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Performance of Landsat TM in ship detection in turbid waters

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ABSTRACT

The visible and near infrared bands of Landsat have limitations for detecting ships in turbid water. The potential of TM middle infrared bands for ship detection has so far not been investigated. This study analyzed the performance of the six Landsat TM visible and infrared bands for detecting dredging ships in the turbid waters of the Poyang Lake, China. A colour composite of principal components analysis (PCA) components 3, 2 and 1 of a TM image was used to randomly select 81 dredging ships. The reflectance contrast between ships and adjacent water was calculated for each ship. A *z*-score and related *p*-value were used to assess the ship detection performance of the six Landsat TM bands. The reflectance contrast was related to water turbidity to analyze how water turbidity affected the capability of ship identification. The results revealed that the TM middle infrared bands 5 and 7 better discriminated vessels from surrounding waters than the visible and near infrared bands 1–4. A significant relation between reflectance contrast and water turbidity in bands 1–4 could explain the limitations of bands 1–4; while water turbidity has no a significant relation to the reflectance contrast of bands 5 and 7. This explains why bands 5 and 7 detect ships better than bands 1–4.

1. Introduction

Dredging is an important economic activity with significant environmental impact. The potential of remote sensing for monitoring dredging impact has been long recognized. Dredging impacts are typically inferred from increased water turbidity patterns revealed by remote sensing images (e.g., Merry et al., 1988; Jorgensen and Edelvang, 2000). Wu et al. (2007), however, argued that it remains difficult to infer dredging impact from remotely sensed water turbidity patterns alone, as increased turbidity might reflect natural variability. They suggested that the plausibility of inference of dredging impact would be corroborated when ships could be associated to the observed turbidity patterns. Thus, ideally a remotely sensed dredging impact assessment system would combine water turbidity assessment and ship detection.

Basically two remote sensing techniques have been employed for ship detection. The potential of optical remote sensing has been explored since the launch of Landsat in 1970s. McDonnel and Lewis (1978) demonstrated the possibility to detect ships of 100 m length using Landsat MSS. Burgess (1993) applied Landsat TM and SPOT data to identify smaller ships. McDonnel and Lewis (1978) suggested that water turbidity might complicate and possibly inhibit ship detection while decreasing the signal-to-noise contrasts of the visible and near infrared bands of Landsat MSS. In addition, optical remote sensing has a limited potential in operational monitoring since it does not work at night and in the presence of clouds. As a consequence, a second technique, Synthetic Aperture Radar (SAR) with capacity to image day and night under most meteorological conditions (Winokur, 2000), became the state of the art technique for ship detection (Crisp, 2004). For example, Liu et al. (2003) used ERS SAR to monitor illegal fishing ships, Tunaley (2004) employed RADARSAT-2 SAR to detect ships, and Tello et al. (2006) applied space-borne SAR to assist authorities in monitoring ship traffic. However, Zhang et al. (2006) reported limitations of SAR in identifying smaller ships in inland waters.

Dredging impact assessment based on the association between ships and water turbidity patterns requires the simultaneous monitoring of ships and water turbidity. Simultaneity is necessary because both the location of ships and water turbidity patterns might change rapidly. Which remote sensing system(s) would be the most appropriate to achieve this simultaneous monitoring of ships and water turbidity? Greidanus (2006) concluded that SAR was most suitable for ship detection. However, SAR has no capability in water

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turbidity assessment due to its strong absorption by water. Optical remote sensing has been employed successfully to map water turbidity (e.g., Fraser, 1998; Gan et al., 2004; Vignolo et al., 2006). However, it is difficult to combine SAR with optical remote sensing simultaneously, because the overpass time of the platforms carrying these sensors is not synchronous. Simultaneity could be achieved when deriving the information of ships and water turbidity from the same sensor system. In this view, it is interesting to reconsider the capability of traditional optical remote sensing systems for ship detection.

Landsat TM has two bands in the middle infrared spectrum, which are less influenced by water turbidity. The potential of these middle infrared bands for ship detection has so far not been investigated. This paper, with the northern Poyang Lake as a case study, analyzes the performance of six Landsat TM bands for detecting dredging ships in turbid water.

2. Materials and methods

2.1. Study area

Poyang Lake (115°47′–116°45′E, 28°22′–29°45′N), the largest freshwater lake in China, is located south of the Yangtze River (Fig. 1). Intensive sand dredging for construction started around 2001 in the northern Poyang Lake (Zhong and Chen, 2005). Recent reports (e.g., Zhong and Chen, 2005; Fok and Pang, 2006) suggest that dredging has a negative impact on this ecosystem. Since 2003 hundreds of dredging ships have been found between Hukou and Sand Hill. Due to these intensive dredging activities, the water turbidity in this region decreased from Secchi disk depths of 1.5 m in the past to less than 0.5 m at present (Wu et al., 2007).

2.2. Landsat TM image

One Landsat TM image (path 121/row 40) of 30 July 2006 was obtained from the Chinese Remote Sensing Satellite Ground Station. The cosine approximation model (COST) described by Chavez (1988, 1996) and Chen et al. (2004) was applied to atmospherically correct the image. Topographic maps of 1:50,000 were employed to register the image to the Beijing 54/Gauss–Kruger projection using a first-order polynomial and nearest neighbour approach. The root mean square error (RMSE) for positional accuracy was within half a pixel. Land areas and small water bodies were removed using a binary mask created through visual interpretation of an unsupervised classification of the image. Only bands with 30 m resolution (bands 1–5 and 7) were used in this study. We subjected the water areas of the northern Poyang Lake and Ganjiang River to a principal component analysis to enhance the visibility of vessels.

2.3. Sampling vessels

During repeated field visits to Poyang Lake, we noted that barges transporting sand passed by in regular order with distances of several hundreds of meters between individual ships. We further observed that these barges had a carrying capacity of 2000–4500 ton and a size of around 60 m by 20 m. A colour composite of principal components analysis (PCA) components 3, 2 and 1 (Fig. 2A) of the processed TM image revealed around 180 regular spaced linearly arranged objects. We concluded these objects to be barges because their uniform size and linear arrangement perfectly matched the size and linear arrangement of vessels observed during our field observations. Eighty-one of these 180 objects were randomly selected for further analysis.

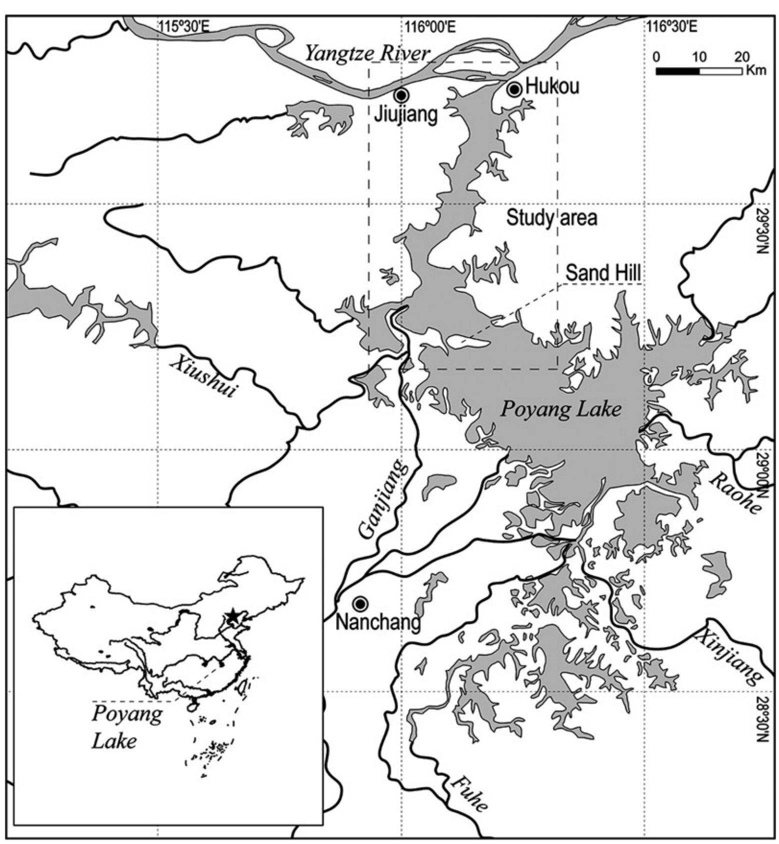

Fig. 1. Map of Poyang Lake and the study area (dashed rectangle) in the northern Poyang Lake.