). The main application of these techniques is for flood protection (e.g. observation of surge or potential threats of water withdrawal from the riverbed) (Hammam et al., 2022; Farhadi et al., 2022). However, the raster information on water extent obtained in this way can be easily converted to a vector layer using the basic functionality of GIS programs. Efficient and automatic land cover classification is made possible by using artificial intelligence (AI) algorithms dedicated to GIS software, which reduces analytical work, information acquisition time and interpretation errors (Thakur & Manekar, 2022).

Limitations related to scene coverage, cloud cover and field pixel size prevent the acquisition of uniform water extent information over a large area such as the bed of a river of several hundred metres in a single day (Absalon et al., 2023). It could be achieved using commercial high-resolution satellite platforms (Mullen et al., 2023), which in turn entails large financial outlays and the need to process large amounts of data.

In practice, the most problematic is the water course of small rivers (up to 100 km), for which aerial or low-altitude remote sensing (using unmanned aerial vehicles- UAV) can be applied (Ozdemir et al., 2024; Acharya et al., 2021; Tymków et al., 2019). In this case, a major limitation is the dense forest cover and shrubbery of the channel, especially the spring area. For this reason, the optimal period for performing a photogrammetric raid is early spring, or late autumn, or warm winter periods (the maximum tolerance of the UAV battery is -4 °C). Where it is not possible to acquire surface water information, field mapping is used, using a high-precision GPS with the geodetic accuracy of which can nowadays be achieved even in forested areas (ABDI ET AL., 2022).

An alternative method of acquiring surface water extent data is the processing of Digital Terrain Models, which are also acquired based on aerial or satellite remote sensing. The sensor in this case is a laser scanner, and the most used method is LiDAR (TOSCANO ET AL., 2015), which involves recording the position of a point based on its reflection from various surfaces (including the water surface, through which the scanner beam doesn't penetrate). Limitations related to the size and accuracy of the data are similar to those of multispectral imagery (size of the acquired data, range of the raid) excluding, however, adverse weather conditions. Based on Digital Terrain Models, it is possible to delineate clearly outlined watercourse beds, or the extent of reservoirs, but also to model current directions of water run-off, flow accumulation, or to delineate the extent of catchment areas (CHOWDHURY, 2023).

Efficiency in processing raster and vector data simultaneously is possible by automating repetitive tasks using tools such as Model Builder/Model Designer or programming environments implemented into GIS software such as 'Python' or 'R' (SCHÜRZ ET AL., 2023; MASETTI ET AL., 2022; SILALAHI & HIDAYAT, 2020).

When the hydrographic network is accurately mapped, the problem of maintaining up-to-date information about its extent arises. Surface waters, in virtually every inhabited place in the world, are of interest to a set of specialists - scientists or staff of entities responsible for water management in a given country. The development of a virtual geo-information space easily allows for a platform where authorised members can simultaneously insert or edit data (e.g. on the course of a watercourse) at the same time, also in real time via mobile applications (ESRI, 2024). JONES & BARRETT (of The Ohio Department of Natural Resources) were already using ESRI ArcGIS software in 2006 to maintain an official repository of data (spatial and attribute) for Ohio's waters entitled *Division of Water.* The cited authors emphasise the increased efficiency of analysis with integrated and collected water data (both surface and groundwater) in one place. Ongoing updating by all logged-in users of topographic elements is done within the Open Street Map (OSM) (CURRAN ET AL., 2012). Following the example of the OSM project, it seems that with appropriate oversight and the involvement of water management professionals only, such a platform for hydrographic data could solve the problem of ongoing data updating.

## 6. Summary and conclusions

This article shows that there is a lack of a unified source of hydrographic data for the whole world. Most often, to visualise the current state of the hydrographic network on a continental or broader basis, models are created to automatically depict the extent of surface water based on satellite imagery or global digital terrain models.

Our review shows that uniform data on the hydro-graphic network, along with coherent management systems (in terms of data entry and updates), are key factors for effective water management, especially at a regional scale,in particular for international water regions.

HECHT (2000) posits that the most effective way of collecting and sharing of hydrographic data is to present them in vector format with precise and concise attribute descriptions. This is facilitated by GIS tools, virtual data storage, and platforms that allow for real-time editing of spatial and attribute data by multiple users simultaneously. Furthermore, modern geoinformation, remote sensing, and programming tools, as well as AI algorithms, enable the automation of hydrographic data updates.

An undeniably important issue remains the consistency of spatial data that is closely related to the digital-textual database of inland surface waters. Regardless of the administrative level at which hydrographic data is collected and updated, both the methodology and the database structure should be compatible so that in the case of broad analysis (e.g., extending beyond the territory of one country), rapid integration is possible. Such methodology should at least define the scope of the source data, the methods of acquisition and processing, the type of spatial data, the scope, type, and arrangement of numerical and textual data, and the coding of relational fields.

Drawing on the example of the work done by BAROVIĆ ET AL. (2016), it should be stated that the creation of a complete surface water database should proceed in the following stages:

1. preliminary classification of the terrain based on existing data,
2. data acquisition (e.g., using remote sensing methods),
3. processing using GIS tools to convert the obtained materials into vector layers representing the hydrographic network (e.g., flow direction analysis based on DEM),
4. creation of the database structure (required attributes),
5. implementation - systematic acquisition and supplementation of data.

It seems reasonable to utilize virtual space for collaborative real-time entry and updating of hydrographic data by a closed group of experts. It is essential to transfer existing data into a unified structure. The greatest challenge remains the harmonization of these efforts at the local, governmental, and supranational levels. For this reason, research should be conducted using a coherent methodology for creating surface waters, starting from the national level (or internal state units).

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