DISEASE INVESTIGATION OF STONE CARVING BY SPATIAL ANALYSIS: A CASE STUDY ON THE STONE CARVING OF DAZU THOUSAND-HAND BODHISATTVA

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ABSTRACT:

Cultural relics are often threatened by nature and human, especially stone carving relics which have immovable characteristics. Compared with other cultural relics, the diseases of stone carving relics are more complex, and they can affect carvings' cultural and artistic value to a great extent. This article selects Dazu thousand-hand bodhisattva as a case, not only because it has a strong representation in Chinese stone carving art, but also considering that there are many complex diseases in the whole range after a long history, therefore the Dazu thousand-hand bodhisattva has high research value, and scientific investigation methods are essential for the protection and research of cultural relics. The main purpose of this paper is to investigate the arm diseases of Dazu thousand-hand bodhisattva by using the two methods of GIS spatial analysis: kernel density analysis and trend analysis. The past investigation methods are difficult to achieve the expected results because of their strong subjectivity and narrow range, and the use of spatial analysis to investigate the diseases of stone carvings can study the spatial characteristics and coupling relationship of stone carvings from the macro level.

1. INTRODUCTION

Stone carving is an important category of plastic arts, which has a long history in China, and it is also the crystallization of human labor and wisdom. In the world, the number and variety of stone carvings are very rich. However, because the stone carvings are immovable cultural relics, they are more likely to be eroded by diseases compared with other cultural relics. In addition, the varieties and quantity of stone carving diseases are complex, which brings great difficulty to information collection and analysis (Hou et al., 2016a; Wang et al., 2019; Wang et al., 2018; Wenzei, 2016).

Disease investigation is a very important part of stone carving protection work. Traditional disease investigation mainly used CAD for disease extraction, followed by qualitative analysis (Moropoulou et al., 2013; Logothetis et al., 2017), but the analysis results obtained in this way were usually lack of macroscopic characteristics and coupling relationship between diseases. In view of this, this paper puts forward a method of disease investigation of stone carvings using spatial analysis, which can jointly analyze the attribute information and location information of a large number of diseases and extract their potential information. Besides, this paper takes the Dazu thousand-hand bodhisattva as an example, expecting to find the spatial distribution characteristics and coupling relationship of arm diseases through spatial analysis.

Dazu thousand-hand bodhisattva is located in the great mercy storied-pavilion, and the pavilion is on the south cliff of Dafo bay, stone carving district of mount Baoding, with a height of 7.2 meters, a width of 12.5 meters and a facade of 88 square meters.

In 2008, during the rescue protection project of Dazu thousand-hand bodhisattva, a survey was carried out on the preservation status of the stone carvings, and it was finally found that the total number of arms of Dazu thousand-hand bodhisattva was 830, which cracked the rumor that there were 1007 hands in Dazu thousand-hand bodhisattva for a long time. On the whole, Dazu thousand-hand bodhisattva looks like a peacock, and its momentum is very magnificent. Dazu thousand-hand bodhisattva is not only the largest cliff statue with stone material, color painting and gold foil in one, but also an important representative work of stone carving in the world cultural heritage, which has high historical and artistic value (Hou et al., 2016b; Jin et al., 2020).

However, under the influence of long-term natural forces and human activities, the overall and local damage of Dazu thousand-hand bodhisattva is very serious, resulting in gold foil warping and shedding; color painting cracking and warping; stone incompletion and other diseases, which not only greatly affect the cultural value and artistic value of the statue, but also seriously endanger the safety of the statue (Wang, 2007; Wei, 2017). As Dazu thousand-hand bodhisattva is a famous ancient stone carving art in China, it is highly representative in stone carvings, so it is selected as a case study, which can also be used for reference to the disease investigation of other stone carvings.

The main purpose of this paper is to investigate the diseases of stone carvings by means of spatial analysis, and to express the global distribution and coupling relationship of diseases more intuitively, so as to provide a scientific basis for the protection and restoration of cultural relics. This paper is organized as

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follows: after the introduction of the basic situation, the second section reviews the literature on the use of different methods to investigate cultural heritage and the use of kernel density analysis or trend analysis to study regional spatial characteristics. The third section briefly introduces the two methods of kernel density analysis and trend analysis used in the disease investigation, and describes the general process of the investigation and the source data which is used in this paper. The fourth section mainly analyzes the results obtained by the above two investigation methods, including the global distribution characteristics and coupling relationship of the diseases. Finally, the fifth section summarizes the full text and analyzes the problems existing in the research.

2. RELATED WORKS

As this paper takes stone carving relics as the research object, and uses two spatial analysis methods of kernel density analysis and trend analysis in GIS, this part sorts out the research status of cultural heritage investigation methods and spatial analysis applications. As a part of GIS spatial analysis, kernel density analysis is mainly used to calculate the density of elements in its surrounding neighborhood, while trend analysis is mainly used to reflect the subject characteristics of objects in the spatial region (Tang et al., 2012).

As the traditional kernel density analysis and trend analysis inevitably have some limitations, scholars from various countries have made a series of improvements to the traditional methods based on the actual needs and combined with brand-new science and technology. In view of the shortcomings of the traditional kernel density method, the cyberspace kernel density calculation model can be used as an optimization scheme to analyze the expansion mode of the method in which the kernel density method is embedded in the network structure, and then the effects of attenuation threshold and height extremum on the kernel density can be discussed deeply (Yu and Ai, 2015). By examining the relationship between traffic accidents and urban characteristics, such as population, road factors and spatial factors, a traffic accident density estimation model can be established, and kernel density estimation (KDE) technology can be used to effectively evaluate these relationships (Hashimoto et al., 2016). For urban management, we can also analyze the seasonal variation and long-term trend of heat island intensity of several mega-cities on a continent in recent years from the macro characteristics of urbanization (Lee et al., 2020). In the fight against the epidemic, Iranian scholars carried out spatial modeling, risk mapping, change detection and outbreak trend analysis for the spread of COVID-19, and compared Iranian coronavirus data with global trends, and used regression models to predict mortality trends (Pourghasemi et al., 2020).

For the investigation of cultural heritage, the traditional method was to use tools such as drawings, rulers and pencils to measure and draw objects by hand. However, with the development and application of computer, photogrammetry, laser scanning and geographic information technology, this method had long been out of the historical stage (Xiao et al., 2019). As cultural heritage is often destroyed by nature and human, in order to improve the effectiveness of conservation strategies, we can consider combining laser scanning, photogrammetry and digital technology based on computer vision with GIS (Geographic Information system) (Campanaro et al., 2016). The spatial data of historical maps are integrated into GIS to determine the landscape vulnerability of cultural heritage. This method can also be applied to the survey of cultural heritage sites (Nicu, 2016). In addition, there is a method which combines terrestrial laser

scanning (TLS) measurement, deviation analysis (DA) with finite element (FE) numerical simulation to identify the structural health of historic buildings, and explain the structural health status of historic buildings according to the identification results (Korumaz et al., 2017).

From the relevant research, it can be found that: (1) the spatial analysis based on GIS is seldom applied to cultural heritage; (2) the disease investigation and coupling analysis of cultural heritage are developed to quantitative research; (3) when using spatial analysis methods to investigate objects, only a few studies can combine kernel density analysis with trend analysis.

3. MATERIAL AND METHODS

3.1 Investigation Method

In this paper, two methods, that is to say, kernel density analysis and trend analysis in spatial analysis are used to investigate the diseases of arms of Dazu thousand-hand bodhisattva. In order to find out the spatial distribution characteristics and the coupling relationship between the diseases in the global range in an intuitive way, these two methods are introduced in this part.

Kernel density analysis (Lv et al., 2003; Kim and Scott, 2012) uses kernel functions to calculate the value of each unit area according to point or broken line elements, and according to this, each point or broken line is fitted into a smooth conical surface. Its purpose is to obtain a density function that can approximately represent the distribution of data, and then use this function to calculate the estimated value of each element, subsequently show the distribution and aggregation area of the data. Kernel density analysis can be used to measure building density, obtain crime reports, and identify roads or facilities that affect cities and towns. In short, kernel density analysis may be used in all investigations on the spatial distribution and aggregation of research targets. The elements for kernel density analysis may be points or lines (figure 1), wherein the point-based kernel density analysis is used to calculate the density of the point elements around each output grid pixel, while the line-based kernel density analysis is used to calculate the density of the linear elements in the neighborhood of each output grid pixel. In the kernel density analysis, it is generally believed that within a certain range of space, a certain event can occur at any location, that is, there is a density at any element in the study area, but in different locations, the probability of the event is not the same, if there are more times of an event in a certain area, it is considered that the frequency of the event is high in this area, and vice versa.
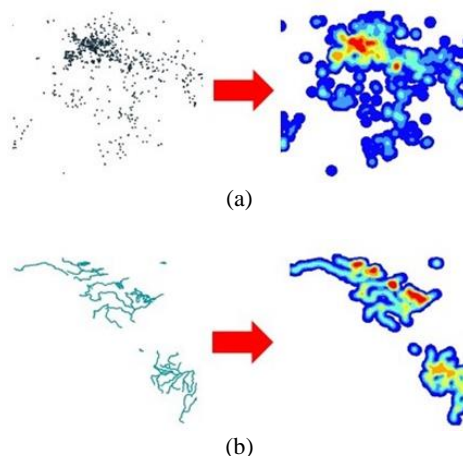

(a)

(b)

Figure 1. The point-based and line-based kernel density analysis

Trend analysis (Guo and Lu, 2009) is a statistical method to establish a binary polynomial regression model by fitting sample data with mathematical surfaces with the help of the least square method, besides, it can eliminate accidental variation and local variation and show the overall distribution of the sampled data in the study area (figure 2). Usually the positive direction of the y-axis indicates the north direction and the positive direction of the x-axis indicates the east direction. In the trend analysis, the position of the sampling points is drawn on the x-y plane, and above each sampling point, the value is given by the height of the rod in the z dimension, and then the value is projected as a scatter diagram to the x-z plane and y-z plane, and the changing trend in different directions is reflected by fitting polynomials. Generally speaking, for a large number of spatial data that need to be analyzed, the changing trend is mainly composed of two parts, one is a determined global trend, and the other is random short-range variation. The global trend reflects the overall characteristics of the quantitative change of spatial data in the distribution area, and it can directly represent the main law of the change of the spatial data. The accurate fitting and quantification of the global trend is not only conducive to the analysis of the overall law of spatial data, but also can be beneficial to eliminating the trend, so as to analyze the short-range variation of the data.
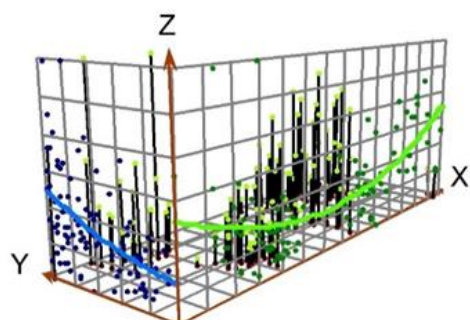

Figure 2. Trend analysis which can show the overall distribution law

3.2 Research Process

In this paper, based on the elevation line drawing of Dazu thousand-hand bodhisattva, the diseases of arms were investigated by using kernel density analysis and trend analysis in GIS spatial analysis after a series of processing of the line map data. Furthermore, the visualization results were analyzed and studied (figure 3). The specific research process is described as follows.
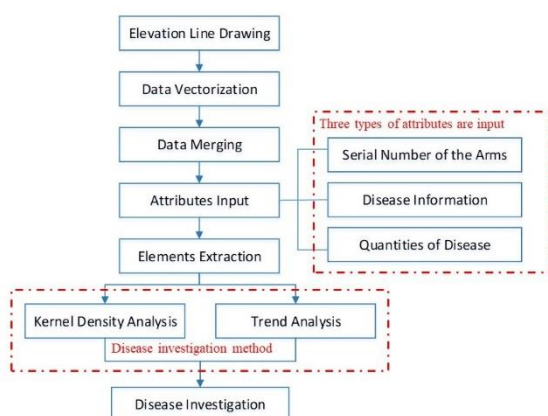

Figure 3. Research process of the disease investigation

First of all, according to close-range photogrammetry, take the line drawing of the thousand-hand bodhisattva as the base map, import the line drawing into GIS software and convert it into a vector data format that is easy to deal with, subsequently merge and supplement the fine fracture segments to make it a complete base map with complete topological relationship and can be analyzed in GIS. Secondly, referring to the preliminary study on the rescue protection project of the thousand-hand bodhisattva statue (Zhan et al., 2015), it is found that there were 33 kinds of diseases (Table 1). These diseases are divided into six categories according to different damage forms: structural diseases, changes of surface integrity, changes of surface morphology, changes of surface color, biological diseases and human intervention. According to the material types of the thousand-hand bodhisattva, the diseases are divided into stone material, gold foil or color painting diseases, and the global distribution of all the diseases found in the investigation is plotted. In this paper, the spatial distribution map of each disease, as one of the original data, played a very important role.

	Structural Diseases	Changes of Surface Integrity	Changes of Surface Morphology	Changes of Surface Color	Biological Diseases	Human Intervention
Stone Material	Incompletion, Fracture	Pulverization and Exfoliation, Flaky Exfoliation	Dust, Hollowness	\	Biological Disease	Coating
Gold Foil	\	Shedding Plasters, Shedding Dots, Shedding Foil, Cracking and Crimping of Multiple Layers, Cracking	Warping, Hollowness, Dust	Fumigation	Biological Disease	Coating
Color Painting	\	Shedding Plasters, Shedding Dots, Shedding Painting, Pulverization	Bubbling, Warping, Bubbly Warping, Waterlogging, Cracking, Hollowness, Dust	\	Biological Disease	Coating, Fumigation

Table 1. The total diseases of the thousand-hand bodhisattva

In the rescue protection project of Dazu thousand-hand bodhisattva, in order to facilitate protection and research, the thousand-hand bodhisattva entirety was divided into 9 rows from the lower layer to the upper layer, and it was also divided into 11 columns from the east to the west (that is, from the left to the right side of the bodhisattva's frontage), ultimately the bodhisattva is divided into 99 areas. In addition, all arms and artifacts on it are numbered. With regard to the designated arm numbers, it is suitable to enter it as an additional attribute of the line drawing, so that each arm of the thousand-hand bodhisattva can be queried and displayed in GIS. On this basis, with reference to the spatial distribution map of various diseases, all the disease information on each arm is inputted into the base map according to the arm serial numbers, afterwards the serial numbers of all arms and the disease information on each arm are bind. Subsequently the total number of diseases on each arm and the number of diseases of different materials and disease categories are counted for subsequent investigation and analysis.

Finally, in order to make the analysis process more effective, the elements that need to be analyzed and investigated (such as all arms of thousand-hand bodhisattva, or certain arms with some

common characteristics, etc.) are extracted from the whole data. The extracted data are investigated by kernel density analysis and trend analysis respectively, and the visualization results are analyzed and summarized.

3.3 Source Data

In order to realize the disease investigation of Dazu thousand-hand bodhisattva by using spatial analysis methods, effective original data is essential. In this paper, the elevation line drawing, disease distribution map and infrared thermal images of thousand-hand bodhisattva were used as the original data of disease investigation. The source data will be introduced in this section.

The elevation line drawing of Dazu thousand-hand bodhisattva was photographed and processed by surveyors in the rescue protection project (Zhan et al., 2015) using close-range photogrammetry, subsequently it was modified and perfected by archaeologists and artists (figure 4). The (a) image is the global line drawing and the (b) image is the local line drawing. The vertical line drawing can be used as the base map for the investigation, restoration and protection of thousand-hand bodhisattva. In order to facilitate the research, the grid layout method in the field is also used to the line drawing, and the whole drawing is divided into 99 areas with a total of 9 rows and 11 columns.
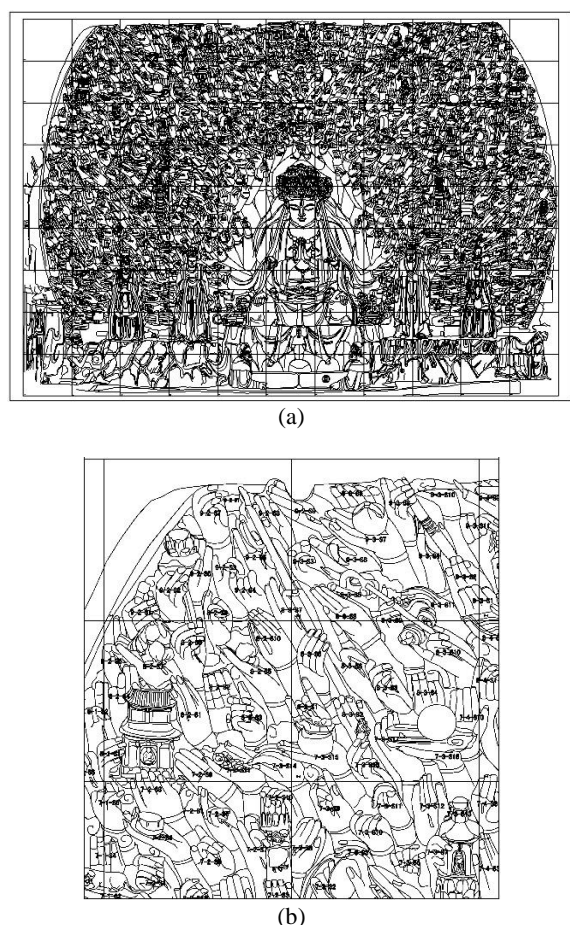

(a)

(b)

Figure 4. The line drawing of Dazu thousand-hand bodhisattva

The disease distribution map of thousand-hand bodhisattva is drawn by the project staff, which is as large as the real object as the base map. In the process of drawing, the draftsman prepared

three polyester films for each area in the line drawing, drew the location and shape of each disease according to the prescribed disease terms and diagrams, and used blue, red or green markers to depict on the film. These three colors represent stone diseases, gold foil diseases and color painting diseases respectively, and then summarized and combined all the disease pictures to obtain the general picture of the diseases of the three materials (figure 5).

(a)

(b)

(c)

Figure 5. The disease distribution drawings of Dazu thousand-hand bodhisattva

In order to detect the distribution of water in Dazu thousand-hand bodhisattva, the project staff (Zhan et al., 2015) applied infrared thermal imaging technology to the study of condensation water diseases in stone carving, and drew a thermal infrared images of the bodhisattva (figure 6). In the protection project, two detections were carried out in November 2009 and April 2010,

respectively. The infrared image region of the water in the picture is red, yellow and green, the infrared image of the rock mass is light blue and dark blue, and the red is the area with high water content. Besides, the water content in the blue area is lower. In the thousand-hand bodhisattva, due to the influence of spring water in the east, the water content on the surface of the rock mass in the east is obviously more than that in the west, while the upper part of the carving has good ventilation conditions, so the water content in the upper part of it is generally lower than that in the lower part.
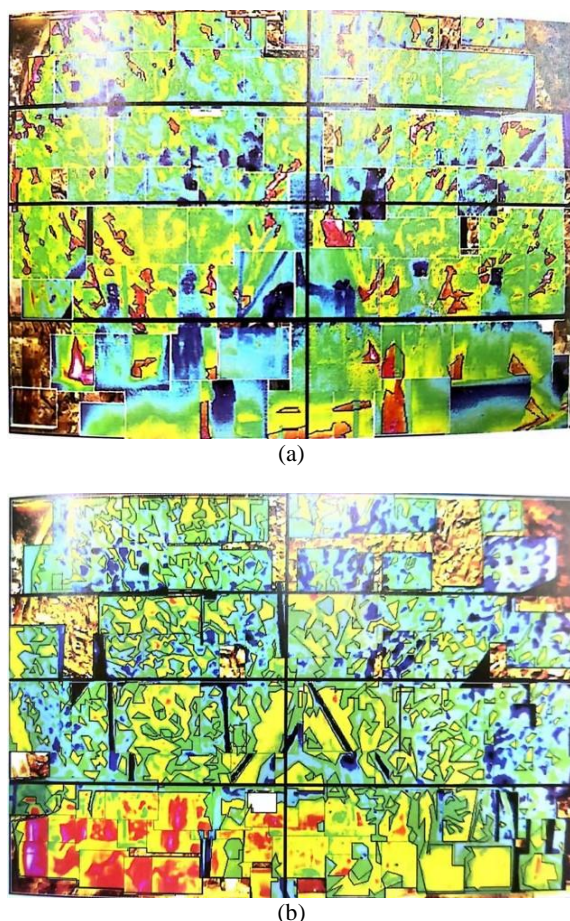

(a)

(b)

Figure 6. The infrared images of the thousand-hand bodhisattva

4. RESULTS AND DISCUSSION

4.1 Kernel Density Analysis

As mentioned earlier, the kernel density analysis can show the distribution and aggregation area of the data, considering the variety and complexity of diseases in the arms of Dazu thousand-hand bodhisattva, in this paper, the kernel density analysis is used to investigate the distribution of each specific disease on the arms of the thousand-hand bodhisattva. The following will be analyzed from two aspects: the specific diseases related to condensate water disease and the relationship between stone material, gold foil and color painting diseases.

By comparing the infrared images of Dazu thousand-hand bodhisattva (figure 6) with the results of kernel density analysis of various diseases, it can be found that the distribution characteristics of four diseases are obviously correlated with the distribution law of water content. As shown in figure 7, (a)-(d) show the kernel density analysis results of gold foil cracking,

gold foil shedding plasters, gold foil warping and gold foil shedding respectively. The distribution trend of (a) and (d) is similar to that of water content, while that of (b) and (c) is opposite to that of content.
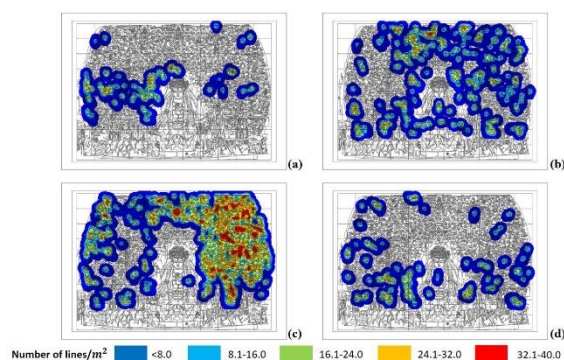

Figure 7. The outcomes of kernel density analysis which can be related to condensate water disease

As the thousand-hand bodhisattva is located in the great mercy storied-pavilion, the closed indoor environment causes poor air circulation in the stone carving area, thus having the necessary conditions for the production of condensed water (Fang et al., 2009). For other creatures, water is the source of life, but for cultural relics, water is the source of evil, and this is no exception for Dazu thousand-hand bodhisattva. There is frequent rainfall in Dazu area, and water is the most important factor causing weathering and damage of Dazu stone carvings. Many diseases are caused or aggravated by the participation of water. A careful study of the infrared images of the thousand-hand bodhisattva shows that the water content of the stone inscription is lower in winter and higher in spring, indicating that the interior and surface of the stone carving have a certain amount of water all the year round. What's more, the water is mainly concentrated in the lower layer, especially in the east.

Gold foil is mainly attached to the arms of thousand-hand bodhisattva, and only a few arms are attached with the color painting. Sticking gold foil on the arm not only has the role of decoration, but also can play a strong role in protecting the stone under it (Wang, 2007), so as far as the arm is concerned, condensate water disease is more harmful to gold foil. The condensate water is attached to the surface of the stone carving, which caused the weathering and diseases of the gold foil.

For stone material, gold foil, color painting diseases, due to the long history of the bodhisattva, the diseases of these three materials were very serious. Because the color painting of the arms was less, on the surface it seemed that painting diseases were less than stone and gold foil diseases, but from figure 5 (c) it could be found that the existence of painting diseases on the artifacts were also very serious. Figure 8 shows the more serious specific diseases in the stone, gold foil and color painting, in which figure (a)-(b) show shedding dots, cracking and crimping of multiple layers of gold foil, figure (c)-(d) show shedding, shedding plasters of color painting, and figure (e)-(f) show pulverization and exfoliation, incompletion of stone. By observing figure 8, it can be found that although the diseases of gold foil and color painting were widely distributed and seriously damaged, the distribution of stone diseases was also widespread, but considering that the damage degree of stone diseases was somewhat good in the case of extremely serious gold foil diseases, it shows that gold foil has a strong protective effect on the stone. In addition, from fig. 8 (b), it can be found that the cracking and

crimping of multiple layers of the gold foil was extremely serious, and there was this disease on almost every arm, indicating that in history, the thousand-hand bodhisattva has been repaired and pasted many times, and the multi-layer gold foil has cracked and crimped under the action of its own gravity and stress because of its age. Fig. 8 (c)-(d) show that the color painting diseases were mostly distributed on the hands and hands' eyes of the thousand-hand bodhisattva, so the large area damage of gold foil and the shedding of color painting had caused serious peeling and defective diseases of the stone.
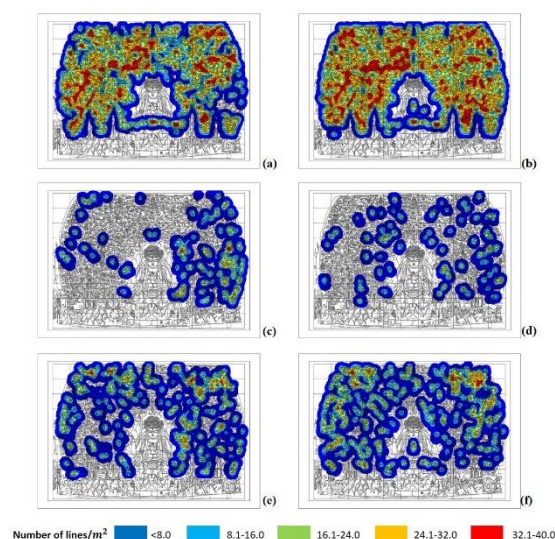

Figure 8. The outcomes of kernel density analysis which can reflect coupling relation among diseases

4.2 Trend Analysis

As the trend analysis can show the overall distribution of the sampling data in the study area, for this paper, the position of all arms in the Dazu thousand-hand bodhisattva is taken as sampling data. The facade is placed flat on the x-y plane as the research area (figure 9). Comparing the global line drawing of the 4(a) with figure 9, it is easy to find that the origin of the x-y plane coordinate is the lower left vertex of the line drawing, the positive direction of the x axis is the direction of the bodhisattva from east to west, the positive direction of the y axis is the direction of the bodhisattva from bottom to top, and the z value (that is, the height of each rod) is the number of diseases that need to be analyzed on each arm.
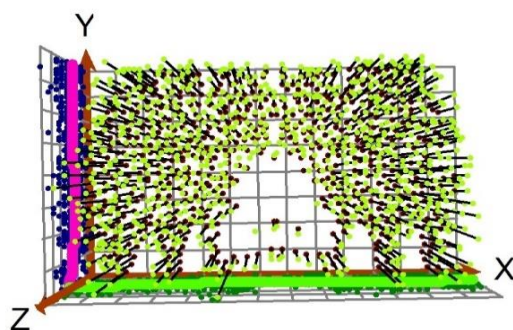

Figure 9. Top view of the X-Y plane

In this paper, the total number of diseases on each arm, the number of diseases produced by different materials (stone, gold foil and color painting) and the types of diseases (structural diseases, changes of surface integrity, changes of surface morphology, changes of surface color, biological diseases, human intervention) were investigated.

Through observation, it can be found that the arms of thousand-hand bodhisattva were seriously damaged on a global scale. For example, in figure 10(a), the curves projected to the x-z plane and y-z plane are very smooth and have a certain height, which shows that most of the bodhisattva's arms had a considerable amount of diseases in the upper-lower and east-west dimensions. It is also consistent with the above investigation results.
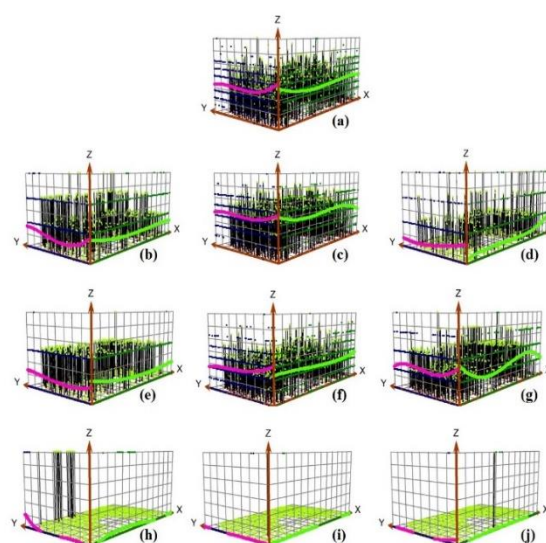

Figure 10. The outcomes of trend analysis which can reflect trends of various diseases

Among the diseases of stone, gold foil and color painting (figure 10(b)-(d)), the number of gold foil diseases on the arms is the most, the number of stone diseases is the second, and the number of color painting diseases is the least, in which the gold foil disease curve is very gentle in two dimensions, indicating that the gold foil diseases were serious and evenly distributed. The stone diseases change gently from east to west, showing a weak trend of falling first and then rising from bottom to top, indicating that the stone diseases were less in the middle, and the they were mainly distributed in the upper and lower parts; the diseases of color painting rise slightly from east to west and decrease slightly from bottom to top, indicating that the diseases of color painting were mild and mainly concentrated in the lower part of the west. As mentioned earlier, the rare diseases of color painting on the arms are due to the fact that the painting is mainly distributed on the artifacts, and most of the arms are covered with gold foil.

In addition, among the six types of diseases (figure 10(e)-(j)), the number of changes of surface integrity and changes of surface morphology was the largest, the number of structural diseases was the second, and the number of changes of surface color, biological diseases and human intervention was the least, and they have the lowest impact on the safety and artistic value of cultural relics. Among them, except for the disease types with changes of surface morphology, the other five disease types change slowly in the east-west and upper-lower dimensions, indicating that these disease types were evenly distributed and no disease occurred only in a certain area. As for the type of changes of surface morphology, there is an obvious trend of falling first and then rising in the two dimensions, indicating that several diseases of this type were mainly distributed around the thousand-hand bodhisattva, and it was somewhat rare in the middle part.

5. CONCLUSIONS

To investigate the diseases of stone carving cultural relics, the traditional methods were to use paper and pen to draw by hand, or to draw the location of the disease distribution in the computer with the help of CAD. However, the traditional investigation methods were either highly subjective, low precision, or drawn separately, and the range was narrow, so it is difficult to analyze the spatial distribution characteristics of diseases in the global scope and the coupling relationship between diseases. In view of this, this paper puts forward the method of disease investigation of stone carvings by means of GIS spatial analysis, and selects 830 arms of Dazu thousand-hand bodhisattva as a case study, in order to find the global spatial relationship of the diseases.

Through the research of the related works, it is found that although GIS has a strong ability of spatial analysis and can draw the results intuitively, few scholars apply GIS spatial analysis to the disease investigation of cultural relics, and scholars in the field of cultural relics also study many methods of quantitative analysis when carrying out disease investigation, so this paper chooses the means of spatial analysis to investigate the diseases of stone cultural relics, and it is undoubtedly of value and significance for the protection of cultural relics. The purpose of this paper is to study the distribution characteristics and coupling relationship of diseases from multiple angles, and to express them intuitively and clearly.

After using the above two methods to investigate the diseases of the arms of Dazu thousand-hand bodhisattva, it is found that the disease of condensed water has a great impact on the gold foil, because the gold foil has many layers attached to the stone material, and there are few color paintings attached to the stone, so when the bodhisattva's arms absorb a certain amount of condensed water, it will first cause damage to the gold foil. Although the damage of gold foil is very serious, the influence of condensed water on stone is relatively slight, indicating that gold foil has a strong protective effect on stone. In addition, among the six disease types of thousand-hand bodhisattva, except for the changes of surface morphology, the other types were evenly distributed in the whole range, and most of the arms of thousand-hand bodhisattva had a considerable number of diseases. That condition proved the necessity of implementing the rescue protection project for the thousand-hand bodhisattva at that time.

Although this paper uses the means of spatial analysis to investigate the arm diseases of Dazu thousand-hand bodhisattva, there are still some shortcomings. For example, this paper is based on the line drawing of stone carving, it means only the diseases on the front of the bodhisattva can be investigated, but the diseases on the side and back may be ignored. And the disease information is attached to it as the attribute value of the arm, which leads to the analysis that a disease is distributed in the whole hand. In view of these problems, more comprehensive and detailed research will be considered in the future. Although this paper only investigated the Dazu thousand-hand bodhisattva, considering the universality of this method and the representativeness of the thousand-hand bodhisattva, it can also be extended to the investigation of other stone carvings.

REFERENCES

Campanaro, D. M., Landeschi, G., Dell'Unto, N., Touati, A. M. L., 2016. 3D GIS for cultural heritage restoration: A 'white box'workflow. Journal of Cultural Heritage, 18, 321-332.

Fang, F., Fang, Y., Yan, X. F., Shang, C. L., Huang, L., 2009. Analysis of groundwater seepage mechanism in Dazu thousand-hand bodhisattva carving in Chongqing. Sciences of Conservation and Archaeology, 21(04), 1-4. (in Chinese)

Guo, F.Y., Lu, Z., 2009. Research progress of disease geography based on spatial analysis. Geomatics World, 7(006), 22-26.

Hashimoto, S., Yoshiki, S., Saeki, R., Mimura, Y., Ando, R., Nanba, S., 2016. Development and application of traffic accident density estimation models using kernel density estimation. Journal of traffic and transportation engineering (English edition), 3(3), 262-270.

Hou, M. L., Hu, Y. G., Wu, Y. H., Zhao, X. S., 2016b. 3D DOCUMENTATION AND DATA MANAGEMENT IN THE DAZU THOUSAND-HAND BODHISATTVA STATUE IN CHINA. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 5, 273-276.

Hou, M. L., Li, S. K., Jiang, L. L., Wu, Y. H., Hu, Y. G., Yang, S., Zhang, X. D., 2016a. A new method of gold foil damage detection in stone carving relics based on multi-temporal 3D LiDAR point clouds. ISPRS International Journal of Geo-Information, 5(5), 60, 1-17.

Jin, S. T., Bai, X. L., Zhao, G., Guo, J. S., Zhang, X., Cao H., Ren, F., 2020. A preliminary study on the Environmental quality of Dazu thousand-hand bodhisattva carving. Dazu academic journal, 326-335. (in Chinese)

Kim, J., Scott, C. D., 2012. Robust kernel density estimation. The Journal of Machine Learning Research, 13(1), 2529-2565.

Korumaz, M., Betti, M., Conti, A., Tucci, G., Bartoli, G., Bonora, V., Korumaz, A.G., Fiorini, L., 2017. An integrated Terrestrial Laser Scanner (TLS), Deviation Analysis (DA) and Finite Element (FE) approach for health assessment of historical structures. A minaret case study. Engineering Structures, 153, 224-238.

Lee, K., Kim, Y., Sung, H. C., Ryu, J., Jeon, S. W., 2020. Trend analysis of urban heat island intensity according to urban area change in Asian mega cities. Sustainability, 12(1), 112, 1-11.

Logothetis, S., Karachaliou, E., Stylianidis, E., 2017. From OSS CAD to BIM for cultural heritage digital representation. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 42, 439-445.

Lv, A.M., Li, C.M., Lin, Z.J., Shi, W.Z., 2003. Spatial continuous distribution model of population density. Acta Geodaetica et Cartographica Sinica, 32(4), 344-348.

Moropoulou, A., Labropoulos, K. C., Delegou, E. T., Karoglou, M., Bakolas, A., 2013. Non-destructive techniques as a tool for the protection of built cultural heritage. Construction and Building Materials, 48, 1222-1239.

Nicu, I.C., 2016. Cultural heritage assessment and vulnerability using Analytic Hierarchy Process and Geographic Information Systems (Valea Oii catchment, North-eastern Romania). An approach to historical maps. International Journal of Disaster Risk Reduction, 20, 103-111.

Pourghasemi, H. R., Pouyan, S., Heidari, B., Farajzadeh, Z., Shamsi, S. R. F., Babaei, S., Sadeghian, F., 2020. Spatial modeling, risk mapping, change detection, and outbreak trend analysis of coronavirus (COVID-19) in Iran (days between February 19 and June 14, 2020). International Journal of Infectious Diseases, 98, 90-108.

Tang, G. A., Yang, X., 2012. ArcGIS Geographic Information System spatial analysis experiment course (Second edition). Science Press. (in Chinese)

Wang, H., Luo, Y., An, C., Chu, S., Shen, Z., Huang, L., Zhang, D., 2019. Application of imaging polarimeters to enhanced detection of stone carving. Journal of Cultural Heritage, 40, 92-98.

Wang, J.H., 2007. Special study on preservation and diseases of Dazu thousand-hand bodhisattva. Scientific research of Chinese cultural relics, (02), 70-78.

Wang, K., Xu, G., Li, S., Ge, C., 2018. Geo-environmental characteristics of weathering deterioration of red sandstone relics: a case study in Tongtianyan Grottoes, Southern China. Bulletin of Engineering Geology and the Environment, 77(4), 1515-1527.

Wei, Z. Y., 2017. Between willing: comment on the restoration project of the Dazu thousand-hand bodhisattva carving. Research on Heritages and Preservation, 2(03), 17-22. (in Chinese)

Wenzel, C., 2016. Monumental Stone Sūtra Carvings in China and Indian Pilgrim Sites. Journal of Chinese Buddhist Studies, 29, 51-89.

Xiao, Y. J., Mao, Z. P., Wu, H., Wu, S. Q., Fang, B. S., Yang, K. Y., 2019. Application of computer drawing and surveying technology in the finishing of unearthed Bamboo slips. Jianghan Archaeology, 1, 122-125. (in Chinese)

Yu, W.H., Ai, Y.H., 2015. Visualization and analysis of POI points in cyberspace supported by kernel density estimation. Acta Geodaetica et Cartographica Sinica, 44(1), 82-90.

Zhan, C.F., Wang, J.F., Gao, F., et al., 2015. Preliminary study on rescue protection project of Dazu thousand-hand bodhisattva. Chinese Academy of Cultural Heritage.