Hyperspectral mapping of riparian wetness gradients

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ABSTRACT

Determination and description of groundwater systems is essential for the management and development of ecological values, especially in the valley parts of river basins. At the land surface, groundwater systems appear as infiltration (relatively dry) and discharge zones (relatively wet). Groundwater discharge zones offer a high potential for nature values because of their constant moisture presence and their specific water quality. Current methods for the determination of discharge and infiltration zones use either detailed time-consuming fieldwork or data intensive numerical simulation models. Consequently, there is a direct need for repeatable, area covering, mapping possibilities for the determination of moisture gradients and more specifically discharge and infiltration zones. Within the framework of the CASI-SWIR campaign 2002, the Department of Hydrology and Hydraulic Engineering of the Vrije Universiteit Brussel (VUB) executed a combined airborne hyperspectral remote sensing and field campaign to analyze moisture or wetness gradients in the Doode Bemde, a riparian nature reserve. The main objective of the study is to test the best hyperspectral analysis and mapping method, using the hyperspectral CASI-SWIR data, for the known, based upon field and simulation data, wetness gradients in the Doode Bemde area.

Keywords: Hyperspectral remote sensing, wetness gradients, mapping, hydrological modeling, vegetation.

1 INTRODUCTION

Determination and description of groundwater systems is essential for the management and development of ecologically valuable areas, especially in the valley parts of river basins. At the land surface, groundwater systems appear as infiltration (recharge) and discharge zones; the latter are relatively wet because of the upward groundwater seepage, while the former are relatively dry. Groundwater discharge zones offer a high potential for nature values because of their constant moisture presence and their specific water quality [1]. Figure 1 shows a typical situation of a groundwater system in valley areas.

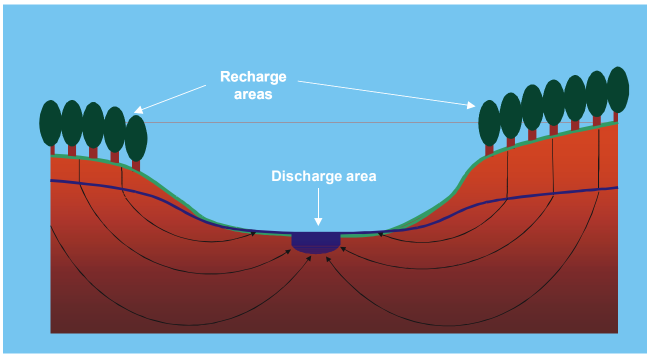

Figure 1: Typical groundwater system in lowland valleys.

Valleys usually have a complex pattern of moisture gradients and infiltration/discharge zones, caused by a complex interaction of regional groundwater flow with local influences of differences in soil type, vegetation and topography.

To gain insight in groundwater systems, numerical groundwater simulation models are often essential. These numerical models enable the calculation of groundwater levels and flow, as well as the determination of discharge and infiltration zones. Main disadvantage of this method is the fact that it is very data intensive. To meet the needs for this type of modeling, detailed time-consuming fieldwork is often required. These disadvantages clearly show that there is a direct need for repeatable, area covering, mapping possibilities for the determination of moisture gradients and more specifically discharge and infiltration zones. Remote Sensing can possibly be a very useful tool to do this [2].

Within the framework of the Belgian CASI-SWIR 2002 campaign, the Department of Hydrology and Hydraulic Engineering of the Vrije Universiteit Brussel (VUB) executed, in cooperation with the Flemish Institute for Technological Research (VITO) – operating on behalf of the Belgian Science Policy Office - an airborne hyperspectral remote sensing and field campaign to analyze moisture gradients and discharge/infiltration zones in the Doode Bemde, a riparian wetland (nature reserve). The main objective of the study is to test the best hyperspectral analysis method, using the hyperspectral CASI-SWIR data, for the known, based upon field and simulation data, moisture gradients in the Doode Bemde area.

2 DATA AND METHODOLOGY

2.1 Study area

The study area is situated in the central part of Belgium, in Flanders, 8 km to the south of Leuven, in the middle course of the Dijle River. The area contains large parts of the nature reserve 'Doode Bemde', a riparian wetland. Extensive hydro-ecological research was carried out in the study area during the last five years, providing a detailed dataset and knowledge about the flow systems [1] [3] [4]. This wetland, as well as the River Dijle, and several smaller rivers and ditches in the study area, are predominantly fed and determined by discharging groundwater. The area is hydro-chemically uniform, and has clear, relatively constant moisture gradients with associated differences in vegetation on a small scale caused by groundwater flow differences. The study area mainly consists of grasslands (partly agricultural), reed and forest, and contains several ponds.

2.2 Data collection and processing

2.2.1 Airborne hyperspectral remote sensing campaign

The hyperspectral CASI-SWIR dataset was acquired on September 13, 2002, in the late afternoon, in three North-South oriented flight lines, covering the total study area. During the analysis of the dataset certain bands seemed to be incorrect and/or not suitable for further analysis, so they where removed. It concerns the last bands of the CASI dataset [5] and approximately 60 bands of the SWIR dataset. Finally 165 spectral bands were used for further analysis.

2.2.2 Hydrological field campaign

At the same day of the flight the Department of Hydrology and Hydraulic Engineering (VUB) executed an extensive hydrological field campaign. At many locations, widely spread over the study area, different types of measurements were performed: soil moisture, (ground)water levels, vegetation temperature and spectral characteristics of some key vegetation species (phreatophytes [6]).

Additionally, one parcel (grass field), of approximately 100 by 100 meter, was selected for detailed soil moisture measurements (Theta probe) at 85 locations. A Spline interpolation was used to create a spatially distributed soil moisture grid for this field, with the same spatial resolution (2.44 m) as the hyperspectral dataset (Fig. 2a). The western and northern parts of this field are the wetter zone, with values up to 100% (near or in the ditches), while the eastern part is relatively dry (values varying from 20 to 50 %). This moisture gradient is strongly correlated with the topography, going from higher to lower from Southeast to Northwest.

2.3 Groundwater modeling

To obtain additional indirect 'field information' (ground truth), a detailed numerical groundwater model, with the same spatial resolution of 2.44 by 2.44 meter, was developed for the study area. The groundwater modeling was performed with MODFLOW [7]. Calibration of the model was performed using the measured piezometric data.

One of the main results of this modeling is a groundwater depth map. The largest part of the valley has shallow groundwater, except close to the Dijle River. In Figure 2b the detailed groundwater depth map for the selected grass field is given. If we compare this groundwater depth map with the interpolated soil moisture map we notice a relatively good correspondence (r^2 = -0.6132); a drier part in the (South)East and a wetter part in the West and North of the field.

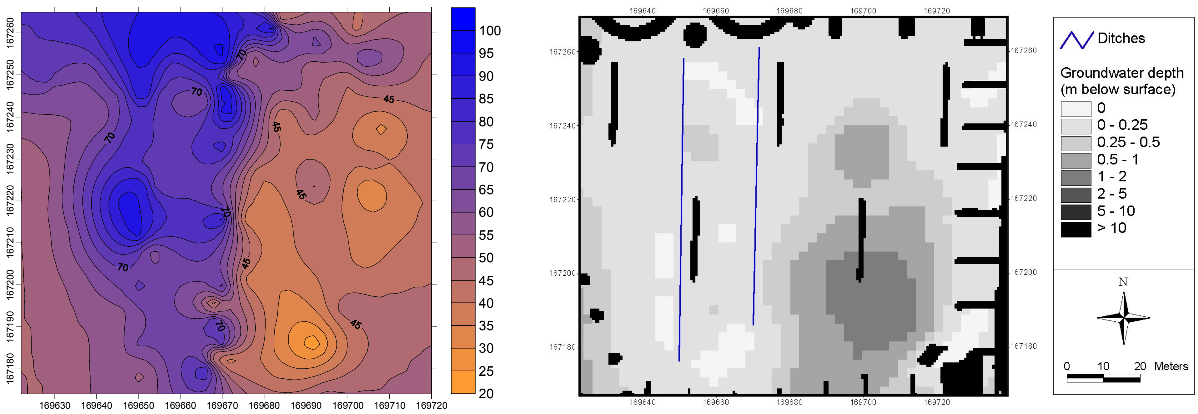

Figure 2: Interpolated soil moisture (a) and groundwater depth (b) for a selected grass field.

2.5 Hyperspectral analysis and comparison with field measurements

Analysis of the results of the field campaign, in particular soil moisture, and of the numerical groundwater modeling, show clear differences in moisture or wetness in the study area (Figure 2). The main objective of this study is to find the best method for the analysis and mapping of these moisture gradients, using the hyperspectral CASI-SWIR dataset. A first step in this analysis is a statistical comparison of the obtained field measurements and simulation results with each individual spectral band. Also the use of a combination of two or more bands will be studied. This can be done using existing indices or ratios. Quite some water and vegetation indices have already been developed [8] [9] [10]. The field and simulation results are statistically compared to each of these indices. Once a relationship between the field and simulation results and the hyperspectral dataset is established, the analysis results are used for classification purposes, in order to try a mapping of wetness differences and gradients in the study area. This methodology will be tested first for one selected field (grass), which was the subject of intensive field measurements, and will, in a later phase, be extended to the rest of the study area.

3 RESULTS AND DISCUSSION

The hypothesis is that the observed moisture differences in the field are reflected in the hyperspectral image. A comparison of the spectral signatures of a wet (northwest) and a dry (southeast) vegetation target, clearly show a difference in reflectance around 0.55 µm and in the near IR. This difference is possibly related to a difference in moisture content, but could also be caused by a difference in chlorophyll content, leaf structure, etc. Analysis of the hyperspectral dataset should give an answer to this, but the fact there is a difference already offers a possibility for differentiation of wetter and drier zones.

3.1 Soil moisture and groundwater depth

A statistical comparison of the interpolated soil moisture for the selected grassland with each individual band of the hyperspectral CASI-SWIR dataset shows the highest correlation (r^2 = -0.6871) for band 26 (0.5690 µm) and the surrounding bands (Figure 8). Another peak is reached around band 50 (0.7060 µm). The spectral bands 94 to 97 (around 1.29 µm) show the lowest correlation values (around -0.24). The correlation curve for the groundwater depth shows a similar pattern, but with lower correlation values (Figure 3).

The use of existing indices, like NDVI or NDWI, did not give a better correlation than the individual bands. Possibly another index or combination of several bands might ameliorate the correspondence. Further analysis is needed and will be done.

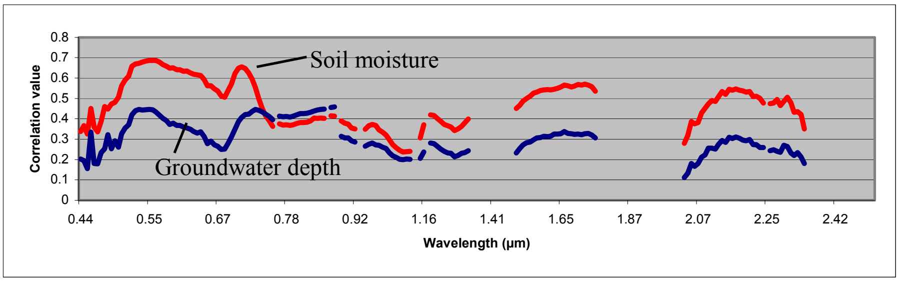

Figure 3: Correlation curve between soil moisture and groundwater depth and each individual CASI-SWIR band.

3.2 Vegetation

Within the framework of one of the previous studies [4] in the 'Doode Bemde' area vegetation data was collected for a part of the study area. For 527 grid cells, of 20 by 20 meter, plant species were mapped. The mapping was mainly limited to plant species growing under the influence of groundwater, so called phreatophytes [6]. The use of the available vegetation data was until now limited, but probably this detailed dataset will be very useful for further analysis of and comparison with the hyperspectral image. Most probably, this dataset can be used as 'ground truth' for the classification and mapping of wetness differences and gradients in the area.

3.3 Mapping

Based on the first analysis results a first attempt for classification of wetness differences in the selected grass field was made. The objective is to use the hyperspectral dataset to determine or differentiate the wetter and drier zones. For this first attempt a supervised ('Maximum Likelihood' [11]), as well as an unsupervised classification ('K-means' [12]) was performed (Figure 4). For both classifications the bands with the highest correlation with the interpolated soil moisture (21-27, 50) will be used.

The results of these classifications are given in Figure 4. Both classification give similar results. The supervised classification clearly differentiates dry (white) zones at the southeastern and wet zones (gray) at the western and northern side of the field. There are a few non-classified pixels (black) and the shadow (dark gray) is also clearly visible in the southwest. In the case of the unsupervised classification four classes were used. Going from dry (white) to wet (dark gray), with a transition zone in between (light gray). The black color represents the shadow. A visual comparison with the field observations (soil moisture, vegetation, groundwater depth) clearly shows a good correspondence.

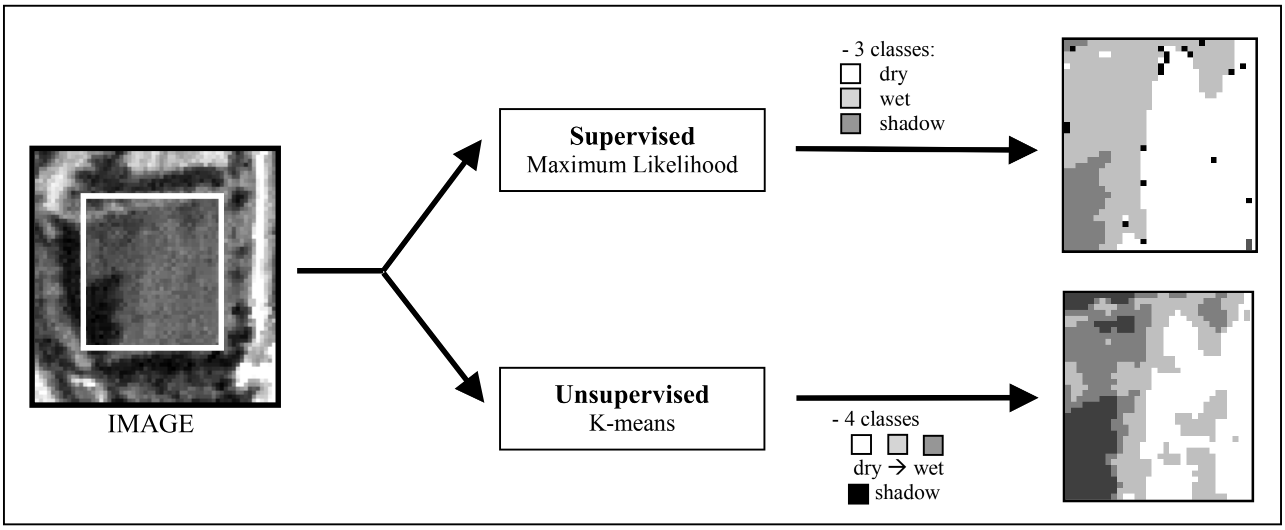

Figure 4: Supervised and unsupervised classification in an attempt to map moisture differences or gradients in the selected field.

The results of this analysis should, in a later phase, form the basis for a mapping method of moisture or wetness gradients in the study (and other) area(s). These classification methods will be further analyzed and compared with other methods. Objective accuracy values will be used for the evaluation of further classifications.

4 CONCLUSIONS

The main objective of the study is to test the best hyperspectral analysis method, using the hyperspectral CASI-SWIR data, for the known, based upon field and simulation data, moisture or wetness gradients in the Doode Bemde area. The method of analysis consists of statistical comparison of moisture gradients, obtained from measurements and simulations, with individual bands, a combination of bands and multivariate derivatives. The results look promising and show that hyperspectral remote sensing offers new possibilities, in combination with 'traditional' methods, for the analysis and mapping of moisture or wetness gradients in valley areas.

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