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GEOSTATISTICAL MAPPING OF POTTERY VARIATION: THE NORTHERN LANDS OF WESTERN ASIA DURING THE MIDDLE BRONZE AGE

1. Introduction

In archaeology, the conventional visual representation of ceramic variation often presents a static and potentially misleading view of the past. This is particularly evident in distribution maps of ceramic 'cultures', where sites yielding a specific pottery assemblage are represented as dots enclosed within a geometric feature that aims to display a homogeneous, coherent, and bounded cultural entity. Such a mapwork, rooted in Cultural History (Webster 2008; Crellin 2020, 28-30), considers pottery as the product of a distinct human group (Childe 1929, v-vi) and interprets the presence of similar ceramic repertoires or attributes across different sites, even those geographically distant, as evidence of the diffusion of that culture over those sites (Babić 2007, 75; Johnson 2020, 20).

Despite technological and methodological advancements in map-making, particularly with the introduction of Geographic Information Systems (GIS) and GIS-based mapping and spatial analysis software, the culture-historical paradigm still underlies the visualisation of prehistoric cultural groups, particularly in ancient western Asian contexts (e.g., Aurenche, Kozlowski 2011). However, this culture-historical, diffusionist approach to representing ceramic variation falls short of acknowledging the intricate and diverse nature of cultural phenomena. Although simplification is necessary and inevitable in the spatial investigation of archaeological artefacts (Wheatley, Gillings 2000, 8), conventional distribution maps risk representations of only 'geometries on descriptive maps' enclosed within what can be perceived as a fixed cultural landscape. Secondly, cultural-historical mapping is biased by what we may define as 'similarity primacy', i.e. the emphasis on shared ceramic traits at the expense of pottery differences. Lastly, this map-making process eventually ignores 'blank' areas, i.e. those empty zones between sites (Hodder 1977, 38; Aldred, Lucas 2018, 28). In this context, distribution maps of diagnostic sherds, types, or styles describe similarities, ignoring differences – the other half component of the overall variation – and most of the landscape.

This paper addresses the limitations above by introducing a novel methodological strategy for mapping ceramic variation. Our approach considers similarities and differences in ceramic traits and incorporates geostatistical methods, i.e. kriging, to visually represent the intrinsic complexity and diversity of pottery distribution. By doing so, we seek to move beyond the static cultural-historical mapping approach and provide a more nuanced understanding of the complex nature of pottery-driven archaeological landscapes. To achieve this, we will apply our analysis to a case study involving legacy pottery data, demonstrating the practical application and potential insights gained from our proposed methodology. Through this work, we aspire to contribute to the advancement of archaeological methods and foster a more comprehensive understanding of the past.

2. The case study

The 'Northern Lands' of western Asia indicate the wide area encompassing the territories of modern eastern Turkey, northeastern Syria, northern Iraq, northwestern Iran, Armenia, Georgia, Azerbaijan, and the Nakhchivan Autonomous Republic. These areas are historically known as eastern Anatolia, upper Mesopotamia, and the southern Caucasus (Fig. 1). Since the late 19th century, archaeological research in the Northern Lands has aimed to reconstruct its chronological framework and cultural landscape from material culture, due to the lack of written sources before the first millennium BCE. Amongst all the periods identified by archaeologists, the end of the third to the first half of the second millennium BCE – or Middle Bronze Age in Caucasian archaeology – is one of the most intriguing concerning ceramic productions. Overall, the area experienced a fragmentation of the cultural homogeneity of the third millennium BCE, represented by two main broad ceramic horizons, the Kura-Araxes and the Ninevite V assemblages (Rova

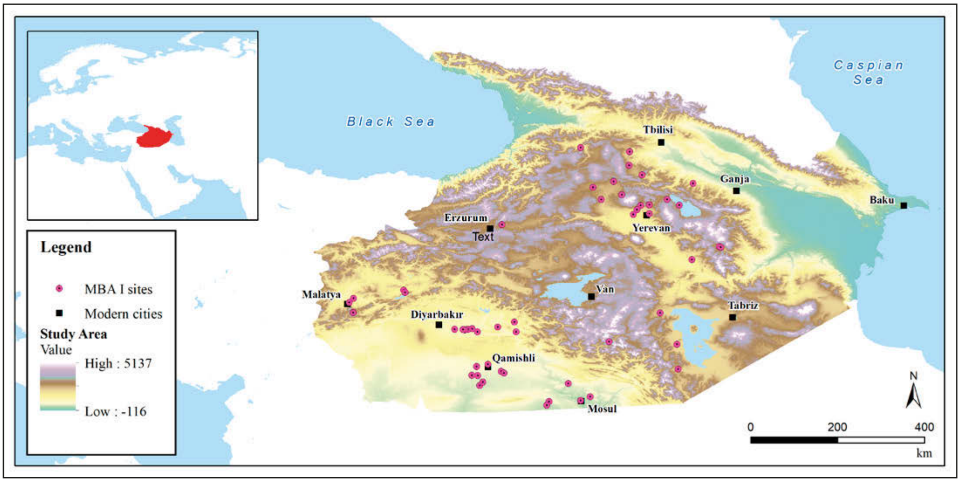

Fig. 1 – The Northern Lands of western Asia with the sites (in pink) used for analysis.

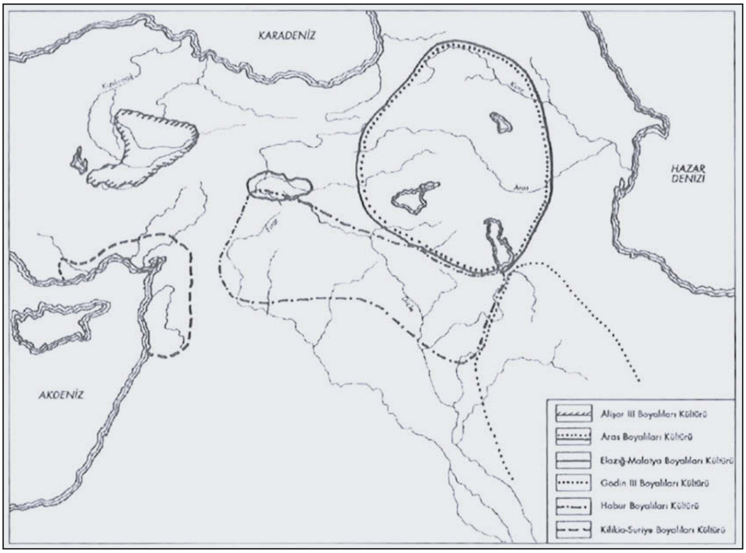

Fig. 2 – Ceramic cultures in the Northern Lands during the Middle Bronze Age (modified from Özfırat 2001, fig. 1).

1988, 151-157; Palumbi 2008; Sagona 2011, 695). Towards the beginning of the second millennium BCE, more regionalised, mainly painted ceramic repertories emerged, which scholars linked, amongst other factors, to shifts in subsistence economy and increased human mobility (Kramer 1977; Baysal 2012; Sagona 2018, 331-332).

A. Özfırat (2001) analysed and summarised data from previous studies, offering the first distribution map of the ceramic groups of the Northern Lands during the Middle Bronze Age. In her mapwork, ceramic groups of the phase between 2000 and 1600 BCE are graphically shown by shapes with differently hatched outlines (Fig. 2). Özfırat's endeavour is commendable for its pioneering efforts in synthesising available data and presenting a visual representation of ceramic distribution, serving as a valuable reference point for further archaeological inquiries. However, a reassessment of legacy pottery data was undertaken to provide a new visual understanding of the complex ceramic diversity of the Northern Lands during the Middle Bronze Age.

3. Methods and analysis

The analytical strategy implemented here involved three main steps: 1) data collection and preparation; 2) quantification of ceramic variation; and 3) mapping. Data was organised and analysed using the R language program (R

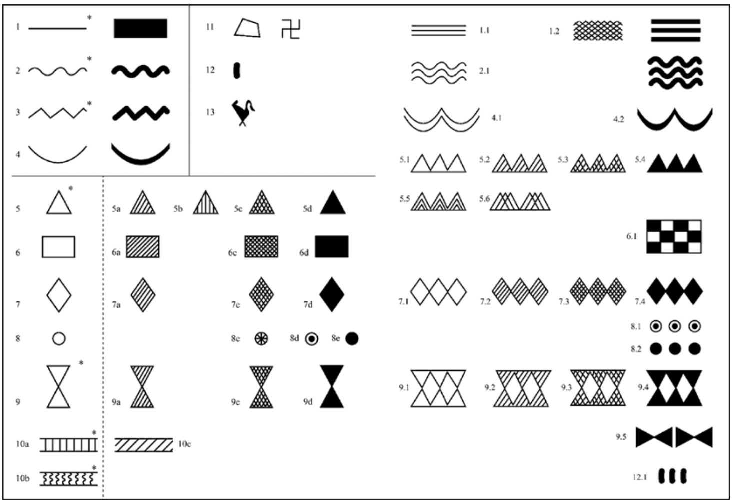

Fig. 3 – Sample of decorative traits analysed in this paper.

Core Team 2020) and the ArcGIS 10.8.2 platform (Esri 2021)[1]. This paper presents only the analysis of decorative traits – thus excluding shapes – for the period between 1950 and 1750 BCE (i.e., MBA I, Middle Bronze Age I).

3.1 *Data collection and preparation*

The re-evaluation of legacy pottery data included the scrutiny of approximately 300 publications, either preliminary excavation reports, final studies, or specialist contributions, written in several languages (e.g., English, Italian, French, Turkish, German, Japanese, Armenian, Azeri, and Russian). This allowed the identification of 51 sites yielding 67 MBA I site phases and 132 pottery decorative characteristics analytically and chronologically relevant (Fig. 3). This information was organised in a relational dataset. Excavated sites were univocally classified by assigning unique IDs. Other fields included site location (if not explicitly published, coordinates were obtained by visual detection on Google Earth Pro), cultural affiliation (membership to specific cultural groups as defined by archaeologists) and chronological details (relative or absolute dating) (Fig. 4a). Site phases - i.e., 'PhaseCode' in the matrices

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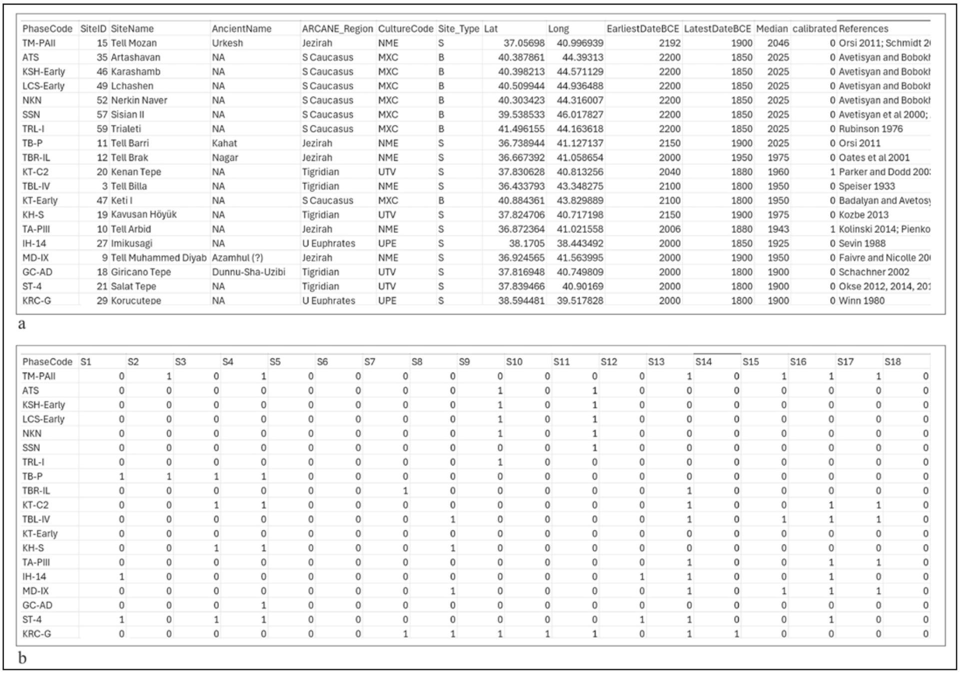
[1] As this research is part of my doctoral work, codes and models will be published in open access once the embargo on the dissertation expires. To enhance data reusability, the dataset used will be published according to the FAIR (Findable, Accessible, Interoperable, Reusable) principles (Wilkinson *et al*. 2016). Hence, data will be assigned a globally unique and persistent identifier (DOI), stored in a freely accessible repository (Apollo, University of Cambridge), and released with a clear and accessible data usage licence (CC BY 4.0).



PhaseCode	SiteID	SiteName	AncientName	ARCANE_Region	CultureCode	Site_Type	Lat	Long	EarliestDateBCE	LatestDateBCE	Median	calibrated	References
TM-PAII	15	Tell Mozan	Urkesh	Jezirah	NME	S	37.05698	40.996939	2192	1900	2046	0	Orsi 2011; Schmidt 2
ATS	35	Artashavan	NA	S Caucasus	MXC	B	40.387861	44.39313	2200	1850	2025	0	Avetisyan and Bobok
KSH-Early	46	Karashamb	NA	S Caucasus	MXC	B	40.398213	44.571129	2200	1850	2025	0	Avetisyan and Bobok
LCS-Early	49	Lchashen	NA	S Caucasus	MXC	B	40.509944	44.936488	2200	1850	2025	0	Avetisyan and Bobok
NKN	52	Nerkin Naver	NA	S Caucasus	MXC	B	40.303423	44.316007	2200	1850	2025	0	Avetisyan and Bobok
SSN	57	Sisian II	NA	S Caucasus	MXC	B	39.538533	46.017827	2200	1850	2025	0	Avetisyan et al 2000;
TRL-I	59	Trialeti	NA	S Caucasus	MXC	B	41.496155	44.163618	2200	1850	2025	0	Rubinson 1976
TB-P	11	Tell Barri	Kahat	Jezirah	NME	S	36.738944	41.127137	2150	1900	2025	0	Orsi 2011
TBR-IL	12	Tell Brak	Nagar	Jezirah	NME	S	36.667392	41.058654	2000	1950	1975	0	Oates et al 2001
KT-C2	20	Kenan Tepe	NA	Tigridian	UTV	S	37.830628	40.813256	2040	1880	1960	1	Parker and Dodd 200
TBL-IV	3	Tell Billa	NA	Tigridian	NME	S	36.433793	43.348275	2100	1800	1950	0	Speiser 1933
KT-Early	47	Keti I	NA	S Caucasus	MXC	B	40.884361	43.829889	2100	1800	1950	0	Badalyan and Avetos
KH-S	19	Kavusan Höyük	NA	Tigridian	UTV	S	37.824706	40.717198	2150	1900	1975	0	Kozbe 2013
TA-PIII	10	Tell Arbid	NA	Jezirah	NME	S	36.872364	41.021558	2006	1880	1943	1	Kolinski 2014; Pienko
IH-14	27	Imikusagi	NA	U Euphrates	UPE	S	38.1705	38.443492	2000	1850	1925	0	Sevin 1988
MD-IX	9	Tell Muhammed Diyab	Azamhul (?)	Jezirah	NME	S	36.924565	41.563995	2000	1900	1950	0	Faivre and Nicolle 20
GC-AD	18	Giricano Tepe	Dunnu-Sha-Uzibi	Tigridian	UTV	S	37.816948	40.749809	2000	1800	1900	0	Schachner 2002
ST-4	21	Salat Tepe	NA	Tigridian	UTV	S	37.839466	40.90169	2000	1800	1900	0	Okse 2012, 2014, 20
KRC-G	29	Korucutepe	NA	U Euphrates	UPE	S	38.594481	39.517828	2000	1800	1900	0	Winn 1980

a

PhaseCode	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18
TM-PAII	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	1	1	0
ATS	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
KSH-Early	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
LCS-Early	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
NKN	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
SSN	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
TRL-I	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
TB-P	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TBR-IL	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
KT-C2	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	0
TBL-IV	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1	1	0
KT-Early	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KH-S	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
TA-PIII	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0
IH-14	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0
MD-IX	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1	1	0
GC-AD	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ST-4	1	0	1	1	0	0	0	0	0	0	0	1	1	0	0	1	0	0
KRC-G	0	0	0	0	0	0	1	1	1	1	1	0	1	1	0	0	0	0

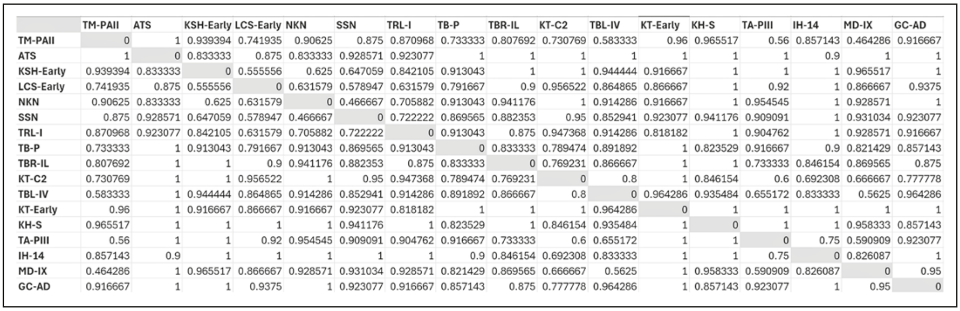
b

Fig. 4 – Snapshots of the dataset organisation: a) site information and b) presence-absence matrix (PAM).

and unique identifiers for each level at a site – were then associated with the stylistic traits in a presence-absence matrix (PAM) with site phases as rows and attributes as columns. Here, each trait's presence or absence (respectively, 1 and 0 values) could be registered for each site phase (Fig. 4b).

3.2 *Quantification of ceramic variation*

Using the 'vegan' package in R (Oksanen *et al*. 2022), Jaccard distance was computed on the PAM to quantify how individual sites differed in stylistic traits. Jaccard distance measures the dissimilarity between a pair of samples: the result is a symmetric matrix of sites with zeroes on the diagonal and numerical indices ranging between 0 (identical shared traits) and 1 (complete dissimilarity with no shared attributes) on the other fields (Fig. 5). Compared to other distance measures, the Jaccard distance is handy for archaeological data as it ignores shared absent values (Shennan 1988, 203). In partial archaeological datasets, in fact, the absence of attributes does not necessarily imply that those were not used at the site but that perhaps they have not been found yet. This, together with the assumption that all traits are



	TM-PAII	ATS	KSH-Early	LCS-Early	NKN	SSN	TRL-I	TB-P	TBR-IL	KT-C2	TBL-IV	KT-Early	KH-S	TA-PIII	IH-14	MD-IX	GC-AD
TM-PAII	0	1	0.939394	0.741935	0.90625	0.875	0.870968	0.733333	0.807692	0.730769	0.583333	0.96	0.965517	0.56	0.857143	0.464286	0.916667
ATS	1	0	0.833333	0.875	0.833333	0.928571	0.923077	1	1	1	1	1	1	1	0.9	1	1
KSH-Early	0.939394	0.833333	0	0.555556	0.625	0.647059	0.842105	0.913043	1	1	0.944444	0.916667	1	1	1	0.965517	1
LCS-Early	0.741935	0.875	0.555556	0	0.631579	0.578947	0.631579	0.791667	0.9	0.956522	0.864865	0.866667	1	0.92	1	0.866667	0.9375
NKN	0.90625	0.833333	0.625	0.631579	0	0.466667	0.705882	0.913043	0.941176	1	0.914286	0.916667	1	0.954545	1	0.928571	1
SSN	0.875	0.928571	0.647059	0.578947	0.466667	0	0.722222	0.869565	0.882353	0.95	0.852941	0.923077	0.941176	0.909091	1	0.931034	0.923077
TRL-I	0.870968	0.923077	0.842105	0.631579	0.705882	0.722222	0	0.913043	0.875	0.947368	0.914286	0.818182	1	0.904762	1	0.928571	0.916667
TB-P	0.733333	1	0.913043	0.791667	0.913043	0.869565	0.913043	0	0.833333	0.789474	0.891892	1	0.823529	0.916667	0.9	0.821429	0.857143
TBR-IL	0.807692	1	1	0.9	0.941176	0.882353	0.875	0.833333	0	0.769231	0.866667	1	1	0.733333	0.846154	0.869565	0.875
KT-C2	0.730769	1	1	0.956522	1	0.95	0.947368	0.789474	0.769231	0	0.8	1	0.846154	0.6	0.692308	0.666667	0.777778
TBL-IV	0.583333	1	0.944444	0.864865	0.914286	0.852941	0.914286	0.891892	0.866667	0.8	0	0.964286	0.935484	0.655172	0.833333	0.5625	0.964286
KT-Early	0.96	1	0.916667	0.866667	0.916667	0.923077	0.818182	1	1	1	0.964286	0	1	1	1	1	1
KH-S	0.965517	1	1	1	1	0.941176	1	0.823529	1	0.846154	0.935484	1	0	1	1	0.958333	0.857143
TA-PIII	0.56	1	1	0.92	0.954545	0.909091	0.904762	0.916667	0.733333	0.6	0.655172	1	1	0	0.75	0.590909	0.923077
IH-14	0.857143	0.9	1	1	1	1	1	0.9	0.846154	0.692308	0.833333	1	1	0.75	0	0.826087	1
MD-IX	0.464286	1	0.965517	0.866667	0.928571	0.931034	0.928571	0.821429	0.869565	0.666667	0.5625	1	0.958333	0.590909	0.826087	0	0.95
GC-AD	0.916667	1	1	0.9375	1	0.923077	0.916667	0.857143	0.875	0.777778	0.964286	1	0.857143	0.923077	1	0.95	0

Fig. 5 – Snapshot of the Jaccard dissimilarity matrix.

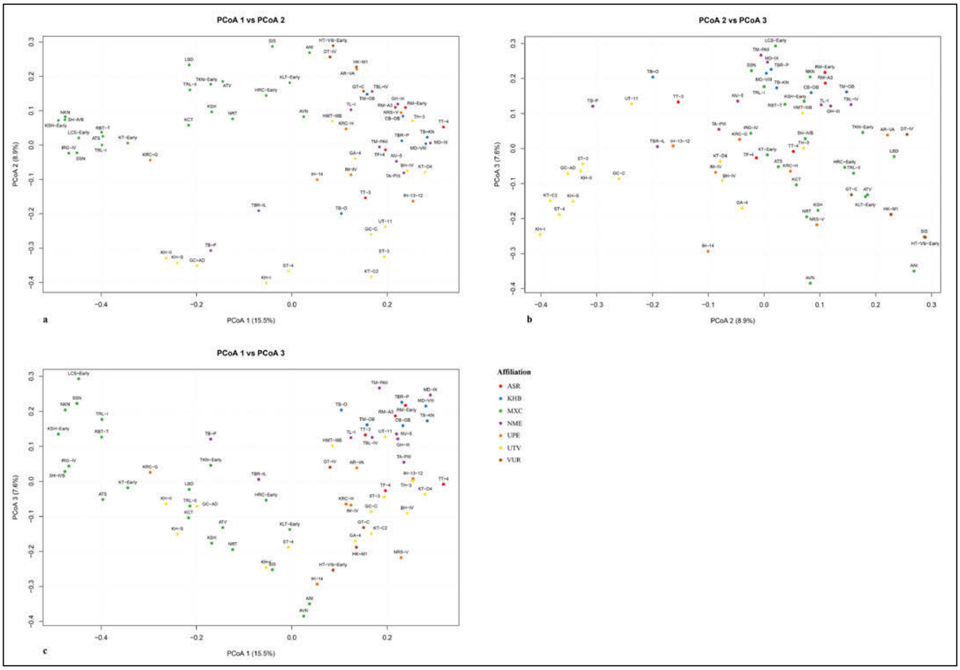


Fig. 6 – Plots showing the results of the first three PCoA axes.

independent from the cultural affiliation attributed by archaeologists, makes the Jaccard distance a powerful tool for analysing archaeological inter-site dissimilarity (Shennan *et al.* 2015).

At this step, multivariate analytical techniques can be implemented to explore and visualise individual or group differences (Wilkinson, Edds 2001). This study used Principal Coordinate Analysis (PCoA), an ordination

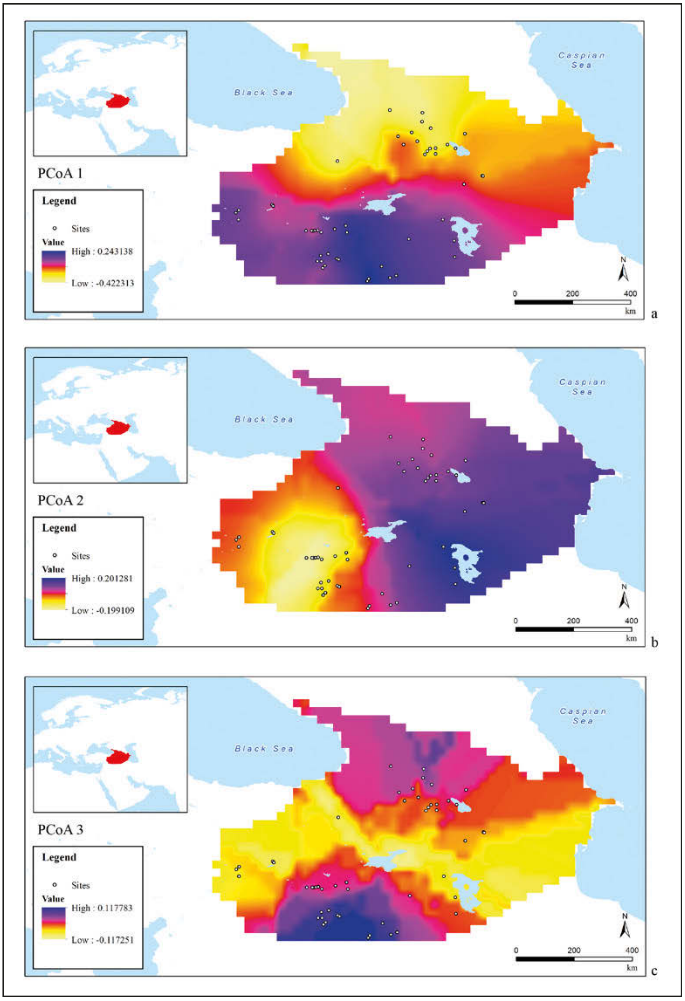


Fig. 7 – Interpolated maps using Ordinary Kriging showing the geographic representation of the first three PCoA axes. Similar colours describe similar values in cultural variation.

technique applicable when analysing binary data and based on an eigenvalue equation, that allows the display of how much 'dissimilar' sites are to one another based on several variables simultaneously (Gower 1966). PCoA finds the 'principal' axes explaining variation through a distance (e.g., Jaccard) matrix and then plots these axes against each other in a low-dimensional Euclidean space (Zuur *et al*. 2007, 259-264). In this space, sites ordinated closer together have smaller dissimilarity values than those ordinated further apart. Here, PCoA was computed through the 'stats' (R Core Team 2020) and 'ape' (Paradis, Schliep 2019) packages in R.

One can visually understand between-site differences by plotting and contrasting PCoA axes (Fig. 6). For our case study, only the first PCoA three axes are considered. These explain 32% of the overall ceramic variation. The plots show a weak regionalisation, with only sites of the southern Caucasus being dissimilar from the other cultural groups, which instead tend to be closer or overlap. This might be related to high mobility, exchange, or assimilation phenomena that favoured the spread of ceramic traits in these regions (e.g., the Old Assyrian Trade Network in northern Mesopotamia).

3.3 *Mapping*

After obtaining the scores of the PCoA axes, geostatistical maps were created in ArcGIS through interpolation methods to display better cultural variation. This paper applied ordinary kriging (OK), which is based on the spatial arrangement of empirical observations to estimate the value of a variable over a continuous spatial field (e.g., Divíšek *et al.* 2016). In this sense, using PCoA axes, OK informs us on how varied the cultural landscape is, also providing the probability of how much variation is at a non-sampled specific location. The outputs are several maps, each for a single PCoA axis, visualising a fraction (15.5%, 8.9%, and 7.6%) of ceramic variation predicted for the areas that were not sampled (Fig. 7). In this case as well, results show a heterogenous landscape, with only a main N-S distinction in terms of ceramic diversity.

4. Conclusions and further directions

PCoA performed on the pottery-based dissimilarity distance matrix and OK interpolation allowed a nuanced visualisation of the ceramic variation in decorative traits of the Northern Lands during the MBA I. Geostatistical maps in Fig. 7 visualise only a fraction (32%) of the overall diversity, highlighting that the distribution of pottery attributes is far less static than commonly represented in distribution maps. Hence, such maps show the dynamic and complex essence of cultural phenomena, which cannot be encapsulated into one cartographic device.

More importantly, geostatistical map-making addresses some of the limitations of conventional distribution maps. First, our data-driven approach considers both similarities and differences within ceramic assemblages, thus avoiding the 'similarity primacy'. Secondly, it predicts values in blank areas based on measured variation at sampled sites. In this sense, it shows a less homogeneous cultural landscape, hinting at areas that could have served as boundary or 'mixing' zones.

The approach presented here opens possibilities for further investigation: for instance, analysis can attempt to reassess the existence or extent of ceramic cultures and their boundaries; test the dataset for spatial correlation to build hypotheses on the socioeconomic, cultural, or environmental factors that may generate the variation patterns; check individual site behaviour to acquire information on whether a site was prone to share or isolate a specific ceramic trait. Through these efforts, our study advances archaeological methods and deepens our understanding of past societies within the Northern Lands during the Middle Bronze Age phase.

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ABSTRACT

This paper challenges conventional mapping methods of Bronze Age ceramic variation in western Asian archaeology, which often oversimplify the complexity of cultural phenomena. Drawing on geostatistical techniques, we propose a novel approach that considers both similarities and differences in ceramic traits. By incorporating Principal Coordinate Analysis (PCoA) and kriging interpolation techniques, our methodology aims to provide a nuanced representation of pottery distribution, moving beyond static cultural-historical mapping. We argue that this approach offers a more comprehensive understanding of archaeological landscapes by acknowledging the diversity of pottery variation. Through a case study utilising legacy pottery data – which will be published in the future according to the FAIR principles – we demonstrate the practical application and potential insights of our methodology, which seeks to advance archaeological methods and contribute to a richer interpretation of the past.