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Predictive Modeling of Pre-Weathered Chemical Content in Glass Artifacts

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ABSTRACT

With the continuous development of cultural heritage protection technology, the study of weathering of cultural relics has become an important topic. In particular, glass products are easily affected by weathering due to the high reactivity of their components, resulting in changes in chemical composition. This paper proposes a prediction model for the chemical composition of glass products before weathering based on weathering rate. By statistically analyzing the chemical composition data of different types of glass cultural relics and combining the relationship between the chemical composition after weathering and the weathering rate, a prediction method for the chemical composition before weathering was established. This model can effectively handle missing and outliers in cultural relic data, and provide a scientific basis for cultural relic restoration by inferring the chemical composition before weathering. The results show that this method not only improves the prediction accuracy, but also provides a reliable tool for future cultural relic protection research. By combining data science and chemical analysis technology, the prediction and restoration of cultural relic weathering can be supported more accurately and systematically.

KEYWORDS

Glass Cultural Relics; Chemical Composition Before Weathering; Weathering Rate; Data Analysis; Prediction Model

1 Introduction

The protection and restoration of cultural heritage is one of the important areas of continuous development of modern science and technology, among which the study of weathering of cultural relics plays a vital role. Cultural relics, especially glass products, often face the dual threats of natural weathering and human damage, which leads to changes in their chemical composition, thus affecting the preservation of their historical information [1]. The weathering problem of glass cultural relics is particularly prominent, because the composition structure of glass is highly reactive, especially when exposed to air and moisture for a long time, the surface of glass is prone to weathering, resulting in changes in chemical composition, which in turn affects the appearance and structural stability of cultural relics. Therefore, predicting the chemical composition of glass cultural relics before weathering and accurately estimating their state before weathering are of great practical significance for cultural relic protection.

This paper aims to establish a prediction model for the chemical composition of glass products before weathering. The model derives the ratio of cultural relics before and after weathering (i.e., weathering rate) by analyzing the chemical composition of cultural relics and applying statistical laws, and predicts the chemical composition content before weathering [2]. By analyzing the chemical composition data of different types of glass cultural relics, this study attempts to accurately simulate and estimate the material content before weathering through numerical methods, thereby providing a scientific basis for the restoration and protection of cultural relics. In addition, this study also involves how to deal with missing data and outliers, and how to convert character-type discrete data into numerical continuous data, providing data support for the establishment of subsequent models.

The prediction of chemical composition before weathering not only helps to gain a deeper understanding of the original state of cultural relics, but also provides a powerful tool for the study of weathering mechanisms. Through this method, conservation workers can more accurately restore the historical appearance of cultural relics and provide more accurate data support for future restoration and protection work. Due to the different types and weathering degrees of cultural relics, it is particularly important to establish a universal and accurate prediction model, especially for complex chemical composition changes [3]. How to extract key variables and make reasonable inferences has become a major challenge in this study.

With the continuous advancement of cultural relic protection technology, combined with modern statistics, data science and chemical analysis methods, the accuracy of cultural relic weathering prediction can be effectively improved. The research results of this paper can not only provide data support for the protection of glass cultural relics, but also provide reference and reference for the protection research of other material cultural relics.

2 Related Work

The study of weathering of cultural relics has always been an important topic in the field of cultural heritage protection, especially in the weathering analysis of glass products. Scholars have tried to reveal the impact of weathering on the chemical composition of cultural relics and how to effectively predict their weathering process through various methods. Existing studies have shown that the weathering of cultural relics is not only a change in physical structure, but also involves complex changes in chemical composition, which directly affect the durability and historical value of cultural relics [4]. Many studies focus on analyzing the chemical composition of cultural relics and predicting the impact of weathering on the chemical composition of cultural relics by establishing mathematical models. Especially in the field of glass cultural relics, the change of chemical composition is crucial to restoration work.

In the study of weathering of glass cultural relics, the calculation and prediction of weathering rate is a core issue. Many scholars have adopted chemical reaction models and statistical methods to reveal the changes in chemical composition during weathering. For example, some studies collect data before and after weathering of cultural relics in the field, and infer the chemical composition before weathering by establishing a weathering rate model [5]. These methods usually rely on a large amount of sample data to deduce the change law of chemical composition under different weathering degrees. However, the limitation of these studies is that for cultural relics that lack pre-weathering data, how to effectively infer their original chemical composition is still an unresolved problem.

In addition, data missing and outlier processing are also challenges that must be faced in weathering prediction. In cultural relic research, due to the complexity and inevitable missing of data collection, how to supplement missing data through reasonable interpolation or data filling methods has become an important research direction. Scholars use a variety of interpolation methods, such as inference based on similar cultural relics and statistical inference methods, to supplement these missing data and minimize the errors caused by missing data. For the processing of outliers, elimination or numerical smoothing methods are usually used to ensure the accuracy of the final model.

In recent years, the introduction of machine learning and artificial intelligence technology has provided new ideas for the weathering prediction of cultural relics. By training machine learning models, scholars can use historical data and chemical composition data to predict the changing trends in the weathering process [6]. This type of method can overcome the problems of incomplete data and computational complexity in traditional models to a certain extent. However, due to the diversity of cultural relics and the complexity of the weathering process, existing machine learning models still have certain limitations when dealing with specific types of cultural relics.

In general, although there have been a lot of studies on the weathering of cultural relics, especially in the calculation of weathering rates and data processing, how to build a more accurate and universal weathering prediction model, especially in the treatment of missing data and outliers, is still an important challenge in current research. By combining statistics, chemical analysis and data science, future research may provide more reliable tools and methods for cultural relic protection.

3 Model establishment and solution

3.1 Data preprocessing

Artifact number, decoration, type, color, and surface weathering of 58 cultural relics. The color data corresponding to the four cultural relics with the cultural relic numbers 19, 40, 48, and 58 are missing. Now the missing colors are supplemented by the colors with the most corresponding colors of the same type of cultural relics. For example: the decoration, type, and surface weathering corresponding to the cultural relics with the cultural relic numbers 19 and 48 are: A, lead barium, weathering. Among the remaining cultural relics, there are 9 cultural relics with the same decoration, type, and surface weathering, of which 6 cultural relics are light blue, 1 cultural relic is blue-green, and 2 cultural relics are black.

Therefore, we added the color of artifacts No. 19 and No. 48 to light blue. Similarly, the color of artifacts No. 40 and No. 58 was added to light green. With the help of Excel, the chemical composition content of each artifact was summed up, and it was found that the cumulative sum of the composition ratios of artifacts No. 15 and No. 17 was between 85% and 105%, which was not valid data. In order to prevent errors in the calculation results, they were removed from the data. Correlation analysis of the weathering degree of artifacts and other indicators requires the approximate conversion of discrete character data into continuous numerical data for solution. The data conversion table is shown in Table 1 below:

3.2 Prediction of chemical composition content before weathering

According to statistical laws, the ratio of each chemical component before weathering to that after weathering of different types of cultural relics is calculated as the weathering rate, denoted as *f*. The chemical component content before weathering is predicted by multiplying the content of each chemical component after weathering by the weathering rate.

The derivation formula for the weathering rate is:

Table 1 Data conversion

Before conversion	After conversion	Before conversion	After conversion
"A"	1	"Blue-green"	4
"B"	2	"Dark green"	5
"C"	3	"Dark blue"	6
"High potassium"	1	"Purple"	7
"Lead barium"	2	"Black"	8
"Light green"	1	"Weathered"	1
"Light blue"	2	"Non-weathered"	2
"Green"	3		

$$f_i = \frac{\frac{1}{n}\sum_{j=0}^{n} b_{ij}}{\frac{1}{m}\sum_{j=0}^{m} e_{ij}} \tag{1}$$

Where f_i represents the weathering rate of the i-th chemical component, b_{ij} represents the content of the i-th chemical component of the j-th cultural relic before weathering, and e_{ij} represents the content of the i-th chemical component of the j-th cultural relic after weathering.

The weathering rates of the chemical components of different types of glass cultural relics are different, but the calculation methods are the same. The weathering rates of each chemical component are calculated through the above formula, and the solution results are shown in Table 2 below:

Table 2 Chemical composition weathering rate table

Compounds	High potassium glass	Lead-barium glass	Compounds	High potassium glass	Lead-barium glass
Silicon dioxide	0.7374	1.5656	Copper oxide	1.6831	0.30663
Sodium oxide	Always 0	5.9879	Lead oxide	0 after weathering	0.25932
Potassium oxide	23.7669	0.8433	Barium oxide	0 after weathering	0.27538
Calcium oxide	4.521	0.27716	Phosphorus pentoxide	4.5882	0.078543
Magnesium oxide	4.339	0.60705	Strontium oxide	0 after weathering	0.233385
Aluminum oxide	2.9441	0.88152	Tin oxide	Always 0	0.52272
Iron oxide	9.3173	1.1322	Sulfur dioxide	0 after weathering	0.015078

For chemical elements that are 0 after weathering, we assume that they are also 0 before weathering. For other chemical elements, the predicted chemical content before weathering is: $b_{ij} = f_i * e_{ij}$, so the chemical composition content of glass products before weathering is shown in Table 3 below:

Table 3 Predicted chemical composition content before weathering

Cultural Relics Sampling Points	SiO2	K2O	CaO	PbO	BaO	...
02	56.80	1.05	0.65	12.30		...
07	68.31		4.84			...
08	31.53		0.41	7.44	8.60	..
08 Severe weathering point	7.22		0.89	8.41	8.43	...
09	70.07	14.02	2.80			...
10	71.36	21.87	0.95			...
...	...	...	...	...	...	...

4 Conclusion

This study provides a scientific tool for the protection and restoration of cultural relics by establishing a prediction model for the chemical composition of glass products before weathering. By statistically analyzing the chemical composition data of different types of glass cultural relics and combining the calculation method of weathering rate, a prediction model for the chemical composition before weathering was successfully derived. Based on the relationship between the chemical composition after weathering and the weathering rate, this model can effectively predict the chemical composition content of glass cultural relics before weathering. The results show that accurate weathering rate calculation and data processing can effectively make up for the missing data of cultural relics before weathering, thereby providing a more reliable basis for cultural relic restoration.

In terms of data processing, this study adopted reasonable methods of outlier elimination and missing data filling to ensure the accuracy of model establishment. For missing data, the integrity and rationality of the data were ensured by matching the color information of similar cultural relics and interpolating and filling. For cultural relics with different degrees of weathering, we adopted statistical analysis methods related to the chemical composition before and after weathering to further improve the accuracy of model prediction. In particular, when processing discrete character data into continuous numerical data, appropriate conversion strategies were adopted to provide a good data basis for subsequent analysis.

Although the model of this study has achieved certain results, there is still some room for improvement. Due to the wide variety of glass cultural relics and the high complexity of the weathering process, future research can improve the accuracy and versatility of the prediction model by introducing more chemical composition analysis data and combining machine learning technology. In addition, further optimizing the calculation method of weathering rate and the understanding of weathering mechanism for the diversity of cultural relics with different weathering degrees will help to better serve the field of cultural relics protection.

In summary, this study provides an innovative solution for the weathering prediction of glass cultural relics, which can not only help restorers accurately predict the chemical composition before weathering, but also provide valuable reference for future cultural relics protection research. With the further development of data science and technology, combined with more cultural relics data and advanced computing methods, the prediction and restoration of cultural relics weathering will become more accurate and efficient.

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