T−S Fuzzy remote sensing monitoring model of snail distribution by Landsat 8 and Sentinel 2 data

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Abstract: Approximately half of the world's population is at the risk of at least one vector-borne parasitic disease. The survival of intermediate hosts of vector-borne parasitic diseases is governed by various environmental factors, and remote sensing can be used to characterize and monitor environmental factors related to intermediate host breeding and reproduction, and become a powerful means to monitor the vector-borne parasitic diseases. Schistosomiasis is a parasitic disease that menaces human health. Oncomelania hupensis (snail) is the unique intermediate host of schistosoma, so monitoring and controlling the number of snail is key to reduce the risk of schistosomiasis transmission. In this paper, Landsat 8 OLI and Sentinel 2 MSI data had been used to obtain the environmental factors (vegetation, soil, temperature, terrain et al.), which are related to the multiplying and transmission of intermediate host. Then this study used T-S (Takagi-Sugeno) Fuzzy RS model to establish a new suitable index membership function due to the different RS data, and a long time series monitoring of snail distribution in Dongting Lake from 2014 to 2018 was achieved. A comparative analysis was performed to validate the predicted results against the field survey data. The results demonstrated the accuracy of the developed model in predicting the distribution of snails.

Key words: Schistosomiasis; snail; Landsat 8; Sentinel 2; T-S Fuzzy

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1 INTRODUCTION

The transmission of vector-borne diseases rely heavily on the development of their intermediate host species. And the spatial distributions of the vector species are governed by various environmental factors of the habitats. Then Remote Sensing (RS) can be used to characterize and monitor environmental factors related to intermediate host breeding and reproduction, and become a powerful means to monitor the vector-borne diseases. Schistosomiasis japonica (*S. japonicum*) is one of many zoonotic parasitic diseases in the south of China. In spite of great efforts and the remarkable progress made over the past 50 years since the inception of the national programme on schistosomiasis control, hyper-endemic areas still remain in lake and marshland regions, as well as in some of the mountainous regions in seven provinces of southern China, especially, in the lake and marshland regions (Yuan et al, 2002; Utzinger et al, 2005; Zhang et al, 2008). Therefore, it is necessary to predict the distribution of S. japonicum for sustained control of schistosomiasis, under the current situation (Zhao et al., 2005). The amphibious snail- Oncomelania hupensis (*O. hupensis*) is the most important intermediate host of *S. japonicum*, and its spatial distribution corresponds strongly with that of S. japonicum in China. The survival of *O. hupensis* (snail) is governed by various environmental factors, and then remote sensing can be used to characterize and monitor environmental factors related to snail breeding and reproduction, and become a powerful means to monitor the distribution and density of snail (Zhou et al, 2005). Successful applications of RS and Geographic Information System techniques have been reported across different ecological, epidemiological and socio-cultural settings for the major human schistosome species, including

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S. japonicum in China (Zhang et al., 2005; Simoonga et al, 2009). But these research are only applicable to specific study areas or fixed RS data, not suitable for regional and national monitoring and disease control, especially long-time series monitoring should make full use of evolving new RS data. It is because the uncertainty relationship between snail and various environmental factors is very complex, which is a key problem limit the application of remote sensing data. Based on the T-S (Takagi-Sugeno) fuzzy information theory, a quantitative remote sensing monitoring model of snail at Junshan, Dongting Lake has been developed by using the field snail data and the relevant environmental data retrieved from RS data(Landsat 5\7, ENVISAT ASAR, MODIS, and ASTER DEM) (Liu et al. 2012, 2015). The validation results demonstrated the success of the developed model in monitoring the distribution of snails at Junshan, Dongting Lake. These studies also showed good application prospects of the developed model for long time series monitoring of snail spatial distribution. Then the T-S Fuzzy RS snail monitoring model was improved by adjusting environmental suitability index in order to be applied to different places, different time series, and take Xinmin beach, Gaoyou Lake as new research area, carry out 20 years (1990—2010) dynamic monitoring to validate the effectiveness of the T-S Fuzzy RS snail monitoring model (Liu et al. 2014). In this study, using recently new RS data of Landsat 8 OLI (Operational Land Imager) and Sentinel 2 MSI (MulitSpectral Instrument) data, taking Junshan, Dongting Lake as research area, carry out 5 years (2014—2018) snails' distribution monitoring, to further improve the T-S Fuzzy RS snail monitoring model by adjusting environmental suitability index in order to be applied to multi-source RS data. The effectiveness of the T-S Fuzzy RS snail monitoring model was validated by field snail surveys.

2 MATERIALS

2.1 Study area and survey data

This study was conducted in Junshan City, the northeast of Hunan Province of China, which is located beside Dongting Lake in the middle and lower reaches of Yangtze River. The total area of Junshan City is 2,681 km^2. This area was a high schistosomiasis epidemic area in history, due to its ecological conditions suitable for the breeding of schistosomiasis host snail, especially in the marshland and lake regions along the Yangtze River. Although the schistosomiasis is under control now, but the situation of snail is still worried (Xu et al., 2005).

The geographical distribution of host snail is consistent with that of schistosomiasis endemic areas. The suitable snail habitus requires necessary mild climate and abundant rainfall for snail population, i.e., annual average temperature of over 14℃ and an annual average precipitation of over 750 mm. In China, the program of snail survey is carried out annually, aiming for obtaining information about snail distribution and density as well as the environmental characteristics of habitats. The snail field survey data of spring 2014 and spring 2015 had been obtained from the National Institute of Parasitic Diseases, Chinese Center for Disease Control and Prevention. The survey data include snail GPS location, survey area, number of survey frames, number of living snails within a frame (area of a frame is 0.11 m^2), etc. These survey data will be used to improve the snail remote sensing model and validate the effectiveness of the model in monitoring snail distribution.

The biologic characteristics and environment of snail in Dongting Lake are shown in Table 1. Based on the analysis of the environment of snail and its biological characteristics, snail is found mainly relating to environmental factors such as water distribution, temperature, elevation, vegetation, water, soil, etc., which will help to identify the RS environmental parameters extracted from Landsat 8 and Sentinel 2 data. And the RS image observation time should be spring or autumn in accord with field survey time, especially the best month is April or September. Because the relationship between snail and various environmental factors is very complex, so only if it could build a quantitative suitability relationship between RS environmental parameters to the biologic characteristics of snail, the RS model can be applied to regional and national long time-series monitoring, with the increasing new RS data.

Table 1 Biologic characteristics and Environment of snail in Dongting Lake

Environment of snail	Biologic Characteristics
Types of distribution	Lake type
Influence of water distribution	Winter Land, Summer Water
Time of medication and field survey	Spring(April) and Autumn (September)
Temperature	suitable breeding between 20 ℃ to 25 ℃
Elevation	20—35 m (between lowest water lever to flood line)
Vegetation	Cover the sunshine, adjust humidity
Water	Necessity, too little or drown, it will die
Soil, Sunshine, food, oxygen	……

2.2 Remote Sensing Data and Environment parameters extraction

Landsat 8 and Sentinel 2 Remote Sensing data were acquired in this study, the detail information of Remote Sensing data and retrieved Remote Sensing environmental factors are listed in Table 2. The environmental factors related to snail biologic characteristics, for example, water distribution, soil, elevation, and vegetation, etc. are represented by distance from water, Tasseled-cap transformation wetness Index (TC_Wetness), Tasseled-cap transformation brightness Index (TC_Brightness), DEM, Normalize Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI).

Table 2 RS Data acquisition and Identify RS Environmental parameters

ID	*Acquisition time*	*Satellite*	*Spatial resolution/m*	*RS environmental factors*
1	2014-04-04	Lansat 8	30	• Vegetation: NDVI • Soil: TC_Brightness, TC_Wetness • Water distribution: NDWI • Distance to the water, etc.
2	2015-04-16	Lansat 8	30	
3	2016-04-18	Lansat 8	30	
4	2017-05-18	Sentinel 2	10/20/60	
5	2018-04-18	Sentinel 2	10/20/60	
6	----------	ASTER DEM	30	• Elevation

3 METHODOLOGY

3.1 Fuzzy theory

Fuzzy theory is a form of probabilistic logic, and it deals with complicated matter that is approximate rather than fixed and exact. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between 1 (completely true) and 0(completely false) by building membership functions (Zadeh L.1997; Leutner D, 2002).

The T-S fuzzy model is described by fuzzy IF-THEN rules which represent relations of a nonlinear problem. It is suitable for reducing the number of rules and can express the dynamics of each fuzzy implication (rule) by a linear model (Takagi and Sugeno 1985; Kukolj D. and Levi E. 2004). The T-S fuzzy model provide a better method to explore the relationship between snail density and remote sensing environmental factors by establishing suitable index membership functions, which described the quantitative suitability relationship between snail breeding and RS environmental parameters (distance from water, TC_Brightness, TC_Wetness, DEM, NDVI, etc), then a snail distribution monitoring model was built by only using remote sensing environmental parameters as input data. In this study, the T-S Fuzzy RS monitoring model of snail was improved by adjusting the environmental suitability index membership function to be applied to Landsat 8 and Sentinel 2 data.

3.2 Improved T-S Fuzzy RS monitoring model of snail

In the previous work, a T-S Fuzzy RS monitoring model of snail at Junshan, Dongting Lake has been developed by using relevant environmental factors retrieved from Lansat 5\7 RS data from 2003 to 2009. (Liu et al. 2012, 2015). Because the spectral band and spectral response function are different from Landsat8 and Sentinel 2, to guarantee the consistency of measurements and fully use the T-S Fuzzy RS monitoring model of snail in long-time series quantitative applications, a Spectral Band Adjustment Factor (SBAF) radiometric cross-calibration was carried out (Cibele et al. 2018). Although the radiometric cross-calibration has been done to compensate the Landsat 8 and Sentinel 2 reflectance to match the previous model, the coefficients was developed uniformity in tasseled-cap transformation based on Landsat TM, ETM+, OLI as well as other sensors, such as Sentinel 2 (Muhammad et al. 2014). So, in this study, half of snail field survey data from 2014 and 2015 were used to build the new suitable index membership functions of TC_Brightness and TC_Wetness, which were divided into testing data set and training data set, the RMSE will be improved until reach the accuracy requirement. Then the new quantitative suitable index membership functions of TC_Brightness and TC_Wetness were built to be applied to Landsat 8 and Sentinel 2 data, and the suitable index membership function of other RS environmental parameters, such as distance from water, DEM, NDVI use previous work results.

Some examples of membership functions of distance from water, NDVI, TC_Brightness, and DEM are showed as Fig. 1. The quantitative suitability relationship between snail breeding and RS environmental parameters as showed in Fig.1 are accord with the biological characteristics and Environment of snail as listed in Table 2.

The T-S remote sensing monitoring model of snail is as follows

The Fuzzy rules

$$\begin{aligned}&(1)\ \text{If}\,(w\ \text{is}\ \mu W1)\ \text{and}\,(v\ \text{is}\ \mu NDVI1)\ \text{and}\,(b\ \text{is}\ \mu B1)\text{and}\\&\quad(d\ \text{is}\ \mu D1)\ \text{and}\,(e\ \text{is}\ \mu E1)\ \text{then}\,(u\ \text{is}\ u1)\\&(2)\ \text{If}\,(w\ \text{is}\ \mu W2)\ \text{and}\,(v\ \text{is}\ \mu NDVI2)\ \text{and}\,(b\ \text{is}\ \mu B2)\ \text{and}\\&\quad(d\ \text{is}\ \mu D2)\ \text{and}\,(e\ \text{is}\ \mu E2)\ \text{then}\,(u\ \text{is}\ u2)\end{aligned}\tag{1}$$

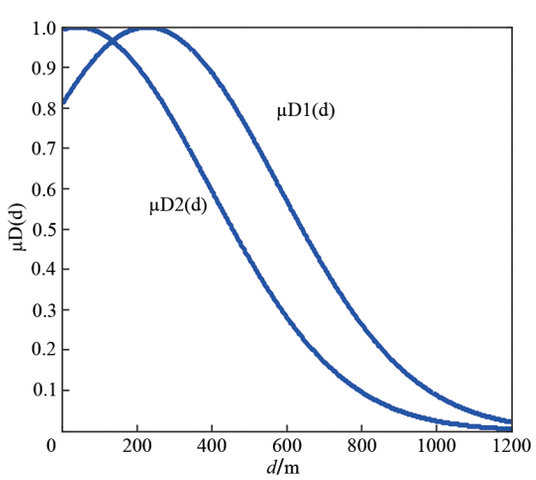
where $\mu W, \mu NDVI, \mu B, \mu D, \mu E$ are the suitable index membership functions of TC_Wetness, NDVI, TC_Brightness, distance from water, elevation, respectively.

$$\begin{aligned}u1 &= 30.76w - 4.193v + 1.174b + 0.0309d + \\&\quad 0.4223e - 14.77\\u2 &= -8.4w - 9.667v - 0.7263b + 0.1526d + \\&\quad 0.5436e + 1.767\end{aligned}\tag{2}$$

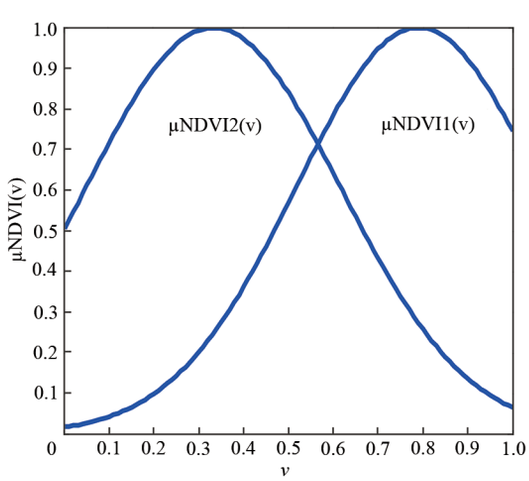
T-S Fuzzy model

$$u=\frac{\sum_{k=1}^{2}\left(\mu W_k(w)\wedge\mu NDVI_k(v)\wedge\mu B_k(b)\wedge\mu D_k(d)\wedge\mu E_k(e)\right)u_k}{\sum_{k=1}^{2}\left(\mu W_k(w)\wedge\mu NDVI_k(v)\wedge\mu B_k(b)\wedge\mu D_k(d)\wedge\mu E_k(e)\right)}\tag{3}$$

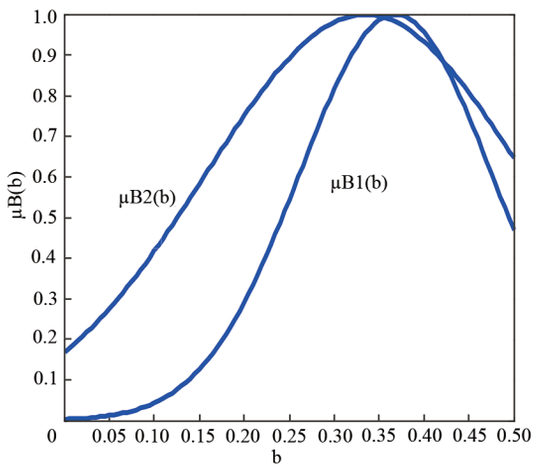
Then the T-S Fuzzy RS model of nail was improved by setting up new suitable index membership function of TC_Brightness and TC_Wetness, and the radiometric cross-calibration has been done to compensate the Landsat 8 and Sentinel 2 reflectance to match the previous model.



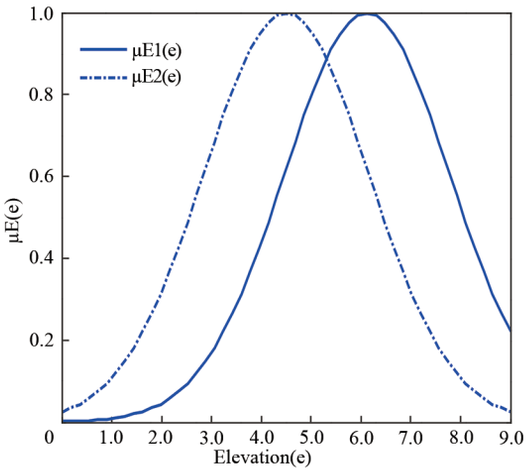
(a) Distance from water



(b) NDVI



(c) TC Brightness



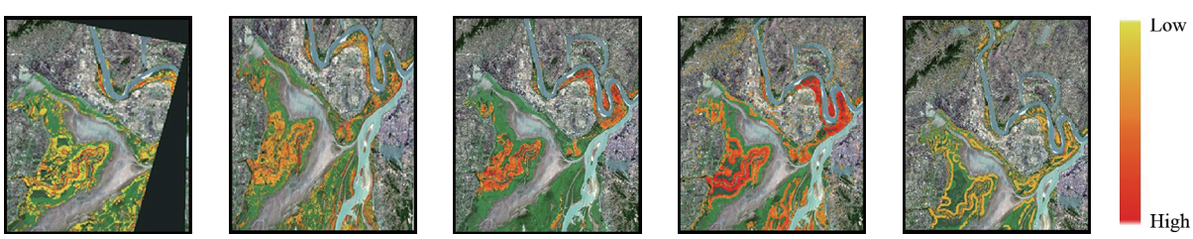
(d) Elevation

Fig.1 Suitable index membership functions of environmental factors extracted from RS data

4 APPLICATION AND VALIDATION

4.1 2014—2018 monitoring results of snail spatial distribution

Taking the RS environmental parameters (distance from water, TC_Brightness, TC_Wetness, NDVI) retrieved from Landsat8 and Sentinel 2 as input data, the improved T-S Fuzzy RS monitoring model of snail was applied to predict the snail spatial distribution in Dongting Lake from 2014 to 2018. The results are shown in Fig. 2, where the base map is Sentinel 2 true-color RGB image (band 4/3/2), the yellow to red areas are the model predict results of snail spatial distribution, and the color of yellow to red describes the density of snail is from low to high.



(a) 2014 (b) 2015 (c) 2016 (d) 2017 (e) 2018

Fig.2 Monitoring results of snail spatial distribution and density by only using environmental factors retrieved from Landsat 8 and Sentinel 2 data

4.2 Validate the monitoring results with survey data

A comparative analysis had been performed to validate the predicted results of 2014 and 2015 to against the field survey data (half field survey data weren't used in building new suitable index membership functions of TC_Brightness and TC_Wetness), as showed in Fig.3, where the red circle is wrong to predict sites, and the blue circle is right to predict sites. The statistical accuracy of predict snail distribution is shown in Table.3. The accuracy of 2014 and 2015 is 81% and 86% respectively. The validation results are quite good to demonstrate the accuracy of the improved model in monitoring the distribution of snails by Landsat8 and Sentinel 2 RS data. The T-S Fuzzy RS monitoring model of snail used in this study has a great potential for long time series regional and national monitoring of snail distribution by future sensors and new RS data.

(a) 2014 (b) 2015

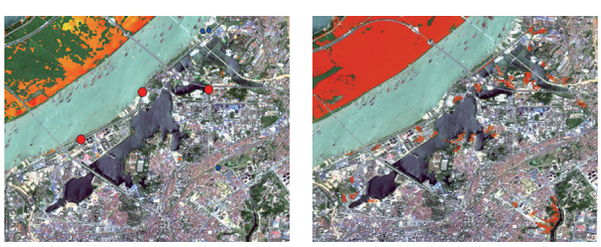
Fig.3 The monitoring results with survey data(red circle: wrong predict site, blue circle: right predict site)

Table.3 Accuracy of monitoring snail distribution

	Number of Survey	*Right Predict*	*Accuracy/%*
2014	22	18	81
2015	108	93	86

5 CONCLUSION AND DISCUSSION

The T-S Fuzzy RS model of nail was improved by establishing new suitable index membership functions of TC_Brightness and TC_Wetness to be applied to Landsat 8 and Sentinel 2 data and achieved a long time series monitoring of snail distribution in Dongting Lake from 2014 to 2018. The successful applications of improved model in 2014 and 2015 were validated by field survey data. Although the biological characteristics and environment of snail were considered as much as possible in this study, there are still many factors that are not taken into account. For examples, drug molluscicide for snail control, environmental changes in succession, and the effects of floods, these factors could lead to the incorrect monitoring results. In the future, medication for snail control, new RS data and environment factors such as Sentinel 1 soil moisture, EAT (Effective Accumulated Temperature), Vegetation classification data, etc. and combing the monitoring results from different years will be studied to further improve the T-S Fuzzy RS model of nail. Although the field survey data between 2016 to 2018 are not opened now, the validation results are quite good to demonstrate the accuracy of the improved model in monitoring the distribution of snails and show great potential in long time series regional and national monitoring of snail distribution by using increasing new RS data. Fig.4 displays the comparison of Yueyang urban area monitoring results between Landsat 8 (2015) and sentinel 2 (2017). Although the field survey data of 2017 is not opened, but based on field survey information from National Institute of Parasitic Diseases, Chinese Center for Disease Control and Prevention, Yueyang urban area near river or lake are snail breeding area for many years. The Landsat 8 (2015) monitoring result shows that there isn't a snail breeding area, but Sentinel 2 can succeed monitor perhaps because of its high spatial resolution. Further validations are therefore necessary, and the cross-comparison between Landsat8 and Sentinel 2 RS data also will be studied in the next work.



(a) Landsat 8(2015) (b) Sentinel 2(2017)

Fig.4 Yueyang urban area monitoring results from Landsat8 (2015) and Sentinel2 (2017)

The objective of our research tries to build an RS monitoring model of snail, which can be applied in different places, different time series and different RS data, with the inputs are only extracted from RS data. When the T-S Fuzzy RS monitoring model of snail built from Dongting Lake was applied in other places, such as Xinmin beach, Gaoyou Lake, the model was improved by only establishing a new suitable index membership functions of elevation, because the different terrain between Dongting Lake and Gaoyou Lake. And when the model was applied in different RS data, such as Landsat 8 and Sentinel 2 data in this study, the model was improved by establishing new suitable index membership function of TC_Brightness and TC_Wetness, and only radiometric cross-calibration need to be done to compensate the new RS data to match the previous model. The reason why the model is so adaptable is that it describes the quantitative suitability relationship between biologic characteristics of snail and RS environmental parameters. Base on the analysis of the environment and biological characteristics of nails, the RS data acquisition time and RS environmental parameters were identified. Then T-S Fuzzy theory was used to build the RS monitoring model of snail, and its quantitative suitability relationships of RS environmental parameters are accord with the biologic characteristics of snail. Furthermore, the input data of the T-S Fuzzy RS monitoring model with no need for other field data or geographic information only comes from RS data. So we can get the distribution of sail only if we can get the RS data. It is easy to use in practical application and especially suitable for emergency and disaster situations. Further validation and studies are therefore necessary to new propagation regions of schistosomiasis, e. g., mountain snail habitat, to ensure the reliability of the T-S Fuzzy RS monitoring model of snail distribution used in this study. And it will go on to carry out a long time series (1985—2020) monitoring of snail distribution in Dongting Lake by combining Landsat5/7/8, CBERS02B, Sentinel l/2, MODIS, and other RS data, to further improve the model, and cross-comparison and uncertainty analysis of multi-source RS retrievals.

Besides, at present, the main methods of snail control are drug molluscicide and environmental hardening, which adverse to health and damage the environment. From the work of T-S Fuzzy RS monitoring model of snail, it is easy to think about whether snails can be eliminated if only a little environment factor is changed to make it unsuitable for the survival of snails, without destroying the environment. The relevant ground environment modification experiments are being carried out, and the RS data are used to monitoring the change of environment, to find an effective way to realize the natural extinction of snail after several years of minimal environment changes. Obviously, comparing with the traditional medication control and environmental hardening method, the new environment modification method can minimize negative impacts on environment and adverse side-effects on public health from the excessive use of chemicals in vector control, both benefits to human health and environment, and not easy to break out again and improves the actual prevention and control effect. RS technology is not only a means of monitoring, but also can play an important role in snail control practice.

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