Estimation of the water table depth of the Calarasi district Island (Romania) at the Danube River using ASTER/DEM data

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Abstract
The water table is the top level of ground water by definition. Therefore surface water is an exposed part of the water table. Airborne measurements, resistivimeters determinations or perforation analyses can be used to determine the water table depth. These methods require, approximately, taking a sample per hectare, which is a very expensive and time-consuming procedure. However, remote sensing constitutes an ideal alternative to determine water table depth, because unlike the existing methodologies, which are very expensive due to equipment and travel expenses, the proposed methodology is cheap and simple. The ASTER GDEM data is available at no charge to users via electronic download and also its resolution is appropriate to the size of the study area chosen. Using ASTER GDEM data, the water table depth of an island has been calculated. In that case, the water table depth can be approximately calculated by means of the difference between the altitude of each point in the island and the altitude of the river at that moment. In this work, an island of the Danube River, located near the Rosetti village (Calarasi district) in Romania was selected as study area and the measurements carried out by ASTER/DEM were used to obtain the water table depth. The water table depth of the island, measured on June 30, 2008, was variable between 1 and 8 m. These results were compared to a topographical map of the area made by the URSS Army Cartographic Service, drawn in a fifty thousand to one scale and dating from 1991. Finally values were validated taking some in situ samples at the island wells. An Root Mean Square Error (RMSE) of 1 m was obtained.

Keywords: ASTER/DEM, island, water table depth.

Introduction
The water table is a level beneath the surface of the Earth. It represents the edge of unsaturated soil and groundwater. An area’s water table may rise as more water, such as rain or snow, seeps downward from the surface. The exposed part of the water table is actually called surface water. An illustration of the term is shown in Figure 1.
The water table depth in a riverine island is strongly affected by the water level of the river, in our case, by the Danube’s level. The river changes significantly during the year because of the melted snow, the rains, drought periods, etc. causing seasonal fluctuations in the water table depth. The zone of intermittent saturation is a region, in vertical extent, in which the water table fluctuates in response to those changes in river level and evapotranspiration. It indicates the difference between the level of the winter and summer water table. (See Figs. 3a and 3b) According to the ground water and streams interaction [Winter et al., 1998], a river may gain water from ground, it may be disconnected from the groundwater system by an unsaturated zone, surface water may seep to ground water or a rapid river rise could cause the creation of streambanks (Fig. 2). For agricultural purposes, the worst case scenario is a gaining stream, where water table depth may be over the river surface.

In order to clarify and determine the characteristics of our study area, geographical features must be analysed [Burt et al., 2002]. Land slopes are predominant in the central region of Romania, where the Transylvanian Alps and Carpathian Mountains are located. The Danube delta is an exception to this trait. In Southern Dobruja, most of the land is distributed as flat ground adjacent to the river. For larger rivers, as in our study area, if terraces are present in the alluvial valley,
local ground-water flow systems may be associated with each terrace [Winter et al., 1998] (See Fig. 3b). Therefore the level of the water table depth in the island, a rather small and flat area, is the same as the river level [Boluda, 2011]. After the fall-winter rising, during spring, the worst case scenario occurs when the rising Danube could partially flood the study area.

Figure 3a - Representation of seasonal fluctuations in a riverine area with big land slopes. This figure includes climatic contribution, e.g. rain, to the river rising, and an example of leak as evapotranspiration.

Figure 3b - Representation of seasonal fluctuations in our study case. A large riverine area where terraces are present. Water table may rise, due to rain or melted snow, and flood terraces or the island shore. This figure includes climatic contribution, e.g. rain, to the river rising, and an example of leak as evapotranspiration.
Traditionally, routine table depth samples require flights, analyses using resistivimeters or perforations as basic techniques to determine the subterranean water level of an area under study. These diagnostic methods are deemed reliable based on the extensive research involved and the huge number of tests that have been conducted since their establishment [Barcelona et al., 1985]. Surface water elevations have been measured routinely by the generation of topographic digital line graphs (DLGs) and digital elevation models (DEMs). Most of them are created from stereographic aerial photos [U.S. Geological Survey, 1998; Geological Survey of Canada and Geomatics Canada, 2007]. During this process, open water surfaces (i.e., lakes, seas, oceans) are forced to be perfectly flat by manually corrected elevation to ancillary stage data (USGS 1992). Remote altimetry provides the potential for a significant improvement over published data sources [Becker, 2006].

Most agricultural and environmental plans need water table depth analysis as an input. Samples are normally composites consisting of 15 to 20 individual samples for an area of 12 to 20 ha. In some cases, where precision agriculture is conducted, recommendations call for one water table depth sample per hectare [Nanni and Dematte, 2006]. Another traditional procedure would require drilling wells along the study area. This is not an easy and trivial process because a conscientious analysis of the soil, water flow and the equipment required is necessary before the start of the digging process [Barcelona et al., 1985], in order to preserve the samples. While it is clear that soil analyses are necessary, they are very expensive, labour intensive and time-consuming [Reutov and Shutko, 1992].

Remote sensing is an alternative method to determine water table depth [Rodell and Famiglietti, 2002; Abdel-Hady and Karbs, 1971]. In the last few years, different remote sensing projects are making it possible by developing less time-consuming analysis procedures [Rodell et al., 2007; Strassberg et al., 2007]. Information from the Earth surface is obtained, without any physical contact with the target area of investigation. This technique estimates the Electromagnetic Radiation (EMR) reflected by all kind of objects by sensors on-board a satellite. The EMR spectrum is classified in bands. Most common bands in satellite remote sensing are the visible (VIS, wavelength 0.4-0.7 μm), infrared (IR, wavelength 0.7-100 μm) and microwave regions (wavelength 0.1-100 cm). The IR region has three subdivisions: near IR (NIR, 0.7-1.3 μm), mid IR (MIR, 1.3-3 μm) and thermal IR (TIR, 3-5 μm and 8-14 μm).

Remote sensing is, as explained, an economical data provider and it permits a global vision. Unfortunately, it is also less accurate than in situ measurements requiring comparisons and validations.

**Data**

**Study area**

The purpose of this article is to supply maps of water table depth using VNIR bands from ASTER/DEM and remote sensing techniques for an island of the Danube River, located near the Rosetti village (Calarasi district) in Romania for June 2008. The geographical coordinates of the island are: between 44° 07’ and 44° 13’ N latitude and between 44° 07’ and 44° 13’ E longitude, and its area includes approximately 16,000 ha of mollisols soils [Soil Survey Staff, 1999]. In other words, the study area is located at the last eighth fraction of the river, 370 km away from the Danube’s estuary. (Fig. 4).
This island has special features. It has been used throughout the years for agriculture purposes. As a result of this, a type of dyke was built all along the water line and poplar trees were planted outside in order to protect crops from river rises. A blue border between the useless part of the island and crop area has been demarcated in Figure 5.

Figure 5 - False color image of the island. Landsat TM bands 5, 4 and 1 have been used to obtain an RGB representation (June 5th, 2008). Healthy vegetation appears in shades of reds, browns, oranges and yellows. Soils may be greens and browns. Urban features are white, cyan and grey. Finally, clear deep water will be very dark in this combination.
ASTERO/DEM data

At the beginning of the study there were no soil content or geological maps of the island available, so ASTER/DEM images were selected because of its suitable resolution to study the chosen island and also its availability. The ASTER/DEM data is available at no charge to users via electronic download from the Earth Remote Sensing Data Analysis Center (ERSDAC) in Japan and NASA’s Land Processes Distributed Active Archive Center (LP DAAC).

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is an instrument on board the satellite Terra. The ASTER Global Digital Elevation Model was developed jointly by the Ministry of Economy, Trade and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA) [Japan Space Systems et al., 2013]. It was launched by NASA in December 1999, as part of EOS (Earth Observation System). It has a long track stereoscopic capability using its near infrared spectral band and its nadir-viewing and backward-viewing telescopes to acquire stereo image data with a base-to-height ratio of 0.6. Spatial resolution is 15 meters in the horizontal plane. Besides, one nadir-looking ASTER visible and near-infrared (VNIR) scene consists of 4,100 samples by 4,200 lines, corresponding to about 60 km-by-60 km ground area. Extra information about the features of the ASTER/DEM [Japan Space Systems et al., 2013] is shown in Table 1.

| Output format     | GeoTIFF, signed 16 bits          |
|-------------------|----------------------------------|
| Tile Size         | 3601-by-3601 pixels (1-by-1 degree) |
| Posting interval  | 1 arc-second                      |
| DN values         | 1m/DN referenced to the WGS84/EGM96 geoid-9999 for void pixels, and 0 for sea water body |
| Coverage          | North 83 degrees to south 83 degrees, 22,600 tiles |
| Data acquisition period | 2000 ~ ongoing                  |
| DEM accuracy (stdev.) | 7~14 m                          |
| Posting interval  | 30 m                            |

URSS map

In order to compare ASTER/DEM height and water table depth results, a topographic map of the study area was used. The map is a composition of four different charts: L-35-139-B, L-35-139-D, L-35-140-A and L-35-140-C. Corresponding to the north-west, south-west, north-east and south-east of the island
respectively. Made by URSS Army Cartographic Service, these maps are drawn in a fifty thousand to one scale and dated from 1991.

Figure 6 - Island topographic maps composition made by URSS dated from 1991. Released by the Cartographic Institute of Catalonia. (Source: Cartographic Institute of Catalonia).

Results & validation

Results
In order to obtain the height of the river waters, a grid of 1.5 km² cells was made. Thirty five averages were calculated, one for the area of each cell. Two different averages, north and south respectively, of the water height were finally used to represent the river level, because, at the study zone, Danube’s river shows a fork and surrounds the island, causing a significant difference of 1 m between both branches.

The water table depth was settled on the difference observed between the ground elevation measured by the ASTER/DEM and the closest height average of the Danube’s waters obtained for each image. An error of ±1.4 m was obtained due to

$$ε_{Δh}^2 = 2ε_h^2 \quad [1]$$

being $ε_h = ±1 \text{ m}$. $ε_{Δh}$ and $ε_h$ are the water-table depth and the ASTER/DEM errors respectively.

The map of the water-table depth for the island is shown in Figure 7. The bank is hardly over the river water and it presents flooded areas. Also the dyke built along the shore is easily noticeable in the results by a deeper water table line. Inside this border, variable ground water deep is shown. Values fluctuate between 1m to 8 m. However it is possible to conclude that this island is mostly flatland.
It is also important to emphasize that, due to the kind of instrument chosen, an instrument on board a satellite, it was required to filter erroneous data in order to obtain the surface elevation. ASTER/DEM data does not filter buildings, trees, or any other entities which contribute to skyline. So basically, in this work, it was necessary to correct the incorrect data from the river bank because there were poplars planted along it. Using the average height of poplars in the area a mask was shaped. And applying the mask based on the white poplar conservation stands in the Republic of Moldova [Koskela et al., 2003], the neighbouring country, shore altitude of the island was corrected and water table depth of the bank remained between 0 m and 1 m. See Figure 7.

The results extracted from Figure 7 are summarized in Table 2.

| Hectares (ha) | Depth (m) |
|---------------|-----------|
| 8279          | 2 or less |
| 1504          | 3         |
| 1095          | 4         |
| 712           | 5         |
| 649           | 6         |
| 506           | 7         |
| 976           | 8 or more |

Comparison

To compare the data, a topographic map of the URSS Army Cartographic Service, released by the Cartographic Institute of Catalonia, has been used to draw a height map of the island in the first place. Therefore, by using the same procedure used with ASTER/DEM images, the water-table depth of the island was obtained (See Fig. 8).
Figure 8 - Map of the water-table depth obtained from the topographic URSS map. The units are meters. The topographic map of the URSS dates from the summer of 1991. Since the island elevation has not changed between those dates, the topographic map and the ASTER images are completely comparable.

As the reader can observe, it is easy to identify an accurate correspondence between both maps, except in the south of the island (near the coordinates 44°9’N 27°26’E) where the URSS map dating from 1991 (Fig. 8) shows higher values in that area than the ASTER/DEM one, obtained for June 2008 (Fig. 7). The main cause for this difference is some demolition work that was carried out during the period between the dates both maps were released.

**Validation**

The water table depth in the study area obtained for June 30th 2008, generated values between 1 and 8 m. These values, which had been compared with the topographic map, were also validated by 10 “in situ” samples (Fig. 7) carried out in the island wells the days around the ASTER data was recorded. The in situ data error was ±1m and the resulting RMSE was 1m. (Tab. 3 and Fig. 9).

Table 3 - Measurements validation.

| Point | Measured in situ (m) | Determined using ASTER/DEM data (m) | Observed difference (m) |
|-------|----------------------|-------------------------------------|-------------------------|
| 1     | 0.7                  | 2                                   | 0.3                     |
| 2     | 1.9                  | 1                                   | 0.9                     |
| 3     | 3.7                  | 3                                   | 0.7                     |
| 4     | 3.5                  | 2                                   | 1.5                     |
| 5     | 8.2                  | 7                                   | 1.2                     |
| 6     | 1.1                  | 2                                   | 0.9                     |
| 7     | 1.6                  | 1                                   | 0.6                     |
| 8     | 1.4                  | 2                                   | 0.6                     |
| 9     | 2.0                  | 3                                   | 1.0                     |
| 10    | 1.2                  | 2                                   | 0.8                     |

Average of observed difference (m) 0.9  
Standard deviation (m) 0.3
Conclusions

Analyses using resistivimeters or perforations are usually used to produce water table depth maps. These procedures require lots of time and makes this type of study expensive. Remote sensing constitutes a good tool to determine water table depth maps, since it requires less resources and time.

ASTER/DEM images have been used to study the subterranean water level for one Danube’s island because its appropriate resolution. Generally the water-table depth in an island depends on the river’s water-level. So, the water-table depth may change during the year, making the time of study a very relevant factor.

In this study, the water table depth obtained for the area of study (conducted on June 30, 2008) ranged between 1 and 8 meters. These values were compared using a topographical map of the area made by the URSS Army Cartographic Service, drawn in a fifty thousand to one scale and dating from 1991.

Finally results were validated using 10 “in situ” measurements in wells. The resulting RMSE was 1 m makes these results applicable to islands with similar size and features to the one which has been studied in this paper.

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