Development of a monitoring system for the evaluation of the hydromorphological status of small and medium sized rivers in the Free State of Saxony

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Abstract

The European Water Framework Directive establishes the basis for a sustainable water policy in the European Union. The member states of the European Community require a comprehensive knowledge and possibilities to acquire, integrate and organize the information for the implementation of management actions in order to fulfill the requirements of this directive. Different mapping procedures have been developed to gather information about the waterbodies. In this context the PhD project shall concentrate on the identification of important features of rivers that can be detected and described using methods of remote sensing, image processing and geoinformatics. The acquisition of data is performed on various spatial scales and involves ground-based images as well as digital aerial and satellite imagery.
Keywords: Water Framework Directive, Remote Sensing, Hydromorphology

1 Introduction

Environmental policy in the European Community went through various stages of development. During the first stage the policy was more in line with the german environmental legislation which can be characterised by technical standards and emission limit values that have only little reference to ecological consequences. The anglo-scandinavian influence on the european environmental legislation became more important in the second stage. Since the mid-1980s these emission-oriented technical standards have been replaced by the establishment of environmental quality objectives and environmental protection experienced a shift from the sectoral to a more integrated environmental protection (Durner and Ludwig, 2008).

In order to avoid a long-term deterioration of water quality a programme aiming at sustainable management and protection of water resources of the Community has been requested in the 1990s. As a result the European Water Framework Directive has been established in the year 2000. In principle all water resources of the European Community shall be monitored and transferred into the 'good status' by 2015 (European Communities, 2000). Biological measures are also used to a greater extent than before when water quality was mainly described by the chemical status. In addition the distinction between water quality and ecological quality is an important part of the directive (Moss *et al.*, 2003).

In order to prevent a decline in water quality, to protect the water bodies and their riparian zones and to force a sustainable interaction with the water resources the European Union established the Water Framework Directive (Directive 2000/60/EC) to obligate the member states to achieve the good ecological status of their water bodies (European Communities, 2000). This proof requires an extensive and periotic monitoring program which considers data from a biological, chemical and hydromorphological perspective. As a result different data acquisition systems have been established. While biological and chemical parameters are usually monitored using measurement stations along a river the hydromorphological status of a river is usually assessed by field surveys or manual image interpretation.

At this point the PhD project shall identify possibilities, requirements and limiting factors for a monitoring system that meets the requirements of small and medium sized rivers representing the bulk of the total length of Saxon rivers. The thesis focuses in particular on:

- Identification of important features of rivers and riparian zones according to the European Water Framework Directive that can be detected in a variety of image products ranging from Ground-based data, Unmanned Aerial Vehicle data (UAV) to satellite imagery
- Development of methods to extract information mainly without user interaction for the use at multiple spatial scales
- Evaluation of these methods with respect to the assessment of rivers and their environment according to the European Water Framework Directive
- Transferability and Verification of these methods
- Application of multitemporal analyses

In this regard this position paper shall give a brief introduction to the European Water Framework, possible applications of remote sensing and proposed methods.

2 Background

2.1 European Water Framework Directive

In principle the Water Framework Directive introduces the environmental objectives for an integrated environmental protection. In order to achieve these objectives a clear time frame has been defined. By 2015 all water bodies should have reached the 'good status' (Article 4.1). The good status itself is defined as "the status achieved by a surface water body when both its ecological status and its chemical status are at least 'good' "(Article 2.18). In addition the good chemical status is defined as "the chemical status required to meet the environmental objectives for surface waters established in Article 4(1)(a), that is the chemical status achieved by a body of surface water in which concentrations of pollutants do not exceed the environmental quality standards established in Annex IX and under Article 16(7), and under other relevant Community legislation setting environmental quality standards at Community level" (Article 2.24). The (good) ecological status (Article 2.21/2.22) as well as the ecological potential (Article 2.23) are evaluated according to the classification found in Annex V of the Water Framework Directive. In this connection the ecological status can be characterised by a biologic component (e.g. composition and abundance of aquatic flora, benthic invertebrates and fish fauna), a physico-chemical component (e.g. temperature, oxygen concentration, salinity, nutrients, pollutants) and a hydromorphological component (e.g. morphological conditions, continuity, hydrological regime) (Annex V Nr. 1.1). As stated in Article 4.4 and Article 4.5 various opportunities exist to extend the deadlines until the year 2027 and to achieve less stringent environmental objectives under certain circumstances. (European Communities, 2000).

However there was and is clear evidence that the planned period of time to reach the objectives is insufficient; even the possible extension for up to 12 years. Exemptions will be the rule rather than the exception (Petersen *et al.*, 2009). Hering *et al.* (2010) stated that a time frame of 15 or even 30 years is not sufficient to fully recover aquatic ecosystems which also means that it will not be possible to reach the aim of a good status for most European water bodies.

The aim of a good status of all surface waterbodies exerts pressure on the member states of the European Community to become active to improve the condition of their waterbodies and to justify their inaction. The obligating character of the Water Framework Directive and the prohibition of deterioration shall contribute to the success of the Water Framework Directive and the protection and preservation of natural resources (Petersen *et al.*, 2009).

To improve the quality of surface waterbodies water policy has shifted from the consideration of administrative borders as boundaries of management to hydrological catchments as objects of observation. The definition of environmental quality objectives and the characteristics that have to be assessed mark an important step towards the harmonisation of monitoring and management methods across Europe (Hering *et al.*, 2010).

The monitoring of surface water bodies with regard to their material pollution and hydromorphological conditions and the conditions of the biocenosis provides the basis for the review of environmental objectives as a basis for planning the program of actions and the monitoring of the implementation of the measures, the monitoring of long-term trends and the determination of the degree and impact of accidental pollution incidents. The Water Framework compiles a monitoring and assessment plan for the waterbodies of the European Community and specifies the requirements for an effective monitoring. (cf. Annexes II and V). The transposition of the Water Framework Directive into national law is one of the tasks of the German Working Group on Water Issues of the Federal States and the Federal Government (Bund/Länder Arbeitsgemeinschaft Wasser, LAWA). To ensure a consistent monitoring of german waterbodies the LAWA has developed a framework for the assessment of surface waterbodies (‘Rahmenkonzept Monitoring’) (LAWA-Ausschuss „Oberirdische Gewässer und Küstengewässer“ 2005).

This working group has developed two mapping procedures to obtain data about the hydromorphological status of a river and the riparian zone: an on-site method (Bund/Länderarbeitsgemeinschaft Wasser, 1999) and an overview method (Bund/Länderarbeitsgemeinschaft Wasser, 2002). The on-site method represents the traditional way of capturing data. The acquisition of the 25 parameters according to the mapping guidelines is a time consuming and labour-intensive process to gather information about a river and its environment. The mapping takes place at fixed measurement intervals. In contrast the overview method uses aerial imagery and different cartographic products for the assessment of 9 parameters. At this juncture there are only insufficient approaches available and there is often a need for a manual extraction of relevant information. In this context methods of remote sensing, geoinformatics and image processing are of particular interest.

The general monitoring guidance of the Water Framework Directive has led to a harmonization of monitoring and management approaches within the European Union. Over the past 50 years water quality of german waterbodies has improved but further actions are necessary to transfer all waterbodies into a good status. These include the recovery of natural hydromorphology and the reduction of nutrient loss in agricultural areas (Arle *et al.*, 2016).

2.2 Possible Applications of Remote Sensing in the Scope of the Water Framework Directive

Since several decades remote sensing data has proved to be an effective instrument for the observation of objects and processes of the earth surface and the atmosphere on different spatial, spectral and temporal scales. The increasing amount of newly acquired data will constantly extend the existing archive. The utilised sensors are capable to acquire information at different spectral wavelengths (visible, infrared, microwave) and at high spatial (ranging from sub-metre to kilometre) and temporal resolutions (multiple observations per day) (Rosenqvist *et al.*, 2003a). The information can be acquired by various sensors at the same time and over a longer period of time. Due to this fact remote sensing data is capable to make a considerable contribution to the investigation of surface water properties (Lindell *et al.*, 1999). Despite the comprehensive amount of data the usability is often limited to a certain extent since spatial and temporal resolutions are partly insufficient. Especially for high spatial resolutions there is a priority for data acquisition and an unequal temporal coverage of particular areas that lead to a lack of observational data which in fact has an important impact on time series analyses. Therefore, the systematic data acquisition over a long period of time at an appropriate repetition frequency for the observation of temporal variations is essential (Rosenqvist *et al.*, 2003b).

The Water Framework Directive provides several possibilities for the application of remote sensing data such as:

- the implementation of a systematic monitoring of surface waterbodies to evaluate their condition (Article 8)
- the detection of the spatial distribution of surface waterbodies alterations for the restoration of modified waterbodies (Article 4)

- the mapping and monitoring of particular substances such nitrate, nitrogen and phosphor (Article 10)

Previous investigations demonstrated the usefulness of remote sensing imagery for the monitoring of waterbodies. A variety of parameters were in the focus of investigation such as chlorophyll-a (Markogianni *et al.*, 2013), suspended matter and turbitity (Forget and Ouillon, 1998) and water surface temperatures (Díaz-Delgado *et al.*, 2010). The hydromorphological quality element is frequently object of investigation in terms of change of river channel planform ((Parsons and Gilvear, 2002); (Chakraborty and Mukhopadhyay, 2015)), fluvial landforms and land cover ((Gilvear *et al.*, 2004); (Parsons and Gilvear, 2002)) and the determination of erosion and deposit areas and volumes (Lane *et al.*, 2003). Apan *et al.* (2002) investigated the changes of riparian vegetation, which in fact plays an important role concerning the filtering and reduction of sediment, nitrate and phosphate (Borin *et al.*, 2005; 2010), and the biodiversity and stability of river banks (Vought *et al.*, 1995).

3 Study Area

The currently selected study area is located in the catchment area of the river Freiberger Mulde between the cities of Nossen and Leisnig. It comprises the border region between the Central Saxon Loess Upland and the Mulde Loess Hills. The river Freiberger Mulde has its origin in the czech part of the ore mountains. The area can be characterized by gently rolling hills and deepened valleys (Haase and Mannsfeld, 2008b). The land-use may be described almost exclusively by agriculture and vegetable cultivation with high yields due to the soil fertility of the loess region (Haase and Mannsfeld, 2008a).

4 Methology

Datasets at multiple spatial, spectral and temporal scales will be used to analyse the identified parameters. Among these datasets several types of aerial and satellite imagery are available that form the basis for a general survey. These include in particular the acquired data provided by the United States Geological Survey and the European Space Agency. Furthermore, aerial imagery and topographic maps as well as elevation information will provide another view on the river and its environment. Additional data will be acquired by Unmanned Aerial Vehicle (UAV) and boat surveys that allow a flexible acquisition of high resolution imagery for detailed analyses and a spatial densification of the available data base. Therefor a mirrorless interchangeable lens camera has been modified to capture wavelengths of the near infrared. This camera can be used in connection with an unmodified camera which is identical in construction to capture information in the visible and near infrarde part of the electromagnetic spectrum. Both cameras can be mounted on the UAV and the boat to acquire images of different spectral wavelength of the river and the surrounding area. The images in turn can be used to generate 3D point clouds and high resolution digital elevation models on the basis of the structure-from-motion approach (Javernick *et al.*, 2014). The realisation of UAV surveys provides the possibility to capture short-term variations, for example seasonal variations throughout the year. In addition, the collection of different datasets offers the opportunity to implement functionalities from the domain of data fusion. The ongoing acquisition of data allows the application of multitemporal analyses and provides not only the possibility to investigate the current state but also to detect qualitative and quantitative development trends. The extraction of relevant features will be carried out by means of different methods of remote sensing, geoinformatics and image processing based on single image elements and image objects.

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