

# Improving Methods for Viewshed Studies in Archaeology: The Vertical Angle

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## Abstract

As many authors have observed, binary viewsheds are too simplistic a way to represent visibility around a particular viewpoint. Several deficiencies, very well summarized in Wheatley and Gillings (2000), must be corrected in order to make computer-generated viewsheds more realistic and geared to archaeological purposes. One of those required improvements relates to the vertical angle of vision. Viewing from a low angle gives less perception of detail than viewing from a high angle. Standard viewsheds do not allow the identification of this kind of perceptual issue. In the real world, visible areas at eye level are seen as a narrow strip; however, on the ground they can extend for many kilometres. The map thus gives a false representation of visibility. Dividing the viewshed calculation into several vertical angles helps to analyze the result in a more realistic way than is customary, especially in warlike contexts where dominant visibility could have been important for military purposes.

## Keywords

Viewshed, total viewshed, isocrones, ArcGIS, path distance tool.

## 1. The importance of visual control during the Late Iron Age in Spain

During the Roman conquest period in Spain (II-I centuries BC), in several areas of Andalusia, some new settlements were located on hilltops, with extensive visibility.

This fact has been interpreted in two ways:

- as a wish to visually supervise indigenous settlements;
- as a way to show Rome's presence in the area, and to reinforce its power.

In particular, in the Guadalquivir River Valley, this fact has been observed in two adjoining areas. Romo *et al.* detected two new settlements on hilltops during the Roman republican period in Gilena. The authors think that these sites were established in order to (visually) control indigenous settlements, in the unstable context of the beginning of the roman conquest of Hispania (Romo *et al.* 1988, 312–313). Keay *et al.* suggest that intervisibility between Roman sites and indigenous sites was a way to demonstrate Rome's presence in the area of Carmona (Seville) during the conquest period (Keay *et al.* 2001). A

similar phenomenon has been observed east of these zones, in an area shared by the current provinces of Seville and Cordoba, in the Genil River Valley (Zamora in press).

### 1.1. The Priego-Alcaudete basin

The Priego-Alcaudete basin is located east of the Sierras Subbéticas, in the southern part of the provinces of Cordoba and Jaen (Andalusia, Spain). The area is adjacent to the Genil River Valley (Fig. 1).

During the Middle Iberian period (prior to the beginning of the Roman conquest) there was no

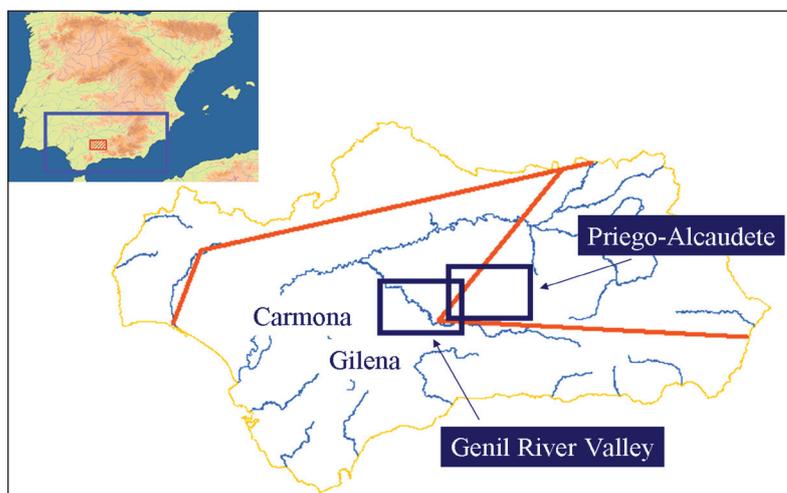


Fig. 1. Areas mentioned in the text.

settlement in the northern part of the basin (considered a 'black hole' area). For that reason, this part of the basin has been interpreted as a border between different political areas north and south of the Guadajoz River (Murillo *et al.* 1989; Vaquerizo, Quesada, Murillo 2001).

During the Late Iberian period (Roman conquest period), the settlement distribution in the basin was reorganized (Vaquerizo, Murillo, Quesada 1991; Vaquerizo, Quesada, Murillo 2001). One important settlement was abandoned, while a neighbouring hill, with better natural defences (and better landscape visibility), was settled. Some other sites appeared in the aforementioned 'black hole' area (e.g. the Cerro de la Celada site, in the northern part of the Priego-Alcaudete basin). Since a frontier line has been identified here, this reorganization has been interpreted as a consequence of the pressure of the northern political groups coming South (Murillo *et al.* 1989; Ruiz Rodríguez and Molinos 1989). The new settlement organization has also been interpreted as a population expansion (Vaquerizo *et al.* 2001), taking into account the possible consequences of both Roman and Punic presence in the area.

Considering the importance of changes in settlement distribution from the Middle Iberian period to the Late Iberian period in the Priego-Alcaudete basin, a spatial analysis using GIS was started. Since one of the hypotheses for settlement distribution in this area is the expansion of a different political group, visual control of other sites could have been an important factor for settlement location. Viewsheds from every settlement were

calculated; in order to take account of the possibility of the observer's mobility to nearby vantage points, viewpoints were defined as an area covering the hill site as well as neighbouring hills (Zamora 2006b).

## 2. The study of visual control using GIS

As many authors have observed (Fisher 1992, 1993, 1996; Wheatley 1995; Ruggles and Medyckyj-Scott 1996; Llobera 2003; Tschan *et al.* 2000; Gillings and Wheatley 2001; Wheatley and Gillings 2000, 2002:214–216; Van Leusen 2002; Zamora 2002; Lock 2003, 177–182; Constantinidis 2004 among others), binary viewsheds are too simplistic a way to represent visibility around a particular viewpoint. Several deficiencies, very well summarized in Wheatley and Gillings (2000), must be corrected in order to make computer-generated viewsheds more realistic and geared to archaeological purposes. One of those required improvements relates to the vertical angle of vision.

Viewing from a low angle gives less perception of detail than viewing from a high angle (Ribas 1992, 207). The observer's perceptive response is different depending on both the size of the angle and the relationship with the horizon (Felleman 1986b, 55). We get more visual information (visual control) about what is happening in the landscape if we see it from a dominant position.

Standard viewsheds do not allow the identification of this kind of perceptual issue. In the real world, visible areas at eye level are seen as a narrow strip; however, on the ground they can extend for many



*Fig. 2. Visibility in the field. Radius length: 1, 5 and 10km. Areas far away from the observer represent a small part of the view.*

kilometres. The map thus gives a false representation of visibility. The magnitude of ‘visual exposure’ (Llobera 2003) in the real world does not correspond to the magnitude of visibility represented in a conventional viewshed (Figs 2–3).

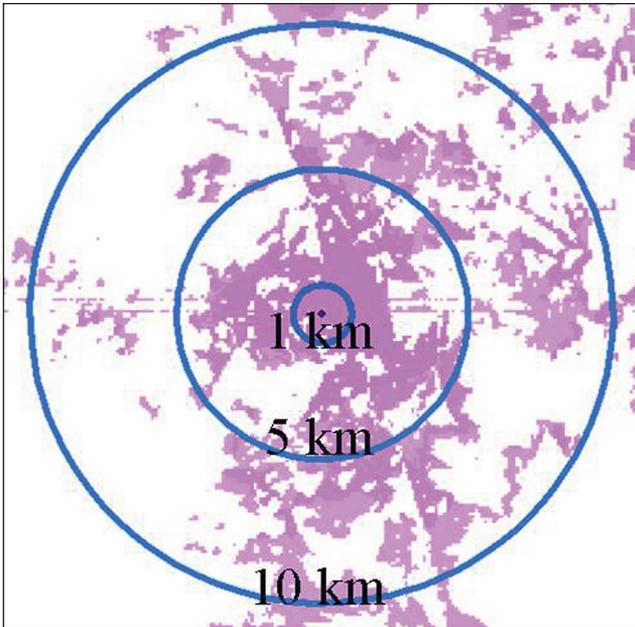


Fig. 3. Visibility represented on a map. Radius length: 1, 5 and 10km.

The different relative altitude between viewpoints (sites) permits different ways of visual approach to the surrounding landscape. Consequently, in order to identify the critical view at eye level, it is convenient to divide the viewshed calculation into several vertical angles.

GIS programs offer the possibility of changing parameters in viewshed calculations. One of those parameters is the vertical angle to limit the scan. In ArcGIS, parameters are defined as follows:

- VERT1: upper limit of the scan
- VERT2: lower limit of the scan

Default values in ArcGIS are: upper limit +90°; lower limit = -90°. The horizontal plane is 0°, and it

corresponds to the z-value of the observation point plus the value of OFFSETA.

In the present study, the visible area has been set from -1° to -90°. This measure is based on fieldwork observation, and it can differ depending on context (Zamora 2006a, 2006b, in press) (Fig. 4).

Since every viewpoint (every archaeological site) has its particular geographical characteristics, choosing a common radius for all sites for viewshed calculation is not always a good choice. In the particular case of the Genil River Valley, if we calculate viewsheds using the same radius from each site, we would get a skewed result. The site of Estepa is located on the southern edge of the Genil River Valley, on a hilltop in the Northern part of Sierra de Estepa, looking north to the Genil basin. It is located at an altitude of 606m, while sites in the basin are located at a mean altitude of 250m. This fact makes Estepa’s location an exceptional viewpoint in the area. Since lines of sight are blocked to the south by topography, the viewshed from the site of Estepa forms a semicircle, halving the theoretical visible area compared with sites located in the basin. If we considered visibility from these sites in terms of the amount of visible surface, and we use the same radius for all of them, we would miss the excellent visibility from Estepa’s location. Calculating by separated vertical angles of vision is a better approach (Zamora 2006a; 2006b).

In the case of the Priego-Alcaudete basin, viewsheds from sites were calculated from -1° to -90°. In general terms, new sites of the Late Iberian period (Torre Alta, Cerro de la Celada) had very good conditions for landscape visibility. From the Celada site you get one of the largest viewsheds in the area, especially if we take the site (790m height) and also its neighbouring hill (961m height) as the viewpoint area.

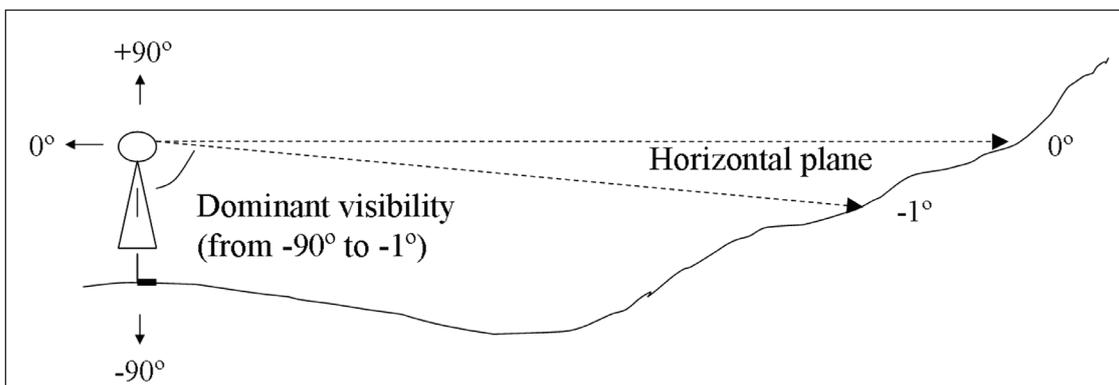


Fig. 4. Visual vertical angles defined in this study.

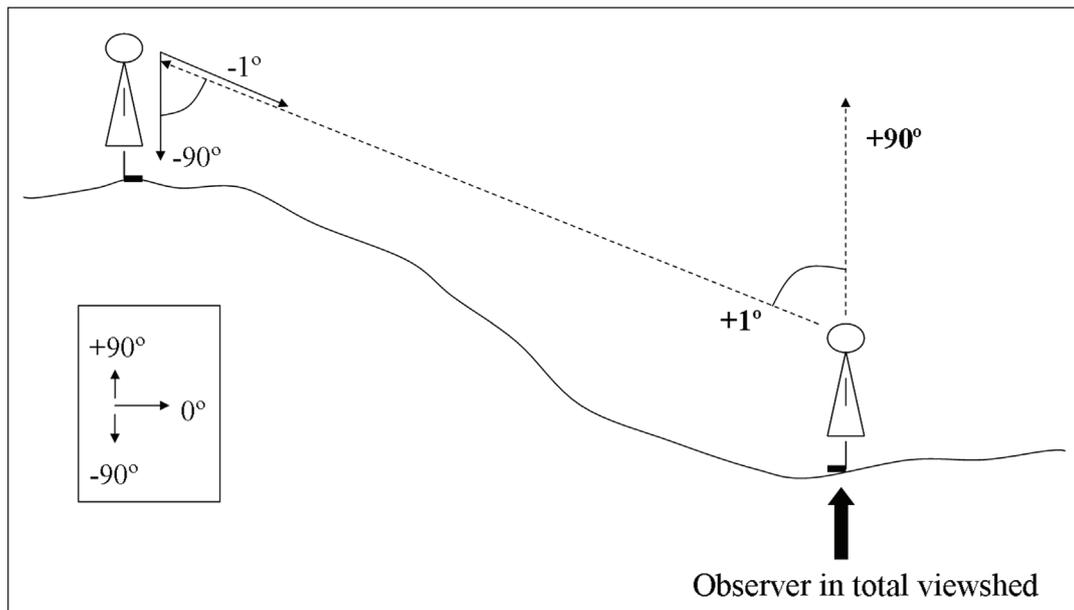


Fig. 5. Defined parameters in the total viewshed using ArcGIS.

To demonstrate that sites were located on the places with the best visibility, it is convenient to compare their visibility to places where no site has been found. Also, it is interesting to analyze other landscape variables in order to know their role in settlement location.

### 2.1. Test 1: total viewshed

Test number 1 was a total viewshed (Llobera 2003). The aim was to determine if the Celada site was located on one of the best places in the landscape to view the land from a dominant position.

According to this aim, the total viewshed should be performed so that the value of each cell is the number of cells visible from that particular cell (which is the opposite of the result in total viewshed, where the value of each cell is the number of observers that can see the cell). That is, we need 'views-from', not 'views-to'. Since cell values on the total viewshed are 'views-to', the calculation here was adapted in order to enforce reciprocity in vision.

– OFFSET A and B:

To see B from A does not mean that the opposite is true (to see A from B) (Fraser 1983, 301–303; Fisher 1996, 1298; Lee, Stucky 1998, 893–894; Wheatley, Gillings 2000; 2002, 210–211; Gillings, Wheatley 2001, 32). Differences in the viewer height can result in visibility existing in one direction only. When both viewer and target are set at the same height, then visual reciprocity can be assumed (Fisher 1996, 1298; Llobera 2003, 35).

– Inverse angle:

As shown in Fig. 5, vertical opposite angles are equal, so, the opposite angle would permit reciprocity in vision.

Parameters were set up as follows:

- OFFSET A = 2m
- OFFSET B = 2m
- VERT1 = +90
- VERT2 = +1

Since OFFSETA and OFFSETB are equal, and the scan angle is the opposite of the required angle ( $-1^\circ$  to  $-90^\circ$ ), the value of each cell in the resulting viewshed would be the number of viewpoints (cells) that can be seen from that cell  $1^\circ$  below the horizontal line.

In order to make the calculation easier, viewpoints were separated at a rate of 1 point every 1.1km, which makes the calculation not a complete total viewshed, but an abstract cumulative one.

Once the cumulative viewshed was finished, a statistical analysis of the viewshed was carried out. Data were grouped into intervals of number of seen cells.

Viewshed values were grouped in to intervals of number of cells seen from other cells in the DTM. A comparison between visual values in the whole landscape and visual values in site locations was done (Fig. 6).

Visibility from Cerro de la Celada site (and its neighbouring hill) was statistically significant (1 per cent of locations in the landscape from which it is possible to see a greater number of cells below the

Visual value	DTM			Settlements		
	Nº Cells	%	Cumulative %	Nº Sites	%	Cumulative %
0	78631	36	36	0	0	0
1–50	130071	59,6	95,6	5	71,4	71,4
51–100	6632	3	98,6	1 (Cerro de las Cabezas, and Celada Site)	14,2	85,6
101–150	1980	0,9	99,5	0	0	85,6
151–200	581	0,26	99,76	1 (Celada Site + Neigh. hill)	14,2	99,8
201–250	155	0,07	99,83	0	0	99,8
251–480	99	0,03	99,86	0	0	99,8
	218149	99,86			99,8	

Fig. 6. Statistical analysis of the total viewshed. For example, in row number 4, there are 1980 cells from which it is possible to see between 101 and 150 cells.

horizontal line of sight). Even if we consider just the settlement hill, the visual value is 73. This is not true for the rest of the sites, since they have values as low as 15 or 5 (cells seen).

Similar results were obtained by the same analysis in the black hole area, for which the Celada site also obtained a good result (not shown here).

**2.2. Test 2: weighting other variables**

In order to assess the importance of visibility in site location, other landscape variables were analysed. These variables were soil type, and proximity to rivers (water), since they are the most basic requirements for settlement.

An area of 1 hour walking distance around each site was calculated using an algorithm for walking on footpaths in hilly terrain (Tobler 1993). On flat terrain, this algorithm works out to 5km/h (Fig. 7). On hilly terrain, isochrones of 1 h distance cover less than 5km.

The procedure to calculate 1 h distance isochrones around each site in ArcGIS was as follows:

1. Calculation of slope in percent, based on the DTM.
2. Raster calculator: slope/100 (in order to know the mathematical slope).
3. Raster calculator (Tobler’s algorithm):  $6 \text{ Exp} (- 3.5 \text{ Abs}([\text{math\_slope}] + 0.05))$ , (in order to know the speed of a human walking in every cell, in km/h).
4. Raster calculator: Speed in km/h raster multiplied by 1000 (in order to know the speed in m/h, since map units were metres).

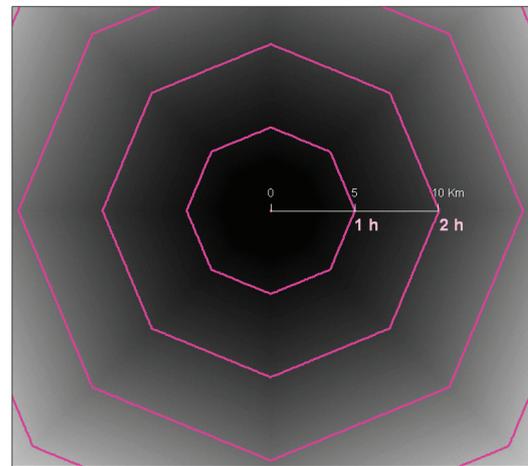


Fig. 7. Tobler’s hiking algorithm tested on an unreal flat DTM using ArcGIS Path Distance tool. Isochrones of 1 hour walking cover 5km.

5. Raster calculator: 1/speed in m/h, the inverse of the resulting raster from the previous point, because ArcGIS works with time per unit length.
6. Path distance: to each site, using as cost surface the resulting raster from the previous calculation (speed in h/m).
7. Contour: where contour interval = 1 (intervals of 1 h walking distance).
8. The nearest contour line to the site was selected (1 h distance to the site), and then it was converted to a polygon.

The obtained polygon was used for two tasks:

1. to calculate the area of 1 h walking distance around each site (Fig. 8);
2. as a mask to extract spatial data from soil type layer (Figs 9 and 10), from the altitude raster surface and from the distance to the river layer.

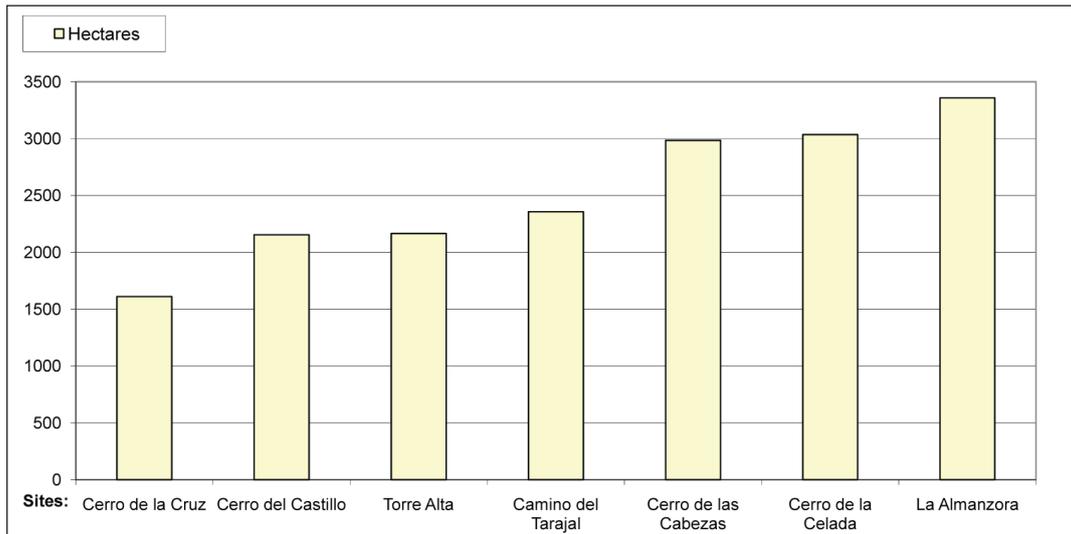
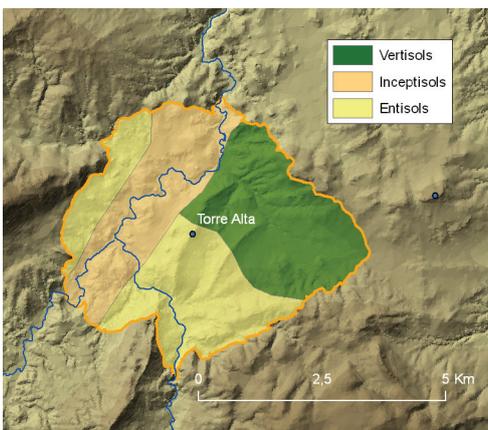
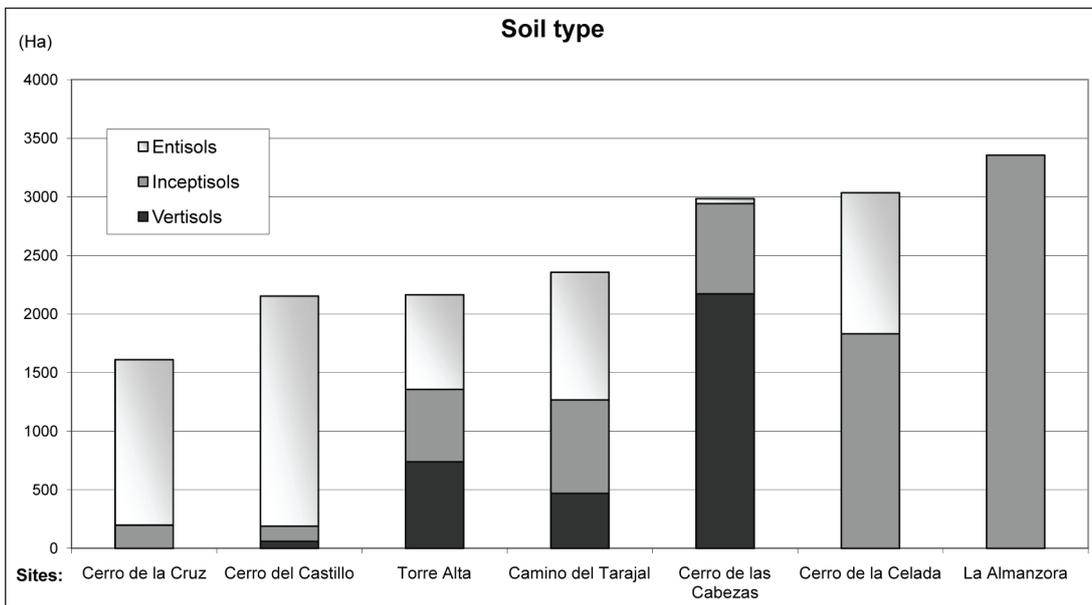


Fig. 8. Hectares in 1 h walking distance around sites (Tobler's algorithm).



Figs 9 (top) and 10 (bottom). Soils around settlements (within 1 hour walking distance from each site). Entisols are soils that do not have any profile development other than an A horizon. Inceptisols are more developed soils. Vertisols are considered one of the best soils for agriculture, and they are related to historical population growths (Gómez-Miguel 2008:182).

Soil type was based on the Soil taxonomy (USDA, United States Department of Agriculture), following the information published by the Spanish National Geographic Institute (Gómez-Miguel 2008).

Mean altitude inside the polygon formed by every 1 h isochron line was calculated.

Distance to main water courses from every settlement was also calculated using the Straight Line tool, in order to know the minimum distance from each site to the nearest water course.

The values obtained from the four preceding analyses (extent of the 1 h walking distance area around each site, soil type, altitude and distance to rivers) were compared to the values obtained from the total viewshed calculation.

Fig. 12 shows that Cerro de la Celada site has extreme values: big site catchment

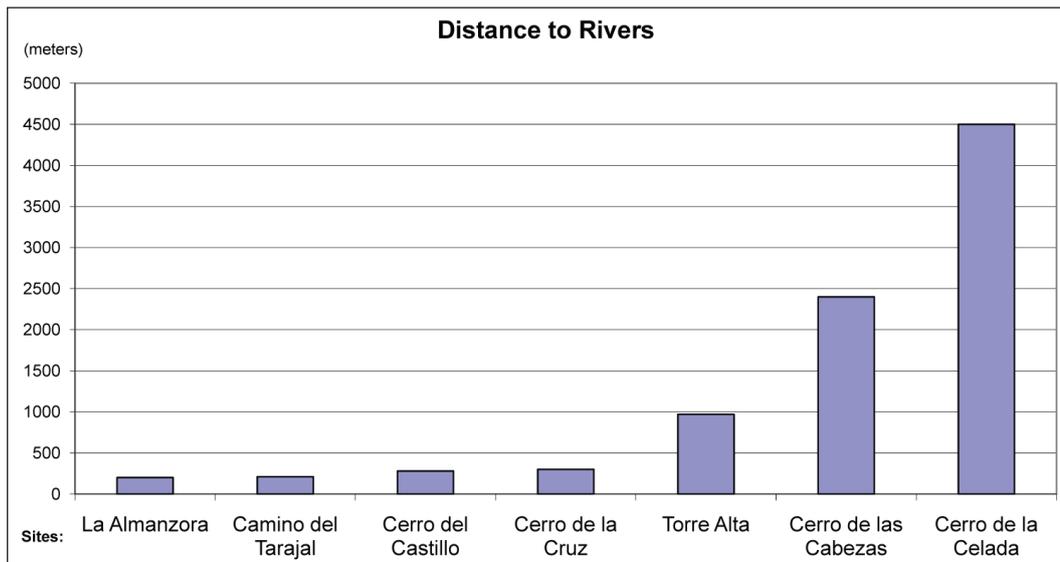


Fig. 11. Distance to Rivers (in metres).

	Visibility	SCA	Altitude	Soil Type	Proximity to Rivers
1	Cabezas,	Almazora	Celada	Cabezas	Almazora
2	Celada	Celada	Cruz	Almazora	Tarajal
3	Cruz	Cabezas	Cabezas	Celada	Castillo
4	Torre	Tarajal	Castillo	Torre	Cruz
5	Castillo	Torre	Torre	Tarajal	Torre
6	Tarajal	Castillo	Tarajal	Castillo	Cabezas
7	Almazora	Cruz	Almazora	Cruz	Celada

Fig. 12. Sites relative values. High 1- Low 7.

area, high altitude, and it is 5km away from the nearest river. Although soils are medium quality, the area around the site is appropriate for agriculture (it has a wide 1 h isochron), which fits in with the idea of a population expansion as the cause of this new occupation. However, the visibility from the site is significant enough to combine both factors (visibility/defence and good land for farming).

More analyses need to be done before considering visibility as a factor for site location, especially because the reason for settlement in a 'black hole' area may be as simple as the fact that there was no previous settlement. In any case, dividing the viewshed calculation into several vertical angles helps to analyze the result in a more realistic way than is customary, especially in warlike contexts where dominant visibility could have been important for military purposes.

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## References

- Constantinidis, Dora (2004). The Interconnectivity of Cultural Sites: Sights and Sounds across a Landscape. In: Karin F. Ausserer, Wolfgang Börner, Maximilian Goriany and Lisa Karlhuber-Vöckl (eds.) *[Enter the Past] The E-way into the Four Dimensions of Cultural Heritage: CAA2003, Vienna*. Oxford: BAR International Series 1227, 258–262.
- Felleman, John P. (1986). Landscape visibility. In: Smardon, R. C., Palmer, J. F. and Felleman, J. P. (eds) *Foundations for visual project analysis*. Nueva York: John Wiley & Sons, 47–62.
- Fisher, Peter F. (1992). First Experiments in Viewshed Uncertainty: Simulating Fuzzy Viewsheds.

- Photogrammetric Engineering & Remote Sensing*, Vol. 58, No 3, March, 345–352.
- (1993). Algorithm and implementation uncertainty in viewshed analysis. *International Journal of Geographical Information Systems*, vol. 7, No. 4, 331–347.
- (1996). Extending the Applicability of Viewsheds in Landscape Planning. *Photogrammetric Engineering & Remote Sensing*, Vol. 62, N° 11, November, 1297–1302.
- Fraser, David (1983). *Land and Society in Neolithic Orkney*. Oxford: British Archaeological Reports, 117.
- Gillings, Mark and David Wheatley (2001). Seeing is not believing. Unresolved issues in archaeological visibility analysis. In Slapšak, B. (ed.) *On the good use of geographic information systems in archaeological landscape studies*. COST Action G2 Ancient Landscapes and Rural Structures, Proceedings of the COST G2 WG2 round table, Ljubljana, 18 to 20 December 1998, 25–36.
- Gómez-Miguel, Vicente (Coord.) (2006). *Geología, Geomorfología y Edafología*. Monografías del Atlas Nacional de España, Instituto Geográfico Nacional, Madrid. *Soil Map of Spain 1:1.000.000*. Instituto Geográfico Nacional (cartographic editing), Vicente Gómez-Miguel (thematic information), 2005.
- Keay, Simon J., David Wheatley and Sara Poppy (2001). The territory of Carmona during the Turdetanian and Roman periods: some preliminary notes about visibility and urban location. In: Antonio Caballos (ed) *Carmona romana*. Actas del II Congreso de Historia de Carmona, 29 Sept.–2 Oct. 1999, Carmona (Sevilla), 397–412.
- Lee, Jay and Dan Stucky (1998). On applying viewshed analysis for determining least-cost paths on Digital Elevation Models. *International Journal of Geographical Information Science*, vol. 12, n° 8, 891–905.
- Llobera, Marcos (2003). Extending GIS-based visual analysis: the concept of *visualscapes*. *International Journal of Geographical Information Science*, vol. 17, no. 1, London: Taylor & Francis, 25–48.
- Lock, Gary (2003). *Using Computers in Archaeology: Towards virtual pasts*. London and New York: Routledge.
- Murillo, Juan F. Fernando Quesada, Desiderio Vaquerizo, José R. Carrillo and José A. Morena (1989). Aproximación al estudio del poblamiento protohistórico en el sureste de Córdoba: unidades políticas, control del territorio y fronteras. In: Francisco Burillo (ed.) *Fronteras, Arqueología Espacial* 13, 151–172. Teruel.
- Romo Salas, A. S., F. Sierra Alonso and Vargas Jiménez, J. M. (1988). Prospección arqueológica superficial del T.M. de Gilena (Sevilla). *Anuario Arqueológico de Andalucía* III, 306–314.
- Ruiz, Arturo and Manuel Molinos (1989). Fronteras: Un caso del siglo VI a. N.E. *Fronteras, Arqueología Espacial* 13. Teruel.
- Ruggles, Clive L. N. and David J. Medzyckj-Scott (1996). Site Location, Landscape Visibility, and Symbolic Astronomy: A Scottish Case Study. In: Maschner, H. D. G. (ed.) *New Methods, Old Problems. Geographic Information Systems in Modern Archaeological Research*. Carbondale: Southern Illinois University Center for Archaeological Investigations Occasional Paper No. 23, 127–146.
- Tobler, Waldo (1993). Three presentations on Geographical Analysis and Modelling: 1) Non-isotropic modelling 2) Speculations on the geometry of geography 3) Global spatial analysis. *National Center for Geographic Information and Analysis, Technical Report 93–1* ([http://www.ncgia.ucsb.edu/Publications/Tech\\_Reports/93/93-1.PDF](http://www.ncgia.ucsb.edu/Publications/Tech_Reports/93/93-1.PDF) visited 30/05/08).
- Tschan, André P., Włodzimierz Raczkowski and Malgorzata Latalowa (2000). Perception and viewsheds: are they mutually inclusive? In: Gary Lock (ed.) *Beyond the Map. Archaeology and Spatial Technologies*. Proceedings of the NATO Advanced Research Workshop, Ravello, Italy, 1–2 October, 1999. Amsterdam: IOS Press, 28–48.
- Van Leusen, P. Martin (2002). *Pattern to Process. Methodological Investigations into the Formation and Interpretation of Spatial Patterns in Archaeological Landscapes*. PhD. Thesis, Rijksuniversiteit Groningen ([http://www.ub.rug.nl/eldoc/dis/arts/p.m.van.leusen/visited 13/07/04](http://www.ub.rug.nl/eldoc/dis/arts/p.m.van.leusen/visited%2013/07/04)).
- Vaquerizo, Desiderio, Juan F. Murillo and Fernando Quesada (1991). Avance de la prospección arqueológica de la Subbética cordobesa: la depresión de Priego-Alcaudete. *Anales de Arqueología Cordobesa* 2, 117–170.
- Vaquerizo, Desiderio, Fernando Quesada and Juan F. Murillo (2001). *Protohistoria y romanización*

- en la Subbética cordobesa. Una aproximación al desarrollo de la cultura ibérica en el sur de la actual provincia de Córdoba.* Junta de Andalucía, Servicio de Publicaciones de la Universidad de Córdoba.
- Wheatley, David (1995). Cumulative viewshed analysis: a GIS-based method for investigating intervisibility, and its archaeological application. In Gary Lock and Zoran Stančić (eds.) *Archaeology and Geographical Information Systems: A European Perspective*, 171–185. London.
- Wheatley, David and Mark Gillings (2000). Vision, perception and GIS: developing enriched approaches to the study of archaeological visibility. In: Gary Lock (ed.) *Beyond the Map: Archaeology and Spatial Technologies*, Amsterdam: IOS Press, 1–27.
- (2002). *Spatial Technology and Archaeology. The archaeological applications of GIS*. London, New York: Taylor & Francis.
- Zamora, Mar (2002). Computerised and real viewsheds. An example from the Genil River valley, Southern Spain. *Archaeological Computing Newsletter* 58, Oxford: Institute of Archaeology, 7–10.
- (2006a). Visibilidad y SIG en Arqueología: mucho más que ceros y unos. In: Ignacio Grau (ed.) *La Aplicación de los SIG en la Arqueología del Paisaje*, Actas de las Jornadas de Arqueología Territorios Antiguos y Nuevas Tecnologías. *La aplicación de los SIG en la Arqueología del Paisaje*, 18 y 19 de noviembre de 2004, Universidad de Alicante, 41–54.
- (2006b). *Territorio y espacio en la Protohistoria de la Península Ibérica. Estudios de visibilidad: el caso de la cuenca del Genil*, Universidad Autónoma de Madrid, PhD Thesis, Ediciones UAM, cd-rom (2008).
- (in press). Cálculos de visibilidad en arqueología: La visibilidad del territorio desglosada en ángulos verticales y su aplicación al período ibérico tardío de Andalucía central. *V Simposio Internacional de Arqueología de Mérida*, Noviembre 2007, Consejo Superior de Investigaciones Científicas, Mérida.