Scientific Research Publishing

Open Journal of Applied Sciences, 2022, 12, 614-630
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Overview of Grassland Degradation Research Based on Remote Sensing Monitoring

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How to cite this paper: Zheng, L.P., Zhao, L.J., Xiao, B., Tan, L., Zheng, F.L. and Like, A.S.M. (2022) Overview of Grassland Degradation Research Based on Remote Sensing Monitoring. *Open Journal of Applied Sciences*, **12**, 614-630.
https://doi.org/10.4236/ojapps.2022.124042

Received: March 22, 2022
Accepted: April 26, 2022
Published: April 29, 2022

Abstract

In recent years, grassland degradation has become one of the most important ecological problems in China under the interwoven influence of environmental and human factors. Based on the analysis of the spatial-temporal characteristics and driving factors of grassland degradation and in order to deeply understand the research status of grassland degradation monitoring methods and evaluation index system, this paper mainly investigates the research progress of grassland degradation remote sensing monitoring methods and evaluation indicators. Furthermore, this paper summarizes the more commonly used remote sensing monitoring methods and evaluation methods, analyzes the problems existing in the evaluation indicators of grassland degradation, and points out the research direction of the evaluation indicators in the future. Finally, a comprehensive remote sensing monitoring and evaluation system are established in this paper. Research findings: because of the variety of grassland degradation types and the emergence of remote sensing monitoring and evaluation methods, establishing a comprehensive remote sensing monitoring and evaluation system to classify and summarize the research methods of different grassland degradation can lay a foundation for the development of grassland degradation evaluation and monitoring in the future and provide research ideas. It is the trend of grassland degradation remote sensing research in the future.

Keywords

Grassland Degradation, Remote Sensing Monitoring, Remote Sensing Evaluation Index

1. Introduction

Vegetation is the most important type of cover on the surface and a core com-

ponent of the entire terrestrial ecosystem [1]. Vegetation not only plays a key role in the biosphere, atmosphere, and world carbon cycle, but also is an important link to natural elements such as soil, water, and energy [2]. The grassland vegetation here is the largest renewable resource in the world's terrestrial ecosystem [3]. It has an extremely important ecological role and economic value [4]. In ecological construction, grassland vegetation has a great impact on cultivating soil fertility such as farmland, preventing and controlling groundwater soil loss, and maintaining the balance of the terrestrial ecosystem. In the agricultural economy, grassland vegetation can also feed herbivores and make food, medicinal and industrial raw materials for people, and so on [1].

However, the ecosystem habitat of grassland is very fragile and susceptible to disturbance from the outside environment, which leads to grassland degradation [5]. Grassland degradation refers to the phenomenal process of reduced grassland productivity and deterioration of the natural environment due to unreasonable management, excessive use, and poor ecological and geological conditions [6]. Its specific manifestations are that the quality of grassland (vegetation, soil, etc.) decreases, the grassland grass-producing capacity, economic potential, and service function decreases, the environment deteriorates, the ecological diversity or complexity decreases, and the soil remediation function weakens or loses its remediation ability [7].

In the traditional study of grassland degradation monitoring by remote sensing, the degree of grassland degradation is evaluated only based on the results of temporal and spatial changes of grassland degradation monitoring combined with simple and general grading indexes, and only the important factors affecting grassland degradation are studied. With the further development of ground remote sensing technology and the deepening of all aspects of grassland degradation research in academia, more index factors reflecting different study area characteristics can be added to the evaluation index system of grassland degradation, which will also provide a more powerful scientific and technical support for grassland degradation monitoring and impact research. However, in the above research results, there is no systematic collation and summary because there are many starting points and research methods. Therefore, this paper mainly summarizes the current research progress of grassland degradation from two aspects, including remote sensing monitoring methods and evaluation methods of grassland degradation, and also points out the direction for future monitoring of grassland degradation remote sensing technology in China.

To further elaborate the relevant content, so that readers can have a more comprehensive understanding of its research field. The article is divided into six parts. Part 2 is the status of the grassland degradation. It mainly summarizes the starting point and progress of grassland degradation research by most scholars in remote sensing monitoring and evaluation index. Part 3 is a summary of methods for monitoring and evaluating grassland degradation by remote sensing. Part 4 is the problems and future development of grassland degradation evaluation index. Part 5: Establishment of a system for remote sensing monitoring and

evaluation of grassland degradation. The last part is the conclusion and outlook of the review.

2. Research Status of Remote Sensing Monitoring and Evaluation Index for Grassland Degradation

Scholars at home and abroad have done a lot of research on grassland degradation remote sensing monitoring and evaluation index.

In the research and development of grassland degradation detection methods, the traditional method of collecting grassland degradation data by manual or on-site is more accurate and accurate in a small area, but it would be time-consuming and inefficient to popularize in a larger area [8]. Later, with the gradual development of remote sensing technology, its advantages also quickly emerged. With the wide coverage, short time period and low cost of remote sensing technology, more reasonable monitoring methods can be proposed in the study of grassland degradation [9]. However, in practical application, remote sensing technology is not perfect, not all grassland degradation indicators can be obtained by using remote sensing technology [10]. So the combination of traditional on-the-spot investigation and rapidly developing RS, GIS and GPS technologies are the most efficient monitoring method at present [11] [12]. In this kind of grassland degradation monitoring method, most of them use ordinary remote sensing satellites to monitor grassland degradation in areas where no weeds or poisons invade based on vegetation coverage, aboveground biomass, forage edibility and aboveground biomass [13] [14] [15] [16]. However, many researchers have found that weeds invade during grassland degradation, which often results in increased vegetation coverage. Consequently, traditional remote sensing monitoring methods for grassland degradation based on the decline of total vegetation coverage, productivity and grass yield cannot reflect the change characteristics of grassland degradation in vegetation population [17] [18] [19] [20] [21]. So many researchers use hyperspectral data-based methods to monitor grassland degradation weed invasion, combining ground spectral measurements with quantitative analysis of weak spectral differences in species characteristics of degraded grasslands. It can effectively identify weed species in the community, and invert the proportion of area, height and coverage of the community. It can provide important indicators of the community succession process and situation for grassland degradation monitoring and control [22] [23] [24].

In the remote sensing evaluation index of the grassland degradation process, most of the previous studies used the change detection method based on the vegetation index [25] [26]. Based on the vegetation coverage data VFC (Vegetation Fractional Cover) (0<VFC<=1) in the study area, Wei *et al.*[27] summarized the existing research results, and based on the characteristics of the actual grassland types in the study area, realized classification of grassland. First grade grassland: VFC > 0.6; Secondary grassland: 0.3 < VFC ≤ 0.6; Level 3 grassland: 0 < VFC ≤ 0.3. With the deepening of grassland degradation research, more and more

scholars use a combination of monitoring indicators in their actual research. Based on the Grading Indicators of Natural Grassland Degradation, Desertification and Salinization (GB 197377-2003), most researchers extract the corresponding grassland degradation indices from various signals such as land-use change maps and land-use type transfer matrix maps in a certain area [28] [29] [30] [31]. Xu [10], based on the degradation classification of the national standard and the measured status of the study area, selected several relatively important indicators such as vegetation coverage, height, edible rate, biomass and soil organic matter to construct the evaluation index of grassland vegetation degradation in the study area.

According to the characteristics of the study area, for example, according to the construction theories and principles of different regions, many scholars take other things with specific measurement significance as the main evaluation indicators of grassland degradation [32]. For example, Tong *et al.* [33] used biomass, vegetation coverage and the rate of decline of vegetation height, grassland erosion, and repair time as evaluation indicators for the degradation of grasslands on the ground in the study area. On this basis, a grassland degradation index and an area-weighted grassland degradation index are given to evaluate the degree of grassland degradation on the target sample plot and scale in the study area.

In summary, there are many starting points for the study of remote sensing monitoring and evaluation index of grassland degradation, so there are a large number of evaluation methods available. Therefore, there is a lack of a holistic summary and summary, and a perfect system is established to classify and summarize their different research entry points and evaluation methods into the system on demand.

3. Summary of Remote Sensing Monitoring and Evaluation Method for Grassland Degradation

The method of monitoring the spatial and temporal changes of grassland degradation by remote sensing combined with a corresponding evaluation index of grassland degradation can analyze and study the specific changes of grassland degradation more accurately and completely, and provide accurate data support for grassland resource prevention and control, and the driving force of grassland degradation.

1) Remote Sensing Monitoring Method for Grassland Degradation

Based on field surveys, although grassland degradation indicators can have relatively high accuracy in a small range, they cannot be evaluated on a large scale, and field survey is time-consuming and of low quality [34] [35]. The advantages of remote sensing technology are that the image data covers a wide area, has a very short time period, and has a low cost. Therefore, the application of remote sensing technology provides a more reasonable research method for grassland degradation monitoring [36].

Coverage [13], height, aboveground biomass [14], grass yield, and net primary

productivity [15] are often used as monitoring indicators in remote sensing monitoring of grassland degradation. In the actual study, many scholars used multiple indicators to conduct a comprehensive analysis [16] [37]. Its monitoring methods can be divided into regression model method, machine learning method, subpixel decomposition method, visual comprehensive interpretation method, and based on physiological and ecological process methods [32]. Their respective characteristics are as follows:

a) Visual comprehensive interpretation method

It takes the coverage as the grassland degradation index. The advantage is that when the interpreter understands the research area, the interpretation accuracy is high. The disadvantage is that when the research area is large, the amount of work on this method is large and the time period is long [38] [39] [40].

b) Regression model method

It takes coverage, biomass, grassland height, edible rate of forage, soil water content and net primary productivity as grassland degradation index. The advantage is that the regression model has high accuracy when the scope of the study area is small. Corresponding to the disadvantages, with the increasing area of the detection area, its accuracy will gradually decline. At the same time, a hard defect of the regression model is its poor portability, which can't meet the popularization application [15] [41] [42] [43].

c) Subpixel decomposition method

It takes the coverage as the grassland degradation index. Its advantage is that the model is relatively mature, intuitive and easy to use. The main defect is that the research results are easily saturated by NDVI, so it is not suitable for the research area with too many pure pixel values [44] [45].

d) Machine learning method

It takes vegetation coverage, ground biomass, soil organic matter content, nutrients and water content as important indicators to evaluate grassland degradation. The advantage is that compared with the traditional regression model, it has a certain improvement in accuracy. The disadvantage is that the determination of parameters and the selection of appropriate training samples have a certain impact on the accuracy of the prediction model [46] [47].

e) Based on physiological and ecological process method

It takes the net primary productivity as the grassland degradation index. Its advantage is that the models are diverse and mature. The disadvantage is that the model parameters are complex and diverse [48] [49].

In general, in a small study area, to obtain an accurate degree of degradation, the visual comprehensive interpretation method and the regression model method can be used. When analyzing some study areas with sparse vegetation, the sub-pixel decomposition method has better results. In the case of an in-depth understanding of various vegetation growth characteristics in the study area and a variety of vegetation data in the study area, the method based on physiological and ecological processes can more accurately reflect the grassland degradation status. At present, with the continuous maturity of machine learning technolo-

gies, their application scope has gradually penetrated into various research fields. In grassland degradation research, the frequency of use of machine learning is gradually increasing. As long as there are good training samples, it is possible to quickly derive the degradation of grassland.

2) Grassland grading evaluation index system

Generally, the process of forming sandy land, Gobi, semi bare land, bare land, bare rock and swamp after the decline of vegetation coverage is also defined as grassland degradation [50]. According to the summary of many documents, according to the summary of many papers, the classification methods of grassland degradation in China can be divided into four kinds [32], referring to the national standard method, expert consultation method, cluster analysis method and local experience method.

a) Refer to national standard law

According to the requirements of the national standard law, the Grading Indicators of Natural Grassland Degradation, Desertification and Salinization (GB 197377-2003), if more than 50% of the project indexes in the necessary monitoring project index set exceed the relative specific value range, the grassland is said to be degraded grassland [51]. In practice, it is difficult to fully use the index of more than 50% of the monitoring value to evaluate grassland degradation. Therefore, in the current general grassland degradation research and investigation, most of them use the simplified index of a single index or multiple index parameters. Among them, vegetation coverage is the most important index [4] [52], followed by net primary production [53] and biomass [46]. Some researchers adjust the relevant classification levels in the national standards and modify the corresponding data threshold to adapt to the current regional characteristics of the study area, so as to make a more accurate evaluation of grassland degradation in the study area [5] [54].

b) Expert consultation method

The expert consultation method is to formulate the corresponding grassland degradation evaluation index, grading standard and so on [55].

c) Cluster analysis

Cluster analysis is the clustering of similar characteristics in vegetation and soil indicators to derive different degrees of grassland degradation and grading results from soil indicators [56] [57]. Tong *et al.* [33] assessed the degradation of ground grasslands using correlated change ratios (including biomass, coverage, and height), the severity of soil erosion impact, and repair time as important indicators. On this basis, an index and an area-weighted index for assessing the extent of grassland decline on the monitoring site and scale are given.

d) Local Empirical Method

The local empirical method is based on the main characteristics of the study area and gives more reasonable evaluation indexes and standards accordingly. The main features are the characteristics of the ecological environment system and grassland type in the study area. Li [58], on the basis of understanding the characteristics of the Natural Mowing grazing system in the study area, devel-

oped a reasonable degradation system and classification criteria for the study area through the local experience method. Jiang *et al.* [59] gave a new grading standard for the study area based on the characteristics of the grassland degradation mechanism of black soil type alpine meadow. Wang *et al.* [60] studied the sensitivity of various degradation indicators, including vegetation richness, diversity, and spatial heterogeneity, in the case of overgrazing.

The above classification methods are not independent of each other, nor are they absolutely binding. There are various types of grassland degradation in different study areas. Therefore, in the research on methods for evaluating grassland degradation, there is a situation of "one area, one standard", that is, the above classification methods are improved or cross-referenced. Make it more in line with the actual situation of the study area.

4. Problems and Future Development of Evaluation Indicators for Grassland Degradation

In the study on the evaluation index of grassland degradation, most researchers describe and evaluate the grading from grassland yield, grassland biomass, grassland productivity, and grassland degradation index [1] [6] [14] [33]. Regardless of any of the above methods for grading grassland degradation, remote sensing vegetation coverage indices are used directly or indirectly. The remote sensing vegetation index is often used to calculate vegetation coverage and is also an important parameter in the inversion calculation of grassland biomass. Therefore, the remote sensing vegetation index can be used directly as a remote sensing classification index of grassland degradation to a certain extent [27].

However, timeliness and regionality are the main drawbacks of the remote sensing vegetation index. Because the growth of vegetation is influenced by the natural ecological environment and atmospheric conditions, seasonal factors and geographical characteristics will directly affect the accuracy of the entire grassland degradation study.

1) Timeliness of vegetation index

The timeliness of the vegetation index means that the growth status of grassland vegetation is very different in different seasons. When using vegetation coverage for remote sensing monitoring of grassland degradation, some researchers, such as Li *et al.* [61], used the grassland data from the start year as the initial value, *i.e.*, the grassland was non-degraded. Some researchers, such as Gao [55] and Ma [62], selected the annual data of maximum vegetation cover (or maximum biomass) as the status of grassland non-degradation during the study period. Other researchers, such as Mao [63], chose to extend the study period to obtain a more accurate analysis. After removing the years of maximum vegetation cover (or biomass) from the study period, they selected the years of higher vegetation cover (or biomass) for the rest of the study period and used the sliding average method to calculate the reference values for non-degraded grasslands. There is a critical problem in the above research scheme. When using grassland conditions with high vegetation coverage as the basis for declining

grasslands, it is easy to overestimate the degradation of grasslands. However, if the grassland condition in the beginning year of the study period of deteriorated grassland is the baseline of non-deteriorated grassland, it is easy to underestimate the degradation of grassland. Therefore, different criteria will directly affect the accuracy of the results.

2) Regionality of vegetation index

When measuring vegetation coverage in different study areas, different vegetation indices should be used. Otherwise, the calculated vegetation coverage deviation will be large. For example, Yang *et al.* [4], through studying the linear and non-linear relationship between different vegetation indices and vegetation coverage, and then comparing different grassland types in the study area, the best vegetation index and model for the study area are obtained. The results of experiments by Yang *et al.* [4] show that NDVI and RVI vegetation indices are not suitable for the study area of land cover, similar to the area where desertification started. Compared with the two vegetation indices, SAVI, MSAVI and GNDVI are the best choices. Therefore, in the study of grassland degradation monitoring, it is necessary to correctly identify the type of grassland resource cover, and then select the optimal vegetation index to calculate.

3) Future research direction of evaluation index

Because the types of grassland degradation are diverse, the actual situation of grassland degradation and the selection of indicators are different in each region, and it is difficult to unify the grading standards of grassland degradation [32]. However, any simple remote sensing analysis index has some limitations [61]. In the future, more attention should be paid to comprehensive data analysis and evaluation index systems for remote sensing monitoring and evaluation of grassland degradation. Some researchers have started to do meaningful research work. For example, when Luo *et al.* [57] evaluated the grassland degradation in the study area, they used a variety of different methods (including spatial overlay method, comprehensive data weighting method, sample points and NDVI related model method, etc.) to analyze the study area in an all-round way, and then, according to the standards and grading norms of Grassland Classification [64], Grading Indicators of Natural Grassland Degradation, Sandification and Salinization [51] and Technical Regulations for Remote Sensing Monitoring of Grassland Rocky Desertification in Karst Areas [65], the grassland degradation status in the study area was evaluated.

5. Establishment of Remote Sensing Monitoring and Evaluation Method System for Grassland Degradation

Since the actual status of grassland degradation in different regions is not the same, it is found in many literatures that scholars have used an endless stream of methods when studying such problems, so the accuracy of the conclusions drawn also varies from person to person [66] [67] [68] [69]. Therefore, this paper establishes the following relatively complete remote sensing monitoring and evaluation system, which is used to summarize the research methods under dif-

ferent grassland degradation conditions, and provide ideas for future research on grassland degradation in other regions.

As for the natural grassland, it can be divided into the following three types according to the differences in natural conditions and production benefits: 1) the northwest temperate grassland area, located in the area north of the 400 mm rain band. The natural grassland land area accounts for about 41% of the total grassland land area in my country. The natural grassland is concentrated and contiguous, with a high grass yield and high utilization efficiency. It is the most important grassland and animal husbandry production area in my country. At the same time, the northwest region of my country is also the region with the most prominent sandstorm hazards and desertification problems in China, and its palatable vegetation is gradually decreasing; 2) Qinghai-Tibet Alpine In the grassland area, the natural grassland area accounts for about 38% of the total grassland area in my country. The natural grassland has poor water and heat conditions, low output efficiency, and a lack of mowing and cold season grazing grassland. Due to the reduction of vegetation caused by the influence of global warming and human development in recent years, the pest and rodent damage has increased; 3) The secondary grassland areas in southern and eastern China are mainly secondary grasslands formed after deforestation; the land area accounts for about 21% of the total grassland area in my country, but the grassland distribution is sporadic, mostly in areas where agriculture and forestry are interspersed. The grassy slopes of massive grassy hills have a higher grass yield, but their grass quality is poor. The main form of grassland degradation is the change of vegetation community, and the grassland degradation indicator plants gradually increase.

Therefore, according to the geographical characteristics, climatic environment, human factors and grassland characteristics of different regions, it can be concluded that grassland degradation generally has the following different characteristics, as shown in **Table 1**.

In the previous section, we summarized and analyzed the advantages and disadvantages of each remote sensing monitoring index, and also introduced four commonly used evaluation methods. Here, combined with the different grassland degradation types in **Table 1**, a complete grassland degradation monitoring and evaluation index system is established, which is suitable for the study of different types of grassland degradation status, as shown in **Figure 1**.

In the process of establishing this system, first, it is necessary to understand the general situation of the study area, for example, to judge the size of the study area, the type of grassland degradation in the study area, and the current grassland vegetation coverage in the study area.

Secondly, according to the acquired grassland degradation characteristics and data in the study area, correspondingly select the monitoring method for its adaptation. For example, the sub-pixel decomposition method is suitable for monitoring areas with sparse grassland vegetation and mostly bare surfaces.

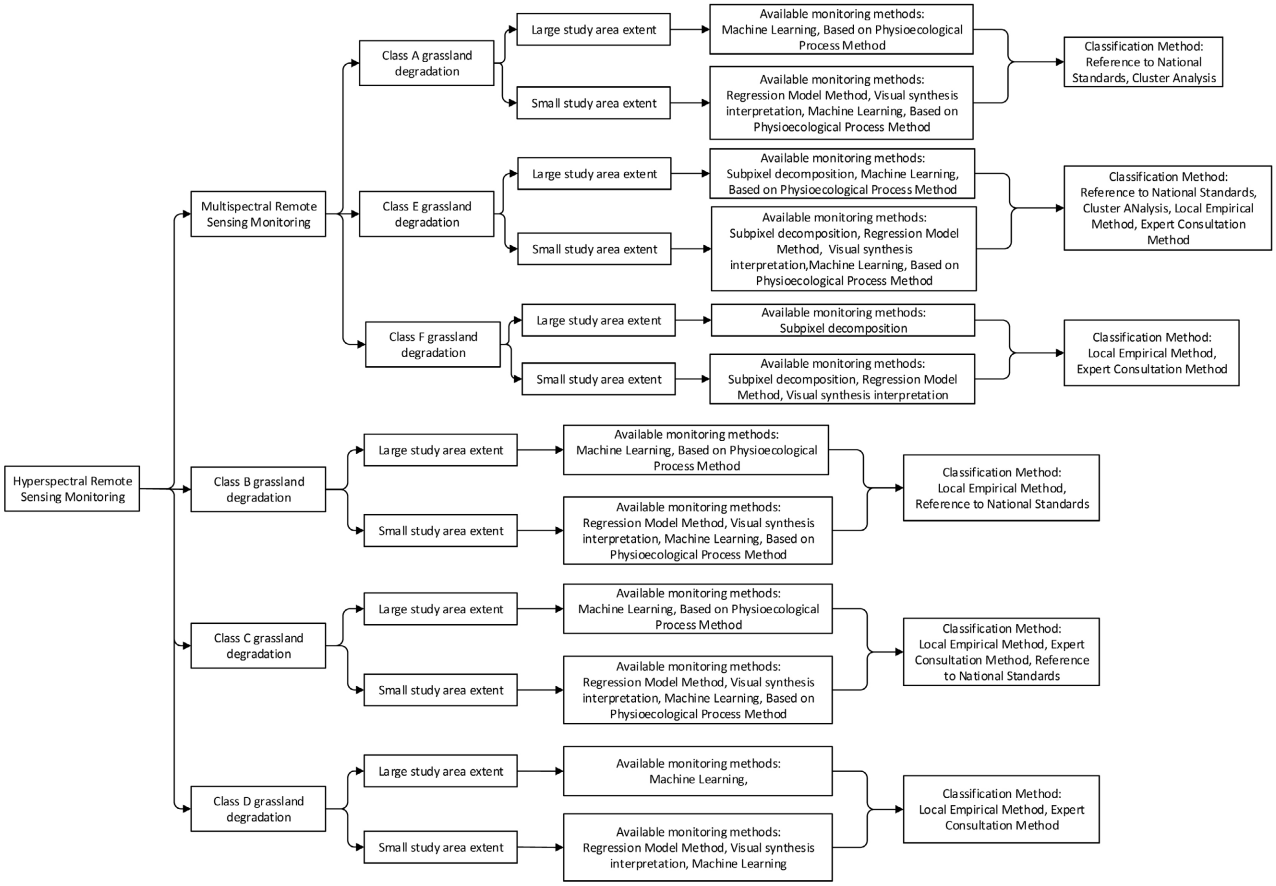

Figure 1. Remote sensing monitoring and evaluation index system establishment.

Table 1. Classification of grassland degradation.

Classification number	Content
A	Grass vegetation types are reduced, height becomes lower, vegetation cover is reduced, and the construct is simple.
B	The growth or development of the dominant plants in the grass is gradually debilitating, declining in number or yield, and gradually regressing or even disappearing.
C	Relatively well adapted, palatable vegetation declined, and virulent grass plants gradually increased and invaded.
D	An increase in the number of plants marking grass degeneration.
E	The deterioration of the natural environmental situation of grasses, which is characterized by severe surface saline alkalinization, aggravated wind (water) etching, an increase in the amount of soil surface gravel, and an increase in the compactness of the surface soils.
F	Detritivores such as ground rat pests increase, whereas their counterparts decrease. Scattered distribution of vegetation.

Corresponding to the grassland degradation type table, the sub-pixel decomposition rule is applicable to E and F grassland degradation.

Finally, when choosing an evaluation method, consider not only the general conditions of the study area, but also the unique characteristics of the study area. Therefore, in this system, only the main categories of evaluation methods are given. In the specific experimental process, researchers need to adjust and supplement the corresponding evaluation methods in combination with the characteristics of the study area. At the same time, it can also be used as a reference in combination with a variety of adaptive evaluation methods.

As can be seen from the above figure, when the grassland degradation status in the study area is different, the corresponding remote sensing monitoring and evaluation methods are also different.

For example, when the study area belongs to C-type meadow degradation, that is, when vegetation types with strong adaptability but poor palatability and inedible, poisonous and harmful vegetation types gradually expand and invade, ordinary multispectral remote sensing is used. Monitoring greatly reduces the accuracy of the results, because the vegetation coverage in the study area may remain stable during such grassland degradation processes, and multispectral remote sensing cannot identify the coverage of effective vegetation types, which makes research the result is meaningless.

For another example, when selecting the remote sensing monitoring method, if the survey target area is in the E-type grassland degradation situation, that is, the natural environmental conditions of the grassland deteriorate, the wind erosion, water erosion, salinization, and sandstorms increase significantly, the amount of surface sand and gravel increases, or the surface soil is compacted. When the intensity is enhanced, the sub-pixel decomposition method can be preferentially selected, because this kind of grassland degradation will not cause NDVI easy saturation and pure pixel value selection. It is simple, and can greatly enhance the accuracy of the research results. If the B or C grassland is degraded, the sub-pixel decomposition method cannot be used, because the grassland vegetation is rich and the NDVI is easily saturated.

Finally, the selection of evaluation indicators should also be determined according to the specific conditions of the study area. If the study area belongs to the F-type grassland degradation state, that is, grassland rats, insect pests and other harmful organisms increase, while the corresponding number of predators decreases. When the national standard method was used to assess the degradation status of the study area, it was out of character, and the results were not accurate. However, the regional local empirical method was used to evaluate the main ecosystem and grassland characteristics in the study area. The most reasonable evaluation indexes and standards of grassland degradation in the study area can be given, which are more suitable for the actual situation of the study area.

6. Conclusions and Outlook

1) Remote Sensing Monitoring Method of Grassland Degradation.

Among them, the regression model method is the most widely used. However, when the study area is wide, the model accuracy will drop significantly, Regression models are less portable. Compared with regression models, machine learning methods can achieve better accuracy and portability but require a certain number of training samples, and the quality of the samples also determines the accuracy of the experimental results. In the absence of actual data, the inversion of vegetation coverage by sub-pixel analysis can make up for the lack of measured data. In order to further improve the accuracy of remote sensing image observation and improve the spatial heterogeneity in different research fields, it is the main direction of future development. At the same time, the accurate remote sensing monitoring of grassland degradation indicators and the potential exploration of remote sensing science and technology rely on actual data analysis, and the verification of remote sensing monitoring results is based on field monitoring data analysis. Therefore, the combination of grassland degradation remote sensing monitoring application and field monitoring real-time data is an important cornerstone of future scientific research.

2) Selection and Evaluation Criteria of Grassland Degradation Indicators.

In the grassland degradation evaluation index system, most of the researchers expounded and classified the classification research of grassland degradation from the aspects of grassland biomass, grassland biomass, grassland productivity and grassland degradation index. Through the above methods, remote sensing vegetation indices can be applied directly or indirectly. The remote sensing vegetation index is often used in the calculation of vegetation coverage, and is also used as an important parameter in the calculation of grassland biomass inversion, so the remote sensing vegetation index can be directly used as a remote sensing classification index of grassland degradation to a certain extent. The hard disadvantage of the remote sensing vegetation index is that it has obvious timeliness and regionality, which will greatly reduce the accuracy of the evaluation index. Therefore, in the future remote sensing monitoring and evaluation of grassland degradation, a comprehensive analysis should be emphasized, and a hierarchical index system should be established to discuss and analyze different regions and seasons.

3) Establishment of Remote Sensing Monitoring and Evaluation Method System for Grassland Degradation.

Due to the diversity of grassland degradation types, the selection of indicators for remote sensing monitoring and evaluation of grassland degradation, and the emergence of remote sensing monitoring and evaluation methods, a comprehensive remote sensing monitoring and evaluation system have been established to classify and evaluate different grassland degradation research methods. In reference, it lays a foundation and research ideas for the development of remote sensing evaluation and monitoring in the future.

Acknowledgements

This paper is sponsored by the Project of Engineering Consulting Center of Xin-

jiang Academy of Animal Science (XJXMKXY_2021), entitled "Development of an intelligent management platform for grassland resources".

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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