ANALYSIS OF DENSE TIME-SERIES SENTINEL-1 IMAGES FOR RISKS MANAGEMENT IN THE DRINKING WATER RESOURCE

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ABSTRACT

This paper analyzes the potential of dense time-series Sentinel-1 images for risks management in the drinking water resource. Totally 50 SAR images ranging from March 8, 2015 to August 18, 2017 were employed to monitor land cover/use changes around the Yuqiao reservoir in Tianjin Province, China. Firstly, 49 change maps were obtained by comparing the image acquired on March 8, 2015 with all other 49 images. Then with the help of statistical procedures and very high spatial optical images from Google Earth, 258 intensive local changes in various sizes were collected and analyzed in both a visual and quantitative way. Results indicate that land cover/use changes a lot in the study area in the past three years. Among the selected changes, some are due to phenology or cultivation; a few are sudden changes on the time of imaging, while most are human induced land cover/use changes with specific purposes. Meanwhile, no human induced changes were found within the core protection region of the Yuqiao reservoir, except a few buildings were dismantled indicating the effectiveness of the environmental protection regulation. Overall, the dense time-series Sentinel-1 images can accurately capture high spatial and temporal variability of land cover/use which indicate their great potential in risks management in the drinking water resource. In the future, we will work on more features and procedures to detect changes and discriminate change types in a more intelligent way.

***Index Terms*—**change detection, risks, drinking water resource, analysis, Sentinel-1

1. INTRODUCTION

Nowadays, making drinking water safe is a priority in China. Serious health and social problems concentrate in areas where the water quality is poor. In the last decade, great efforts have been made on tackling the drinking water pollution in China. The very recent one is the issuance of the prominent water pollution control action plan (simply called 10 water rules) by the central government in 2015. Among all possible factors contributing to the drinking water pollution, human activities nearby the drinking water resources cannot be neglected. So monitoring land cover/use changes in the drinking water resource become a regulate task in the Environmental Protection Agency in China.

Most of the efforts in China for drinking water resources monitoring are based on optical remote sensing, e.g., [1], [2]. Due to frequent cloud cover, smog, haze and sand storms, however, optical data may not be available during critical monitoring cycles. Multitemporal SAR images, on the other hand, have been increasingly used in change detection studies [3]-[5] due to SAR's independence of atmospheric and solar illumination conditions and its unique information content. With the launches of ESA's Sentinel-1, free high spatial resolution multitemporal SAR data are routinely available in global, thus providing an excellent opportunity for monitoring changes in the drinking water resource.

Therefore, the objective of this research is to investigate the potential of dense time-series Sentinel-1 images to monitor land cover/use changes in the drinking water resource using change detection, statistical procedures and manual interpretation with the help of very high spatial optical images in the Google Earth.

2. METHODOLOGY

A hybrid approach is developed to analyze the dense time-series Sentinel-1 images. The flowchart is shown in Figure 1 and is explained as follows.

(1) Change intensity maps are produced by comparing the base image (acquired in the earliest date here) and all other images using the log ratio method [6];

(2) Mean filtering (default 3*3) on the spatial domain is conducted on each change intensity map, and then change intensity maps in the same quarter are aggregated into one map based on mean filtering on the temporal domain;

(3) PCA and ICA are separately performed on the filtered change intensity maps to enhance essential changes in the time-series SAR images;

(4) Informative components obtained from PCA and ICA are interpreted with the help of very high spatial optical images in the Google Earth, and then intensive change areas are manually extracted and analyzed extensively.

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3. STUDY AREA AND DATA

The study area was selected in the Yuqiao reservoir in Tianjin Province, China, an area of approximately 1500 km^2. Yuqiao reservoir is the key drinking water resource for Tianjin and plays important role in Tianjin economic development. In the past ten years multiple strategies have been employed to tackle the water pollution in the Yuqiao reservoir. To monitor land cover/use changes around the Yuqiao reservoir, totally 50 Sentinel-1 SAR images (IW-GRD, 10m, only VV mode is used) ranging from March 8, 2015 to August 18, 2017 were acquired from ESA Scientific Data Hub **[7]**. The study area and selected dataset are illustrated in Figure 1.

4. RESULTS AND ANALYSIS

Totally 49 change intensity maps were obtained by comparing the image acquired on March 8, 2015 with all other 49 images using the log ratio method. Then the 49 temporal change maps were spatially filtered and temporally aggregated into 10 change maps with each representing net changes within a specific quarter. Furthermore, PCA and ICA were performed on the 10 change maps respectively. Informative bands mostly at the top three components after the transformation were interpreted with the help of very high spatial optical images from Google Earth.

258 typical areas in various sizes were collected. Those areas cover most intensive land cover/use changes around Yuqiao Reservoir during 2015 to 2017. Those changes can be largely divided into three types: human induced land cover/use changes (216, type 1), changes caused by phenology and/or cultivation (25, type 2) and randomly sudden changes (17, type 3) as illustrated in Figure 2. Type 1 change indicated by red boxes is the largest and the most diverse group. It includes constructions of various artificial objects such as roads, buildings, parking areas and high-voltage power lines etc.. It scattered a lot spatially, however, no human related changes were found within the core protection region of the Yuqiao reservoir, excepting few buildings were dismantled, which indicates the effectiveness of the environmental protection regulation. Type 2 change indicated in blue boxes concentrates at the right-bottom of the study area. Although croplands abound in the study area, most of them showed faint changes compared to the selected areas which were quite distinct on the change intensity map. Initial exploration showed that this area covers plenty of greenhouses and their dynamic properties in the SAR image may be related to cultivation behaviors. Type 3 change indicated in the green boxes is mainly moving targets at the time of imaging. It locates alongside the highway. However, there may be more sudden changes and were not counted in our study due to their small sizes. Moreover, informative components from PCA and ICA are not only helpful for manual interpretation but also may be used to discriminate changes types and this property needs to be further exploited.

To analyze the ability of the time-series SAR images in capturing temporal variability of land cover/use in the study area. The collected change areas were extensively analyzed on the original 10 change intensity maps. Six typical areas representing three change types were shown in Figure 3. Also typical change profiles of those areas on the intensity maps are compared as show in Figure 4. Results indicate that the time-series SAR images can characterize quarterly dynamics of land cover/use very well, such as buildings and parking construction (as indicated by s1, s2 and s6), phenological changes of trees and crops (as indicated by s3 and s4), and also randomly sudden changes caused by moving vehicles on the time of imaging (as indicated by s5). It should be noted that original Sentinel-1 images can work on a higher temporal resolution without our temporal filtering. These timely land cover dynamics are invaluable to risks management in the drinking water resource. Dense change monitoring as shown here will be hard if not impossible with optical images. The situation will be worse in the tropical areas. Furthermore, from Figure 3 and 4, spatial-temporal patterns can be seen in different types of changes and this opens a door to further exploration the potential of the dense time-series SAR images [8].

5. CONCLUISONS

This paper analyzed land cover/use changes around the Yuqiao reservoir in Tianjin Province, China by using 50 Sentinel-1 images ranging from 2015 to 2017. Results show that land cover changes a lot in the study area in the past three years. Those changes can be quarterly captured in a detail way by using dense time-series Sentinel-1 images. Meanwhile, no human induced changes were found within core protection region of the Yuqiao reservoir, except a few artificial targets were removed, and this indicates the effectiveness of implementation of the environmental protection regulation. Overall, dense time-series Sentinel-1 images show great potential in risks management in the drinking water resource. To further unleash the potential of Sentinel-1 images, our next step is to exploit more features and more intelligent ways to detect changes and also discriminate change types [8] [9].

6. ACKNOWLEDGEMENT

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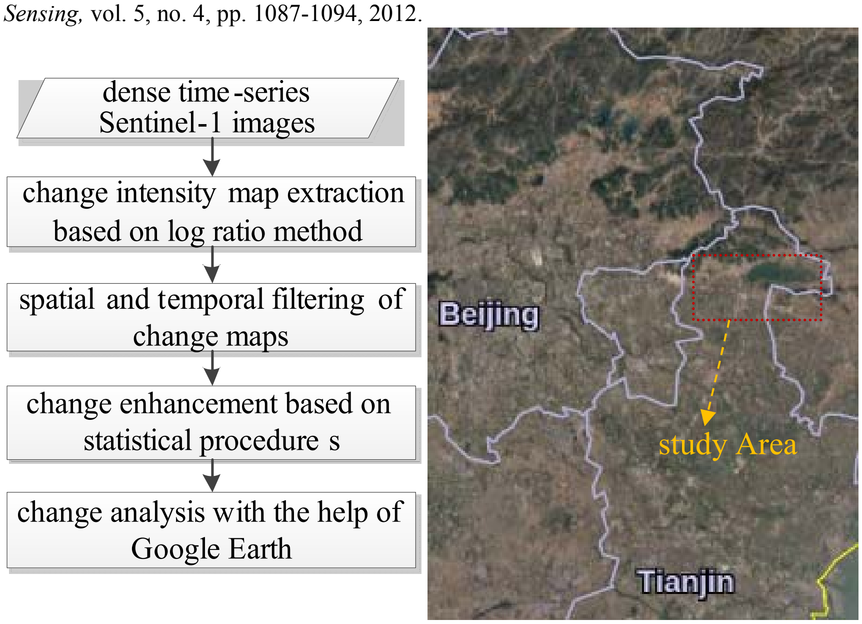


	2015	2016	2017
Quarter 1	2015-3-8	2016-1-2 2016-1-14 2016-1-26 2016-2-7 2016-2-19 2016-3-2 2016-3-14 2016-3-26	2017-1-2 2017-1-14 2017-1-26 2017-2-7 2017-2-19 2017-3-3 2017-3-15 2017-3-27
Quarter 2	2015-4-1 2015-4-25 2015-5-19 2015-5-31	2016-4-7 2016-4-19 2016-6-6 2016-6-30	2017-4-8 2017-5-2 2017-5-14 2017-5-26 2017-6-7 2017-6-19
Quarter 3	2015-9-28	2016-7-12 2016-8-29 2016-9-28	2017-7-1 2017-7-13 2017-7-25 2017-8-6 2017-8-18
Quarter 4	2015-11-15 2015-11-27 2015-12-9 2015-12-21	2016-10-10 2016-11-3 2016-11-15 2016-11-27 2016-12-9 2016-12-21	

Figure1. Flowchart of our method (left); study area (middle) and dataset (right) used in the experiment

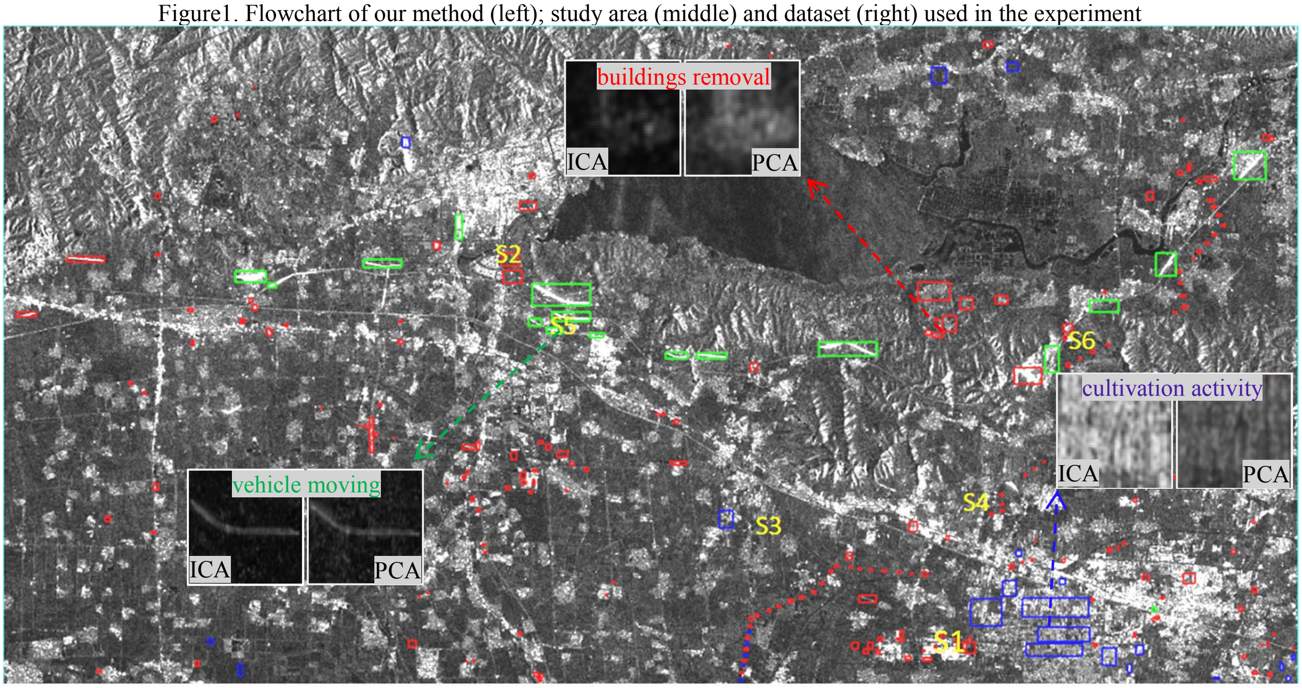


Figure 2 Illustration of 258 selected changing areas on the SAR image acquired on March 8, 2015; areas enclosed by red, blue and green boxes are human induced land cover/use changes (216, type 1), changes caused by phenology and/or cultivation (25, type 2) and randomly sudden changes (17, type 3) respectively. Three typical subsets from PCA and ICA components are also shown for visual comparison.

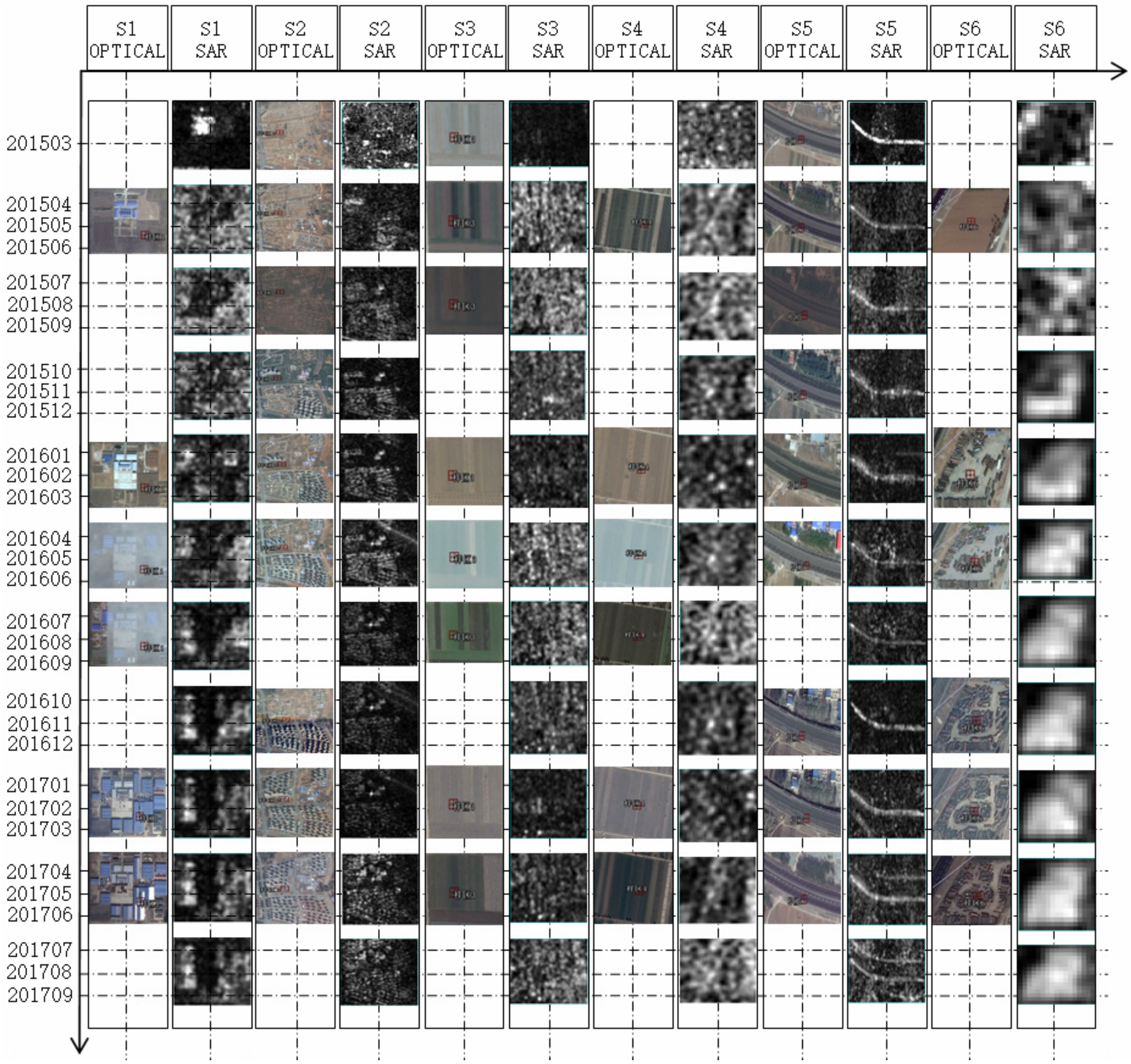
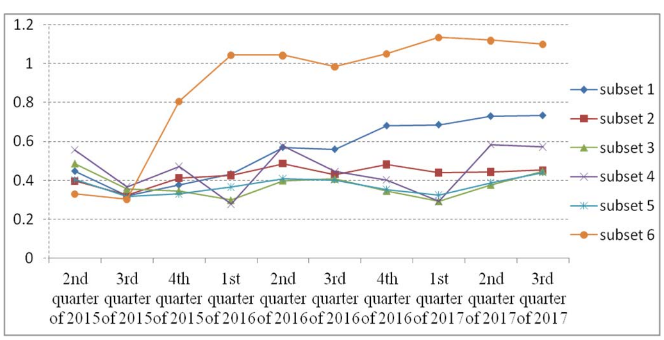


Figure 3 From top to bottom, 10 temporal SAR change maps ranging from 2015 to 2017 and their accompanying optical data in the same time of the range (excepting the first row which refers to SAR image acquired on March 8, 2015).From left to right, six pairs of optical image and SAR change map with each referring to a sample area labeled on the top(optical images are not always available).



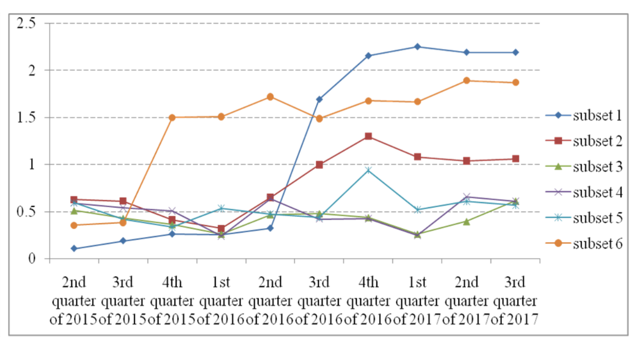


Figure 4 change profiles of the six selected subsets (corresponding to S1-S6 in Figure 3), left: values in the y-axis of the profiles are obtained by mean change density in the subset; right: values in the y-axis of the profiles are obtained by manual selection of interested locations in the subset.