THE RESEARCH ON EXTRACTION METHOD OF BLACK-ODOR WATER BODY BASED ON TRIPLESAT CONSTELLATION REMOTE SENSING DATA

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ABSTRACT: The appearance of black-odor water body belongs to the extreme phenomena of water organic pollution. Resulting from the discrepancy of constituent contents, the spectral responses of black-odor water body differ from those of clean water body, which lays the foundation for monitoring black-odor water body with remote sensing methods. With the pretreatment of TripleSat constellation remote sensing data and object-oriented technique process, the extraction rule set of black-odor water body was carried out based on the corresponding apparent characteristics. Consequently, the distribution information of black-odor water body was acquired. The typical small and medium river channels in rural area were selected as the research objects, and the measurements of water quality parameters were conducted in the channels. According to the authoritative water quality criteria, 8 of the sample points were confirmed to be black-odor water body. With the object-oriented extraction process, all the 8 black-odor water bodies were extracted accurately. 127 objects were extracted from water areas, which embodied the consistency with the black-odor sample points in the relative location, tone, and texture. Furthermore, the method was then applied to the typical river channels in urban area, and the producer's accuracy of extracted black-odor water body reached 88%. With the combination of TripleSat constellation remote sensing data and the object-oriented technique process, the macroscopic and rapid monitoring of black-odor water body was realized, providing a reference for the black-odor watercourse modification and natural ecology restoration.

1. INTRODUCTION

The water body that presents disgusting color or throws off a nasty smell can collectively be called black-odor water body. As a consequence of continuous pollution, the hydrodynamic conditions of black-odor water body are less favorable with the weak self-purification ability, resulting in the hard degradation of nitrogen and phosphorus organic pollutant (Liu et al., 2011; Lv et al., 2014). The spectral and textural characteristics of black-odor water body differ from those of clean water body, presenting the discrepancy of water color in remote sensing images, which lays the foundation for monitoring spatial-temporal distributions and variation situations of water quality with remote sensing methods (Yu et al., 2014). Previously, most of the existing remote sensing methods for monitoring polluted water body were conducted with the confirmed water boundary (Patrick et al., 2015; Xu et al., 2011). However, the pollution phenomenon of black-odor water body differs from each other, and there are some difficulties in obtaining accurate water boundary. Hence, the extraction of black-odor water body needs to be conducted within the scene containing total land surface features. The object-oriented remote sensing information extraction method turns image objects into information carriers with segmentation, reflecting a stronger extraction ability. Moreover, the technique process satisfies the needs for dynamically monitoring the black-odor water body in a large area. In this paper, the typical river channels in rural and urban areas were selected as the research

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objects. The extracction method of black-odor water body was proposed based on the TripleSat constellation remote sensing data and object-oriented rule set, intending to provide a reference for the black-odor watercourse modification and natural ecology restoration.

2. DATA PREPARATION

2.1 High Resolution Remote Sensing Data

The TripleSat constellation was launched at July 11^{th}, 2015 in Sriharikota, India. The constellation consists of 3 optical remote sensing satellites, and each of them carries a multi-spectral and panchromatic imager. The revisit period of TripleSat constellation for anywhere in the world is 1-2 days, which provides the possibility for the high-density and dynamic monitoring of black-odor water body in temporal scale. The breadth of each satellite reaches 24km, and provides 0.8m resolution panchromatic image (450-650nm) and 3.2m resolution Blue (440-510nm), Green (510-590nm), Red (600-670nm), NIR (760-910nm) multi-spectral image, satisfying the primary demand for monitoring water quality with remote sensing methods.

The typical river channels in rural and urban areas were selected as the research objects, corresponding to two TripleSat constellation images at April 5^{th} and October 7^{th}, 2016, respectively. The pretreatments of the images were conducted, including radiation correction, geometric correction and bands fusion. With the reference of topographic map, the geometric correction of the images was conducted by selecting enough ground control points, and the precision was controlled within one pixel. And then, the Gram-Schmidt transform method was adopted to realize the fusion of the panchromatic and multi-spectral images. The fusion images kept the spectral information of multi-spectral images, and the spatial resolution was improved on the basis the original images.

2.2 Water Quality Measurements

The measurements of water quality were conducted in the rural river channels, and 52 sample points were determined with the GPS. The sampling time and the passing time of satellites were kept to be quasi-synchronization at April 5^{th} 2016. The measurements included water temperature (temp), pH, dissolved oxygen (DO), chemical oxygen demand (COD), electricity conductivity (EC), content of NH_3-N, total nitrogen (TN) and total phosphorus (TP). The Ministry of Housing and Urban-Rural Development of PRC released *The Modification Guidance of Urban Black-Odor Water Body* in August 2015, and specified the evaluation criterions and the grading standard, providing a reference for the determination of black-odor water body.

3. METHODS

3.1 Rule Set based on the Apparent Characteristics

Compared with the traditional classification methods, the object-oriented information extraction methods focus on the operation of image objects, making full use of the spatial, spectral and textural characteristics of the extraction objects. The methods assemble adjacent pixels for the operations of segmentation and classification, intending to realize the vector exportation of the classification results (Navuluer, 2007; Ursula et al., 2004; Xie et al., 2012).

1）Mean values of the spectral bands

Mean value of a certain band represents the average of all the pixel values in each image object. The mean value of red band (Mean_R) and blue band (Mean_B) are usually used to eliminate most of the construction lands and factory houses with blue roofs, respectively. However, the surfaces of black-odor water body used to be covered by the aquatic plants, which induces the range of its NDVI values to be close to those of the aboveground vegetation. The extraction with NDVI values results in the mixed classified objects, so the mean value of near-infrared band (Mean_NIR) can be adopted to expand the differences between the aboveground vegetation and the black-odor water body covered by the aquatic plants. The value of brightness also belongs to the mean value of the spectral bands, which used to be calculated with all the image levels. The feature of brightness performs well to distinguish the black-odor water body with the adjacent ground objects, especially the shadows of buildings. As shown in Table 1, the threshold values of the rule set used in the rural river channels were listed.

2）Value of NDWI

NDWI was proposed by Mcfeeters, intending to rapidly extract the information of water body with the ratio operations (McFeeters, 1996; Xu, 2005). Influenced by the particles of suspended matter or plankton, the rays of sunlight in polluted water body used to be absorbed and scattered, which results in the differences with clean water body (Feng et al., 2015). Based on the analysis about rural river channels, the NDWI values of black-odor water body remain above 0, and most of them lie between 0.03 to 0.12, showing apparent differences to clean water body.

3）Value of NDVI

NDVI used to be adopted as a best indicator to reflect the vegetation growth status and vegetation coverage. Resulting from the surface covers and suspended matter in black-odor water body, the spectral characteristics get much closer to those of non-water ground objects, showing apparent differences from those of clean water body. According to the statistic results, the NDVI values of black-odor water body remain below 0, and most of them in rural river channels lie between -0.09 to -0.02.

Table 1 The Threshold Values of the Rule Set Used in the Rural River Channels

Type	Rule set	Parametric representation	Threshold value
Spectrum	mean value of red band	Mean_R	≥ 200
	mean value of green band	Mean_G	185 - 209
	mean value of blue band	Mean_B	≥ 227
	mean value of near-infrared band	Mean_NIR	152 - 187
	brightness	Brightness	181 - 199
	normalized differential water index	NDWI	0.03 - 0.12
	normalized differential vegetation	NDVI	-0.09 - -0.02
Texture	homogeneity	GLCM Homogeneity	0.027 - 0.077
	contrast	GLCM Contrast	1780 - 5980

3.2 Extraction Process of Black-Odor Water Body

In this paper, the object-oriented extraction technique was adopted. The image objects were turned into information carriers with the operation of multi-resolution segmentation. According to the apparent characteristics such as the spectrum and texture, the extraction rule set of black-odor water body was established to get rid of other ground objects.

First, the TripleSat constellation images were pretreated with radiation correction, geometric correction and bands fusion. Then the operation of multi-resolution segmentation was conducted, and the segmentation results preliminarily reflected the differences among the varieties of ground objects. The combinations of different bands were made full use of to establish the extraction process, and the construction lands, shadows of buildings, vegetation and clean water body were eliminated successively, producing a preliminary extraction result. Moreover, according to the measurements and water affairs data, the extraction result was further examined and confirmed, producing a detailed list of black-odor water body. However, both the study area and time were taken into consideration for the adjustment of the mean values of each band, the values of brightness, NDWI and NDVI. Especially the determination of NDWI values, needs to be tested repeatedly based on the actual conditions of the study area, pursuing a better extraction result.

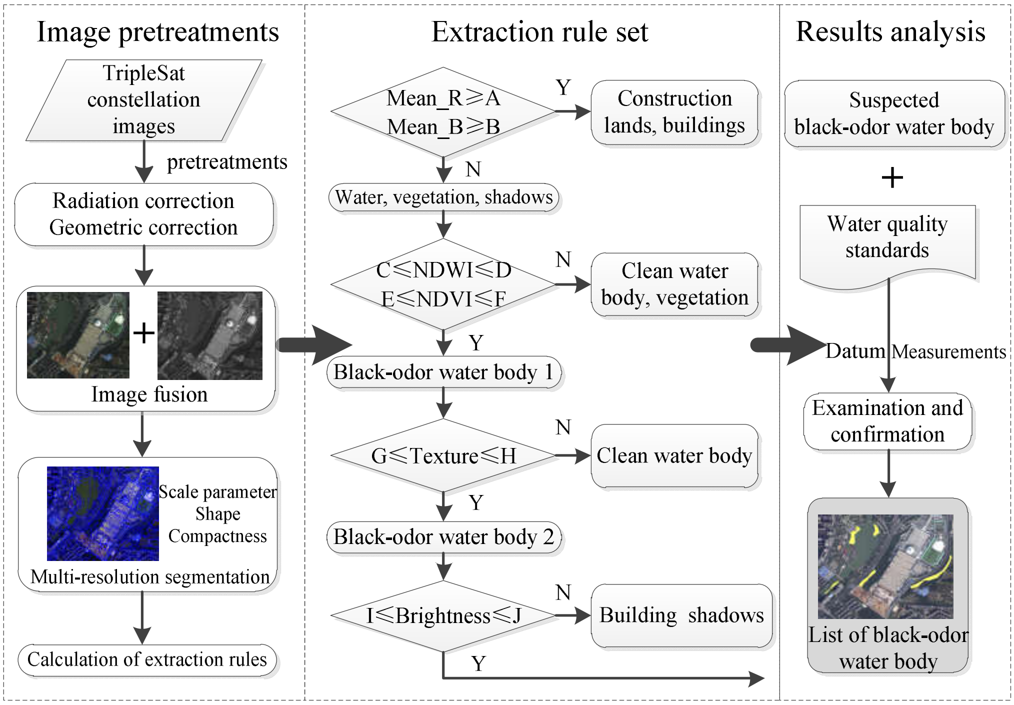

Figure 1 The Technique Flow Chart of the Extraction of Black-Odor Water Body

4. RESULTS AND DISCUSSION

4.1 Multi-Resolution Segmentation

According to the black-odor water quality standards in *The Modification Guidance of Urban Black-Odor Water Body*, 52 sample points in rural river channels were further examined, and 8 of them were confirmed to be black-odor water body. As shown in Table 2, the contents of DO of the black-odor sample points remain above 2 mg/L, reflecting that the oxygen contents were higher than the threshold value. But the contents of NH_3-N remain above 8 mg/L, belonging to black-odor water body, and 3 of them belonged to severe black-odor water body (Figure 2). The confirmation of black-odor sample points provided a reference for the threshold values of rule set, also contributing to the verification of the extraction results.

Table 2 Water Quality Parameters of the Black-Odor Sample Points in Rural River Channels

Number	pH	Tem (℃)	DO (mg/L)	NH_3-N (mg/L)	COD (mg/L)	TN (mg/L)	TP (mg/L)
1	7.45	7.8	9.49	15.95	86.9	32.63	3.89
2	7.71	7.1	5.39	32.26	68.7	52.00	2.04
3	7.92	8.0	9.36	9.75	42.6	24.21	3.25
4	7.76	8.2	8.03	13.27	78.7	19.23	2.17
5	7.94	15.2	2.43	13.17	42.6	15.98	1.27
6	8.02	11.1	8.66	8.37	37.8	11.38	0.25
7	7.87	12.0	4.91	67.92	81.4	80.09	2.85
8	7.70	7.6	5.10	9.31	37.6	7.62	0.47

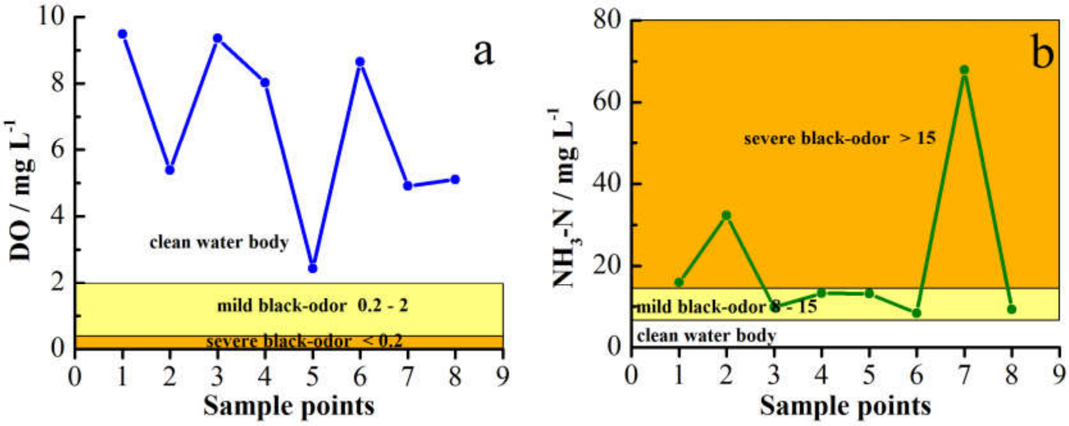

Figure 2 Contents of DO and NH_3-N of the Black-Odor Sample Points

The operation of multi-resolution segmentation was first conducted to TripleSat constellation images of rural river channels, and the feature values reflected the average of all the pixel values in each image object. Usually, a higher value of the segmentation scale resulted in the poor homogeneity of image objects, meanwhile inducing the fuzzy water boundary. The mixed image objects brought difficulties for the subsequent extraction process. A lower value of the segmentation scale corresponded to the preferable homogeneity of image objects and clear water boundary, but inevitably resulted in a low extraction efficiency in the subsequent process (Figure 3). The segmentation scale was finally set as 15 (shape parameter 0.1, compactness parameter 0.5) after the repeated experiments, intending to assemble the pixels with similar spectral and textural characteristics as one image object (Baatz et al., 2001; Thomas et al., 2003).

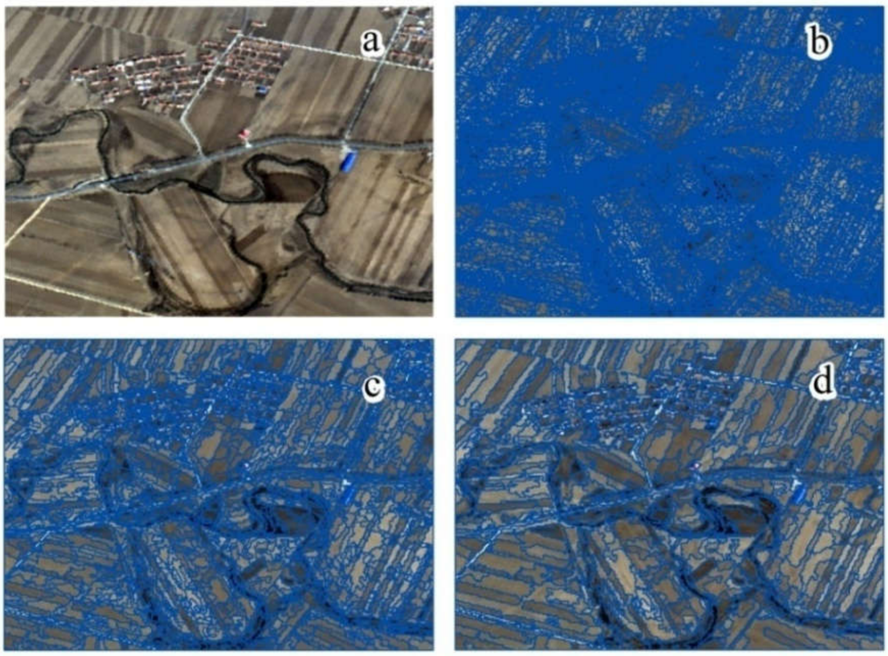

Figure 3 The Variations of Image Objects in Rural River Channels with Different Segmentation Scales ((a)represents the original TripleSat constellation images, the segmentation scales in (b), (c) and (d) are 5, 15 and 30, respectively）

4.2 Analysis of the Extraction Results in Rural Areas

The 8 black-odor sample points in rural area were adopted as the references, and their corresponding image objects were further confirmed as suspected black-odor water body. And then, the threshold values of the rule set were adjusted based on the feature values of the image objects. In the extraction results with rule set methods (blue), the number of black-odor image objects reached 187, and 127 of them lay in the river channels (total area was 7407.3 m^2). Especially, the 8 black-odor sample points were all involved in the extraction results (Figure 4). The few image objects besides water body were verified to be vegetation, roads and shadows of the buildings, which occupied 32.1% of the total number of extracted image objects. Most of the 127 extracted image objects in rural rivers lay in corners or intersections of the channels, where the water flow was slow and retarded. And the spectral and textural characteristics of the extracted image objects showed a higher consistency with those of the black-odor sample points. However, the rural rivers in the study area belong to the small and medium river channels in flatlands, and the water quality used to be influenced by the seasons, weather conditions and human factors.

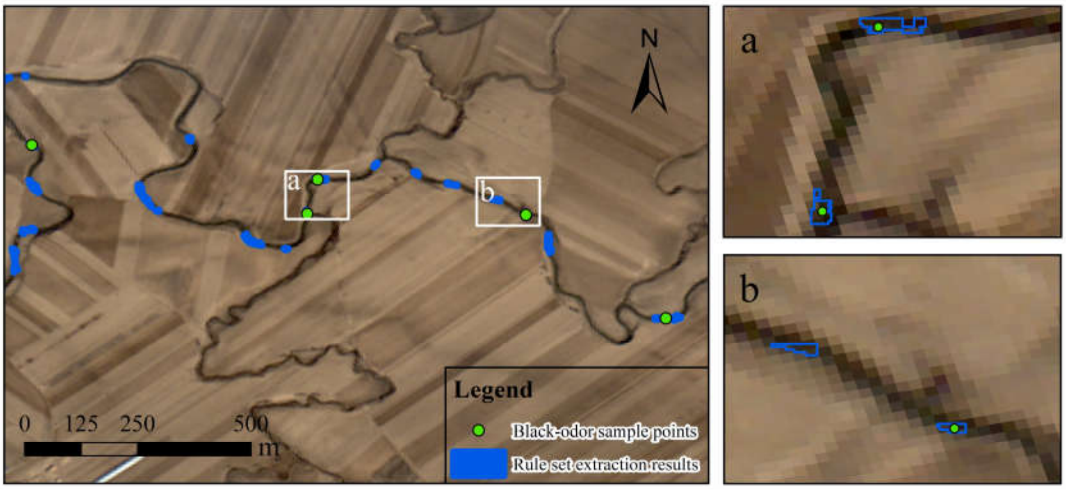

Figure 4 The Extraction Results of Black-Odor Water Body in Rural River Channels

A large number of villages and farmlands lay besides the rural river channels, which resulted in a non-point source pollution. Hence, the water body was always polluted by varieties of pollution sources, including the pollution loads from rainfall and the waste water from the livestock breeding activities (Meng and Xu, 2015; Wang et al., 2013). The high concentration of NH_3-N in rural rivers was proved to be the primary inducing factor of black-odor water body, and NH_3-N used to be produced from the agrochemical, sanitary sewage and industrial wastewater (He et al., 2015; Wang et al., 2014). Affected by the oxygen and microorganism, the organic nitrogen in water body used to be unstable, and then was converted to be inorganic nitride under the effects of ammonization and nitrification. A large amount of oxygen was consumed in the process, resulting in the black-odor water body. Besides, the experiment time belonged to the early spring season of the local area, and the runoff volume was relatively low, inducing the poor self-cleaning capacity of the rural rivers.

4.3 Evaluation of the Applications to Urban Areas

The extraction process was applied to typical urban river channels, and the threshold values of the rule set were then adjusted. According to the visual interpretation of the image object features, the black-odor water body lay in the narrow river channels, where the water flow was slow and retarded. The majority of the land covers on both sides of the river channels used to be concentrated living quarters or factory houses. Specially, there were two types of black-odor water body in the study area. The first type was covered by the aquatic plants, which induced the characteristics to be close to those of the aboveground vegetation with lower NDWI values and higher brightness values. The second type contained more particles of suspended matter or plankton, resulting in higher NDWI values and lower brightness values. Hence, it is necessary to set up two threshold sections for the NDWI values in the extraction process. The black-odor water body resulted in an irregular and fuzzy water boundary, meanwhile producing the lighter tone and granular sensation. On the contrary, clean water body corresponded to a clear boundary and a much darker tone. As shown in Figure 5, the colors of black-odor water body were dark green or off-white.

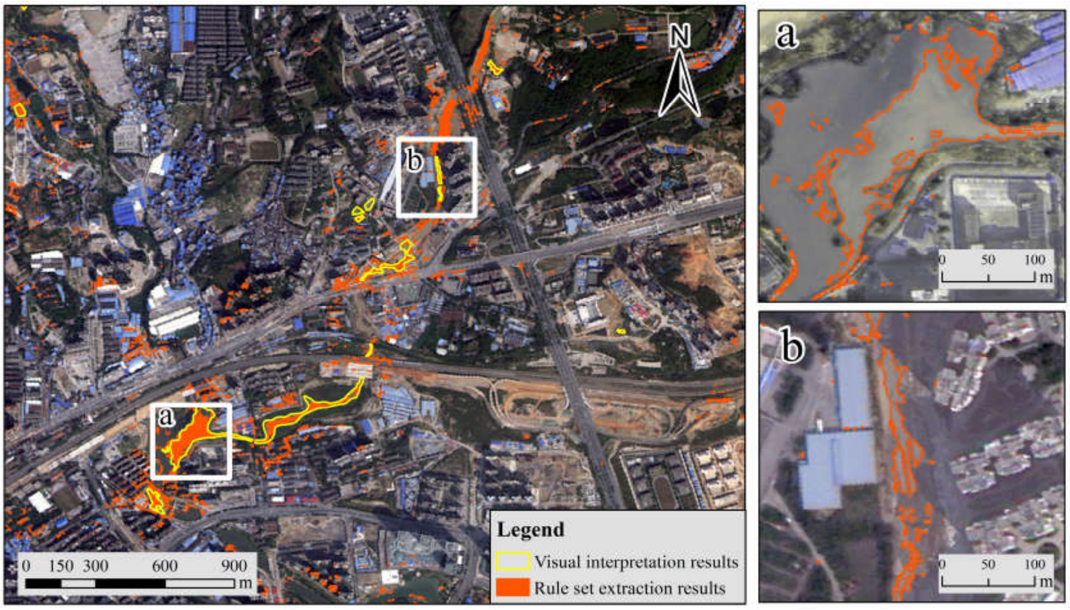

Figure 5 The Extraction Results of Black-Odor Water Body in Urban River Channels

According to the local authoritative list of black-odor water body, 16 water bodies were confirmed as references in the image with visual interpretation. And then the 16 water bodies were compared with the extraction results of rule set, the wrong image objects in the extraction results were primarily vegetation, roads and shadows of the buildings. 14 of the 16 water bodies were basically covered by the extraction results of rule set, and the producer's accuracy reached 88%, the missing 2 objects were small enclosed water bodies.

5. CONCLUSION

The typical river channels in rural and urban areas were selected as the research objects in this paper. Based on the TripleSat constellation remote sensing data and the object-oriented technique process, the macroscopic and rapid monitoring of black-odor water body was realized. With the high spatial resolution of TripleSat constellation images, the spectral and textural characteristics of black-odor water body differ from those of clean water body, reflecting the discrepancy of water color in remote sensing images. The extraction of black-odor water body in the study areas were conducted within the scene containing total land surface features, reflecting a better performance in the mixed land covers. The method contributed to obtain the distribution and area of the black-odor water body even when its surfaces were covered by the aquatic plants or garbage. Moreover, the selection of features and the process design in the rule set took different pollution conditions into consideration, presenting a stronger adaptation and generalization. The method guaranteed to realize the extraction of every suspected black-odor water body, intending to reduce the omission as far as possible.

However, the method has a large space for the possibility of improvements in the area of engineering application. 1) The threshold values of the rule set need to be adjusted when the method was applied to other typical river channels, and more attentions should be paid on the automatic determination of threshold values in further work. 2) The method focused on the information extraction with apparent characteristics of water body, but also encountered the lack of supports from the quantitative retrieval. The examination and verification of black-odor water body calls for a further combination of qualitative and quantitative methods. 3) The appearance of black-odor water body results from the emissions of organic pollutant form surroundings, so the quantitative weighting methods of the nearby pollution sources also need to be taken into consideration, intending to support the extraction process.

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