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RESEARCH ARTICLE

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A model of spatial location: New data for the Gor River megalithic landscape (Spain) from LiDAR technology and field survey

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Abstract

The megalithic cluster of the Gor River valley (Andalusia, Spain) is one of the biggest dolmenic groups in Europe, made up of 151 preserved megaliths. In spite of this high number of known monuments, increasing loss and destruction of many of the graves has taken place during the last decades due to enormous soil erosion and anthropogenic activities. With the aim of recording the location of these lost megaliths, Digital Terrain Models and LiDAR data have been used to analyse the terrain showing a high quantity of structures that seem similar to those actually documented in the zone but that were not noticed until now. These possible new burial mounds have been tested by archaeological surface survey, choosing three contrasting areas as samples. Results have shown a high success rate for this methodology, even allowing the discovery of new megalithic graves in heavily researched areas. We interpret the likely higher number of burial mounds in the area to indicate greater territorial control in boundary areas between 4th and 3rd millennium BC.

KEYWORDS

Iberian southeast, LiDAR mapping, megalithic sites, preservation and destruction patterns, spatial statistics, surface survey

1 | THE MEGALITHIC LANDSCAPE OF THE GOR RIVER VALLEY

The megalithic cluster of the Gor River valley, situated at the NE of Granada province (Andalusia, Spain), is one of the biggest dolmenic groups in Europe, made up of 151 preserved megaliths according to the last catalogue recorded in the summer of 2019 (Cabrero et al., 2021) (Figure 1).

Despite the high number of megalithic monuments, loss and destruction of many of them has been continuous in recent decades as over 240 burial mounds existed in the area according to catalogues from the end of 19th century (García-Sánchez & Spahni, 1959; Siret, 2001), which means that, at least, 36.56% of the megaliths have been lost or destroyed (Spanedda et al., 2014). This is due to a relative lack of preservation measures (Montufo, 2019) and fewer research projects conducted in the area in recent decades, where only partial surface surveys have been carried out (Afonso et al., 2006; Spanedda et al., 2014).

Results of past research projects allow selection of areas to be visited (Manarqueoteca, 2001), definition of burial mound roles as displacement route markers from the ravines to the surrounding plateau (Afonso et al., 2006; Spanedda et al., 2014), discovery of a general

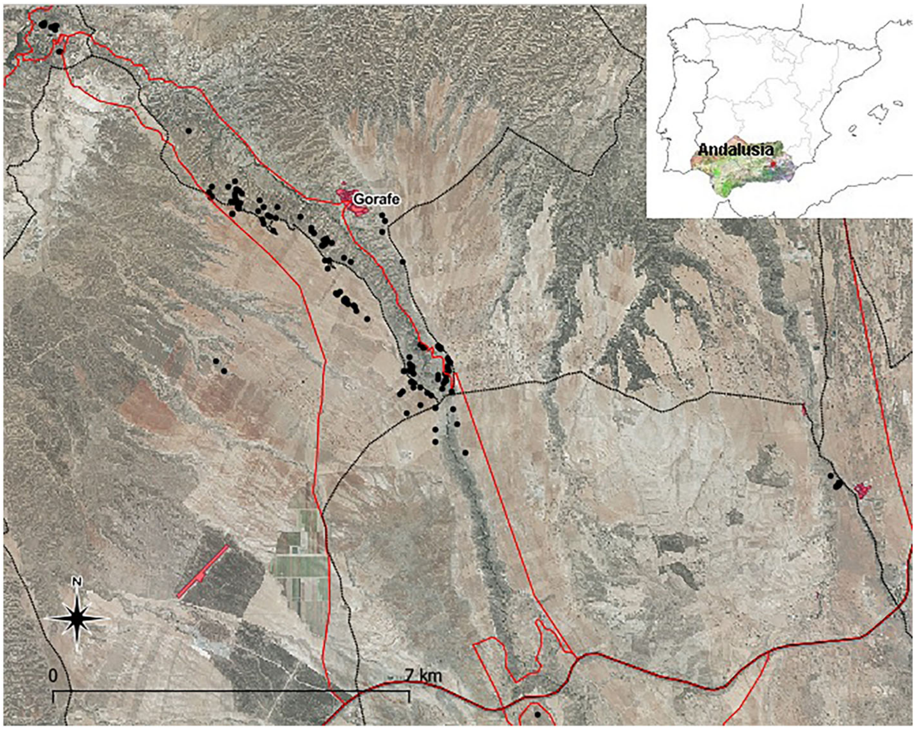

FIGURE 1 Location of the preserved dolmens in the Gor River valley (black dots) over orthophoto and topographic vector map (red lines: road network, black lines: municipal borders) (Cabrero et al., 2021) [Colour figure can be viewed at wileyonlinelibrary.com]

intervisibility system throughout the valley (Cabrero et al., 2020) and documentation of reuse processes, mainly during the Final Bronze Age and Early Iron Age (around 1300–750 cal BC) (Lorrio, 2008). Although no radiocarbon dates are available, dates of nearby necropolises (Aranda et al., 2018, 2022) and materials recovered in tombs suggest a process of construction and initial use between the Late Neolithic and the Late Chalcolithic (around 3500–2200 cal BC).

The starting point for this work is the cited catalogue carried out in 2019, which focused on burial mounds placement, associated terrain characteristics and other variables also related to the territory such as the orientation of the dolmens relative to the main geographic landmarks. In the same way, an evaluation of dolmen preservation status was made (Cabrero et al., 2021). The results gave rise to several questions related to preservation-disappearance patterns of these burial mounds. For example, in the area named "Llano del Instituto" (necropolis of Llano de la Cuesta de Guadix), 13 mounds that are supposed to be preserved dolmens appear covered by small to medium stones (creating so-called "majanos"), and only some orthostates or supposed burial chamber spaces are visible (Figure 2).

FIGURE 2 "Majanos" situated in the subgroup of Llano del Instituto [Colour figure can be viewed at wileyonlinelibrary.com]

This fact necessitates reference to past archaeological research results, including old bibliographical references and maps, in order to identify partially destroyed megaliths, attending to previous and limited data about their placement, sometimes with imprecise locations. Notwithstanding, the complete area (around 1.3 km^2) is full of these stone mounds, so we may ask: Why has it been considered that only some of them and not others (or all of them) cover a megalithic structure, if, in any case, there are no visible orthostates because of the accumulated stones? This question is especially important if we consider the above-mentioned problem regarding the amount of possible lost megaliths from the first researches (Siret, 2001). As we will show, the possibility of hidden but not totally destroyed dolmens has gained weight in a recent evaluation by means of LiDAR (light detection and ranging) data in order to try to identify the location of these lost and missing megaliths, some of them perhaps documented in the past. This remote surface survey has given results that have largely exceed expectations: 230 new possible burial mounds have been identified, and many are very similar to the characteristics that can be observed in maps for currently preserved dolmens (coinciding with them in shape and size).

These 230 points (mounds) have been identified by size, shape or distance between each other, so only figures that are similar to the others recorded in the previous catalogues have been marked. In this paper, we propose a methodology for the study of prehistoric burial mounds distribution at Gor River, combining ancient bibliographical data, remote sensing and systems to test the resulting locations in order to select the most likely to be (or to have been) megaliths, by using statistical analyses and surface surveys. This non-traditional method addresses the difficulty of identifying structures that cannot be observed on the surface because of poor preservation or complete burial. Results can be useful not only to increase our catalogue of dolmens in the area or to provide better results regarding burial mounds distribution patterns or preservation ratios but also to evaluate the possibilities of LiDAR in the identification of small and medium size archaeological sites, in this case, the megaliths, as have been tested in other Iberian cases (Berganzo-Besga et al., 2021; Carrero-Pazos et al., 2014; Carrero-Pazos & Vilas, 2015; Cerrillo-Cuenca, 2016, 2017; Cerrillo-Cuenca & Bueno-Ramírez, 2019; Rodríguez-Del Cueto & Carrero-Pazos, 2021).

This project created a new web of points containing possible locations of megaliths using LiDAR-derived DTMs. Then, points that closely match known dolmens are statistically filtered according to shape, size and placement. These results allowed us to plan intensive archaeological surface surveys in specific areas with the aim of contrasting with others (as made in other areas, Davis et al., 2020, 2021), which could also include archaeological geophysical prospections and limited excavations to get better conclusions in the future.

2 | LiDAR BACKGROUND AND PREHISTORIC BURIAL MOUNDS

LiDAR data, DTMs derived from them, and other similar tools and products are closely related to GIS technology and multidisciplinary research, as well as to the recent so called "spatial turn" (Cinnamon & Schuurman, 2013), which refers to the practice of approaching any phenomenon or reality from its spatial dimension and its relationship with the surrounding geographic territory. This perspective is particularly relevant to this project due to the close relationship between the location patterns of the dolmens and their surrounding area.

LiDAR uses a pulsed laser beam sent from an aircraft to the ground surface (Chen, 2007; Shan & Aparajithan, 2005). This light is sent and received several times in order to generate a point cloud of the terrain that allows to know its geography in detail by measuring the time that the laser takes to return to the aircraft (Csanyi & Charles, 2007; Kraus & Pfeifer, 2001). Every point in the point cloud is georeferenced by its XYZ coordinates, and it is also classified according to the type of layer that reflected the laser pulse. This classification was standardized by the American Society for Photogrammetry and Remote Sensing (ASPRS) and includes basic geographical or urbanistic categories as soil or bare earth terrain, water, low, medium and high vegetation, edifications and others.[1] Each point composes independent layers classified in these categories, which represents the main strength of this technology (Devereux et al., 2005; Liu et al., 2007). The data package of every point or point cloud captured by the movements of the laser is mostly presented in LAS format (or LAZ, a compressed version of LAS), which is the common exchange format for LiDAR data, also created by ASPRS. In the case of the dataset created by the National Geographic Institute (IGN) and referred in this work, only the data obtained during the first LiDAR coverage of the Spanish territory, carried out between 2009 and 2015, were available.[2] These data have been collected within the project PNOA–LiDAR in the framework of the National Plan of Aerial Orthophotography since 2009, which were freely downloaded (https://pnoa.ign.es/el-proyecto-pnoa-LiDAR, accessed 28 July 2022). A second IGN LiDAR campaign is currently in progress and only partially published. This means that the datasets are in continuous improvement and that a higher level of precision is planned. While the minimum density of points in the first coverage is 0.5 points/m^2, a minimum of 0.5–4 points/m^2 is found in the second one, including selected areas where a higher density was achieved due to special conditions, and a grid spacing of 2 × 2 m. The difference between measured and observed Z or RMSE Z is ≤40 cm in the first coverage and ≤20 cm in the second one, while the estimated altimetric precision is ≤30 cm in both cases. This means that the application of this method to archaeology may also be reviewed as this technology will advance with the aim of refining the methodology and improving results. Nevertheless, these conditions and the creation of a Triangulated Irregular Network (TIN) allows a resolution of 1 m^2/pixel. The data are distributed in digital files with LAS/LAZ format that cover 2 km^2 each, which means that the first coverage is composed of 325 files for the entire country.

As it allows us to work on independent layers of the terrain, this type of mapping is especially useful, as leftover elements like the constructions, that were not present in prehistoric times, can be easily omitted in order to facilitate the analysis on the surface features. Moreover, this technology is highly useful for studying areas with dense vegetation, very wide zones, difficult-to-access areas or even effective prospection of areas that cannot be physically accessed due to distance or authorizations (Bourgeois, 2013; Ebert et al., 2016; Fryskowska et al., 2017; Myers, 2010; Rodríguez-del Cueto & Carrero-Pazos, 2021; Schindling & Gibbes, 2014). Some of these scenarios are particularly interesting, as dense vegetation or difficult-to-access areas tend to facilitate the preservation of archaeological structures as they are rarely travelled or anthropomorphically modified (Cerrillo-Cuenca, 2017; Doneus et al., 2008). Besides, the advantages of non-invasive methods must be highlighted, as they cause no damage to archaeological heritage and they allow an enormous saving in terms of time and costs if we compare them to traditional archaeological interventions, including pedestrian surface surveys (Kvamme, 2003). A comparison with data of successive previous researches is, however, expected in order to contrast the obtained results (Berganzo-Besga et al., 2021; Davis et al., 2020, 2021; Sánchez Díaz et al., 2022).

This tool allows not only to document new structures but also to review already known sites in order to find new spaces and shapes, sometimes not visible on the surface (Albrecht et al., 2019; Davis, Lipo, & Sanger, 2019; Davis, Sanger, & Lipo, 2019; Sánchez Díaz et al., 2022). Even though the application of LiDAR data in archaeology is an increasingly common practice, its possibilities have been scarcely explored in relation to megaliths and other burial mounds (Berganzo-Besga et al., 2021; Carrero-Pazos et al., 2014; Carrero-Pazos & Vilas, 2015; Cerrillo-Cuenca, 2016, 2017; Cerrillo-Cuenca & Bueno-Ramírez, 2019; Davis et al., 2020, 2021; Davis, Lipo, & Sanger, 2019; Davis, Sanger, & Lipo, 2019; Gaffney et al., 2013; Guyot et al., 2018; Rodríguez-Del Cueto & Carrero-Pazos, 2021), probably because of the difficulties that this phenomenon presents especially considering that most of the monuments with burial mounds are less than 20 m in diameter and chambers are less than 20 m^2. DTMs based on LiDAR data (at least the open access data currently available) have at the moment a maximum resolution of 1 m^2/pixel, which means that few megaliths are easily recognizable (only the largest ones) and most of them (as the ones that we find in the SE of the Iberian Peninsula, for example, in the Gor River valley) are not easily visible because of their small size (median chamber length of 2 m, median corridor length of 1 m, following Esquivel et al., 2021). Even the burial mounds, with a size expected to be easily recognizable by LiDAR analysis, have been eroded and destroyed especially in plain and cultivable areas. These difficulties become apparent mainly in comparison with larger archaeological structures and buildings (Cerrillo-Cuenca & López López, 2020; Monterroso-Checa, 2019; Sánchez Díaz et al., 2022). Nevertheless, in the few cases in which this type of mapping has been applied to megalithic phenomena in Iberia, LiDAR data have led to precisely relocating features from old archaeological interventions (Carrero-Pazos & Vilas, 2015), identifying new megalithic structures in difficult-to-access areas (Berganzo-Besga et al., 2021), producing more accurate survey plans, prospections and excavations (Cerrillo-Cuenca, 2016) and reviewing structures that were previously thought to be dolmens but are not (Carrero-Pazos, 2018). LiDAR has also recently been used to estimate population increase and land exploitation in Southern Iberia during Late Prehistory considering that a denser web of megalithic structures could be related to a denser web of settlements, very often walled or ditched (Cerrillo-Cuenca & Bueno-Ramírez, 2019). In any case, at the moment, works that integrate digital results and fieldworks in order to test features in situ are not being fully developed, which is a downside for the research as DTMs cannot show many defining archaeological elements that are smaller in size, such as ceramics or other items, which are necessary in order to get a relative chronology and a site characterization.

3 | LiDAR ANALYSIS AT GOR RIVER: MATERIAL AND METHODS

Our starting point for this paper depends on two sources. First, we use the catalogue of preserved megaliths documented in the Gor River valley in 2019 by archaeologists J. A. Bueno-Herrera and C. Cabrero-González (Cabrero et al., 2021). Second, LiDAR data collected by National Geographic Institute during the National Plan of Aerial Orthophotography 2009–2015.

The first step for preparing the cartography is to choose and download LAZ datasets that cover our study area, followed by conversion of these files to DTMs in GeoTIFF format. GIS software used in this work is QGIS (version 3.16.11, available in https://qgis.org, accessed 25 June 2022), using the LAStools plugin, which allows to process point clouds in several LiDAR data formats, including LAZ, LAS or ASCII (http://rapidlasso.com/LAStools/, accessed 27 June 2022). The main objective of LAStools is to process each of the downloaded files choosing only the classified points of interest for the present research, in this case, the bare earth (without vegetation or any constructions). This processed layer, which contains only the relevant elements of the landscape, becomes a DTM presented as a georeferenced TIFF file, and already compatible and viewable in many softwares. The last step is to filter the TIFF files creating a hillshade by modifying illumination, azimuth and exaggerating Z values in order to clearly analyse the terrain, which depends mostly on the particularities of the topography. In our case, several tests have been made and the final best results have been accomplished by creating a hillshade with double vertical exaggeration, an 315° azimuth and 35° light inclination. Once obtained the hillshade images are systematically reviewed, analysing the terrain in parallel strips in a north–south direction, emulating the parallel linear transects that guides any traditional archaeological surface survey but in a digital domain. This translation of the traditional method to the digital level has been preferred in order to organize our analysis and to keep the same attention to all the areas, systematizing the work and maintaining objectivity. These maps, a total of 22, each 2 km^2, cover the whole valley—enough terrain around the documented dolmens—and were reviewed individually with the aim of maintaining the highest possible degree of objectivity. The same level of compliance has also been applied for the (a priori) non dolmenic areas of the valley. With the objective of consulting all available information, the hillshade images were contrasted with other elements including orthophotos, aerial images, historical maps and digital elevation models, all of them available publicly from IGN. Only the orthophotos, due to their high resolution, have yielded successful results. As the layers were reviewed, the location of the new anomalies that seem similar to the well recorded and preserved dolmens were marked, so a web of points containing the new possible burial mounds was composed.

4 | STATISTICAL ASPECTS

As the main objective of this work is to register the location of possible lost megaliths in an area already studied by fieldwork with LiDAR technology, once the candidate burial mounds have been identified, the next step is to statistically analyse their plausibility. The recorded dolmens exhibit a lack of autocorrelation. Therefore, if the candidates are indeed burial mounds, by including their locations this characterization should hold, as it has already been suggested in order to contrast possible sites in other similar studies (e.g., Berganzo-Besga et al., 2021; Cerrillo-Cuenca & Bueno-Ramírez, 2019). This would be statistically supportive but not conclusive. Finally, the last step is a verification by means of archaeological surface survey, as done in other studies (Davis et al., 2020, 2021).

The statistical study consists of two analyses. First, whether the spatial structure is non-random by means of a statistical test of spatial randomness. In the case of concluding that it is not random, semivariograms are compared by considering the spatial distance between neighbouring dolmens for the dataset composed of recorded megaliths and the one composed of registered and candidate burial mounds. Both techniques are presented below.

4.1 | Spatial randomness test

When it comes to the statistical analysis of a spatial point process, a common first step is to check whether the data show complete spatial randomness. If the data show complete spatial randomness, this implies that there is no underlying structure in the data and therefore little can be gained from further analysis. In this paper we test the spatial randomness of certain point patterns based on quadrat counts using the quadrat.test function available in the R package spatstat. This test evaluates the statistical evidence that leads to reject or support the null hypothesis of complete spatial randomness (see Cressie & Read, 1984). Then, in the case of obtaining a p value lower than 0.05, it is concluded that there is sufficient evidence to say that there is spatial structure in the data. By convention, a result is statistically significant if $p < 0.05$, it is highly significant if $p < 0.01$, it is very highly significant if $p < 0.001$, and it is not significant if $p > 0.05$.

4.2 | Semivariogram

A set of elements is said to present spatial autocorrelation regarding a measurable characteristic when the nearby points tend to have more similar values of this characteristic than the distant points. This concept can be derived from the First Geographical Law of Tobler (Tobler, 1979), which says that "everything is related to everything, but things close to each other are more related than things which are distant." In this case, it seems that considering the average distance between neighbour burial mounds as a measurable characteristic, there is no difference between a specific area and the rest. This phenomenon can be quantified and studied with a series of indices, as well as elements such as semivariograms or correlograms. In this case, we use the semivariogram, which is basically a graphic representation of the values of the semi-variance $\gamma(h)$ as a function of the distance h for a set of data. The semivariance is obtained by averaging, for discrete distance classes, the values of semivariance obtained within that class or range of distances. For a given class, the semivariance $\gamma(h)$ is calculated as

$$\gamma(h) = \frac{1}{2n_h} \sum_{i=1}^{n_h} [z(x_i) - z(x_i + h)]^2$$

where n_h is the number of pairs of points that are at a distance h and z (x_i) and z ($x_i + h$) are the values that a measured variable takes at points x_i and $x_i + h$.

In this way, if the data distribution is spatially independent, the semivariogram will be essentially flat. There are two practical rules (Journel & Huijbregts, 1978) that must be taken into account when calculating the semivariogram:

- The experimental semivariogram must consider distances h for which the number of pairs is greater than 30.
- The value of the semivariance is no longer reliable for distances less than the maximum distance divided by two.

The empirical semivariogram presents three parameters of interest (see Figure 3 obtained from Lianheng et al., 2018). The height of the semivariogram jump at the origin is the Nugget (C0), the limit of the semivariogram tending to infinite lag distances is the Sill (C0 + C), and the distance at which the difference of the semivariogram with respect to the sill becomes negligible is the Range (a). Then, the Sill represents the threshold at which the pairs of samples become independent. That is, if the distribution of the data is not spatially autocorrelated, the semivariogram will be essentially flat.

5 | RESULTS FROM LiDAR DTMs

In order to reduce subjectivity, the final result was not viewed until the end of the remote survey with the aim of avoiding bias. The final result conforms to a logical distribution of points that follows the previously documented pattern of megaliths (Figure 4). It is also interesting that the marked anomalies are similar to the previously documented mounds of the area, but also to the megalithic structures identified by LiDAR data for other areas (Carrero-Pazos et al., 2014, p. 7). The final result, composed of 230 new possible locations, is presented below (Figure 4).

In order to organize the large quantity of available information, the 230 points were classified according to the clarity of the possible megalithic structure inside the supposed burial mounds. With this aim,

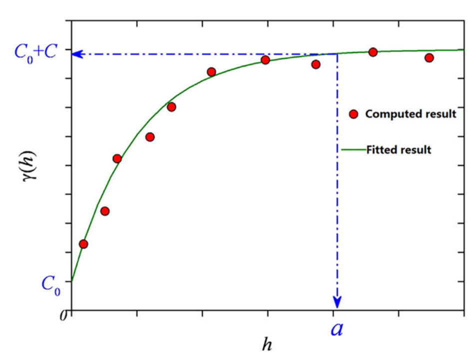

FIGURE 3 Diagram of the theoretical semivariogram obtained from Lianheng et al. (2018) [Colour figure can be viewed at wileyonlinelibrary.com]

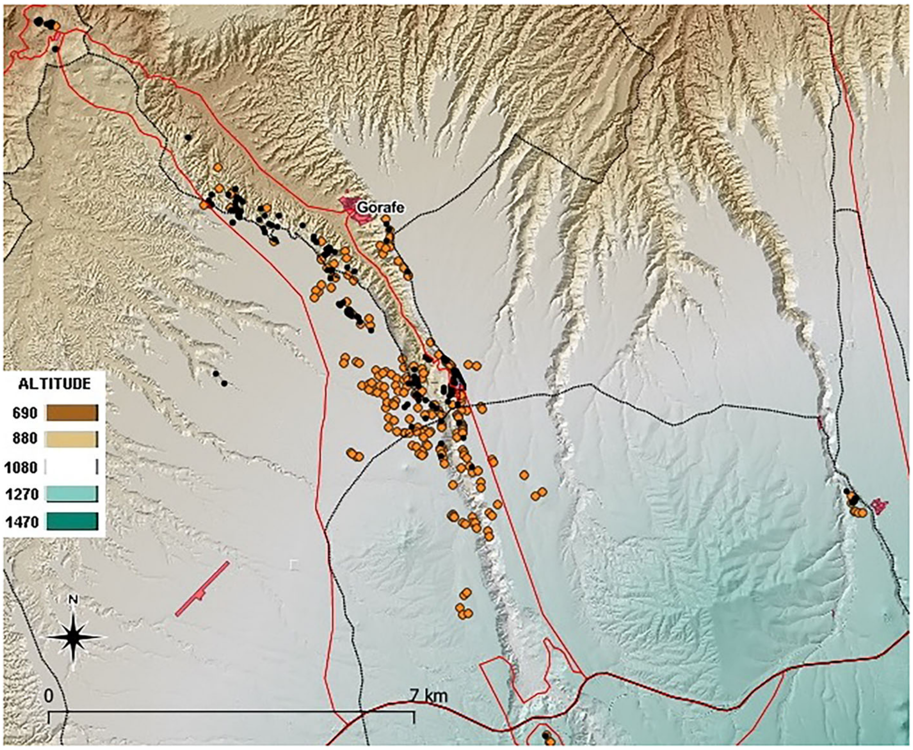

FIGURE 4 In black, megaliths previously identified. In orange, new possible burial mounds identified by LiDAR DTMs [Colour figure can be viewed at wileyonlinelibrary.com]

a statistical classification was attempted, but low resolution prevented any metric or quantification beyond the identification of the possible mound itself. The classification was made by means of visual comparison to the preserved dolmens. The 230 new placements were categorized as clear (81), when the anomaly is absolutely equal to the shape and size observed in the maps for the already recorded dolmens, probable (79), when the anomaly is highly similar to the shape and size observed for the preserved dolmens, and possible (70), when the anomaly presents similarities with the shape and size of the documented dolmens but they seem to be more fuzzy. The objective of this internal classification was to check the reliability of the LiDAR DTM, to see if the possible structures apparently more similar in the digital plan to the currently preserved dolmens correspond more often to real burial mounds or if the resolution prevents more precise characterization, which has been a core pillar in other similar researches that, on the other hand, start from more defined archaeological data (Caracausi et al., 2018; Gárate et al., 2020; Verhagen & Whitley, 2012) (Figure 5).

Regarding the spatial distribution of the previously recorded dolmens, the spatial randomness test based on quadrat counts (Cressie & Read, 1984) concludes that the spatial distribution of the dolmens is not random with a high degree of significance (p value less than 2.2e−16).

In statistical terms, this characteristic points to a lack of spatial autocorrelation. A set of elements is said to have spatial autocorrelation when the nearby points tend to have more similar values than the distant points. As said before, this concept can be derived from the First Geographical Law of Tobler (Tobler, 1979). In this case, it seems that considering the average distance between neighbouring

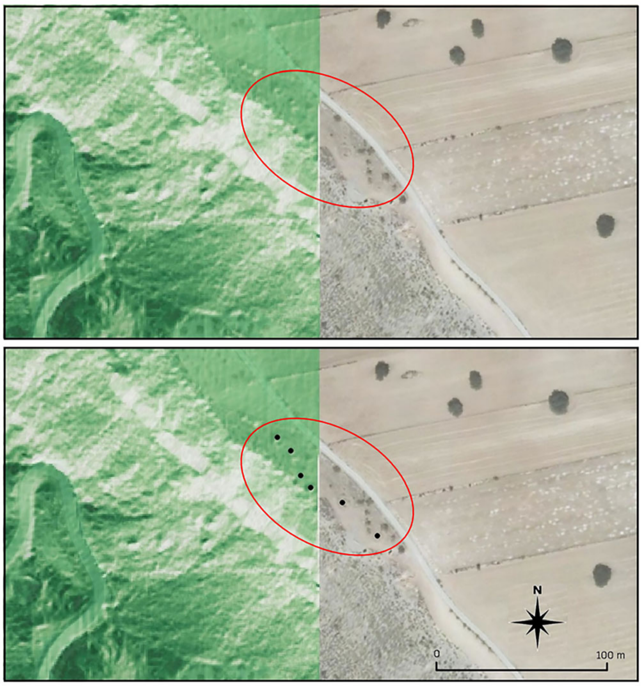

FIGURE 5 Megalithic structures corresponding to four previously documented dolmens as they are seen in DTMs [Colour figure can be viewed at wileyonlinelibrary.com]

dolmens as a measurable characteristic, there is no difference between a specific area and the rest. As referred before, we use the semivariogram, which is basically a graphic representation of the values of the semi-variance γ(h) as a function of the distance h for a set of data in order to quantify this phenomenon.

In Figure 6, the experimental semivariogram obtained for the set of registered dolmens is shown in red, taking as a measure the average distance between neighbours (considering neighbouring dolmens less than 50 m from a specific megalith). In this graphic, an absence of spatial autocorrelation can be seen as the estimated curve of the semivariogram is significantly flat.

An indication that the possible new locations are indeed prehistoric burial mounds will be the fact that when incorporated into the recorded set, the lack of spatial autocorrelation is maintained, as it has already been showed in other similar studies in order to contrast possible new sites (Davis et al., 2020). The estimated curve for the set of registered dolmens plus the candidates is shown in blue in Figure 6. It can be seen how the curve trend continues to be flat and therefore the candidate burial mounds do not break the pattern of lack of spatial autocorrelation. Another significant aspect is the considerable decrease in the variability between the distances of the same class, visible both in the lower values of the semi-variance and in the decrease in the variability band of the estimated curve.

In archaeological terms, the scarce available scientific literature resulting from past campaigns seems to reinforce our hypothesis: In 1943, Georg and Vera Leisner published an approximate situation map for the megaliths of the Gor River valley and the surrounding area, according to L. Siret researches between the end of the 19th century and the beginning of the 20th century. In that map, G. and V. Leisner (1943) indicate the existence of megaliths in zones where no dolmens are apparently preserved neither recently referred but that, following the present review, still host or would have hosted destroyed burial mounds (Figure 7). This fact is especially evident in the west bank of the Gor River, where LiDAR data have shown many mounds that can be related to this ancient publication.

In addition, several megaliths of the Gor River valley have deep foundations, so are not easily visible on the surface except for their tumulus, sometimes hardly preserved. Some burial mounds in already well-known and defined necropolis such as Hoyas del Conquín presented dolmens were only discovered (or rediscovered) during excavations of the early 2000s, as with n° 239 (Manarqueoteca, 2001). The same situation can be observed in the contiguous necropolis of Fonelas, in which systematic excavations carried out in the 1980s revealed several dolmens that were hidden after tumulus destruction (Ferrer et al., 1988). It is therefore possible that some dolmens in the study area are still underground and present very low burial mounds (or almost flat), so they are not visible on the terrain, but identifiable through remote sensing. This problem, related to hidden and disappearing landscapes, has been systematically treated for different kind of sites (Bintliff et al., 1999; Evans et al., 2013; Freeland et al., 2016; Masini et al., 2018), and the application of new technologies seems to help overcome this difficulty in many cases (David & Thomas, 2016; Davis et al., 2021; Gaffney et al., 2013; Guyot et al., 2018; Wheatley et al., 2012).

5.1 | Testing through archaeological surface survey

In order to test the results obtained in the digital realm, an archaeological surface survey was carried out in three sample areas with the aim of testing if vestiges or possible structures can be seen coinciding with the locations identified by LiDAR. Fieldwork was completed between May and August 2021 by José Antonio Bueno-Herrera, Antonio Sánchez-Benítez and Carolina Cabrero-González, using a systematic and intensive visual inspection in the areas where DTMs suggested the presence of burial mounds. Inspection took place at different hours of the day and included recording and photographing where a visible structure, compatible with a dolmen, was observed. The identification of these locations was done with the free software Google Earth, which allowed us to upload coordinates of the sites on mobile phones, facilitating the work and saving time. This technique

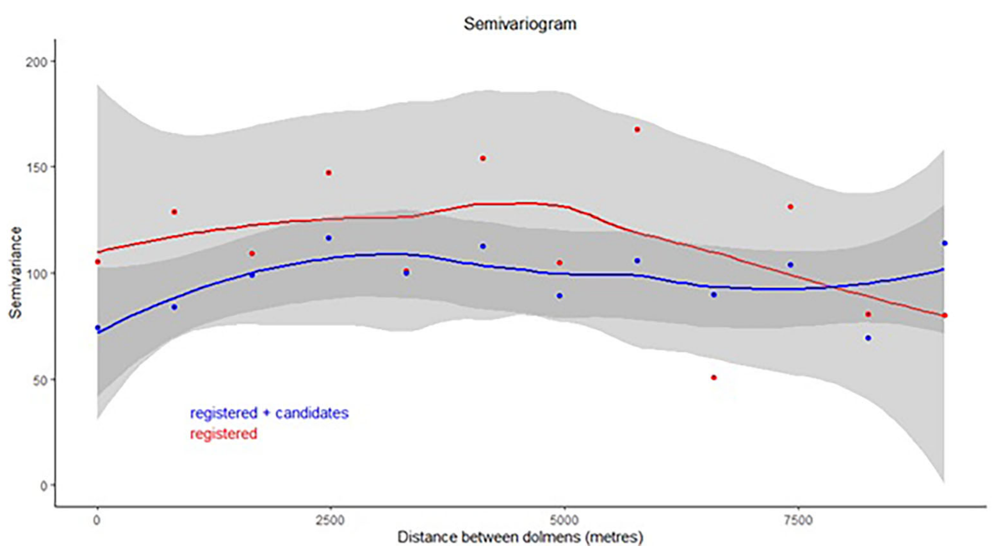

FIGURE 6 Semivariance showing the average range of distances between the previously documented dolmens and the possible new locations given by LiDAR [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 7 Approximate situation map of the megaliths in the Gor River following Leisner and Leisner (1943, p. 177) [Colour figure can be viewed at wileyonlinelibrary.com]

has been especially useful due to the ruggedness of the explored territory. Faced with the impossibility of visiting each of the 230 locations, three sample areas were chosen according to these criteria:

a. Zones not very anthropized have been prioritized as it is more difficult to identify structures in cultivated soils.
b. Relatively isolated areas have been preferred as they better preserve archaeological remains due to lower risk of plunder.
c. Areas with a high level of erosion have been avoided, as some parts of the territory are "badlands," where erosion has destroyed the soil and almost all archaeological remains.

According to these criteria, the three sample areas are as follows: in the subgroup of La Sabina (4 km^2), in the area of Conquín Bajo (2 km^2) and in the subnecropolis of Llano de Olivares (1.5 km^2); the last two can be considered one as they are only separated in height (Figure 8).

5.1.1 | La Sabina area

This area has been chosen due to its isolation, as it is far from any inhabited zone. Before completing the surface survey, two main problems related to this zone were taken into account:

- While it is true that this zone is not very anthropized, it is common to find "hunting nests," which are round structures formed by small to medium stones and straw or other kind of light vegetation. These structures are usually used by hunters to hunt birds and small animals, and they are very easily confused with dolmens because of their shape and size. In fact, it is relatively common to find megalithic graves converted into these constructions. Structures documented by remote survey could actually be hunting nests, sometimes not related to prehistoric burial structures.
- An enormous erosion index exists in this area due to its gradient and an extreme cliff slopes, which has created the so-called "badlands." This makes surface survey much more difficult. For this reason, only a small part of this area was chosen for surface inspection, as it was necessary to establish the accuracy of LiDAR data regarding the less accessible areas, a question that was central in other studies on megalithic areas in Iberia (e.g., Berganzo-Besga et al., 2021).

The survey showed that one of the 10 checked points corresponded to a hunting nest, while five corresponded to rather destroyed dolmens and four did not show any kind of archaeological trace (Figure 9). The hunting nest could be a previously intact megalith grave, but no orthostates have been preserved or remain invisible and no substantial elevation suggests the existence of a burial mound.

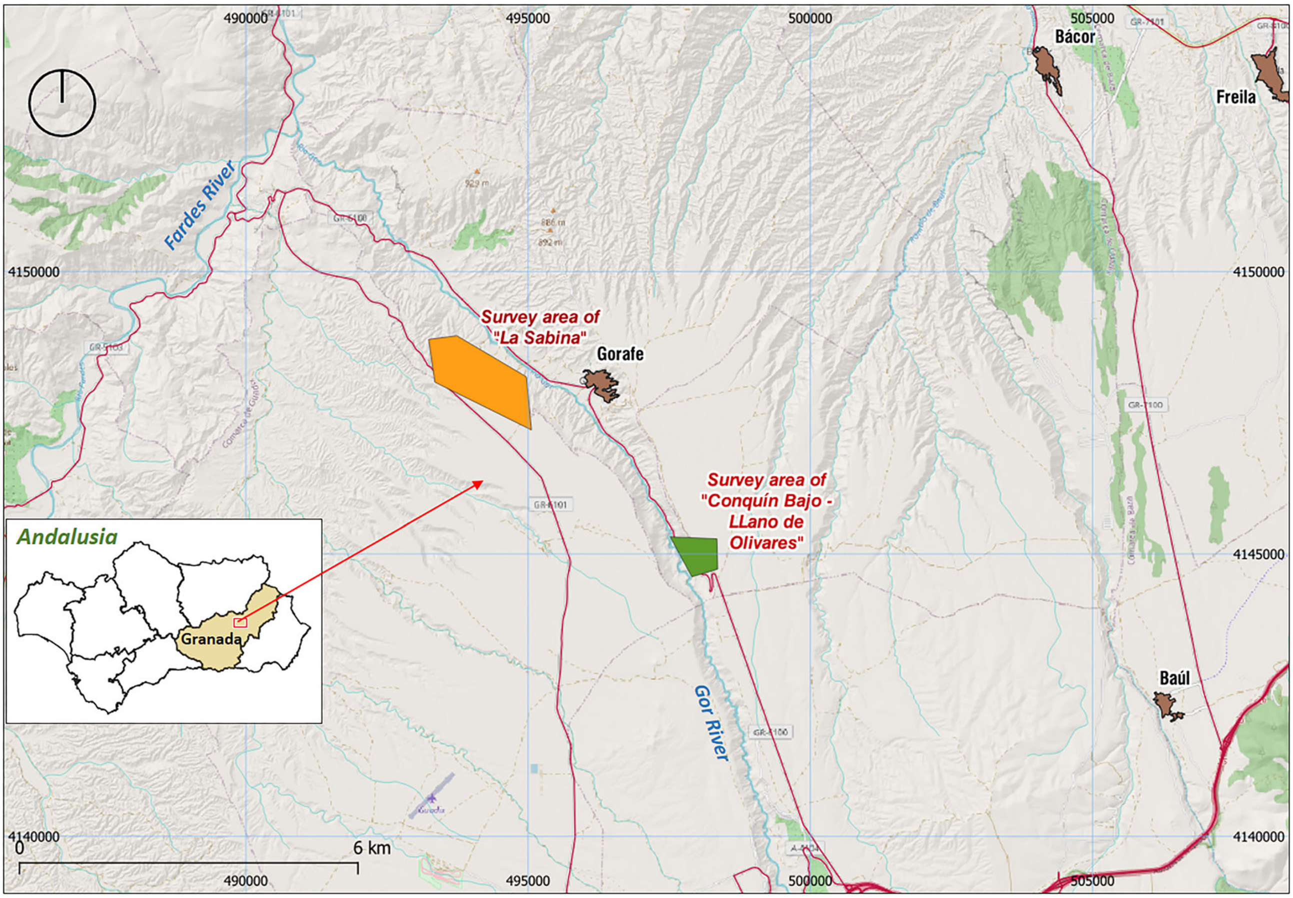

FIGURE 8 Selected surface survey areas seen in the general context of Gor River megalithic group [Colour figure can be viewed at wileyonlinelibrary.com]

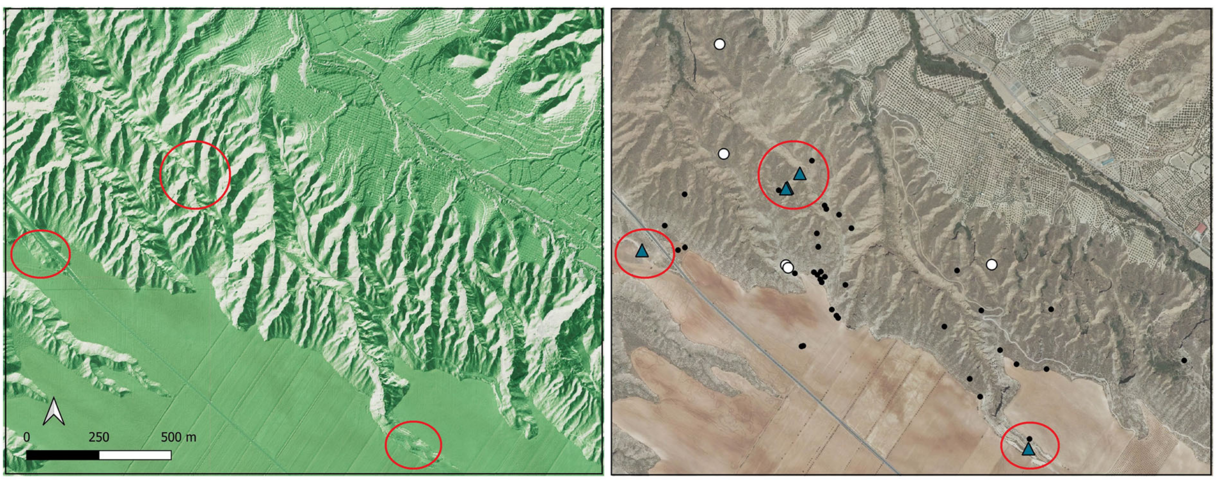

FIGURE 9 Currently documented megaliths (black dots), reviewed and discarded locations (white dots) and validated burial mounds (blue triangles) given by LiDAR DTMs (image on the left) in La Sabina area [Colour figure can be viewed at wileyonlinelibrary.com]

In addition, it must be highlighted that only three of the new possible burial mounds can be confirmed as destroyed dolmens (Figure 10), while in the other two cases strange rock clusters without clear organization that would indicate a megalithic grave were documented. Most of the locations documented through the DTMs in this area were previously marked as probable (6) or possible (3), as the terrain is also very difficult to analyse even by remote survey because of steep gradient and erosive processes.

FIGURE 10 Three of the possible new burial mounds recorded in La Sabina and the hunting nest (at the bottom to the right) [Colour figure can be viewed at wileyonlinelibrary.com]

5.1.2 | Conquín Bajo area

This area is also especially isolated and difficult to access, as it is much smaller than La Sabina with a very rough and rugged terrain. While only two possible new burial mounds were documented by remote survey, it was very interesting to check both locations as human presence is extremely limited in this zone. A possible dolmenic grave was documented, although only a toughly rammed orthostate corresponding to an almost 1-m-long slab was actually visible. This site showed a very consistent placement in relation to surrounding megaliths in terms of shape and size, according to features seen in the DTM (Figure 11).

This new site was considered as "probable" in the previous valuation, while the other one was noted as "possible."

5.1.3 | Llano de Olivares area

The case of the subnecropolis of Llano de Olivares has been very surprising. This area is included within the three megalithic itineraries created for public exhibition of the dolmens in the Gor River valley since the research made in 2000s, so the zone is visited daily. It was also one of the groups that received more attention in terms of cleaning and preservation in the beginning of the 21st century, including excavation of several megaliths (Manarqueoteca, 2001). These facts seem to suggest that no new archaeological vestiges would be discovered, but DTMs showed several structures equal in shape and size to the preserved megaliths on this necropolis. These new points are situated on very suitable locations, continuing the demarcation of the edge of the plateau, in the same way as the recorded and often-visited dolmens of the group of Llano de Olivares (Figure 12).

While it is true that not all of the possible points have resulted in positive results, in the space of 450 m long transect that has been reviewed, at least three locations correspond to destroyed megalithic monuments. Although it is clear that the structures are not perfectly observable at the present, the disposal of the stones, their shape and position (toughly rammed in vertically) and their location in relation to the territory and to the other megaliths allow us, without any doubt, to interpret them as megaliths (Figure 13), even with their poor preservation. This means that even in the most intensively researched zones, where traditional archaeological surface surveys and excavations have been performed, new features can be discovered by the application of new technologies that allow us to go beyond the ground perspective.

In one of the cases there was even evidence of plunder next to (what should have been) the chamber. This is undoubtedly indicative of the existence of buried archaeological remains, perhaps found, removed and partially destroyed after metal detector use by tomb raiders.

The three new archaeological sites were considered as "clear" following the remote survey, while between the discarded points of this area, six were also considered as "clear" and the other four were marked as "possible."

6 | DISCUSSION

While statistical analyses suggest a high probability that the 230 new locations correspond to previously unknown burial mounds, the surface survey found that, out of 25 predicted burial mounds in the sample areas, at least nine of them correspond to partially destroyed megalithic graves, possibly after the first archaeological interventions

FIGURE 11 Currently documented megaliths (black dots), reviewed and discarded location (white dot) and validated dolmenic structure (blue triangle) given by LiDAR DTMs (image on the left) in Conquín Bajo area. At the bottom, the validated structure [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 12 Currently documented megaliths (black dots), reviewed and discarded locations (white dots) and validated burial mounds (blue triangles) given by LiDAR DTMs (image on the left) in Llano de Olivares area [Colour figure can be viewed at wileyonlinelibrary.com]

or perhaps never referenced in archaeological literature due to poor preservation or scarce visibility on the surface. This number corresponds to the 36% of the proposed new locations. The sample areas encompass 10.86% of the locations identified by remote sensing; therefore, 83 new burial mounds could be present in the entire study area. This prediction would increase the number of preserved dolmens in the area from 151 (Cabrero et al., 2021) to 234—close to the estimates from old catalogues (Spanedda et al., 2014).

Recent works have tried to use several multiscalar and multitechnique methods to test and improve the accuracy of LiDAR data. Not only has it improved the accuracy of identifying previously documented archaeological structures, it has also reduced the ratio of false positives (Berganzo-Besga et al., 2021; Davis et al., 2021; Trier et al., 2021; Verschoof-van der Vaart et al., 2020).

If the first aspect is not a problem in our case study because all known sites are visible through LiDAR, it must be emphasized that the

FIGURE 13 Two of the new possible megalithic structures of the subgroup of Llano de Olivares [Colour figure can be viewed at wileyonlinelibrary.com]

ratio between true and false positives in the present work (with a maximum of 64%) can be considered as significant compared with other examples of LiDAR analysis on burial mounds (Davis et al., 2021; Trier et al., 2021; Verschoof-van der Vaart et al., 2020) especially considering that most of these conclusions are susceptible to change if tested by fieldwork. In addition, it must also be highlighted that statistical methods alternative to those used in this paper and in the above-mentioned papers are supportive but not conclusive, as proven for other areas (Sánchez Díaz et al., 2022).

Considering terrain loss due to the erosion and extreme terrain diversity in the Gor River valley and the difficulty of predicting the number of new monuments based on the sample studies, it is suggested that a high rate of points identified by remote sensing could be related to destroyed megaliths according to similarities in placement and proximity. A lower number can be confirmed from surface survey (at least a 28% of the total set, 64 burial mounds if data of the three sample areas can be extrapolated) even preserving some orthostats in certain cases. Some areas, according to results from surface survey, offer fewer false positives than others, with 50% in La Sabina and Hoyas del Conquín Bajo and 76% in Llano de Olivares. Although the number of cases in Conquín Bajo (1 out of 2) prevents definitive conclusions, it is interesting that the more accessible area provided the worst results regarding the ratio between new burial mounds (3) and false positives (10). Future research could develop a model that takes into account several anthropogenic factors describing current landscape conditions, including a reconstruction of the terrain affected by erosion (Nwaogu et al., 2017).

The present study must be considered as a preliminary, as almost all the areas analysed are very isolated and relatively small due to the difficulty of finding areas not very anthropized and eroded. Nevertheless, results of surface survey reveal the need to continue working in order to approach a more complete spatial model including non-visible structures to reconstruct the past distribution pattern. In addition, our surface survey was limited to visual terrain observation, without use of other more detailed methods such as geophysical prospection, which could be more conclusive. Other possibilities include low-altitude photogrammetry to reveal the exact shape of the anomalies. If fact, it is possible that no structures or stones are visible on the surface because elements may be buried deep under the soil, especially if deep foundations were made for chambers and/or corridors. These funerary buildings could also be placed under a relatively low tumulus that has disappeared, as it was recorded for several dolmens of the neighbour megalithic necropolis of Fonelas (Ferrer et al., 1988) as is common for the megalithic phenomenon of Southern Iberia (Cámara, Spanedda, et al., 2021). Deep foundations and low mounds are aspects closely linked to the hypogeic tradition best known in western Andalusia (Cámara et al., 2010) and other areas (Davis et al., 2021; Hawkins et al., 2003). For these reasons, this work may be considered as a first approach as for the study of new possible burial mounds lost or not known in the Gor River valley, with the idea to complete the analyses with more surface surveys and aerial photogrammetry.

Finally, it must also be emphasized that even though the application of new spatial technologies and modern cartography to archaeology clearly yield very innovative results, these methods must always be followed by traditional testing on the ground. Otherwise these methods only pose hypotheses as other decisive archaeological remains including material culture are not considered. Still, it is undeniable that the use of new technologies represents a very versatile approach to understanding territorial distributions and identifying features and areas where archaeological remains more probable, saving considerable time an effort.

7 | CONCLUSIONS

The application of LiDAR with the aim of reviewing the megalithic landscape of the Gor River valley (Granada, Andalusia, Spain) has led to the identification of a high number of locations that seem very similar in shape and size to the previously documented and effectively preserved dolmens. This remote sensing survey has been carried out by extrapolating the classic method of surface survey to the digital realm, allowing us to filter LiDAR DTMs and identify 230 new possible burial mounds. Statistical analyses have revealed relationships between known megaliths and possible new ones, finding high correlation of the average distances between the locations in each group. A final surface survey in selected areas was performed to test the results from the ground. One problem was selecting three testing areas that were isolated enough that they were not too impacted by extreme erosion nor cultivated in a way that destroys visible archaeological remains. The chosen areas were with part of the subnecropolis of La Sabina, Conquín Bajo y Llano de Olivares, where 25 locations were reviewed, from which nine clearly corresponded with very eroded and destroyed burial mounds.

The following are summary points from this work:

1. LiDAR analysis suggests the existence of a larger network of burial mounds in the Gor River valley than previously recorded, suggesting that the proposed systems of territorial control from burial mounds and their function as territorial markers is more complex than previously thought (Cabrero et al., 2020; Spanedda et al., 2014). Similar spatial patterns were found for known dolmen and 230 new possible burial mounds.
2. If the data confirmed by surface survey is taken into account, a minimum number of 83 new burial mounds is estimated (nine of them confirmed by surface survey in the sample areas).
3. If we consider that the current catalogue includes 151 well-preserved dolmens, the results would imply at least an increase of 55%. More significant is the fact that the total number of dolmens could reach 234, close to estimates for the megalithic distribution in the area according to the old data (Spanedda et al., 2014).
4. The total amount of burial mounds could be higher, not only because some of the locations identified by LiDAR could correspond to destroyed sites but also because, as surface surveys have shown, preservation varies depending on factors the degree of isolation and intensity of farming practices. In this sense, in some areas 50% of identified points could be related to unknown burial mounds.
5. These Results make the case for more intense research and preservation (Montufo, 2019). Fieldwork, including surface surveys, excavations, aerial photogrammetry and other methods, and laboratory analysis (starting with radiocarbon dates and anthropological studies) are necessary. Results from recent research in nearby Panoria necropolis (Darro, Granada) (Aranda et al., 2018, 2022) are a good example of a continuous project.

The importance of these new discoveries is emphasized considering that the megalithic cluster in the Gor River valley is one of the biggest dolmenic groups in Europe, with important implications for understanding socioeconomic dynamics and changes that took place from the 4th millennium BC. The results indicate even more control of the territory than previously proposed (Cabrero et al., 2020), and may have other implications. On the one hand, the multiplication of cohesion and identity symbols, regarding the cult of ancestors, can be related to definition of the borderlands, especially as megaliths are unknown in eastern Granada. These identity strategies are not only played by the megaliths themselves but also by the frequency of human figures in the area (Ferrer et al., 1988; Manarqueoteca, 2001; Siret, 2001). The display of symbols to define boundaries and identity is also found in neighbouring areas. In the case of Los Millares, not only has the use of megaliths to complement the control exercised by hill-forts been tested (Cámara, Spanedda, et al., 2021), but it has also been possible to record the use of representations of the ancestors on defensive walls of the village and nearby in hill-forts, possibly to define who had the right to access those places and, by extension, their resources (Cámara, Dorado, et al., 2021). Second, the exponential multiplication of tombs, and other resources mobilized in funerals as grave goods, could also generate, precisely in moments of crisis in which these items were most necessary for social justification, costs that were difficult to assume, contributing, in the long run, to the end of a social system and its ritual mechanisms, at the end of the 3rd millennium cal BC.

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CONFLICT OF INTEREST

The authors have no conflict of interest in relation to this work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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ENDNOTES

[1] This classification can be consulted online here https://resources.arcgis.com/es/help/main/10.1/index.html#//015w0000005q000000

[2] All the technical specifications are available here https://pnoa.ign.es/especificaciones-lidar

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