Surface water coverage tracking of an inland delta in a regulated river basin

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Abstract

Tracking surface water coverage changes tracking is a complicated task for many regions in the world. Particularly, tracking floods and droughts are critical to study the biological changes and bioproductivity in the landscape. The objective of this paper is to present a GIS based automated routine calculation based on the modified Normalized Difference Water Index (mNDWI) to extract the surface water coverage area (SWCA) from optical satellite datasets, called the surface water extraction coverage area tool (SWECAT). Processing the satellite data is a time and resource consuming task. The tool was applied to measure SWCA during drought and flood peaks from the satellite datasets: Landsat (30 m pixel size); SPOT (10 m) and RapidEye (5m). Landsat results are compared and validated with Canadian National Hydro Network (CNHN) GeoBase data. The difference between the SWCA shapefile and the base CNHN GeoBase shapefile is two percent. The difference level between the extracted SWCA shapefile from Landsat and the higher resolution commercial satellites SPOT and RapidEye is also two percent. Based on the comparison results, using the commercial high resolution database (e.g. SPOT and RapidEye) may not be financially justified in the tested site (1,315 square km) because the level of difference between products is only two percent which is not significant. Imagery from the freely available and consistent Landsat, with 16 day temporal resolution, provides much value for similar large-scale studies. The high resolution satellite datasets are potentially more applicable smaller size areas requiring fine-resolution details.

Background and Relevance

The study area for our method is the Saskatchewan River Delta (SRD) in the northwest area of the Saskatchewan River Basin (SRB) in Canada (Fig.1). The areal extent of our research area within delta is 1,315 km^2. Field work is complicated by the remoteness and large area of shallow water, bogs, fen, swamps and marshes, such as the Summerberry Marsh (DUC, 2011). DUC (2011) applied satellite data to SRD and SRBPartners (2008) carried out a study to characterize the delta's land surface. The United States Geological Survey (USGS), using the ArcGIS platform has developed the user friendly, easily downloadable visualization tool LandsatLook (http://landsatlook.usgs.gov/). Moreover, the Environmental Sciences Research Institute (ESRI) recently created the online Landsat land surface change tracking tool for the whole earth (http://www.esri.com/changematters). These tools do not allow extracting areas of interests, to track water coverage changes during this time, for example: the existing USGS and ESRI tools do not have currently the SWECAT capacity.

Fig.1. Study area within the Saskatchewan River Delta (SRD); the hydrometric stations are at Tobin Lake and Cumberland Lake

Methods and Data

Due to the remoteness of the SRD and shortage of hydrological and ecological information, satellite imagery is required to aid assessment of surface water coverage changes. Water related GIS datasets such as the flow network, and the water coverage of the research area were acquired from CNHN (http://www.geobase.ca). The freely available Landsat satellite data was obtained from USGS Earth Resources Observation and Science Center (EROS) Global Visualization Viewer (GLOVIS, http://glovis.usgs.gov/). Using the University of Saskatchewan credit system, the SPOT datasets were acquired from Alberta Terrestrial Imaging Center (ATIC). From the various surveyed methods for extracting the SWCA, normalized spectral indexes, manual translation, and parametric classification of images are the most widely used and are reviewed and summarized here. In comparison with other methods, spectral indeces have many advantages, our method uses preliminary transformation of numerical values which decreases the background effects, reduces data dimensionality, provides a level of standardization for comparison purpose and enhances the required signal for specific land cover and land use areas (Reed et al., 1994). Thus, normalized indices increase the separation ability of information extraction from remote sensing data. Because of the spectral differences between the response of diverse land cover and land use areas, the areas can be calculated from different combinations of remote sensed image bands depending on the type of analyzed surface, e.g. water areas, vegetation, or urban territories (As-Syakur *et al.*, 2012). The current research adapted the approach of normalized spectral difference indices for water area identification widely used in the scientific community (Gao, 1996; Xu, 2006; Jensen, 2007; Lacaux *et al.*, 2007; Ji *et al.*, 2009). In this research, the normalized difference water index (NDWI) in the form of modified NDWI (mNDWI) was used for the delineation of open surface water areas within the study region:

$$\text{mNDWI} = \frac{B_{\text{green}} - B_{\text{SWIR(NIR)}}}{B_{\text{green}} + B_{\text{SWIR(NIR)}}} \tag{1}$$

where B_{green} and $B_{\text{SWIR(NIR)}}$ are sensor spectral green, short-wave infrared, and near infrared band values respectively. The satellite parameters for this study are in Table 1.

Table 1 - The mNDWI threshold for open surface water areas for Spectral band's parameters, by satellite sensor Landsat MSS, Landsat TM, Landsat ETM+, SPOT and RapidEye

Group	Sensor	Band	Wavelength, μm
(a)	Landsat MSS	Band 4 (green) Band 6 (NIR)	0.5-0.6 0.7-0.8
(b)	Landsat TM	Band 2 (green) Band 5 (SWIR)	0.52-0.6 1.55-1.75
(c)	Landsat ETM+	Band 2 (green) Band 5 (SWIR)	0.53-0.61 1.55-1.75
(d)	SPOT2 HRV	Band 1 (green) Band 3 (NIR)	0.50-0.59 0.78-0.89
(e)	SPOT4 HRVIR	Band 1 (green) Band 4 (SWIR)	0.50-0.59 1.58-1.75
(f)	SPOT5 HRG	Band 1 (green) Band 4 (SWIR)	0.50-0.59 1.58-1.75
(g)	RapidEye JSS56	Band 2 (green) Band 5 (NIR)	0.52-0.59 0.76-0.85

The automated routine (Fig.2) was prepared and a GIS based toolset was designed for the surface water coverage extraction from different satellite datasets.

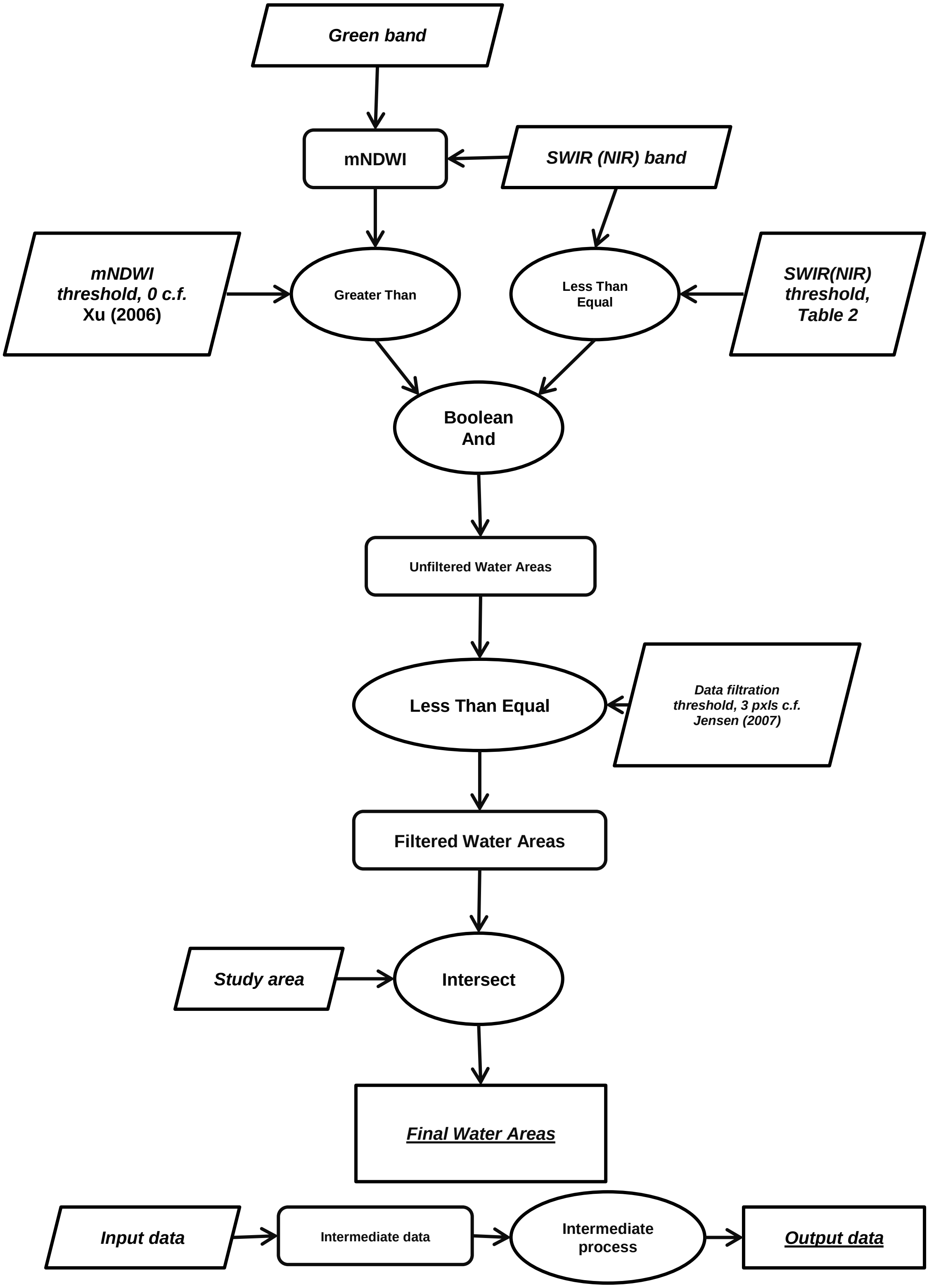

Fig.2. The conceptual scheme of mNDWI tool: the modified Difference Water Index (mNDWI) automated routine calculation algorithm to extract SWCA from Landsat TM, SPOT and RapidEye satellite datasets.

The automated routine was prepared and a GIS based toolset SWECAT was designed for the surface water coverage extraction from different satellite datasets. We designed SWECAT using Esri ArcGIS visual programming capabilities and applied it to extract SWCA from the satellite datasets. The tool logic includes: (i) mathematical calculations, i.e. mNDWI calculation with the input of green and SWIR (NIR) band values (Eq. 1) and the application of mNDWI, SWIR (NIR), and data filtration 3 pixel thresholds; (ii) Boolean operation, i.e. AND between mNDWI and SWIR(NIR) layers after respective thresholds application; (iii) and the overlay operation, i.e. Intersect, which extracts the final SWCA within the study area. The applied methodology and the introduced automated routine, which we prepared to extract SWCA from the optical satellite datasets, is a time and data efficient approach. The extracted images include SRD SWCA with different levels of surface coverage, smallest SWCA minimum (drought), average SWCA (regular), flooded SWCA, and peak flooded SWCA for the different times and satellite imagery. An example of the largest SWCA is shown in Fig.3.

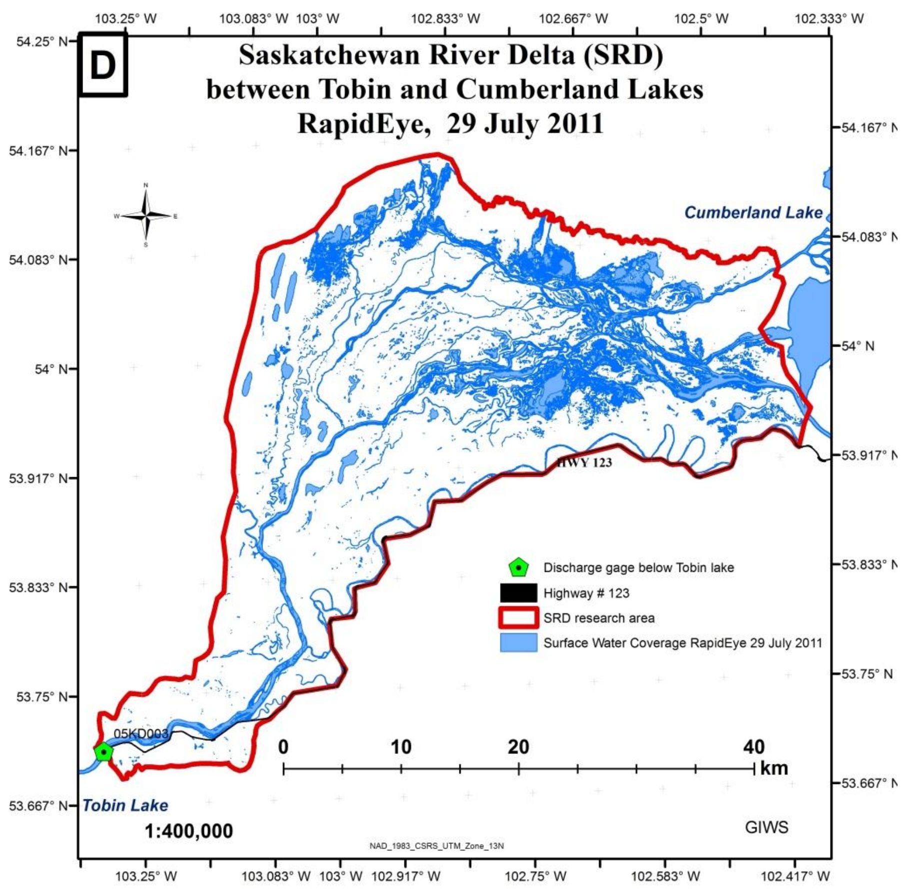

Fig.3. Example of the extracted SRD SWCA (D) RapidEye, 29 July 2011 – 178 km2, the highest SWCA

Conclusions

The objective of this work, to determine the SWCA and to track surface water coverage changes in the delta, was successfully achieved. The SWCA was extracted from satellite imagery, including Landsat, SPOT, RapidEye. For the SWCA extracted from Landsat, comparison of the SWCA from CNHN, SPOT and RapidEye were applied. Extracted images representing a wide range of hydrological conditions with different levels of surface coverage were processed: smallest SWCA minimum (drought), average SWCA (regular), flooded SWCA, and peak flooded SWCA for different capture times and different satellite images. The difference level of the extracted SWCA shapefile in comparison with the base CNHN shapefile is two percent. The difference of the extracted SWCA shapefile from Landsat (30 m pixel size) in comparison with the higher resolution commercial satellites SPOT (10 m) and RapidEye (5m) is two percent. Hence, for large-scale studies, Landsat imagery may very well suffice, especially if research budgets are very constrained and leave little room for the purchase of commercial imagery. For small scale studies with fine-resolution requirements, the research may have to resort to other sensors, such as SPOT and RapidEye.

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