

Construction of Urban Black and Odorous Water Remote Sensing Recognition Model Based on Feature Band

Zepei Wang^{1, a}

¹School of Surveying and Land Information Engineering, Henan Polytechnic University, Jiaozuo 454003, China

^a212104020023@home.hpu.edu.cn (Z.W.)

Abstract: In recent years, with the rapid development of urban and rural areas in China, the discharge of industrial wastewater and household sewage has increased greatly, which has been directly discharged into pits and rivers, causing serious pollution of these bodies of water. In this study, the sampling points were first divided into black and odorous water bodies and general water bodies. Combined with remote sensing images, the best threshold value of the most effective feature bands in the classification of the study area was explored through the threshold method, and the accuracy performance of different feature bands in the classification process was comprehensively evaluated. In the algorithm of black and odorous water body identification based on characteristic bands, the thresholds of the single-band method, the difference method of black and odorous water body and the slope index of black and odorous water body in the experimental area of Nanning are 0.0186, 0.004 and 0.007 respectively. These three algorithms are used as thresholds to distinguish black and odorous water bodies from ordinary water bodies. The normalized black and odorous water index model determines that the range of black and odorous water is 0.007-0.137.

Keywords: Black and odorous water; Characteristic band; Spectral information; Threshold method.

1. Introduction

As an important issue of general concern to all sectors of society, environmental governance has always attracted much attention. In many fields of environmental governance, water body governance has been recognized as the core and key of environmental governance due to its unique challenges, such as difficult remediation, complex process, easy recurrence and difficult monitoring[1].

The classical single band method and difference index method are needed for the preliminary identification of black and odorous water bodies. Based on the single band method, Wen et al. proposed the band ratio method by studying the spectral curve of black and odorous water bodies[2]. This innovative method provides an important reference for subsequent research. Yao Yue et al. further improved the band ratio method and proposed the Black and Odorous Water Index (BOI) model[3]. Combined with the color of the water body and the black and odor condition, the model can realize the rapid identification of the black and odor water body based on the remote sensing image. To evaluate the normal Index of Water bodies, Li et al developed WCI (Water Cleanliness Index) index, which is widely used in water quality monitoring[4]. Based on the BOI model, Zhang et al. proposed a series of HCI models, including HCI1 and HCI2 models, which further improved the accuracy of remote sensing recognition methods in the study area[5]. Yao et al. developed the HI model and proposed the standardized black and odorous water body index NDBWI[6]. Qi et al improved

BOCI[7] on the BOI model, which innovatively proposed the concept of classifying black and odorous water bodies by remote sensing for the first time. Meanwhile, many scholars only stayed at the level of water body identification, and it was challenging to propose this method, which was of great significance for water quality monitoring. Taking Guangzhou as an example, Gao et al. used BOI model combined with remote sensing visual interpretation method to classify black and odorous water bodies[8]. Han et al. adopted the NDBWI model to realize the identification of black and odorous water bodies through remote sensing[9].

In this paper, multiple spectral characteristics of black and odorous water bodies are obtained by the feature band method, and the black and odorous water bodies are identified by the fuzzy theory. The performance of the model is optimized and the accuracy of the model is improved by adjusting the model parameters and changing the feature selection strategy.

2. Study Site and Data

2.1. Study area and sampling point distribution

In this study, Nanning city of Guangxi Province is selected as the research area, which is located in the southern part of the Tropic of Cancer and the central part of Guangxi. Nanning is a typical subtropical monsoon climate with an average altitude of 76.5 meters, an average annual temperature of 21.8°C and an average annual rainfall of 1,286 mm. It is characterized by abundant precipitation, long summer and short winter[10].

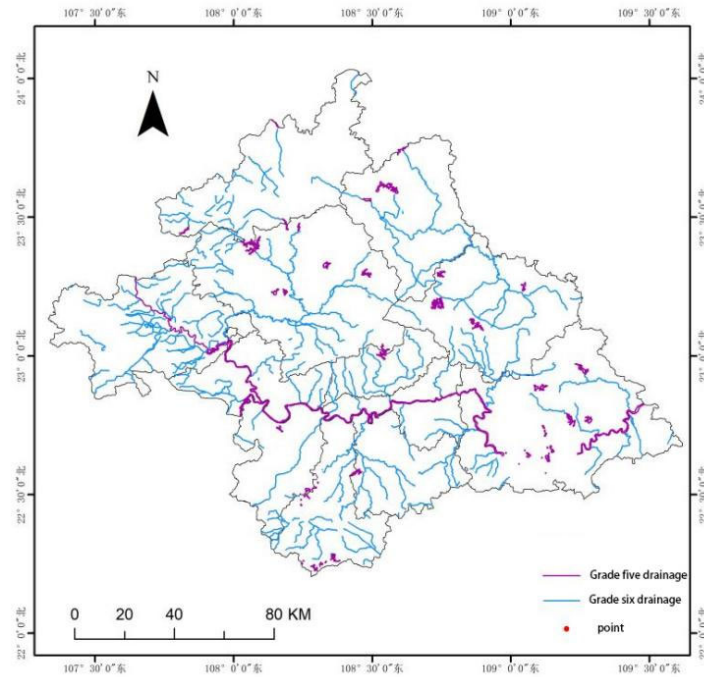


Figure 1. Distribution of water samples in Nanning in 2018

2.2. Water quality information collection

The water quality data used in this paper are from the water quality monitoring website and the official list released by the Nanning Municipal government. After strict screening, 62 water samples were selected for in-depth analysis in this study. According to the urban standard for classifying black and odorous water bodies, 26 of these samples were judged to be normal water bodies, and the remaining 36 were judged to be

black and odorous water bodies.

2.3. Image and preprocessing

Sentinel-2 image has the characteristics of high time resolution and high imaging resolution, and Sentinel-2 satellite imager has the ability to obtain vegetation, soil and hydrological information. The Sentinel-2 satellite system consists of two satellites, Sentinel-2A and Sentinel-2B[11].

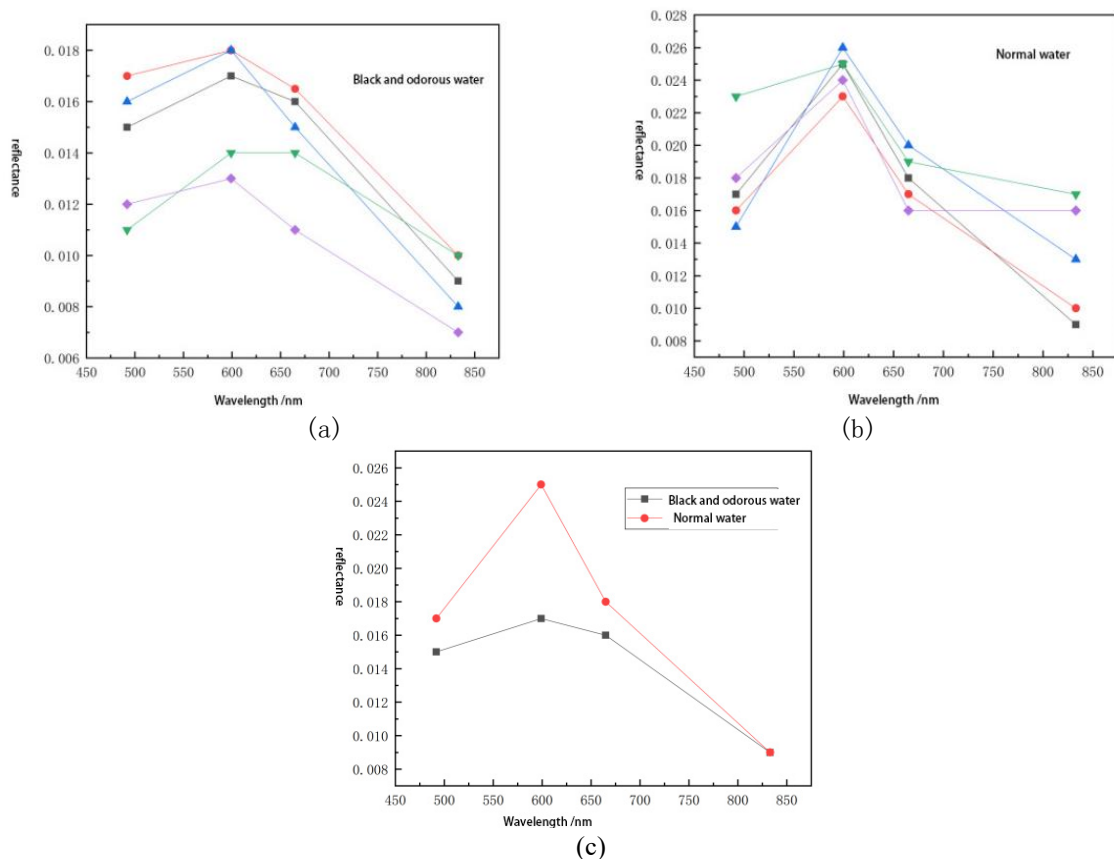


Figure 2. Spectral curves of black and odorous water bodies in typical cities (a), Spectral curves of normal water (b), Comparison of spectral curves between normal water and black and odorous water (c)

The satellite images of the main urban area of Nanning and its surrounding areas from July to October 2018 were obtained by ESA Sentinel-2 data download service, with the data Level of Level-1C product. The images used in this study cover the main urban area of Nanning, and the weather conditions in the images are sunny and the cloud cover meets the requirements. Images can be used to identify the features of the study area. The main land types in the main urban area of Nanning city include roads, woodlands, towns, agricultural land, water and woodlands. The topography of the image shows the features of higher terrain in the northern region and gentle terrain in the central and southern regions.

3. Construction of Black and Odorous Water Body Recognition Model by Remote Sensing

3.1. Optical characteristics analysis of remote sensing reflectance of urban black and odorous water bodies

By comparing the spectral information of normal water bodies in Nanning city, the unique spectral characteristics of black and odorous water bodies are highlighted. In this process, the data of non-black and odorous water bodies are taken from water samples with normal water quality in urban river channels, while the data of black and odorous water bodies are from water samples with substandard water quality in urban river channels. As shown in Figure 2, the black and odorous water bodies show significant differences from normal water bodies.

As shown in Figure 2 (a), this study found that the remote sensing reflectance value of urban black and odorous water bodies in the visible range was generally lower than 0.025sr-1, and the average value reached the lowest level. Further observation of Figure 2 (c) shows that the remote sensing reflectance of urban black and odorous water bodies shows a relatively flat trend in the band of 550nm to 700nm. Although there are fluctuations during the period, no significant peak and valley characteristics are formed. This unique spectral performance can be used as a basis for remote sensing recognition.

3.2. Construction of urban black and odorous water body identification algorithm based on feature band

The difference of remote sensing reflectance between urban black and odorous water bodies and normal water bodies was compared. In order to distinguish the two water bodies accurately, this study determined different characteristic bands according to different methods to distinguish the black and odorous water bodies. In the process of model construction, water data is combined with remote sensing satellites. In this section, the ratio of normal water to black and odorous water in the modeling sample is 2 to 3. Based on these analysis results, this study proposes four methods based on feature bands for effective identification of urban black and odorous water bodies.

3.2.1. Single band threshold method

(1) Single band threshold method

On the global scale, the green reflectance of urban black and odorous water is lower than that of normal water.

Therefore, this study uses the remote sensing reflectance value of green light band to identify urban black and odorous water bodies. The specific recognition algorithm can be found in formula (1).

$$0 \leq R_{rs}(\text{Green}) \leq T \quad (1)$$

In the formula, it refers to the remote sensing reflectance value of Sentinel-2 image green band after atmospheric correction, and T represents a preset constant threshold.

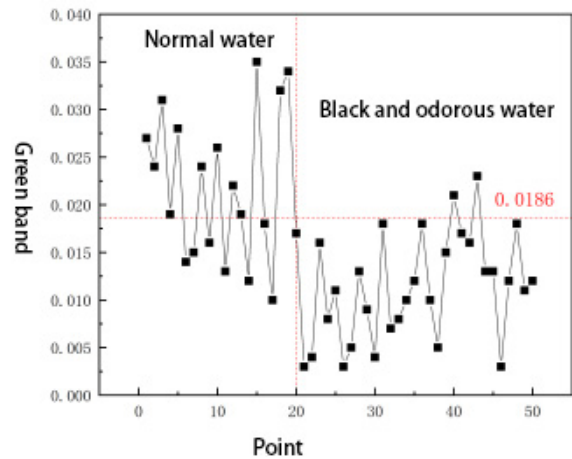


Figure 3. Single band method

3.2.2. Black and odorous Water Difference Index (DBWI)

(1) DBWI calculation

According to the in-depth analysis of the reflectance characteristics of urban black and odorous water in a specific wavelength range, this study found that the reflectance of the water body showed a slow rising trend in the spectral range from 480nm to 550nm, especially near 550nm, the crest shape of the reflectance curve was particularly broad, and the reflectance value reached the lowest at this point. This finding provides a new perspective for this study to examine the spectral characteristics of urban black and odorous water bodies.

In the blue-green band of Sentinel-2, the spectral slope of the urban black and odorous water body shows an obvious uniqueness, that is, the slope value reaches the lowest point in all the observed bands. This property provides an effective means to distinguish and identify urban black and odorous water bodies.

In order to quantify this criterion more accurately, a new index, the difference index of black and odorous water bodies, was introduced in this study. The calculation method of this index is shown in Equation (2). It is based on the difference of remote sensing reflectance of blue-green band in Sentinel-2 image, which provides a scientific and objective index for this study to evaluate and identify urban black and odorous water bodies.

$$DBWI = R_{rs}(\text{Green}) - R_{rs}(\text{Blue}). \quad (2)$$

After atmospheric correction, the remote sensing reflectance values of the green and blue bands of Sentinel-2 image are respectively represented by $R_{rs}(\text{Green})$ and $R_{rs}(\text{Blue})$, and the unit of DBWI is sr^{-1} .

Category of water body =

$$\begin{cases} \text{black and odorous water, } DBWI \leq 0.00448\text{sr}^{-1} \\ \text{Normal water, } DBWI > 0.00448\text{sr}^{-1} \end{cases} \quad (3)$$

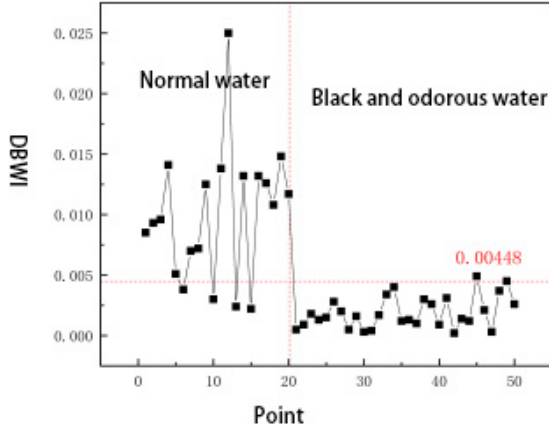


Figure 4. The difference in remote sensing reflectivity in the blue-green band

3.2.3. Slope of Black-odorous Water Index (SBWI)

(1) Calculation of SBWI

After in-depth analysis of the spectral characteristics of the black and odorous water body in Nanning City, this study found that the spectral curve of the black and odorous water body showed a gentle trend in the wavelength range of 550nm and 700nm, especially in the blue, green and red bands of Sentinel-2 image. When transitioning from blue band to green band, the black and odorous water body is relatively smooth. Although the absolute value of its slope is small, it is still different from the normal water body to some extent.

The Slope of Black-odorous Water Index (SBWI) was used to identify Black and odorous water more accurately. The index is obtained by calculating the product of the spectral slope of the blue band and the green band, aiming to quantify the spectral characteristics of the black and odorous water in this specific wavelength range. The specific calculation method is shown in formula (4).

$$SBWI = \frac{|R_{rs}(\text{Green}) - R_{rs}(\text{Blue})|}{\Delta\lambda_1} \times \frac{|R_{rs}(\text{Green}) - R_{rs}(\text{Red})|}{\Delta\lambda_2} \quad (4)$$

In the formula, $R_{rs}(\text{Blue})$, $R_{rs}(\text{Green})$ and $R_{rs}(\text{Red})$ represent the reflectance values of the blue band, green light, and red light bands of Sentinel-2 images, respectively. In addition, the center wavelength interval between the green and blue bands of Sentinel-2 images is described $\Delta\lambda_1$, and the difference between the center wavelength of the green band and the center wavelength of the red band is described $\Delta\lambda_2$, and the unit of SBWI is sr^{-2} .

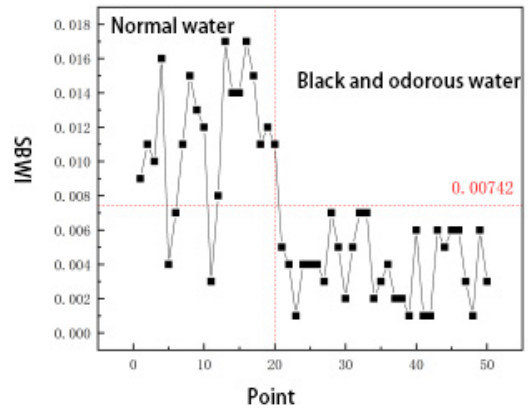


Figure 5. The slope index of black and odorous water is constructed

3.2.4. Normalized Difference Black and odorous Water Index (NDBWI)

(1) NDBWI calculation

After in-depth analysis of the spectral characteristics of urban black and odorous water bodies, as shown in Figure 6, it is found that the slope value of the spectral curve reaches the lowest in the spectral range of 550nm to 700nm. The corresponding central wavelength of green band and red band is 556nm and 666nm respectively, which can be used to reflect the spectral characteristics of urban black and odorous water bodies. Based on the above analysis, this study selected the ratio of remote sensing reflectance Difference and sum of the two bands as the discrimination Index, and defined it as the Normalized Difference Black and odorous Water Index (NDBWI). The index is calculated according to the formula (5).

$$NDBWI = \frac{R_{rs}(\text{Green}) - R_{rs}(\text{Red})}{R_{rs}(\text{Green}) + R_{rs}(\text{Red})} \quad (5)$$

In the given expression, and represent the remote sensing reflectance values of the green and red bands of Sentinel-2 image after atmospheric correction respectively, and the NDBWI value is a dimensionless parameter.

Category of water body =

$$\begin{cases} \text{black and odorous water, } 0.0788 \leq NDBWI \leq 0.1371\text{sr}^{-1} \\ \text{normal water, } NDBWI < 0.0788 \text{ or } NDBWI > 0.13713 \end{cases} \quad (6)$$

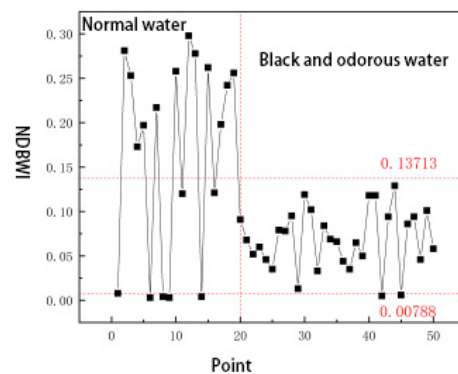


Figure 6. NDBWI construction patterns

4. Result

4.1. Evaluation of algorithm recognition accuracy

The calculation method of recognition accuracy rate is shown in equation (7) :

$$\text{Accuracy} = \frac{N_{\text{right}}}{N_{\text{total}}} \times 100\% \quad (7)$$

Where N_{right} indicates the number of samples with correct identification results, which N_{total} is the total number of verification samples.

After collecting the measured water quality data of black and odorous water bodies in Nanning City in July 2018, a total of 12 sample points were selected in this study. Based on these detailed sample data, this study carried out the identification accuracy evaluation to ensure its accuracy and reliability in practical application.

4.2. Algorithm accuracy evaluation and optimal algorithm screening

As shown in Figure 3, the range of normal sampling points in the green band is 0.0186 sr^{-1} - 0.035 sr^{-1} , and the range of sampling points in black and odorous water is 0.002 sr^{-1} - 0.0186 sr^{-1} . The overall recognition accuracy rate is 62.79% when the threshold value of 0.0186 sr^{-1} is adopted. As shown in Figure 4, the DBWI algorithm for normal water ranges from 0.0048 sr^{-1} - 0.025 sr^{-1} , and for black and odorous water

ranges from 0.0001 sr^{-1} to 0.0005 sr^{-1} . With the threshold value of 0.0048 sr^{-1} , the overall recognition accuracy rate is 90.7%. Figure 5 shows the value of SBWI algorithm. The value of normal water body is 0.00742 sr^{-2} - 0.017 sr^{-2} , and that of black and odorous water body is 0.001 sr^{-2} - 0.00742 sr^{-2} . The threshold value is 0.00742 sr^{-2} , and the overall recognition accuracy rate is 79.07%. Figure 6 shows the application of the NDBWI method, and the normal water value is mainly distributed in the range of 0.0089 to 0.3046. The sample values of black and odorous water were mainly concentrated in the range of 0.008 to 0.137. According to the set threshold range of 0.06 to 0.115, this study successfully identified all non-black and odorous water samples, and 9 black and odorous water samples were accurately identified. In summary, the overall recognition accuracy reaches 93.02%.

4.3. Precision comparison under different algorithms

Through the comprehensive analysis of the field collection and observation data of 12 sample points, this study can evaluate the recognition accuracy of black and odorous water bodies based on synchronous Sentinel-2 images.

In this study, 12 validation sets were used to evaluate the recognition results. Table 2, Table 3, Table 4 and Table 4-5 show the accuracy of the recognition results of the four methods. In the case that whether the sample is black or not is known, the accuracy of each algorithm is calculated in this study, so as to comprehensively evaluate its performance in practical application.

Table 2. The sample values and identification results were verified based on the black and odorous water single band method

Point	Single band method		The actual black smell
	Calculation result / sr^{-1}	Identification result	
P1	0.0195	Normal	Normal
P2	0.0183	Black and odorous	Normal
P3	0.0126	Black and odorous	Black and odorous
P4	0.0278	Normal	Black and odorous
P5	0.0104	Black and odorous	Black and odorous
P6	0.0159	Black and odorous	Black and odorous
P7	0.0199	Normal	Black and odorous
P8	0.0233	Normal	Normal
P9	0.0171	Black and odorous	Normal
P10	0.0145	Black and odorous	Black and odorous
P11	0.0101	Black and odorous	Normal
P12	0.0224	Normal	Normal

According to the data provided in Table 4-2, the judgment results of the single-band algorithm can be obtained. Under the set threshold of 0.0186 sr^{-1} , there are three sample points that are wrong in the judgment of non-black and odorous water. For the judgment of black and odorous water, two sample points were also misjudged as non-black and odorous water bodies (as shown in Table 2, their single-band values were greater than 0.0186 sr^{-1} of the sample points of black and odorous water bodies).

After detailed analysis of all verified samples, this study found that the identification results in P1, P4, P5, P6 were

basically consistent with the actual situation. However, when the judgment of all sample points is considered comprehensively, it is found that the overall recognition accuracy of this method is only 58.3%. This result fully shows that although the single-band algorithm shows certain accuracy in some specific sample points, its recognition accuracy still needs to be further improved in practical applications. Therefore, this study needs to continuously optimize and perfect the algorithm in subsequent studies to improve its performance in practical applications.

Table 3. Verifies the sample values and identification results based on the difference index of black and odorous water bodies

Point	DBWI		The actual black smell
	Calculation result /sr ⁻¹	Identification result	
P1	0.0054	Normal	Normal
P2	0.0033	Black and odorous	Normal
P3	0.0057	Normal	Black and odorous
P4	0.0019	Black and odorous	Black and odorous
P5	0.0011	Black and odorous	Black and odorous
P6	0.0018	Black and odorous	Black and odorous
P7	0.0029	Black and odorous	Black and odorous
P8	0.0038	Black and odorous	Normal
P9	0.0074	Normal	Normal
P10	0.0025	Black and odorous	Black and odorous
P11	0.0029	Black and odorous	Normal
P12	0.0071	Normal	Normal

Table 3 shows the comparison between the difference index method identification results and the actual results. With the threshold value of 0.00448sr⁻¹ in the training model, two

points in the normal water body were misjudged, and two points in the black and odorous water body were misjudged, and the accuracy of the method was 66.67%.

Table 4. Verifies sample values and identification results based on the slope index of black and odorous water bodies

Point	SBWI		The actual black smell
	Calculation result	Identification result	
P1	0.0085	Normal	Normal
P2	0.0085	Normal	Normal
P3	0.0030	Black and odorous	Black and odorous
P4	0.0081	Normal	Black and odorous
P5	0.0018	Black and odorous	Black and odorous
P6	0.0095	Normal	Black and odorous
P7	0.0063	Black and odorous	Black and odorous
P8	0.0089	Normal	Normal
P9	0.0094	Normal	Normal
P10	0.0071	Black and odorous	Black and odorous
P11	0.0068	Black and odorous	Normal
P12	0.0104	Black and odorous	Normal

According to the data in Table 4, the threshold of the slope index of the black and odorous water body is 0.00742sr⁻¹, and one point in the non-black and odorous water body is

misjudged. At the same time, there were also two points in the black and odorous water body that were misjudged. The recognition accuracy of this method is 66.67%.

Table 5. Verifies sample values and identification results based on normalized black and odorous water index

Point	NDBWI		The actual black smell
	Calculation result /sr ⁻²	Identification result	
P1	0.1381	Normal	Normal
P2	0.1401	Normal	Normal
P3	0.0686	Black and odorous	Black and odorous
P4	0.2061	Normal	Black and odorous
P5	0.0712	Black and odorous	Black and odorous
P6	0.0739	Black and odorous	Black and odorous
P7	0.1698	Normal	Black and odorous
P8	0.1536	Normal	Normal
P9	0.4261	Normal	Normal
P10	0.1246	Black and odorous	Black and odorous
P11	0.1091	Black and odorous	Normal
P12	0.0062	Normal	Normal

According to the data in Table 5, the threshold values of the two intervals selected by this method in the pattern book are 0.008 and 0.137, that is, the calculated results are identified as black and odorous water bodies within the interval. Specifically, there are 1 point misjudgment in normal water and 2 misjudgments in black and odorous water, and the model accuracy of normalized black and odorous water index is 0.75.

The identification accuracy of index NDBWI and DBWI is high through this verification method. This indicates that the thresholds of the two methods are stable in this study area. However, slope method and single band algorithm need to adjust the partition threshold to adapt to different data sets and study areas.

5. Discussion

5.1. Analysis of the causes of identification errors by different algorithms

Table 2, Table 3, Table 4 and Table 5 are the discrimination results of four different black and odorous water body identification algorithms to verify whether the sample points are black and odorous. The identification accuracy of each method is obtained by calculating and analyzing the data in the table. The single-band threshold method and DBWI method proved great errors in the identification of non-black and odorous water bodies. Combined with the water quality information of Yongjiang River obtained from field tests, the water quality of Yongjiang River was normal and no black and odorous occurred. The above misclassification phenomenon was analyzed for the following reasons.

After atmospheric correction, the blue wavelength is still affected by the atmosphere, and the remote sensing reflectance of the blue wavelength in the image shows some uncertainty and lacks obvious rules. The calculations for both DBWI and SBWI rely on Sentinel-2's blue band. Due to the effect of atmospheric correction in blue light band, the calculated results of these two indices are biased.

5.2. Algorithm applicability analysis and optimal algorithm screening

The single-band method is mainly based on reflectance values of specific bands in remote sensing images to identify black and odorous water bodies. Taking the green band of Sentinel-2 data as an example, the band is highly sensitive to suspended substances and chlorophyll in water, so it can reflect key information such as turbidity and chlorophyll content of water bodies. By setting thresholds scientifically, this study can identify black and odorous water bodies with relative accuracy. However, the single band method does face certain limitations in practical application. When encountering water bodies with overlapping spectral ranges, a single threshold setting is often difficult to ensure accurate differentiation, which may lead to bias in identification results.

In this study, it has been verified that the NDBWI shows a certain accuracy and stability in identifying the black and odorous states of the modeling sample points and the verification sample points. Among the four methods, NDBWI can be used as the primary algorithm to identify black and odorous water bodies, and NDBWI index plays a certain role

in the extraction of black and odorous water bodies in built-up areas of Nanning City.

References

- [1] Issued by the central people's government of the People's Republic of China, the State Council on water pollution prevention plan of action to inform [EB/OL]. [2015-4-16]. http://www.gov.cn/zhengce/content/2015-04/16/content_9613.htm.
- [2] Wen Shuang. Urban Black and odorous water body recognition by remote sensing based on GF-2 image [D]. Nanjing: Nanjing Normal University, 2018.
- [3] Yao Y. Research on urban black and odorous water body recognition model based on GF multispectral image [D]. Lanzhou: Lanzhou Jiaotong University, 2018.
- [4] Li Jiaqi, Li Jianguo, Zhu Li, et al. Identification and ground verification of black and odorous water by Remote Sensing in Taiyuan [J]. *Journal of Remote Sensing*, 2019, 23 (4) : 773-784.
- [5] Zhang Xue, Lai Ji Bao, Li Jianguo, et al. Remote sensing identification of black and odorous water bodies in Shenzhen based on Gaofen-1 image [J]. *Science Technology and Engineering*, 2019, 19(04): 268-274.
- [6] Yao Huanmei, LU Yannan, GONG Zhuqing. Research on black and odorous water body identification method based on PlanetScope image in Qinzhou, Guangxi [J]. *Environmental Engineering*, 2019, 37(10): 35-43.
- [7] Seven Ke Ke, Shen Qian, Luo Xiaojun, et al. Remote sensing classification of black and odorous water bodies in Shenyang based on GF-2 image [J]. *Remote Sensing Technology and Application*, 2020, 35(2): 424-434.
- [8] Gao Li, Zhang Lulu, Leaf Vein, et al. Remote sensing identification of black and odorous water bodies in built-up areas of Guangzhou based on GF-6 image [J]. *Environmental Ecology*, 2019,3(05):13-18.
- [9] Han Wencong, Zhang Xiaoyu, Chen Jiaying, et al. Urban black and odorous water body monitoring by remote sensing based on Gaofen-2 image [J]. *Environmental Ecology*, 2019, 3(01):63-71. (in Chinese)
- [10] Phiri D, Simwanda M, Salekin S, et al. Sentinel-2 data for land cover/use mapping: A review[J]. *Remote Sensing*, 2020, 12(14): 2291.
- [11] Drusch M, Del Bello U, Carlier S, et al. Sentinel-2: ESA's optical high-resolution mission for GMES operational services[J]. *Remote Sensing of Environment*, 2012, 120: 25-36.