Multivariate Statistical Approaches in Archeology: A Systematic Review

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Abstract: One of the most important achievements of New Archaeology was a tendency toward application of variables and statistical analysis in archaeological research. Each statistical method should be applied to certain areas of archaeological studies; it is important to extract biological, economic, social and cultural information properly via statistical methods. In this study, which is a review through previously published research, articles in which multivariate statistical method are applied in archaeological investigations have been extracted from three worldwide databases, i.e. PubMed, Scopus and Science Direct, based on a protocol designed to search for related articles from January 2000 to January 2016. After application of inclusion and exclusion criteria, finally 384 articles were selected for this investigation. All of the 384 articles were classified based on multivariate statistical methods and then the application of these methods in archaeology and cultural material types was determined. They show that methods, including Cluster analysis, Principal Component Analysis, Discriminant Analysis, Multivariate Multiple Regression, Factor Analysis and Multidimensional Scaling have had respectively the highest application in archaeological investigations. The results of this systematic review indicate that cluster analysis is one of the most applied statistical analysis, perhaps because of usage, method and simple interpretation, compared to other methods of data reduction. This method is used for data reduction or clustering archaeological sites based on their similarities and helps with the comparison between site structures. Principle Component Analysis is the second most widely used methods due to its application in any data structure and simplicity of interpretation compared to other methods of dimensionality reduction.

Keywords: Multivariate, Archaeology, Cluster Analysis, Principle Component Analysis.

Introduction

New Archaeology as a new school of archaeological studies began in the 1960s as a result of efforts of Lewis Binford and David L. Clarke. One of the most important achievements of the new school was a tendency toward application of variables and statistical analysis in archaeological research. Hence archaeology passed the stage of description and entered into a stage of scientific analysis. Because statistics with its unique power to change the language of data from the description to numbers and analyzing the numbers helps with clarifying the situation of hypotheses in various science fields (Gowland and Western 2012). In fact, application of statistical methods had been introduced in archaeology since 1950s, but it was only used in descriptive and discovering the structure of sites, comparison of sites and distinction of cultural finds (Myers 1950). Since 1975 statistical methods were used in different archaeological studies, for example advanced statistical methods were used in geological studies in Egypt, the results of which were published as a book chapter (El Shazly 1957). Then DH Thomas investigated about statistics in archaeology in 1978. By this process many researchers around the world have used statistical techniques to analyze the archaeological material, for example L. Xiancen and his colleague who studied the use of statistics and mathematics in processing archaeological data in 1995 (Xiancen and Renping 1995). Then Baxter from the department of statistics of Bowling Green State University used exploratory multivariate analysis in archaeology (Baxter 2009). Then J. de Leeuw from the department of California, Los Angeles university was the first researcher who introduced Correspondence Analysis in archaeology in 2007 (de Leeuw 2007). From

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2000, application of Multivariate statistical methods was increased remarkably, according to the published articles. In 2008, Philip L. Walker from the Department of Anthropology, university of California used Discriminant Analysis for sex determination in skulls of different nationalities which had an accuracy of forecasts of over 80% (Walker 2008). Drennan started educating theories and applications of statistical methods, especially multivariate methods in archaeology by publishing a valuable book (Drennan 2009). The book serves as an educational valid reference in statistical methods used in archaeology around the world.

Statistics is a group of strategies to collect the data and information in order to achieve a certain purpose; it is a useful means of interpretation of the collected information to make reasonable and correct decisions. In other words, statistics is a group of methods in which logical order and statistical reasoning is used to analyze data and finally inferences are made based on the analysis. After several decades of archaeological excavations, wide databases have been created and developed around the world. Archaeology as a science dealing with massive amounts of data like pottery, chipped stones, figurines, fauna, etc., can use statistics as a tool to clarify its hypotheses and scientific expectations. Advanced statistical methods, e.g. multivariate statistical methods, are commonly applied in extensive inter-related collections.

Each statistical method should be applied to certain areas of archaeological studies; it is important to extract biological, economic, social and cultural information properly via statistical methods. For example, multivariate statistical methods and cluster analysis are commonly used in classification of archaeological sites which have most resemblances based on the measured variables; on the other hand, they could be applied in investigations of cultural interactions. Principle Component Analysis is mostly applied in classification of cultural data (pottery, coins, fauna, etc.) from archaeological sites.

The basic statistical tools described above provide for fundamental, quantitative description and comparison, for establishing the confidence with which the samples available permit characterizations of the populations from which they come, and for assessing the strength and significance of the relationships between pairs of variables. Advanced statistical methods are also often used in archaeology: cluster analysis, factor analysis, principal components analysis, discriminant analysis, multidimensional scaling, multivariate regression, and others (Drennan 2009).

Following Binford and Clarke, statistical analyzes were applied extensively by European and North American researchers, but unfortunately statistical methods were not developed in archaeological studies by Near Eastern archaeologists. In Iran, except for a few articles by Enayatollah Amirlu and Abdolrahman Rasekh (Rezalo 2009), Kamalaldin Niknami who has published two educational books for students, statistical methods are almost ignored by the archaeologists. On the other hand, there seems to be a lack of systematic reviews over multivariate statistical methods in archaeological studies. In this article, a systematic review of the articles representing applications of multivariate statistical methods in archaeological studies is provided using the worldwide databases including Scopus, PubMed and ScienceDirect. Various applications of multivariate statistical methods in different archaeological areas are investigated and examined.

Materials and Methods

In this study, which is a review through previously published research, articles in which multivariate statistical method is applied in archaeological investigations have been extracted from three worldwide databases, i.e. PubMed, Scopus and Science Direct, based on a protocol designed to search for related articles from January 2000 to January 2016. We searched in the databases by using the following keywords: "Archeology", "multivariate analysis", "anthropology", "complicated statistical tools" with "OR" and "AND" and "NOT" Boolean Operators in the Title/Abstract/Keywords field (Table 1). Then the articles were controlled in order to be consistent with inclusion and exclusion criteria of the research. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) as a powerful and a common checklist in systematic reviews has been used for assessing the quality of the articles selected for this research. (http://www.prisma-statement.org).

The inclusion criteria in the selection of related articles are:

- Period of publication: from January 2000 to January 2016.
- Language: English.
- Databases: PubMed, Scopus, Science Direct.
- Methods: using a multivariate statistical method including cluster analysis, factor analysis, principal components analysis, discriminant analysis, multidimensional scaling and multivariate multiple regression.

These articles were excluded based on the exclusion criteria:

- Irrelevant articles.
- Duplicate articles.
- Articles that lacked full-text.
- Conference papers.

After application of inclusion and exclusion criteria, finally 384 articles were selected for this investigation. Then the details of the statistical methods and their application in archaeological research was extracted (details are shown in the Figure 1).

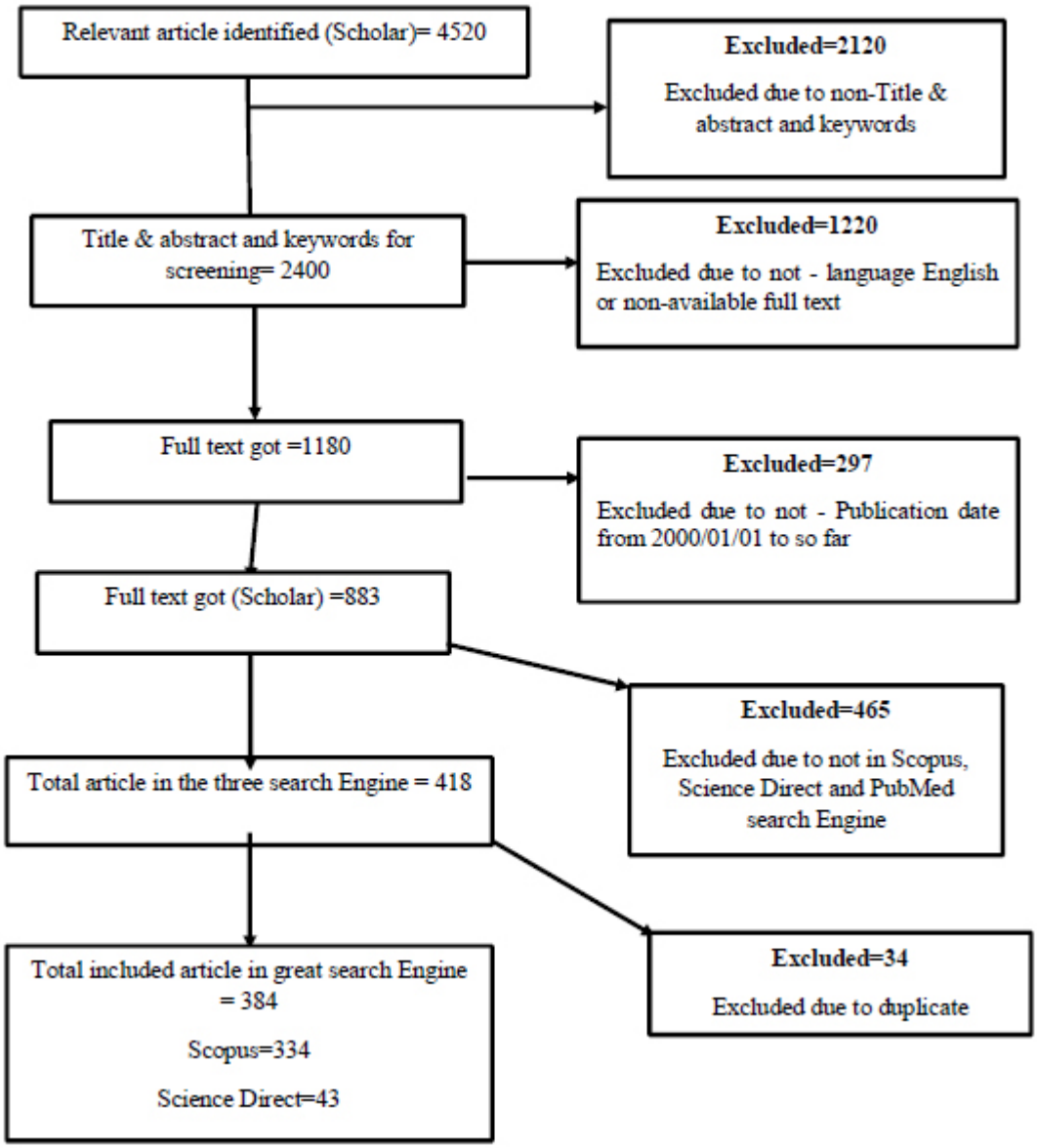

Fig. 1: Bibliographical search and inclusion process (PRISMA diagram).

To assess the quality of the articles, PRISMA check list was used. The list has 27 items and each item has a score or rating. PRISMA can assess all parts of an article including the title, abstract, introduction, methods, results as well as discussion and conclusion. Each part of an article could be assessed by maximum points in PRISMA and is assessed separately, for example the title has a maximal of 1 point, the abstract 1 point, the introduction 2 points, the method 12 points, the results 7 points and for discussion and conclusion there are 4 points. Hence and article could be assessed from 0 points to a maximum of 27 points. In this research, article with less than 15 points have been excluded due to unacceptable quality.

Next, each author investigated the articles separately and independently and extracted the required information from articles including:

- Authors specifications.
- Publication year.
- Journal specifications.
- Multivariate statistical methods applied.
- Cultural material under investigation.

All this information was documented in a database with proper structure in Excel (Table 2 in the Appendix).

Table 1 shows the search strategy of global databases in this research. In other words, it clarifies how inclusion and exclusion criteria have been applied for filtering period and language and other criteria to select specific articles properly. Using this search strategy makes it possible to use advanced search box in each of global databases for finding related articles.

Table 1: Search strategy
Search strategy in PubMed/ Scopus/Science Direct
((("Archeology"[MeSH Terms] OR "anthropology" [MeSH Terms]) AND ("multivariate analysis" [MeSH Terms] OR "complicated statistical tools" [Text Word]) OR ("cluster analysis"[MeSH Term]) OR "factor analysis"[MeSH Term]) OR "principal components analysis"[MeSH Term]) OR "discriminant analysis"[MeSH Term]) OR "multidimensional scaling"[Text Word]) OR "multiple regression"[MeSH Term]) OR "multivariate regression"[MeSH Term])) AND language (English) AND (Filters: Publication date from 2000/01/01 to so far)

Results

Using the strategy described above, a total of 4520 articles were retrieved from the three databases mentioned. 2120 of them were excluded because of irrelevant titles, abstracts and keywords. In the next step, 1220 articles were excluded due to non-English language or the unavailability of their full texts. From 1180 remaining articles, 292 articles were excluded because their publication year was earlier or later than the specific period of this research (i.e. 2000 - 2016); another 465 articles were excluded because they were not in the index of three databases (i.e. Scopus, Science Direct and PubMed); 34 more articles were excluded due to doubleness. Finally, after application of inclusion and exclusion criteria, 384 remaining articles were selected for the systematic review of this research (Figure 1).

Table 2 presents the information from some of the articles, including authors' specifications, titles, journals, publication year, etc. Articles concerning statistical methods in archaeology are mostly published in 2013 and the least of them are published in 2000. The results indicate that application of multivariate statistical methods in archaeology increased from 2009 and culminated in 2013. More than 50% of the article reviewed in this research have been published after 2010. Most of these articles are from Journal of Archaeological Science in the field of "Arts and Humanities" and are under publications of Springer and Elsevier. More than 30% of them are from American Scholars.

All of the 384 articles were classified based on multivariate statistical methods and then the application of these methods in archaeology and cultural material types was determined. In addition, more than one multivariate method was applied in some articles. Figure 2 presents the total number and relative frequency of application of each multivariate statistical method in archaeology. It shows that methods, including Cluster analysis, Principal Component Analysis, Discriminant Analysis, Multivariate Multiple Regression, Factor Analysis and Multidimensional Scaling have had respectively the highest application in archaeological investigations. In addition, Cluster Analysis (as a method of data reduction) was the most applied method in clustering archaeological sites based on similarities in cultural materials; also, Principal Component Analysis (as a dimensionality reduction method) was mostly applied in dimensionality reduction of cultural materials from archaeological sites. Various cultural materials have been analyzed in these articles and include human bones, fauna, pot sherds, chipped stones, flora and archaeological structures.

Table 2: Descriptive statistics for any type of multivariate approach.

Multivariate approach	The total number of each method have been used in the whole of 384 articles
Cluster Analysis	124 (32.4%)
Factor Analysis	21 (5.4%)
Principal Component Analysis	104 (27%)
Discriminant Analysis	83 (21.6%)
Multidimensional Scaling	10 (2.7%)
Multivariate Multiple Regression	42 (10.9%)

* All of cells reported according to frequency (percentage %)

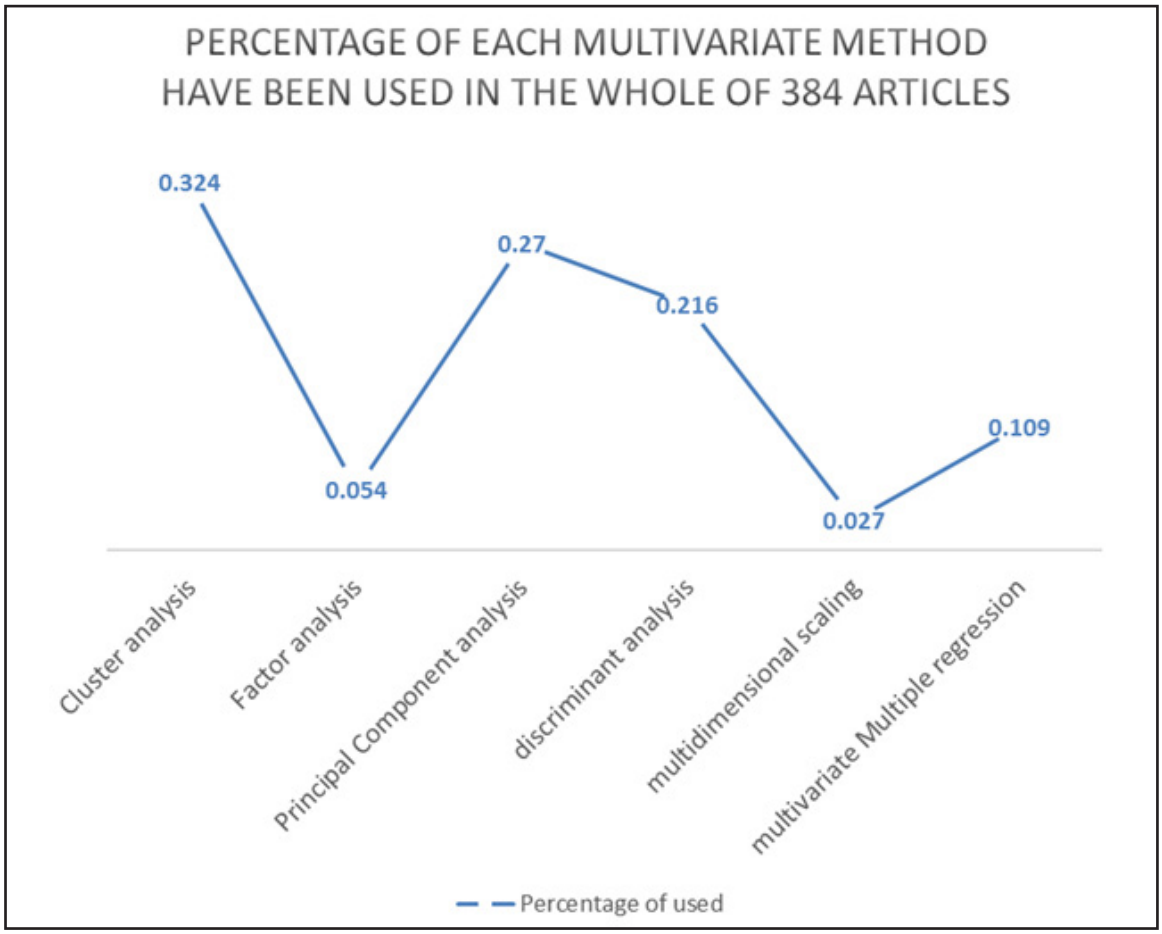

Fig. 2: Graphical display of percentages of multivariate approaches.

Discussion and Conclusion

There are two subsets of statistics in archaeology (Niknami 2012):

1) Primary statistics for describing various cultural material, e.g. chipped stones, fauna, bones, etc.

2) Analytical statistics for deduction, comparison and interpretation of archaeological data and their structures.

Although primary statistics have always been more used in description of cultural material (Froehle *et al.* 2012), in recent decades' application of advanced statistical methods in analytical research has notably increased; especially advanced multivariate statistical methods have been particularly applied since 2009, indicating the significance of statistical methods in archaeological research covering description to interpretation. Advanced statistical methods, one of the most important of which is multivariate methods, helps the researchers to improve their analysis and interpretation of individual to collective and help with the descriptions by considering errors in measurements (Stutz and Estabrook 2004).

Most of multivariate statistical methods are applied in surface surveys and there are a limited number of excavations in which the researcher has used Multivariate Multiple Regression for prediction. In surface survey and sampling, multivariate approaches are used in comparisons between collections (of chips, stones, organic materials, ceramics, etc.) from different sites or comparison and interpretation of site structures (Drennan 2009; Craig *et al*. 2006).

This study aims to encourage archaeologists to use advanced statistical methods, esp. multivariate methods in archaeological research. Advanced statistical methods could have a wide variety of applications. They have various applications in archaeology as well, as in most areas of archaeological research from surface survey to excavation and archaeological interpretation.

The results of this systematic review indicate that cluster analysis is one of the most applied statistical analysis, perhaps because of usage, method and simple interpretation, compared to other methods of data reduction (Kovarovic *et al.* 2011). This method is used for

data reduction or clustering archaeological sites based on their similarities and helps with the comparison between site structures (Papageorgiou and Liritzis 2007; Hart and Matson 2009).

Principle Component Analysis is the second most widely used methods due to its application in any data structure and simplicity of interpretation compared to other methods of dimensionality reduction. Methods of dimensionality reduction are mostly applied in the cultural material classification and categorizing archaeological material from surface sampling and simple interpretation of archaeological sites. It seems that in future research more data reduction methods and dimensionality reduction methods would be applied, because more surface surveys than excavations are encouraged.

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Conflict of interest:

All authors declare that there is no conflict of interests in the current study.

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